Anthropogenous Vegetation Changes in Alpine Tundra, a Remote Sensing Study from the Krkonoše Mountains, Czech Republic. Preliminary Results

J. MÜLLEROVÁ

Tundra represents a specific ecosystem, fragile and sensitive to any kind of anthropogenous impact, such as ruderalization, eutrophication, climate change, air pollution and many others (CRAWFORD 1997; REYNOLDS et TENHUNEN 1996). Human induced expansion of alien (or even local) species is a remarkable phenomenon in this highly vulnerable environment. There are many ways to study problem of invasion. The possibilities of remote sensing methods (aerial photography) used for this purpose have not been much explored. They could offer us an interesting perspective and new views if we were able to make the detection and further analyses accurate enough.

Krkonoše Mountains (Giant Mountains, Riesengebirge) are located in the northern part of the Czech Republic on the border with Poland. They represent the highest mountain range of the country (maximum 1,602 m a.s.l.). The area has been protected as a National Park since 1963, in 1992 it was designated as a bilateral Biosphere Reserve. It covers an area of 60,000 hectares of which 55,000 hectares fall within the Czech Republic (FLOUSEK 1994).

From the geomorphological, botanical, and zoological point of view the most valuable and interesting part of the Biosphere Reserve is to be found in the uppermost areas above timber-line (in Krkonoše between 1,200 m and 1,300 m a s.l.) (JENÍK et LOKVENC 1962). It represents a particular landscape system displaying affinities to both subarctic and high-mountain regions (SOUKUPOVÁ et al. 1995). Together with peaks it includes the Eastern and Western Plateaus at an altitude between 1,300 m and 1,400 m a.s.l. belonging to the subalpine and alpine zone. This area is subject to extreme climatic conditions such as an exposition to strong cold northwestern winds, average temperature of 0 to +1°C, daily averages below 0°C for more than half the year, snow cover lasting more than 180 days per year and high annual total of 1,400 mm precipitation and periodical regelation and deflation (SOUKUPOVÁ et al. 1995). The Plateaus are formed by crystalline metamorphic rocks covered by poor acidic soils of the alpine sod podzol type, patches of peatlands and raised bogs, and polygonal and patterned soils. Treeless summits of Krkonoše preserved a number of physiographic components unique to the country such as relic populations and relic community types. The ecosystem developed under the extreme environmental conditions is called „alpine tundra“. JENÍK et SEKYRA (1995) proposed a special term/subcategory for the Krkonoše Mountains: „arctic-alpine“ tundra.

The study site is located on the Western Plateau (1,300 m - 1,350 m a.s.l.) along the source of the River Elbe and covers 3 square kilometers belonging to the vegetated-cryogenic zone of tundra (SOUKUPOVÁ et al. 1995). The most typical plant species include dwarf pine (*Pinus mugo*), creating large polygons of dense shrub cover; *Nardus stricta* - a typical graminoid dominant, as well as *Calamagrostis villosa* and *Molinia coerulea*. Characteristic natural vegetation types according to JENÍK (1961) and MORAVEC et al. (1995) are listed below:

- Alliance *Nardo-Caricion rigidae* (NORDHAGEN 1936). Dense uniform stands of short-grass *Nardus stricta* (partly of secondary origin) at the localities of high snow cover (100-150 cm) and deeper soils of humus podzol type based on granites, pH around 4.5.
- Alliance *Pinion mughi* (PAWLOWSKI et al. 1928). Dwarf pine alliance representing the primary shrub communities of subalpine zone with acidophilous and oligotrophic species.
- Alliance *Calamagrostion villosae* (PAWLOWSKI et al. 1928). Acidophilous communities of tall-grasses (*Calamagrostis villosa*, *Molinia coerulea*) and flowering herbs on granite based wind-protected soils with long-lasting snow cover.
- Alliance *Oxycocco-Empetrion hermaphroditi* (NORDHAGEN 1936). Oligotrophic communities of boreoarctic and alpine raised bogs with prevalence of shrub form and *Sphagnum*.

The National Park, and this area in particular, represents a popular tourist destination (more then half a million visitors per year in 1995, daily maximum over 2,000 visitors in 1989; MÁLKOVÁ et WAGNEROVÁ 1995), and therefore suffers from rather heavy anthropogenous impact causing various problems. Among these are: mechanical disturbance of soil and plant cover (i. e. trampling); dispersal of undesirable and alien plant diaspores (synantrophization and ruderalization); fragmentation of habitats; airborne and other pollution; eutrophication; acid rain and climate change.

