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MOLLUSCAN ASSEMBLAGES FROM CALCAREOUS TUFA IN THE SKALSKI STREAM VALLEY (PIENINY MOUNTAINS, SOUTHERN POLAND) AND THEIR APPLICATION FOR RECONSTRUCTION OF NATURAL AND ANTHROPOGENIC ENVIRONMENTAL CHANGES

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Abstract: Rich and diverse molluscan assemblages have been found in calcareous tufa exposed in the valley of the Skalski stream in the Pieniny Mountains. 59 samples representing 10 profiles were subjected to malacological analysis. Very rich malacofauna (over 20 000 specimens belonging to 78 species) was the basis for carried out reconstruction. Three faunistic assemblages differing in composition and structure, as well as age, were separated. The oldest of them (the assemblage with shade-loving species) is characteristic of forest habitats and corresponds to the Middle Holocene (Atlantic Phase). Two younger assemblages (the assemblage with open-country species and the assemblage with Bythinella austriaca) represent historical period. The first of the mentioned is characteristic of the agricultural zones subjected to strong anthropogenic impact on the environment, mainly deforestation. The second one is typical of areas with unfavourable terrain conditions which are therefore not used for agricultural purposes. Such a diversity in malacocenosis allows the assessment of the degree of anthropogenic changes to the environment and of the intensity of anthropogenic impact on the environment.

Key words: calcareous tufa, molluscan assemblages, human impact, Holocene, Pieniny Mts, Southern Poland

1. INTRODUCTION

Calcareous tufa are one of the most characteristic types of interglacial Quaternary deposits. They are formed through the precipitation of calcium carbonate from water as a result of physico-chemical or biological processes. Mechanisms of the precipitation and deposition of calcareous tufa was a subject of a large number of studies (e.g. Hennig et al., 1983; Pedley, 1990, 2009; Pentecost, 1995). The discussed deposits create particularly favourable conditions for preservation of shells of snails and bivalves in a subfossil state. It is connected, on the one hand, to the relatively peaceful course of sedimentation and, on the other hand, to a high content of calcium carbonate. The first of these factors minimises the risk of damage to shells during deposition, while the other makes chemical dissolution and physical breaking of shells located in the deposit difficult. Simultaneously, the redeposition of shell material occurs on a limited scale, which greatly facilitates the interpretation of changes in the nature of habitats, and consequently of environmental conditions in the immediate vicinity of deposition zone. Molluscan assemblages found in the discussed deposits reflect both regional and local conditions. The first of these aspects is the basis for specifying trends of paleogeographic and climatic changes on a scale of geographical regions, while the other one provides a unique and typically unattainable by means of other methods chance of reconstruction of local conditions both in land and water habitats (Alexandrowicz, 2004; Alexandrowicz & Alexandrowicz, 2011).

Numerous sites of calcareous tufa were described from the Polish Carpathians. Their presence is connected with zones of limestones, marlstones and calcareous sandstones outcrops. Over a dozen of these sites represent long periods of time, and the beginning of their formation fell to the Late Glacial or Early Holocene. They were described mainly from the Podhale Basin (Alexandrowicz, 1997, 2001, 2004, 2013a; Alexandrowicz & Rybska, 2013;

Alexandrowicz et al., 2014), and less frequently from the area of the Pieniny Mountains and the Flysch Carpathians (Alexandrowicz & Alexandrowicz, 1995a, b; Alexandrowicz, 2004, 2013b; Alexandrowicz et al., 2016). However, the vast majority consists of calcareous tufa precipitated contemporarily or nearly contemporarily representing the period of the last several hundred years (Alexandrowicz, 1997, 2004, 2009a, 2010, 2013c; Alexandrowicz S.W., 1997). Molluscan assemblages occurring in these deposits allow not only to characterise features of the natural environment, but also to assess the effect of human activity and the degree of intensity of anthropogenic impact on the environment (Alexandrowicz, 1997, 2004; Alexandrowicz et al., 1997, 2014, 2016).

The main purpose of the present study is to reconstruct the evolution of the Pieniny Mountains area environment based on the characteristics of malacocenoses occurring in calcareous tufa. Diversification in composition and structure of molluscan assemblages is the basis, as well as the characteristics of environmental changes generated by natural factors, mainly climate, and, the assessment of the impact of human activity (colonization, cultivation and shepherding) marking itself in the period of the last several hundred years.

2. STUDY AREA

The Pieniny Mountains are a part of the Pieniny Klippen Belt stretching in a curve with a length of about 600 km and a width of several hundred meters to 20 km. It does not create a compact mountain range but rather a series of isolated rocks dissected as a result of the activity of denudation processes from under the Paleogene, Neogene and Quaternary deposits. In Poland and Slovakia, the Pieniny Klippen Belt forms a small, short but relatively compact mountain range - the Pieniny Mountains. The Pieniny Mountains are characterised by a very complex geological structure and the Mesozoic limestones play the main role. The discussed profiles of calcareous tufa are located along the valley of the Skalski stream. It is a deeply incised valley with the rocky ground and partly rocky slopes. The Skalski stream is a left-bank tributary of the Grajcarek stream and flows into the stream in the village of Jaworki, about 5 km east from Szczawnica (Fig. 1). In the riverbed of the Skalski stream and on slopes of the valley, there are exposed Mesozoic deposits represented mainly by various types of limestones belonging to two stratigraphical-facial units: Niedzica and Czorsztyn (Birkenmajer, 1977). Quaternary deposits are represented by alluvial gravel and sand forming terraces along the riverbed of the Skalski stream, slope loams and calcareous tufa. Numerous shells of molluscs are found in calcareous tufa and also sometimes in slope deposits. The middle, forested part of the Skalski stream valley is and under legal protection as a landscape reserve. The lower and upper parts are deforested. In the lower part, there are cultivated fields and in the upper part - grassy glades and pastures (Fig. 1).

