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Applying geomathics to determination of landscape altitudinal zones in the mountains

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Abstract: The paper presents a method enabling determination of the extent of landscape zones, based on the criterion of area coverage by vegetation. This method made it possible to objectively determine the extent of landscape zones both in the entire Tatra Mts. and in their particular parts. The altitude, at which dominant type of vegetation changes, is considered to mark the boundary of a landscape zone. Boundaries distinguished in this way in the Tatra Mts. are presently situated at: 1,510 m a.s.l. (forest zone), 1,730 m a.s.l. (subalpine zone), and 1,880 m a.s.l. (alpine zone).

Key words: landscape altitudinal zones, geomatics, Tatra Mts.

Introduction

Vertical zonality of natural features in the mountains is a well known and frequently described phenomenon. Basic properties of natural environment showing such zonality include: air temperature, type and totals of precipitation, disappearance of warm seasons, type and intensity of some morphogenetic processes and rock weathering, types of soil cover and rates of soil-forming processes. Changes of these properties lead to development of different types of plant ecosystems and associated faunal species.

Representatives of various disciplines tend to build their own classification schemes dealing with the zonality of natural environment. For instance, climatic (Hess 1974), geoecological (Kotarba 1987), vegetation (Pawłowski 1927, 1972), landscape (Kondracki 1967, Kalicki 1989), and hygrographic (Wit-Jóźwik 1974) zones have been distinguished.

In most cases, the boundaries between individual zones coincide with either disappearance or appearance of different types of ground coverage: forests, dwarf pine, alpine vegetation, rocky terrains and permanent snow line.

A critical overview of different views on vertical environmental zonality in the Tatra Mts. presented by Balon (1991) indicated that boundaries between individual zones used to be distinguished subjectively, and that altitudes quoted by different authors are only roughly estimated. A belt-like character of the majority of boundaries and related mosaics of different types of ground coverage in the transitional zone are now basic difficulty in determining boundaries between individual vertical zones.

The main goal of this paper is to construct a method that would objectively help in distinguishing the boundaries in question.

Material and method

Two types of classification of mountain landscape typology exist in the Polish literature. Kondracki (1967) distinguished four types of mountain landscape: intramontane plains, lower forest, upper forest, and – treated jointly – subalpine and alpine ones. A modification of this subdivision proposed by Kalicki (1989) separates the subalpine and alpine types, deletes the intramontane plains landscape type, and additionally introduces the subnival landscape. This typology is related to that of vegetation zones distinguished by Pawłowski (1927); hence, according to our opinion, it classifies the Tatra landscape best.

The Kalicki's (1989) typology is as follows:

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Class: Mountain landscapes
- Genus: Landscape of middle and low mountains
  - Species: Landscape of low forest zone
  - Species: Landscape of upper forest zone
- Genus: High-mountain landscape
  - Species: Subalpine landscape
  - Species: Alpine landscape
  - Species: Subnival landscape

One can use different criteria of distinguishing landscape zones, like: anthropogenic, hydrographic, geomorphic or "classical", i.e. based on dominant plant community or assemblage (Balon 2004). The quoted author noted that in transitional zones interfingering of individual plant communities takes places and that it is sometimes difficult to specify, which community is a dominating component. A solution to this problem consists in selecting an objective method that would take into account the degree of coverage of the area occupied by the altitudinal zone by individual plant communities. Such a dominant component should be searched for among four types of ground coverage: forest, dwarf pine, grass vegetation, and rocky terrains. Forest dominates in landscapes of the lower and upper forest zones, dwarf pine in the subalpine landscape, grass communities in the alpine landscape, and rocky terrains in the subnival landscape. The method described below can also be used for analysing landscape changes during longer time intervals, because we can see the changes but do not know how to measure them.

As already noted by Balon (2004), applying vegetation criterion to determination of landscape zones forces one to omit separate character of other landscape elements, like geological structure and landforms, reducing thereby our knowledge of landscape structure. From our point of view, however, it is the most important criterion, since it is based on physiognomy of the landscape, and because its application is methodologically justified (Balon 2004).

The "infilling" method used in this work is based on raster algebra, i.e. spatial analysis of raster data containing information pertaining to ground coverage, macro-aspect, mountain group and altitude. The method consists in calculating the degree of infilling (percentage coverage) by the analysed types of ground coverage of the surfaces of 10-m-high altitudinal zones. Based on the dominating type, altitudinal ranges are assigned to individual landscape zones.

