STRUCTURAL DYNAMIC OF BUMBLEBEE COMMUNITIES (*Hymenoptera: Bombini)* IN FOREST AREAS DESTROYED BY ACID RAINS IN THE KARKONOSZE MOUNTAINS OF POLAND

Tadeusz Pawlikowski

Institute of Ecology and Environmental Protection,
Nicolaus Copernicus University, Gagarina 9, 87-100 Toruń, Poland
E-mail: pawlik@biol.uni.torun.pl

Recieved 13 January 2010; Accepted 25 March 2010

S u m m a r y

The structure of bumblebee communities was investigated in forest areas transformed by acid rains in the Polish Karkonosze mountains. The bumblebee communities were studied at intervals for five years. It was found that the number of species decreased as the altitude increase. This increase and decrease took place at similar ratios relative to the natural distribution of the number of species recorded in the Tatra Mountains. In the dynamic of bumblebee density within the vegetation floors of the Karkonosze Mts, a significant twofold increase was recorded in the values for lower subalpine forest. A threefold decrease in the values for upper subalpine forest was recorded and a twofold decrease in the values for the dwarf pine floor. The result of these changes was a significant increase in the general diversity (H') of communities in the upper subalpine forest and the dwarf-pine floor. Equalization of frequency of individual species in communities was the reason for the significant increase. While observing the progressing successive restoration of forests, one can assume that the recorded structural changes in bumblebee communities represent their transitional state. Together with the restoration of destroyed forest stands, the dynamics peculiar to the high mountains of Central Europe should be preserved for bumblebee communities in those areas.

Keywords: *Hymenoptera*, *Bombini*, bumblebees, community structure, forests, Karkonosze Mts.

INTRODUCTION

Structural changes in communities of melitophagous social hymenopterans depend mainly on nutritional resources and the climate-forming spatial organization of vegetation in an ecosystem. These transformations were initially determined in environments of the eastern Karkonosze Mts. An attempt was made to use the changes in order to evaluate the extent of transformations in mountain environments (Pawlikowski, 1992). So far, no research has ever been conducted on this aspect transformations in the mountain landscape of the whole Karkonosze Mts.

The main mechanism in the development of the bumblebee community structure is the abundance of nutritional resources from flowering herbaceous plants (Ruszkowski and Żak, 1974). This mechanism remains under the strong influence of microclimatic conditions, which in the mountains ultimately depend on the structure of vegetation floors, and particularly of subalpine forests.

During the 1990s, forest destruction in the Karkonosze Mts intensified. As a consequence of inappropriate forest management in the past, as well as post-industrial acid precipitation, a mass extinction of the forests took place. A further consequence was the clearings of dead tree stands which changed the natural composition of the forests in Karkonosze. The forest areas became fragmented, and consequently xerisation of the environment, began to proceed quickly. Thickets and tall forb communities encroached on clearings. Dead spruce-tree stands has been thinned out by windthrows. Nutritionally these areas are much more attractive for bumblebees.

The present paper is a study of the transformations in the structure of bumblebee communities in the forest areas transformed by acid rains within the massif of the Karkonosze Mts. The study took place over a five year period. Furthermore, the objective was to see it the bumblebee communities could be used as bioindication of the extent of subalpine forests damage in the Karkonosze Mts.

MATERIALS AND METHODS

The research was conducted between July 3 and 23, 1989 in the eastern part of the Karkonosze Mts and between August 15 and 29, 1994 in the western part of the Karkonosze Mts. Those were periods when the development of bumblebees' colonies was at its peak. Materials from the first research season were collected at 10 sites and then provisionally published (Pawlikowski, 1992). Materials from the second research season were collected at 20 sites, in a similar way as was done during the research on social wasps (Pawlikowski, 2009).

