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Chapter 18

Effect of Climate Change on Mountain Pine Distribution in Western Tatra Mountains

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Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/54724

1. Introduction

1.1. Climate change in the high mountains

The world is experiencing a period of climate change, which is very frequently discussed on both local and global levels. The growth in the global mean surface temperature by 0,74 °C ± 0,18 °C, over the last 100 years (1906-2005) is probably related to greenhouse gas emissions and further warming will cause many changes in the global climate system during the 21st century (IPCC, 2007). These changes will affect both the abiotic and biotic conditions of the environment.

High mountains ecosystems represent unique areas for the detection of climate change and the assessment of climate-related impacts (Beniston, 2003). Climate change associated with global warming at higher elevations is more pronounced than at low elevations (Beniston & Rebetez, 1996; Giorgi et al., 1997; Diaz & Bradley, 1997). The effect of elevation on surface warming is especially marked in the winter and spring seasons, since it is mostly associated with a decrease in snowpack and is thus enhanced by the snow–albedo feedback (Giorgi et al., 1997). The main ecological driving force is climate, with temperature and the duration of the snow cover as key factors (Gottfried et al., 1999). Changes in air temperature can extend the length of the average annual growing season (Menzel & Fabian, 1999) and can also cause a shift in phenology (Parmesan & Yohe, 2003; Visser & Both, 2005).

1.2. Climate change effect on high mountain ecosystems

Climate change is an important driving force on natural systems (Parmesan & Yohe, 2003). Many studies show that high mountain ecosystems are vulnerable to climate change (e.g. Theurillat & Guisan, 2001; Dullinger et al., 2003a, 2003b; Dirnböck et al., 2011). Global climate change resulting in warmer climate may cause a variety of risks to mountain

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habitats (Beniston, 2003). Climate change mainly affects the distribution of plant and animal communities (Beckage et al., 2008) and under the expected climate scenarios in the final perspective results in the loss of rare species of alpine habitats (Dirnböck et al., 2011). In the global meta-analyses from Parmesan & Yohe (2003) and Root et al. (2003) significant range shifts toward the poles or toward higher altitudes for many organisms were documented. Large part of these changes may be attributed to increased global temperatures.

In general terms, we expected that climate related changes in mountain ecosystems will be most pronounced in the "ecoclines" (boundary ecosystem), or Ecotones (Theurillat & Guisan, 2001). Distribution of endemic mountain species is typically severely restricted as a spatial response in mountain areas, however, because of mountain topography (Huntley & Baxter, 2002) and, often, the availability of suitable soils (Theurillat et al., 1998). The upper forest limit is commonly referred to as tree line. Timberline or forest line represents one of the most obvious vegetation boundaries (ecoclines). In reality the transition from the uppermost closed montane forests to the treeless alpine vegetation is commonly not a line, but a steep gradient of increasing stand fragmentation and stuntedness, often called the tree line ecotone or the tree line park land (Körner & Paulsen, 2004).

1.3. Climate change-induced shift of ecosystem boundaries

Scenarios of upward plant species and vegetation shifts are widely discussed in many current research articles. Theurillat & Guisan (2001) released a review discussing this matter concluding that although the alpine vegetation can tolerate an increase of 1-2 °C of average air temperature, in the case of a sharper increase we can expect major changes. Loss of diversity of the alpine communities and fragmentation of plant populations caused by climate warming is expected for comparable high mountains around the world (Grabherr et al, 1995; Sætersdal et al., 1998).

Results from Dirnböck et al. (2003) support the hypothesis, that alpine plant species above the forest line will be affected by heavy fragmentation and habitat loss, but only if the average annual temperature increases by 2 °C or more. Most of these lost alpine plant species habitats are expected to be caused by the expansion of *P. mugo* in the Alpine zone. The coniferous forest zone has a general tendency to expand to higher elevations (Mihai et al., 2007; Sitko & Troll, 2008). Nicolussi & Patzelt (2006) describe the alpine timberline zone as very sensitive to climate variability. The rise of temperatures during the vegetation period over long periods also induces a rise of the tree line, with higher forest stand density. The tree line is considered to be primarily by temperature controlled, so increases in temperature should result in their upslope expansion (Moen, 2006). Growth and fertility of *Pinus mugo* is mostly controlled by temperature (Dullinger et al., 2004). Thus the main limiting factor of *Pinus mugo* growth at high altitude could be the soil temperature (Smith et al., 2003) although Rossi et al. (2007) refers to varying soil temperature thresholds at different sites, indicating that soil temperature may not be the main factor limiting xylogenesis of conifers and provides strong evidence that air temperature is a critical factor limiting xylem cell production and differentiation at high altitudes. However, the air

