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Staphylinid beetles as bioindicators

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Abstract

The family Staphylinidae is one of the largest beetle families and is distributed worldwide in almost all types of ecosystems. The morpho-ecological characteristics of staphylinid beetle adults and developmental stages are summarized, and features pertaining to their potential use as bioindicators are highlighted. Methods of study and practical examples are given for the application of staphylinids as bioindicators both in seminatural and cultural landscapes. The structure of staphylinid communities in biotopes with various management practices is described. Future refinements in identification and sampling methods should result in increased use of staphylinids as bioindicators, possibly in combination with studies of other insects competing for the same resources. ©1999 Elsevier Science B.V. All rights reserved.

Keywords: Staphylinidae; Communities; Seminatural and rural areas; Management; Bioindicators

1. Staphylinid beetles – general biology

The family Staphylinidae is one of the largest families of beetles, with about 32,000 known species (Newton, 1990). The family is distributed worldwide and is found in practically all types of ecosystems. About half of the staphylinid species are found in litter, forming one of the most common and ecologically important insect components of the soil fauna. Knowledge of the broad habitat requirements of common staphylinid species and the fact that the family is distributed in practically all semi-natural and man-made habitats are two features that make staphylinids attractive as potential bioindicators. In spite of this, staphylinids are used less often in bioindicative studies compared with ground beetles, primarily because of the practical difficulties associated with staphylinid taxonomy. Nevertheless, the excellent keys for determination of staphylinids of central Europe by Lohse (1964) and Lohse et al. (1974) make it possible to identify practically all common species of staphylinids in central Europe. This paper presents general information about the morphology and ecology of staphylinid adults and developmental stages, followed by data regarding the possible application of staphylinids as bioindicators and a description of the structure of beetle communities in selected biotopes. The data concerning staphylinids as bioindicators are based on studies made in three biogeographic zones: taiga (southern part), lowland forest and forest steppe. The literature cited focuses mainly on western, central and eastern Europe.

1.1. Staphylinid beetles – morphological characteristics

Staphylinid adults are usually easily distinguished from other beetles by their short truncate elytra, which leave more than half of the rather flexible abdomen exposed (Fig. 1). The body is ovoid to very elongate, with a yellowish to dark color; other colours (red, blue, yellow) are rare. Body shape,

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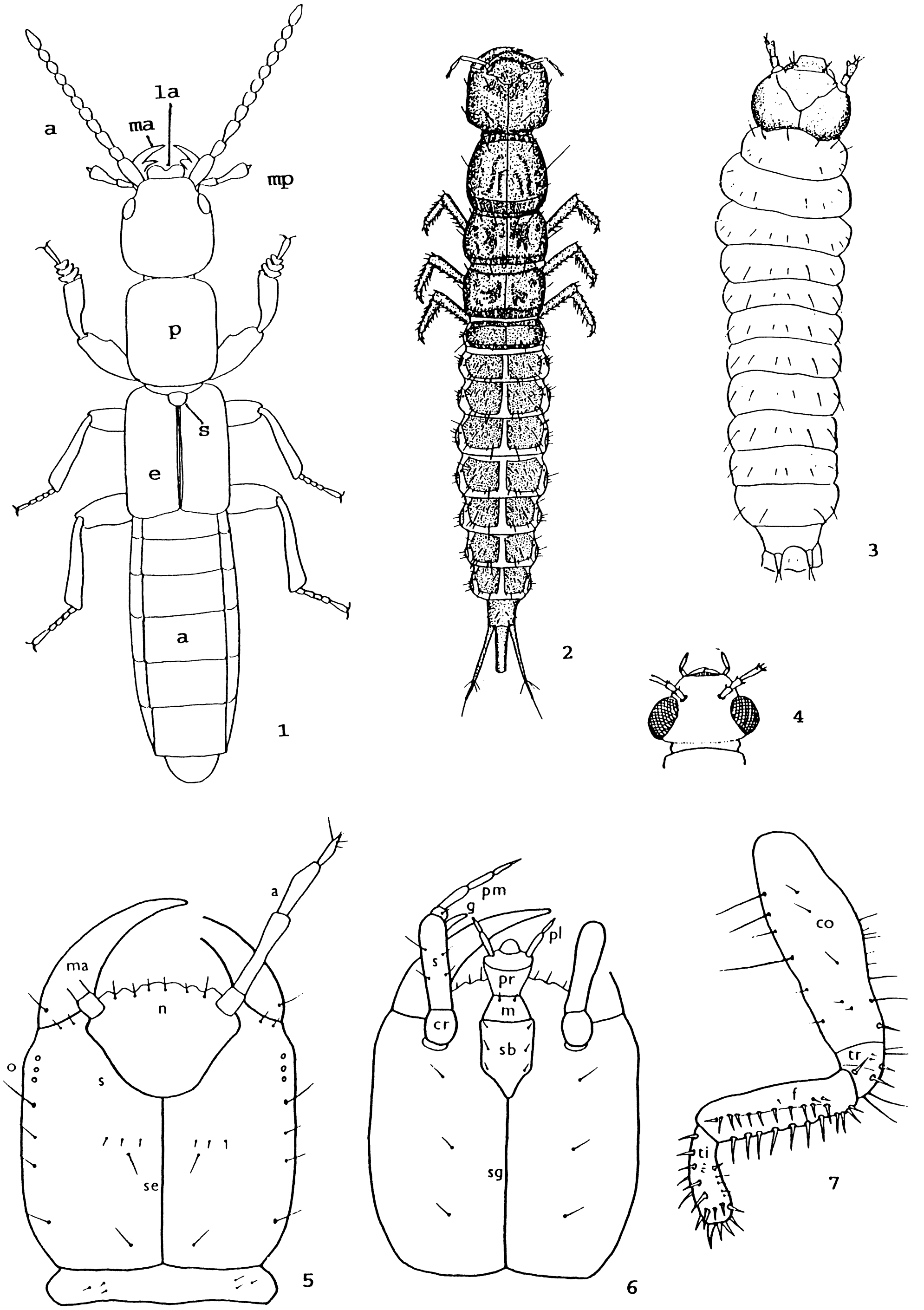
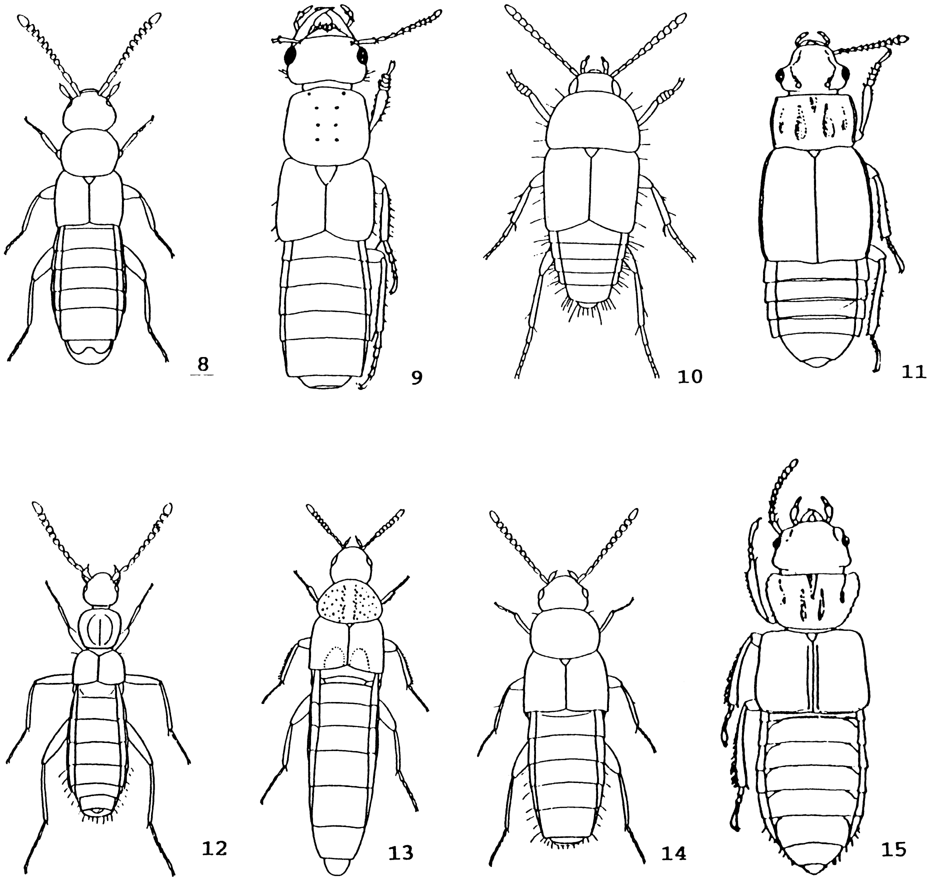


