LINKS BETWEEN VEGETATION AND MORPHODYNAMICS OF HIGH-MOUNTAIN SLOPES IN THE TATRA MOUNTAINS

ANNA KOZŁOWSKA*, ZOFIA RĄCZKOWSKA** and BOGDAN ZAGAJEWSKI***

*Institute of Geography and Spatial Organization, Polish Academy of Sciences,
Twarda 51/55, 00-818 Warszawa, Poland
E-mail: a.kozl@twarda.pan.pl

**Institute of Geography and Spatial Organization, Polish Academy of Sciences,
Sw. Jana 22, 31-018 Kraków, Poland
E-mail: raczk@zg.pan.krakow.pl

***Warsaw University, Faculty of Geography and Regional Studies,
Krakowskie Przedmiescie 30,00-927 Warszawa, Poland
E-mail: bogdan@uw.edu.pl

Abstract: This study examines the propositions that: 1. in high-mountain areas, the differentiation of vegetation units at the landscape (supra-ecosystem) scale is closely linked to variations in the geomorphology of slopes and valley bottoms across various morphodynamic units; 2. morphodynamic units constitute the natural boundaries of the vegetation-related landscape units; 3. different types of geomorphological unit at the landscape scale are characterized by the vegetation types growing on them. These propositions were tested by comparing overlays of digital maps of vegetation and geomorphology. A characteristic combination of plant communities was determined for each of the five types of morphodynamic unit identified.

Key words: geomorphology, morphodynamic units, vegetation, landscape units, vegetation-relief links, Tatra Mountains, Poland.

INTRODUCTION

The diversity of mountain vegetation depends upon an entire complex of factors, including, first and foremost, climate and bedrock geology. The dependent relationships have been the subject of numerous studies that have emphasised zonality, differences between calcareous and non-calcareous substrates, and the influence of snow (Mirek and Piękoś-Mirkowa 1992 a,b; Piękoś-Mirkowa and Mirek 1996; Kozłowska and Rączkowska 2006). The resulting differentiation is apparent on vegetation maps at different scales, ranging from small-scale maps showing climatic and vegetation belts to detailed-scale maps like that of high-mountain vegetation in part of the Tatra Mountains (Figure 2.1)[1]. This map

[1] The map (Figure 2.1) is to be found under the band on the inside back cover.

reflects the influence of multiple factors and portrays the diversity of habitats. However, the primary factor conditioning all others is the relief of the mountain massif itself, namely the pattern of ridges, slopes and valleys, and the dynamics of the geomorphological processes that take place there. The relief forms the structural and geometric basis for any kind of diversification on the Earth's surface, including the geoecological one (Barsch 1990). It is relief that determines the differentiation of habitats and vegetation in mountains into units of supra-ecosystem rank (i.e. landscape units).

Slopes can be differentiated into a number of component units (Hreško 1994, 1997), such as gullies, cones and rockwalls. Experience to date shows that it is not possible to demonstrate a close relationship between such narrowly defined units of relief and vegetational units, since the differentiation of vegetation is the result of many and varied factors, not only linked with slope morphology. This ensures that boundaries of units determined on the basis of just a single abiotic criterion (relief) coincide poorly with those of vegetational units. For this reason, the results of such comparisons have often been vague and imprecise (Kozłowska *et al.* 1999; Rączkowska and Kozłowska 1994).

A similar problem was also encountered by Balcerkiewicz and Wojterska (1985), who assigned the plant associations in the Dolina Pięciu Stawów Polskich in the Tatra Mts. (The Valley of Five Polish Tarns) to narrowly defined categories of meso-forms of relief and obtained a highly complex picture of the dependence of vegetation upon geomorphological units. It was only when the number of relief units was reduced through combination into units of higher rank, and landscape vegetation units of the so-called sigma-associations were considered (Beguin and Hegg 1975, 1976; Géhu 1976; Balcerkiewicz and Wojterska 1978), that it became possible to determine the types of vegetation complexes characteristic of geomorphological units defined sufficiently broadly for landscape-scale vegetational types to be fully developed.

