

## **Problems in geocological 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 geocological 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.

**Key words:** high-mountain landscape, relief, vegetation, geocological approach, Tatra Mts.

### **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 geocological 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 & 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”.

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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

**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 accumulation	accumulation of debris flows	creeping of turf and soils over boulders	solifluction, terracettes	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
<i>Pinetum mughi carpaticum</i>	V														
<i>Pogonato-Oligotrichetum</i>		V													
<i>Luzuletum alpino-pilosae</i> in a complex with in a complex with <i>Festuca picta</i> - community			IV												
<i>Oreochloa distichae-Juncetum trifidi caricetosum sempervirentis</i> in a complex with <i>Calamagrostietum villosae tatricum</i>				IV											
<i>Oreochloa distichae-Juncetum trifidi typicum</i> , mossy form					III										
<i>Oreochloa distichae-Juncetum trifidi salicetosum herbaceae</i>						III									
<i>Luzuletum alpino-pilosae</i>							V	III	III						
cryptogamic plant communities on scree, initial phase I										IV					
cryptogamic plant communities on scree, initial phase II										III					
<i>Rhizocarpetalia</i>											V				
<i>Oreochloa distichae-Juncetum trifidi</i> , form with <i>Juncus trifidus</i>											IV				
<i>Oreochloa distichae-Juncetum trifidi</i> post-grazing subalpine form												IV			
<i>Calamagrostietum villosae tatricum</i>												III			
<i>Empetro-Vaccinietum</i>												III			
<i>Vaccinium myrtillus</i> - community													V		
<i>Vaccinium myrtillus</i> - community in a complex with <i>Oreochloa distichae-Juncetum trifidi</i> subalpine form													IV		
<i>Oreochloa distichae-Juncetum trifidi</i> subalpine form in a complex with <i>Vaccinium myrtillus</i> - community													III	III	
<i>Oreochloa distichae-Juncetum trifidi sphagnetosum</i>														V	
<i>Oreochloa distichae-Juncetum trifidi caricetosum sempervirentis</i> dry form with <i>Nardus stricta</i>														III	
<i>Oreochloa distichae-Juncetum trifidi typicum</i> mossy form in a complex with <i>O.d.-J.t.salicetosum herbaceae</i>														III	III
tall herb community with <i>Alchemilla sp.</i>															III
community similar to <i>Seslerion tatrae</i>															V
tall herb communities of the alliance <i>Adenostyilion alliariae</i>															V
<i>Oreochloa distichae-Juncetum trifidi typicum</i> mossy form in a complex with <i>Luzuletum alpino-pilosae</i>															V
<i>Oreochloa distichae-Juncetum trifidi cetrarietosum</i>															V
<i>Oreochloa distichae-Juncetum trifidi carietosum sempervirentis</i> in a complex with <i>Calamagrostietum</i>															V
<i>Oreochloa distichae-Juncetum trifidi typicum</i>															III
<i>Oreochloa distichae-Juncetum trifid</i> i anthropogenic form with <i>Juncus trifidus</i>															III

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 approach 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 & Boltžiar (2001) and Boltžiar (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 & Kozłowska (1994) and Kozłowska *et al.* (1999) for the Tatra Mts., or Kozłowska & 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 (Boltžiar, 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.

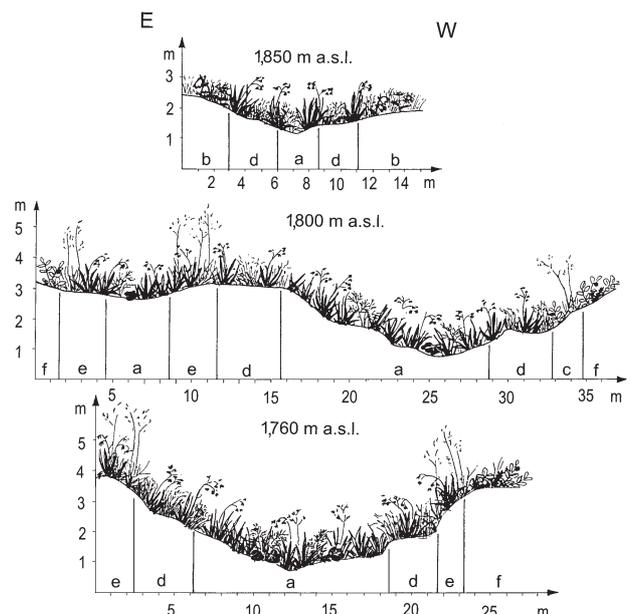
By assuming the key role of vegetation in the study of the environment of high mountains and omitting other geocomponents, an economy of time and financial outlays is achieved. The results obtained allow for singling out other significant elements for further studies. Such complementary analyses are, 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 biocenotic, rank.



