THE USE OF MALACOLOGICAL ANALYSIS IN STUDIES ON ANTHROPOGENIC TRANSFORMATIONS IN MICROHABITATS: AN EXAMPLE FROM THE CRACOW REGION, SOUTHERN POLAND

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With 9 figures and 2 tables
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Summary: The presented study is dedicated to the assessment of the scope and degree of anthropopressure, and the dependence of its intensity on the characteristics and nature of micro-environments. The research was based on the subfossil remains of molluscs. Eleven profiles of Late Holocene sediments in the Dulówka valley near Cracow were subjected to malacological analysis. In the upper part of the valley, there are calcareous tufas containing rich molluscan assemblages with a large share of shade-loving species. In the lower part, malacofauna dominated by open-country snails occurs in fluvial sediments. Radiocarbon dating has shown that mollusc-bearing deposits represent the last 2,000 years. The diversity of ecological features of molluscan assemblages in different parts of the valley depends on the intensity of anthropopressure. In the upper part, natural forest communities have survived to the present day, and anthropopressure has only been marked to a limited extent. The lower section has undergone a major transformation, mainly due to deforestation and the development of agricultural areas. Unfavorable terrain conditions for the human economy should be considered the major cause of the low anthropopressure intensity in the upper part of the valley. The malacological analysis used in the study allowed showing a significant diversity of microhabitats within the valley and its uneven susceptibility to human interference in natural processes.

Zusammenfassung: Die vorliegende Studie widmet sich der Beurteilung des Umfangs und des Ausmaßes der anthropogenen Beeinflussung sowie der Abhängigkeit ihrer Intensität von den Merkmalen und der Art der Mikro-Umgebung. Die Forschung basiert auf subfossilen Überresten von Mollusken. Elf Profile spätholozäner Sedimente im Dulówka-Tal bei Krakau wurden einer malakologischen Analyse unterzogen. Im oberen Teil des Tals befinden sich kalkhaltige Tuffe, die reiche Molluskenansammlungen mit einem großen Anteil an schattenliebenden Arten enthalten. Im unteren Teil tritt von Freilandschnecken dominierte Malakofauna in fluvialen Sedimenten auf. Radiokarbondatierungen haben gezeigt, dass die molluskenhaltigen Ablagerungen die letzten 2.000 Jahre repräsentieren. Die Vielfalt der ökologischen Merkmale der Molluskenansammlungen in den verschiedenen Teilen des Tals hängt von der Intensität des anthropogenen Drucks ab. Im oberen Teil haben sich bis heute natürliche Waldgesellschaften erhalten, die nur in geringem Maße anthropogen beeinflusst wurden. Der untere Teil hat sich hingegen stark verändert, vor allem durch die Abholzung von Wäldern und die Erschließung von landwirtschaftlichen Flächen. Ungünstige Geländebedingungen für die menschliche Wirtschaft dürften als die Hauptursache für die geringe anthropogene Überformung im oberen Teil des Tals angesehen werden. Die verwendete malakologische Analyse ermöglichte es, die Vielfalt unterschiedlicher Mikrohabitate innerhalb eines Talsystems herauszuarbeiten und deren unterschiedliche Überprägung durch anthopogne Einflüsse aufzuzeigen.

Keywords: malacofauna, anthropopressure, calcareous tufa, fluvial sediments, landscape history, Late Holocene, Poland

1 Introduction

Human activity affecting the environment is referred to as anthropopressure. The basic factor determining its scale and intensity is the number and density of the human population. Generally, the larger and more advanced the population inhabits a given area, the stronger and more complete anthropopressure is, covering and transforming all types of natural habitats. On most of the Earth's surface, human activity is rather more selective. Areas with favorable natural conditions are transformed first. Less attractive zones are transformed later and often to a lesser extent. This regularity can be observed both today and in the geological past. In the latter case, the effects of anthropopressure are preserved in the sediments and the fauna and flora communities found in them.

The intensity of anthropopressure over large areas can be analyzed using a variety of methods. Trying to assess human activity on a local scale is much more difficult. The possibility of reconstructing microhabitats is of vital importance for learning about natural processes, as well as for recognizing

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the extent of human impact on the environment. One of the methods used in the study of microhabitats is malacological analysis. Mollusc species show attachment to specific types of natural habitats. Most species produce a calcium shell that is preserved in sediments. However, certain conditions must be met. Firstly, the sediments should have an increased calcium carbonate content, which hinders the chemical dissolution of shells. Secondly, the decomposition of the shell's organic components following the death of an organism adversely affects its resistance to mechanical damage. Therefore, shells are usually not preserved in sediments accumulated in high-energy environments (Alexandrowicz and Alexandrowicz 2011; Lyubas et al. 2019). As a result of the aforementioned restrictions, the composition and structure of subfossil malacocenoses is consistent with local conditions prevailing during sedimentation. Consequently, malacological analysis allows reconstruction of microhabitats with accuracy difficult to achieve using other methods (Alexandrowicz and Alexandrowicz 2011; Allen 2017; Alexandrowicz et al. 2018).

Malacological analysis is often used for the reconstruction of microhabitats in relation to areas where environmental changes occur rapidly, often in a short time. Such a course of habitat transformation is particularly characteristic of the phases of intense anthropopressure, the most glaring manifestation of which is extensive deforestation. It leads to the replacement of primary shady habitats by secondary open and often dry meadow biotopes. Such processes were documented based on changes in the composition and structure of mollusc communities at numerous sites throughout Europe (e.g. Juřičková et al. 2013; Alexandrowicz 2013, 2019a, b, 2020; Granai and Limondin-Lozouet 2014; Gallmetzer et al. 2017; Jamrichová et al. 2018).

The presented article considers two elements. Firstly, it shows environmental changes generated by natural and anthropogenic factors on the marginal, southern edge of the Cracow-Częstochowa Upland. The second, more universal and primary purpose of the study is to present the possibilities of using malacological analysis in microhabitats reconstruction. In this aspect, special emphasis will be placed on the role of human activity as one of the major factors determining environmental changes. The possibility to reconstruct microhabitats will also allow for classifying the diversity of duration and intensity of anthropopressure, depending on the natural environment's original features.

2 Study area

The Cracow-Częstochowa Upland is located in southern Poland. Its base comprises Triassic and Jurassic limestones with Paleozoic formations. i.e. Upper Devonian and Lower Carboniferous limestones and Permian volcanic rocks playing a minor role. On the interface between Cretaceous and Palaeogene, a monocline has formed, leaning and gently sloping to the north-east direction. In the Early Neogene, the Carpathian Flysch Belt came to the southern edge of the Upland. As a result, numerous faults were created, forming a system of horsts and tectonic ditches (e.g. Gradziński 1974; Rutkowski 1989). In the Quaternary, the Upland area was covered by loess, with a thickness of several meters. Currently, the Cracow-Częstochowa Upland is a plateau with a gentle, hilly relief cut through with wide, flat-bottomed valleys. Only its southern edge is characterized by steep slopes and narrow, partly rocky valleys with significant falls (Walczak 1965).

The relatively gentle relief, favorable weather conditions and the presence of fertile soil allowed the area of the plateau of the Cracow-Częstochowa Upland to be inhabited by people rather quickly. Traces of human activity are marked in the Neolithic, together with the arrival of the first agricultural cultures (e.g Kruk et al. 1996; Kruk and Milisauskas 1999; Gradziński et al. 2017; Moskal del-Hoyo et al. 2017, 2018). The necessity to secure arable land forced deforestation, which could be seen in vast areas of the plateau but only slightly affected the southern edge of the Upland. This was undoubtedly associated with unfavorable terrain conditions in this area. This trend is clearly visible in many profiles described from Cracow-Częstochowa Upland in terms of both sediment lithology as well as fauna and flora accumulations present therein (e.g. Alexandrowicz 1983, 1992, 1997; Rutkowski 1987; Rutkowski and Starkel 1989; Alexandrowicz et al. 1997; Alexandrowicz 2004, Alexandrowicz and Skoczylas 2017). The intensity of anthropopressure in the southern part of the Upland only becomes noticeable in the early Middle Ages and is associated with increased settlement and significant demographic growth.