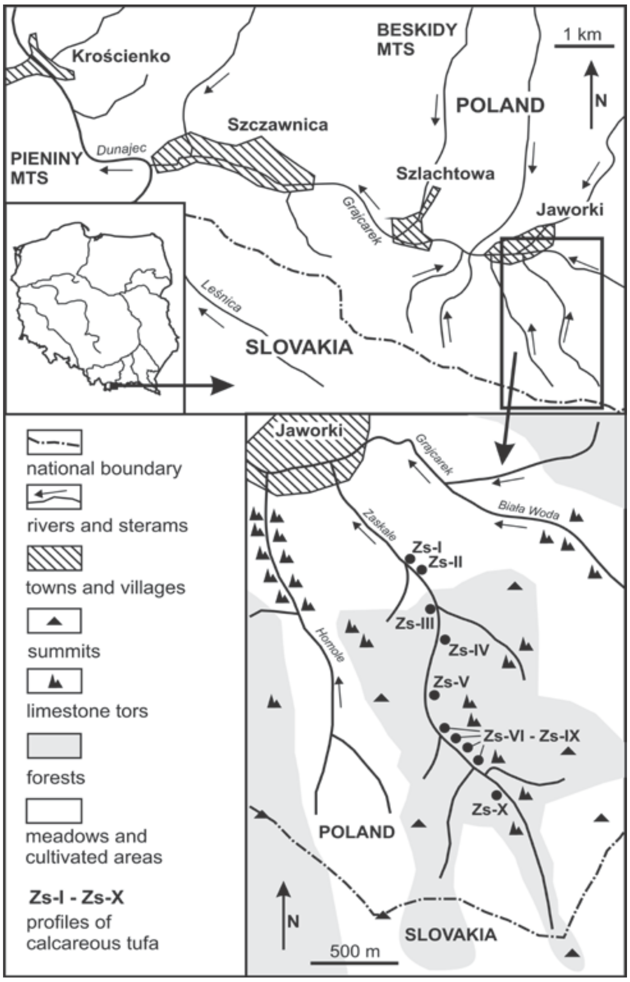

Figure 1. Location of the profiles of slope deposits and calcareous tufas in Skalski stream valley

The profiles of calcareous tufa, which are the subject of this study, stretch along the valley of the Skalski stream at a length of about 1500 m. The GPS coordinates for the outermost sites are: 49˚23’58” N; 20˚33’49” E (profile Zs-I) and 49˚23’10” N; 20˚34’16” E (profile Zs-X) (Fig. 1). Calcareous tufa occur in two morphological-genetic varieties differing from each other both in the lithological structure and conditions of sedimentation. The first variety is represented by coarse-grained tufa often containing large fragments of hard, porous white travertines. Also cobbled or angular clasts of local rocks occur commonly. The discussed type of deposits appears always in the vicinity of sources, often filling small depressions. During the field works, over a dozen outcrops of such sediments were located. The majority of them forms very thin inserts with thickness not exceeding 5 cm. In six profiles (profiles Zs-I – Zs-V and Zs-X), sequences with greater thickness ranging from 20-40 cm were exposed. The material taken from those sites was subject to malacological analysis (Fig. 1). The other variety are medium and fine-grained tufa and calcareous muds building a thin terrace shelf exposed in the right slope in the middle part of the valley and stretching for a distance of about 300 m (Fig. 1). Calcareous deposits are underlain by solifluction sediments covering slightly cobbled, strongly gritty river gravels reposing upon a low bed rock. The top of the profile is made up of slope clays with numerous sharp-edged blocks of limestones. The thickness of the entire sequence exposed in four profiles (Zs-VI – Zs-IX) ranges from 1.5 - 2 m, of which tufa are 0.7 - 1.0 m (Fig. 1).

3. MATERIAL AND METHODS

Material for malacological analyses came from ten profiles of calcareous tufa (Zs-I – Zs-X) located along the Skalski stream valley (Fig. 1). From these profiles 59 samples in total were collected for malacological analysis. Particular samples weighed about 2.0 kg and included intervals of 10-15 cm. Laboratory treatment of materials consisted in maceration and elutriation of rocks, and then selection of all complete shells of molluscs and determinable fragments of shells. The number of species and specimens was determined in separate samples. Fragments of shells were converted into complete specimens in accordance with the scheme proposed by Alexandrowicz (1987). The number of species in particular samples changed from 12 to 63, while the number of specimens ranged from 105 to 1830. In total, the analysed material consisted of over 20 000 specimens belonging to 78 taxa. Calcareous plates of slugs impossible to determine have common name of *Limacidae* (Table 1).

Malacological analysis was carried out based on standard methods described by Ložek (1964), Alexandrowicz (1987) and Alexandrowicz & Alexandrowicz (2011). Individual species were classified into the following ecological groups: F – shade-loving species, O – open-country (meadow) species, M – mesophilous species, H – hygrophilous species and W – water species. Taxonomic analysis including the dendrogram and correspondence analysis enabled to determine similarities between particular samples and to determine groups of samples characterised by the presence of molluscan assemblages with similar composition and structure. For the construction of dendrogram, a method described by Morisita (1959) was used. The statistical calculations were completed, using the PAST statistical software package (Hammer et al., 2001). The zoogeographic structure of assemblages was characterised on the basis of schemes of molluscan division into zoogeographic groups (Ložek, 1964; Alexandrowicz, 1987; Alexandrowicz & Alexandrowicz, 2011).

The age of molluscs-bearing deposits from valley of the Skalski stream was determined indirectly and directly. In the first case, the comparison of composition and structure of fauna with other well-documented stratigraphically profiles lying in the close vicinity (e.g. Alexandrowicz, 1993a, 1996, 2001, 2003, 2004, 2009a, 2010, 2013a, b, c; Alexandrowicz & Rybska, 2013; Alexandrowicz et al., 2014, 2016) and with the results of palynological researches per formed on the peatbogs located within the Podhale Basin (Obidowicz, 1990) constituted a basis for drawing a conclusion. The direct determination of the age of deposits was possible due to radiocarbon dating of a sample from the profile Zs-VII conducted in the Gliwice Radiocarbon Laboratory. The result was calibrated on the basis of the calibration curve (Stuiver et al., 1998), using the OxCal V 3.9 software package (Bronk Ramsey, 2001).

4. RESULTS

4.1. Malacofauna

The contemporary malacofauna of the Pieniny Mountains land snails includes 110 species (including 17 taxa of slugs) (Riedel, 1988). In the profiles of calcareous tufa exposed in the valley of the Skalski stream there is very rich and diverse malacofauna consisting of over 75% of forms living contemporarily in the Pieniny. All species recognised in the discussed sites are known from the contemporary malacofauna inhabiting the Pieniny.

Shade-loving species (ecological group F) are the most numerous and the most diverse group of molluscs. It contains 48 taxa (Table 1). The majority of them are the European species, especially mountain and upland ones. Also the Boreal-Alpine and South-European taxa play an important role.

Apart from the common snails belonging mainly to families *Helicidae* (*Monachoides vicinus Isognomostoma isognomostomos*, *Faustina faustina*, *Petasina unidentata*) and *Zonitidae* (*Vitrea diaphana*, *Vitrea crystallina*, *Aegopinella pura*, *Aegopinella minor*) there also appear very rare taxa with a small range of occurrence, which are Carpathian endemic species: *Acicula parcelineata*, *Vestia gulo*, *Vestia turgi*da, *Balea stabilis*, *Faustina rossmassleri* (Table 1).

Table 1. List of species recognized in profiles of calcareous tufas in Skalski stream valley.

