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Stratification and diversity of beetles (Insecta, Coleoptera) in native elm forests of the Ussuri Nature Reserve, Russia

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ABSTRACT

The vertical stratification of beetles (Coleoptera) in native elm forest in the Komarovka River valley (Primorsky Krai) was studied for the first time. The highest number of species was observed in the shrub stratum. Migration of beetles from the crown and the ground strata to the shrub stratum increases its taxonomic diversity. The trophic group plays a crucial role in vertical stratification of beetles. It was found by analyzing the features of vertical stratification of beetles in native elm forest that beetle species with a broader trophic spectrum (phytophages assemblages) are observed as one proceeds from the ground stratum to the upper canopy stratum, which is associated with the diversity of the vegetation. Furthermore, the abundance of phytopages rises, while that of zoophages, coprophages, and necrophages decreases. Thus, the proportion of phytophages in the ground and crown strata is 11.8% and 77.3%; the ratio between zoophages and necrophages is 52.9 and 32.4% in the ground stratum and 9.1 and 4.5% in the crown stratum, respectively.

Keywords: Coleoptera - Diversity - Trophic groups - Elm - Valley forests - Primorsky Krai.

INTRODUCTION

Forest ecosystems of the southern part of the Primorsky Krai are characterized by complex vertical stratification (i.e., the presence of several vertical strata formed by various life-forms of plants). Biocenoses with a complex spatial structure are known to form a greater variety in microclimatic conditions [2],[14]. A number of researchers have mentioned that a more complex structure of a community has a positive effect on species diversity for many animals. In particular, complication of the vertical structure of forest communities provides more potential ecological niches for birds [5], [9] and insects [1], [3, 4], [19-20], [11]. A number of studies have been carried out to test this relationship [14]. Many of them have proved the hypothesis [6-7], [10], [13], [15], [17].

The hypothesis has not been studied yet for the representatives of beetles inhabiting the forest ecosystems in the southern part of the Primorsky Krai, although some data on distribution of insects have been obtained in the framework of International Biodiversity Observation Year (IBOY) [18].

The purpose of this study was to investigate the vertical distribution of beetles over different vegetation strata in natural ecosystems that have not been subjected to human impact (i.e. the Ussuri Nature Reserve).

MATERIALS AND METHODS

The vertical stratification of beetles was studied using the conventional window and pitfall traps [8], [18]. The vertical series consisted of two window traps and fifteen pitfall traps placed below them. The window traps were composed of a yellow plastic container 36 cm in diameter with lidded plexiglass plates (surface of trap) attached to it. The yellow color of the collecting jar (most likely) also acted as a coloured pan trap attracting flower visiting insects. 3% formalin solution was placed on the bottom of the container. The traps were suspended over pulleys at heights of 1 and 11 m above ground (Figure 1), the average canopy heights reaching 19-16 m.

Figure 1: A conventional window trap in the Ussuri Nature Reserve

The pitfall traps were composed of 200 mL plastic cups with a 6 cm diameter filled with preservative solution (3% formalin solution) by one-third of their volume. Fifteen pitfall traps were set up in a series at a distance of 1.5 m away from each other. Sampling was carried out between May and October 2012; the traps were checked every 10 days.

The sampling site was located in the Komarovka River basin (Figure 2) in the Ussuri Nature Reserve (Primorsky Krai, Russia). The sampling site was characterized by multi-species stands (*Ulmus davidiana var. japonica, Tilia amurensis, Juglans mandshurica, Acer mandshuricum,* and *Pinus koraiensis*); the total canopy closure was 80%.