The research presented in this article was carried out in the valley of the Dulówka Stream, between the villages of Psary and Karniowice, approx. 30 km west of Cracow (Fig. 1). The Dulówka Stream cuts through the southern edge of the Cracow-Częstochowa Upland. Its source section is located on a flat, deforested plateau. The middle part is a nar-

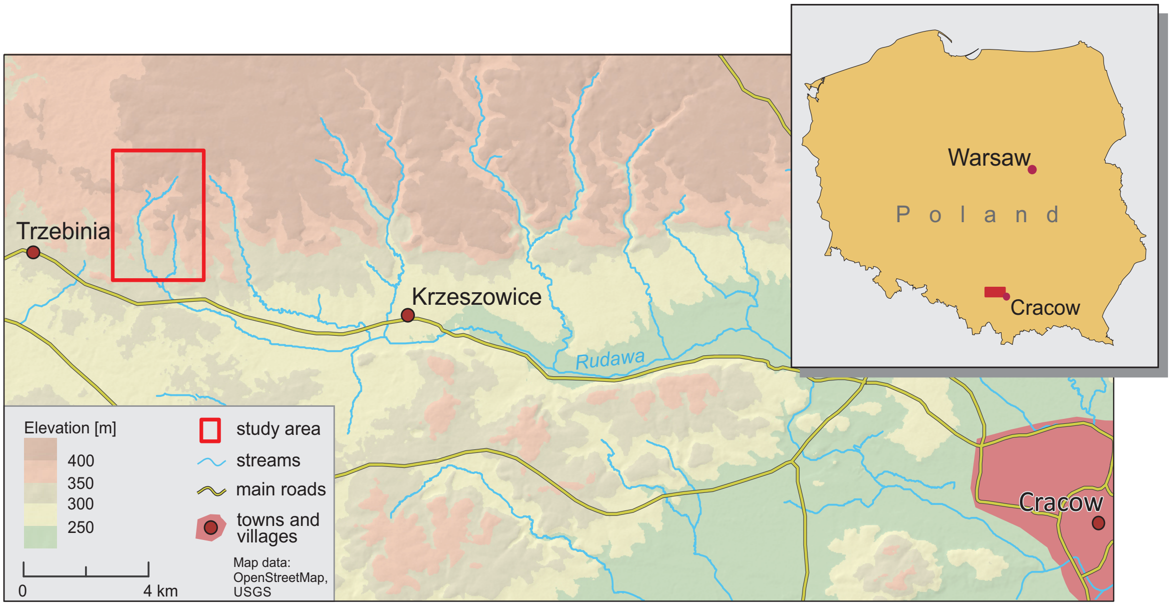

Fig. 1: Location of study area

row valley with steep banks and a relatively major slope covered with mixed forests, and its bottom – with shrub thickets with a large share of alder and willow. The lower section has a flat, wide bottom, gentle banks, and a slight gradient. There is a low terrace stretching along the riverbed. Its surface is completely deforested and used for agriculture as arable land or pastures, and large parts are occupied by settlement areas. (Fig. 2 and 3).

3 Material and method

Malacological analysis included 74 samples taken from 11 profiles (Ps-I - Ps-XI, Fig. 2 and 3). Mollusc shells were found in 46 samples. The remaining 28 samples did not contain detectable shell fragments.

Shell material designations were made based on keys (Wiktor 2004; Welter-Schultes 2012; Horsák et al. 2013). The number of individual species was determined in each sample. The shell material was subjected to standard malacological analysis (Ložek 1964; Alexandrowicz and Alexandrowicz 2011). Individual taxa were classified into ecological groups according to the scheme described by Ložek (1964), Alexandrowicz and Alexandrowicz (2011) and Juřičková et al. (2014). The percentage shares of ecological groups were the basis for constructing malacological diagrams. The diversity of fauna communities has been illustrated in triangular diagrams. In the analyzed material, mollusc communities were

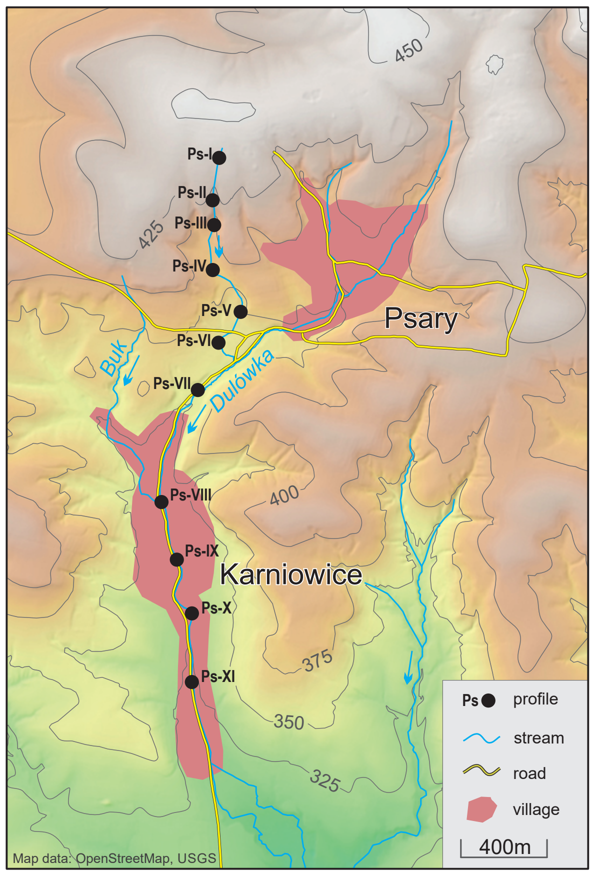

Fig. 2: Hypsometric map of the study area and location of sampling profiles Ps-I - Ps XI in the valley of the Dulówka Stream