E	ZG	TAXON	PROFILES Zs-									
			I	II	III	IV	V	VI	VII	VIII	IX	X
F	Ma	*Acicula parcelineata* (Clessin, 1911)		**R**	**N**	**R**	**S**					
F	Me	*Platyla polita* (Hartmann, 1840)	**N**	**R**	**N**	**S**	**R**	**C**	**C**	**C**	**N**	
F	Pl	*Acanthinula aculeata* (Müller, 1774)	**S**	**R**	**C**	**N**	**R**	**N**	**N**	**N**	**N**	
F	Em	*Sphyradium doliolum* (Bruguière, 1792)		**S**				**R**		**R**		
F	Ma	*Argna bielzi* (Rossmässler, 1859)		**N**	**C**	**N**	**N**					**S**
F	Ep	*Vertigo pusilla* Müller, 1774	**R**	**S**	**S**			**R**	**R**	**N**	**S**	
F	Me	*Ena montana* (Draparnaud, 1801)	**N**	**N**	**C**	**N**	**N**	**C**	**C**	**C**	**N**	**S**
F	Ep	*Cochlodina laminata* (Montagu, 1803)	**R**	**N**	**N**	**S**		**N**	**R**	**N**	**R**	
F	Me	*Cochlodina orthostoma* (Menke, 1828)	**R**	**R**	**R**		**R**					
F	Ee	*Ruthenica filograna* (Rossmässler, 1836)	**N**	**R**	**C**	**C**	**N**	**C**		**N**		
F	Ma	*Macrogastra tumida* (Rossmässler, 1836)			**R**	**S**						
F	Ma	*Macrogastra borealis* (Boettger, 1878)		**R**	**R**	**S**	**R**		**R**		**S**	
F	Ep	*Macrogastra plicatula* (Draparnaud, 1801)	**S**	**R**	**N**	**R**		**C**	**N**	**C**	**N**	
F	Ba	*Clausilia cruciata* (Studer, 1820)	**R**		**N**			**S**				
F	Me	*Balea biplicata* (Montagu, 1803)	**S**	**R**	**R**	**S**	**S**	**N**		**N**		
F	Ma	*Balea stabilis* (L.Pfeiffer, 1847)	**S**		**R**	**N**	**R**					
F	Ma	*Vestia gulo* (Bielz, 1859)	**R**	**R**	**N**	**C**	**R**					**S**
F	Ma	*Vestia turgida* (Rossmässler, 1836)	**S**	**R**	**C**	**N**	**S**	**C**	**N**	**C**	**N**	
F	Me	*Bulgarica cana* (Held, 1836)			**R**							
F	Pl	*Discus ruderatus* (Hartmann, 1821)	**R**	**R**	**S**			**N**	**N**	**N**	**N**	
F	Me	*Discus rotundatus* (Müller, 1774)	**S**		**N**	**R**				**S**		**S**
F	Eb	*Discus perspectivus* (Mühlfeld, 1816)	**N**	**R**	**C**	**R**	**R**	**C**	**S**	**N**		
F	Em	*Vitrea diaphana* (Studer, 1820)	**C**	**N**	**V**	**A**	**C**	**C**	**N**	**C**	**N**	**R**
F	Ma	*Vitrea transsylvanica* (Clessin, 1877)	**N**	**N**	**A**	**N**	**N**	**A**	**C**	**A**	**C**	**R**
F	Em	*Vitrea subrimata* (Reinhardt, 1871)	**S**	**N**	**A**	**A**	**C**	**S**		**R**		**R**
F	Ep	*Vitrea crystallina* (Müller, 1774)	**C**	**N**	**V**	**A**	**C**	**V**	**V**	**A**	**V**	**R**
F	Em	*Daudebardia rufa* (Draparnaud, 1805)		**S**	**S**	**S**						
F	Em	*Daudebardia brevipes* (Draparnaud, 1805)			**R**							
F	Ma	*Morlina gabra* (Westerlund, 1881)			**S**							
F	Me	*Mediterranea depressa* (Sterki, 1880)	**R**	**N**	**R**	**S**	**S**	**N**	**R**	**N**	**R**	**S**
F	Ep	*Aegopinella pura* (Alder, 1830)	**N**	**N**	**A**	**C**	**C**	**A**	**C**	**A**	**C**	**S**
F	Me	*Aegopinella minor* (Stabile, 1864)	**N**	**N**	**C**	**N**	**N**	**C**	**C**	**C**	**N**	**S**
F	Me	*Aegopinella nitens* (Michaud, 1831)	**R**	**C**	**N**	**R**	**S**	**C**	**C**	**C**	**C**	
F	Me	*Semilimax semilimax* (Férussac, 1802)	**R**	**R**	**N**	**R**	**S**	**R**	**R**	**S**	**R**	
F	Ma	*Semilimax kotulae* (Westerlund, 1883)							**R**	**R**	**N**	
F	Ma	*Eucobresia nivalis* (Dumont&Mortillet, 1854)	**N**	**N**	**N**	**N**	**N**	**C**	**N**	**C**	**R**	
F	Ep	*Fruticicola fruticum* (Müller, 1774)	**N**	**N**	**C**	**C**	**R**	**N**	**R**	**C**		
F	Ma	*Petasina unidentata* (Draparnaud, 1805)	**N**	**N**	**A**	**A**	**C**	**S**	**S**	**C**	**R**	**R**
F	Me	*Monachoides incarnatus* (Müller, 1774)	**R**	**S**	**C**	**C**	**R**	**R**		**N**	**R**	**S**
F	Ma	*Monachoides vicinus* (Rossmässler, 1842)	**N**	**N**	**C**	**A**	**C**	**A**	**C**	**A**	**C**	**R**
F	Ee	*Perforatella bidentata* (Gmelin, 1791)	**R**		**C**	**R**						
F	Ma	*Urticicola umbrosus* (C. Pfeiffer, 1828)		**R**				**S**	**S**	**N**	**C**	
F	Me	*Arianta arbustorum* (Linnaeus, 1758)	**N**	**R**	**A**	**A**	**C**					**N**
F	Ma	*Faustina faustina* (Rossmässler, 1835)	**N**	**N**	**A**	**C**	**N**	**N**	**N**	**C**	**N**	**N**
F	Ma	*Faustina rossmassleri* (L. Pfeiffer, 1842)	**N**	**N**	**C**	**C**	**R**	**R**	**N**	**C**	**R**	**N**
F	Me	*Isognomostoma isognomostomos* (Schröter, 1784)	**N**	**N**	**A**	**A**	**C**	**C**	**C**	**A**	**C**	**N**
F	Ew	*Cepaea hortensis* (Müller, 1774)	**S**		**N**	**N**	**N**		**R**			**S**
F	Em	*Helix pomatia* Linnaeus, 1758		**S**	**S**	**S**	**S**		**R**	**S**	**R**	
O	Hl	*Vallonia costata* (Müller, 1774)	**V**	**A**	**S**		**N**	**C**	**C**	**C**	**N**	
O	Hl	*Vallonia pulchella* (Müller, 1774)	**A**	**A**	**R**	**S**	**R**			**R**		**S**
O	Hl	*Pupilla muscorum* (Linnaeus, 1758)	**C**	**C**	**R**		**S**					
O	Hl	*Vertigo pygmaea* (Draparnaud, 1801)	**C**	**C**	**R**		**S**		**S**	**S**		
O	Pl	*Ceciloides acicula* (Müller, 1774)	**C**	**C**								
M	Ep	*Carychium tridentatum* (Risso, 1826)	**A**	**A**	**V**	**A**	**C**	**V**	**V**	**V**	**V**	**S**
M	Es	*Succinella oblonga* (Draparnaud, 1801)	**S**		**N**							
M	Hl	*Cochlicopa lubrica* (Müller, 1774)	**R**	**N**	**R**	**S**	**N**	**N**	**N**	**N**	**N**	
M	Hl	*Columella edentula* (Draparnaud, 1805)		**S**	**S**			**R**	**R**	**R**	**N**	**S**

