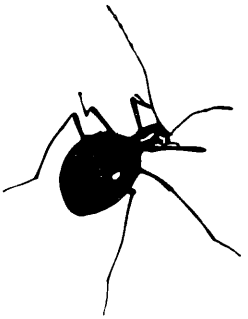

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GROUND BEETLE (COLEOPTERA: CARABIDAE) FAUNA OF TWO OAK WOODS WITH TWO DIFFERENT WATER BALANCES

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Abstract The community structure of ground beetles had been explored on two sampling sites within the Zoological reserve Varoški Lug, situated in the plain part of Croatia at an average altitude of 105 m. Two plant subcommunities have been chosen for research: *Genisto elate-Quercetum roboris caricetosum remotae* (VL1) and *Genisto elate-Quercetum roboris caricetosum brizoides* (VL2) from the order *Populetalia albae*. 29 species of ground beetles with 6469 specimens have been recorded. The dominant species are *Carabus ullrichi, C. granulatus, C. violaceus, Pterostichus melas* and *Abax parallelus*. Although the distance between the sampling areas is very short and there are no obstacles which could prevent the mixing of the faunas of the two sites, their fauna is different. This difference is evident from species which inhabit the certain site, but especially by the population abundance and the annual cycles. The diversity of both communities is very high but it is higher at the site VL2. The site VL1 has acid soil with high moisture due to the underground waters especially in spring and summer. The soil at the site VL2 is pseudogley characterized by the occasional moisture with different duration of the dry and the moist phase. Once or twice a year the site VL1 is flooded. Water in the soil is an ecological factor which influences the ground beetle fauna the most, so it is possible that longer retention of water at the site VL1 is less favourable to the species dominant at the site VL2. The share of the flying species is high in both communities. Since the sampling sites are surrounded by open biotopes there is also a great number of species inhabiting open habitats or the species indifferent to the shaded habitats. The high underground waters combined with the continental climate are favourable to the hygrophilic species. The annual cycles of the beetle numbers at the site VL1 shows greater regularity than that at the site VL2. The maximum specimen activity of all

species at the site VL1 is in May and June. After that the number of specimens rapidly drops. The number of beetle specimens of all species at the site VL2 is high during the whole year. The activity starts in April and lasts till September.

KEY WORDS: ground beetles, community structure, flooded oak woods, population dynamics, habitat selection

Izvleček – FAVNA KREŠIČEV (COLEOPTERA: CARABIDAE) DVEH HRASTOVIH GOZDOV Z DVEMA RAZLIČNIMA VODNIMA REŽIMOMA

Raziskali smo sestavo združb krešičev na dveh vzorčevalnih mestih v zoološkem rezervatu Varoški lug, ki se nahaja na ravninskem delu Hrvaške, na povprečni višini 105 m. Za raziskavo smo izbrali dve rastlinski podzdružbi: *Genisto elate-Quercetum roboris caricetosum remotae* (VL1) in *Genisto elate-Quercetum roboris caricetosum brizoides* (VL2) iz reda *Populetalia albae*. Našli smo 29 vrst krešičev s 6469 primerki. Prevladujoče vrste so *Carabus ullrichi, C. granulatus, C. violaceus, Pterostichus melas* in *Abax parallelus*. Čeprav je razdalja med vzorčevanima območjema zelo majhna in ni ovir, ki bi lahko preprečevale mešanje favn obeh mest, se njuni favni razlikujeta. Razlika se kaže v vrstah, ki poseljujejo posamezno območje, predvsem pa v gostoti populacij in letnih ciklih. Raznovrstnost obeh združb je zelo velika, vendar je višja na mestu VL2. Mesto VL1 ima kisla tla, močno namočena s talno vodo posebno spomladi in poleti. Prst na mestu VL2 je psevdoglej, za katerega je značilna občasna namočenost z različnimi dolžinami suhega in mokrega obdobja. Mesto VL1 je enkrat ali dvakrat na leto poplavljeno. Vsebnost vode v tleh je ekološki dejavnik, ki najmočneje vpliva na favno krešičev, zato je možno, da je daljše zadrževanje vode na kraju VL1 manj ugodno za vrste, ki prevladujejo na mestu VL2. Delež letajočih vrst je visoko v obeh združbah. Ker so vzorčevalna mesta obkrožena z odprtimi predeli, je veliko tudi vrst, ki naseljujejo odprte življenjske prostore ali vrst, ki jih osenčenost ne moti. Visoka podtalnica skupaj s celinskim podnebjem je ugodna za vlagoljubne vrste. Letni cikli števila hroščev na mestu VL1 kažejo večjo rednost kot na mestu VL2. Največja dejavnost primerkov vseh vrst na mestu VL1 je v maju in juniju. Pozneje se število primerkov močno zmanjša. Število primerkov hroščev vseh vrst na kraju VL2 je visoko skozi vse leto. Dejavnost se začne v aprilu in traja do septembra.