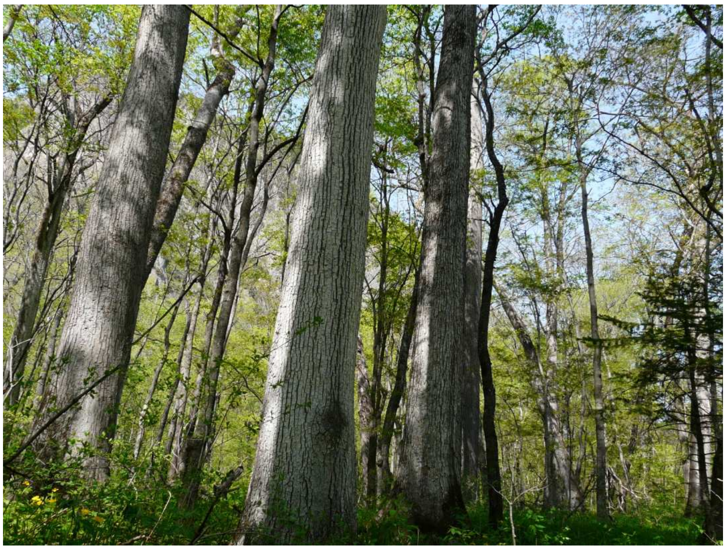

Figure 2 Native elm forest in the Ussuri Nature Reserve

Thin understory was 2-5 m high and consisted of *Acer barbinerve*, *Eleutherococcus sessiliflorus*, *Euonymus sacrosancta*, *Lonicera praeflorens* and *Lonicera maackii*. Liana species included *Actinidia kolomikta* and *Vitis amurensis*. There was a continuous ground cover of herbs (up to 0.9 m high). The most abundant herb species was *Matteuccia struthiopteris* and other tall-grass species being less dominant. Soil was represented by gleyic brown soil with a well-developed profile in the alluvial deposits. The sampling site was an old growth ecosystem not subjected to human impact.

The beetle assemblages dwelling in different strata of this native elm forest were compared by the method of graph class inclusions; the inclusion measure was determined using the formula [16]:

$$K_{0(a;b)} = \frac{\mu(a \cap b)}{\mu(b)},$$

where $K_{0(a;b)}$ is the measure of inclusion of the descriptive set b into a;
is the weight of conjunction of descriptive sets a and b;
is the weight of descriptive set b.

All calculations and plotting of graphical illustrations were performed using Microsoft Office Excel 2003 software.

RESULTS

A total of 1471 beetle individuals belonging to 32 families were collected using pitfall (for ground stratum) and window traps (for shrub and upper strata) (Table 1). This table also mentions the feeding strategy of each species inside the different strata.

Ground stratum: 880 beetle individuals and 43 species belonging to 7 families were collected in the ground stratum. The families can be ordered by decreasing species number: Carabidae (21 species), Silphidae (10), Histeridae (4), Scarabaeidae (4), Lucanidae (2), and Geotrupidae (1). The total abundance of representatives from the families Carabidae and Scarabaeidae in the ground stratum was 59.5% of the entire sample.

Among 21 Carabidae species, four species (*Carabus granulatus*, *Carabus smaragdinus*, *Carabus billbergi*, *Carabus canaliculatus careniger*) were dominant (>5% of all specimens); three species (*Carabus venustus, Carabus vietinghoffi*, *Carabus hummeli*) were subdominant (≥2-5%), and six species (*Calosoma cyanescens*, *Calosoma chinense*, *Carabus constricticollis*, *Carabus schrenckii*, *Carabus arcensis*, *Cychrus koltzei*) were scarcely collected (≤1% specimens) rare.

Shrub stratum: The greatest number of species (95 species belonging to 29 families) was observed in the shrub stratum. The Family Cerambycidae has the highest number of collected species, while the family Scarabaeidae is characterized by the greatest number of collected individuals. *Cucujus haematodes* (Cucujidae) is the dominant species; the subdominant species include *Dendroxena sexcarinata* (Silphidae), *Holotrichia sichotana*, *Lasiotrichius succinctus* (Scarabaeidae), *Mordella holomelaena* (Mordellidae) and *Chrysolina aurichalcea* (Chrysomelidae). The study of the vertical stratification of beetles has demonstrated that the shrub stratum was characterized by the highest species abundance, since most flowering plants that many beetle imagoes feed on are concentrated in this stratum.

Table 1: Numbers of individuals of all species collected at Ussuri Nature Reserve given by stratum type and ordered by families. Trophic group: Z=zoophages, P=phytophages, M=mycetophages, N=necrophages, C=coprophages.

