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ANNA B. KOZŁOWSKA (WARSZAWA), ZOFIA RĄCZKOWSKA (KRAKÓW)

THE SPATIAL RELATIONS OF RELIEF AND VEGETATION

INTRODUCTION

Where research into the geographical environment is concerned, most interest has focused on the collection and synthesis of information on particular components. It is far rarer to come across a study seeking interlinkage between geocomponents, which requires an interdisciplinary approach to the subject. The need for improved knowledge on the links of this kind between geomorphology and other disciplines has been underlined by Klimaszewski (1978), who wrote that: "The distribution and types of vegetation are in many cases decided by relief, while the influence of aspect, slope, valley form, ridge size etc., is expressed very clearly in plant geography. On the other hand, a knowledge of vegetation cover is necessary for the geomorphologist, because vegetation determines the dimensions and intensity of morphogenetic processes" (p. 19).

Theoretical bases for the links between geocomponents are to be found in the papers from complex physical geography mentioned by Richling and Solon (1994), while the interdependence of vegetation and relief has been stressed in many geomorphological or botanical studies (e.g. Kotarba 1976; 1986 respectively). However, rather few studies have ever been devoted to the more precise definition of these relationships. Those that have chosen to do so have employed various methods in the analysis of the links between relief and vegetation, including typological methods (Balcerkiewicz and Wojterska 1986), the analysis of same-scale vegetation and relief maps for a selected uniform area (Kozłowska 1986) and the analysis of vegetation and contemporary morphogenetic processes on various elements of the relief (Rączkowska and Kozłowska 1994). Also to be found are examples of the more detailed description of relationships. For example, Somson (1983) designated certain plant species as being indicative of Pyrenean talus slopes of differing dynamics and grain-size composition, which is to say that he linked the vegetation not only with a process but also with its intensity.

The aim of the present study was thus to describe the linkage between relief and vegetation in geographical space of various scales. Providing the basis for the analysis were geomorphological and geobotanical maps taking account of both elements of the environment with an accuracy appropriate for the given scale. The analysis augmented the results of the authors' own detailed research, which had been done on one relief form. Attempts were also made to answer a question concerning the identity of factors determining the links between the two geocomponents at particular levels of structure of natural spatial units.

THEORETICAL ASSUMPTIONS

The possibility of seeking links between relief and vegetation derives from the following theoretical premises (Matuszkiewicz 1974, Matuszkiewicz 1975, Richling and Solon 1994):

— that the natural environment represents a system of interlinked elements having mutual influence on one another, and that the elements in question — geocomponents — may be arranged hierarchically from the point of view of their scope of influence on other components (Fig. 1);

— that relief joins geological parent rock and zonal climate on the list of factors which play a leading role and to a great extent condition other components, including vegetation, while at the same time being subject to minor changes;

— that vegetation is the geocomponent which is in practice dependent on all other factors, either directly, or — as in the case with relief — indirectly, and that vegetational diversity provides a synthetic reflection of all the relationships holding sway in natural systems, and is the basis for phytoindication;

— that vegetation is a component subordinate to relief, but one that is still able to modify it, and impact upon the processes ongoing within it.

ANALYSIS OF RELIEF–VEGETATIONAL RELATIONS ON VARIOUS SCALES

RELIEF–VEGETATIONAL RELATIONS ON THE GENERAL SCALE

Providing the basis for the comparisons were *Przeglądowa mapa geomorfologiczna Polski* (*A geomorphological review map of Poland*), from 1980, at the scale 1 : 500 000 and *Potencjalna roślinność naturalna. Mapa przeglądowa* (*Potential natural vegetation. A general map*) from 1995, at the scale 1 : 300 000.

Analysis of the two maps revealed a number of similarities, albeit with the degree of similarity varying from region to region. In general, it may be said that "megaforms" (under the classification from Klimaszewski 1978) are well-mirrored in the vegetation.

One "megaform" of uniform glacial genesis — the lowland of central and northern Poland — is not a single entity on the geomorphological map on