KLJUČNE BESEDE: krešiči, sestava združb, poplavni hrastovi gozdovi, populacijska dinamika, izbira habitatov

Introduction

The beetle fauna of certain area results from the interaction of biotic and abiotic environmental factors in recent and historic periods. It is hard to determine which of these factors is vital for the presence of some species and for the forming of the com-

munity in certain area. However, the choice of explored sampling sites differing only in one abiotic factor which causes also some changes in the composition of the biocenosis of this area, enables better insight into the species demands and into the possible reasons of their presence at the site.

The flooded forests are specific habitats which are due to the occasional stagnant waters suitable for species which are hygrophylous or wide-spread. The ground beetle species dwelling here vary from the species of other wood habitats but they can be found also in the open habitat. The oak woods of the plain part of Croatia are influenced by the water level of the Sava and the Drava rivers. As there are certain plans for building a flood-gate for hydro-electric power plant which would change the water level in the woods we were interested to investigate how would that reflect on the ground beetle fauna because they lead the majority of their life cycles in the ground. The soil moisture and the humidity of the air layer near the ground are extremely important factors in limiting distribution of the ground beetles as well as the water balance (Thiele 1977, Fuellhass 2000).

This research had been made in two sampling sites, one not far away from the other. First chosen wood is flooded twice a year due to the high underground waters (VL1). Another sampling site (VL2) is not under the influence of the underground waters, but the moisture is here also high during the whole year. This research has been carried out in the area where the moisture quantity, respectively the annual water balance is the prevailing distinguishing factor, while other factors (as: temperature, altitude, inclination) are the same. The difference in water quantity in the habitat causes also differences in the composition of the plant component, but this is the secondary characteristic of the community. Also the composition of the ground beetle fauna and the annual cycles of the dominant and subdominant species had been explored, so that one can see in which way the community structure is changed depending on the difference of the water balance.

Study area

The Zoological reservation "Varoški lug" is situated in the north-western part of the Republic of Croatia, in the plains of the south-western part of the Bjelovar basin (Mayer 1994). Its ackerage is 843 ha close to the Glogovnica river regulated by high dams. In the reservation two sampling sites have been chosen: Varoški lug 1 (VL1) and Varoški lug 2 (VL2). Both sites are at an average altitude of 105 m (Basch 1983) and on the plain ground. The soil of the site VL1 is a pseudogley characterized by the occasional stagnant moisture with different durations of the moist and the dry phase. The soil on the sampling site VL2 is acid soil with high moisture contents due to the high underground waters especially in spring and summer. Once or twice a year the site VL1 is flooded. In the sampling area two plant subcommunities have been chosen for research: *Genisto elate-Quercetum roboris caricetosum remotae* (VL1) and *Genisto elate-Quercetum roboris caricetosum brizoides* (VL2).