M	Ba	*Vertigo substriata* (Jeffreys, 1833)	**N**	**S**	**N**	**R**	**R**	**R**	**N**	**N**	**N**	
M	Ba	*Vertigo alpestris* Alder, 1837	**S**	**S**	**S**			**S**				
M	Me	*Clausilia rugosa* (Férussac, 1807)			**S**			**S**			**S**	
M	Me	*Clausilia dubia* Draparnaud, 1805	**R**	**N**	**C**	**N**		**C**	**N**	**C**	**N**	
M	Pl	*Punctum pygmaeum* (Draparnaud, 1801)	**N**	**R**	**R**	**S**	**R**	**N**	**N**	**N**	**N**	
M	Ep	*Vitrea contracta* (Westerlund, 1971)		**S**	**S**	**S**	**S**					**S**
M	Hl	*Euconulus fulvus* (Müller, 1774)	**N**	**R**	**R**	**S**	**R**	**N**	**N**	**N**	**N**	
M	Pl	*Perpolita hammonis* (Ström, 1765)	**S**			**S**		**S**	**S**	**R**	**R**	
M	Ba	*Perpolita petronella* (L. Pfeiffer, 1853)						**S**			**S**	
M	Pl	*Vitrina pellucida* (Müller, 1774)	**N**	**C**	**N**	**N**	**R**	**N**	**N**	**C**	**N**	
M		*Limacidae*		**R**	**S**	**S**	**S**	**S**				**S**
M	Ma	*Trichia villosula* (Rossmässler, 1838)	**N**		**N**	**N**	**C**			**R**		**R**
H	Es	*Carychium minimum* Müller, 1774	**C**	**C**	**A**	**A**	**N**	**A**	**A**	**A**	**A**	
H	Es	*Succinea putris* (L.)			**N**		**S**					
H	Pl	*Oxyloma elegans* (Risso, 1826)			**R**							
W	Ma	*Bythinella austriaca* (Frauenfeld, 1857)	**C**	**C**	**V**	**V**	**V**					**V**
W	Hl	*Galba truncatula* (Müller, 1774)	**R**	**R**	**N**	**S**	**N**	**N**	**R**	**N**	**R**	
W	Me	*Radix peregra* (Linnaeus, 1758)			**S**		**N**					
W	Hl	*Pisidium casertanum* (Poli, 1791)			**S**	**S**						
W	Ep	*Pisidium personatum* Malm, 1855	**S**		**N**	**S**	**S**			**S**		
W	Pl	*Pisidium obtusale* (Lamarck, 1818)			**S**		**S**					

E. ecological groups of molluscs (after Ložek, 1964; Alexandrowicz, 1987; Alexandrowicz & Alexandrowicz, 2011): F. shade-loving snails, O. open-country snails, M. mesophilous snails, H. hygrophilous snails, W. water snails; Frequency of specimens: S. single (1–3), R. rare (4–10), N. few (11–32), C. common (33–100), A. abundant (100–300), V. very abundant (>300) ZG. zoogeographical groups of molluscs (after: Alexandrowicz & Alexandrowicz, 2011): Hl. Holarctic species, Pl. Palearctic species, Ep. European species, Es. Euro-Siberian species, Me. Central-European upland species, Ma. Central-European mountain species, Ee. East-European species, Eb. Balcan species, Em. South-European species, Ew. West-European species, Ba. Boreal-Alpine species.

Shade-loving species occur in all profiles. Their biggest share is observed in sites in the upper part of the valley (profiles Zs-II – Zs-X), where they can constitute even up to 85% of the assemblage (Fig. 1).

Snails typical of open environments (ecological group O) are represented by 5 taxa (Table 1). A very numerous occurrence of *Vallonia pulchella* and *Vallonia costata* in profiles Zs-I and Zs-II with the simultaneous relatively small share of shade-loving forms is noteworthy. This indicates a lack of dense forests in the zone of sedimentation of sinters exposed in these profiles. The presence of *Ceciloides acicula* in profiles Zs-I and Zs-II is also worth stressing. It is a species leading underground lifestyle, particularly often found in areas of cultivated fields. Its presence is the indicator of agricultural human activity (Alexandrowicz at al., 1997; Alexandrowicz, 1997, 2004, 2013c; Alexandrowicz, S.W., 1997). In sites Zs-I and Zs-II, the share of open-country species can be up to 40% of the assemblage, in the remaining profiles they appear sparsely or do not occur at all.

Mesophilous species (ecological group M) are represented by 16 taxa, among which the most numerous is *Carychium tridentatum* (Table 1). Those forms occur commonly, their presence was indicated in all profiles. However, they always constitute only a complementing element of assemblages and their share usually does not exceed 20%.

Hygrophilous taxa (ecological group H) comprise only three species (Table 1). Apart from *Carychium minimum*, which is present in almost all samples, the remaining two appear very rarely and only as single individuals. The significance of hygrophilous snails for the present fauna is marginal.

Water molluscs (ecological group W) include three species of snails and three species of bivalves (Table 1). Among water taxa, only *Bythinella austriaca* occurs in large numbers, and is often simply a dominant species. It is a stenotopic form typical of source zones. As a result of revision of *Bythinella* genus, several new species were separated (Falniowski, 1987; Glöer, 2013). Those distinctions were performed on the basis of anatomical studies, while differences in morphology of shells are very small and usually impossible to discern. For this reason, the *Bythinella austriaca* species is understood in the broad sense in the present study and taxa separated due to the revision are included in the species. On the other hand, these species appear in very similar types of habitats and often coexist and *Bythinella austriaca* species itself is the most common among them. The discussed form is noted from very numerous sites of contemporarily precipitated calcareous tufa from the area of the Podhale Basin (Alexandrowicz, 1997, 2001, 2004, 2010; Alexandrowicz et al., 2014), the Pieniny Mountains (Alexandrowicz, 1990, 1993a, b, 2004, 2010, 2013b; Alexandrowicz et al., 2016) and the Flysch Carpathians (Alexandrowicz, 2004, 2009a).

