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Problems in geoecological approach to high-mountain environment (based on studies of relief-vegetation relationships)

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Abstract

The paper discusses the issues associated with the geoecological rendition of high mountains, taking as a basis the authors' studies of interrelations between relief and vegetation. The fundamental prerequisites for these studies are presented, with emphasis on the fact that the relation between the two elements is indirect and takes place via the intermediary of the habitat. With respect to the scales, both spatial and temporal, applied in the study of landscape, it is established that the majority of relations between vegetation and relief is analysed on the micro-scale, and much less frequently on the meso-scale. Application of areal methods in respective studies provides the possibility of determining the measure of relation between the elements considered. The linear methods (like, e.g., the catena method) allow for grasping the gradient differentiation of the spatial patterns on high mountain slopes. It was established that the main source of problems with landscape representation of high mountains is the mosaic character of the landscape structure. Due to this, even though the interrelations between the elements of the environment – including relief and vegetation – are distinctly visible, they have not been made precise enough with the mathematically defined dependencies, which make development of models of structure and functioning of high mountain slopes more difficult.

Introduction

The environment of high mountains, treated as a set of elements (climate, relief, vegetation) is the subject of study of particular domains of science (such as climatology, geomorphology, geobotany), while being, as a whole, the subject of study of geoecology. The purpose of the paper is to present the achievements and the difficulties in resolving geoecological issues, typical for the environment of high mountains, treated as a whole, i.e. through the landscape approach. However, the way of the holistic study of the environment is influenced by the way of study used in the original discipline of science of the researcher. In the case of the present paper the basis is constituted by the experiences associated with the analysis of interrelations between relief and vegetation, conducted at various spatial scales. These experiences serve in assessing the feasibility of adopting the relation between relief and vegetation as the method for presenting the structure and the processes taking place in the high mountain landscapes.

Specific features of the high mountain landscape

Landscape, according to Richling and Solon (2002, p. 14), is the "complete, but heterogeneous whole, functioning within the laws of nature, endowed with the self-regulation capacity and characterised by definite individual features".

High mountain landscape has quite specific features, distinguishing it from other landscape types. If we assume as the starting point the features of landscape according to Zonneveld (1990), the specificity is made apparent with respect to each of them. And thus:

1. A landscape occupies a **segment of space** and can be presented on a map. Cartographic rendition of the high mountain areas brings about appearance of the highly congested image. So, in particular, the climatic-vegetation belts above the forest line constitute in the planar projection on the map narrow stripes, although areas of slopes within the individual belts are actually much bigger in terms of surface area.
2. A landscape is characterised by a definite **physiognomy**. In high mountains landscape often has mosaic-stripe structure, with the magnitude of elements of the mosaic being often highly differentiated – side by side with large units, encompassing areas homogeneous as to their physiognomy, like, e.g. dwarf mountain pine shrubs or rock walls, a mosaic of small patches can be observed (Balon, 2004; Kozłowska, 2006). There are numerous elements of the high mountain relief, such as rock walls or debris slopes, that do not appear in other areas. This applies also to other geocomponents.
3. A landscape is a **dynamic system**. The dynamics of landscape processes, mainly the geomorphological ones, in high mountains, causes constant emergence of new elements of the landscape mosaic, while all the areas are continuously subject to transformation.
4. A landscape undergoes **changes**; has an own history. High mountain landscape, in distinction from other mountain landscapes, has glacial origins, and hence also features, which do not exist in other mountains and are different from the glacial landscape of the plains. The glacial origins of the relief are one of the three criteria for the geo-ecological distinction of the high mountain areas, according to Troll (1973). Evolution of the high mountain landscape takes place owing to the geomorphological processes commonly appearing in the mountains, but also due to processes that are specific only for these areas, e.g. the periglacial processes. Besides, in high mountains human impact is more limited than in other areas.

This specificity of the high mountainous environment brings about the need of considering the theoretical and methodological assumptions, applied in a standard manner in the landscapes studies, of the areas situated at lower altitudes, and of modifying these assumptions.