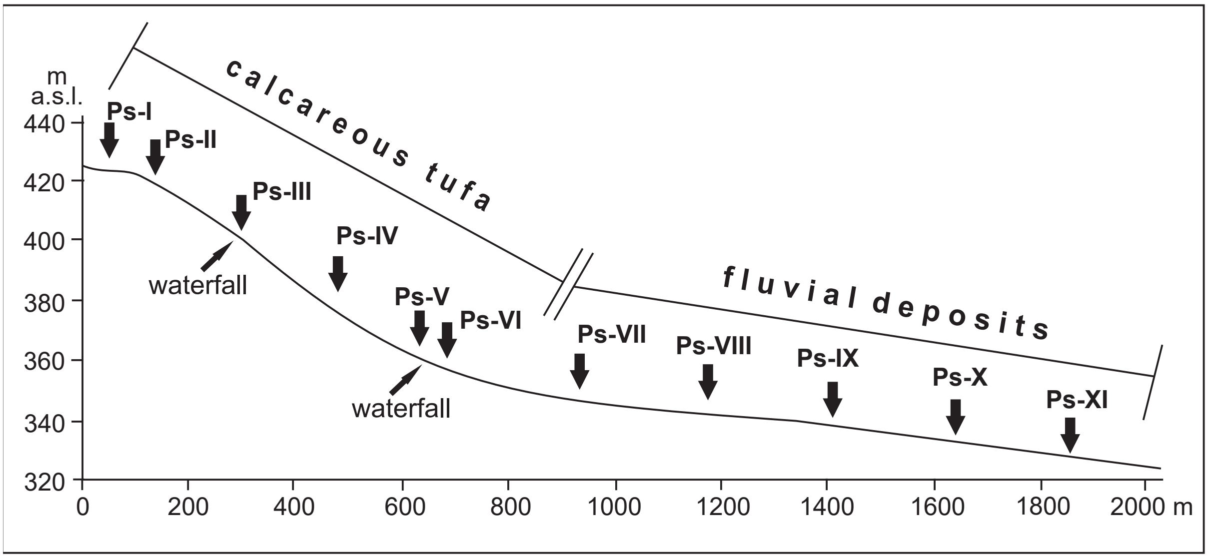

Fig. 3: Longitudinal profile of the Dulówka valley

defined, characterized by a specific composition and structure, as well as environmental requirements, including such environmental features as the degree of shade and substrate humidity. The use of principal component analysis (PCA) allowed distinguishing two basic types of fauna. Statistical calculations were made using the PAST statistical software (Hammer et al. 2001). The resulting data was the basis for reconstructing environmental changes, particularly those directly related to human activity. The stratigraphic position of individual communities was determined based on age measurements of 6 samples using the radiocarbon method. Results of age determinations were calibrated with the application of OxCal V 3.9 software (Bronk Ramsey 2003). Palaeoenvironmental reconstructions and age determinations were backed up with data and conclusions resulting from malacological studies carried out in other sites with Holocene deposits in the southern part of Cracow-Częstochowa Upland (e.g. Alexandrowicz 1983, 1989, 1992, 1997, 2004; Alexandrowicz et al. 1997; Alexandrowicz and Skoczylas 2017).

4 Results

4.1 Lithology of sediments

Mollusc shells have been found in two types of sediments: in calcareous tufa and fluvial deposits.

Calcareous tufas occur in the upper section of the valley (profiles Ps-I - Ps-VI, Fig. 4 and 5). They build a terrace with a height about 0.5 m above the recent bed of the Dulówka Stream. Calcareous tufas reach the greatest thickness near two small waterfalls (profiles Ps-III and Ps-VI, Fig. 3). At the bottom of some profiles, there are visible Middle Triassic limestones forming the rock socle (Fig. 4 and 5). Several lithological variants of calcareous tufa can be distinguished. The first one is hard, porous, white and yellow travertines. They form layers with a thickness of 0.25 m, clearly separated from the sediment (Fig. 4 and 5). The second lithological type is loose granular medium- and fine-grained calcareous tufa consisting of carbonate crumbs of fine gravel and sand fractions, with added carbonate silt. The last type are carbonate silts (with silty fraction constituting 70 %). Loose varieties of calcareous tufa have numerous and well-preserved mollusc shells. In this section of the Dulówka Stream, calcareous tufas are sometimes accompanied by fine-grained gravel and sands. The highest profile (Ps-I) contains a series of calcareous silts with plant debris resting on carbonate sediments is visible (Fig. 4).

In the lower part of the analyzed valley, river deposits replace the calcareous tufa (Ps-VII - Ps-XI) (Fig. 5 and 6). They build a terrace rising up to 1 m above the Dulówka Stream. The lower part of the terrace is formed from sediments of the channel facies: fine-grained gravels with an abundant sandy matrix. Gravels sometimes rest on a rock socle formed of Middle Triassic limestone (Fig. 5 and 6). A layer of medium and fine-grained sands usually lies on gravels. The upper parts of the profiles are made of sediments of overbank facies. They are yellowish or brown calcareous silts and

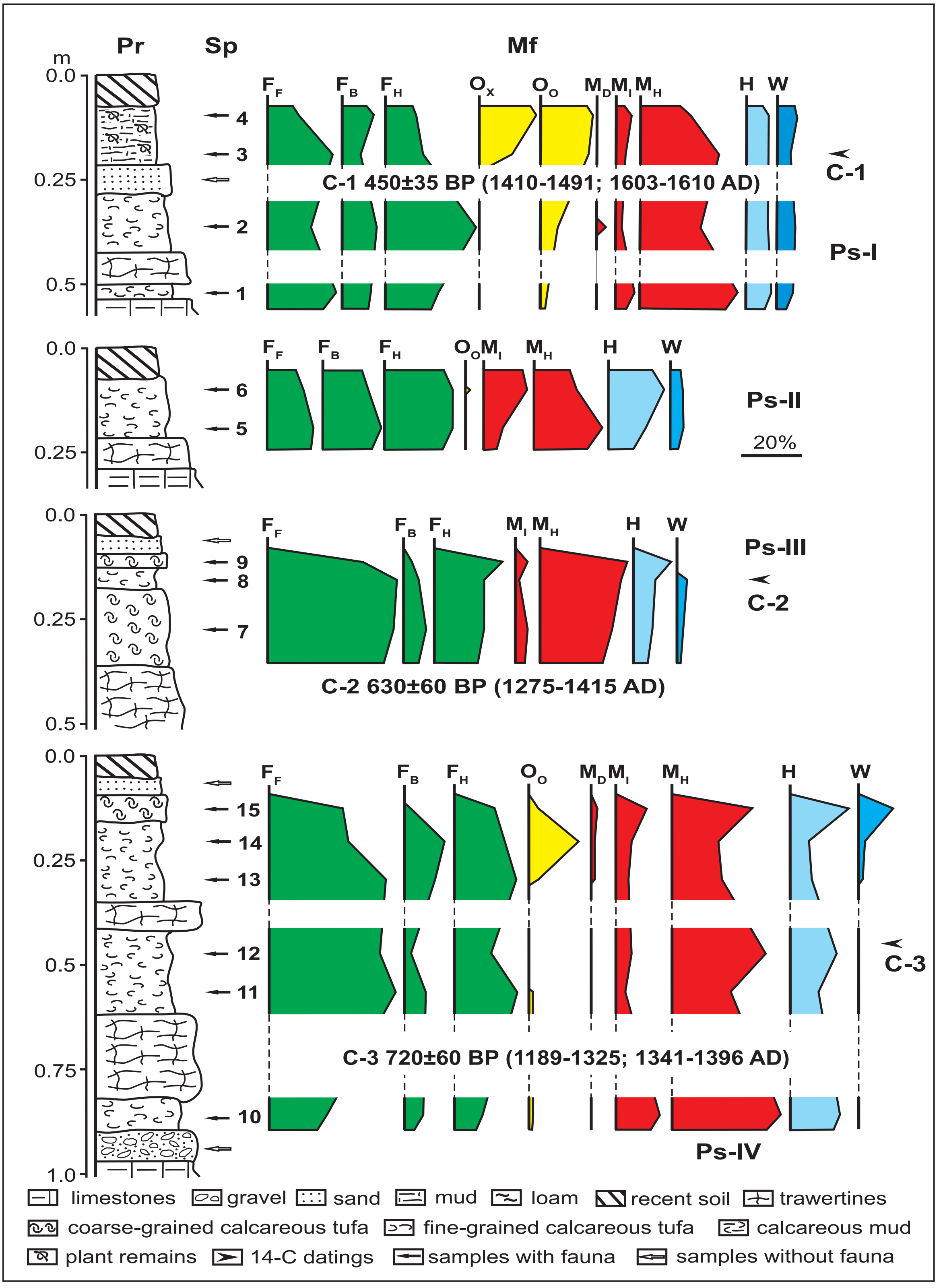

Fig. 4: Lithology and malacological diagrams of the profiles Ps-I - Ps-IV. Pr - profile, Sp - samples, Mf - malacofauna; F_F, F_B, F_H, O_X, O_O, M_D, M_I, M_H, H, W - ecological groups of molluscs - for explanations see Tab. 1.