This species appears only in tufa deposited over the last few hundred years and is not known from profiles exposing older deposits (Alexandrowicz, 1997, 2004, 2009a, 2010). For this reason, it is successfully used as an indicator of the age of deposits (Alexandrowicz & Alexandrowicz, 1995a; Alexandrowicz, 2004, 2009b; Alexandrowicz et al., 2014, 2016). Numerous shells of *Bythinella austriaca* were found in samples from profiles Zs-I – Zs-V and from profile Zs-X. While the discussed species did not occur in profiles Zs-VI – Zw-IX.

Zoogeographical composition of fauna is diverse. The widely distributed, mainly Holarctic, Palearctic and European species are common. The Central European mountain and upland taxa constitute another significant group. The European snails with a limited range usually constitute complement of assemblages, although sometimes the share of the South-European forms can exceed 10% (Table 1).

4.2. Molluscan assemblages

The malacofauna recognised in particular profiles of calcareous tufa exposed in the Skalski stream valley is evidently diverse. This diversity is the basis for separating and defining three types of faunal assemblages. They refer to different features of environment in which calcareous tufa deposition took place. Reasons for separating assemblages are: the share of shade-loving species, the share of species of open-country taxa and the presence of or lack of *Bythinella austriaca*. Particular types of fauna were distinguished on the basis of the conducted dendogram and correspondence analysis (Figs 2, 3). Assemblage with shade-loving species is a very rich and diverse malacocenosis in which the dominant role is played by species preferring shaded habitats.

Taxa characteristic of dense mixed forests (*Ena montana*, *Eucobresia nivalis*, *Faustina faustina*, *Faustina rossmassleri*), forms inhabiting the areas covered by bushes or sparse light-saturated forests (*Vitrea crystallina*, *Aegopinella minor*, *Fruticicola fruticum*) and snails typical of shaded places with the increased humidity of the ground (*Vestia turgida*, *Monachoides vicinus*) are present here. The share of the shade-loving element is very high and usually ranges between 70-80% of the assemblage, sometimes exceeding even 90%. Mesophilous species constitute the complement of the assemblage. Snails of open environments and hygrophilous species occur very rarely. Water molluscs are also sparse. It is necessary to underline the absence of *Bythinella austriaca*.

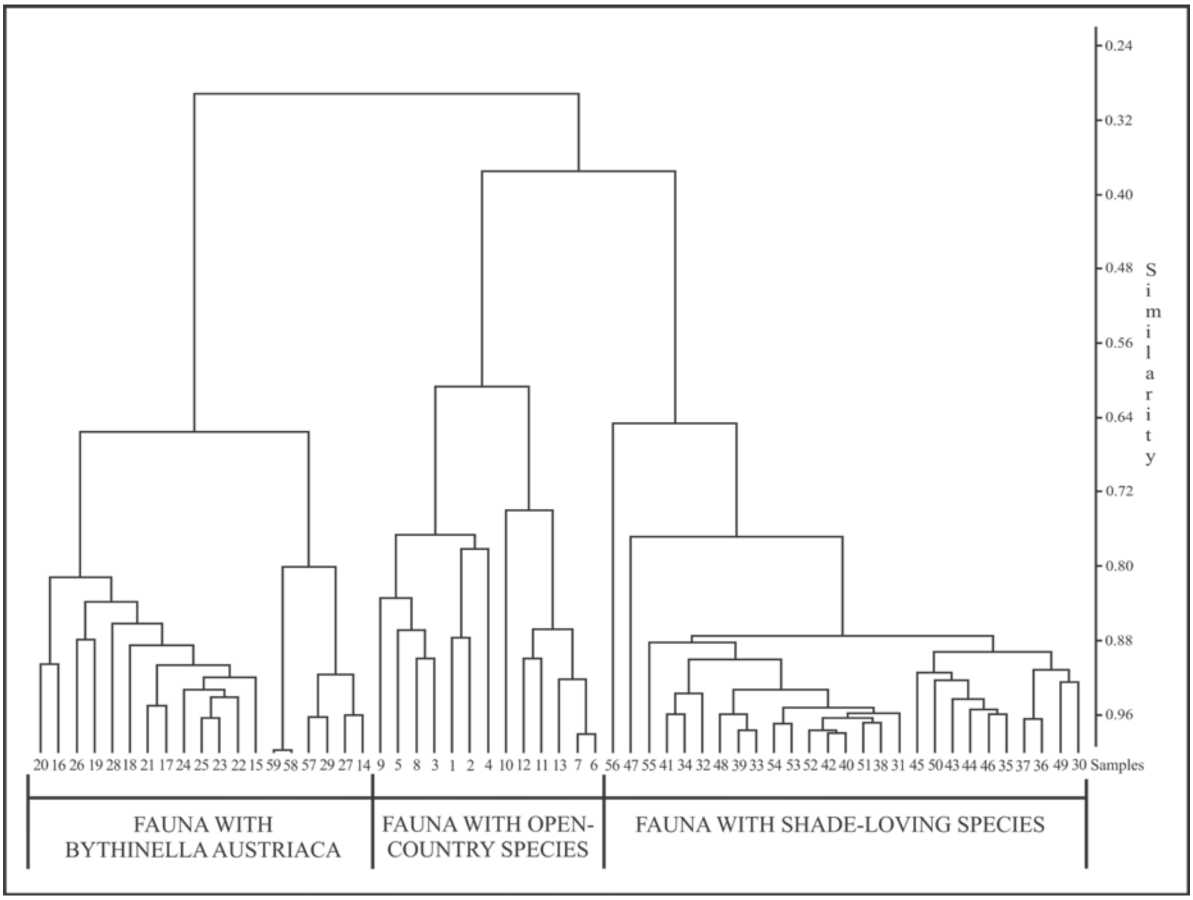

Figure 2. Types of molluscan fauna from profiles of calcareous tufa in Skalski stream valley.

In zoogeographical structure the dominant role is played by the broadly distributed European snails. The Central European mountain and upland forms are important components of the fauna. The remaining zoogeographical groups are of lesser importance (Fig. 4). The discussed assemblage was recognised in samples from profiles Zs-VI – Zw-IX (Figs 2, 3).