Taking into account the results of previous studies, the following propositions were investigated in this study:

- that the differentiation of vegetation in high-mountain areas among units of supra-ecosystem (landscape) rank is closely linked to variations in the geomorphology of slopes and valley bottoms across various morphodynamic units;
- that morphodynamic units provide the natural boundaries for vegetation landscape units;
- that different types of morphodynamic unit are characterized by particular types of vegetation growing on them.

The purpose of the present paper is to establish the relationships between the high-mountain vegetation and the landforms and geomorphological processes modelling the slopes of the Tatra Mountains, and to test the proposition that these relationships are only fully manifested at the meso-scale (i.e. within relief units of appropriately large area).

STUDY AREA AND METHODS

The study encompassed the area in the Polish Tatras above the treeline as shown on Figure 2.2. This area has alpine relief, with steep slopes rising up to 2301m a.s.l., above glacial cirques and troughs filled with glacial drift deposits (Klimaszewski 1988). Granites and metamorphic rocks dominate in bedrock geology, but calcareous and quartzite outcrops occur as well (Mapa geologiczna Tatr Polskich 1979). The following maps at a scale 1:10,000 were prepared: a vegetation map developed from field mapping, and a map of morphodynamic units compiled from existing geomorphological information, aerial photography, a topographical map at 1:10,000 scale and knowledge of the terrain. The maps were prepared in digital form.

The method of preparation of the vegetation map was described by Kozłowska and Plit (2002). The foundations for the construction of the legend were laid by the