Spatial data used in the analysis come from remote sensing and classification of an orthophotomap made by IKONOS–2 satellite (Guzik et al. 2006), obtained in August 2004. Basing on a remote sensing key, the empirical upper timber line (ETL), i.e. the line linking the upper forest limit, was distinguished. Heterogeneous areas were mapped above this line (Table 1). The remaining area, composed of homogeneous objects, underwent qualified classification, owing to which four types of objects were singled out: rocks, dwarf pine, clearings and alps, as well as ponds and shaded areas. A detailed description of the classification method together with analysis of its resolution was presented by Guzik (2008). During generalization procedure conducted for the sake of landscape analysis, heterogeneous objects were assigned to one of the four types listed above, or classified as a forest-type terrain.

Results

Characteristics of the area situated above the empirical timberline (ETL)

More than 45% of the Tatra area is situated above the ETL. The greatest share of this surface is allocated to the Western (47%) and High Tatra Mts. (47%), the remaining area occurs in the Belianske Tatra Mts. (5%) and Sivý vrch Group (1%).

Nearly 65% of the area located above the ETL is covered with vegetation. Dwarf pine is the most important component (>32%), the second one are grass communities (29%). Rocky terrains (including scree slopes) comprise more than 29% of the area. For 5.6% of the area no ground coverage has been determined. Shaded areas occur mainly upon steep and rocky slopes, therefore, the lack of identified ground coverage at these places should not affect analyses pertaining to vegetation cover.

The Sivý vrch Group (Fig. 1a) is characterised by a high amount of dwarf pine (>50%), very small share of rocky terrains (1.6%), nearly 10% amount of areas covered with dwarf mountain pine with spruces and deciduous species (cat. 8), and the same as for the entire Tatras percentage of grass vegetation (28.9%).

In the Western Tatra Mts. (Fig. 1b), a high percentage of grass-covered areas (44.1%) is to be noted, as well as lower than in the entire Tatras amount of rocky terrains (11.9%). Dwarf mountain pine covers nearly 37% of the area.

The High Tatra Mts. (Fig. 1c) are typified by a very small share of grass-covered area (11.7%) and the highest, nearly 50% amount of rocky terrains. Also high is the amount of shaded and unclassified areas (8.7%). Dwarf mountain pine occupies more than 27% of the High Tatra Mts. area.

The Belianske Tatra Mts. (Fig. 1d), in turn, are characterised by the highest amount of grass vegetation above ETL (>47% of the area), low share of rocky terrains (13.3%), and more than 28% high amount of dwarf mountain pine.

Comparing the areas situated on the northern and southern sides of the Tatra Mts., one should take notice of a nearly 4% higher amount of grass-covered area in the north, and 6% higher share of rocky terrains in the south. Such a distribu-

Table 1. Categories of ground coverage based on a remote sensing key, and types of coverage, to which individual categories have been assigned owing to generalization procedure

Category of ground coverage	Description	Type of coverage
1	Clearing, alp (area covered with grass, sedge and herbaceous plants)	clearings and alps
2	Single spruces on a clearing or alp	clearings and alps
3	Single spruces trees on scree slopes	rocks
4	Spruce biogroups, low, tightly growing spruces on a clearing or alp	forest
5	Deciduous biogroups on a clearing or alp	forest
6	Spruces and deciduous species overgrowing areas devoid of tree vegetation (e.g., avalanche routes, windfall areas, places left after fires)	forest
7	Dwarf mountain pine, spruces and deciduous species overgrowing areas devoid of tree vegetation(e.g., overgrowing of clearings and alps)	dwarf mountain pine
8	Spruces, Swiss stone pines and deciduous species occurring within dwarf mountain pine	dwarf mountain pine
9	Dwarf mountain pine and spruces overgrowing areas devoid of tree vegetation	dwarf mountain pine
10	Spruce or Swiss stone pine avenues and biogroups, tight patches of spruces within dwarf mountain pine	forest
11	High spruces and Swiss stone pines growing within dwarf mountain pine close to empirical timberline	dwarf mountain pine
12	Single spruces growing within dwarf mountain pine	dwarf mountain pine
13	Deciduous species growing within dwarf mountain pine	dwarf mountain pine
14	Single deciduous and coniferous trees and shrubs growing within dwarf mountain pine	dwarf mountain pine
15	Dwarf mountain pine encroaching upon high-mountain alps	dwarf mountain pine
16	Dwarf mountain pine	dwarf mountain pine
17	Rocks (including scree slopes)	rocks
18	Ponds, streams	ponds and shaded areas
19	Shaded area	ponds and shaded areas
20	Unidentified area	ponds and shaded areas

tion results mainly from proportions occurring in the High Tatra Mts.