The assemblage with open-country species is characterised by evidently smaller diversity in species than the one described above. Shade-loving taxa occur commonly but are less numerous. This reduction in number is particularly evident in relation to forms typical of dense forests and less evident in the group of taxa inhabiting bushy areas and light-saturated forests. The share of shade-loving element does not exceed 40%. Snails of open environments, and particularly of grassy habitats (*Vallonia pulchella*, *Vallonia costata*) play a significant role in the discussed fauna. The presence of a snail related to agricultural areas – *Ceciloides acicula* – is also characteristic. The share of open-country forms can be up to 40% and increases towards the tops of profiles. Mesophilous taxa are the complement of the discussed fauna. Water species are represented mainly by *Bythinella austriaca*. In the discussed assemblage, the most significant role is played by the broadly distributed Holarctic and European taxa, while the Central European mountain and upland forms are of lesser importance (Fig. 4). The presented assemblage is present in samples from profiles Zs-I and Zs-II (Figs 2, 3).

The assemblage with Bythinella austriaca is characterised by a significant share of shade-loving species constituting the most diverse component in terms of species composition. The common occurrence of taxa typical of dense forests demonstrates a significant forestation of zones of calcareous tufa sedimentation. Shade-loving taxa usually constitute 50-60% of the discussed fauna. Mesophilous forms constitute the complement of the assemblage, while species of open and wet environments are rare. However, the most characteristic feature of this assemblage is the common occurrence of *Bythinella austriaca*. It is dominant and, in extreme cases, its share in the discussed fauna can be even up to 90%; however, usually reaches 60-70%. In zoogeographical structure, a large share of the Central European mountain taxa, the broadly distributed European snails and South-European species is marked (Fig. 4). This malacocenosis was recognised in profiles Zs-III – Zs-V and in profile Zs-X (Figs 2, 3).

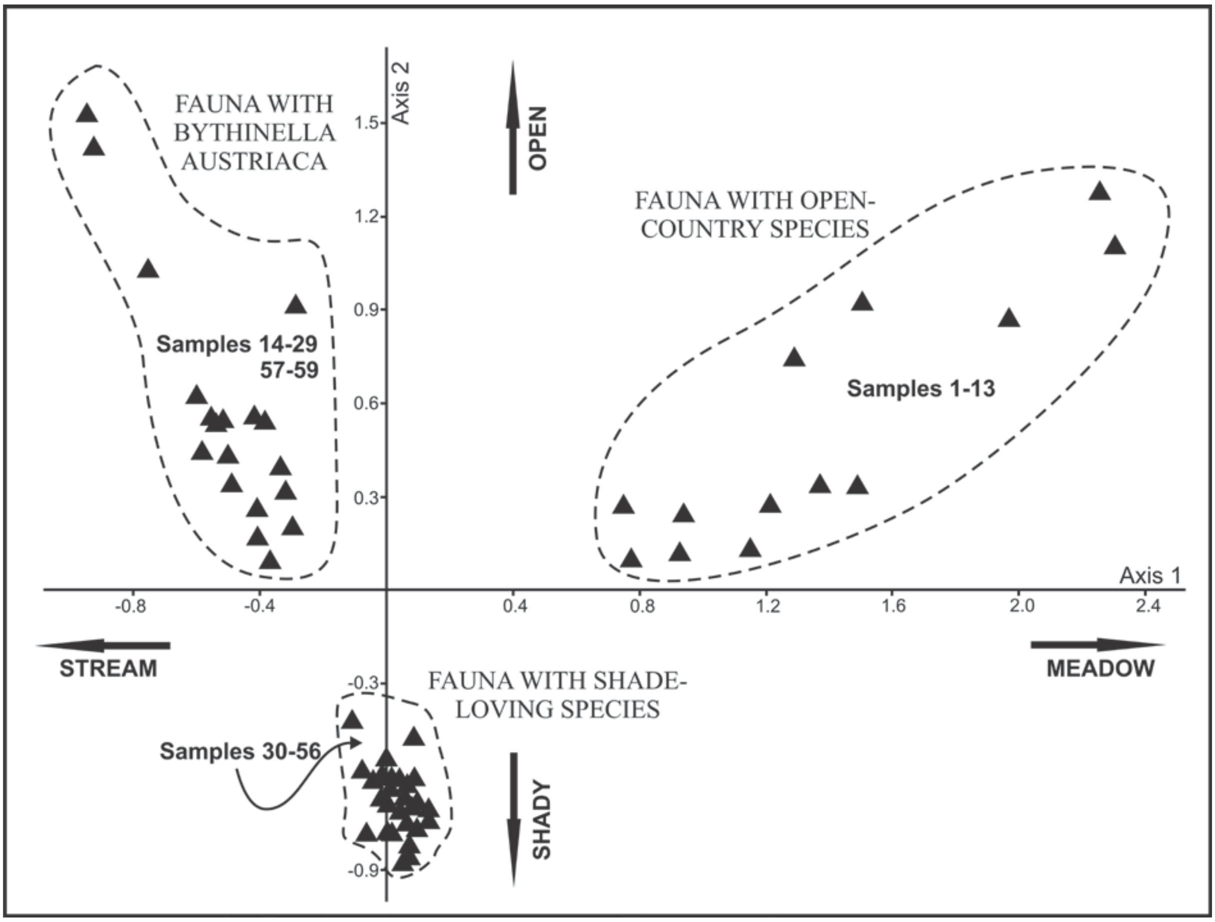

Figure 3. Differentiation of molluscan assemblages in profiles of Middle and Late Holocene calcareous tufa in Skalski stream valley.

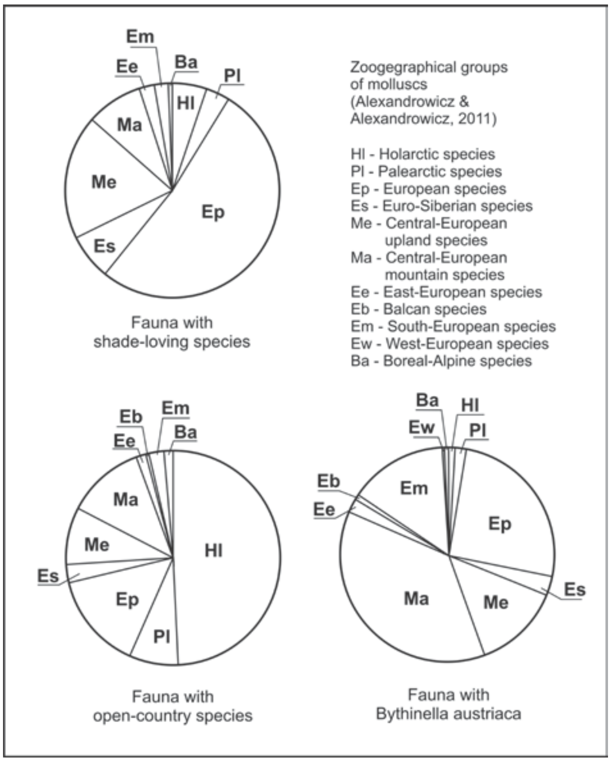

Figure 4. Zoogeographical structure of molluscan assemblages from profiles of calcareous tufa in Skalski stream valley.