temperature alone may not be the dominant factor determining tree line position, because the direct influence of temperature may be masked by interactions with other factors such as precipitation, cold-induced photoinhibition, disturbance or plant - plant interactions (Harsch, 2009). This evidence is therefore in conclusive. Differences in expert opinions on this matter have lead Smith et al. (2009) to formulate six current hypotheses of the causes of upper tree limit movement: climatic stress, mechanical disturbance, insufficient carbon balance, limitations of the cell growth and tissue formation, limited nutrient supply, and limited regeneration. In the global meta-analyses from Parmesan & Yohe (2003) and Root et al. (2003) significant range shifts toward the poles or toward higher altitudes for many organisms were documented. Large part of these changes may be attributed to increased global temperatures. The expansion of tree line forming species (sub-alpine zone) to higher altitudes is evident in the Pyrenees (Camarero & Gutiérrez, 2004; Peñuelas et al., 2007), in the Alps (Dullinger et al., 2003a, 2003b; Gehrig-Fasel et al., 2007; Vittoz et al., 2008), in the Carpathians (Martazinova et al., 2009; Mihai et al. 2007; Švajda et al., 2011), Sweden (Kullman, 2002), Caucasus (Akatov, 2009) but also in Patagonia (Daniels & Veblen, 2004) and Himalaya (Song et al., 2004; Becker et al., 2007).

Lapin et al. (2005) detected climate changes in the Slovak mountains. The results showed a significant increase in temperature and a decrease in relative humidity in the April to August season after 1990. From 1901–2005, air temperature increased (annual mean) moderately and precipitation decreased (Melo, 2007). This trend of warming is expected to continue in the Slovak mountains. By 2075 the annual average air temperature in Slovakia is expected to increase by 2-4 ° C (with greater warming expected in the winter) and more significant effects of increasing temperatures is expected at the higher altitudes (Mindáš & Škvarenina, 2003). Generally, climate conditions and land use in high mountain areas have been shown to influence the distribution of mountain pine. Since 1965 the ban on grazing in the High Tatras has not yet been raised. This study assesses a potential scenario after the grazing in Tatra Mountains will have been resumed. The potential model of timberline is based on the assumption that climate change as a factor in forest regeneration is primarily responsible for moving the upper limit of the natural forest above the original climatically determined timberline, while the abandonment of farming in the country should be the dominant factor determining forest regeneration below this line.

2. Study area

2.1. Description of study area

The Tatra Mountains are situated at the Slovak–Polish border (20°10′E, 49°10′N) and constitute the highest mountain massif within the Carpathian Range of Central Europe. The highest summit reaches 2656 m; the massif is classified as a high-mountain landscape covered by subalpine and alpine zones.

The study area (Figure 1) is situated in the western Tatra Mountains. The geology of the investigated area is based on crystalline bedrock. The western Tatra Mountains contain a significant amount of metamorphics (gneiss and mica schist), in addition to granodiorite

(Nemčok et al., 1993). The vegetation of the alpine zone is dominated by alpine meadows (dry tundra with mostly *Festuca picturata*, *Luzula alpino-pilos*a, *Calamagrostis villosa*, and *Juncus trifidus*), with patches of dwarf pine (*Pinus mugo*) and an increasing percentage of rocks (bare or covered with lichens—commonly *Rhizocarpon*, *Acarospora oxytona*, and *Dermatocarpon luridum*) above the upper tree line of 1800 masl (Vološčuk, 1994).

The average annual air temperature decreases with elevation by 0.6°C per 100 m, being 1.6 and 23.8°C at elevations of 1778 and 2635 m, respectively (Konček & Orlicz, 1974). The amount of precipitation increases with elevation, varying from ~1.0 to ~1.6 m yr^{-1} between 1330 and 2635 masl but reaching >2.00 m yr^{-1} 21 in some valleys (Chomitz & Šamaj, 1974). Precipitation is generally higher in the northern part than in the southern part of the mountains, as is runoff, which averages 1.42 and 1.57 m yr^{-1} for the south and north, respectively (Lajczak, 1996). Snow cover usually lasts from October to June at elevations > 2000 masl.