Figs. 1–7. 1. *Lathrobium filiforme*; a: antenna, la: labrum, ma: mandible, mp: maxillary palp, p; pronotum, s: scutellum, e: elytra, a: abdomen. 2. *Ocypus nero semialatus*, larva. 3. *Platystethus nitens*, larva. 4. *Stenus comma*, head. 5. *Ocypus* sp., head of larva, ventral view; pm: maxillary palp, g: galea, pl: labial palp, s: stipes, sb: submentum, m: mentum, pr: prementum, cr: cardo, sg: gular suture. 6. *Ocypus* sp., head of larva, dorsal view; ma: mandible, n: nasale, a: antenna, se: epicranial suture, sf: frontal suture. 7. Anterior leg of larva of the genus *Staphylinus*; cvo: coxa, tr: trochanter, ti: tibiotarsus, f: femur.



Figs. 8–15. Habitus of staphylinid species common in agricultural landscapes. 8. *Oxytelus rugosus* 9. *Omalium rivulare* 10. *Philonthus cognatus* 11. *Tachyporus chrysomelinus* 12. *Amischa analis* 13. *Atheta fungi* 14. *Drusilla canaliculata* 15. *Aleochara bipustulata* (from the book of Lohse (1964) and Lohse, Benick and Likovsky (1974)).

sensory adaptations, thoracic and basal abdominal structure and leg specializations can be explained in terms of locomotory specialization (Coiffait, 1972; Tikhomirova, 1973). Mouthpart adaptations reflect both the type of food and particular feeding method employed (Evans, 1964; Tikhomirova, 1973). The compound eyes vary from greatly reduced in size (terricolous species) to quite large (e.g. predaceous species of the genus *Stenus*) (Figs. 4 and 12). Details about staphylinid morphology are given by Blackwelder (1936), Smetana (1958), Lohse (1964), Coiffait (1972), Tikhomirova (1973), Naomi (1987) and Newton (1990). Larvae of staphylinid beetles have been poorly studied despite the fact that they are a relatively common component of the soil fauna. Most staphylinid larvae can be distinguished from most other beetle larvae by the presence of a pair of articulated appendages (urogomphi) at the apex of the ninth abdominal tergum (Fig. 2, 3). Staphylinids usually have three (rarely two) larval instars, with instars 2 and 3 more similar in structure than instar 1. Details about larval morphology are given by Paulian (1941), Pototskaya (1967), Topp (1978) and Bohac (1982). Staphylinid eggs are ovoid or oval (Hinton, 1981). The chorion is well developed and its surface pattern is characteristic for various taxonomic groups (Szujecki, 1966; Bohac, 1982). Small aeropyles are present on the egg surface. The eggs absorb water during their development and grow in size. Staphylinid pupae are of the pupa libera or pupa obtecta type (Bohac, 1982, 1988a). Pupa libera can actively move in the substrate.