Analysis of the ground coverage on both sides of the state boundary indicates that in the Western Tatra Mts. the grass-covered areas occupy more than 50% on the Polish side and 42% on the Slovak side. The Slovak side, in turn, bears more terrains overgrown by dwarf mountain pine (nearly by 10%).

Comparing the spatial distribution of areas allocated to individual categories of ground coverage with the share of individual mountain groups within the total area of the Tatra Mts., one can see that some categories occur more frequently in certain mountain groups (Table 2).

The Western Tatra Mts. are typified by the occurrence of a large amount of grass communities (cat. 1), single spruces growing on alps (cat. 2), terrains devoid of tree vegetation and presently being overgrown by spruce and dwarf mountain pine (cat. 7), as well as areas showing succession of dwarf mountain pine (cat. 15). Relatively small areas are occupied by high spruces and Swiss mountain pines occurring

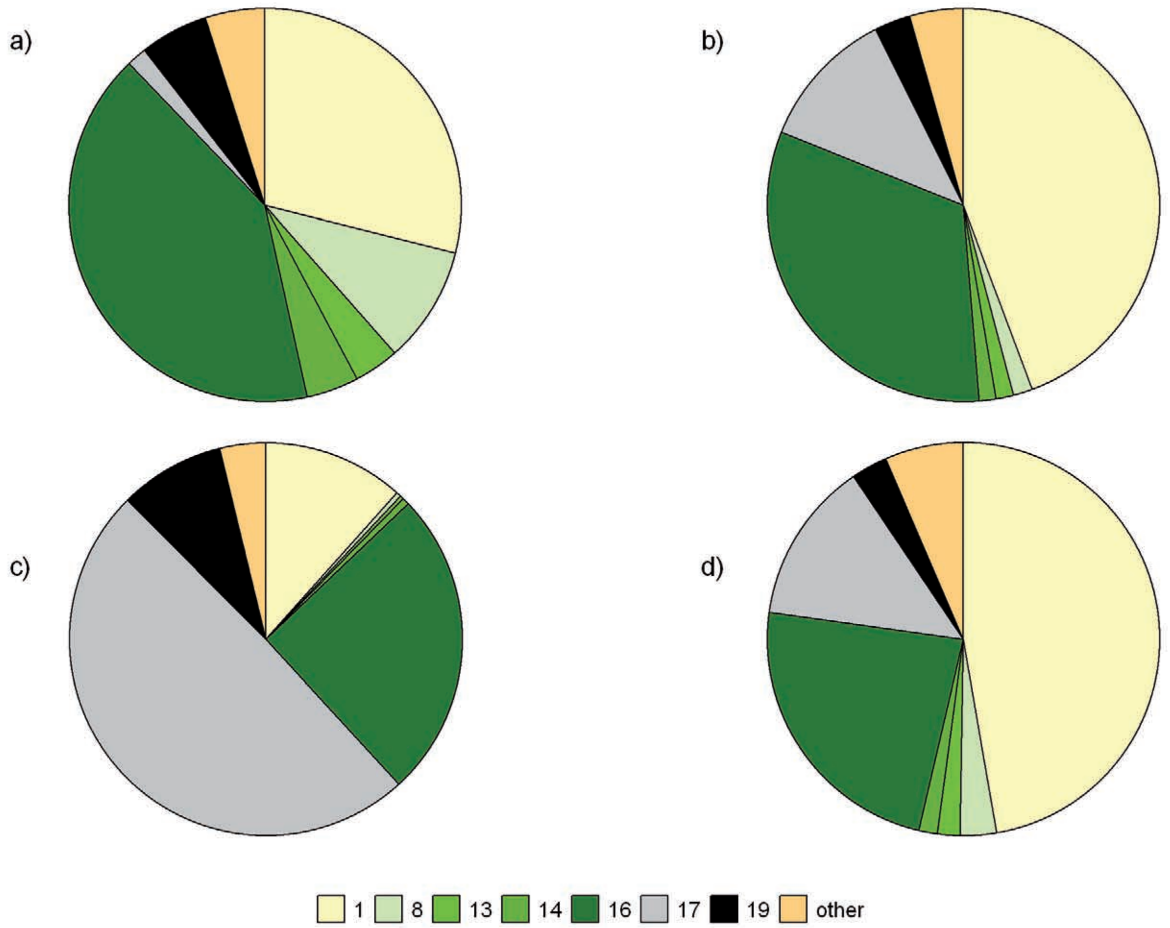

Fig. 1. Percentage of selected categories of ground coverage above ETL for individual mountain groups: a) Sivý vrch Group, b) Western Tatra Mts., c) High Tatra Mts., d) Belianske Tatra Mts. Categories: 1 – Clearing, alp (area covered with grass, sedge and herbaceous plants), 8 – Spruces, Swiss stone pines and deciduous species occurring within dwarf mountain pine, 13 – Deciduous species growing within dwarf mountain pine, 14 – Single deciduous and coniferous trees and shrubs growing within dwarf mountain pine, 16 – Dwarf mountain pine, 17 – Rocks (including scree slopes), 19 – Shaded areas

above the ETL within dwarf mountain pine (cat. 11) and by rocky terrains (cat. 17).

The High Tatra Mts. reveal a relatively high percentage of areas covered with high spruces and Swiss stone pines within dwarf mountain pine (cat. 11) and rocky terrains (cat. 17). Most of categories, the total surface of which exceeds 100 ha (cat. 1, 2, 7, 8, 13, 14, 15), occur in smaller quantities.

Among valleys of the Tatra Mts. (Fig. 2), a large share of grass-covered areas (exceeding 50%) reveal: the Miętusia Valley and area situated north of Organy (52.0%), Kamienista (53.6%), Mała Łąka (54.6%), Chochołowska (59.2%) valleys, as well as valleys dissecting the southern slope of Sivý vrch Mt. (82.9%). The lowest share of this category (less than 10%) characterizes: the Waksmundzka Valley and the eastern slopes of Wołoszyn Mt. (9.3%), Mengusovská Valley (6.8%), valleys situated south-east of Lomnický štít Mt. (6.6%), Studená Valley (3.2%), and valleys located south of Gerlachovský štít and Slavkovský štít peaks (3.0%).