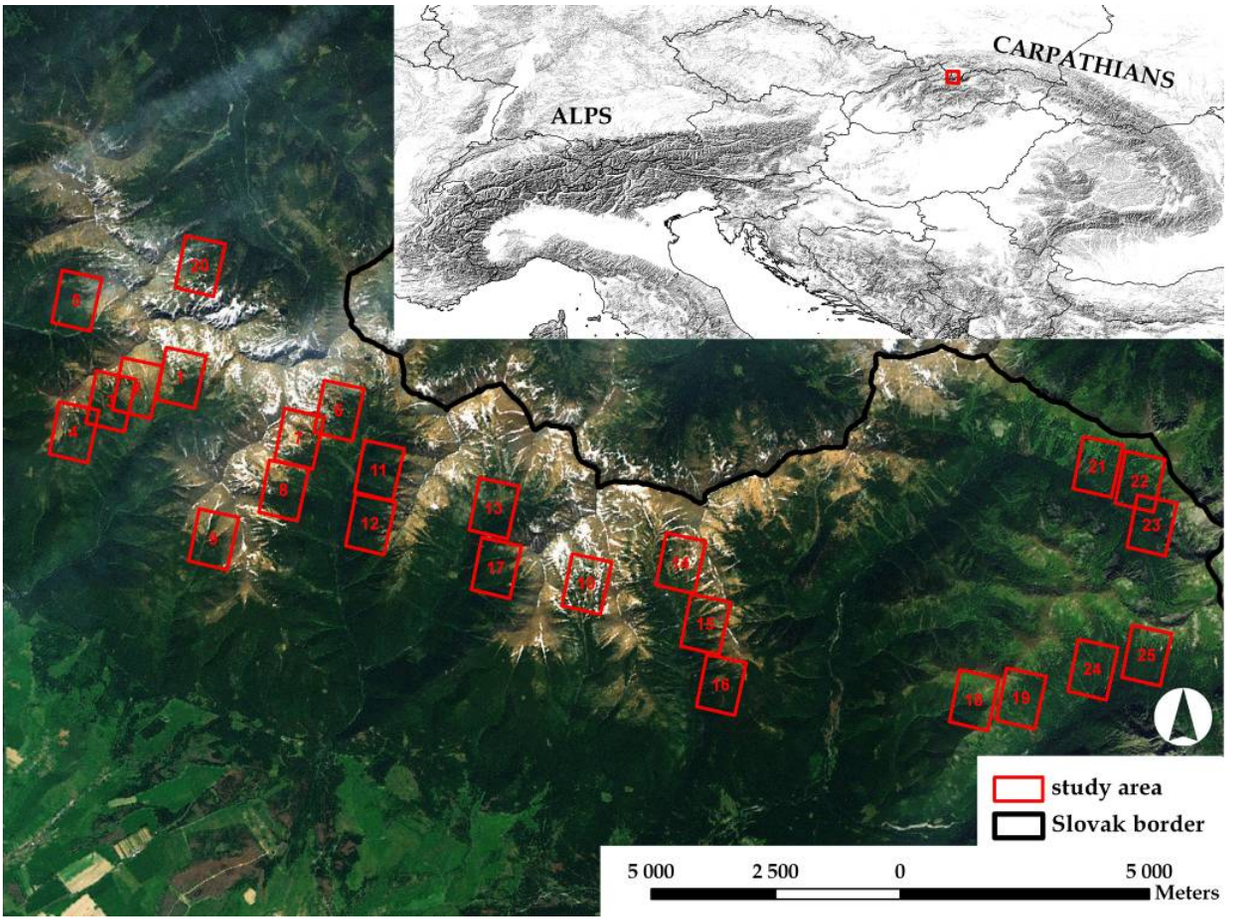


Figure 1. Western Tatra Mountains in Slovakia and detailed view of the 25 sites in the study area (from west to east: Roháče, Baníkov, Baranec, Bystrá, Jamnická, Račkova, Kamenistá, Tichá, Kôprová, and Špania valleys). (Map by Jaroslav Solár)

The relationship between climate conditions of the environment (microclimate and vertical climate) and phytocenoses is expressed at different altitudinal zones in the forest. Constant climate conditions definitively influenced the natural distribution of forest species from the

sub-Atlantic period (around 2000 years ago), when the current altitudinal zones were formed. Significant changes of forest stratification were caused by the intense human activity since the 13th century. Ecologically, forest altitudinal zones represent vertical classification of vegetation. Horizontal classification is determined by growth condition of forest societies, differentiated especially according to soil conditions, ecological rows, interrows, and hydric files of forest type groups. The climate-driven tree line in the Tatra Mountains is located around 1550 masl and partly includes natural ecotones with individual conifers reaching ages of 350–450 years (Büntgen et al., 2007).

P. mugo is an obligatory prostrate pine with adult canopy height varying between 0.3 and 2.5 m in the study area. The typical dwarf pine altitudinal (subalpine) zone extends from 1500 to between 1850 and 1900 masl. Mountain pine zone developed especially in the western Tatras with glacial-meadow relief, with great antierosion and water retention potential. Closed mountain-pine thickets stretch up to 300 m above the timberline, reaching approximately 1600–1750 masl in the Tatras and encompassing the upper part of the forest alpine tundra ecotone. Mountain pine plays a significant role in the natural environment: it protects the soil and stabilizes the snow cover, thus restricting the release of avalanches, and it provides habitat for many species of flora and fauna (Jodłowski, 2006).

2.2. Climate change in study area

On slovakia in the period 1881-2007 was increase of annual temperature in 1,6°C and annual precipitation decrease in 24 mm (Lapin et al., 2009). The temperature series show an upward trend in all seasons, especially in the spring (Melo et al., 2009). Over the past 20 years, it seems much warmer and especially in the months of January to August (Faško et al., 2008). Warming scenarios based on applied GCM (General Circulation Model) for Slovakia represent the increase in average annual temperature of 2-4 °C until the end of the 21st century (Melo et al., 2009). The climate in the Slovak mountain region is thus becoming warmer. Figure 2 shows a general trend that could partially explain the dynamics of the vegetation zones.