Species	Stratum			Trophic group
	Ground	Shrub	Upper canopy	
Family Carabidae				
Amara orienticola	23	–	–	P
Amara plebeja	32	–	–	P
Calosoma chinense	10	–	–	Z
Calosoma cyanescens	12	–	–	Z
Carabus arcensis	5	–	–	Z
Carabus billbergi	124	–	–	Z
Carabus careniger	122	–	–	Z
Carabus constricticollis	12	–	–	Z
Carabus granulatus	105	–	–	Z
Carabus hummeli	43	–	–	Z
Carabus schrenckii	4	–	–	Z
Carabus smaragdinus	76	–	–	Z
Carabus venustus	36	–	–	Z
Carabus vietinghoffi	38	–	–	Z
Cychrus koltzei	15	–	–	Z
Pterostichus interruptus	24	–	–	Z
Pterostichus nigrita	16	–	–	Z
Pterostichus orientalis	11	–	–	Z
Pterostichus subovatus	5	–	–	Z
Pterostichus sutschanensis	6	–	–	Z
Pterostichus tuberculiger	8	–	–	Z
Family Histeridae				
Hister sibiricus	10	2	–	C
Hister unicolor	1	1	–	C
Hololepta amurensis	5	2	–	P
Hololepta plana	2	1	–	P
Family Leiodidae				
Liodopria maculicollis	–	1	1	M
Family Silphidae				
Calosilpha brunnicollis	6	5	–	N
Dendroxena sexcarinata	10	15	7	N

Necrodes littoralis	1	1	–	N
Nicrophorus concolor	1	1	–	N
Nicrophorus praedator	1	1	–	N
Nicrophorus quadripunctatus	5	7	11	N
Nicrophorus vespilloides	1	–	–	N
Oiceoptoma subrufum	1	1	–	N
Oiceoptoma thoracicum	6	5	–	N
Ptomascopus morio	2	–	–	N
Family Lucanidae				
Hemisodorcus rubrofemoratus	5	2	–	P
Lucanus maculifemoratus	–	1	–	P
Macrodorcas recta	–	1	–	P
Prismognathus dauricus	11	2	–	P
Family Geotrupidae				
Geotrupes koltzei	18	1	–	C
Family Scarabaeidae				
Gnorimus subopacus	–	9	–	P
Holotrichia sichotana	–	13	1	P
Holotrichia diomphalia	–	7	1	P
Lasiotrichius succinctus	–	12	–	P
Maladera renardi	2	3	–	P
Mimela holosericea	–	9	–	P
Mimela testaceipes	–	6	–	P
Onthophagus atripennis	2	–	–	C
Onthophagus gibbulus	2	–	–	C
Onthophagus uniformis	56	–	–	C
Osmoderma caeleste	–	–	1	P
Protaetia marmorata	–	2	–	P
Sericaria fuscolineata	–	3	1	P
Family Buprestidae				
Lamprodila amurensis	–	–	1	P
Lamprodila bellula	–	–	1	P
Lamprodila suyfunensis	–	–	1	P
Lamprodila virgate	–	–	1	P
Family Eucnemidae				
Microrhagus foveolatus	–	4	–	P
Microrhagus mystagogus	–	2	–	P
Family Throscidae				
Aulonothroscus longulus	–	1	–	P
Family Elateridae				
Ampedus pomorum	–	1	–	P
Ampedus pomonae	–	1	–	P
Denticollis cinctus	–	3	–	P
Elater luctuosus	–	8	–	P
Lacon altaicus	–	4	–	P
Melanotus castanipes	–	7	–	P
Melanotus pygmaeus	–	5	–	P
Family Lycidae				
Lycostomus porphyrophorus	–	3	–	P
Plateros kurentzovi	–	1	–	P
Family Dermestidae				
Dermestes lardarius	5	3	6	P
Family Lymexylidae				
Elateroides dermestoides	–	2	1	P
Family Trogossitidae				
Temnoscheila japonica	–	2	1	Z
Family Cleridae				
Trichodes sinae	–	2	1	Z
Family Monotomidae				
Rhizophagus japonicus	–	1		M
Family Silvanidae				
Silvanus bidentatus	–	2	1	M
Silvanus ubidentatus	–	1	1	M
Family Cucujudae				
Cucujus haematodes	–	36	14	M
Family Erotylidae				
Dacne notata	–	1	–	M
Dacne picta	–	1	–	M
Episcapha morawitzi	–	4	–	M
Family Endomychidae				
Mycetina marginalis	–	2	–	M
Family Mycetophagidae				
Mycetophagus intermedius	–	1	–	M
Family Melandryidae				