Material and sampling methods

The ground beetle fauna has been collected by the pitfall traps (Dahl 1896, Barber 1931). Although Briggs (1961) and Löser (1972) are of the opinion that this method can be used only in the faunal research, less ancient investigations of Baars (1979), Den Boer (1982) and Braid & Panizzi (1994), shows that the results achieved by this method can be used in the quantitative research of the ground beetles in the habitat. Twenty pitfall traps have been put on both sampling sites far from the edge, in order to avoid the edge effect. They have been placed in four rows, five pitfalls each. The distance between the traps was 7 m, and between the sampling sites about 500 m. The traps are made of plastic, cone shaped, upper opening diameter 10 cm, volume 0,5 l. As killing and preserving fluid the mixture of ethanole, water and vinegar has been used, because it has been recommended by authors who used this mixture in earlier research of this and neighbouring areas (Brandmayer et al. 1983, Drovenik 1978, Durbešić 1982, Vujćić-Karlo 1999, etc.).

The pitfall traps were exposed at each sampling site during two seasons in the years 1991 and 1993. They were exposed from the period the water withdraw from the site VL1 until the period when it flooded the site VL1 again. Therefore, in spite of the problems in connection with the interpretation of the results gained by this method of collection, and due to the fact that the research lasted two years and that the sampling sites covered rather big area and were far from the edge, what reduced the edge effect, the results show the real status of the ground beetle community abundance as well as their activity during the year.

The ground beetle determination was done according to Freude et al. 1976, Kuhnt 1911, Reitter 1908, Trautner & Geigenmüller 1987.

On both sampling sites the abundance of species has been determined. On each site the possible number of species has been determined by the Jacknife estimate method (Krebs 1989), the variance of number of species and the method reliability limits. The number of possible species determined by this method has been mainly overestimated and according to Krebs (1989) the method cannot be used if the expected number is twice the determined one. For this estimate the programme RICHNESS from the package KREBS has been used.

In the cases where the final number of species is not known as in this research, Krebs (1989) recommends Brillouni index for the estimate of the community diversity. This index is most sensitive to the species abundance with small number of individuals. The programme DIVERS from the KREBS package has been used for the estimate. The faunistic similarity of the researched communities (Jaccard and Sörensen) has been estimated according to Krebs (1989) with the programme SIMILAR from the Krebs package. All the diagrams have been made in the programme STATISTICA.

Results

During the two years of research on two sampling sites 6469 individuals and 29 species of ground beetles have been collected (Tab 1). Due to the catch efforts used, from the established number of species, the expected number of species has been estimated by the Jackknife estimate method. This number has not shown considerable divergence in regard to the established number. On the site VL1 25 species have been determined and 28,8 species are being expected (min.-max 24,1-33,5; st.dev. 2,22). On the site VL2 22 species have been determined and 27,2 species are being expected (min.-max. 23,5-31,9; st.dev. 2). 11 species have been found only on one site. Due to the great number of mutual species the faunistic similarity is considerable and amounts to: 0,6206896 (Jaccard) and 0,7659574 (Sörensen). For the determined species, the data on some morphological characteristics of the species have been collected from the literature (Tab.1).

The annual cycles have been monitored only in the species, which in one of the research years have been in the group of the dominant or the subdominant species, that is they have been represented by more than 1% in the sample (Fig.1, Fig.2). On the sampling site VL1 two species are dominant: *Carabus ullrichi* and *C. granulatus*, and on the station VL2 five species: *Abax parallelus*, *C. coriaceus*, *C. ullrichi*, *C. violaceus* and *Pterostichus melas*. The annual cycles of most of the species on the same site has not been considerably different within the two years of research. The dominant species at the sampling site VL1 have reached the activity peak mainly in spring (May-June). On the site VL2 except this increased spring activity there exists also the autumn activity which for example at species *C. urllichi* and *P. melas* is higher than the spring one. Only the species *C. coriaceus* and *C. cancellatus* have the similar annual cycles on both sites. It is interesting to mention that the species *C. coriaceus* is the only one which on the site VL1 has an increased activity in autumn and not in spring period. The species *C. ullrichi* has completely different cycles on the sites. This could be the result of the considerably smaller number of individuals observed at the site VL2. On the site VL2 besides the increased spring activity there comes also to the increased autumn activity, which could be in connection with the drop of the number of individuals at the site VL1. It is quite possible that the increase of the numbers has been caused by the ground beetles passing over from the low areas to the higher ones, which would not be flooded. *C. granulatus* on the VL1 has the highest activity end of June and on the VL2 there are three activity peaks, the 140th the 220th and the 290th day. *C. violaceus* on the VL2 has got only one peak at the same time as on the site VL1 but the number is more constant during the season than on the earlier mentioned site. *Ag. krynickii* and *Ab. carinatus* also on the VL2 have got besides the spring activity peak the autumn one too but the latter is considerably lower. On the VL1 they have got only one peak. *Ab. parallelus* has different annual cycles on both sites. On VL1 this species has been represented by smaller number of individuals than on VL2. On the VL2 this species has got two peaks in spring, end of March and in autumn beginning of October. On the VL1 the highest

