DISCUSSION ON GROUND BEETLES AND ROVE BEETLES AS INDICATORS OF SUSTAINABLE AGRICULTURE IN LATVIA: REVIEW

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Abstract
Ground beetles (Coleoptera: Carabidae) and rove beetles (Coleoptera: Staphylinidae) as predators of many pests and weeds in every crop are significant elements of integrated pest management. Worldwide studies show that ground beetles reflect different soil tillage methods, crop rotation, chemical and genetic pollution, usage of fertilizers and landscape fragmentation. All these factors are the parameters based on which it is possible to assess agriculture whether it is sustainable or not. Ground beetles also can indicate different farming systems and potentially serve as keystone indicators of pest abundance. Thus ground beetles can be good indicators of sustainable agriculture, but rove beetles have a good potential to do it. Researches on crop dwelling ground beetles and rove beetles have been done infrequently in Latvia. Mainly these are faunistic studies not paying attention to agricultural environmental factor effect to ground beetles and rove beetles. For using ground beetles and rove beetles as indicators of sustainable agriculture in Latvia, studies on these beetles reaction to different farming activities should be done. These studies must occur in different crops and different places of country, because ground beetle and rove beetle reflection to changes of agricultural environmental factors may be crop- and site - or even field-specific.
Overview of literature on ground and rove beetles' ecology in agroecosystems recorded in Latvia, other European countries and Northern America has been used for this study.
Key words: Carabidae, Staphylinidae, beneficial insects, integrated pest management.

Introduction

It is possible to find many definitions that define sustainable agriculture. C. A. Francis and M. B. Callaway (1993) summarize that sustainable agriculture is an integrated system including economy of resources, maintenance of productivity, reduction of environmental degradation and promotion of short- and long-term profitability. According to M. Kogan and P. Jepson (2007) sustainable agriculture and integrated pest management (IPM) are complementary concepts. IPM is a system of ecologically safe plant protection, and biological pest control is important element of it (Kapitsa, 2012). Many researches show that ground beetles (Coleoptera: Carabidae) and rove beetles (Coleoptera: Staphylinidae) play significant role as predators of pests in different crops. Thus, ground beetles and row beetles are inalienable elements of IPM and sustainable agriculture.

Ground and rove beetles are two beetle families containing many species living in Central Europe (Freude et al., 1964, 1974, 1976). More than 300 ground beetle species and more than 600 rove beetle species are found in Latvia (Barševskis, 2003; Telnov, 2004). Almost all ground beetles and many rove beetles are soil dwelling or epigeic insects. Ground beetles mostly are carnivores, but there are many species which can be classified as herbivores or omnivores. Carnivorous ground beetles feed on different invertebrates: insects, spiders, slugs, snails etc. Herbivorous ground beetles feed on pollen, small sized seeds or sprouts of different plants. Omnivorous ground beetles feed on food objects most readily available in their immediate habitat. In fact, carnivorous ground beetles can become temporal herbivores when there is lack of prey (Riddick, 2004). Almost similar situation is among species of rove beetles – many species are predators, but also many species are herbivores, fungivores, coprovores or omnivores. Some groups of rove beetles feed on decomposing fungi, plant or animal material, but species included in *Aleochara* genus are parasitoids in fly pupas (Frank and Thomas, 2004).

Review on ground beetles occurring in agrocenoses in Latvia is done by A. Bukejs et al. (2009). Researches on ground beetles were done in 15 crops. Mostly species compositions and dominance structure, but in some cases influence of pesticides on ground beetles, is analysed. In Latvia, here are no researches on influence of different agrotechnical activities to ground beetles done. There are only few faunistic researches on rove beetles occurring in agrocenoses done in Latvia, e.g., studies on rove beetles living in strawberry fields (Cibuļskis and Petrova, 2002; Petrova et al., 2006).

Objectives of this study are as follows:
1. To discuss ground and rove beetle role in IPM and possibilities to use these beetles as indicators of sustainable agriculture in Latvia.
2. To discuss necessary researches on ground and rove beetles living in agrocenoses in Latvia.