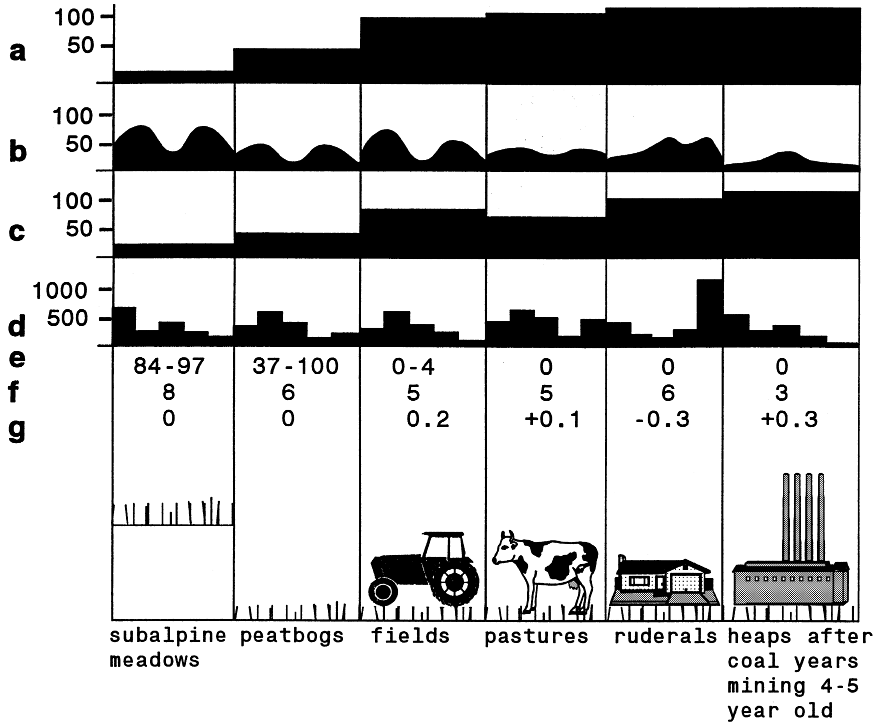


Fig. 16. The influence of man on communities of staphylinid beetles in non-forest landscapes: a: percentage of eurytopic species, b: seasonal dynamics (spec./m^2), c: percentage of species with good migrating ability, d: distribution of individuals in relation to body size (spec.), e: index of community, f: number of life forms, g: sex ratio (female – male/*N*). Bars in panel D represent body size Groups I–V (from left to right) ranging from smallest to largest, respectively (see text) (after Bohac and Fuchs, 1991).

1.2. Size groups of staphylinids

The body length of adult staphylinids varies between 0.5–60 mm in the Holarctic region and most frequently ranges from 1 to 35 mm. Species with such varied body size have different roles in ecosystems: often they are not in contact in the same biotope, with small species living mainly in the crevices of the soil and large species on the soil surface. Bohac and Ruzicka (1990) studied the size structure of staphylinid communities in different biotopes, including meadows, fields, oak forest, steppe forest, pond littorals and a transect through a valley of a brook comprising the brook shore, *Aceri–Carpinetum* type and oak forest and rocky steppe. The various species were assigned average size values based on published data (Lohse, 1964; Lohse et al., 1974), and the abundances of the species were plotted against their average body size in geometric scale with a quotient of 1.10 (Ruzicka, 1985). The abundances in relation to body size were centered around certain values rather than distributed uniformly. The positions of the abundance maxima were roughly the same in the different biotopes examined. The boundaries in the minima were established from the obtained diagrams, and refined on the basis of the authors' experience and measurements of the principal species collected from the communities. Five size groups were established, with Group I having a body length of up to 3.0 mm; Group II, 3.1–4.5 mm; Group III, 4.6–7.0 mm; Group IV, 7.1–11.0 mm; and Group V, greater than 11.0 mm. The frequency of size groups was found to differ in staphylinid communities in various biotopes (Bohac, 1988a; Bohac and Fuchs, 1991). The largest species (i.e., those in size Group V) prevail in ruderal biotopes in Central Europe (Fig. 16).

1.3. Trophic habits of staphylinids

The trophic groups of staphylinids serve as the basis for the hierarchic classification of their life forms (see

Section 1.5), which is used in biomonitoring. The majority of staphylinids are known as non-specific predators, feeding on various soil arthropods such as nematodes, mites, Collembola, small insect imagos and larvae, etc. Staphylinid predators do not normally live under stones, but merely take shelter there, especially nocturnal species. Some species of Oxytelinae feed on various organic substances and thus their gut contents include quantities of organic matter. Species of the genus *Bledius* feed on algae. Species of the large genus *Eushalerum*, which feed on pollen, are trophic specialists. It is evident that many staphylinid species are mycetophagous (Newton, 1984; Bohac, 1988a). Some staphylinid beetles possess mycangia, which serve for transport of spores (Crowson, 1981). These mycangia are situated in cavities on the base of the mandibles and are very similar to those of other mycetophagous beetle species, e.g., *Dendrophagus* spp. (Cucujidae). Myrmecophilous and termitophilous staphylinids are specialized groups of predators eating ants and termites, respectively, or saprophages living on waste in or near ant or termite nests. The complicated relationships between staphylinids and social insects have been described by many authors (e.g., Wilson, 1971; Kistner, 1979). Some members of the genus *Aleochara* are known to be parasitoids of fly puparia (Fuldner, 1960; Frank, 1982; Ienistea and Alex, 1982, Frank, 1991).

1.4. Diurnal activity and migrational possibilities of staphylinids

Staphylinid beetles are active mainly during the day (Tikhomirova, 1973; Spicarova, 1982). However, the majority of staphylinids prefer dark or shaded microbiotopes and live in litter, under stones, etc., and their maximal activity is influenced by the intensity of lighting. Many staphylinids possess great migrational possibilities (Crowson, 1981); this ability differs among various species and groups. Many species are good flyers (e.g., species of the genera *Oxytelus*, *Philonthus*, *Amischa*, *Atheta* etc.), and many small species are carried by the wind for long distances (e.g., species of the genera *Oxytelus*, *Amischa*, *Atheta*). Some of these species, which are common in agricultural landcapes, can be found at high elevations on mountains. Some species can be transported by man and have been distributed in this way all over the world (e.g., *Lithocharis nigriceps*). In recent years the expansion of some species has occurred mainly from southeast Asia (e.g., *Oxytelus migrator*, *Philonthus spinipes*) (Bohac, 1988a). A high frequency of species with good migrating ability within a given staphylinid community indicates a strong influence of man on the biotope (Fig. 16).