The sites were distributed within 5 vegetation floors described by Fabiszewski (1985): the foothills in the habitat of *Galio-Carpinetum* (FH) - 360-500 m asl.; the lower subalpine forest, spruce forest in the habitat of *Luzulo luzuloidus-Fagetum* or *Dentario enneaphyllidis-Fagetum* (LF) - 500-1000 m; the upper subalpine forest, spruce forest in the habitat of *Plagiothecio-Piceetum hercynicum* (UF) - 1200-1250 m; the subalpine floor together with the association of dwarf mountain pine *Pinetum mughi sudeticum* (SF) - 1250-1450 m; the alpine floor (mountain pastures) together with the association of *Carici-Festucetum* (AF) - above 1450 m.

Sites of the second research season were located in the following vegetation zones: LF - 12 sites (WS33 Szklarska Poręba), UF - 3 sites (WS33 Czeska Ścieżka, environs of Łabski Szczyt, Kamieńczyk), SF - 2 sites (WS32 Łabski Szczyt, Trzy Świnki), AF - 1 site (WS32 a meteorological station near Śnieżne Kotły).

The number of bumblebees caught and recorded while bees were busy with their activities collecting pollen and nectar, or honeydew during a half an hour period over an area of 2x100 m or 4x50 m, with optimal weather conditions (10:00-17:00 CET, nice weather, air temperature of 19-25°C), was accepted as a calculation unit (a sample). Bumblebees were identified to the species level, mainly in the field with the use of a hand-held magnifying glass (x20). The bees were released afterwards. A sample that was collected in a half an hour time period, was accepted as the smallest representative value describing the hunting ability (density) per 200 m^2 (Pawlikowski, 1992). The total number of collected samples and the total number of bumblebees recorded at the sites in the vegetation floors are presented in Tab. 1. All the samples were used for defining the main parameters of the structure of bumblebee communities.

The structure of each community was described by the number of species (S), the density expressed as an average number of individuals recorded during a 30 min walk in the area of 200 m^2 (D), the index of general species diversity (H') and by the index of potential species diversity (J). Differences between the D values from particular years were statistically assessed with the t-test. The formula of the general species diversity index was accepted after Shannon and Weaver (1963):

$$H' = -\sum p_i \log_2 p_i$$

where $p_i = n_i / N$ and denotes a fraction of the i^{th} species in a community that consists of S species, and n_i stands for the count of the i^{th} species in a community with the total size of N individuals. The potential species diversity index, also known as the evenness index of qualitative species distribution in a community, was accepted after Pielou (1966):

$$J' = H' / \log_2 S$$

where $\log_2 S$ denotes the maximum

value of the H' index (H'$_{max}$). The J' index assumes values within the range of 0 < J' < 1; while decreasing the value till 0 means the increasing tendency of superdomination, and increasing the value up to 1 means the increasing tendency of codomination. The statistical significance of differences between values of the index H' was assessed according to Hutcheson (1970) by applying the formulas of estimation variance and the number of degrees of freedom for estimating the differences between H' values (t-test). In all statistical comparisons, the significance of the difference (P) was accepted at the level equal and not higher than 0.05.

RESULTS

At 30 locations in the Polish Karkonosze Mts, 1064 specimens of 15 species of bumblebees were collected for two seasons (Tab. 1). Most of the individuals were collected at the foothills (FH) and in the lower subalpine forest (LF). There were fewer bees collected in the upper subalpine forest (UF). The least amount of bees was collected in the dwarf-pine floor (SF) and in the alpine-forest floor (AF). The average density (D) of bumblebees in individual zones changed according to an approximate ratio of 10(FH) : 9(LF) : 16(UF) : 7(SF) : 1(AF) in 1989 and 17(LF) : 5(UF) : 4(SF) : 1(AF) in 1994. The number of species (S) in the distinguished communities of bumblebees revealed a similar tendency of variability, i.e. 5(FH) : 5(LF) : 4(UF) : 4(SF) : 1(AF) in 1989 and 2(LF) : 1(UF) : 1(SF) : 1(AF) in 1994. And thus, for 5 years, the habitat attractiveness (expressed by S and D) of vegetation floors developed according to a gradient that decreased together with the altitude. In other words according to a natural gradient, typical for high mountains with properly developed forest floors (Dylewska, 1958).