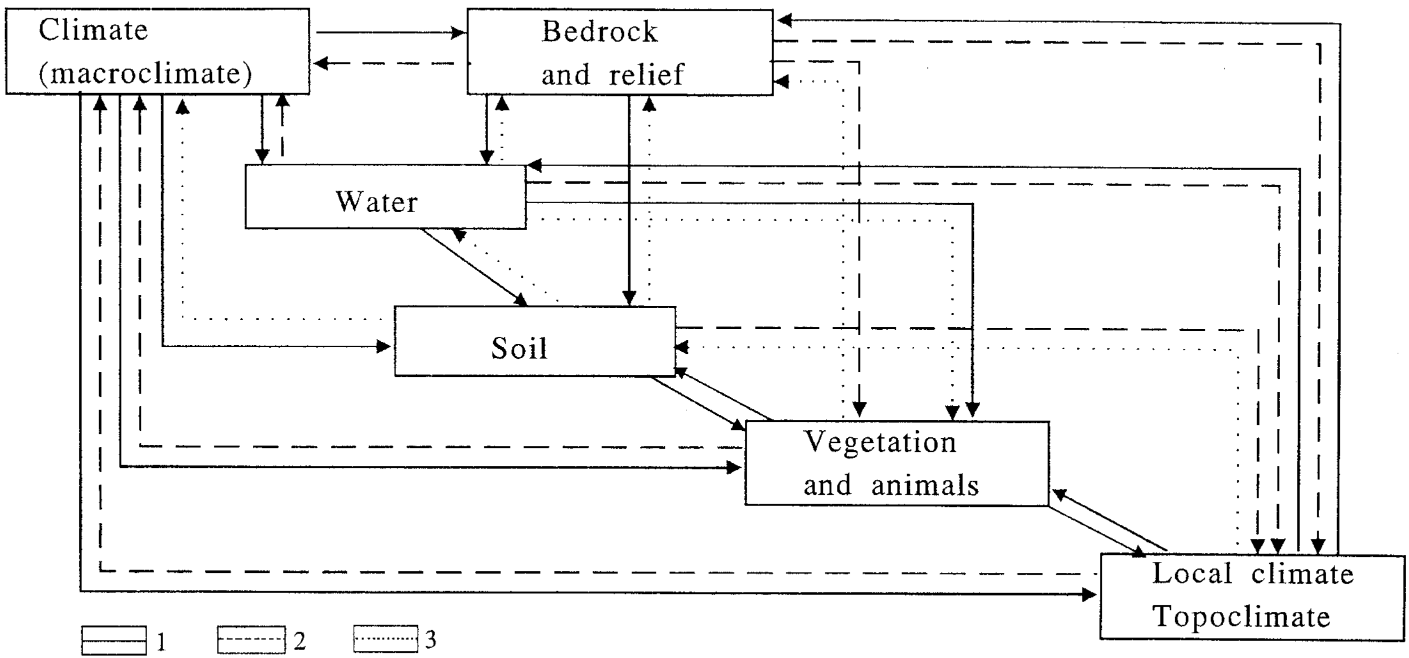

Fig. 1. Scheme of interlinkage between geocomponents. 1 — the strongest linkage, 2 — weaker, 3 — the weakest
Ryc. 1. Schemat zależności pomiędzy geokomponentami. 1 — zależności najsilniejsze, 2 — słabsze, 3 — najsłabsze

account of the presence of various elements of relief like outwash plains and morainic plateaux. In turn, the vegetation of the area constitutes a diversified mosaic of coloured patches on the map. The dominant influence in this case is exerted by climate, from the sub-Atlantic in the west to the continental and sub-boreal in the east. The only element of the relief to be very clearly reflected in the vegetation are the ridges of frontal moraine from the Pomeranian phase of the Vistulian Glaciation. Frontal moraine from the earlier phases of this glaciation, or from even earlier glaciations, is much harder to distinguish on the map of potential vegetation, and sometimes only fragmentarily possible. The spatial distribution of floodplain forests shows the boundaries between the Middle Polish and Vistulian Glaciations. The vegetation of the lowlands reflects the genetic differentiation of sediments if it is expressed in their varying grain-size composition. For example, outwash and accumulation plains (Galon 1972) are very visible on the vegetation map, while the differences between the plains from particular glaciations are not evident.

Comparison of the two maps does in contrast reveal very great similarities in the pictures from mountain and upland areas. Easily discernable on the map of potential vegetation are the boundaries of areas with high or middle mountains, foothills and uplands. The confirmation of this was given when statistical methods were applied following the superimposition of maps for the given area (the eastern part of the Polish Flysch Carpathians) which are uniform from the point of view of relief and vegetation (Fig. 2). In the case of mountains and foothills it is indeed relief which is the factor determining vegetation. Things are different in the case of uplands and interfluve of the foothills, where this simple relationship is distorted by the decisive role of weathering cover on vegetational diversity.