Native vegetation of the area is often dominated by *Nardus stricta*, a species with a low competitive ability and a high vulnerability to mechanical disturbance (e. g., trampling). Communities of this dominant are endangered by increasing expansion of grasses, mainly *Deschampsia flexuosa, Calamagrostis villosa* and *Molinia coerulea* (HUSÁKOVÁ 1986). Communities dominated by *Calamagrostis villosa, Molinia coerulea, Veratrum lobelianum, Senecio nemorensis* or *Cirsium heterophyllum*, i. e., species produ-

Author: Jana MÜLLEROVÁ, Institute of Botany, Academy of Sciences of the Czech Republic, CZ-25243 PRUHONICE

cing higher biomass, are found in the surroundings of *Pinus mugo* shrubs, on sites with long-lasting snow cover, in terrain depressions, stream alluvia or on disturbed sites.

The most pronounced changes in plant composition are caused by unsuitable alkaline building material (dolomitic limestone; melaphyre) used in the 1970s and 1980s for paving some roads and walking trails in the area. This interference led to an alteration of chemical soil properties. Normal pH values range from 3 to 3.6, however close to the road they can reach up to pH 8 (MÁLKOVÁ et KÙLOVÁ 1995). The calcareous material has a profound effect on the environment that was originally nutrient poor. Alkaline ions are continuously washed out and spread into the surroundings. This process is enhanced by a high humidity of the area.

The disturbance facilitates an expansion of many problematic species. These are (i) typical ruderal species such as *Urtica dioica* or *Rumex alpinus* (the latter introduced probably by local farmers in the 16th and 17th centuries as pig forage); (ii) species native to the Krkonoše Mountains, but occurring naturally at lower altitudes, such as *Senecio fuchsii, Hypericum maculatum, Cirsium arvense, Tussilago farfara,* and *Epilobium angustifolium* or (iii) expansive native species favourized by the conditions, growing naturally on humid tundra patches richer in nutrients such as little depressions, stream alluvia, surroundings of *Pinus mugo* shrubs and snow fields (*Senecio nemorensis; Cirsium heterophyllum; Veratrum lobelianum; Deschampsia caespitosa; Callamagrostis villosa* or *Bistorta major*). All these species are penetrating far into low competitive natural communities, forming lobes reflecting the terrain conditions.

This phenomenon (the so-called ecotone effect) can be studied by remote sensing methods because the species poor or even monospecific stands of affected sites are remarkable taller, producing higher biomass than the oppressed natural communities, typically dominated by *Nardus stricta*. In this study, airborne data are analysed by digital classification using software Chips developed at the Institute of Geography, Copenhagen University, Denmark. Historical and current field data, GPS measurements, and historical panchromatic photographs are used as an additional source of information. Different sources and methods are compared and possibilities for application of these methods for vegetation mapping are considered. Similar studies in arctic and alpine environment were done for example by JORIA et JORGENSON 1996, TIMONEY et al. 1992 and SPJELKAVIK 1995.

Data available are panchromatic photographs from 1936, 1964 and 1998; multispectral photographs from 1986 (channels 1, 2, 3, 6) and 1989 (channels 2, 3, 4, 6), channel wavelength: Ch1 - 0.48 nm, Ch2 - 0.54 nm, Ch3 - 0.60 nm, Ch4 - 0.66 nm, Ch6 - 0.84 nm; color slides (1996); orthophotographs (1997); digital terrain model; botanical mapping based on photographs from 1989 (FIŠEROVÁ 1992) and GPS measurements (VÍTEK in BRANIŠ et al. 1997). National Park authorities or the authors kindly supplied most of these data.

Methodology [further explanation can be found in CAMPBELL (1987) or JENSEN (1986)]:

❶ *Scanning*. Transformation from analogous photography to digital image form.

❷ *Geometric corrections, rectification*. Registration image-to-image (i.e., different channels or different years) or image-to-map (i.e., image to orthophoto).

❸ *Image arithmetics*, such as filtering, calculation of normalized difference vegetation index (NDVI) and other indices, that provide further information on the vegetation characteristics, just as the principal component analysis that can also be used in change detection by comparison of the data from different years.