Materials and Methods

Monographic method has been used for this study. Available literature on ground beetle and rove beetle ecology in agroecosystems recorded from Latvia, other European countries and Northern America had been used for the study. Check-list of Latvian beetles (Telnov, 2004) has been used for nomenclature of beetle species.

Results and Discussion

Ground and rove beetles as plant protectors

Different studies show that carnivorous ground and rove beetles as pest and weed controllers are important elements of agroecosystems. For example, these beetles can significantly decrease abundance of leaf beetles (Chrysomelidae), aphids (Aphidodea) and slugs in cereals (Sunderland and Vickerman, 1980; Sotherton et al., 1984; Sunderland et al., 1987; Winder et al., 1994; Wiltshire and Hughes, 2000; Lang, 2003; Schmidt et al., 2003). Rove beetles are widespread in every agroecosystem where they mostly feed on aphids and fungi – causal agent of mildew, but *Aleochara* spp. rove beetles are parasitoids of fly pupas, i.e., they are significant controllers of *Delia* spp. flies in cruciferous fields (Petrova et al., 2006; Balog et al., 2008, 2009).

Retrospectively, an opinion on herbivorous and omnivorous ground beetles as beneficial insects has been changed since the middle of the 20th century. For example, E. Ozols (1963) calls *Harpalus rufipes* as strawberry pest, but *Harpalus affinis, Amara apricaria, Bembidion lampros, Bembidion properans, Poecilus cupreus* and *Pterostichus melanarius* – as cereal pests which should be controlled. More precise studies show that these ground beetle species mostly act like pest and weed predators. K. D. Sunderland (1975) made study on diet of predatory arthropods in cereal crops. This study was based on gut dissection of different insect species and one centipede species. Results showed that *Bembidion lampros* is absolute carnivorous species feeding mostly on springtails (Collembola), aphids and dipterans (Diptera). But *Harpalus rufipes* is omnivorous species – guts of two thirds of individuals contained remains of different insects, mostly aphids, beetle adults and beetle larvae. One third of *Harpalus rufipes* guts contained unidentified plant material. Similar study of K. D. Sunderland and G. P. Vickerman (1980) showed that *Bembidion lampros* and *Pterostichus melanarius* together with fore more ground beetle species feed on aphids independently of aphid density in cereal fields. Even *Amara* spp. ground beetles, which are considered to be herbivores, feed on aphids, when aphids are particularly abundant (>100 m^{-2}) in cereal fields. S. Skaldere (Скалдере, 1981) observed that *Amara aenea* and *Harpalus affinis* feed on aphids in barley (*Hordeum vulgare*). One more study on ground beetles feeding on aphids in cereals shows that *Bembidion lampros, Pterostichus melanarius* and *Amara aenea* are significant aphid predators before start of flowering of cereals (Sunderland et al., 1987).

Pterostichus melanarius is mentioned as a significant predator of slugs in winter wheat (*Triticum aestivum*) (Wiltshire and Hughes, 2000); of blueberry maggot *Rhagoletis mendax* in highbush blueberries (*Vaccinium corymbosum*) (Renkema et al., 2012) and of Colorado beetle *Leptinotarsa decemlineata* in potato (*Solanum tuberosum*) fields, along with *Poecilus cupreus* and *Harpalus rufipes* (Koval, 1999). Studies in oilseed rape (*Brassica napus*) show that *Poecilus cupreus, Harpalus affinis* and *Harpalus rufipes* are predators of brassica pod midge *Dasineura brassicae* and pollen beetle *Meligethes* spp. larvae. *Harpalus affinis* and *Harpalus rufipes* also feed on rape seeds, but predation on pest larvae is more noticeable (Schlein and Büchs, 2006a). Studies on *Amara similata* feeding habits show that this ground beetle species can be a significant controller of oilseed rape pod midge larvae. Microcosm study proved that *A. similata* distinguishes uninfested pods from infested ones which are preferred (Schlein and Büchs, 2006b). If *A. similata* cannot find enough infested rape pods, it starts to feed on various plants, also rape, seeds (Schlein and Büchs, 2006a, 2006b).