Where the "macroforms" from Klimaszewski's typology are concerned, the diversity of relief does correspond with that of the vegetation in units of regional significance (albeit potentially of varying typological rank). Thus, for example, the macroform of the Sudetic Mountains is corresponded to by Sudetic beech forest, Sudetic spruce forest of the upper montane belt and Sudetic scrub of dwarf mountain pine. In contrast, the Carpathians may be characterized by the occurrence of Carpathian beech forests, Carpathian spruce forest of the upper montane belt and Carpathian scrub of dwarf mountain pine. In turn, the Western and Eastern Carpathians are respectively typified by the West and East Carpathian vicariants of Carpathian beech forest. All of this indicates that climate, and the origin and ranges of plant species, are responsible for the differences in the plant communities, rather than varied relief.

The above considerations lead it to be concluded that differences in vegetation on the general scale are in many cases concordant with differences in relief. A certain similarity in the pictures given by the two maps cannot however support conclusions regarding a direct and simple relationship between typological units of relief and vegetation. To put it another way, it is not possible

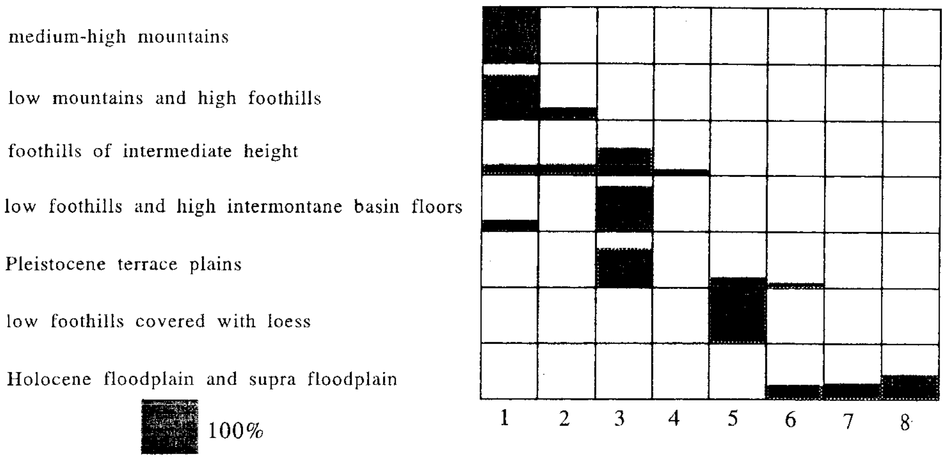

Fig. 2. Characteristic of relief units using potential natural plant communities. 1 — *Dentario glandulosae-Fagetum* montane form, 2 — *Dentario glandulosae-Fagetum* submontane form, 3 — *Tilio-Carpinetum* submontane form, rich variant, 4 — *Tilio-Carpinetum* submontane form, poor variant, 5 — *Tilio-Carpinetum* upland form, rich variant, 6 — *Ficario-Ulmetum typicum*, 7 — *Ficario- Ulmetum* chrysosplenietosum, 8 — *Alnetum incanae*

Ryc. 2. Charakterystyka jednostek rzeźby przy użyciu zbiorowisk roślinności potencjalnej. 1 — *Dentario glandulosae-Fagetum* forma reglowa, 2 — *Dentario glandulosae-Fagetum* forma pogórska, 3 — *Tilio-Carpinetum* forma pogórska, postać żyzna, 4 — *Tilio-Carpinetum* forma pogórska, postać uboga, 5 — *Tilio-Carpinetum* forma wyżynna, postać żyzna, 6 — *Ficario-Ulmetum typicum*, 7 — *Ficario-Ulmetum chrysosplenietosum*, 8 — *Alnetum incanae*

to unambiguously ascribe a defined unit of vegetation to a defined unit of relief, because — at this level of the structure of natural systems — climate is as important a factor in the differentiation of other geocomponents as the morphological and genetic expression of relief.

RELIEF–VEGETATIONAL RELATIONS ON THE INTERMEDIATE SCALE

The next attempt was made on the basis of the maps of much greater scale which were published in the *Atlas of the Tatra Mountains National Park* (1985). Specifically, the maps in question are Klimaszewski's 1 : 30 000 geomorphological map, and the 1 : 50 000 vegetation map drawn up by Pienkoś-Mirkowa and Baryła. It was considered that such a typically montane area would see a clear influence on vegetational diversity exerted by relief — the leading factor creating the conditions for the existence and generation of other geocomponents.