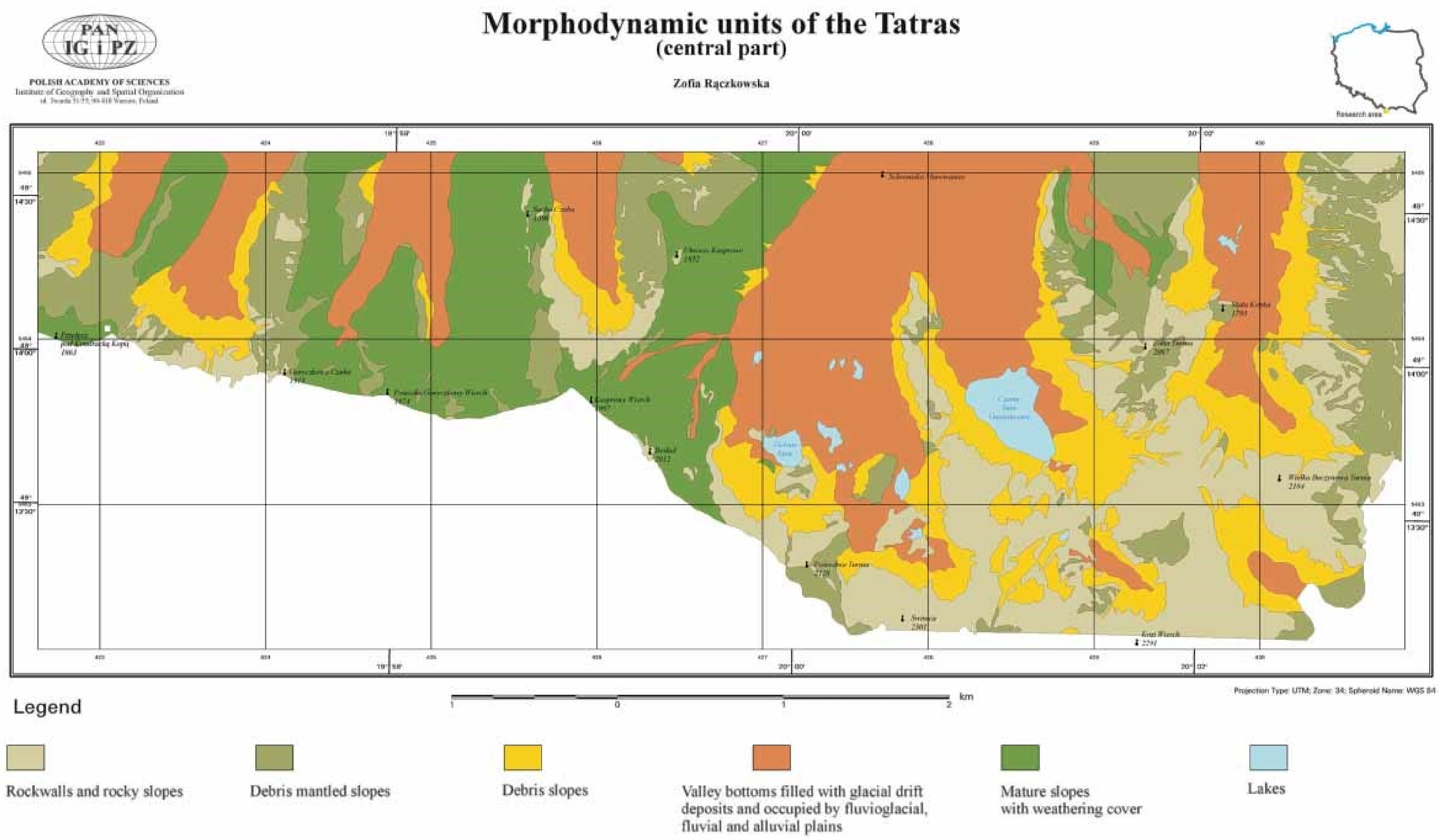

Figure 2.2. Morphodynamic units of the Tatras

Source: elaborated by Z.Rączkowska (2006) work of Balcerkiewicz (1984) for the aforementioned Dolina Pięciu Stawów Polskich in the Tatra Mountains, including the types of plant communities distinguished by him in line with the Braun-Blanquet's phytosociological approach. These types were modified and adapted to the larger area encompassed by the map presented here.

The geomorphological map of the area initially had seven legend units, distinguished using morphological, morphometric, genetic and morphodynamic criteria, but these were later reduced to five. Smaller relief forms existing within their boundaries were treated as attributes of a given unit (for example, debris-flow levées in the 'mature' slope unit).

The strength of the links between vegetation and relief was analyzed by overlaying the digital vector layers of vegetation and geomorphology (using ArcGIS software-overlay procedure) and calculating the index of strength of these linkages (Richling 1992). The basis of this index is the ratio of the area occupied by spatial units having given properties and the theoretically maximal area over which a given relationship may occur. The indicator of the strength (W) of an interrelationship is expressed by the formula:

$$W = P_{vg}/P_g, \text{ when } P_g < P_v,$$
$$W = P_{vg}/P_v, \text{ when } P_v < P_g,$$

where:

P_{vg} is the area of the units, in which both features v and g appear together, as corresponding to the area with the vegetation category v and geomorphology category g;

P_v is the total area of spatial units with feature v of the vegetation;

P_g is the total area of spatial units with feature g of geomorphology.

The values of the index range between 0 and 1. The maximum value of 1 occurs when the boundaries of two analyzed categories coincide fully. The value of the index decreases to 0 when the components considered do not coincide at all. High values for the index correspond to persistent and stable associations, which play a leading role in the structure of the environment. The values obtained were grouped into five classes (after Bezkowska 1986):

I: W = 0.0–0.2—very weak linkages
II: W = 0.21–0.4—weak linkages
III: W = 0.41–0.6—moderate linkages
IV: W = 0.61–0.8—strong linkages
V: W = 0.81–1.0—very strong linkages.

In the subsequent analysis, the linkages belonging to class I were neglected as incidental. The values of moderate to very strong linkages (classes III to V) were used in the assessment of plant communities as indicators of the morphodynamic types of relief.

THE VEGETATION MAP

The legend of the vegetation map of the study area (Figure 2.1) comprises 41 units (listed in Table 1).