**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

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 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 Boltziar (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 geocological 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 interdependencies, 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.

## References

- Allen, T.F.H. & Starr, T.B., 1982: Hierarchy: Perspectives for ecological complexity. *University of Chicago Press*, 310 pp.
- Balon, J., 1992: *Struktura i funkcjonowanie polskiej części zlewni Białki w Tatrach*. Unpublished Ph.D. thesis, IG UJ Kraków, 1992.
- Balon, J., 2000a: Piętra fizycznogeograficzne Polskich Tatr. *Prace Geograficzne UJ*, 105: 211–233.
- Balon, J., 2000b: Z metodyki prowadzenia granic regionów fizycznogeograficznych w górach. In: Pietrzak, M. (Ed.) *Granice krajobrazowe. Podstawy teoretyczne i znaczenie praktyczne*. PAEK Poznań: 33–47.
- Balon, J., 2004: O trudnościach zastosowania koncepcji płatów i korytarzy w obszarze wysokogórskim. In: Cieszevska, A. (Ed.), *Płaty i korytarze jako elementy struktury krajobrazu – możliwości i ograniczenia koncepcji*. *Problemy Ekologii Krajobrazu*, 14: 168–176.
- Balon, J., 2007: Stabilność środowiska przyrodniczego Karpat Zachodnich powyżej górnej granicy lasu. *Instytut Geografii i Gospodarki Przestrzennej UJ*, Kraków, 262 pp.
- Bayfield, N. G., 1984: The dynamics of heather *Calluna vulgaris* stripes in the Caingorm Mountains, Scotland. *Journal of Ecology*, 72: 515–527.
- Boltiziar, M., 2007: *Štruktúra vysokohorskej krajiny Tatier. Veľkomierkové mapovanie, analýzy a hodnotenie zmien aplikáciou údajov diaľkového prieskumu Zeme*. UKF, ÚKE SAV & SNK MAB, Nitra, 248 pp.
- Değórski, M., 1999: Zróżnicowanie pokrywy glebowej pięter wysokogórskich w bezwęglanowych rejonach Tatr Polskich. In: Kotarba, A. & Kozłowska, A. (Eds.), *Badania geoekologiczne w otoczeniu Kasprowego Wierchu*. *Prace Geograficzne IG i PZ PAN*, 174: 25–36.
- Delcourt, H. R. & Delcourt, P. A., 1988: Quaternary landscape ecology: relevant scales in space and time. *Landscape Ecology*, 2, 1: 23–44.
- Géhu, J.-M. (Ed.), 1986: Végétation et géomorphologie. *Colloques phytosociologiques*, 13: 1–277.
- Gerdol, R. & Smiraglia, C., 1990: Correlation between vegetation pattern and micromorphology in periglacial areas of central Alps. *Pirineos*, 135: 13–27.
- German, K., 2000: Obiektywizm i subiektywizm w wydzieleniu granic fizycznogeograficznych. In: Pietrzak, M. (Ed.), *Granice krajobrazowe; Podstawy teoretyczne i znaczenie praktyczne*. *Problemy Ekologii Krajobrazu*, 7: 153–164.
- Hreško, J., 1994: The morphodynamic aspect of high mountain ecosystem research (Western Tatras-Jalovec valley). *Ekologia*, 17, 3: 311–315.
- Hreško, J., 1998: The morphodynamic system as spatial units of the high mountain landscape. *Ekologia*, 13, 3: 309–332.
- Hreško, J. & Boltiziar, M., 2001: The influence of the morphodynamic processes to landscape structure in the high mountain (Tatra Mts.). *Ekologia*, 20, Suppl. 3: 141–149.
- Jahn, A., 1979: On the Holocene and present-day morphogenetic processes in the Tatra Mountains. *Studia Geomorphologica Carpatho-Balcanica*, 13: 111–128.
- Jodłowski, M., 2007: Górna granica kosodrzewiny w Tatrach, na Babiej Górze i w Karkonoszach. *Instytut Geografii i Gospodarki Przestrzennej UJ*, Kraków, 188 pp.