Analysis concerned the possibility of using geobotanic units to characterize mesoforms of relief. However, it emerged that this was not possible because the pictures of the spatial variability of the two geocomponents studied were so different. The reasons for such a lack of concordance with relief at this level of organization of natural systems should be sought in the

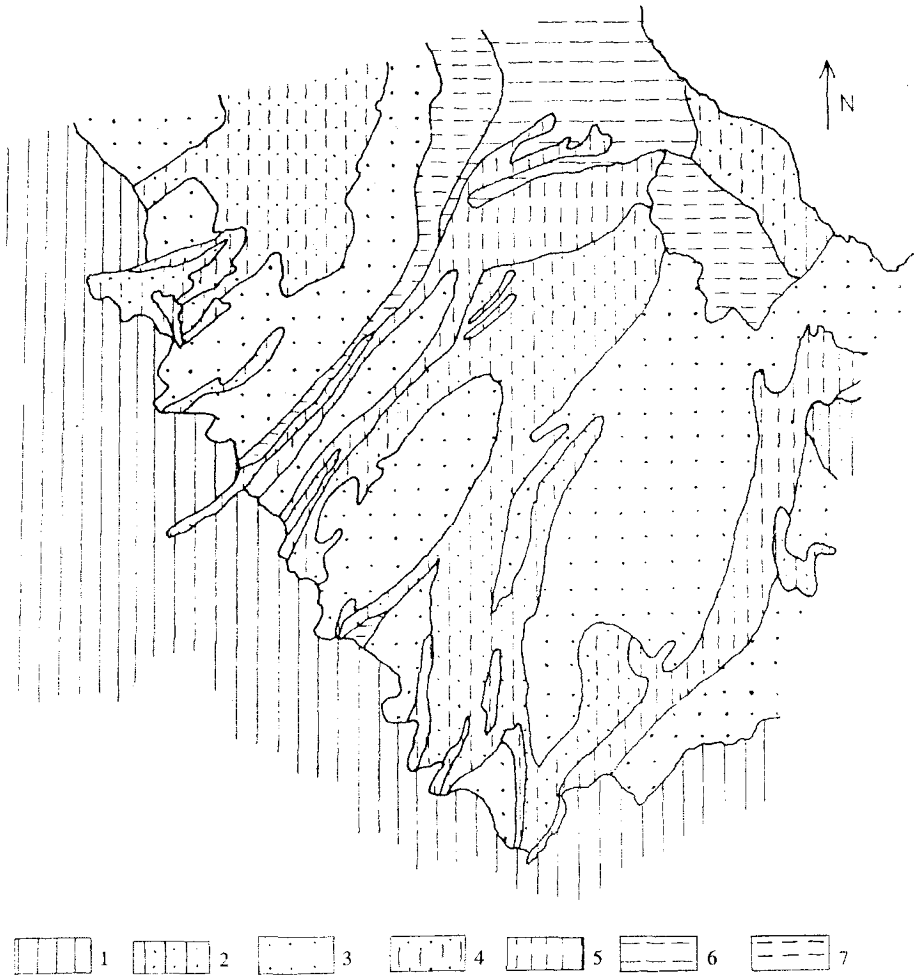

Fig. 3. Morphological types of the slope surface on the slope of Skrajna Turnia; slope modelled by: 1 — weathering and corrasion, 2 — weathering and debris creeping, 3 — debris creeping, 4 — creeping and torrential processes, 5 — torrential processes, 6 — soil creeping, 7 — solifluction and soil creeping

Ryc. 3. Morfologiczne typy powierzchni stokowych na stoku Skrajnej Turni; stok modelowany przez: 1 — wietrzenie i korazję, 2 — wietrzenie i spełzywanie gruzu, 3 — spełzywanie gruzu, 4 — spełzywanie i procesy torrencjalne, 5 — procesy torrencjalne, 6 — spełzywanie gleby, 7 — soliflukcja i spełzywanie gleby

likely superior impacts on vegetation of the geological substrate and the climate. As an example of the phenomenon, it may be noted that talus slopes were found to correspond to two completely different vegetational units related to substrate (carbonate or non-carbonate); smooth, mature slopes were overgrown with sward communities in turn differentiated with altitude into those of the alpine and subalpine zones.

The aforementioned lack of accord between the two maps, and hence the difference in the spatial variability of relief and vegetation, is the result of the totally different factors determining differences in the elements studied at this particular scale. In the case of relief this is mainly structurally–conditioned genesis, while in the case of the vegetation it is the vertical zonation associated with climate, as well as the properties of the substrate, i.e. the character of the weathering cover. It is for example for this reason that forests of the upper montane belt grow both on slopes and in valley bottoms filled with glacial or fluvioglacial drift deposits.

On the other hand, the contemporary transformation of both relief and vegetation is conditioned climatically. It is for this reason that the similarities are decidely greater when the aforementioned vegetation map is compared with Kaszowski and Kotarba's map of contemporary morphogenetic processes from the same *Atlas of the Tatra Mountains National Park*. The reason is not only that climate influences the transformation of relief, but also that vegetation and contemporary geomorphological processes in the mountains influence each other. The relations in question will be considered more closely on the basis of examples at the detailed scale.