Winter precipitation in the high-mountain positions of Slovakia is abundant and increases with altitude. (Ostrožlík, 2008, 2010). Sensitivity of snow cover will vary depending on the climate and altitude. Also sensitivity causes maritime climates and less continental climate of cold and dry winters, where precipitations play an important role in the variability of snow cover duration. (Brown & Mote, 2009). The Tatra Mountain have significanly more snow cover days on the northern slopes. More over the less windy and forested areas have higher and longer snow cover as well. (Lapin et al., 2007). Snow cover duration on the northern slopes is critical in altitude of about 1800 m and on the southern slopes of about 2300 m. In this altitudinal level in Tatra mountain should be zone, above which would not even occur to the loss of snow cover duration. (Vojtek et al., 2003). It seems that variability and trends in snow cover characteristics are influenced both by air temperature and precipitation variability. This influence depends significantly on the altitude and local topography conditions. Increase of air temperature by about 1,2 °C and change of

precipitation totals from -10% to -20% in the November-April season are the main reasons of obtained trends (Lapin et al., 2007).

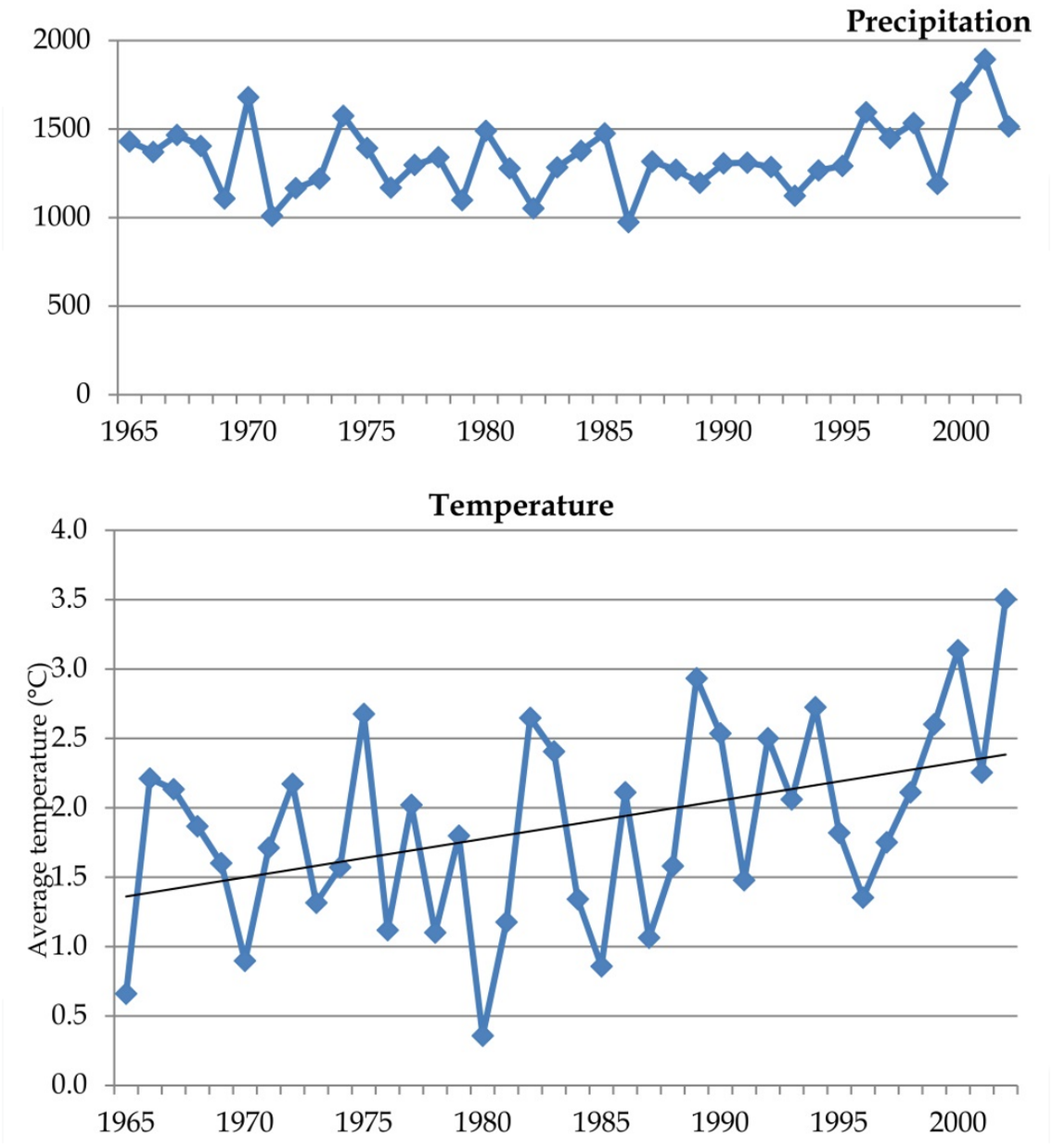


Figure 2. Trends in annual average temperature (in degrees Celsius) and annual total precipitation (in millimeters) from 1965 to 2002 at the meteorological station of Skalnate´ pleso (1751 masl), Slovak Institute of Hydrometeorology (Švajda et al., 2011).