Foothills and the lower subalpine forest, were considered the most appealing floors. These floors clearly differed in the species composition from other vegetation floors. In communities from FH and LF, the presence of species with a long life cycles was particularly evident: *Bombus hortorum, Bombus lucorum, Bombus lapidarius, Bombus pascuorum*, as well as the presence of one species with a short life cycle - *Bombus soroeensis*. In the less appealing zone of the upper subalpine forest, the aforementioned five species from the foothills were not recorded. The dwarf-pine and alpine floors were the least attractive habitats. Only three species of bumblebees with a long life cycles nested there: *Bombus lucorum, Bombus pascuorum* and *Bombus pratorum*, as well as one species with a short life cycle - *Bombus soroeensis*.

The average density of bumblebees in a community ranged from 16.47 to 1.42 specimens during a 30 min. walk over the area of 200 m^2 in the season of 1989 and 16.91-1.50 specimens in the season of 1994. Thus, it appears that the ranges of density fluctuations were similar during the studied seasons (Tab. 2). Whereas, changes in the density values in particular zones followed a different pattern. In the community from LF a significant increase was recorded, in the communities from UF and SF - a significant drop, and in the community from AF - not significant density values.

Qualitative and quantitative characteristics of the structure of the community of social wasps was described by indices of general (H') and potential (J') species diversity (Tab. 2). Similar H' values were confirmed for the structure of communities from LF and AF. Whereas in the communities from UF and SF, the H' values significantly increased ($P \leq 0.05$). Generally, the structure of the interactive species complex within the higher floors (SF and AF) had simplified, and consequently, despite very low density, high values of $J' \geq 0.8$ were recorded there. Whereas, diversification in the structure of *Bombini* communities was recorded at the foothills and in subalpine forests. In the area of LF and AF, these changes were connected with the decrease of J' values (i.e. the increase of species domination

Table 1

Domination (%N) of bumblebees in floors of vegetation of the Karkonosze Mts. in 1989 (according to Pawlikowski 1992) and 1994

Species	Floors of vegetation																	
	FH		LF				UF				SF				AF			
	1989 n = 10		1989 n = 13		1994 n = 24		1989 n = 15		1994 n = 11		1989 n = 13		1994 n = 13		1989 n = 12		1994 n = 10	
	n_i	%N	n_i	%N	n_i	%N	n_i	%N	n_i	%N	n_i	%N	n_i	%N	n_i	%N	n_i	%N
1. *Bombus hortorum* (L.)	4	3.9	4	3.6	61	16.4	1	0.4	-	-	1	1.1	-	-	-	-	-	-
2. *Bombus hypnorum* (L.)	4	3.9	2	1.8	9	2.4	13	5.2	-	-	1	1.1	-	-	-	-	-	-
3. *Bombus jonellus* (K.)	-	-	-	-	-	-	-	-	-	-	1	1.1	-	-	-	-	-	-
4. *Bombus lucorum* (L.)	2	1.9	11	9.8	51	13.7	20	8.1	11	20.0	14	15.0	7	13.7	4	23.5	6	40.0
5. *Bombus lapidarius* (L.)	11	10.1	1	0.9	22	5.9	-	-	-	-	-	-	1	1.9	-	-	1	6.6
6. *Bombus muscorum* (F.)	2	1.9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7. *Bombus pascuorum* (Scop.)	38	37.6	38	33.9	80	21.5	19	7.6	3	5.5	3	3.2	15	29.4	2	11.7	1	6.6
8. *Bombus pratorum* (L.)	25	24.7	36	32.1	6	1.6	177	71.3	-	-	57	61.3	1	1.9	6	35.3	1	6.6
9. *Bombus ruderarius* (Müll.)	3	2.9	1	0.9	-	-	-	-	-	-	-	-	-	-	-	-	-	-
10. *Bombus soroeensis* (F.)	2	1.9	3	2.6	127	34.1	3	1.2	27	49.1	3	3.2	16	31.3	-	-	6	40.0
11. *Bombus sylvarum* (L.)	3	2.9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
12. *Bombus terrestris* (L.)	7	6.9	6	5.2	7	1.9	2	0.8	-	-	2	2.1	-	-	5	29.4	-	-
13. *Bombus wurfleini* (Rad.)	-	-	16	14.3	3	0.8	13	5.2	3	5.5	11	11.8	-	-	-	-	-	-
14. *Bombus (Ps.) bohemicus* (Seidl.)	-	-	-	-	4	1.0	-	-	1	1.8	-	-	-	-	-	-	-	-
15. *Bombus (Ps.) rupestris* (F.)	-	-	-	-	2	0.5	-	-	10	18.1	-	-	11	21.5	-	-	-	-
Total number of specimens [N]	101	100	112	100	372	100	248	100	55	100	93	100	51	100	17	100	15	100