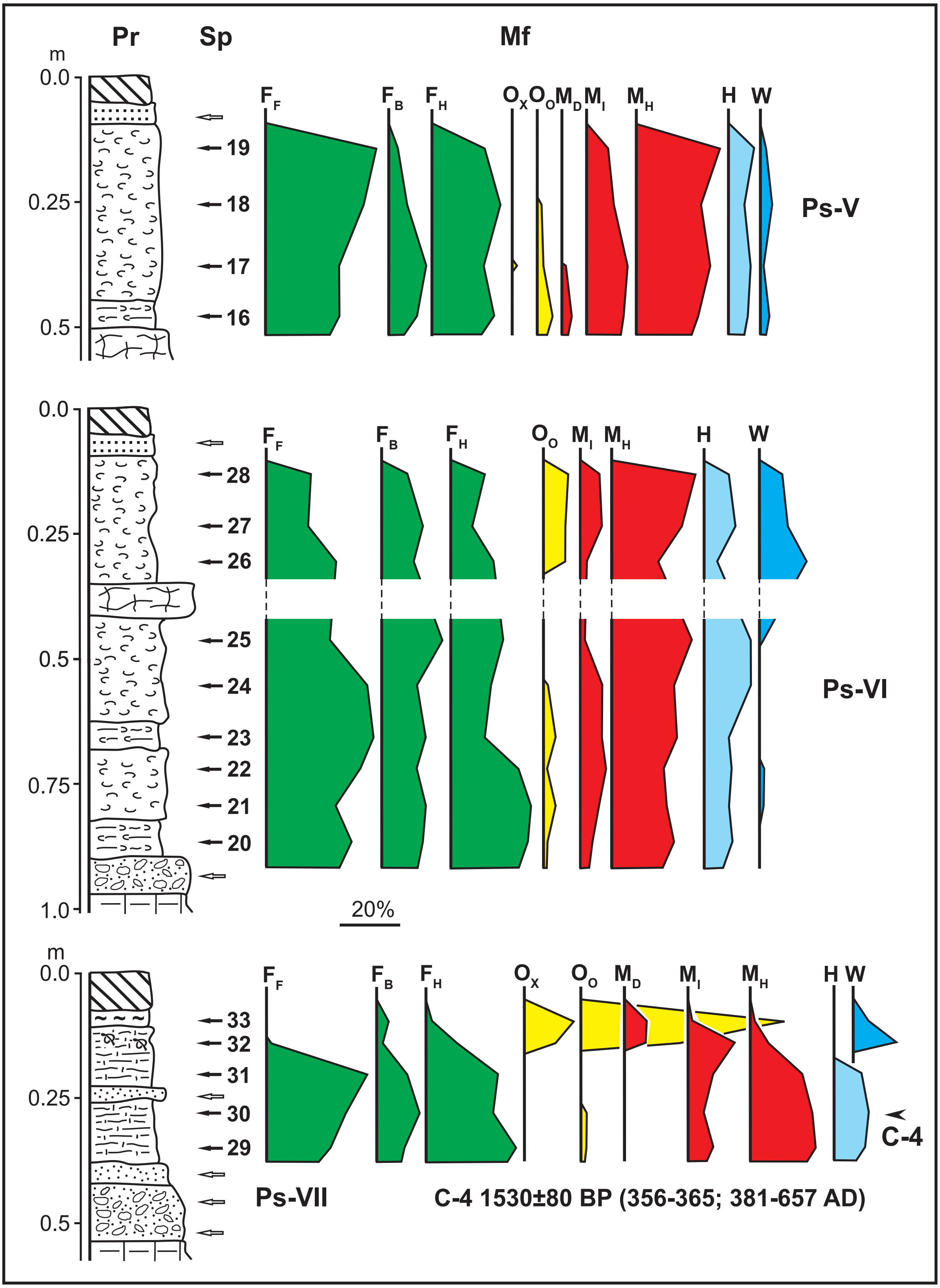

Fig. 5: Lithology and malacological diagrams of the profiles Ps-V - Ps-VII. For explanations see Fig. 4 and Tab. 1.

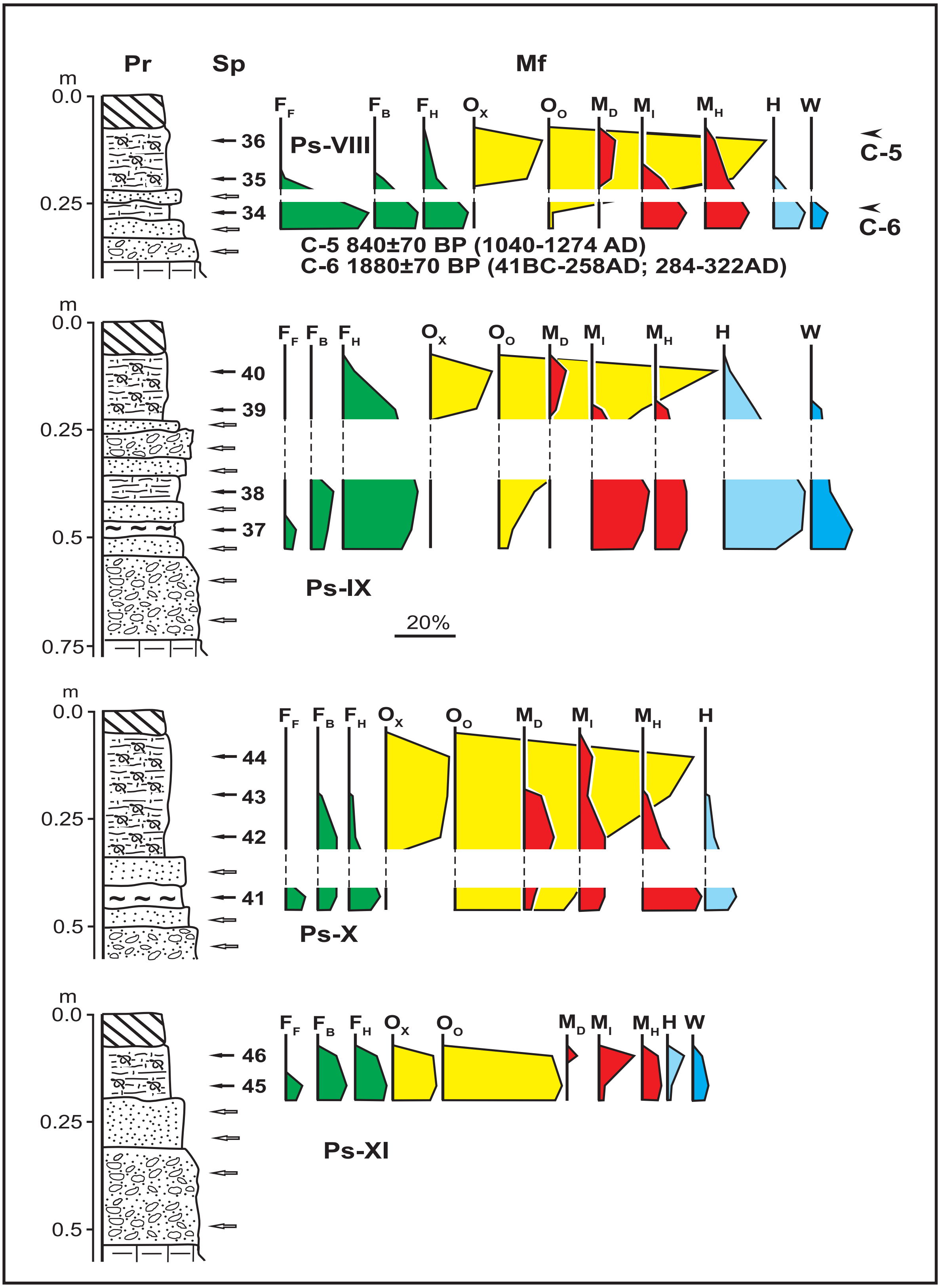

Fig. 6: Lithology and malacological diagrams of the profiles Ps-VIII - Ps-XI. For explanations see Fig. 4 and Tab. 1.

dark gray clays. Plant debris is often present in the silt. Mollusc shells occur only in sediments of overbank facies (Fig. 5 and 6).