❹ *Digital classification* of the multispectral images:

a) Unsupervised. An automatic classification run by a computer according to a clustering algorithm, in which spectraly distinct clusters are identified through an iterative procedure. Only minimum-maximum numbers of classes and number of iterations are to be defined by the user. In this case the ISO classification has been used (described for example in CIHLAR et al. 1996).

b) Supervised. Class characteristics are defined by the user through identifying each channel spectral boundaries directly (*Parallelepiped classification,* as in this study) or more typically by means of training classes (other types of supervised classification).

❺ *Interpretation of results and ground truthing.* One of the most important steps, where the results are verified and a meaning of each class is determined, mainly in the case of unsupervised classification. The great spatial detail of the airborne data (pixel size 0,4 m) lead to a variety of side information that are difficult to interpret, such as soil water content, health status of the vegetation etc.

❻ *Final arrangements.* Filtering of the classified image on account of reducing the number of misclassified pixels and simplifying the polygons that are too diverse. The aim is to make the results comprehensible, useful, and possible to vectorize and to present.

❼ *Vectorizing of the resulting image* on account of transfering it into GIS and making it available to broader range of users.

❽ *Performing class statistics*, comparison of resulting data derived from different years, accuracy assessment and further analyses.

The supervised classification resulted in nine classes: open water; wet areas; dwarf pine polygons; *Nardus* dominated stands (alliance *Nardo-Caricion rigidae*); higher vegetation (tall-grass and herbs communities of *Calamagrostion villosae* alliance); ecotone effect (altered vegetation along the roads); paved roads; walking trails and unclassified pixels. The study is in preliminary stage; therefore the final results cannot be presented here. The vegetation analysis so far showed clear evidence of growing extension of road affected area over time. The „ecotone effect“ can easily be recognized on multispectral images, and its extend agrees with the GPS ground measurements done by BRANIŠ et al. in 1997-1998, with the first method far less time consuming than the second.

The use of aerial photography (i. e., analogous data) converted into digital form causes technical problems related to rectification (e.g., fitting channels together), radiometric and geometric correction with often unknown parameters, differences in exposure, light adjustment etc. (BAKER et al. 1995). On the other hand, digital analysis of these photographs provide unique enhancements, facilitates the correction of differences in viewing geometry and statistical analysis, make printing and presentation of results easier and provide other functions, which would be more difficult with manual techniques (POPE et al. 1996). Its great advantage over the satellite imagery is the high spatial resolution, indispensable for detailed vegetation studies (BAKER et al. 1995). Furthermore, historical data sets covering the entire country since the 1950s are available (from the archive of the Military Institute of Topography in Dobruška) and aerial data are relatively inexpensive to obtain in the Czech Republic. Use of satellite and aerial data for the vegetation mapping in tundra environment has been compared in the study of Mosbech et HANSEN (1994).

Remote sensing has many advantages as well as disadvantages over other methods. One has to understand what to expect from such a method, what is possible to detect and in which detail. Vegetation in remotely sensed images is described as a continuum rather then as distinct classes. Owing to this fact our effort to classify pixels into few definite classes can lead to mistakes and confusion. The images contain complex of information about the whole stand rather then detailed information about individual plants, therefore it is not usually possible to describe the vegetation by classic plant communities (according to the Braun-Blanquet´s conception), but more by a particular dominant species, so-called vegetation mapping units (FRANK 1988, FRANKLIN 1994).

I would like to thank the Krkonoše National Park authorities, Jan ŠTURSA, Dana FIŠEROVÁ and Ondra VÍTEK for help and providing the data, to Birger HANSEN and his team at Copenhagen for the chips software and a guidance, and also to my colleges Lenka PAPÁÈKOVÁ and many others for help and support. The research was partly supported by grant GA CR 206/98/0727. Thanks a lot.

References

BAKER, W.L., J.J. HONAKER, et P.J. WEISBERG, 1995: Using aerial photography and GIS to map the forest-tundra ecotone in Rocky Mountain NP, Colorado, for global change research. *Photogrammetric Engineering and Remote Sensing* 61(3), 313-32.

BRANIŠ, M., M. KRATINOVÁ, et O. VÍTEK, 1997: Study of tourist trail ecotone impact on biodiversity of Krkonoše alpine zone. Ms. (Final Project Report, Depon. in Faculty of Sciences, Charles University, Prague in Czech).

CAMPBELL, J.B., 1987: *Introduction to the remote sensing*.- The Guilford Press, New York, London.

CIHLAR, J., H. LY, et Q. XIAO, 1996: Land cover classification with AVHRR multichannel composites in northern environments. *Remote Sensing of Environment* 58, 36-51.