3. Material and research methods

3.1. Theoretical aspects

Changes in landscape can be well observed through remote sensing (RS). RS data (images, aerial photographs, etc.) are further processed and analyzed using Geographic Information

Systems (GIS). Progressive development of geo-information technologies offer new approaches to the use of remote sensing in GIS. GIS is very useful for its ability to incorporate the complexity of spatial data in to the various models. Remote-sensing based analysis is particularly useful in mountainous areas where the topography is complex and different environmental gradients require special attention to the spatial patterns (Heywood et al., 1994). Although high mountain environments show a high degree of heterogeneity, we can obtain satisfactory results using the appropriate approaches and high-quality materials. Changes in the natural spatial (morphological, bioenergetical) features can be identified in remote sensing images (Feranec et al., 1997). Using GIS applied approach let us identify the most significant variables and phenomena which affect the natural environment components.

Approach of remote sensing and suitability of this method in detecting of lanscape changes in mountain regions of Slovakia was confirmed in the works: Boltižiar, (2001, 2002, 2003, 2004, 2006, 2007); Čerňanský & Kožuch, (2001); Hreško & Boltižiar, (2001); Kohút, (2006); Olah et al., (2006); Falťan & Saksa, (2007); Olah & Boltižiar, (2009). However, this approach can be difficult in countries with politically sensitive situation, where the products of remote sensing are subject to various degrees of secrecy (Heywood et al., 1994). We have come across some other problems arise in relation to data quality and its precision of position placement, which takes into account the high diversity of the relief. Advantage of access interpolation of aerial imagery lies in the fact, that we can carry out their research in a relatively short time. Especially aerial photographs provides a large amount of quantitative and qualitative information about the landscape structure and are particularly important in high mountain areas, where field research is difficult (Boltižiar, 2009).

This study is based on results published in the original study by Švajda, Solár, Janiga & Buliak „Dwarf Pine (*Pinus mugo*) and Selected Abiotic Habitat Conditions in the Western Tatra Mountains“ in journal Mountain Research and Development 31/3 in year 2011. The present analysis was carried out using GIS (ArcGIS 9.3), based on aerial photographs from 1965, 1986 and 2003. The aim of the analysis was to verify the temporal trends in the distribution of *Pinus mugo* and to investigate which environmental variables best explain the changes in the growth and distribution of the mountain pine. The applied modelling approach is based on three major assumptions: (1) The abiotic factors are assumed to be the major driving force of species distribution changes, as well as the post-grazing succession. (2) The models are calibrated using field data, and thus comprise any competitive constraint a species may force upon or experience from its neighbour. (3) The speed of plant migration is consistent with that of climate change so that plant communities are in a permanent equilibrium with their environment (Dirnböck et al., 2003).

3.2. Materials and data processing

Aerial images from 2002 were acquired and georeferenced by Eurosense Ltd. and Geodis Slovakia on the basis of contour lines at a scale 1:10,000 (digital elevation model); we georeferenced aerial photographs from 1986 and 1965 on the basis of orthophotos (Table 1).

Year	Source	Type	Resolution	Width	Height	Format
2002	Eurosense Slovakia	Orthophoto	RBG 72 DPI	2500	2000	.jpg
1986	Topographical Institute	Aerial photo	Gray 2400 DPI	21.829	21.924	.tiff
1965	Knazovicky	Aerial photo	Gray 300 DPI	2164	2175	.jpg
DPI. dots per inch; RBG. red green blue.						

Table 1. Quality and resolution of data features (aerial imagery) (Švajda et al., 2011).

Mountain pine fields were extracted from the aerial photos in gray scale and than reclassified into gray scale range representing mountain pine occurrence in the study area. Each photo was examined individually. If mountain pine on the slide was gray, with a value from 75 to 110, all such values in the range were reclassified as 1. The remaining values from 0 to 75 and 110 to 256 were reclassified as 0. We created a grid where each pixel contained either the value 1 or the value 0. Then the grid was automatically vectorized on the basis of the 2 values.

Habitat conditions were spatially simulated using GIS, digital terrain model, meteorological data and existing maps. In addition we analyzed historical records in order to derive information about past land-use changes. The most significant factors explaining the presence of *Pinus mugo* according to Dirnböck et al., (2003) are the daily temperature, followed by slope, geology, solar radiation in September and duration of snow cover.

To test this hypothesis it was necessary to create an explicit temporal and spatial explicit model of the spread of mountain pine and analyze their sensitivity to predicted climate change trends. Histogram transformation was not carried out due to the misrepresentation of values. The size of the pixels' (cell) grid was equivalentin all RS images, because each image was adjusted to the same size cell size through the transformation of the grid, as well as during georeferencing. Thus all images and the grids had the same pixels (Figure 3).