activity has been noted beginning of October. *Pterostichus ovoideus* on the VL 1 has got the highest activity also at the beginning of October and on the VL2 in May and beginning of June. *P. melas* and *P. niger* in the group of species represented by more than 1% have been observed only on the VL2. *P. melas* is most active in late spring, in June, and *P. niger* has got two peaks also in June and October.

Discussion

Although the ground beetle communities on these sites live at small distances and there are no greater geographical obstacles which would hinder the mixing of the faunas of these two sampling sites, their faunas are different. This difference is not so much evident in the species inhabiting certain site. The number of species found at only one sampling site as single specimens is not small. Considering their ecology they are most probably the colonial species of the neighbouring open habitats.

The faunistic differences between these two sampling sites are characterized also by the fact that the different species are dominant on each site. The certain developing stages of these species are differently sensitive to moisture. On the site VL1, which has been flooded once or twice a year (in spring and autumn) there are only two species in the dominant species category: *C. granulatus* and *C. ullrichi.* The conditions on this site are more extreme and are under influence of underground waters of the Glogovnica River and precipitation. On the sampling site VL1 we find the pseudogley characterised by the occasional stagnant moisture with different durations of the dry and wet phase, whereas VL2 has also very moist soil but without the stagnant moisture. If we examine the absolute numbers of individuals recorded on the sampling sites we can see that the number of individuals of species *C. granulatus* and *C. ullrichi* dominant on VL1 is lower than on the site VL2. The total number of individual ground beetles recorded on the site VL1 is almost twice as low as on the site VL2.

The diversity of both communities is high (Brillouini index: VL1-2,141; VL2-2,928) but on the site VL2 it is higher than of the site VL1. The water in the soil is the ecological factor which has the greatest influence on the ground beetle fauna (Eyre & Luff 1990). It is possible that the longer retaining of water at the site VL1 is less favourable to the species dominant on the site VL2. The portion of ground beetle species that can fly is very high in both communities. The species *C. granulatus* is the only species from this genus that can fly, and the larvae of the species *C. ullrichi* can live up to three months in water at low temperatures. Other ground beetle species observed in this area have no larvae with this kind of adaptation, so maybe this is also the cause of their lower abundance on this site. Since the researched sites have been surrounded by open habitats – plough fields and the shores of the Glogovnica River, there is great portion of the species of open habitats or the species indifferent to the shading. The great quantity of the underground waters is suitable to the hygrophilic species in combination with the continental climate and the mesothermophilous species.

The ground beetle activity becomes the highest in May and June. This is the period when water completely withdraws from the site VL1 and the soil dries a little due to the average air temperature between 15°C and 20°C. Although in May there are no high underground waters, the moisture on either of the sites is not low, primarily because of the constant presence of the Glogovnica River and secondly due to the increased rainfall in this period. The annual cycles of the ground beetle individuals on the site VL1 shows greater regularity than on the site VL2. The maximum activity of the individuals of all beetle species on the site VL1 goes on in May and June and after that the number of individuals rapidly drops. The number of individuals of all ground beetle species on the site VL2 is high during the whole year. It starts in April and lasts till September when it reaches its maximum. The seasonal flooding of the station VL1 obviously influences the beetle fauna which occur on it. The various species can survive the flooding period in different ways.