Theoretical prerequisites for the study of relations between relief and vegetation in high mountains

Holistic approach to the high mountainous environment, represented by geoecology, is possible from the points of view of abiotic nature, biotic nature (mainly vegetation, but also animal meta-populations or home ranges of individuals), and the human impact – although the latter, in this case, to a lesser degree than in other types of landscape (Richling & Solon, 2002).

The most frequent way of approaching high mountainous environment in geoecology is represented by the specialists of comprehensive geography, who analyse the question of boundaries, controlled by various factors, mainly abiotic ones (Balon, 2000a, b, 2007; German, 2000; Jodłowski, 2007). According to Balon (2007), among eight leading factors the most significant for the delimitation of landscape boundaries in the mountains are: landforms, vegetation cover, slope aspect, and climatic influences.

Another manner of interpreting the environment of high mountains is the approach from the point of view of vegetation. Vegetation is the element that is most strongly controlled by all the abiotic and biotic elements of natural environment, and by the human activity, and is, at the same time, easily accessible for direct study. Owing to this, it plays an indicative role, allowing for a rapid diagnosis of the state of the environment, without the necessity of conducting complex laboratory analyses (Matuszkiewicz, 1974).

The majority of the abiotic factors exert direct impact on vegetation. In the case of relief the respective relations are not direct, but take place through the intermediary of soil environment, water and local climate. Simultaneously, it is relief (along with macro-climate) that plays the superior role in the environment of high mountains with respect to other components and in a way enforces a structural framework, within which the spatial pattern of the landscape takes shape.

The interdependencies between relief and the vegetation growing over it have long been of interest to both geomorphologists and geobotanists. However, the interest has tended to be both limited and imprecise. Thus, a more precise description from the point of view of one of the specialisations has usually been associated with a very superficial description from the point of view of the other. Geomorphologists have generally confined their interest to a description of the degree of closure of vegetation cover as an important factor governing the stability of particular landforms (e.g., Kotarba, 1976; Jahn, 1979; Rapp, 1983). In turn, geobotanists have used a very imprecise diagnosis of landforms that are covered by the vegetation they are studying (e.g., Géhu, 1986).

In our geoecological studies we adopt the relation between relief and vegetation (Table 1) as a method of representing the structure and the processes, taking place in the high mountain landscapes (Kozłowska & Rączkowska, 1996, 1999a, b, 2002; Kozłowska *et al.*, 1999, 2006). Many authors adopt a similar ap-

Table 1. Relations between relief and vegetation in the Kocioł Gąsienicowy basin (index of the strength of linkages between vegetation and geomorphic processes – valorized)