4.2 Malacofauna

The shell material comprised almost 12,000 specimens representing 59 taxa. The number of specimens in samples ranged from 100 to 1,467, and taxa from 10 to 47 (Tab. 1). Furthermore, there were over 1,500 shell fragments that could be determined only up to the family category and a large number of indeterminate shards.

Rich mollusc fauna was found in calcareous tufa. The assemblage is dominated by species characteristic of shady environments (ecological groups F_F and F_B). An important component of the fauna are species typical for deciduous and mixed forests growing on substrates rich in calcium carbonate: *Sphyradium doliolum*, *Discus perspectivus*, *Ruthenica filograna*. Taxa preferring shade habitats with significant humidity (group F_H; *Vitrea crystallina*) and mesophilous (group M_H; *Carychilum tridentatum*) are also important. In this community, the share of species characteristic of drier and open environments (groups O_X, O_O, M_D and M_L) is relatively small and does not exceed 15 % (Fig. 4 and 5). A significantly higher share of the abovementioned ecological groups is only observed in the upper section of the Ps-I profile, where it exceeds 40 % (Fig. 4). The described fauna is complete with sparse water species.

Malacofauna of fluvial sediments shows slightly greater ecological diversity. Shadow-loving species are the dominant fauna component in floor sections of the profiles. The high share of taxa typical for high-humidity habitats is characteristic here (group F_H; *Vitrea crystallina*, *Monachoides vicinus*) reaching 25 %. Forms typical of forests are also common (group F_F) (*Aegopinella pura*, *Acanthinula aculeata*). Another important component of the malacocoenoses in the lower parts of the profiles are mesophilous snails, which prefer humid habitats (group M_H; *Carychilum tridentatum*, *Perforatella bidentata*). The share of open-country taxa does not exceed 10 % (Fig. 5 and 6). The species composition of the malacofauna found in the upper sections of the profiles is completely different. Shadow-loving taxa (groups F_F, F_B and F_H) do not occur at all in most samples. The prevalence of moisture-loving snails is also falling rapidly (groups M_H and H) (Fig. 5 and 6). Dry-loving open-country species play the most important role, as their share in the assemblage usually exceeds 60 %, and sometimes reaches even 80 % (Fig. 5 and 6). There are numerous forms typical for grasslands of various humidity (group O_O): *Vallonia pulchella*, *Vallonia costata*. Particularly noteworthy is the presence of two taxa belonging to group O_X: *Ceciloides acicula* and *Meditterranea inopinata*. Both live underground and are considered indicative of anthropogenically transformed areas, particularly by agricultural activities (e.g. Alexandrowicz et al. 1997, 2019; Alexandrowicz 2004; Čiliak et al. 2015)(Fig. 5 and 6).

5 Discussion

5.1 Malacofauna diversity

The composition and structure of mollusc assemblages found in the sediments are consistent with the features of the environment in which sedimentation took place. The low mobility of shells in the sedimentary environment allows conducting detailed analyzes of microhabitat variability. This variability is generated both by natural factors and by human activity. That last element played a particularly important role during the Late Holocene. On the one hand, anthropopressure usually leads to fast and rapid environmental changes. On the other hand, however, the impact of human activity and its intensity are varied. Anthropopressure occurs first in areas with more favorable conditions, and its intensity is usually much higher. In less-favorable areas, the environmental impact of human activities is more limited. This regularity is marked both on a regional and local scale. The diversity of molluscan fauna within river valleys has been the subject of numerous studies, both as regards subfossil units (e.g. Alexandrowicz 1989, 1991, 1997, 2012, 2019a, b; Keen 1990; Schreve et al. 2007; Mishra et al. 2007; White et al. 2013) and thanatocoenoses found in flood sediments (e.g. Alexandrowicz 2002; Čejka et al. 2008; Ilg et al. 2009, 2012; Čiliak et al. 2015).

Analysis of malacofauna found in the Late Holocene sediments in the Dulówka valley indicates the existence of two primary environmental factors determining the composition and structure of the fauna. The first one is the degree of shading in habitats, and the second is the environment humidity.

Taking into account the first of these factors, it is possible to distinguish three groups of samples (Fig. 7A).

Type A-1 fauna is represented in 21 samples. This community is characterized by a large share of

Tab. 1: Malacofauna in profiles of Late Holocene sediments in the Dulówka stream valley

E	Taxon	Ps-I	Ps-II	Ps-III	Ps-IV	Ps-V	Ps-VI	Ps-VII	Ps-VIII	Ps-IX	Ps-X	Ps-XI
	Platyla polita (Hartm.)	6		23	48	16	47	30	13	5		
	Sphyradium doliolum (Brug.)	12	4	54	144	13	82	2	4		2	1
	Acanthinula aculeata (Müll.)	14	8	59	79	37	129	47	18	1	1	1
	Vertigo pusilla Müll.	6		8	15	9	23	31	5	2	1	
	Cochlodina laminata (Mont.)	2		6	21		34	6	2			
	Cochlodina orthostoma (Menke)				7	17	8	2	4			
F_F	*Ruthenica filograna* (Rossm.)	4		8	9	8	64	13	6			
	Macrogastra plicatula (Drap.)			10	11	2	28	5	1			
	Discus perspectivus (M. von Mühlf.)	16	1	56	75	56	202	11	1			1
	Vitrea diaphana (Stud.)	3	4	1	2		28	6	3			2
	Aegopinella pura (Ald.)	37	16	163	234	82	205	34	12		5	2
	Petasina unidentata (Drap.)	11		9	6	10	26		1			
	Faustina faustina (Rossm.)	8	3		2		17	1				
	Isognomostoma isognomostomos (Schr.)			3	12	4	31	3	1			1
	Vertigo alpestris Ald.	6		1	6		5	16	5	10		
	Laciniaria plicata (Drap.)	2			5	2	28			1		
	Alinda biplicata (Mont.)			3	11	12	51	1				
F_B	*Discus rotundatus* (Müll.)	12	24	10	22	4	47	53	23	18	12	5
	Aegopinella minor (Stab.)			3	23	11	19	4	1			
	Fruticicola fruticum (Müll.)	13	3	20	58	18	124	8	3		4	6
	Monachoides incarnatus (Müll.)	25	18	16	18	14	81	6	8			7
	Cepaea hortensis (Stud.)		1				24				3	8
	Columela edentula (Drap.)			10	24	6	10	12	1	5		
	Macrogastra ventricosa (Drap.)	9	10	6	7	29	34	20	6	9		5
	Macrogastra tumida (Rossm.)	5		10	8	2	20	33	3	8		
F_H	*Vestia gulo* (Bielz)						29	5				
	Vestia turgida (Rossm.)	12	10		11	19	68	9		2		6
	Vitrea crystallina (Müll.)	68	16	168	232	91	362	58	15	62	16	7
	Monachoides vicinus (Rossm.)	22	23		14	17	64	56	20	59	5	11
	Truncetellina claustralis (Gred.)			2	2	3						
O_X	*Chondrula tridens* (Müll.)	1						7	16	17	17	7
	Ceciloides acicula (Müll.)	21						24	27	26	52	25
	Meditterranea inopinata (Uli.)	13						15	19	15	33	15
	Vallonia costata (Müll.)	35	1		46	10	32	51	54	70	148	44
O_O	*Vallonia pulchella* (Müll.)	48			36	6	60	80	86	95	202	61
	Truncatellina cylindrica (Fér.)				8		1	17	34	30	19	34
	Vertigo pygmaea (Drap.)						1	25	28	30	46	23
M_D	*Cochlicopa lubricella* (Rossm.)			1	10	4		15	8	14	23	5
	Euomphalia strigella (Drap.)	5				3		11	6		8	
	Cochlicopa lubrica (Müll.)	3	8	1	7	12	27	10	5	20	22	3
	Clausilia dubia (Drap.)	10		4	4	20	30					
	Punctum pygmaeum (Drap.)	9		14	38	24	53	21	7	10	1	
	Vitrea contracta (West.)				6	1			2	17		5
M_I	*Euconulus fulvus* (Müll.)	3	3	7	32	19	16	15	1	4	2	6
	Perpolita hammonis (Ström.)		15	5	20	17	27	17	12	13		16
	Vitrina pellucida (Müll.)	1				3	9	17	11	21	2	
	Limacidae	1					4	2	5	1	11	
	Trochulus hispidus (L.)						32			1		
	Carychium tridentatum (Risso)	153	26	268	428	197	591	104	26		27	17
M_H	*Vertigo substriata* (Jeffr.)	10	1	5	3	11	21	5	1	1		1
	Perpolita petronella (Pfr.)				7					21	2	
	Perforatella bidentata (Gmel.)		21				14	38	22	33	13	4
	Carychium minimum Müll.	44	30	80	190	69	286	44	14	89	20	3
H	*Succinea putris* (L.)	1			5			15	4	36	1	
	Zonitoides nitidus (Müll.)	1	10		12		6	6	8	15		7
	Bythinella austriaca (Frau.)	24			30		56	18				
	Galba truncatula (Müll.)		8	2	2		5	17	3	31		
W	*Pisidium personatum* Malm	10		13	8	13	14	10	1	6		
	Pisidium casertanum (Poli)			1		3	8	9	8	10		12
	Total species	**40**	**24**	**35**	**47**	**40**	**50**	**51**	**48**	**37**	**28**	**32**
	Total individuals	**687**	**266**	**1053**	**1997**	**895**	**3183**	**1049**	**564**	**807**	**698**	**348**