The greatest amount of rocky terrains occurs in the Studená Valley (71.5%) and Mengusovská Valley (64.4), as well as in valleys situated south of Gerlachovský štít and Slavkovský štít peaks (61.1%).

Areas situated above the ETL and covered mostly with dwarf mountain pine (cat.12–16) occur in valleys placed south of Kozie Grzbiety Mts. (81.1%), north of Grześ Mt. (65.8%), and north-west of Brestová and Sivý vrch peaks (58.4%). The reverse situation occurs in valleys of Studená Valley (dwarf mountain pine occupying 14.5% of the area), Mała Łąka (11.2%), as well as in valleys situated north of Giewont Mt. (10.4%) and dissecting the southern slope of Sivý vrch Mt. (0.4%).

Altitudinal extent of landscape zones

Spatial analysis of data grouped into 5 types was conducted with a view to distinguishing boundaries between landscape zones. The analysis consisted in studying the degree of infilling of the surface of altitudinal belts by different types of ground coverage.

The percentage of forest communities in the area of analysed altitudinal belts decreases with altitude.

Table 2. Areal distribution of individual categories of ground coverage within mountain groups (categories dealt with in the text are coloured). 1 – Clearing, alp (area covered with grass, sedge and herbaceous plants), 2 – Single spruces on a clearing or alp, 3 – Single spruces trees on scree slopes, 4 – Spruce biogroups, low, tightly growing spruces on a clearing or alp, 5 – Deciduous biogroups on a clearing or alp, 6 – Spruces and deciduous species overgrowing areas devoid of tree vegetation (e.g., avalanche routes, windfall areas, places left after fires), 7 – Dwarf mountain pine, spruces and deciduous species overgrowing areas devoid of tree vegetation (e.g., overgrowing of clearings and alps), 8 – Spruces, Swiss stone pines and deciduous species occurring within dwarf mountain pine, 9 – Dwarf mountain pine and spruces overgrowing areas devoid of tree vegetation, 10 – Spruce or Swiss stone pine avenues and biogroups, tight patches of spruces within dwarf mountain pine, 11 – High spruces and Swiss stone pines growing within dwarf mountain pine close to empirical timberline, 12 – Single spruces growing within dwarf mountain pine, 13 – Deciduous species growing within dwarf mountain pine, 14 – Single deciduous and coniferous trees and shrubs growing within dwarf mountain pine, 15 – Dwarf mountain pine encroaching upon high-mountain alps, 16 – Dwarf mountain pine, 17 – Rocks (including scree slopes), 18 – Ponds, streams, 19 – Shaded area, 20 – Unidentified area