characteristics	slope stabilized by pinus mugo	anthropogenic erosion and acumulation	accumulation of debris flows	creeping of turf and soils over boulders	solifluction, terraccettes	solifluction	fresh debris flows accumulation	accumulation on aluvial cones and plains	stable slope modelled by deflation	torrential processes, mainly sheetwash and linear erosion	stable slope covered by blockfields	creeping and solifluction	turf creeping over boulder cover	creeping	stable slope
Pinetum mughi carpaticum	V														
Pogonato-Oligotrichetum		V													
Luzuletum alpino-pilosae in a complex with in a complex with *Festuca picta* - community			IV												
Oreochloo distichae-Juncetum trifidi caricetosum sempervirentis in a complex with *Calamagrostietum villosae tatricum*				IV											
Oreochloo distichae-Juncetum trifidi typicum , mossy form					III										
Oreochloo distichae-Juncetum trifidi salicetosum herbaceae						III									
Luzuletum alpino-pilosae							V	III	III						
cryptogamic plant communities on scree, initial phase I										IV					
cryptogamic plant communities on scree, initial phase II										III					
Rhizocarpetalia											V				
Oreochloo distichae-Juncetum trifidi , form with *Juncus trifidus*											IV				
Oreochloo distichae-Juncetum trifidi post-grazing subalpine form												IV			
Calamagrostietum villosae tatricum												III			
Empetro-Vaccinietum												III			
Vaccinium myrtillus - community													V		
Vaccinium myrtillus - community in a complex with *Oreochloo distichae-Juncetum trifidi* subalpine form													IV		
Oreochloo distichae-Juncetum trifidi subalpine form in a complex with *Vaccinium myrtillus* - community													III	III	
Oreochloo distichae-Juncetum trifidi sphagnetosum														V	
Oreochloo distichae-Juncetum trifidi caricetosum sempervirentis dry form with *Nardus stricta*														III	
Oreochloo distichae-Juncetum trifidi typicum mossy form in a complex with *O.d.-J.t.salicetosum herbaceae*														III	III
tall herb community with *Alchemilla sp.*															III
community similar to *Seslerion tatrae*															V
tall herb communities of the alliance *Adenostylion alliariae*															V
Oreochloo distichae-Juncetum trifidi typicum mossy form in a complex with *Luzuletum alpino-pilosae*															V
Oreochloo distichae-Juncetum trifidi cetrarietosum															V
Oreochloo distichae-Juncetum trifidi carietosum sempervirentis in a complex with *Calamagrostietum*															V
Oreochloo distichae-Juncetum trifidi typicum															III
Oreochloo distichae-Juncetum trifid i anthropogenic form with *Juncus trifidus*															III

proach in their studies. Thus, for instance, Hreško (1994, 1998) indicates the morphodynamic system as the basic spatial unit of the high mountain landscape. The influence of the morphogenetic processes (especially the extreme ones) on the structure of the landscape, using the example of the Tatra Mts., is emphasised by, in particular, Hreško and Boltižiar (2001) and Boltižiar (2007).

In our studies, relief is considered in the form of morphodynamic units, while vegetation – in the form of plant communities and vegetation landscapes. Relief, as the most stable component of the environment, controlling other elements, is perceived as opposed to vegetation, which is the component conditioned most intensively by all abiotic and biotic components, and by human impact (Kozłowska & Rączkowska, 1999a). Direct relations between relief and, in particular, its morphodynamics and vegetation, are pointed out and documented for numerous mountain areas, like, e.g., Soutade (1980) and Somson (1983) for the Pyrenées, Bayfield (1984) for Caingorms, Plesník (1956), Rączkowska and Kozłowska (1994) and Kozłowska *et al.* (1999) for the Tatra Mts., or Kozłowska and Rączkowska (2002) for the Scandinavian Mts. Reasoning, based on the vegetation cover, concerning other elements of the environment and human activity, refers to current states, but the record of the boundaries of properties – provided by the forest line and the structure of the landscape is insofar persistent, that it forms the basis for regressing in the study to historical states (Boltižiar, 2007; Wolski, 2007).

When using the indicative role of vegetation in the high mountainous environment one should, however, be aware that it reflects the entirety of influence exerted on it by various factors, and not the individual elements of natural environment.

By assuming the key role of vegetation in the study of the environment of high mountains and omitting other geocomponents, an economy of time and financial outlays is achieved. The results obtained allow for singling out other significant elements for further studies. Such complementary analyses are, however, not always needed. Thus, for instance, a detailed study of soils, carried out at a micro scale in the vicinity of Kasprowy Wierch Mt. (Degórski, 1999) did not bring new information on the environment in comparison with what had been already concluded on the basis of vegetation concerning the trophism of soils and their humidity.

The issue of scale in the geo-ecological studies in high mountains

With respect to the natural spatial units, Delcourt and Delcourt (1988) distinguished four scales of spatio-temporal phenomena: microscale, mesoscale, macroscale and megascale. In the study of high mountainous landscapes the most frequently addressed are the micro- and mesoscales, encompassing the spectrum from concrete locations to entire mountain ranges. Concerning the temporal scale, we usually do not go out of the microscale, and in particular cases enter the mesoscale. Consideration of the macro and mega time scales would require application of entirely different methods, originating from palynology.