Notes: E - ecological groups of molluscs (after: Ložek 1964, Alexandrowicz and Alexandrowicz 2011 and Juřičková et al. 2014): F_F - shadow-loving, forest species, F_B - shadow-loving species living in light forests and bushy zones, F_H - shadow-loving species of humid habitats, O_X - xerophilous species, O_O - open-country species, M_D - mesophilous species of dry habitats, M_I - mesophilous species of moderately wet habitats, M_H - mesophilous species of wet habitats, H - hygrophilous species, W - water species.

shade-loving species. Among them, forest taxa and snails inhabiting moist shady biotopes play an important role. Mesophilous species especially forms typical of moist habitats, supplement the fauna in question. Other ecological groups are less important. The presented fauna is a typical community inhabit-

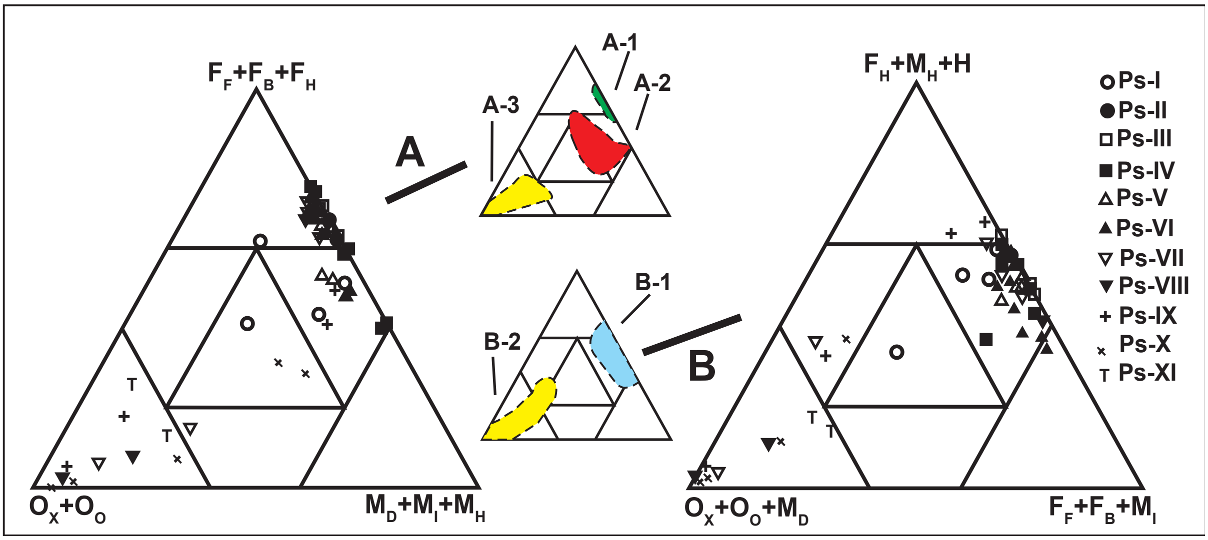

Fig. 7: Triangular diagrams of malacofauna diversity. F_F, F_B, F_H, O_X, O_O, M_D, M_I, M_H, H, W - ecological groups of molluscs. For explanations see Tab. 1, A-1 - A-3, B-1, B-2 molluscan assemblages described in text.

ing the bottoms of river valleys. An assemblage with shade-loving species (A-1 fauna) was recognized in the profiles of calcareous tufas in the upper part of the analyzed valley and the bottom sections of several profiles in the lower section of the valley (Fig. 7A).

Type A-2 fauna was found in 14 samples. It shows a significant share of shade-loving taxa. Compared to the complex described above, there is an increase in the share of mesophilous taxa and/or open-environment species. The malacocoenosis in question represents the valley bottom zone of a moist bed. The greater share of mesophilous species and open-environment forms indicates a smaller range of shaded biotopes (Fig. 7A).

Both types of molluscan assemblages described above (A-1 and A-2 type) were collected from a lot of localities of calcareous tufa and alluvial sediments in the Cracow region (e.g. Alexandrowicz 1983, 1989, 1991, 1997, 2004).

Type A-3 fauna was found in 11 samples. Its primary feature is small species diversity and the dominance of taxa inhabiting open, grassy, and even xerothermic habitats. The occurrence of species living underground, often associated with agricultural areas, is also characteristic. The share of other ecological groups is minuscule. The presented assemblage is typical for open biotopes and anthropogenically transformed agricultural areas (Fig. 7A). Such community was also described in several sites of fluvial deposits located near Cracow (Alexandrowicz et al. 1984, 1997; Alexandrowicz 1989, 1991, 1992).

Environmental humidity is the second factor that significantly affects the diversity of complexes and allows distinguishing two types of malacocoenoses (Fig. 7B).

Type B-1 fauna was found in 33 samples. Its characteristic feature is the dominant share of taxa living in wet and medium wet biotopes, whereas dry-loving species appear very rarely. The fauna in question is characteristic of the bottoms of river and stream valleys. (Fig. 7B).

Type B-2 fauna was found in 13 samples. It is characterized by a large share of taxa preferring dry biotopes. Moisture-loving forms are an accessory component of this fauna. This accumulation is typical of dry, open-environment biotopes, often under the influence of human activity (Fig. 7B).

The types described above (B-1 and B-2) were well recognized in several localities of Late Holocene sediments (e.g. Alexandrowicz 1983, 1989, 1991, 1997, 2004).