FH – foothills, LF - lower subalpine spruce forest, UF- upper subalpine spruce forest, SF - subalpine dwarf-pine floor, AF- alpine floor,
n - number of samples, n_i - number of specimens

Table 2

Characteristics of the bumblebee communities in floors of vegetation of the Karkonosze Mts. investigated in 1989 and 1994

Parameters	Floors of vegetation (as in Tab.1)								
	FH	LF		UF		SF		AF	
	1989	1989	1994	1989	1994	1989	1994	1989	1994
Number of species [S]	11	10	11	8	6	9	6	4	5
Density [D]	9.80	8.62	16.91	16.47	5.00	7.15	3.92	1.42	1.50
Tendency of D values [TD]*	-	↑*		↓*		↓*		ns	
Diversity [H']	1.84	1.77	1.78	1.06	1.37	1.00	1.48	1.32	1.27
Tendency of H'values [TH']*	-	ns		↑*		↑*		ns	
Evenness [J']	0.77	0.77	0.74	0.51	0.77	0.46	0.83	0.94	0.87
Tendency of J'values [TJ']	-	↓		↑		↑		↓	

D – mean number of specimens per 30 min. per 200 m^2; TD – tendency of D value changes with the significance level
H' – Shannon index; TH' – tendency of H' value changes with the significance level
J' – Pielou index; TJ' – tendency of J' value changes
value changes: ↓ – decrease, ↑ – increase
*) significance level P ≤ 0.05: ns – not significance

in a community). In the areas of upper subalpine forest (UF) and the dwarf-pine floor (SF) changes were associated with the increase of potential diversity (that is - the decrease of species domination).

As a consequence of transformations over the five years in the communities, the structure of bumblebee communities from the upper subalpine forest and the dwarf-pine floor changed the most. These changes were characterized by decrease in contribution and a decrease in the number of species due to renaturalization of forest areas in the Karkonosze Mts.