5. DISCUSSION

The discussed above molluscan assemblages differ evidently between each other in terms of taxconomical composition, structure and ecological requirements (Fig. 3). These dissimilarities reflect environmental changes during sedimentation of calcareous tufa and, also refer to the age of deposits. The assemblage with shade-loving species occurring in four profiles (Zs-VI- Zs-IX) represents one continuous outcrop of calcareous tufa in the middle part of the Skalski stream valley. The malacofauna recognised in the mentioned profiles demonstrates a slight diversity (Fig. 3). It represents strongly shaded forest environment with the calcareous ground. The composition of the assemblage indicates mixed forests developed in a relatively warm and wet climate. In the bottom part of profile Zs-VII, the age determination was conducted by the radiocarbon method. The material subjected to the analysis was big shells of *Helix pomatia*. The analysis result: 6500±70 years BP (Gd-9977) (5600-5330 cal BC) indicates that the beginning of the calcareous fufa sedimentation occurred in the Atlantic Phase of the Holocene. It must be noted that the result of radiocarbon dating conducted on the material from the snails shells is often encumbered with an error and the obtained dates are older than the actual ones (Pazdur et al., 1988a, b). The climatic conditions in the middle part of the Holocene particularly facilitated the deposition of calcareous tufa (e.g. Jäger & Ložek, 1968, 1983; Ložek, 1972; Alexandrowicz, 1983, 2004, 2012; Pazdur, 1987; Limondin-Lozouet & Precce, 2004; Gedda, 2006). A large share of broadly distributed European species is characteristic of the discussed type of fauna (Alexandrowicz, 1997, 2013a; Alexandrowicz & Rybska, 2013) (Fig. 4). This period corresponds to the pollen phases *Ulmus*, *Corylus* and *Ulmus-Tilia-Quercus-Fraxinus* described on the Podhale peatbogs by Obidowicz (1990). Fauna with shade-loving species described from profiles in the Skalski stream demonstrates significant similarities to the Middle Holocene malacocenoses recognised in the Podhale Basin (Alexandrowicz, 1997, 2001, 2003, 2004, 2013a; Alexandrowicz et al., 2014) and in the Flysch Carpathians (Alexandrowicz & Alexandrowicz, 1995a; Alexandrowicz, 2004). On the other hand, the evidently smaller frequency of species such as: *Discus perspectivus*, *Discus rotundatus*, *Ruthenica filograna*, and also a small frequency of the thermophilic South-European snails indicates a slightly cooler climate corresponding rather to the younger part of the Atlantic Phase and perhaps also to the older part of the Subboreal Phase. Cooling of the climate falling to this period is documented in the palynological profiles from the area of the Podhale Basin (*Picea*, *Carpinus-Abies* and *Fagus-Abies* phases) (Obidowicz 1990). This period is also associated with the phase of the glaciers advance in the Alps (Bortenschlager, 1982; Ivy-Ochs et al., 2009) and the increase in the fluvial activity of the Carpathian rivers (Starkel et al., 2006) and the intensity of mass movements (Margielewski, 1998; Alexandrowicz, 1996). The gradual reduction of the share of thermophilic forest species in the ending part of the Atlantic was also described from the area of the Podhale (Alexandrowicz, 1997, 2003; Alexandrowicz & Rybska, 2013; Alexandrowicz et al., 2014, 2016). All those observations and the result of radiocarbon dating indicate that sedimentation of calcareous tufa exposed in profiles Zs-VI – Zs-IX occurred in the younger part of the Atlantic Phase or/and at the turn of the Atlantic and Subboreal Phases.

The remaining two assemblages (the assemblage with species of open environments and the assemblage with Bythinella austriaca) are evidently different form the one described above (Fig. 3). Main differences are: clear impoverishment of species diversity of the shade-loving forms and the presence of taxa typical of the historical period. The first of these species is *Bythinella austriaca*. This form was described from very numerous sites of calcareous tufa in the area of the Podhale Basin, the Pieniny Mountains and the Flysch Carpathians

(Alexandrowicz & Alexandrowicz, 1995a; Alexandrowicz, 1997, 2004, 2009a, 2010, 2013b; Alexandrowicz et al., 2014, 2016). However, all those sites represent the period of the last several hundred years, that is *de facto* the Subatlantic Phase. On the other hand, *Bythinella austriaca* was never noted in deposits corresponding to the Subboreal phase and the older part of the Holocene. Therefore, it is used as an important stratigraphic indicator (Alexandrowicz, 2004, 2009b; Alexandrowicz et al., 2014). Another stratigraphically significant taxon is *Ceciloides acicula*. This species is typical of cultivated areas, especially arable fields (Alexandrowicz et al., 1997; Alexandrowicz 2004, 2013c; Alexandrowicz & Gołas-Siarzewska, 2013a, b). Therefore, its presence is directly connected to the development of agriculture and settlement. The first phase of inhabitation of the Pieniny Mountains fell to the period of the XIVth century. The mentions of the first larger settlements date back to this period. Global warming falling to the XIII-XV century (the Medieval Warm Period) (Grove & Switsur, 1994; Huges & Diaz, 1994; Bradley, 2000; Briffa, 2000; Jones & Mann, 2004) was a period facilitating the increase in human population. The direct consequence of the increase in population of the area was the necessity to obtain new areas for cultivation. In effect, this lead to the significant deforestation and appearance of open grassy habitats and cultivated fields replacing the forests. Such a significant change of habitat types marks itself in the zoogeographic structure of the assemblage and is underlined by a significant increase in the share of the Holarctic taxa (Fig. 4). Anthropogenic impact has noted itself mainly in vast, flat stretches of valleys, that is in zones with conditions favourable for the development of agriculture and settlement. Such conditions prevail in the lower part of the Skalski stream valley (profiles Zs-I and Zs-II). Malacocenosis characterised by the high share of species of open environments and numerous occurrence of *Ceciloides acicula* was recognised in those profiles. Assemblages with similar composition and structure dated back to the Medieval Period were described from sites of calcareous tufa and fluvial deposits in the Podhale Basin and Pieniny Mountains (Alexandrowicz, 1990, 1993b, 2004, 2013c; Alexandrowicz et al., 2014, 2016). Anthropogenic deforestation was probably also one of the important factors influencing the start of slope processes (Alexandrowicz, 1993a, 2013b, c, Alexandrowicz S.W., 1997). Manifestations of human activity, especially the introduction of cultivation mark well in the palynological profiles of the Podhale peatbogs (NAP phase) (Obidowicz, 1990).