Mountain group	Surface of the Tatra Mts. [%]	Type of ground coverage within the Tatra mountain groups [%]																			
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Sivý vrch	1.5	1.5	9.8	0.0	12.9	0.0	0.0	3.1	11.5	0.0	3.4	0.0	3.3	5.2	7.1	0.6	2.2	0.1	0.0	0.1	3.1
West Tatras	47.0	71.7	74.1	0.0	51.9	47.5	66.3	75.7	57.2	1.2	43.3	19.1	45.3	69.4	66.4	77.3	52.9	19.2	3.9	23.2	58.2
High Tatras	46.7	19.0	9.3	100	14.8	16.5	32.2	12.4	20.3	98.8	44.9	74.3	43.0	16.6	18.9	22.1	41.0	78.5	96.1	73.9	27.8
Belianske Tatras	4.8	7.8	6.8	0.0	20.4	36.0	1.5	8.8	11.0	0.0	8.4	6.6	8.4	8.8	7.6	0.0	3.9	2.2	0.0	2.8	10.9
Tatra Mts.	100.0	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

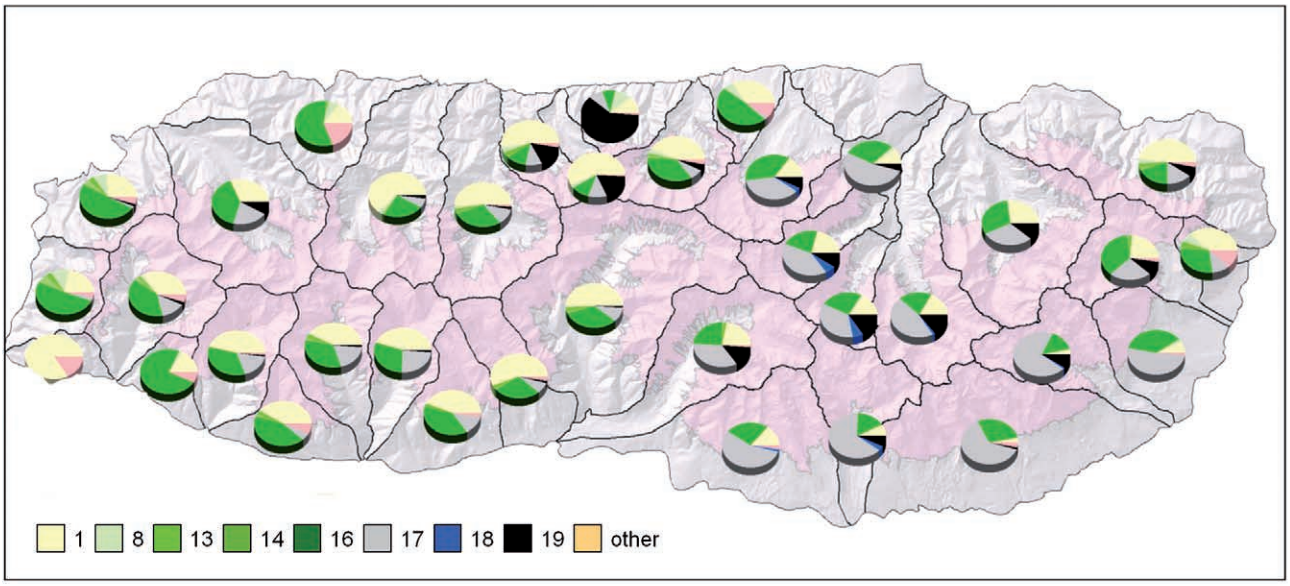

Fig. 2. Percentage of selected categories of ground coverage above ETL for individual valleys. Categories: 1 – Clearing, alp (area covered with grass, sedge and herbaceous plants), 8 – Spruces, Swiss stone pines and deciduous species occurring within dwarf mountain pine, 13 – Deciduous species growing within dwarf mountain pine, 14 – Single deciduous and coniferous trees and shrubs growing within dwarf mountain pine, 16 – Dwarf mountain pine, 17 – Rocks (including scree slopes), 19 – Shaded areas

A change of the dominant community occurs at 1,510 m a.s.l.; higher up dwarf montain pine takes the greatest share. The latter terminates at 1,730 m a.s.l., and the landscape becomes dominated by grass-covered high-mountain alps. This type of ground coverage is replaced at 1,880 m a.s.l. by rocky terrains and talus scree. Figure 3 shows that dominant type of ground coverage should fill ca. 40% of the belt area (dwarf mountain pine – 40%, grass communities – 38%, rocky terrains – 44%).