1.5. Life forms of staphylinids

A hierarchic classification of life forms of staphylinid beetle adults was created by Krivoluckij and Bohac (1989) according to the method of Sharova (1981). On the basis of their trophic specialization, staphylinids were divided into five classes of life forms (Table 1). Zoophages appear to prevail among staphylinids in terms of trophic specialization. However, a significant proportion of staphylinid species are mycetophagous or saprophagous; phytophages and myrmecophils are present in lower numbers.

An investigation of the life form spectrum of staphylinid communities of 155 biotopes showed that the number of life forms can vary from 4 (sandlands) to 11 (cultivated meadows). The greatest variety of life forms was found in staphylinid communities living in natural or semi-natural ecosystems (forest, steppe, nonregulated riversides and brooksides, subalpine meadows, pond borders). For each of these ecosystems there is a characteristic predominance of individuals of certain life forms (Krivoluckij and Bohac, 1989). The spectrum of life forms of staphylinid adults is indicative of various ecological and anthropogenous parameters in ecosystems of open landscapes. Higher numbers of life forms are present in seminatural habitats that are less influenced by man (Fig. 16). The hierarchical classification of life forms of staphylinid larvae is similar to that of imagos (Table 1). A new class of parasitoids has been added to the system of life forms because of the existence of some ectoparasitic larvae of the genus *Aleochara* (Krivoluckij and Bohac, 1989).

2. Staphylinids as bioindicators – methods of study

Communities of staphylinids can be used as bioindicators of the environmental status and particularly of

Table 1
Life form systems of staphylinid adults

Class	Zoophages
Sub-class	Epigeobios
Groups	Epigeobionts, walking, large (*Staphylinus* type)
	Epigeobionts, walking, small (*Philonthus* type)
Sub-class	Stratobios
Groups	living on soil surface and in decaying litter (*Othius* type)
	living in decaying litter (*Medon* type)
	living in decaying litter and under bark (*Dinaraea* type)
	bothrobionts (*Quedius* type)
	troglobionts (*Domene cavicola* type)
Sub-class	Geobios
Groups	Geobionts, running-grubbing (*Phytosus* type)
	Geobionts, edaphic (*Geostiba* type)
Sub-class	Psammocolimbets
Groups	coastal (*Stenus* type)
	living on light and sandy soils (*Astenus* type)
Sub-class	Petrobios (*Domene* type)
Sub-class	Torphobios (*Gymnusa* type)
Class	Phytophages
Group	Dendrochortobionts (*Eusphalerum* type)
	coastal (*Bledius* type)
Class	Saprophages
Group	living in decaying litter and soil (*Omalium* type)
	Epigeobionts, small (*Oxytelus* type)
	Troglophiles (*Ochthephilus* type)
Class	Mycetophages (*Gyrophaena* type)
Class	Myrmecophiles and Termitophiles
Group	Symphiles (*Atemeles* type)
	Synechtres (*Lamprinodes* type)
	Synoecentes (*Thiasophila* type)

human influence on ecosystems (Bohac, 1986, 1988a, 1988b, 1990; Bohac and Ruzicka, 1988; Ruzicka and Bohac, 1994). Staphylinids can be collected by pitfall trapping or by taking soil quadrat samples. The material should be collected during a one-year period and the same method should be used to compare various biotopes. The various indexes of species diversity can be calculated from the number of species and individuals in the sample (Ruzicka and Bohac, 1994). However, these indexes are based only on the species and specimen number and provide no information about the ecological characteristics of staphylinids. The author has proposed an index of staphylinid communities for the evaluation of the degree of human influence on ecosystems which is calculated on the basis of dividing beetles into ecological groups according to their relation to the naturalness of biotopes (Bohac, 1990). These groups are as follows: Group R includes species remaining from communities of past periods, e.g., species with arcto-alpine, boreomontane and boreo-alpine occurrence, inhabiting mainly mountains and peatbogs, or only occurring in remains of forests stands, which because of their high species diversity resemble recent climax forests; Group A encompasses species of both natural and managed forests; and Group E comprises eurytopic species that successfully occupy deforested sites and are also found in areas strongly affected by man. The index of staphylinid communities (IS) is a simple mathematical expression covering all three ecological groups (R, A, E). It is defined as

$$\mathrm{IS} = 100 - \left({}_{i=1}^{n}\mathrm{E} + {}_{i=1}^{n}\mathrm{A}\right)$$

where the first right-hand sum comprises the percentage abundance of individuals of eurytopic species (Group E), and the second the abundances of individuals of species of natural and managed forests (Group A). The value of this index ranges from 0 (only eury-

Table 2
Parameters indicating the critical stage of staphylinid communities

Parameters	
Frequency of ubiquitous specimens	more than 90%
Index of community	less than 35
Number of life forms	less than 4
Frequency of large individuals (IV and V size groups)	more than 20%
Frequency of individuals with summer activity	more than 40%
Non flying species	absence
Frequency of species with higher temperature requirements	more than 70%
Frequency of species with lower temperature requirements	more than 70%
Value of sex ratio index	more than 10% from 1 : 1

topic species are present and the community is highly affected by man) to 100 (only species of group R are present and the community is virtually unaffected by man). Upon establishing the index values for different biotopes it is possible to characterize the degree of man's influence in the examined communities by a single figure, thus avoiding dubious comparisons with sparse controls. In addition, the relationship between the index values for a given biotope and the species abundances within the communities can be employed as an index of the sensitivity of various species to human-induced stress, and can also serve as a refinement of the classification (Bohac, 1990). Ecological analysis for evaluation of community structure was employed in a study of beetle communities in biotopes with different degrees of anthropogenic effects (Bohac and Fuchs, 1991). Various characteristics (frequency of ecological groups according to their relation to the naturalness of biotopes, frequency of species with summer and winter activity of imagos, proportion of winged species, various body size groups, thermo- and hygropreference and geographical distribution) were used during this analysis (Fig. 16). Increased influence by man was found to bring about an increase in the frequency of eurytopic species, an increase in the frequency of species with summer activity of imagos, and a decrease in the proportion of species with winter activity of imagos. One peak in seasonal activity of staphylinids was found in biotopes with increased influence by man in contrast to two peaks in seasonal activity in semi-natural habitats. Furthermore, an increase was also seen in the proportions of winged species and individuals possessing a higher migrating ability, large body size (size Groups IV and V after Bohac and Ruzicka, 1990), species with higher temperature and lower moisture preferences, and species with an area of occurrence wider than Europe. A decrease in the number of life forms was accompanied by a decrease in the beetle community index. More extensive human activity was also shown to bring about an alteration of the sex ratio. The ecological analysis of staphylinid communities was used for evaluation not only of the author's data but also of data collected by other authors (Bohac, 1988a) and was able to identify the critical stage of communities, when staphylinid communities are unstable and their structure is changing year by year, mainly in response to various management practices (Table 2) (Bohac and Fuchs, 1991). Multivariate analysis has recently been applied to compare staphylinid communities of various biotopes (Bohac, 1994; Bohac and Fuchs, 1994a, 1994b, 1995; Bohac et al., 1995).