The specific character of high mountains consists, in particular, in that if we assume as the starting point vegetation, then in the studies concerning spatial landscape units (vegetation landscapes), and not the individual patches of the plant communities, surface areas of magnitude which are treated by the Delcourts as microscale, are considered as the landscape units.

This is linked with the structure of vegetation covering slopes, taking the form of small-area mosaic, frequently encountered in the environment of high mountains. Minimum differences in relative altitude, associated with the micro-relief, cause appearance of the mosaic of vegetation patches, belonging to different typological units, and hence constituting already from the geobotanical point of view a structure of the landscape, and not biocoenotic, rank. This is clearly visible in the nival niche (Kozłowska & Rączkowska, 1996, 2006), see Fig. 1, and also on the basis of other studies on the detailed scale (Rączkowska & Kozłowska, 1994; Kozłowska & Rączkowska, 2002, 2005; Kozłowska *et al.*, 2006; Gerdol & Simraglia, 1990). The issue of spatial scale in high mountains is made yet more complicated by

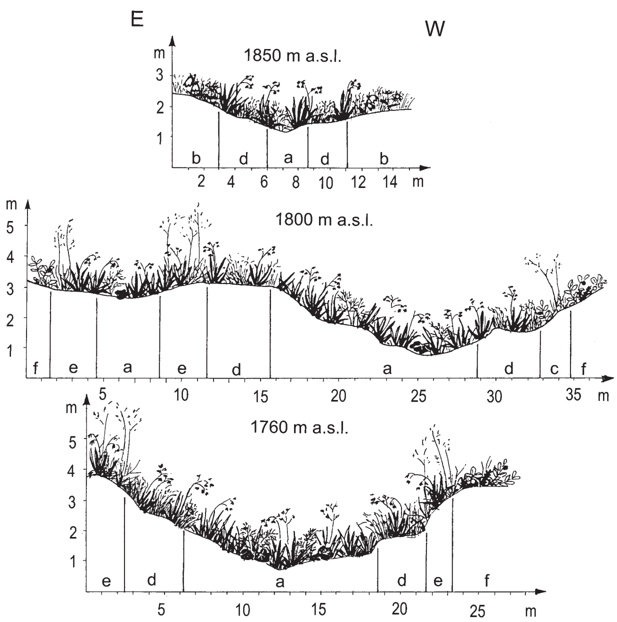

Fig. 1. Differentiation of vegetation on the nival form on Beskid

a – snow-bed vegetation, b – alpine swards, c – subalpine grassland, d – spatial complex of alpine swards and snow-bed vegetation, e – spatial complex of subalpine grasslands and snow-bed vegetation, f – subalpine dwarf scrubs the previously mentioned difference between the actual surface area of slopes and their projection on the plane. Shrinking of the true area of the slopes on maps makes representation of the actual mosaic of units frequently impossible.

The role of methods in the study of the spatial structure of high mountain landscape

Methods used in the study of spatial structure of landscape settings account for their differentiation over the areas or lines, i.e. along definite transects (profiles). Area representation of the spatial structure of high mountain environment can take the form of the projection on the horizontal plane (map), which is more frequent, but also on the vertical plane, allowing for the expression of the differentiation along altitude (Theurillat, 1992). These two ways of representation are put together in the DEM models, applied successfully by many authors, for instance by Boltižiar (2007).

Application of the areal methods gives the possibility of analysing the interrelations between the geocomponents, based on the superposition of maps, constituting their respective reflections, and calculation of the value assumed by some measures of similarity of distribution of the patches in spatial composition (Ostaszewska, 2002). This kind of method was applied to the high mountain environment by Kozłowska *et al*. (1999, 2006).