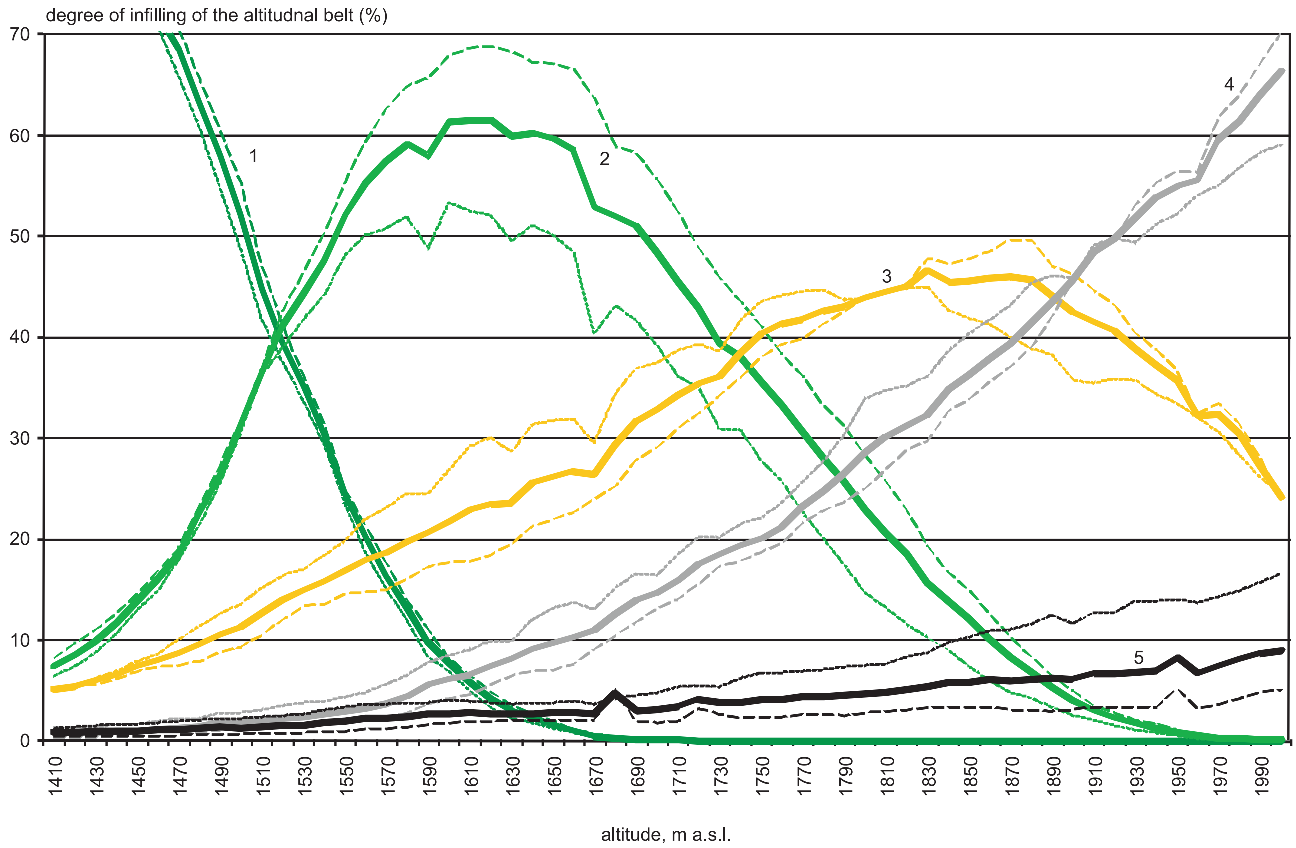

Fig. 3. Areal percentage of individual types of ground coverage within 10-m-high altitudinal belts. 1 – forest, 2 – dwarf mountain pine, 3 – grass vegetation, 4 – rocks, 5 – shaded areas and ponds. Solid lines mark values obtained for the entire Tatra Mts., dotted lines – for northern slopes, dashed lines – for southern slopes.