Herbivorous and omnivorous ground beetles are weed controllers in various crops. Study of M.J. Ward et al. (2011) shows that herbivorous ground beetles reduce weed density of 60-80% during vegetation season. Especially effective weed reduction by ground beetles had been observed in maize (*Zea mays*) fields. After soil tillage, ground beetles and other seed predators consume 22-28% of weed seeds. This is 78-90% of total seed predation rate in crops (Cromar et al., 1999).

Worldwide studies show that even herbivorous and omnivorous ground beetles are significant predators of pests and weeds in agroecosystems. In few cases they feed on crop seeds or sprouts. It means that herbivorous and omnivorous ground beetles along with carnivorous ground beetles and rove beetles are beneficial insects and important elements of IPM in agroecosystems.

Ground and rove beetles as indicators of sustainable agriculture

Comparably large species diversity and density of individuals in agroecosystems, ability to react on different husbandry activities and good knowledge on their ecology are main factors which allow using ground beetles as indicators of sustainable agriculture. Ground beetles poorly indicate overall biodiversity of invertebrates in various habitats. On the other hand, ground beetles reflect human-caused disturbances such as soil tillage, crop rotation, chemical and genetic pollution, usage of fertilizers and landscape fragmentation. All these factors are the parameters based on which it is possible to assess agriculture whether it is sustainable or not. Ground beetles also can indicate different farming systems and potentially serve as keystone indicators of pest abundance (Holland and Luff, 2000; Rainio and Niemelä, 2003; Koivula, 2011; Cameron and Leather, 2012).

Proper soil tillage and crop rotation are important components of IPM. In regard to ground beetles, soil tillage and crop rotation should be discussed complementary, because both these factors depend on each other. Ground beetles react both to crop type and soil cultivation method. Bigger diversity and abundance of ground beetles are observed in winter cereals than in spring root crops (Holland and Luff, 2000). This is due to soil surface loosening in root crops during vegetation season. Soil loosening provides direct mortality of ground beetles up to 51%, and this effect remains within 18 days after performed activity. On the other hand, soil loosening does not affect rove beetle diversity and abundance in crops (Thorbek and Bilde, 2004). According to this, it is possible to say that species composition and abundance of ground beetles in crop may depend on fore-crop in the same field. Soil tillage is ecological disturbance which eliminates large sized ground beetles out of agroecosystem. For example, *Carabus* spp. beetles do not inhabit very intensively tilled fields (Holland and Luff, 2000; Cole et al., 2005). On the other hand, intensively tilled fields provide patchiness of vegetation suitable for small and medium sized ground beetles which are so called visual hunters. For example, density of *Anchomenus dorsalis* and similar species increases within intensively tilled crop fields (Cole et al., 2005). Non-inverse soil tillage maintains organic layer on soil surface and promotes composition of weeds. As a result, abundance of ground beetles increases – herbivorous species are attracted by weed seeds and sprouts, but carnivorous ground beetles are attracted by phytophagous invertebrates feeding on weeds. Weeds also affect soil microclimate positively for ground beetles (Holland and Luff, 2000; Thorbek and Bilde, 2004). Other studies show that ground beetles do not react to soil tillage intensity. For example, J. P. Twardowski (2006) and N. S. Mason et al. (2006) reports that ploughing and non-inverse soil tillage make almost similar effect to ground beetle assemblages in winter oilseed rape. But S. Belaoussoff et al. (2003) accent that, in general, soil tillage does not make statistically significant effect to the ground beetle diversity in farmlands. Also, different studies on ploughing and non-inverse soil tillage effect to rove beetles show different result. According to P. Thorbek and T. Bilde (2004), the rove beetle diversity and abundance are not affected neither by ploughing nor by non-inverse soil tillage. On the other hand, N. S. Mason et al. (2006) report that during July rove beetles have been more abundant in non-inverse tilled crops than in ploughed ones.