The principal component analysis (PCA) carried out indicates the existence of two types of fauna differing in ecological and habitat requirements. The first type is malacocoenosis typical of moist and shaded biotopes. Such conditions prevail in small river and stream valleys, which were not covered by intensive and direct human activity (Fig. 8). The second type of fauna is characterized by dry and open-environment biotopes. The presence of such habitats in river valleys is often associated with human interference, especially through deforestation and changes in water relations. Such malacocoenoses correspond to anthropogenically modified areas, often subjected to intensive agricultural activity and used as arable land and pastures (Fig. 8).

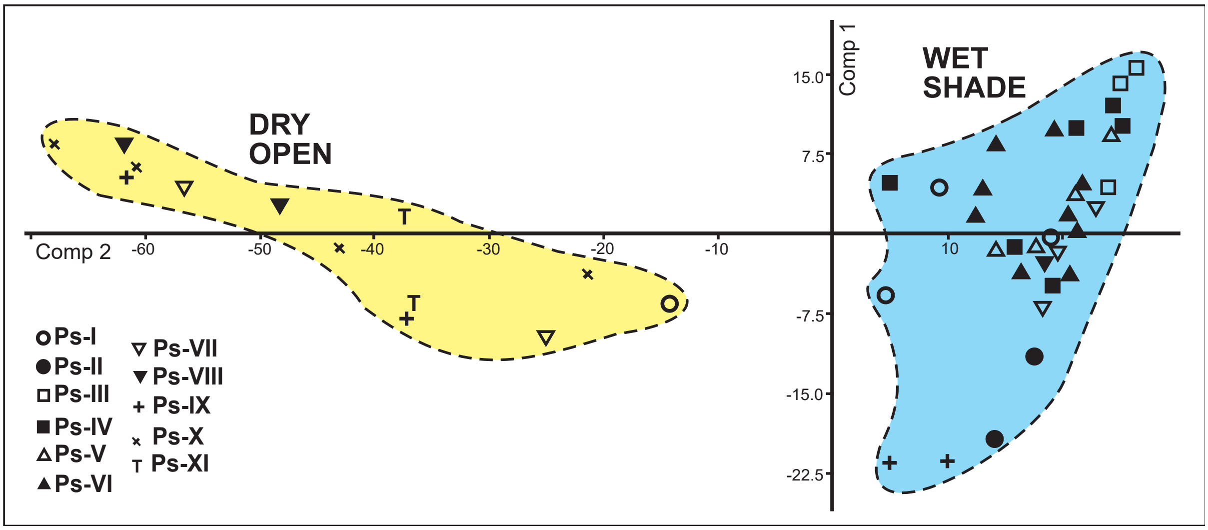

Fig. 8: Principal component analysis (PCA) of malacofauna from Dulówka stream valley

5.2 Natural and anthropogenic changes in the environment

Malacocoenoses described in the sediments in the Dulówka Stream indicate changes in habitat characteristics and the diverse impact of human activities on the environment. The sediments in question represent a relatively short period, covering the last 2,000 years (Tab. 2). The settlement of agricultural cultures significantly impacting the environment in the Cracow-Częstochowa Upland dates back to the early Neolithic (e.g Kruk et al. 1996; Kruk and Milisauskas 1999; Gradziński et al. 2017; Moskal del-Hoyo et al. 2017, 2018). The loess plateau areas characterized by gentle relief were the first ones to be inhabited and anthropogenically transformed. Dense forests growing there were cut down and/or burnt (Broda 1985). The southern edge of the Upland was not directly subjected to anthropopressure during this period. This area is characterized by varied relief, steep slopes, and deeply cut valleys, often in the form of rock gorges. The lack of intensive human activity allowed maintaining natural deciduous and mixed forests inhabited by rich communities of fauna and flora, including molluscs (Alexandrowicz 1983, 1997, 2004; Broda 1985; Rutkowski 1987; Rutkowski and Starkel 1989). Demographic growth, particularly pronounced since the early Middle Ages, significantly affected the intensity and extent of anthropogenic environmental changes. The direct impact of human activity was not only marked in narrow valleys creating unfavorable conditions for both farming and breeding activities as well as for settlement.

The Dulówka valley is a very good illustration of these processes. The presence of molluscs in sediments allows to precisely reconstruct microhabitats and their diversity in time and space. The valley in question can be broken down into three different sections (Fig. 9). The highest fragment is a wide valley cutting through the flat surface of the upland. The bottom of the valley is currently covered by shrub thickets, with pastures around it. The middle section is a narrow valley with steep banks and a significant slope. Both its bottom and slopes are covered with deciduous and mixed forests and dense shrub thickets. In the highest and middle sections, calcareous tufa sedimentation occurred or is still occurring. The lowest part of the valley is wide and flat-bottomed, edged by gentle completely deforested slopes transformed into arable fields and pastures and partly built-up. A low terrace of fluvial sediments stretches along this section of the stream bed (Fig. 9).

The changes in the composition and structure of fauna communities observed in the profiles, as well as the results of age determination using the radiocarbon method, allow determining the chronology and scope of anthropogenic environmental changes. Malacological data indicate that in the initial period of sedimentation, the entire valley was covered with dense forests. This is evidenced by the dominance of moisture- and shade-loving fauna communities found in almost all profiles. Two radiocarbon dates are associated with this interval: 1880±70 BP (41cal BC-258 cal AD and 284 cal AD-322 cal AD; Gd-19180) (profile Ps-VIII; C-6) and 1530±80 BP (356-365 cal AD and 381-657 cal AD; Gd-19216) (profile Ps-VII; C-4) (Tab. 2, Fig. 5, 6 and 9). According to these observations, the

Tab. 2: Results of radiocarbon datings

	Age BP	Lab code	Cal BP	Cal AD
C-1	450±35 BP	Gd-5280	540-459 (94.0%) 348-340 (1.4%)	1410-1491 AD (94.0%) 1603-1610 AD (1.4%)
C-2	630±60 BP	Gd-18145	675-535 (95.4%)	1275-1415 AD (95.4%)
C-3	720±60 BP	Gd-17354	762-622 (75.2%) 610-554 (20.2%)	1189-1325 AD (75.2%) 1341-1396 AD (20.25)
C-4	1530±80 BP	Gd-19216	1594-1585 (0.6%) 1570-1294 (94,8%)	356-365 AD (0.6%) 381-657 AD (94.8%)
C-5	840±70 BP	Gd-6514	911-674 (95.4%)	1040-1276 AD (95.4%)
C-6	1880±70 BP	Gd-19180	1990-1692 (92,1%) 1666-1629 (3.3%)	41BC-258 AD (92.1%) 284-322 AD (3.3%)

analyzed area was not subject to strong anthropopressure during the first millennium AD. There was no extensive deforestation here and no open-environment biotopes related to agricultural activities appeared. Historical sources also do not mention villages being founded in this area before 1000 AD. Malacological and lithological research results in neighboring valleys cutting through the southern edge of the Upland suggest similar conclusions (Alexandrowicz 1983, 1997, 2004; Gradziński et al. 2017; Alexandrowicz and Skoczylas 2017) (Fig. 9). Significant demographic growth has been noted since the early Middle Ages. At the turn of the 11th and 12th centuries, the first major settlements appeared in the region. Meanwhile, there is a reduction in the forest area. Anthropogenic deforestation initially involves the lowest, flat part of the valley. The disappearance of forests and their replacement with grassland biotopes and arable fields led to the impoverishment and fundamental reconstruction of the species in malacocoenoses and the emergence of species associated with agricultural areas. At the same time, there is a change in sediment lithology. Sand and gravel inserts are present in several profiles, indicating an increase in fluvial processes. At the same time, numerous plant debris is observed in the silts. This stage of environmental change involves the radiocarbon date in profile VII (C-5): 840±70 BP (1040-1276 cal AD; Gd 6514) (Tab. 2, Fig. 5 and 9). The rapid intensification of anthropopressure associated with the early Middle Ages is visible in many malacological profiles (e.g. Alexandrowicz 1983, 1989, 1991, 1997, 2004; Gradziński et al. 2017).