CRAWFORD, R.M.M. [ed.], 1997: *Disturbance and recovery of arctic lands*. Kluwer Academic Publ., The Netherlands.

FIŠEROVÁ, D., 1992: Map of actual vegetation of the area River Elbe Spring-Violík. Ms. (Report, Depon. in Agency for Nature Conservation and Landscape Protection of the Czech Republic, Prague in Czech).

FLOUSEK, J., 1994: Krkonoše/Karkonosze Bilateral Biosphere Reserve. In: Jeník, J. et M. F. Price [eds.], *Biosphere Reserves on the crossroads of Central Europe*, MAB, Prague, 17-32.

FRANK, T.D., 1988: Mapping dominant vegetation communities in the Colorado Rocky Mt. Front Range with Landsat TM and digital terrain data. *Photogrammetric Engineering and Remote Sensing* 54 (12), 1727-1734.

FRANKLIN, S.E., D.R. CONNERY, et J.A. WILLIAMS, 1994: Classification of alpine vegetation using Landsat Thematic Mapper, Spot HRV and DEM data. *Canadian Journal of Remote* 20(1), 49-56.

HUSÁKOVÁ, J, 1986: Subalpine turf communities with *Deschampsia cespitosa* along the tracks and paths in the Krkonoše (Giant Mts.) National Park.- Preslia, Prague, 58:231-246.

JENÍK, J., 1961: *Alpine vegetation of Krkonoše, Králický Snì?ník and Hrubý Jeseník Mts*. ÈSAV, Prague (in Czech with German summary).

JENÍK, J. et T. LOKVENC, 1964: *Die Alpine Waldgrenze im Krkonoše Gebirge*. Rozpravy Ès. akademie vìd, Prague, 72/1.

JENÍK, J. et J. SEKYRA, 1995: The concept of arctic-alpine tundra.- In: Soukupová, L. et al. [eds.], Arctic-alpine tundra in the Krkonoše, the Sudetes. *Opera corcontica*, Prague, 32, 6-13.

JENSEN, J.R, 1986: *Introductory digital image processing - a remote sensing perspective*. Prentice-Hall, Englewood Cliffs.

JORIA, P.E. et J.C. JORGENSON, 1996: Comparison of three methods for mapping tundra with Landsat digital data. *Photogrammetric Engineering and Remote Sensing* 62(2), 163-169.

MÁLKOVÁ, J. et A. KÙLOVÁ, 1995: Impact of dolomitic limestone on changes of species diversity of the eastern Krkonoše Mts. *Opera corcontica*, Prague, 32, 115-130 (in Czech with English summary).

MÁLKOVÁ, J. et Z. WAGNEROVÁ, 1995: Man-induced changes of arctic-alpine tundra.- In: SOUKUPOVÁ, L. et al. [eds.]: Arctic-alpine tundra in the Krkonoše, the Sudetes, *Opera corcontica* 32, 68-70.

MORAVEC, J. et al,1995: Plant communities of the Czech Republic and their endangerment. Severoèeskou pøírodou, Litomìnice (in Czech with English conclusions).

MOSBECH, A. et B.U. HANSEN, 1994: Comparison of satellite imagery and infrared aerial photography as vegetation mapping methods in an arctic study area; Jameson Land, East Greenland. *Polar Research* 13, 139-152.

POPE, P., E.VAN EECKHOUT, et C. ROFER, 1996: Waste site characterization through digital analysis of historical aerial photography. *Photogrammetric Engineering & Remote Sensing* 62(12), 1387-1394.

REYNOLDS, J.F. et J.D. TENHUNEN, 1996: *Landscape function and disturbance in arctic tundra.- Ecological studies*, Springer-Verlag, 120.

SOUKUPOVÁ, L., M. KOCIÁNOVÁ, , J. JENÍK, et J. SEKYRA [eds.], 1995: Arctic-alpine tundra in the Krkonoše, the Sudetes. *Opera corcontica*, Prague, 32, 5-88.

SPJELKAVIK, S., 1995: A satellite based map compared to a traditional vegetation map of Arctic vegetation in the Ny-Aalesund area, Svaldbard. *Polar Record* 31(177), 257-269.

TIMONEY, K.P., G.H. LA ROI, , S.C. ZOLTAI, et A.L. ROBINSON, 1992: The high subarctic forest-tundra of northwestern Canada: position, width, and vegetation gradients in relation to climate. *Arctic* (1), 1-9.