The particular patches on the map are rarely uniform in typological terms, usually constituting various types of the complexes distinguished by Seibert (1974). In the majority of cases these are domination complexes, as demonstrated by Balcerkiewicz and Wojterska (1978) in the aforementioned Dolina Pięciu Stawów Polskich. This is especially true of the zonal communities, with the large areas (e.g. of upper montane spruce forest, dwarf mountain pine scrub, post-grazing communities or alpine swards) featuring small-area fragments of other communities. The label of the dominating community is used for entire areas, despite these actually being inhomogeneous as regards vegetation. In other cases, zonation complexes are typical of the numerous gullies existing in the mountain areas, where vegetation changes in a belt-like manner from the edge of the gully towards its axis. This was demonstrated in micro-scale studies (Kozłowska and Rączkowska 2006).

Mosaic complexes are also very frequent, particularly on slopes with varied micro-relief, on narrow rock shelves, or in places in which various dynamic stages of vegetation coexist within a small space, as for instance on the talus cones and during the regeneration of vegetation after grazing. Such mosaic

Table 1. The legend units of the vegetation map

Group of plant communities	No. of unit	Plant community, spatial complex of plant communities
Initial cryptogamic plant communities	1	Initial cryptogamic plant communities
Epilitic lichen communities (*Rhizocarpetalia*)	2	*Rhizocarpetalia*
Scree vegetation (*Androsacetalia alpinae*)	3	*Androsacetalia alpinae*
Snow-bed vegetation (*Salicetea herbaceae*)	4	*Luzuletum alpino-pilosae*
	5	*Salicetum herbaceae, Polytrichetum sexangularis*
	6	*Salicetum herbaceaea* in a complex with *Empetro-Vaccinietum*
Alpine swards on siliceous rocks (*Oreochloo distichae-Juncetum trifidi*)	7	*O. d.-J. t.* subnivale form in a complex with *Oreochloetum distichae subnivale*
	8	*O. d.-J. t. typicum*
	9	*O. d.-J. t. cetrarietosum*
	10	*O. d.-J. t. typicum* in a complex with *O. d.-J. t. cetrarietosum*
	11	*O. d.-J. t. sphagnetosum*
	12	*O. d.-J. t. salicetosum herbaceae*
	13	*O. d.-J. t. salicetosum retusae*
	14	Scree form with *Juncus trifidus*
	15	*O. d.-J. t. caricetosum sempervirentis*
	16	*O. d.-J. t.* subalpine form
	17	*Oreochloo distichae-Juncetum trifidi* in a complex with *Salicetea herbaceae*
	18	*Oreochloo distichae-Juncetum trifidi* in a complex with *Calamagrostietum villosae*
	19	*Oreochloo distichae-Juncetum trifidi* in a complex with *Festuco versicoloris-Agrostietum*
Alpine swards on calcareous rocks (*Elyno-Seslerietea*)	20	*Seslerion tatrae*
Fens, transition mires and peat-bogs	21	*Caricetum fuscae subalpinum*
	22	*Sphagno-Nardetum*, *Polytricho-Nardetum*
	23	*Sphagno-Nardetum, Polytricho-Nardetum* in a complex with *Caltha laeta*-community
Tall-herb and tall-grass vegetation (*Betulo-Adenostyletea*)	24	*Calamagrostietum villosae tatricum*
	25	*Calamagrostietum villosae tatricum* in a complex with *Luzuletum alpino-pilosae* - pioneer form
	26	*Calamagrostietum villosae tatricum* in a complex with wet post-grazing grasslands

	27	*Calamagrostietum villosae tatricum* in a complex with *Pinetum mugo* and subalpine post-grazing grasslands
	28	*Adenostylion*
Semi-natural vegetation after grazing	29	*Festuca picta* community in a complex with *Luzuletum alpino-pilosae*
	30	*Festuca picta* community and wet forms of *Hieracio alpini-Nardetum*
	31	*Deschampsia flexuosa* community, and *Hieracio alpini-Nardetum*, *Agrostis rupestris* community
	32	Semi-natural vegetation after grazing in a complex with *Rumicetum alpini, Rumici obtusifoliae-Urticetum*
Subalpine dwarf scrub communities (*Loiseleurio-Vaccinion*)	33	*Empetro-Vaccinietum*
	34	*Empetro-Vaccinietum* in a complex with *Pinetum mugo carpaticum*
	35	*Vaccinium myrtillus* community in a complex with *Pinetum mugo carpaticum*
	36	*Vaccinium myrtilus* community in a complex with *Betulo-Adenostyletea*
Deciduous shrub communities of clearings (*Epilobietea angustifolii*)	37	*Chamaenerion angustifolium-Salix silesiaca* community, *Rubus idaeus* community
Dwarf pine shrubs (*Pinetum mugo carpaticum*)	38	*Pinetum mugo carpaticum silicicolum*
	39	*Pinetum mugo carpaticum silicicolum* in a complex with *Rhizocarpetalia*
	49	*Pinetum mugo carpaticum calcicolum*
Upper-montane spruce forest (*Plagiothecio-Piceetum*)	41	*Plagiothecio-Piceetum*