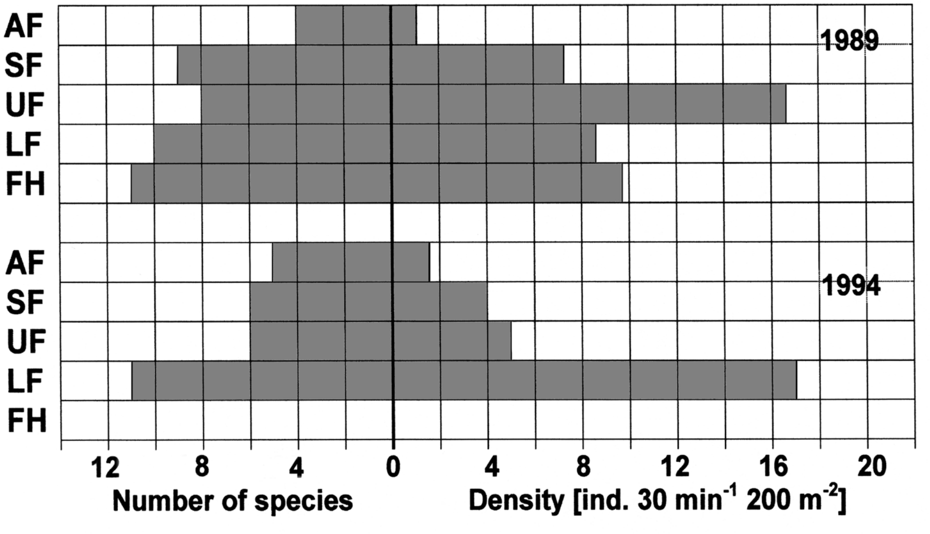

Fig. 1. Qualitative and quantitative changes in the structure of bumblebee communities from the vegetation floors in the Karkonosze Mts determined in 1989 and 1994

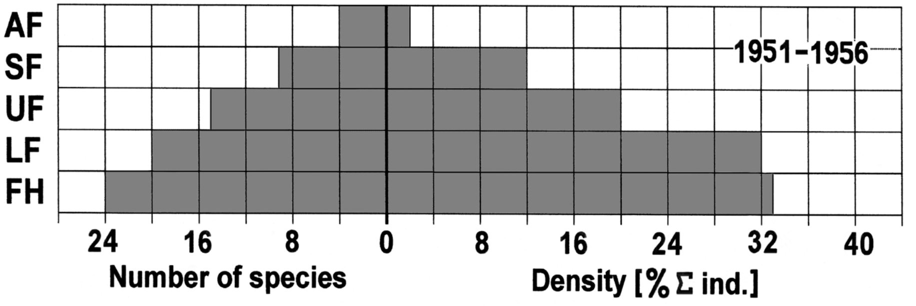

Fig. 2 Qualitative and quantitative changes of bumblebee communities from the vegetation floors of the Tatras according to Dylewska (1958)

DISCUSSION

Subalpine forests in the Karkonosze Mts, which had been degraded by acid rains, became attractive habitats for bumblebees. The main factor, which made the subalpine forests an appealing habitat was the increase in the mosaic of warmer environments of thickets and tall forbs, favourable to the development of bumblebee colonies. Unlike the degraded forests of the Karkonosze Mts, the subalpine forests of the Tatras preserved their natural organization in which, the proportional decrease in the number of species was recorded in the ratio of 6(FH) : 5(LF) : 4(UF) : 2(SF) : 1(AF), as well as the decrease of the relative count (the percentage contribution of species in communities) in the ratio of 16(FH) : 15(LF) : 10(UF) : 6(SF) : 1(AF) (Fig. 2). One can assume that the structure of bumblebee communities in the vegetation floors of the Tatras, represents the optimal dynamics of the species distribution and domination relations in high mountains of Poland. This assumption is mainly supported by the area of the Tatra forests, not devastated during the research period of the 1950s, during which the structure of communities was determined (Dylewska, 1958).

The studied communities of bumblebees in the Karkonosze Mts changed its structure under the influence of new habitat conditions (Fig. 1). This change is particularly true in connection with microclimatic conditions, as well as the spatial organization of vegetation floors. It was proved that subalpine forests, disturbed by clearings, at first significantly affected the decrease of the general species diversity (H') of bumblebees. After a five-year renaturalization process with included planting and self-seedings of spruce, a significant increase in the diversity of bumblebees was recorded in the upper subalpine forest (UF) and the dwarf-pine floor (SF). The increase in bumblebee diversity happened due to a decline in the nutritional attractiveness of these floors, which is proportional to the simplification of the structure of their bumblebee communities.

So, one can state that the observed changes in the dynamics of the structure of bumblebee communities, represent the transitional character of transformations that take place in the reorganized subalpine floors of the Karkonosze Mts. Further successive changes in substitute habitats, on clearings of spruce forests, should make such habitats less attractive for bumblebees. To sum up, together with the restoration of subalpine forest stands in the Karkonosze Mts, the characteristic dynamics of the structure of communities from high mountains of Central Europe, should be preserved in their bumblebee communities.