So for example Fuellhaas (2000) who explored the influence of the flooding waters on the ground beetle fauna of natural meadow habitats and cultivated (tilled) soils, says that in the natural not cultivated soils there is a layer in which during flooding the air is retained. Many species as for example *C. granulatus* can in the adult stage survive in this layer for longer time. The adult individuals of this species (acc. to the same author) can survive flooding by climbing the trees. In Varoški lug where the area of beds and microdepressions exchange in relatively small distance, it is possible that the individuals during flooding simply move from the lower to the higher areas and vice versa. In this way the difference in the annual cycles on this sites can be explained. It is possible that the individuals go from the site VL2 to VL1, and then with the increase of the soil humidity and with the drop of temperature the new generation which could develop after the reproduction in April in May, goes over to the drier habitats. In this way it is possible that the flooding of VL1 influence also the annual cycle of raised areas because the beetles move into these areas. The most sensitive larval stages needing a lot of food could be developed also in the flooded areas where the competition with the larvae of other species from the genus is not so fierce. Günther & Assmann (2000) studied if there were the competition between the four related species from the genus *Carabus* in wood communities and they came to the conclusion that the competition between the co-occurring species which are taxonomically closely related, was reduced by the increase of some differences in biology. However since some of these species have not yet reached the evolution degree in which they would occupy completely different niches, they are partly corresponding.

The ground beetles can adapt to extreme conditions in the flooded area either by submergence during inundation, or by climbing the trees, or they are easily mobile and can quickly fly off (Bonn 2000). The ability of movement is very important for the species living in flooded areas or in the area on the border between water and land. The species of flooded and especially swamp areas are in general better fliers than the species of other habitats. From the Tab.1 it is obvious that on the researched sites there are a lot of easily mobile species. The marsh stands are inhabited by the

ground beetle species being good fliers, in distinction from other areas where these species need not make the majority. Alone the activity of flying is connected with weather conditions (wind, rain) as well as with the flooding cycles. Besides the fact that the flying species can quickly abandon the habitat under the penetration of water, they are also able to be the first to colonize newly created dry area after withdrawal of water. This is a favourable characteristic, because in this area a lot of dead water organisms can be found which remained on the dry land, and also a lot of land organisms which drowned during flooding. The areas from which the water withdrew not a long time ago, are suitable for laying of eggs due to their high moisture degree, what is of essential importance for the sensitive egg stages and for the first larval stages.

Since the use of total biota for assessing impact of human activities over large area is simply impossible as there are too many species and insufficient taxonomic knowledge (Niemelä & Kotze 2000), ground beetles are due to their numerous characteristics suitable for an estimate of the status of a certain ecosystem.

Conclusion

The two investigated oak woods with different water balances differ not much in ground beetle fauna. The greatest differences were observed in seasonal activity. Also, different species were dominant in different woods. Oak wood flooded twice a year has smaller biodiversity and smaller number of specimens especially in autumn period. We consider that they move to the surrounding elevated places where they hibernate and autumn breeders lay their eggs. The changes of water level, which would cause the irrigation of the woods in large area few times a year, would cause changes in the ground beetles fauna in the foreseeable future.

Aknowledgements

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Tab. 1: Abundance of ground beetles (two years sampling period) and some morphological and ecological characteristics of ground beetle species recorded on the researched sites: VL1- *Genisto elate-Quercetum roboris caricetosum remotae*; VL2- *Genisto elate-Quercetum roboris caricetosum brizoidis.*
Legend: A - alae (br - brachipterous, di – wing dimorphic, ma - macropterous), B - colour (- - without metallic lustre, + - with metallic lustre), C - development (sb – spring breeders, ab – autumn breeders, bi - bimodal), D - moisture (hy – hygrophilic, mh - mesohygrophylic, xe - xerophilic), E - temperature (mt - mesothermophilic, thtthermophilic), F - habitat (1- stenotopic, 2- eurytopic), G - vegetation (f – forest, m - meadow, r - riparian)