Selection of the appropriate areas, which represented 25 localities from the study area, and analysis of imagery were realized in ArcGIS 9.2. Differences in the *P. mugo* surface cover between the 2 periods were calculated using Statistica 8.

The increments in dwarf pine were reported as means and standard deviations for potential comparison with other studies, but the values showed a highly skewed distribution in most sample groups. Therefore, a nonparametric approach to the analysis of the data was necessary. The significance of difference between groups was tested using the Kruskal–Wallis nonparametric test. When P , 0.05, the data were considered as significantly different. A digital elevation model of the study area was used for the representation of a selected abiotic habitat conditions. A single matrix was analyzed. GIS intersection of study sites with 3 parameters (slope, aspect, and height masl) has divided the studied sites into 325 smaller areas with unique characteristics related to pine increase. Two sites (nos. 5 and 9; Table 2) were excluded due to lack of data from 1986.

The principal component analysis (PCA)–correlation matrix, a multivariate technique was used to extract the potential relationships between the studied variables. Principal components are linear combinations of original variables (slope, height masl, and relative increase of pine during observed periods), each axis being statistically orthogonal to the others. Integration of the variables slope and elevation m asl in different periods enabled us to follow different processes of mountain colonization by mountain pine during the respective periods. Since this statisticale technique produces statistically orthogonal axes, we were able to examine potentially independent biological phenomena. We used 4 variables; consequently, we evaluated 4 principal components. The proportions of the total variance accounted for by each component are shown in Table 3 (see results).