3. Species diversity and ecological characteristics of staphylinids in managed and unmanaged areas

Many ecological studies have been carried out on communities of staphylinids in various semi-natural and managed ecosystems (Bohac, 1988a). However, direct comparisons of beetle communities of various ecosystems are lacking. The author attempted to compare various communities using ecological analysis of staphylinid communities from published studies and his own data (Bohac, 1988a). The following section summarizes the data concerning staphylinid beetles in forests and wetlands (unmanaged ecosystems) and in fields (managed ecosystems).

Table 3
The number of species and abundance (specimens/m^2) of staphylinid beetles in various natural, semi-natural and unmanaged ecosystems in studied biogeographic zones (1: southern taiga, 2: lowland forests, 3: foreststeppe)

Ecosystem	Country	Zone	Source	No. of species	No. of individuals/m^2
Peat bog *Sphagnum* spp.	Russia	1	Tikhomirova, 1982; Razumovskii et al., 1984; Rybalov and Tikhomirova, 1994	12–27	86–198
Heathland	Russia	1 1	Tikhomirova, 1982; Razumovskii et al. 1984; Rybalov and Tikhomirova, 1994	14–20	78–110
Pine forest	Russia	1	Tikhomirova, 1982; Rybalov and Tikhomirova, 1994	14–35	75–118
Birch forest	Russia	1	Tikhomirova, 1982; Razumovskii et al., 1984; Rybalov and Tikhomirova, 1994	15–28	62–124
Spruce forest	Russia	1	Tikhomirova, 1982; Razumovskii et al., 1984; Rybalov and Tikhomirova, 1994	12–21	99–187
Alder forest	Russia	1	Tikhomirova, 1982; Razumovskii et al., 1984; Rybalov and Tikhomirova, 1994	27–35	675–783
Oak forest	Russia	3	Bohac et al., 1984	52	50–170
Unmowed steppe	Russia	3	Bohac et al., 1984	45	190–220
Mowed steppe	Russia	3	Bohac et al., 1984	46	40–60
Hornbeam forest	Czechia	2	Bohac, 1986, 1988a, 1988b	53	230–380
Oak forest	Czechia	2	Bohac, 1986, 1988a, 1988b	41	160–210
Alder forest	Czechia	2	Bohac, 1986, 1988a, 1988b	81	350–470
Mixed pine–oak forest	Czechia	2	Bohac, 1986, 1988a, 1988b	23	50–100
Lime-maple forest on talus slope	Czechia	2	Bohac, 1986, 1988a, 1988b	45–60	5–80
Littoral of stream	Czechia	2	Bohac, 1988a, 1988b	40–54	60–220
Montane spruce forest	Slovakia Czechia	2	Roubal, 1930 Bohac, 1988a	36–52	30–110
Plantation forest of spruce	Czechia	2	Bohac, 1988a	5–28	5–68
Peat bog	Czechia Germany	2	Bohac, 1988a, Frisch, 1995	31–113	10–160

3.1. Staphylinid communities in forest ecosystems

Staphylinids are very common in semi-natural and managed forest ecosystems. The species diversity and ecological structure of communities differs in various types of forest (Table 3). The greatest differences were found between semi-natural and artificial managed forests. Staphylinid communities of warm oak forests in central Europe are characterized by the presence of rare species with a higher temperature preference (Roubal, 1930; Bohac, 1988a). High species diversity was found in communities of staphylinids in hornbeam-birch (*Carpinus–Betula*) forests (Table 3). Predators and hygrophilous species living in detritus prevail in communities in these forests. Community index measurements revealed that staphylinid communities in such forests were strongly influenced by man (Bohac, 1988a). The highest species diversity was found in alder (*Alnus* spp.) forests (Table 3). Many staphylinid species show higher abundance in this type of forest in comparison with other forest ecosystems; some staphylinid species are known exclusively in alder forests. Staphylinid communities in beech forests are less influenced by man in comparison with other semi-natural forests. A higher frequency of species with restricted geographical distribution (west-European and middle European and mountain species) is characteristic for beetle communities of beech forests (Zerche, 1976; Vogel and Dunger, 1980; Schaefer, 1983; Friebe, 1983; Siebart, 1984; Bohac, 1988c). A high frequency of species with restricted distribution is typical for mountain spruce forests in the Carpathians (Roubal, 1930) and Alps (Chemini and Zanetti, 1982). The species diversity, activity and abundance of staphylinids from mountain spruce forests is lower than in other natural ecosystems (Table 3). Artificial forests in the study were represented by pine forests at lower elevations and by spruce forests at higher elevations in central Europe. The species diversity of staphylinid communities in plantations forests of spruce is low (Table 3) and depends on the type of soil, vegetation cover and soil moisture (Vogel and Dunger, 1980; Vogel, 1982; Keilbach, 1986). Species with higher temperature preferences and tolerant to dessication prevail in plantation forests of pine. The influence of man on communities of staphylinids in plantation spruce communities is high, especially at lower altitudes. Ubiquitous species are dominant in staphylinid communities of such forests. Some species living in open agricultural landscapes penetrate into these forests. The frequency of saprophagous species in artificial forests is lower in comparison with beetle communities of semi-natural forests. In addition, the species with large body sizes (size Group V) are absent from staphylinid communities in man-made forests.