Among the linear methods, the method of catena is used with good results in the mountains. This approach shows the gradient of natural phenomena along mountain slopes (see, e.g., Balon, 1992; Niedźwiedzki, 2006). It was also used by the present authors in the work, the output of which has not been published yet, concerning the valley of Kärkevagge (northern Sweden). The pattern (structure) of the vegetation catenae on slopes was differentiated depending upon the morphodynamics of the slopes, differing for the debris slopes from those with weathering cover. This structure constituted a good representation not only of the nature of the slope, but also of the mode of its shaping. On the slopes with weathering cover the pattern of vegetation catenae was further differentiated, depending upon the character of the geomorphological process acting on a given slope.

The mosaic character of landscape and the problem of generalisation

In our studies, the morphodynamic units of relief are treated as a kind of skeleton, which is filled out by vegetation. On the basis of the strength of linkages we assign to each morphodynamic type of relief a set of characteristic vegetation communities (Kozłowska *et al*., 1999). Such a set has as yet a local validity, but this validity may turn out to be broader when the number of replications is increased. Developing a model of relations having wider applicability (generalisation) is not easy, since slopes differ as to their bedding, exposure, altitudinal belt, and also as to the relief and vegetation. This issue was also pointed out by Balon (1992) and Niedźwiedzki (2006). Yet, the possibility of developing a generalised model of the interrelations is not excluded, in spite of this.

The degree of dependence of the plant associations upon relief, when expressed in numerical terms, is not too high, and implies relations of medium strength (Kozłowska *et al*., 1999). High values of the strength of linkages are observed usually in the cases of very specific habitats, shaped by the activity of the geomorphological processes or the presence of long persisting patches of snow. These weak relations of vegetation and relief may be due to the fact that although it is common that numerous patches of vegetation occur over one (morphodynamic) relief unit, the boundaries of the relief units and of vegetation patches do not have to coincide, and this not only results from various ways the units are delimited. It appears that the dependence of vegetation upon relief has the character of a non-nested hierarchy, where higher levels do not embrace the lower ones, but are structurally different from them (Allen & Starr, 1982). Boundaries at the maps of vegetation and relief are controlled by different factors, whose differentiation takes place on different scales, and so they have a similar course, forming a similar spatial pattern, but not identical one.

The issue of boundaries and of their hierarchy, important for the typology of the landscape, and especially for regionalisation (at meso and higher scales), is not so significant in the considerations on the micro scale. Situation is different in the approach from the perspective of temporal transformations, where changes in the boundaries of relief units (like, e.g., those caused by the debris flows) and the sequencing of the consecutive stages of plant succession require interpretation of the differences in ranges of the phenomena compared.

Although emphasis on the role of high mountain vegetation in the geoecological studies proved appropriate in the case of our analyses, the limitations to the indicative role of vegetation have also been observed, as one enters the subnival belt in the Tatra Mts. or the nival belt in the Scandinavian mountains, that is when conditions for the plant life become disadvantageous (Kozłowska & Rączkowska, 2002).

Conclusions

The issues presented here do not exhaust the list of questions pertinent to geoecology of high mountains. The reasons for these questions to appear are connected with both methods and scales used in the geoecological studies of high mountains, and the very specificity of the natural environment of high mountains.

The multi-directional functional interdependences, along with simultaneous mosaic character of the high-mountain environment constitute the basic difficulties in identification of landscape (geoecological) diversity of high mountains. This is linked with the spatial bi-dimensionality: vertical and horizontal.

The studies to date of the co-appearance of two very different elements of the high mountain landscape (the most constant – relief, and the most variable – vegetation), indicate the existence of the functional interrelations between them, but have not parameterised these interrelations.

The geoecological studies ought to aim at developing a model of functioning of the environment that would possibly precisely describe the relations identified through mathematical formulae, with an adequate database support. Such a model is highly needed, and it would find application in the forecasting of changes in the environment, in particular – connected with climate changes, which is the fundamental problem in the world nowadays, given also strong human expansion (including settlements and other kinds of human activity) into the high mountainous areas. Assignment of special role to relief and vegetation in such a model is fully justified, but it requires further studies of their mutual relations.

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