Source: Kozłowska 2006

complexes are characteristic of the high-mountain vegetation and are even distinguished at the very detailed scale of 1:1,000 (Kozłowska 1999).

THE MAP OF MORPHODYNAMIC UNITS

Five categories of surface were distinguished (Figure 2.2):

ROCKWALLS AND ROCKY SLOPES are completely devoid of a weathering mantle, although the accumulation of small quantities of debris is possible on small shelves within the rocky slopes. Their inclination is always greater than 62–64^{o}, while the rockwalls are vertical or even overhanging. They are cut through by rock gullies of diverse magnitude (Kotarba *et al.*1988). The processes responsible for their contemporary development are weathering (mainly mechanical), rockfall, corrasion, erosion and transport by snow avalanches, as well as debris flows (Kotarba 2002). The intensity of the processes is low. The rate of retreat of the rock walls varies between a few millimetres to more than ten millimetres per annum.

SLOPES WITH DEBRIS MANTLE or blockfield covers have resulted from the degradation of rocky slopes owing to weathering in the periglacial climate, and so they most often exist above the walls of glacial cirques. They are characterized by a convex, non-smoothed longitudinal profile and gradients between 38–62°. There are often small rock walls on these slopes, with a height of several to a dozen metres, as well as blockfields which occupy the ridges (e.g. Pośrednia Turnia) or fragments of cirque slopes weakly transformed by glaciers (e.g. Goryczkowy pod Zakosy). The thickness of the weathering mantle is limited, and varies between several tens of centimetres and two metres. These slopes are shaped by piping, sliding, cryogenic processes, nivation, deflation and aeolian accumulation, erosion and transport by snow avalanche and debris flows (Kotarba 2002).

DEBRIS SLOPES comprise overlapping systems of talus slopes and cones, together with debris cones formed by debris flows and snow avalanches, situated at the foot of the rockwalls and slopes of the glacial cirques. The average thickness of the talus slopes in the High Tatras has been estimated at 15 metres (Lukniš, 1968). These slopes are differentiated by their inclination and degree of stabilization through vegetation, as well as the sorting of the debris building them up. The angle of the talus slopes is approximately 30°, while the debris cones are less steep, at 20–30°. The manner and rate of their development depend upon the morphological and climatic conditions on the rockwalls above. The debris cones are currently modified over their entire surfaces by snow avalanches and by the linear tracks of debris flows. On the talus slopes the material is accumulated over the entire surface, albeit at differing intensities. Their highest parts are most active (Kotarba *et al.*1983). Today, debris slopes are shaped by a range of processes, including (in order of frequency of occurrence) rockfalls and the accumulation of talus, debris flows, debris creeping, deposition of dirty snow avalanche, piping and nivation (Kotarba 2002). These slopes are among the most intensively transformed ones.

BOTTOMS OF VALLEYS filled with glacial drift material and occupied by spreads of fluvial, fluvioglacial and alluvial accumulation deposits are stabilized by vegetation, although fragments of moraines built of large blocks and boulders are completely devoid of vegetation. This morphodynamic unit is highly differentiated morphologically and morphogenetically. Within the the glacial drift deposits covering the valley bottoms, there are distinct moraine ridges with short, steep slopes and relatively shallow undrained depressions of various magnitudes, without fine material or filled with flat spreads of fluvial and fluvioglacial deposits. Alluvial plains appear between the slopes and the lateral moraine ridges. Slopewash and avalanche accumulation are the main processes acting on this unit (Kotarba 2002).