- Kotarba, A., 1976: Współczesne modelowanie węglanowych stoków wysokogórskich na przykładzie Czerwonych Wierchów w Tatrach Zachodnich. *Geographical Studies IG PAS*, 120, 128 pp.
- Kozłowska, A., 2006: Detailed mapping of high-mountain vegetation in the Tatra Mts. *Polish Botanical Studies*, 22: 333–341.
- Kozłowska, A.B. & Rączkowska, Z., 1996: Relacje rzeźba-roślinność w obrębie form niwalnych. *Przeгляд Geograficzny*, 68, 1–2: 168–179.
- Kozłowska, A. & Rączkowska, Z., 1999a: Badania geoekologiczne w otoczeniu Kasprowego Wierchu. Wprowadzenie. In: Kotarba, A. & Kozłowska, A. (Eds.), *Badania geoekologiczne w otoczeniu Kasprowego Wierchu. Prace Geograficzne IG i PZ PAN*, 174: 121–132.
- Kozłowska, A. & Rączkowska, Z., 1999b: Środowisko wysokogórskie jako system wzajemnie powiązanych elementów. In: Kotarba, A. & Kozłowska, A. (Eds.), *Badania geoekologiczne w otoczeniu Kasprowego Wierchu. Prace Geograficzne IG i PZ PAN*, 174: 9–16.
- Kozłowska, A. & Rączkowska, Z., 2002: Vegetation as a tool in the characterisation of geomorphological forms and processes: an example from the Abisko Mountains. *Geografiska Annaler, Ser. A*, 84, 3/4: 233–244.
- Kozłowska, A. & Rączkowska, Z., 2005: Geobotaniczne wskaźniki morfodynamiki stoków wysokogórskich. *Sprawozdania z Posiedzeń Komisji Naukowych PAN Oddział w Krakowie*, 47, 1: 154–157.
- Kozłowska, A. & Rączkowska, Z., 2006: Effect of snow patches on vegetation in the high-mountain nival gullies (Tatra Mts., Poland). *Polish Journal of Ecology*, 54, 1: 69–90.
- Kozłowska, A., Rączkowska, Z. & Jakomulska, A., 1999: Roślinność jako wskaźnik morfodynamiki stoku wysokogórskiego. In: Kotarba, A. & Kozłowska, A. (Eds.), *Badania geoekologiczne w otoczeniu Kasprowego Wierchu. Prace Geograficzne IG i PZ PAN*, 174: 91–104.
- Kozłowska, A., Rączkowska, Z. & Zagajewski, B., 2006: Links between vegetation and morphodynamics of high-mountain slopes in the Tatra Mountains. *Geographia Polonica*, 79, 1: 27–39.
- Matuszkiewicz, W., 1974: Teoretyczno-metodyczne podstawy badań roślinności jako elementu krajobrazu i obiektu użytkowania rekreacyjnego. *Wiadomości ekologiczne*, 20, 1: 3–13.
- Niedźwiedzki, J., 2006: Trudności zastosowania metody kateny geoekologicznej w krajobrazie wysokogórskim. *Przeгляд Geograficzny*, 78, 3: 383–395.
- Ostaszewska, K., 2002: Geografia krajobrazu; wybrane zagadnienie metodologiczne. PWN, Warszawa, 277 pp.
- Plesník, P., 1956: Vplyv vetra na vznik a vývoj niektorých foriem periglaciálnych pôd vo východnej polovici Belanských Tater. *Geografický Časopis*, 8, 1: 42–59.
- Rapp, A., 1983: Impact of nivation on steep slopes in Lapland and Scania, Sweden. In: Poser, H. & Schunke, E. (Eds.), *Mesoformen des Relief im heutigen Periglazialraum*. Vadenhoeck & Ruprecht, Göttingen: 97–115.
- Rączkowska, Z. & Kozłowska, A. B., 1994: Geobotaniczne wskaźniki denudacji stoków wysokogórskich. *Conference Papers IGiPZ PAN*, 20: 75–85.
- Richling, A. & Solon, J., 2002: Ekologia krajobrazu. *Wydawnictwo Naukowe PWN*, Warszawa, 320 pp.
- Somson, P., 1983: *Contribution a l'étude de la végétation des pierriers et eboulis Pyrenées dans ses relations avec la dynamique du modele support*. Unpublished Ph.D. Thesis, Université Paul Sabatier, Toulouse.
- Soutadé, G., 1980: Modelé et dynamique actuelle des versantes supra-forestiers des Pyrénées Orientales. *Imprime Cooperative du Sud-Ouest, Albi*, 452 pp.
- Theurillat, J.P., 1992: Etude et cartographie du paysage végétal (symphytocoenologie) dans la région d'Altesch (Valais, Suisse). *Beitr. Geobot. Landesaufn. Schweiz*, 68 pp.
- Troll, C., 1973: The upper timberline in different zones. *Arctic and Alpine Research*, 5: 3–18.
- Wolski, J., 2007: Przekształcenia krajobrazu wiejskiego Bieszczadów Wysokich w ciągu ostatnich 150 lat. *Prace Geograficzne IGiPZ PAN*, 214: 1–228.
- Zonneveld, J.I.S., 1990: Introduction. In: Svobodova, H. (Ed.), *Cultural aspects of Landscape*. Pudoc, Wageningen: 7–12.