RELIEF–VEGETATIONAL RELATIONS ON THE DETAILED SCALE

The relations between relief and vegetation on the detailed scale were analyzed by using the Skrajna Turnia slope in the High Tatras as well as one relief form — a nival niche as an example.

The influence of geomorphological processes on vegetation is clear on this scale. By superimposing the 1 : 2000 scale map of morphogenetic slope types (Fig. 3) and vegetation at Skrajna Turnia (Fig. 4), it was possible to subordinate to the types of slope modelled by defined processes and distinguished by Kotarba *et al.* (1979), the plant communities correlated with them (Table 1).

Of decisive importance in the action of contemporary processes is the presence or absence of a closed vegetation cover. This is because an area deprived of its protective cover of vegetation will be destroyed by denudational processes, while a closed vegetation cover makes the degradation of high-mountain slopes impossible. Similarly, forms arising as a result of catastrophic events like debris flows are stabilized as vegetation encroaches upon them. Also stabilized are the erosional forms arising as a result of the destruction of closed cover by human activities and the consequent exposure of the substrate to processes (as happened for example on the slopes of Twardy Upłaz in the Western Tatras; Jahn 1979).

The relationships discussed above are most clearly seen within one form or for one process. Fig. 5 shows the differences in the vegetation and geomorphological processes within the nival niche studied in great detail at the level of the geodesic plan. The distribution of plant communities indicates colder

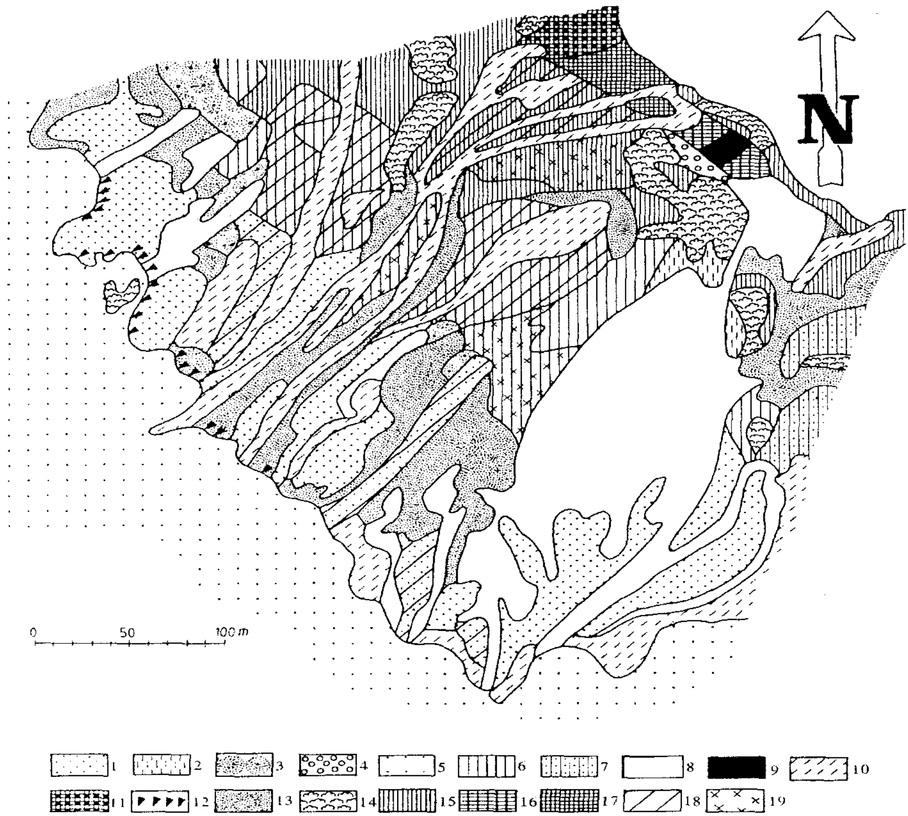

Fig. 4. Vegetation map of the slope Skrajna Turnia. Alpine swards — Oreochloo distichae-Juncetum trifidi; 1 — typicum and cetrarietosum, 2 — Salicetosum kitaibelianae, 3 — scree form with Juncus trifidus, 4 — scree form with Oreochloa disticha, 5 — sparsely covered alpine swards on rockwalls, 6 — subalpine form, 7 — sparsely covered subalpine meadows on rockwalls; Epilitic lichen communities: 8 — Rhizocarpetalia; Snow-bed communities: 9 — Salicetum herbaceae, 10 — Luzuletum spadiceae, 11 — Aconitetum firmi, 12 — Athyrietum alpestris, 13 — Calamagrostietum villosae tatricum; Subalpine scrubs and dwarf shrub communities: 14 — Pinetum mughi carpaticum, 15 — Vaccinietum myrtilli, Empetro-Vaccinietum; Subalpine grassland communities after grazing: 16 — Festuca picta comm., 17 — Hieracio alpini-Nardetum, Deschampsia flexuosa comm.; Spatial complexes: 18 — complex with Luzuletum spadiceae, 19 — complex with Calamagrostietum villosae