Human activity is weak in the middle part of the valley. This is undoubtedly connected with difficult and unfavorable terrain conditions. This section has natural or slightly transformed forest communities (Fig. 9). In the calcareous tufa deposited here, there is a rich malacofauna with a predominant share of shade- and moisture-loving species. Establishing the stratigraphic position of these sediments can be determined using radiocarbon dating: 720±60 BP (1189-1325 cal AD and 1341-1396 cal AD; Gd-17354) (profile Ps-IV; C-3), 630±60 BP (1275-1415 AD; Gd-18145) (profile Ps-II, C-2) and 450±35 BP (1410-1491 cal AD and 1603-1610 cal AD; Gd-5280) (profile Ps-I, C-1) (Tab. 2, Fig. 4 and 9). Low intensity of anthropopressure in areas with unfavorable terrain was described in a series of profiles in the Upland (e.g. Alexandrowicz 1983, 1989, 1991, 1997, 2004; Alxandrowicz and Skoczylas 2017; Gradziński et al. 2017) as well as in the Carpathian Mountains (Alexandrowicz 2004, 2013, 2019a, b, 2020; Alexandrowicz et al. 2014, 2016; Łajczak et al. 2014). Today, the Dulówka valley is transformed to a varying degree as a result of human activity. Anthropogenic changes in the middle part are still relatively small. Forest communities remained there, though their spread was limited only to the valley itself. Calcareous tufa sedimentation is still occurring along the stream bed, particularly near the waterfall rapids. The uppermost and lower sections of the valley are completely transformed due to agricultural human activity and settlements. The past several years were marked by the development of settlement infrastructure, and previously arable fields here have been largely built-up.

6 Conclusions

Due to the possibility of reconstruction of microhabitats, the malacological data complement the conclusions from other studies, especially palynological analyzes describing environmental changes within larger geographic regions.

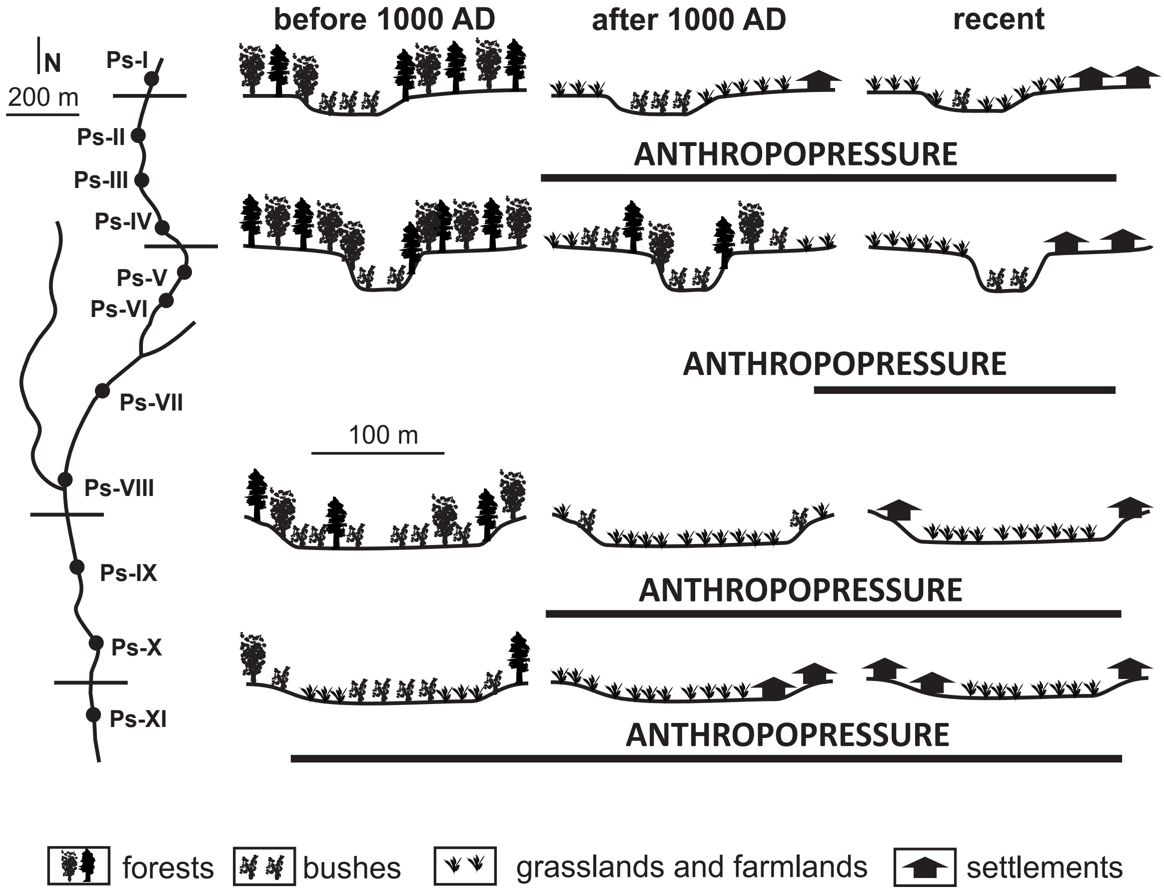

Fig. 9: Natural and anthropogenic environmental changes in the Dulówka stream valley during last 2000 years

Malacological studies of sediments in the Dulówka Stream valley allow for the reconstruction of environmental changes over the last 2000 years. The composition and structure of mollusc communities, as well as radiocarbon dating, indicate that the severity of anthropopressure up to the early Middle Ages was low in the area. Compact forest complexes remained here, constituting a convenient environment for the life and development of rich and diverse fauna and flora communities. The development of settlements dates back to the 11th Century. The arrival of human groups in the area in question initiated the emergence of larger settlements and extensive deforestation, which covered the flat sections of the valley. The consequence of the disappearance of forests was the reconstruction of the species composition in malacocoenoses. Rich and diverse forest malacocenoses were replaced by poor fauna with open-country species. There was also a rapid draining of habitats. Taxa associated with human farming activities also appeared. In the middle section of the analyzed valley, characterized by less favorable terrain, anthropopressure was much less pronounced. The slopes and bottom of the valley were not deforested and have largely maintained their natural character. This state of affairs persists to this day.

The presented analyzes are an example of the use of malacofauna in research on human impact on the environment. Due to their specific nature, research on subfossil mollusc communities is particularly useful for reconstruction carried out on a microregional scale, and with a degree of accuracy difficult to achieve using other methods. The modern natural environment is in fact a mosaic of microhabitats clearly demarcated from one another or smoothly passing into one another. The situation is similar in the geological past. Hence, no precise paleoenvironmental reconstruction can do without the classifying microhabitats.

Human activity often causes rapid and drastic changes in the functioning of natural systems. These changes, at least in the first stages of settlement, are local and initially cover areas that are easier to develop. This leads to rapid differentiation of natural habitats into those that are subjected to strong anthropopressure and those where natural processes prevail. The research conducted in the Dulówka valley indicates that one of the most important factors affecting the extent and intensity of anthropopressure is the terrain.

Due to sensitivity to environmental changes, strictly defined ecological requirements and their prevalence, molluscs can be used on a large scale in research on the role of human impact on the natural environment, particularly on its transformation. This malacological method works well as an indicator of violent and rapid changes related to deforestation and the development of a farming and shepherding economy. The study presented above is an example of the use of such research in paleoenvironmental interpretations.

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