	SPECIES	VL1	VL2	A	B	C	D	E	F	G
1	*Abax carinatus*	43	64	br	-	sb	hy	mt	e	f,m
2	*Abax parallelus*	120	505	br	-	sb	hy	mt	e	f
3	*Agonum assimilis*	1	5	ma	-	sb	hy	mt	e	f,r
4	*Agonum krynickii*	124	46	ma	-	sb	hy	mt	s	f,r
5	*Agonum livens*	29	9	ma	-		hy	mt	s	f,r
6	*Agonum obscurum*	7	1	di	-		hy	mt	e	f,r
7	*Agonum scrobiculatum*	9		br	-	ab	hy	mt	s	f
8	*Agonum sexpunctatum*	2	2	ma	-	sb	hy	mt	c	m
9	Amara sp.	6								
10	*Bembidion dentellum*		1	ma	+	sb	hy	mt	e	m,r
11	*Calosoma inquisitor*	2		ma	+	sb	mh	mt	e	f
12	*Carabus cancelatus*	103	72	br	+	bi	hy	mt	c	f,m
13	*Carabus coriaceus*	97	312	ma	-	bi	xe	mt	e	f,m
14	*Carabus granulatus*	444	138	di	-	bi	xe	mt	e	f,m
15	*Carabus ullrichi*	2098	201	br	-	sb	mh	tht	e	f,m
16	*Carabus violaceus*	152	897	br	-	ab	mh	tht	c	f,m,r
17	*Chlaenius nigricornis*		1	ma	+	sb	hy	mt	e	m,r
18	*Drypta dentata*	1		ma	+	sb	hy	mt	e	f,m
19	*Dyschirius globosus*	7	1	di	-	sb	hy	mt	e	f,m
20	*Gynandromorphus etruscus*	1								
21	*Harpalus rufipes*	5	24	ma	-	ab	mh	tht	e	f,m
22	*Harpalus scaritides*	8	18		-		xe			m
23	*Poecilus cursorius*		1	ma	+				e	f,m
24	*Pterostichus melanarius*		1	di	-	ab	mh	mt	e	f,m
25	*Pterostichus melas*	28	647	br	-		mh	mt	c	f,m
26	*Pterostichus niger*	19	112	di	-	ab	hy	mt	e	f,m
27	*Pterostichus nigrita*	11		ma	-	sb	mh	mt	e	f,m
28	*Pterostichus ovoideus*	59	34	di	-		mh	mt	e	f,m
29	Zabrus sp.	1								
	Σ	3377	3092							
	S	25	22							

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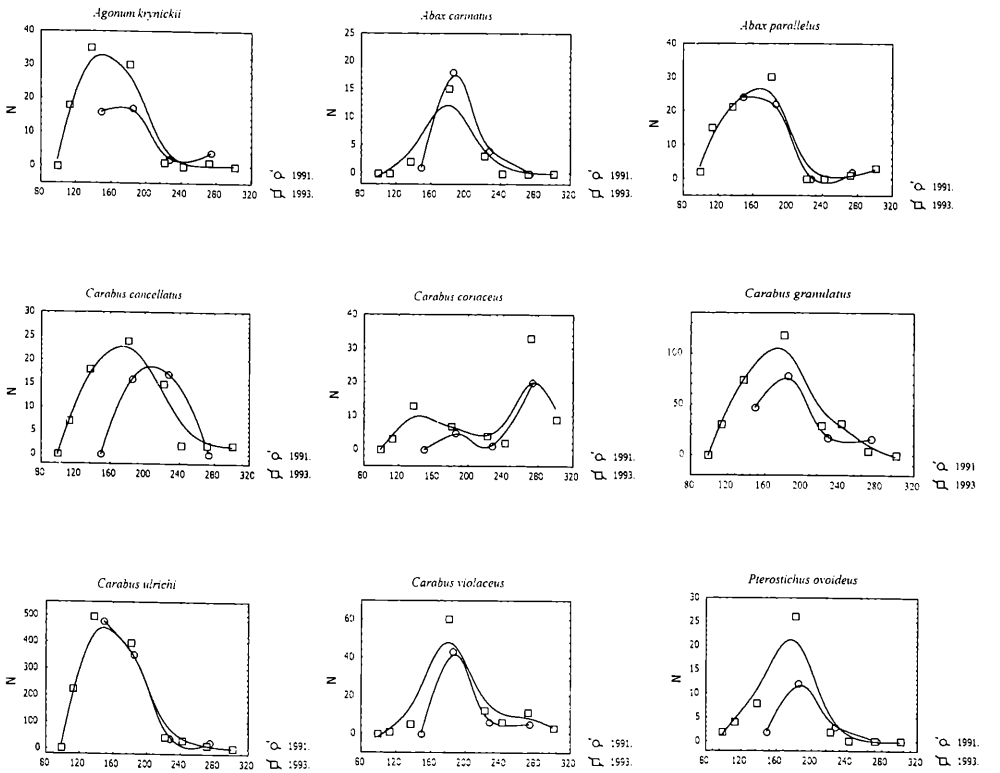