'MATURE' SLOPES are those with a smoothed longitudinal profile and uniform inclination of about 30°. Their relief is little diversified. They are covered with a layer of weathered debris, comprising coarse debris with a mixture of fine material. In the soil, 40 to 60% is gravel and very coarse sand (Degórski 1999). These slopes are overgrown with a compact vegetation cover. On the slope and/or their segments situated at higher altitudes cryogenic processes (gelifluction and frost creep) dominate. On the slopes and/or their segments situated at lower altitudes these are replaced by soil creeping and sliding. The other processes modelling them are nivation, piping, debris-and-mud flows, slopewash and linear erosion, avalanche erosion and transport, deflation and wind accumulation (Rączkowska 2002; Kotarba 2002).

The morphodynamic units outlined above comprise a hierarchy of smaller-scale forms (Brundsen 1996). Thus, for example, 'mature' slopes may contain erosion or nival niches. The individual units also differ in their contemporary process dynamics and even within individual units there are variations in the the types of process and their rates of activity. The micro-structure and differences in dynamics may be responsible for the internal diversification of vegetation growing on a defined type of relief unit.

GEOBOTANICAL CHARACTERISTICS OF THE MORPHODYNAMIC UNITS

Overlaying of the two maps and comparison of the distributions of their respective units allows identification of the characteristic and dominating plant communities supported by the different types of morphodynamic unit (Table 2). It also allows spatial relationships to be determined between the types of morphodynamic unit and the vegetation (Table 3).

Characterization of the morphodynamic units using the percentage of vegetation type present (Table 2) shows that only a few communities exceed 5% of a unit's area, while the very same kinds of communities often dominate in various relief units.

- On the rockwalls and rocky slopes, the largest areas are occupied by fragmentarily developed alpine swards, for both the lime-free habitats (10) and the mylonites (19). A relatively large share is also taken by the dwarf mountain pine scrub (38). The remaining types of plant communities occupy areas less than 5% of the overall area of this morphodynamic type.
- On the debris-mantled slopes, the highest proportion is of dwarf mountain pine scrub (38) and epilithic lichen communities (2). There is a significant (5–10%) proportion of alpine swards: the sub-association *typicum* (8), the form with *Juncus trifidus* (14), as well as the complexes of rock shelf swards (10) and the dwarf scrub communities, especially combined with tall herbs (36).
- The debris slopes have the largest areas covered with communities of epilithic lichens (2) and dwarf mountain pine scrub (38), like the debris-covered slopes. The pioneering communities, like those of cryptogamic plants (1) and vascular plants on taluses and humid gravel (3), and the avalanche meadows (24), also account for significant proportions of the communities on these slopes.
- The bottoms of valleys filled with glacial drift deposits and occupied by spreads of fluvial, fluvioglacial and alluvial deposits are largely covered by dwarf mountain pine shrub (38), upper montane spruce forest (41) and epilithic lichen communities (2). Bilberry scrub (35) also accounts for significant areal cover.
- 'Mature' slopes with weathering covers are characterised by a high proportion of the dwarf mountain pine scrub (38) and a considerable proportion of upper montane spruce forest (41), bilberry scrub (35) and crowberry scrub (33), as well as subalpine sward forms (16) and the typical sub-association of the alpine swards (10).

Examination of the strength of linkages between the plant communities and morphodynamic units reveals different patterns(Table 3). Values of linkage strength above 0.4 (classes III, IV and V) indicate communities moderately to strongly connected with a given relief type, while lower values (class II) show that such linkages are poorly developed.

The highest parts of rockwalls are characterized by plant communities that are very specific, especially in terms of their structure. They are poorly developed by their very nature (subnival swards) or developed only in fragments, and this is the case both when they are complexes of communities of epilithic lichens with various swards belonging either to the dry (*cetarietosum*) or typical (*typicum*) sub-associations with fragments of snowbed communities and scree debris communities, or low tufts of dwarf mountain pine scrub. This type of morphodynamic unit features high values for the index of strength of the interrelationships, corresponding to strong and very strong linkages.