Ground beetles have been implicitly affected by herbicides and fungicides. These chemicals directly reduce food resources for herbivorous species. Chemical weed elimination from agroecosystem also causes rapid changes to soil microclimate and absence of additional food (weed herbivores) for carnivorous ground beetle species (Holland and Luff, 2000; Koivula, 2011). The study of R. A. Chiverton and N. W. Sotherton (1991) shows that activity and cereal aphid consumption of carnivorous ground beetles *Anchomenus dorsalis* and *Pterostichus melanarius* increase as a result of herbicide spraying in spring barley. This may be beneficial effect, but on the other hand, fertility of ground beetle females decreases as a result of lack of additional prey. Caused by herbicide spraying, higher activity of big sized ground beetles can promote predation of small sized ground beetles (Navntoft et al., 2006). Overall, it is possible to conclude that herbicide usage negatively affects long-term density of ground beetles within all trophic groups. Insecticides affect ground beetles directly causing their death. Ground beetle populations in agroecosystem react to insecticides by decreasing their abundance (Holland and Luff, 2000, Koivula, 2011). The study of O. R. Aleksandrowicz (2002) shows that insecticides also cause changes in dominance structure of ground beetle species. Dominants and subdominants may become recedents and subrecedents, but some previously recedent species may become dominant or subdominant. R. Cinītis (1975), J. M. Holland and M. L. Luff (2000) and M. J. Koivula (2011) maintain that insecticides make short-term effect due to habitat fast re-colonization by ground beetles. On the other hand, O. R. Aleksandrowicz (2002) reports that the effect caused by insecticides may last almost two months. Sometimes ground beetles do not indicate usage of insecticides. It happens when insecticides have been sprayed on crop canopy, not hitting the ground (Holland and Luff, 2000; Koivula, 2011). There is less data on insecticide caused effect to rove beetles. It is clear, that rove beetle abundance within crop also decreases due to the usage of insecticides, but this decrease is not statistically significant (Aleksandrowicz, 2002).

M. J. Koivula (2011) mentions that ground beetles can implicitly indicate genetically modified crops or so called genetic pollution in agroecosystem. Pesticide usage rate in genetically modified crops is noticeable high, and it affects ground beetle assemblage and abundance. Opposite opinion had been expressed by D. A. Bohan et al. (2005). According to it, ground beetle species richness does not differ between genetically modified and conventional winter oilseed rape crops. In general, there is lack of experience on ground beetles as indicators of genetically modified crops, thus, researches are needed.

The usage of fertilizers can affect ground beetles in different ways. Organic fertilizers change soil surface; it affects overwintering, burrowing and oviposition. Organic fertilization also promotes presence of earthworms and other saprophagous invertebrates which are prey for ground beetles. Both organic and inorganic fertilizers promote weed assemblages and more dense plant leaf cover over the ground. It all changes soil microclimate (soil is more shaded and humid), creates more shelters for epigeic invertebrates and attracts more herbivores (Holland and Luff, 2000). E. Diehl et al. (2012) accent that weeds foster ground beetles by resource- and structure-mediated effects. Attraction of herbivorous invertebrates is resource-mediated factor which fosters ground beetles more significantly than microhabitats created by weeds (structure-mediated factors) in crops. Inorganic crops are more homogeneous in their density and growth rates than organic crops. It means that organic crops provide more diverse environmental conditions suitable for wider ground beetle species diversity (Holland and Luff, 2000).

Ground beetle diversity and abundance are indicators of landscape fragmentation and heterogeneity. Unmanaged field margins, hedgerows, neighbouring different ecosystems etc. increase ground beetle species diversity in the crop field (Holland and Luff, 2000; Weibull et al., 2003). On the other hand, such linear formations as roads (even thin earth roads) and ditches are hardly surmountable biogeographic barriers for ground beetles (Holland and Luff, 2000). It means that intensively cultivated crop field surrounded by roads and ditches contains lower diversity ground beetle assemblage. Available information on rove beetles shows that they do not indicate landscape heterogeneity. A.-C. Weibull et al. (2003) did not find any correlation between landscape heterogeneity and rove beetle species richness.