3.2. Communities of staphylinids in littoral biotopes and peat bogs

Staphylinids are mostly hygrophilous or mesophilous and many species are often closely associated with wetlands (Zanetti, 1978; Focarille, 1987; Bohac, 1988a; Frisch, 1995; Bohac et al., 1996). Staphylinid beetles are widely distributed near both running water, such as streams and rivers, and standing waters, such as lakes, marshes, and peat bogs. The structure of communities of staphylinids living near running waters depends on various abiotic and biotic factors (soil type, relief of landscape, plant cover, water pollution, regulation of shores by man, etc.). Comparisons of species diversity and activity of staphylinids from various littoral biotopes (Vogel and Dunger, 1980; Keilbach, 1986; Bohac, 1988a; Bohac and Fuchs, 1994a) indicate great differences in the community structure of various biotopes. The frequency of various ecological groups also varies greatly. Littoral communities generally have high species diversity but the frequency of ubiquitous species in these communities is also often very high (Bohac, 1988a). The species of small and middle body size prevail in communities of littoral biotopes (body size Groups II and III). The main trophic groups are zoophages, with a prevalence of ripicolous geobionts (species living in the shore substrate of streams); temperature and moisture preferences of littoral species are often higher than in other biotopes. Species with a wide distribution are dominant in many communities of littoral biotopes, with the exception of mountain biotopes. Peat bogs have a specific staphylinid fauna. The most characteristic ecological groups in these communities are the tyrphobionts and tyrphophiles, which live exclusively or mainly in peat bogs, respectively (Peus, 1928; Horion, 1962, 1965, 1967; Koch, 1989). Many staphylinid species are closely associated with certain plant communities in peat bogs (Frisch, 1995). Some species occur in portions of peat bogs covered with trees, others in swampy areas or exclusively in raised peat bogs. The species with small body size are dominant in European peat bogs. These areas are characterized by a high proportion of northern Palearctic-boreal and central-European montane species of staphylinid beetles (Frisch, 1995). The frequency of specific ecological groups (paludicolous species, tyrphobionts, tyrphophiles) is generally high (about 50%) in bogs which have not been harvested for peat. Peat cutting and drainage lead to a change in the bog vegetation and are also reflected in the staphylinid fauna, mainly by the expansion of species from the surrounding wet biotopes and by the absence of tyrphobionts (Alalikina et al., 1980; Bohac et al., 1995; Frisch, 1995).

3.3. Staphylinid communities in farming areas

Staphylinids are the second most important group of epigeic invertebrates in agricultural landscapes in terms of activity and abundance (Obrtel, 1968). They represent about 19% of all beetles in terms of number of individuals. The number of staphylinid species is often higher than that of carabids (Bohac and Pospisil, 1984), and in some biotopes staphylinid abundance can be 15 times greater than that of carabid specimens (Lubke-Al Hussein and Wetzel, 1993). Staphylinids are important predators of some pests e.g., aphids, caterpillars, wire worms and other invertebrates (Scherney, 1955; Fox and Mac Lellan, 1956; Fuldner, 1960; Jones, 1969, 1976; Ienistea and Alex, 1982; Coombes and Sotherton, 1986; Chiverton, 1987; Dennis and Sotherton, 1994). Table 4 lists dominant staphylinid species living in large arable fields. Figs. 8–15 illustrate habitats of selected common species occurring in rural landscapes. In central and western Europe, the staphylinid fauna of fields

Table 4
Dominant species of staphylinids in various managed ecosystems in studied zones (1: forest steppe, 2: lowland forests)

Ecosystem	Country	Zone	Source	Dominant species
Pasture	Czechia	1 1	Bohac, 1988a	*Philonthus cognatus, Tachyporus hypnorum, Anotylus nitidulus, Platystethus nitens*
Field (maize)	Russia	2	Soldatova et al., 1983	*Anotylus insecatus, Atheta fungi*
Field (wheat)	Russia	2	Soboleva-Dokuchaeva and Soldatova, 1983	*Philonthus rotundicollis, Philonthus laminatus, Tachyporus hypnorum, Tachinus rufipes*
Field (clover)	Russia	2 2	Soboleva-Dokuchaeva and Soldatova, 1983	*Philonthus rotundicollis, Philotnhus laminatus, Tachyporus chrysomelinus*
Field (wheat)	Czechia	2	Bohac and Pospisil, 1984	*Dinaraea linearis, Philonthus cognatus, Tachinus rufies*
Field (maize)	Czechia	2	Bohac and Pospisil, 1984	*Aleochara bipustulata, Oxytelus rugosus, Tachyporus hypnorum, Philonthus cognatus*
Field (clover)	Czechia	2	Bohac, 1988a	*Tachinus signatus, Philonthus cognatus, Tachyporus hypnorum*
Dispersed belts	Czechia	2	Bohac, 1991; Bohac and Pospisil, 1984	*Sepedophilus pedicularius, Xantholinus linearis, Tachyporus chrysomelinus, Rugilus rufipes, Atheta fungi*
Ruderals	Czechia	2	Bohac, 1986, 1988a	*Anotylus rugous, Philonthus politus, Philonthus succicola, Philonthus succicola, Aleochara curtula, Falagria caesa*

Table 5
The number of species and abundance (specimens/m^2) of staphylinid beetles in various managed ecosystems in studied zones (1: forest steppe, 2: lowland forests)

Ecosystem	Country	Zone	Source	No. of species	No. individuals/m^2
Pasture	Czechia	2	Bohac, 1988a	15–20	8–24
Field (maize)	Russia	1	Utrobina and Tikhomirova, 1968	23	3–9
Field (potatoes)	Russia	1	Nadvornyi and Petrenko, 1978	12	2–3
Field (clover)	Russia	1	Nadvornyi and Petrenko, 1978	17	3–7
Field (wheat)	Czechia	2	Bohac and Pospisil, 1984	89	14–35
Field (maize)	Czechia Germany	2	Topp and Trittelwitz, 1980; Bohac and Pospisil, 1984	24–54	5–23
Field (clover)	Czechia	2	Bohac, 1988a	86	23–48
Field (corn)	Italy	1	Paoletti, 1988	28	1.5–7.5
Dispersed shelter	Italy	1	Paoletti, 1988	14	1.2–2.7
Dispersed shelter	Czechia	2	Bohac, 1991; Bohac and Pospisil, 1984	40	46–190
Ruderals	Czechia	2	Bohac, 1986, 1988	27	3–96

is strongly influenced by the surrounding biotopes (Bohac and Pospisil, 1984; Bohac, 1991; Dennis and Lys, 1992; Hulster and Desender, 1984). Generally, the number of staphylinid species in fields increases from one-year cultures to cultures growing for several consecutive years (Table 5). The species diversity and abundance of beetles in fields increase from north (zone of taiga) to south (zone of lowland forests and forest steppe) (Bohac, 1988a).