Fig. 1: Annual cycles of dominant and subdominant species on the site Varoški lug 1 (VL1) in the community *Genisto elate-Quercetum roboris caricetosum remotae* during two years.

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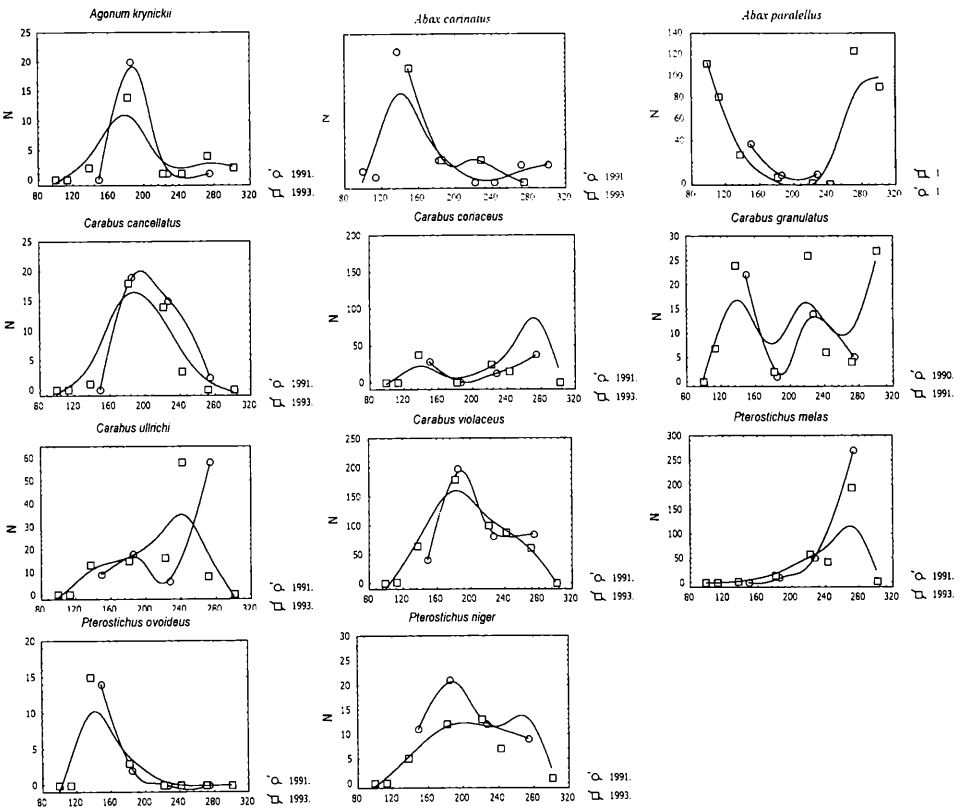

Fig. 2: Annual cycles of dominant and subdominant species on the site Varoški lug 2 (VL2) in the community *Genisto elate-Quercetum roboris caricetosum brizoidis* during two years.

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