Ryc. 4. Mapa roślinności stoku Skrajnej Turni. Murawy alpejskie — Oreachloo distichae-Juncetum trifidi; 1 — typicum i cetrarietosum, 2 — Salicetosum kitaibelianae, 3 — postać piargowa z Juncus trifidus, 4 — postać piargowa z Oreochloa disticha, 5 — murawy alpejskie na stromych półkach skalnych, 6 — postać subalpejska, 7 — murawy subalpejskie na stromych półkach skalnych; zbiorowiska porostów naskalnych: 8 — Rhizocarpetalia; zbiorowiska wyleżynowe: 9 — Salicetum herbaceae, 10 — Luzuletum spadiceae, 11 — Aconitetum firmi, 12 — Athyrietum alpestris, 13 — Calamagrostietum villosae tatricum; zarośla kosodrzewiny i borówczyska: 14 — Pinetum mughi carpaticum, 15 — Vaccinietum myrtilli, Empetro-Vaccinietum; powypasowe zbiorowiska trawiaste: 16 — zbiorowisko z Festuca picta, 17 — Hieracio alpini-Nardetum, zbiorowisko z Deschampsia flexuosa; kompleksy przestrzenne: 18 — kompleksy z Luzuletum spadiceae, 19 — kompleks z Calamagrostietum villosae

Table 1 — Tabela 1

Relations between vegetation and geomorphological processes on the slope of Skrajna Turnia

Związki między roślinnością a procesami morfogenetycznymi na stoku Skrajnej Turni

Vegetation belt	Vegetation community	Dynamic types of slope surface
alpine belt	*Oreochloo distichae-Juncetum trifidi*	torrential and talus creep
upper part of subalpine belt	*Oreochloo distichae-Juncetum trifidi subalpine form*	talus creep and torrential
subalpine belt	*Vaccinietum myrtilli* *Hieracio-Nardetum* *Emperto-Vaccinietum* *Pinetum mughi*	solifluction and soil creep
alpine and subalpine belt	*Aconitetum firmi*	soil creep, torrential
	Athyrietum alpestris	soil creep
	Calamagrostietum	talus creep, torrential
	Luzuletum spadiceae	torrential
	Salicetum herbaceae	deluviaton
	Rhizocarpetum and other lichens comm.	talus creep and weathering-corrasion

and wetter fragments of the niche and is thus an indicator of the length of the period with snow cover and the thickness of the patch — which is to say the activity of the snow as a geomorphological factor determining the course of nivational processes within the niche.

The indicator species defined on the basis of this research (Kozłowska and Rączkowska 1996) may be used in the identification of slope fragments modified by nivation, and are thus a statistically-documented example of a direct correlation between relief and vegetation.

As is clear from the whole study, such a direct correlation, i.e. of a single geomorphological process or a single relief form, is only possible on the microscale.

CONCLUSIONS

The material presented in this study is able to confirm the existence of relief-vegetational relationships and also to detail these further by defining the strength of the interdependence and the factors behind it.

The strength of the relationship between the two elements studied is dependent on the spatial scale at which it is considered. The links are to be seen most clearly at the very detailed scale, but are also evident at the general scale (Fig. 6).