3.3.1. Staphylinids as bioindicators of management in fields

Agricultural measures (tillage, manure, chemical NPK and pesticides) have a lower and more short-term influence on staphylinid communities compared with other factors such as relief of agricultural landscape, surrounding biotopes, soil humidity and crop change (Bohac, 1991). Nevertheless, staphylinid beetles are good indicators of changes in agricultural techniques (Table 6).

3.3.1.1. The influence of crop change on staphylinids. The change of crop from wheat to maize was shown to influence the dominance of staphylinid species in communities (Bohac and Pospisil, 1984). Some species with good migratory ability colonized the maize field but were not found in the wheat field; these species were subdominant in the maize field (e.g., Philonthus

Table 6
The influence of some types of management on staphylinids in agricultural landscapes

Type of management	Influence on agroecosystems	Influence on staphylinids
Change of landscape structure (eg. by collectivization)	mosaic of biotopes (fields, hedgerows, grasslands, pastures) is changed by large fields with minimal frequency of trees, hedgerows, etc.	decrease in differences between field communities and communities in neighboring rural biotopes (e.g., higher frequency of ubiquitous species, etc.)
Manure	increase in soil organic matter content and soil humidity, increase in insect larvae	increase in zoophages and saprophages (e.g., *Philonthus* spp., *Oxytelus* spp.)
Chemical fertilizers (N, P, K)	decrease in soil humidity	decrease in species with higher moisture requirements, absence or lower frequency of sensitive species (e.g. *Lathrobium longulum*, *Tachyporus* spp.)
Pipe drainage	decrease in water table depth, organic matter content and actual moisture	decrease in species with higher moisture requirements about 20%, increase in ubiquitous species and decrease in number of life forms
Crop change	change in micro-climatic conditions and humidity of soil	increase in frequency of species with higher moisture requirements (e.g., *Tachinus signatus*)
Insecticides, herbicides	direct effect	short-term eradication of sensitive species, especially those living on soil surface and climbing on vegetation (e.g., *Tachyporus* spp., *Atheta* spp.)
	indirect effect absence of prey (eg. aphids, absence of ruderal plants, microclimatic changes	decrease in frequency of some zoophages and species with high moisture requirements

rectangulus). The higher humidity of the soil in the maize field facilitated its colonization by hygrophilous staphylinid species (e.g., *Othius punctulatus*, *Philonthus decorus*) from the surrounding biotopes.

3.3.2. The influence of tillage on staphylinids

Observations made to date do not indicate a negative influence of tillage on staphylinid beetles living in fields (Konig and Pawlitzki, 1981; Bohac, 1988a); the species number and abundance of beetles can even increase with tillage (28 species and 270 specimens/m^2 on a plot immediately after tillage and 23 species and 240 specimens/m^2 on a control plot without tillage) (Bohac, 1988a). On the other hand, shortly after tillage the activity of staphylinid imagos and larvae was found to decrease by approximately 20-fold in comparison with their activity before tillage (Bohac, 1988a). This may be explained by the limited ability of imagos from the surrounding biotopes to colonize the disturbed surface soil of fields after tillage (Bohac and Pospisil, 1984).

3.3.3. The influence of manure and NPK fertilizers on staphylinids

The effect of various NPK doses (30 q NPK/ha, 60 q NPK/ha) and farmyard manure on soil macrofauna was studied in fields planted with barley (Bohac and Pokarzhevski, 1987). Staphylinid abundance was stimulated by manure; this effect was also observed for other predators (Carabidae, Chilopoda) and reflected an increase in the quantity of their prey. The manure also raised the soil moisture content and therefore produced an increase in the number of hygrophilous species. The lowest number of staphylinid species was found on the plot with the highest dose of NPK. Some staphylinid species were good indicators of the type and dose of fertilizers. Species of the genus *Tachyporus* had the highest density on the control plot without fertilizers and the density of beetles increased from the plot with a lower dose of NPK to the plot with organic manure. The staphylinid species *Lathrobium longulum* was found only on plots without fertilizers.

3.3.4. The influence of pesticides on staphylinids

The effect of insecticides on staphylinids has been studied both in the laboratory and in field experiments. Various insecticides were tested in the laboratory on two common field staphylinid species, *Philonthus cognatus* and *Tachyporus hypnorum*. The abundance of both species decreased by 40–50% after the treatment (Eghtar, 1969); the larvae of both species were more sensitive than imagos. No increase in beetle sterility was noted after treatment with insecticides. On the other hand, pyrethroids had a negative influence on oviposition by *Aleochara* species under laboratory conditions (Samsoe-Petersen, 1985). Exposure to methoxychlor decreased the activity and abundance of staphylinids in fields (Topp, 1978; Konig, 1983); their activity and abundance were restored to the same level as before treatment after approximately one month. The effect of insecticides on staphylinid communities depended on the vegetation cover and presence of litter (Sustek, 1982). The insecticide influenced staphylinid beetles living in forested landscapes to a lesser extent compared with non-forested landscapes because of the accumulation of insecticide on vegetation and its faster degradation in litter. In contrast, herbicide treatment did not appear to influence activity of staphylinid beetles in a field experiment (Bohac and Pospisil, 1984).