6. CONCLUSIONS

Molluscan assemblages recognised in calcareous tufa in the Skalski stream valley demonstrate the evident diversity in terms of ecological requirements. They also represent different periods of time. Older calcareous deposits are exposed in the middle part of the valley. The result of the radiocarbon dating indicates that those deposits represent the Atlantic phase, probably its younger part. In calcareous tufa there is very rich and diverse malacofauna with a strong dominance of shade-loving species and a very small share of open-country forms. Taxonomical composition and structure of the this malacocenosis demonstrate that the Skalski stream valley was almost entirely forested in the Atlantic Phase (Figs 3, 5). The Middle Holocene molluscan assemblages with a very high share of shade-loving species were described from numerous sites of calcareous tufa in the Polish Carpathians (e.g. Alexandrowicz & Alexandrowicz, 1995a, b; Alexandrowicz, 1997, 2001, 2003, 2004, 2013a; Alexandrowicz & Rybska, 2013; Alexandrowicz et al., 2014, 2016) and from the Central Polish Uplands (Alexandrowicz, 1983, 2004, 2012; Alexandrowicz & Alexandrowicz, 1995b; Alexandrowicz S.W., 1997; Alexandrowicz & Gołas-Siarzewska, 2013a, b).

Younger calcareous tufa exposed in several profiles in the lower and upper part of the valley contain molluscan assemblages with completely different compositions. The presence of *Bythinella austriaca* and *Ceciloides acicula* indicates that they are sediments formed during historical times. The observed diversity of fauna within their borders reflects the phase of the intensive settlement and the related intensity of anthropogenic impact on the environment which occurred in the XIII-XV centuries - the Medieval Warm Period (Grove & Switsur, 1994; Huges & Diaz, 1994; Bradley, 2000; Briffa, 2000; Jones & Mann, 2004). The effect of human activity is significantly stronger in the lower, relatively flat section of the valley. Its manifestation is almost entire deforestation. In the middle and upper part, a large steepness of partly rocky slopes limited the human effect to a significant extent. In these areas, forest communities retained (Fig. 5).

Such a diversity of the terrains utilisation in terms of their relief is commonly observed in the Carpathians (e.g. Alexandrowicz, 1997, 2009a, 2010, 2013c). Cooling of the climate falling to the period of the XV-XIX century (the Little Ice Age) (Bradley & Jones, 1993; Bradley, 2000; Briffa, 2000; Jones & Mann, 2004) does not mark itself in the profiles. The associated with this phase limiting of anthropogenic impact on the environment related to a reduction of the human population enabled the expansion of forests (Fig. 5).

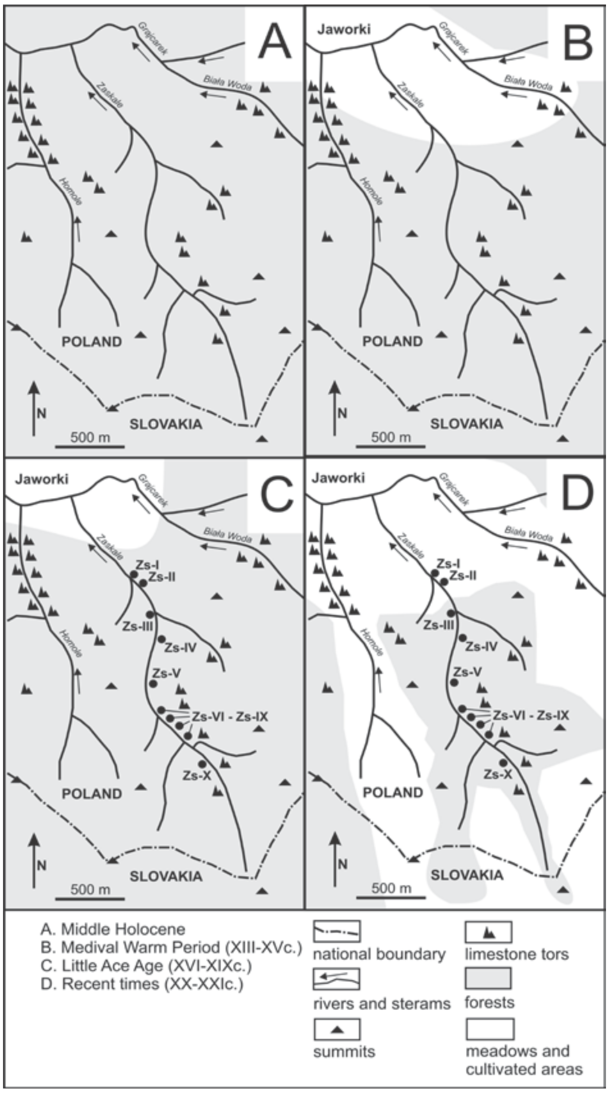

Figure 5. Environmental changes of Skalski stream valley during Middle and Late Holocene.

This phenomenon is well-documented in numerous profiles of fluvial deposits containing the remains of molluscs described in the Podhale Basin (Alexandrowicz, 1997, 2013c; Alexandrowicz et al., 2014). The effect of the climate cooling was also the slowdown or even stoppage in the sedimentation of calcareous tufa. This phenomenon is commonly observed in the Polish Carpathians and is the reason for the lack of the Little Ice Age faunistic record in profiles developed in the Skalski stream valley. The rapid growth in human population in the period of the 20th century led to extensive deforestation (Fig. 5) documented in numerous archival photographs.

Calcareous tufa described from the Skalski stream valley represent the Atlantic and Subatlantic Phases of the Holocene. However, there is a lack of deposits related to the Subboreal Phase. Climatic changes, which had adverse effect on the processes of sedimentation of calcareous tufa, are related to this period. In the Polish Carpathians, there are at least several dozen described sites representing the Middle Holocene (e.g. Alexandrowicz 1997, 2001, 2003, 2004, 2013a) and over 100 profiles of sinters formed in the historical period (e.g. Alexandrowicz 1997, 2004, 2009a, 2010, 2013b). However, profiles corresponding to the Subboreal Phase are very rare. The stoppage, and at least significant limiting of the calcareous tufa deposition tempo in the Subboreal Phase was also described from the area of the Polish Uplands (Alexandrowicz, 1983, 2004; Alexandrowicz S.W. 1997, Pazdur, 1987; Pazdur et al., 1988a, b), and also from the Middle and Western Europe (e.g. Ložek, 1964, 1972, 2000; Jäger & Ložek, 1968, 1983; Precce & Day, 1994; Gedda, 2001, 2006; Meyrick, 2001, 2002; Meyrick & Precce, 2001; Žak et al., 2002; Limondin-Lozouet & Precce, 2004).

Profiles of the Holocene carbonate precipitates in the valley of the Skalski stream in the Pieniny Mountains and the malacofauna occurring there are a good example of the utilisation of molluscs for the purpose of conducting paleogeographical reconstructions and determining the effect of human economy on the course and intensity of geological processes and changes in the natural environment.

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