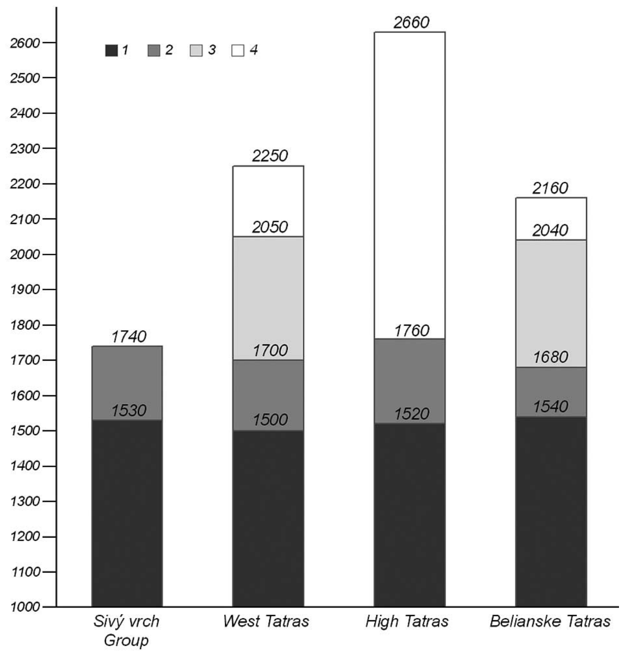

Fig. 4. Boundaries between landscape zones in different parts of the Tatra Mts. 1 – Subnival zone, 2 – Alpine zone, 3 – Subalpine zone, 4 – Forest zone

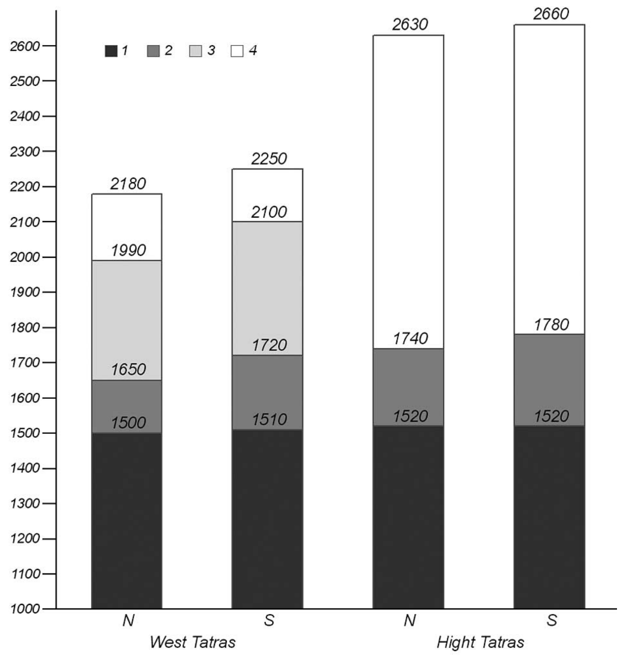

Fig. 5. Boundaries between landscape zones in the Western and High Tatra Mts. depending on macro-aspect. 1 – Subnival zone, 2 – Alpine zone, 3 – Subalpine zone, 4 – Forest zone

The diagram (Fig. 3) illustrates as well different altitudinal extent of individual belts on the southern and northern sides of the Tatra Mts. The lower boundaries of subalpine and alpine belts are placed by 50 m and 60 m, respectively, higher on the southern side.

To detect differences among individual mountain groups, the Sivý vrch Group, Western Tatra Mts., High Tatra Mts. and Belianske Tatra Mts. were analysed separately.

The Sivý vrch Group, owing to its low elevation, does not reach the upper boundary of subalpine zone (Fig. 4). High position of the boundary of subalpine zone in the High Tatra Mts. results from the fact that, following the applied methodology, the alpine zone is impossible to distinguish in this region. Grass vegetation does not occupy the greatest surface in any of the distinguished altitudinal zone. The subalpine zone passes immediately into the subnival one.