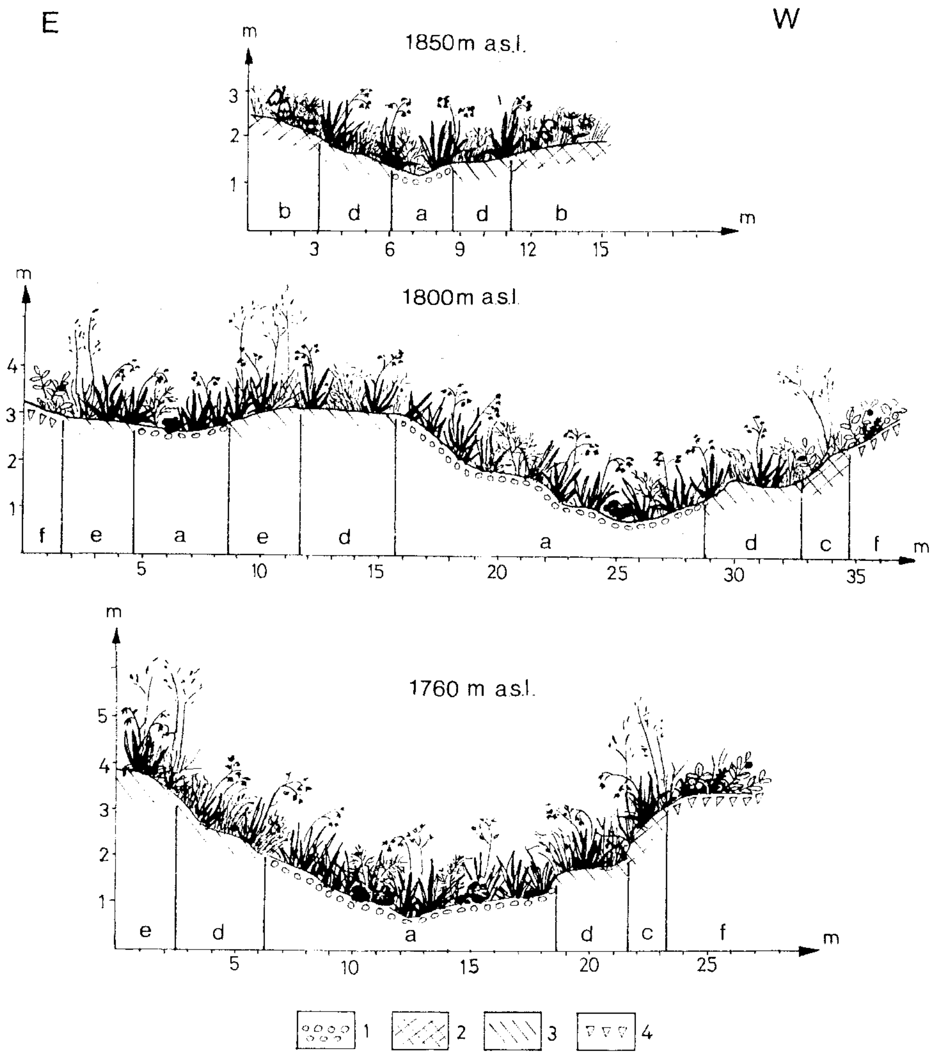

Fig. 5. Differentiation of vegetation and present-day geomorphological processes in the nival niche on Beskid. a — snow-bed vegetation, b — alpine swards, c — subalpine grasslands, d — spatial complex of alpine swards and snow-bed vegetation, e — spatial complex of subalpine grasslands and snow-bed vegetation, f — subalpine dwarf scrubs, 1 — chemical weathering, solute and fluvial transport, sheetwash, 2 — solifluction, soil creeping, 3 — soil creeping, frost action and needle ice, 4 — frost action, wind erosion

Ryc. 5. Zróżnicowanie roślinności i współczesnych procesów geomorfologicznych w niszy niwalnej na Beskidzie. a — zbiorowisko kosmatki brunatnej, b — murawa alpejska, c — murawa subalpejska, d — kompleks przestrzenny murawy alpejskiej ze zbiorowiskiem kosmatki brunatnej, e — kompleks przestrzenny murawy subalpejskiej ze zbiorowiskiem kosmatki brunatnej, f — borówczysko, 1 — wietrzenie chemiczne, rozpuszczanie i transport fluwialny, spłukiwanie, 2 — spełzywanie i soliflukcja, 3 — soliflukcja, spełzywanie i lód włóknisty, 4 — wymarzanie, erozja eoliczna

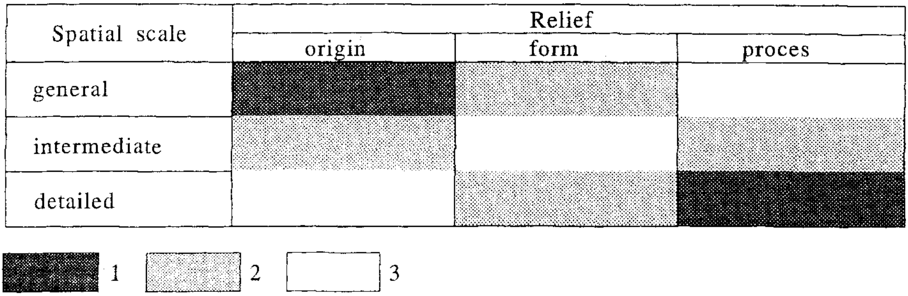

Fig. 6. The spatial relations between relief and vegetation. 1 — clear, 2 — weak, 3 — no relation

Ryc. 6. Przestrzenne relacje pomiędzy rzeźbą i roślinnością. 1 — wyraźne, 2 — słabe, 3 — brak relacji

The links in question are rarely direct in nature, with the factor associated more often being some property of cover, or humidity-related or microclimatic factor, which is conditioned by relief.