Melandrya mongolica	–	1	–	M
Phloiotrya bellicosa	–	1	–	M
Family Mordellidae				
Hoshihananomia auromaculata	–	3	–	P
Mordella holomelaena	–	12	1	P
Mordellistena humeralis	–	2		P
Family Tenebrionidae				
Misolampidius tentyrioides	–	2	1	M
Neatus ventralis	–	1	–	M
Family Oedemeridae				
Chrysanthia integricollis	–	5	–	P
Ischnomera abdominalis	–	1	–	P
Nacerdes atriceps	–	1	–	P
Nacerdes luteipennis	–	1	–	P
Family Pyrochroidae				
Pseudopyrochroa lateraria	–	2	–	P
Schizotus fuscicollis	–	2	–	P
Family Cerambycidae				
Amarysius altajensis sellatus	–	2	2	P
Amarysius sanguinipennis	–	1	2	P
Chloridolum sieversi	–	2	4	P
Cyrtoclytus capra	–	2	–	P
Dorcadion sp.	–	1	–	P
Eutetrapha metallescens	–	6	8	P
Eutetrapha sedecimpunctata	–	1	–	P
Exocentrus marginatus	–	1	–	P
Leptura aethiops	–	1	–	P
Leptura annularis	–	1	2	P
Leptura duodecimguttata	–	3	1	P
Leptura thoracica	–	1	3	P
Menesia sulphurata	–	1	1	P
Mesosa hirsuta	–	1	–	P
Mesosa myops	–	1	–	P
Monochamus urussovii	–	–	6	P
Monochamus sutor	–	–	1	P
Oupyrrhidium cinnabarinum	–	5	–	P
Pachyta bicuneata	–	7	3	P
Pterolophia multinotata	–	1	–	P
Purpuricenus sideriger	–	1	–	P
Rhabdoclytus acutivittis	–	2	–	P
Saperda interrupta	–	–	1	P
Saperda perforata	–	1	–	P
Stictoleptura dichroa	–	1	–	P
Family Chrysomelidae				
Chrysolina aurichalcea	–	17	7	P
Chrysomela populi	–	8	26	P
Family Rhynchitidae				
Byctiscus princeps	–	–	1	P
Family Curculionidae				
Chlorophanus sibiricus	–	2	2	P
Curculio dentipes	–	1	1	P
Curculio ussuriensis	–		1	P
Fronto capiomonti	–	–	1	P
Magdalis koltzei	–	–	1	P
Orchestes mutabilis	–	–	1	P
Orchestes ruber	–	–	1	P
Phloeophagus orientalis	–	–	1	P
Family Scolytidae				
Scolytus jacobsoni	–	3	1	P
Scolytus japonicus	–	2	–	P
Xyleborinus saxesenii	–	1	1	P
Total of species	**43**	**95**	**44**	**–**
Total of individuals	**880**	**459**	**132**	**–**

Upper canopy stratum: 44 species belonging to 17 families were collected in the upper canopy stratum. The longhorn beetles (Cerambycidae), snout beetles and true weevils (Curculionidae), lamellicorn beetles (Scarabaeidae), and jewel beetles (Buprestidae) are the most typical dwellers of this stratum. The dominant species include *Cucujus haematodes*, *Chrysolina aurichalcea* and *Chrysomela populi* (Chrysomelidae), *Pachyta bicuneata*, *Chloridolum sieversi*, *Leptura thoracica*, *Monochamus urussovii* are subdominant species.

DISCUSSION

The species diversity of beetles in the native elm forest was lower at 11 m than at 1 m, similarly the number of beetles captured decreases.

The structure and composition of species assemblages of the ground stratum drastically differ from those of the upper canopy stratum. The share of zoophages, necrophages, and coprophages among collected beetles (their total abundance being more than 90%) emphasizes the unique features of the ground stratum. The limited species diversity of beetles and predominance of dark-colored forms with thick vestiture show an adaptation to the pronounced unfavorable abiotic environmental factors (high humidity and low temperature).

In the forest, rainfall is most intensely absorbed in the canopy crown stratum; hence, a significant diurnal air temperature difference is observed in the intra-crown area as compared to the under-crown area [8]. The most pronounced diurnal variations in relative air humidity depend on temperature and are observed in this stratum. In particular, dew usually condenses both in the herb and canopy crown strata in the forest. Therefore, the diurnal variations in temperature and relative air humidity in the shrub stratum are smoother compared to those in the crown and herb strata characterized by intense energy exchange. Likely, this is the reason that the shrub stratum was characterized by the greatest beetle diversity.