The debris slopes under the rockwalls are habitats for pioneering plant communities, which appear on fine debris (few cm in diameter), as well as the snow-bed areas in the niches under the walls and the avalanche

Table 2. Occurence of vegetation units in the morphodynamic units (in % of area).

Vegetation units No.	Morphodynamic types				
	1	2	3	4	5
1	1.9	0.7	**5.7**	0.2	0.3
2	3.4	**14.3**	**21.7**	**11.1**	1.9
3	1.3	0.7	**5.1**	0.1	0.2
4	1.7	1.8	4.1	0.7	1.8
5	0.2	0.0	1.1	0.5	0.0
6	0.1	0.1	1.0	0.6	0.0
7	3.0	0.1	0.0	0.0	0.0
8	1.6	**8.4**	3.3	0.6	**5.5**
9	0.2	0.9	0.3	0.3	1.7
10	**41.1**	**6.3**	4.4	0.0	2.9
11	0.1	0.2	0.0	0.0	2.6
12	0.4	1.4	0.2	0.1	0.4
13	0.3	0.7	2.0	0.0	0.0
14	4.4	**8.6**	4.3	0.5	1.7
15	0.5	2.9	0.2	0.0	2.5
16	0.4	2.3	1.7	1.1	**8.3**
17	1.5	0.3	3.0	0.4	1.9
18	1.6	1.0	2.2	0.3	0.2
19	**19.7**	1.2	2.7	0.1	0.0
20	0.3	0.4	0.2	0.1	1.4
21	0.0	0.0	0.0	0.1	0.0
22	0.0	0.0	0.0	0.7	0.0
23	0.0	0.0	0.0	0.3	0.0
24	1.1	2.3	**7.9**	1.4	1.6
25	0.3	0.1	0.8	0.0	0.0
26	0.1	0.2	2.4	0.3	0.0
27	0.3	1.7	1.3	0.4	0.1
28	0.0	0.0	0.1	1.3	0.4
29	0.2	0.0	0.6	0.4	0.3
30	0.1	0.4	0.0	3.6	3.1
31	0.1	0.1	0.1	1.2	1.0
32	0.0	0.0	0.0	0.3	0.0
33	1.0	2.6	2.5	1.9	**6.4**
34	0.4	2.2	0.4	0.0	0.8
35	0.5	2.2	3.4	**5.6**	**7.7**
36	0.5	**5.1**	1.9	4.7	3.4
37	0.1	0.1	0.7	0.3	0.2
38	**8.6**	**28.5**	**13.9**	**48.4**	**35.2**
39	2.9	0.6	0.6	0.0	0.2
40	0.0	0.0	0.0	0.1	0.9
41	0.0	1.4	0.2	**12.4**	**5.4**

Values exceeding 5% are in bold .

Table 3. Links between vegetation communities and morphodynamic types (index of strength of interrelationship according to value classes).

Vegetation units No.	Morphodynamic types				
	1	2	3	4	5
7	**V**				
10	**IV**				
19	**V**				
39	**IV**				
12		**III**			
14	II	**III**			
27		**III**	II		
34		**III**			II
15		**III**			**III**
3			**IV**		
26			**IV**		
24			**III**		
1	II		**IV**		
25	II		**IV**		
13		II	**IV**		
5			**III**	II	
6			**III**	**III**	
21				**V**	
22				**V**	
23				**V**	
28				**V**	
32				**V**	
29			II	**III**	
36		II		**III**	
30				**IV**	II
31				**IV**	II
35				**III**	II
38				**III**	II
41				**IV**	II
11					**V**
16					**III**
20					**IV**
40					**V**
33				II	**III**
9		II			**III**
17	II		II		II
2		II	II	II	
18	II		II		
8		II			II
37			II	II	
4			II		

Source: calculations by the authors

meadows (particularly in their pioneering, weakly-compact forms), and in well-drained places—alpine swards with *Salix retusa*.