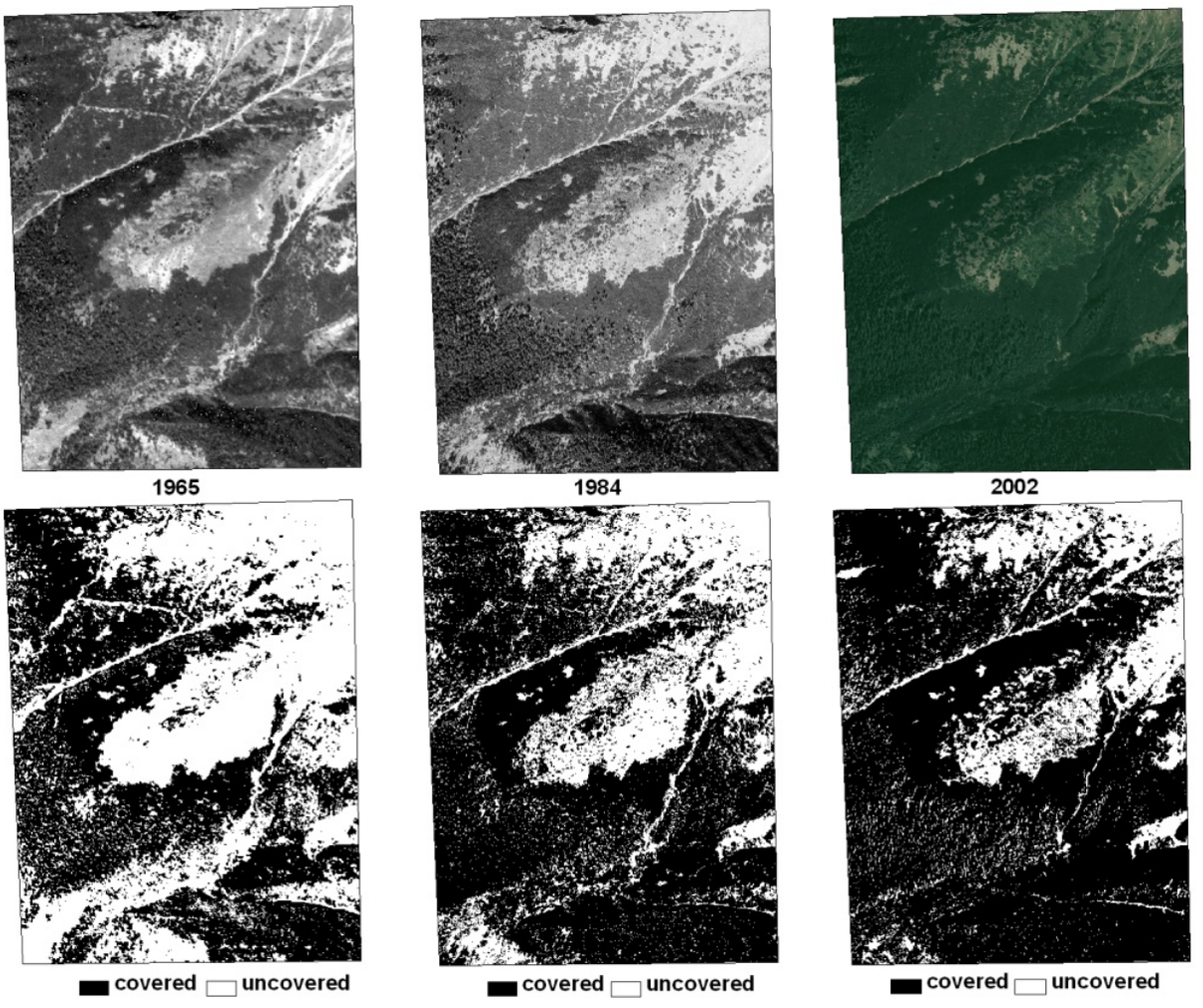


Figure 3. Example of the comparison between aerial photographs: changes between 1965, 1986, and 2002 in 1 analyzed valley (Site 17, Račková valley; Figure 1).

Site number	Average altitude (masl)	Average slope (%)	Covered with *Plnus* (%)	Difference (+/-)
1	1674	34	27	+1/+20
2	1670	46	7	+9/+11
3	1614	44	29	+9/+23
4	1675	36	24	+31/+41
5 (excluded)	1686	42	—	—
6	1614	33	35	+8/+-10
7	1733	28	28	+4/+9
8	1604	40	53	+11/+13
9 (excluded)	1807	34	—	—
10	1825	22	16	+6/+16
11	1511	47	61	+14/+14
12	1533	43	68	+12A16
13	1493	33	47	+8/+10
14	1684	40	19	+4/+12
15	1617	46	21	+11/+13
16	1561	43	62	+3/+10
17	1640	45	48	+18/+28
18	1777	35	34	+6/+11
19	1595	55	45	+10/+12
20	1627	30	42	+6/+23
21	1449	33	49	+21/+20
22	1632	45	42	+11/+31
23	1599	36	68	+11/+20
24	1428	31	59	+20/+16
25	1533	38	65	-2/+2

Table 2. Overview of evaluated sites with different *P. mugo* cover in the period.

4. Results

4.1. Surface cover of mountain pine

Mountain pine cover in the western Tatra Mountains in the period 1965–2002 permanently increased at all observed sites. The total surface area covered by mountain pine increased from 8,173,812 m^2 in 1965 to 10,141,505 m^2 in 1986 and 11,394,461 m^2 in 2002. The percentage of total surface area covered thus increased from 41.8% in 1965 to 51.8% in 1986 and 58.2% in 2002. Only in one case (No. 25) surface area covered by dwarf pine decreased. In two cases (No 21 and 24) the area decreased in the first, and increased in the second period (Table 2, Figure 4). This was probably due to the influence by human activities or avalanches.

The results also indicate that the mean increase of mountain pine surface cover was in all periods about 0.4 percent per year (0.42% first period, 0.40% second period) from the total surface area but results in relation to selected abiotic conditions still showed some differences.

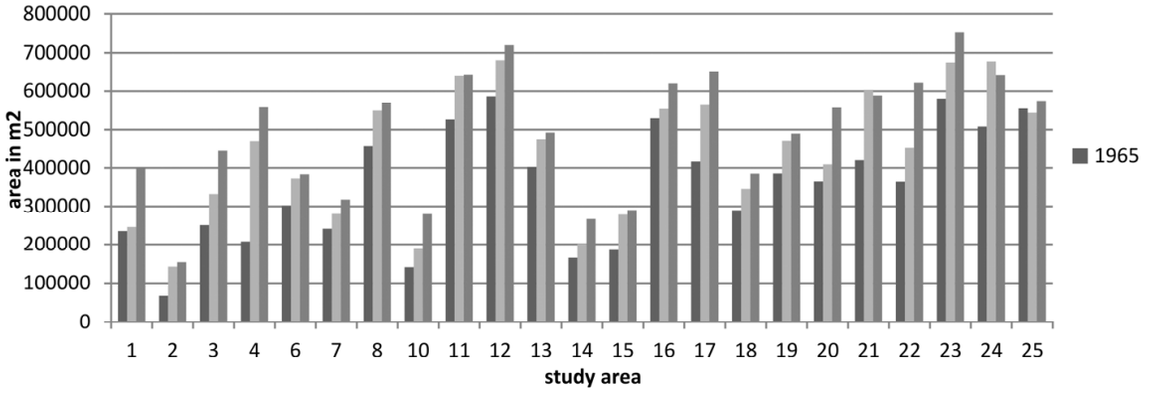


Figure 4. Comparison of area covered with *P. mugo* (23 sites) in 1965, 1986, and 2002, in square meters (Švajda et al., 2011).

4.2. Expansion of mountain pine growth

From 1965 to 1986, mountain pine showed a rapid expansion in surface cover at the lower elevations (Table 3 – PC1, Figure 5A). This could be observed as thickening of mountain pine cover at lower elevations, indicating that the mountain pine is able to recolonize sites of previous occurrence.