The relationships between processes and vegetation are much clearer than those between relief and vegetation. The reason here may be the direct conditioning of processes by the state of the vegetation, and the influence of currently ongoing processes on the possibility for defined types of vegetation to develop.

Anna B. Kozłowska
Department of Geoecology, Institute of Geography and Spatial Organization, PAN,
00-927 Warsaw, Krakowskie Przedmieście 30, Poland

Zofia Rączkowska
Department of Geomorphology and Hydrology of Mountains and Uplands,
Institute of Geography and Spatial Organization, PAN,
31-018 Cracow, św. Jana 22, Poland

REFERENCES

Atlas Tatrzańskiego Parku Narodowego (ed. K. Trafas), 1985. Tatrzański Park Narodowy and Polskie Towarzystwo Przyjaciół Nauk o Ziemi, Zakopane–Kraków.

Balcerkiewicz S., Wojterska M., 1986. *Landforms and plant communities in the high-mountain vegetation belts in the Tatra Mountains*. Colloques Phytosociologiques, 13, 267–277.

Galon R. (ed.), 1972. *Geomorfologia Polski*. T. 2 *Niż Polski*. PWN, Warszawa, pp. 373.

Gehu J.-M. (ed.), 1986. *Vegetation et Geomorphologie*. Colloques Phytosociologiques, 13, pp. 600.

Jahn A., 1979. *On the holocene and present-day morphogenetic processes in the Tatra Mountains*. Studia Geomorph. Carpatho-Balcanica, 13, 111–128.

Klimaszewski M., 1978. *Geomorfologia*. PWN, Warszawa, pp. 1098.

Kotarba A., 1976. *Współczesne modelowanie węglanowych stoków wysokogórskich na przykładzie Czerwonych Wierchów w Tatrach Zachodnich (The role of morphogenetic processes in modelling high-mountain slopes)*. Prace Geogr. IG i PZ PAN 120, pp. 128.

Kotarba A., Kłapa M., Midriak R., Petraš J., Sroka J., 1979. *Field experiments on high--mountain slopes of the Tatra Mts*. Studia Geomorph. Carpatho-Balcanica, 13, 131–148.

Kozłowska A. B., 1986. *Die Zusammenhänge zwischen der potentiell natürlichen Vegetation und den Reliefsformen in den Ostkarpaten*. Colloques Phytosociologiques, 13, 41–44.

Kozłowska A. B., Rączkowska Z., 1996. *Relacje rzeźba-roślinność w obrębie form niwalnych*. Przegl. Geogr., 68.

Matuszkiewicz W., 1974. *Teoretyczno-metodyczne podstawy badań roślinności jako elementu krajobrazu i obiektu użytkowania rekreacyjnego*. Wiad. Ekol., 20, 1, 3–13.

Matuszkiewicz W., 1975. *Ekologiczne podstawy diagnozy i interpretacji krajobrazu*. Rocznik UW, 15, 131–137.

Potencjalna roślinność naturalna. Mapa przeglądowa w skali 1 : 300 000. 1995.

Przeglądowa mapa geomorfologiczna Polski w skali 1 : 500 000 (ed. L. Starkel), 1980. IG i PZ PAN, Warszawa.

Rączkowska Z., Kozłowska A. B., 1994. *Geobotaniczne wskaźniki denudacji stoków wysokogórskich (Geobotanical indicators of denudation of high-mountain slopes)*. Conference Papers IG i PZ PAN, 20, 75–85.

Richling A., Solon J., 1994. *Ekologia krajobrazu*. PWN, Warszawa, pp. 226.

Somson P., 1983. *Contribution a l'étude de la végétation des pierrers et éboulis pyrénéens dans ses relations avec la dynamique du modéle support*. Université Paul Sabatier, Toulouse, pp. 230.

STRESZCZENIE

A. B. Kozłowska, Z. Rączkowska

PRZESTRZENNE RELACJE RZEŹBY I ROŚLINNOŚCI

Na podstawie porównania map rzeźby i roślinności w różnej skali oraz wyników szczegółowych badań własnych, starano się określić związki obu elementów środowiska geograficznego. Stwierdzono, że związki te są bardzo dobrze widoczne na mapach w skali szczegółowej, dobrze także w skali przeglądowej, a najgorzej w skali średniej. Najbardziej wyraźne związki występują pomiędzy procesami geomorfologicznymi a roślinnością.