REFERENCES

Dylewska M. (1958) - The *Bombus* Latr. and *Psithyrus* Lep. fauna of the Polish part of the Tatry Mountains. *Acta Zoologica Cracoviensia*, 3(5): 137-197.

Fabiszewski J. (1985) - Szata roślinna [Vegetation]. [In:] Karkonosze polskie, Jahn A. (ed.), PWN, Wrocław: 191-235.

Hutcheson K. (1970) - A test for comparing diversities based on the Shannon formula. *I. Theor. Biol.*, 29: 151-154.

Pawlikowski T. (1992) - Materiały do studiów nad strukturą zespołów żądłówek (*Hymenoptera, Aculeata*) Polski. 1. Trzmiele (*Bombini, Bombus* Latr.) wschodnich Karkonoszy [The materials to studies on the community structure of *Hymenoptera Aculeata* in Poland. 1. Bumblebees (*Bombini, Bombus* Latr.) of the Eastern Karkonosze Mts.]. *Wiadomości Entomologiczne*, 12(1): 41-44.

Pawlikowski T. (1992a) - Struktura zespołów pszczołowatych (*Hymenoptera, Apoidea*) na obszarach leśnych Kotliny Toruńskiej. [Structure of bee communities (*Hymenoptera, Apoidea*) in forest areas of the Torun Basin]. UMK, Toruń, 115 pp.

Pawlikowski T. (2009) - Structural dynamic of social wasp communities (*Hymenoptera: Vespinae*) in forest areas destroyed by acid rains in the Karkonosze Mountains. *Ecological Questions*, 11: 35-40.

Pielou E.C. (1966) - Shannon's formula as a measure of specific diversity: its use and misuse. *American Naturalist*, 100: 463-465.

Ruszkowski A., Żak B. (1974) - Taśma pokarmowa ważniejszych gatunków trzmieli (*Bombus* Latr.) oraz możliwości ich rozmnożenia. [The feeding-band of more important bumblebee species and possibility of their multiplying]. *Pamiętnik Puławski*, 58 (supl): 27-98.

Shannon C.E., Weaver W. (1963) - The mathematical theory of communication. University of Illinois Press, Urbana, 117 pp.

DYNAMIKA STRUKTURY ZESPOŁÓW TRZMIELOWATYCH (*Hymenoptera*: *Bombini*) NA OBSZARACH LEŚNYCH KARKONOSZY ZNISZCZONYCH PRZEZ KWAŚNE DESZCZE

Pawlikowski T.

Streszczenie

Badano strukturę zespołów trzmielowatych w odstępie pięciu lat na obszarach leśnych Karkonoszy przekształconych kwaśnymi deszczami. Stwierdzono spadek liczby gatunków ze wzrostem wysokości w zbliżonych proporcjach względem naturalnego rozkładu liczby gatunków zarejestrowanego w Tatrach. W dynamice zagęszczenia trzmielowatych pięter roślinnych Karkonoszy odnotowano istotne dwukrotne podwyższenie wartości dla lasu dolnoreglowego, trzykrotne obniżenie wartości dla lasu górnoreglowego oraz dwukrotne obniżenie wartości dla kosodrzewiny. Wypadkową tych zmian był istotny wzrost ogólnego zróżnicowania (H') w reglu górnym i piętrze kosówki, co wynikało z wyrównywania rozkładów częstości poszczególnych gatunków w zespołach. Obserwując postępującą sukcesyjną odbudowę lasów można przyjąć, iż stwierdzone zmiany struktury zespołów trzmielowatych reprezentują ich stan przejściowy. Ostatecznie w miarę odbudowy zniszczonych drzewostanów powinien utrwalić się w zespołach trzmielowatych charakter dynamiki wysokich gór Europy Środkowej.

Słowa kluczowe: *Hymenoptera, Bombini*, trzmielowate, struktura zespołu, lasy, Karkonosze.