Farming system affects ground beetle species diversity, but not abundance of individuals. Conventional crops mostly provide the lowest ground beetle diversity comparing to integrated, organic and biodynamic crops (Holland and Luff, 2000). On the other hand, studies in Sweden show that ground beetle species richness is higher within conventional crops than organic ones. It is explained with inorganic fertilizer usage providing suitable conditions for herbivorous species in conventional crops (Weibull et al., 2003). Ground beetle assemblages contain less herbivorous species within integrated system crops due to farming practices decreasing weed density. Many factors within each farming system determine ground beetle species assemblage of crop field. These factors might be unique within every single crop field (Holland and Luff, 2000). The study of A.-C. Weibull et al. (2003) did not find correlation between rove beetle species richness and farming system.

Ground beetles have potential to serve as keystone indicators in crop fields. Many studies show that ground beetles significantly reduce pest and weed density. Presence and definite density of ground beetle species can indicate decreased pest and weed amount. However, more studies should be done in this aspect (Koivula, 2011).

Necessary researches on crop dwelling ground and rove beetles in Latvia

Researches on ground beetles in Latvian agroecosystems had been done infrequently. Mostly ground beetle fauna in different crops had been analysed (Bukejs et al., 2009). There are also some studies on ground beetle activity changes during twenty-four hours, but some studies report how insecticides affect ground beetles abundance and assemblages within crop fields (Цинитис, 1962; Цинитис и Вилкс, 1962a, 1962b; Cinītis, 1975). Effects of other farming activities had not been studied. Knowledge on rove beetles is similarly poor. As mentioned above, seldom data on rove beetle fauna of agrocenoses are available. It means that it is not possible to use ground and rove beetles as indicators of sustainable agriculture in Latvia right now due to lack of knowledge. But, as it was discussed previously, ground beetles can serve as good indicators of IPM and sustainable agriculture. Also, rove beetles have great potential to do it.

To use ground and rove beetles as indicators of sustainable agriculture in Latvia, a lot of studies should be done. The study of A. Bukejs et al. (2009) shows that ground beetle fauna can be significantly different within different crops and regions of country. It is possible to speculate that rove beetle fauna differs similarly. Previous discussion highlighted that response of ground beetles and rove beetles to farming activities can differ depending on the crop. Also sometimes one husbandry activity, for example, similar soil tillage caused opposite response of ground beetles and rove beetles within different study sites. Thus, it is possible to say, that indication of sustainable agriculture by ground beetles and rove beetles is crop- and site- specific or maybe even field-specific, because theoretically many environmental factors (soil, neighbouring habitats, historical usage of agrochemicals, meso and macro relief etc.) can be unique in every single field. It means that researches on ground beetle and rove beetle reaction to different farming activities, such as discussed in previous subsection of this paper, should be done in different regions of Latvia to cover different environmental and farming factors as more as possible. First step to reach this objective was done in 2012, when researches on ground and rove beetles as indicators for sustainable soil use in winter wheat in Zemgale started. Main objectives of this research are to compare how ground beetles and rove beetles react to soil ploughing and non-inverse tillage and different crop rotation schemes (Gailis and Turka, 2012).

Conclusions

1. Ground beetles and rove beetles are beneficial insects as significant predators of many pests and weeds in any crop; thus, they are important elements of integrated pest management.
2. Worldwide studies show that ground beetles can serve as indicators of sustainable agriculture, but rove beetles have a potential to do it. Reaction of beetles to environmental changes is crop- and site- or even field-specific.
3. Lack of knowledge does not allow using ground and rove beetles as indicators of sustainable agriculture in Latvia right now.
4. Researches on ground beetle and rove beetle reaction to different soil tillage, crop rotation, usage of agrochemicals and other agricultural environmental factors should be done in different crops in different regions of Latvia.

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