4. Staphylinids as bioindicators of land use in agricultural settlements

Staphylinid communities are strongly influenced by the structure of cultural landscapes (Bohac and Pospisil, 1984; Bohac and Fuchs, 1994a, 1994b; Bohac et al., 1995). The effects of land use on staphylinid communities of six villages in two rural areas in south and north Bohemia with different intensities of management were analyzed using pitfall trapping (Bohac and Fuchs, 1994a, 1994b). The entire villages, separate sites within them and surrounding fields were compared. The effect of more intensive land use was distinct: species composition in south Bohemian villages with more intensive management was richer than in north Bohemian settlements, possibly the reason of the higher number of habitats and sharper boundaries among them. The number of beetle species in particular villages did not depend on the size of the settlement. In both regions, the beetle communities of medium and large-sized villages were more similar than in small villages. A dissimilarity was not found between beetle communities in particular sites in villages and in the surrounding fields. The results were practically the same for both staphylinids and carabids.

5. Long-term monitoring of staphylinid communities in montane ecosystems influenced by man

The effect of air pollution and forest decline on epigeic staphylinid communities was studied in the Giant Mountains (north-east Bohemia) (Bohac, 1992; Bohac and Fuchs, 1995). Comparison of staphylinid communities during the years 1983–1984 and 1988–1989 indicated early stages of changes in three out of five ecosystems studied. These ecosystems (damaged spruce forest, peat bog and stony slope) were more diverse during 1988–1989 than during 1983–1984. The greatest changes were found in the damaged spruce forest, where the frequency of ubiquitous and more tolerant species living in open landscapes increased, whereas that of stress-sensitive forest-living species decreased. Some species living beneath the bark of dying trees and in wet open biotopes appeared. There were no distinct changes in ecosystems regularly disturbed by natural factors such as avalanches and water erosion (glacial cirque, mountain floodplain meadow). Staphylinid communities were studied during the years 1986–1996 in mountain forest under the influence of industrial emissions in the Kruçn, mountains, located in the north-western region of the Czech Republic (Kula and Bohac, 1996). The dominance of some species varied significantly in various years. Two groups of species were identified by their changes in abundance from year to year: those species showing important changes in abundance and activity and those species with approximately the same abundance and activity from year to year. The frequency of ubiquitous species was found to have increased in all types of forest at the end of the ten-year monitoring period.

6. Staphylinids in urbanized areas

Urban areas are modified and fragmented by human activity. The spectrum of biotopes in urban areas varies from semi-natural (urban parks, small forests, hedgerows, etc.) to biotopes strongly influenced by man (ruderal situations, spoil banks, human settlements, etc.). The staphylinid fauna of urban areas may be partitioned into ubiquitous and eurytopic species, and habitat specialists. The author carried out a comparison of staphylinid communities living in urban parks and ruderal biotopes within and surrounding Prague (Bohac, 1989a). Beetle communities in Prague parks were found to be very similar to those of semi-natural forests in the vicinity of the city. The ecological structure of beetle communities in studied parks differs depending on management, with parks under weaker management having beetle communities more similar to those of semi-natural forests. The character of staphylinid communities in ruderal habitats is typical for unmatured biotopes. Many species of staphylinid beetles that were found in parks, were not found in semi-natural forests in the vicinity of the city. These were mainly species living in cavities of trees, which can often be found in parks, but are usually removed from managed forests. Parks also contain many other special habitats advantageous for the survival of staphylinids, e.g., nests of small mammals, mushrooms, etc. The species living in ruderal biotopes are often found on various decaying matter, waste or leftovers (Bohac, 1989a). Predators and parasites are the dominant trophic groups here; some species are saprophagous and some may be synanthropic. The large and well sclerotized species that resist drying and possess higher thermopreference prevail in these biotopes. Eurytopic staphylinid species typical for ruderal habitats were found to be dominant in urban parks studied by several authors (Topp, 1972; Klausnitzer et al., 1982; Kroker and Renner, 1983). These observations can be explained by the fact that pitfall trapping was used for collecting staphylinids, a method that selects for the more active and heavies species.

7. Accumulation of metals in staphylinids and their role as bioindicators of radionuclides

With respect to accumulation of heavy metals, invertebrates in terrestrial ecosystems can be divided into three classes, i.e., macroconcentrators, microconcentrators and deconcentrators (Bohac and Pospisil, 1988). For this classification the biological accumulation coefficient k is used, which is defined as the ratio of the metal concentration in the animal body to its concentration in soil. Species with k 2 are classed as macroconcentrators, species, with 1 k 2 are classed as microconcentrators and species, while k 1 are classed as deconcentrators. Although this classification is actually affected by the concentrations of elements in the environment, it is very convenient for evaluation of an insect's ability to accumulate toxic substances in different ecosystems with the same level of pollution. Staphylinids are mainly microconcentrators of heavy metals (Bohac, 1989b), but some are known to be macroconcentrators. Macroconcentrators can be particularly suitable biomonitoring objects. These macroconcentrators mainly belong to certain trophic groups, and the concentration of chemical elements in bodies of staphylinids depends on their trophic patterns. Elevated concentrations of lead were observed in some zoophagous species and elevated concentrations of mercury in some mycetophagous species (Bohac et al., 1989). The elevated mercury levels in mycetophages reflects the fact that some fungi are capable of accumulating this element. Staphylinids are not as sensitive to pollution by radionuclides as some other groups of soil fauna (Krivolutsky and Pokarzhevsky, 1992). The larvae are more sensitive than imagos.

8. Conclusions – perspectives for use of staphylinids as bioindicators

Many species of the family Staphylinidae show good bioindicating features thanks to their ecological specialization. In general, staphylinids are a good source of valuable complementary knowledge in bioindicative studies. In some cases staphylinids are more suitable and sensitive bioindicators than carabid beetles, but their importance for biomonitoring is currently limited because of difficulties in their identification. Furthermore, many species are not easily found using quantitative sampling methods (pitfall trap, soil samples). The fact that some staphylinids, carabids and spiders compete for food sources probably influences the results of bioindicative studies, therefore necessitating more complex bioindicative studies with all types of insects. Future refinements in identification and sampling methods and additional information regarding the interaction of staphylinids with other insects and their environment should result in their increased use as bioindicators of environmental quality.

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