The trophic group plays a crucial role in vertical stratification of beetles. It was found by analyzing the features of vertical stratification of beetles in native elm forest that beetle species with a broader trophic spectrum (phytophages assemblages) are observed as one proceeds from the ground stratum to the upper canopy stratum, which is associated with the diversity of the vegetation. Furthermore, the abundance of phytopages rises, while that of zoophages, coprophages, and necrophages decreases.

Thus, the proportion of phytophages in the ground and crown strata is 11.8% and 77.3%; the ratio between zoophages and necrophages is 52.9 and 32.4% in the ground stratum and 9.1 and 4.5% in the crown stratum, respectively. The presence of *Dermestes lardarius* (Dermestidae) and *Nicrophorus quadripunctatus* (Silphidae) among the beetles collected in the crown stratum in July demonstrates that when searching for food or mates, some representatives of the ground stratum can move to the upper canopy strata [12]. The presence of xylotrophic fungi and myxomycetes in all strata explains why mycetophages were detected among the collected beetles; the greatest number of mycetophages was observed in the shrub stratum (Figure 3).

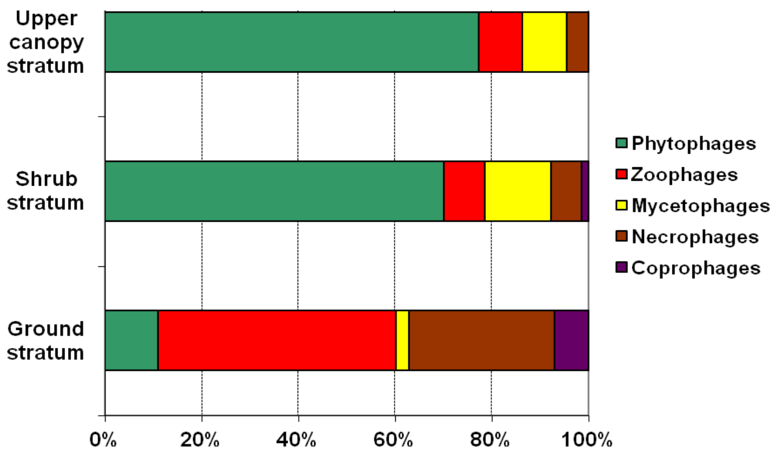

Figure 3: The relationship among trophic groups of beetle species or number of individuals in different strata of native elm forest

An analysis of the data showed that the shrub stratum is the most diverse one in terms of remove species composition (95 species belonging to 29 families, with 53 species found only in this stratum). The reason is that this stratum is the trophic and breeding area for many forest-dwelling species. Ground beetles and beetles dwelling in the upper canopy stratum contribute to the diversity of the shrub stratum. When it is warm and sunny, beetles dwelling in the upper canopy stratum move down to the lower-lying stratum, while ground beetles searching for additional food move upward (Figure 4).

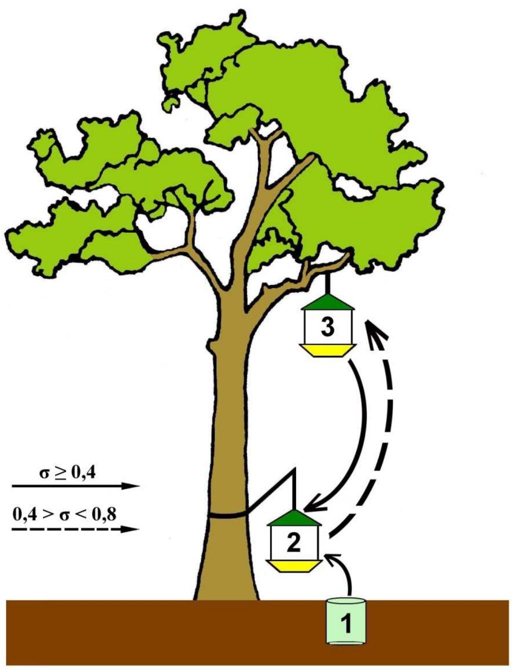

Figure 4: Scheme of stratification of beetle imagoes dwelling in different strata (during the entire survey period). 1 – ground stratum, 2 – shrub stratum, 3 – upper canopy stratum.

The diversity also increases as beetles move to the shrub stratum from the crown and ground stratum. The families Cerambycidae, Curculionidae, Scolytidae and Chrysomellidae were found to have higher abundance indices in the upper canopy stratum. While the families Carabidae, Histeridae and some representatives of Scarabaeidae had higher abundance indices in the ground stratum.

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