The slopes with debris mantles and blockfields are of limited specificity where their floristic characteristics are concerned. There are no strong linkages, only moderate ones. The reason perhaps lies in the limited thickness of the debris cover, as well as the good drainage of the shallowly situated rocks, something which determines the quality of habitats so strongly that altitude-related differentiation does not play a major role in this case. The effect is azonality in both alpine and subalpine zones (and lower). The degree of ground cover by vegetation may be different, depending upon the length of the period since colonization. The debris slopes in the ridge-adjacent locations are covered by alpine swards with *Salix herbacea*. At lower altitudes there are scree forms (with *Juncus trifidus*) of the alpine sward. At lower levels still, more heavily vegetated slopes are covered by post-grazing grassland communities (grazing was carried out not only on the slopes best suited to this purpose), as well as the crowberry scrub in mosaics with dwarf mountain pine and avalanche meadows.

The 'mature' slopes with weathering covers are associated with a large range of plant communities. These are highly compact and form uniform surfaces, frequently of significant dimensions, mainly comprising various alpine swards, ranging from the dry lichen swards to the humid peat-moss swards, as well as the subalpine anthropogenic forms. The latter group includes all the communities on carbonate rocks, as well as large areas of crowberry scrub.

The specific feature of the valleys floors filled with glacial drift and occupied by the spreads of fluvial, fluvioglacial and alluvial deposits is the presence of vegetation related to water flows and humid environments: tall herbs and avalanche meadows, humid post-grazing swards and peatbogs, as well as snowbeds. Similarly, the communities of the subalpine belt and the upper montane belt are also linked with this type of morphodynamic unit: the post-grazing grassland communities, dwarf scrubs, dwarf mountain pine shrubs and the upper montane spruce forest.

Not all of the vegetation types have clear linkages with specific morphodynamic units. A number are only weakly linked (class II linkages), nonetheless, with more than one type of morphodynamic unit. In addition, different morphodynamic units may be associated with similar plant communities. This might be exemplified by a number of plant communities which overgrow the valley bottoms filled with glacial drift deposits, and the 'mature' slopes with weathering covers, with particular focus on the areas of glacial accumulation.

CONCLUSIONS

This study has demonstrated clear links between plant communities and the type of morphodynamic surface on which they grow. The majority of plant communities have their main occurrences in a definite morphodynamic type (i.e. they are associated with a definite type of habitat) and the different types of morphodynamic surface are associated with characteristic sets or combinations of plant communities. In geobotany, characteristic combinations of species are used in describing plant associations, while characteristic combinations of communities are used in the description of landscape-rank units called sigma-associations. The approach applied in the present study is close to the level of sigma-associations, because characterization is provided on the basis of plant communities, and not species. The measures of association are provided by an index of the strength of interlinkage between vegetation types and relief, and not by the areal proportions of plant communities in the higher-rank (landscape) units alone. Areal proportions, as such, constitute a rather imprecise indicator, emphasising the dominating plant communities. These are the zonal ones—the dwarf mountain pine shrub, the upper montane spruce forest, the alpine swards (especially the typical sub-association) but also the extensive post-grazing (grassland and scrub) communities, as well as azonal communities of epilithic lichens. They constitute the main components for individual morphodynamic types.

Application of the index of strength of interlinkage avoided the problem of dominating vegetation communities, which reduces the clarity of specificity of particular habitats. Consequently each of the identified types of morphodynamic unit has its own combination of plant associations strongly linked with it These associations reflect the character of the slope, especially its dynamics or degree of stability.

Only some plant communities exist on one type of slope only. These are the associations linked with a definite type of habitat, such as those that are very dynamic or the those strongly influenced by water. Even those associations which display linkages with several, most often two, types of relief, have strong linkages with just one type of morphodynamic type of surface. The patterns of interrelations between vegetation and relief are more distinct for the large morphodynamic units than for more narrowly defined units of relief, thereby attesting to the role of the large units of relief in the development of vegetation patterns of supra-ecosystem (landscape) rank. Namely large morphodynamic units can be accepted as a basis for delimitation of vegetational landscape units.

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