Comparing macro-aspect data for individual Tatra regions it becomes apparent that differences in the extent of particular zones are particularly well visible in the Western Tatra Mts. The upper limit of the subalpine zone is placed 70 m higher on the southern side compared to the northern one, and even greater difference in altitude, attaining 110 m, is observed in case of the upper limit of the alpine zone (Fig. 5). Such great differences may result from strong pressure exerted by cattle and sheep grazing that took place on the Polish side of the Tatras in the 19th and 20th centuries.

Discussion

Vertical zonality of the Tatra landscape has not yet been studied in detail; specialists of different disciplines concentrated mostly on distinguishing boundaries of such environmental components, like: climate, vegetation or soil cover. Only infrequent papers did concern vertical zonality of environment, also called physico-geographic zonality, which is most closely related to the landscape vertical zonality.

A critical review of studies dealing with determination of environmental zonality in the Tatra Mts. (Balon 1991) shows that individual zones have neither been distinguished nor characterized sufficiently. The authors of various classification schemes, when quoting certain values of altitude and boundaries of the zones, usually do not indicate how these were distinguished and whether they result from statistical procedures or from personal estimation of proxy data. Balon (1991) takes notice of the fact that separation and characteristics of physico-geographic altitudinal zones can only be done owing to detailed studies. That is why, when describing physico-geographic altutudinal zones in the Tatra Mts., he quotes no altitudinal extents. Precise data concerning ground coverage are the basis of the "infilling" method proposed in this paper. Application of this method enables us to precisely determine the boundary value, representing the average altitude of the limit of a landscape zone in the analysed area.

Since landscape zones have not been distinguished in the Tatra Mts. so far, the obtained results can not be compared to other values. At attempt at parallelization of zonal boundaries distinguished for different environmental components of the Tatra Mts. reveals fairly big differences, particularly apparent at the boundaries between subalpine/alpine and alpine/subnival zones (Table 3). In most cases, boundaries between landscape zones are situated lower than those of other environmental components (except for boundaries between the forest and subalpine geoecological belts). Strangely enough, the greatest differences concern boundaries of vegetation zones, although the type of vegetation cover is the basic criterion used in determination of landscape zones.

Table 3. Comparison of altitudes of boundaries between zones of different environmental components in the Tatra Mts. (in metres a.s.l.)

Climatic vertical zones (Hess 1974)	Vegetation zones (Pawłowski 1972)	Morphogenetic zones (Klimaszewski 1967)	Geoecological belts (Kotarba 1987)	Landscape zones
temperate cool <1,150	lower forest < 1,250	forest < 1,550	forest < 1,500	forest < 1,510
cool 1,150–1,550	upper forest 1,250–1,550			
very cool 1,550–1,850	dwarf mountain pine 1,550–1,800	alpine 1,550–2,200	subalpine 1,500–1,670	subalpine 1,510–1,730
temperate cold 1,850–2,200	alpine 1,800–2,300		alpine 1,670–2,150	alpine 1,730–1,880
cold > 2,200	subnival > 2,300	subnival > 2,200	seminival > 2,150	subnival > 1,880

Such great discrepancies in the positions of zonal boundaries can result from:

- too high estimation of the upper boundary of the alpine zone (vegetation zone),
- too low estimation of the upper boundaries of the forest and subalpine zones, being an effect of a few centuries-long cattle and sheep grazing in this region (the "infilling" method does not study the potential of a setting, but takes into account the state from a certain period; that is why this method can also be used for analysing landscape changes).

Conclusions

The proposed method, based on the degree of infilling the space by vegetation, makes it possible to determine altitudinal extents of vertical vegetation zones in an objective manner, and can be applied at both macro- (Tatra Mts.) and meso-scales (single valley). Using this method, one can objectively estimate both landscape changes and their rate.

The conducted studies enable us to conclude that the boundaries of landscape zones distinguished with the use of vegetation criteria occur lower than those of vegetation zones quoted in the literature. Forests in the Tatra Mts. dominate until 1,510 m a.s.l., dwarf mountain pine occurs between 1,510 and 1,730 m a.s.l., grass vegetation between 1,730 and 1,880 m a.s.l., whereas above 1,880 m a.s.l. rocky terrains and scree slopes comprise most of the area. The difference in altitude of zonal boundaries between the southern and northern sides of the Tatra Mts. averages 50 m in case of the subalpine and alpine zones, attaining even 110 m in the Western Tatra Mts. The alpine zone can not be distinguished in the High Tatra Mts. due to insufficient amount of grass communities occurring above the upper timber line.

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