Variable	PCI	PC2	PC3	PC4
Slope	0.51	-0.64	-0.50	0.26
Elevation	-0.71	0.11	-0.63	-0.27
Pine increment (1965-1986)	0.73	0.14	-0.10	-0.64
Pine increment (1986-2002)	-0.38	-0.78	0.30	-0.37
Variability (%)	36.5	26.8	18.9	17.8

PC. principal component.

Table 3. Component vectors (loadings) and percent variance associated with the components indicating the pattern of natural reforestation with dwarf pine in the Tatra Mountains (n 5 325; snaps from aerial photographs) (Švajda et al., 2011).

In the period from 1986 to 2002, pine grew rapidly on steeper slopes (Table 3 – PC2), mainly at elevations from 1500 to 1700 masl (Figure 5B). During the first analyzed period, mountain pine was able to concentrate to such a level at elevations between 1300–1400 m a.s.l. that in the following period it completely covered this zone and further increments were minimal.

The third factor (Table 3 - PC3) is less important for the explanation of the historical pine increments: it shows a positive relation between slope and elevation. PC4 (Table 3) is a

unipolar vector indicating that mountain pine grew more rapidly in the earlier period (1965–1986) than later (1986–2002).

In the earlier period mountain pine grew intensely at all locations (Figure 5C) whereas in the period 1986–2002 it mainly preferred northwest and northeast aspects on steeper slopes, probably the most suitable locations for plant development in the Tatra Mountains. These sites might have more favorable conditions for the growth of the mountain pine due to changes in climate in terms of higher surface temperature of environment.

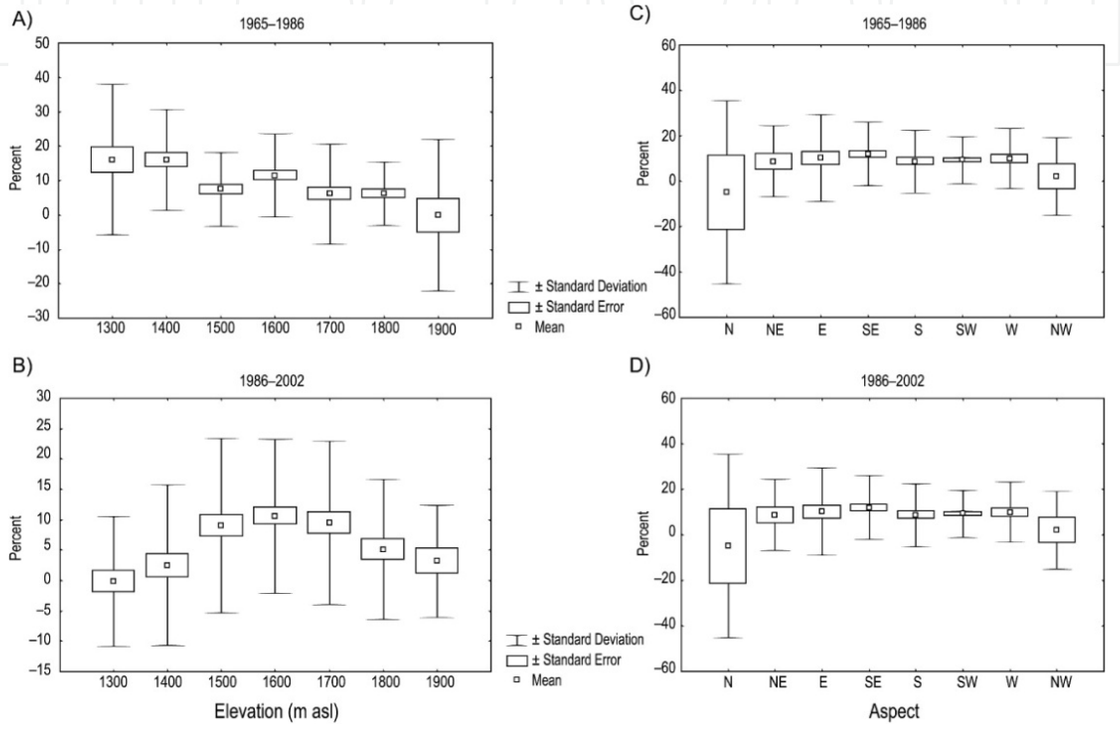


Figure 5. Increments in dwarf pine cover in the western Tatra Mountains in the periods 1965–1986 and 1986–2002, according to (A and B) elevation and (C and D) aspect. In the earlier period, the groups did not differ according to aspect. (C) Kruskal–Wallis nonparametric test at $p = 0.05$. (D) In the period 1986–2002, the following aspects differed significantly: N:NE, N:SW, NE:W, NE:S, NE:SE, SE:SW, S:SW, and SW:W (Švajda et al., 2011).

In both periods, the increments in the areas covered by mountain pine were very low at the elevation of 1900 m, reflecting its natural upper line of occurrence. In the earlier monitored period the increments at 1900 m were 0%, whereas between 1986 and 2002 they were approximately 3% (Figures 5A, 4B). The trend is probably associated with climate warming in the region. Changed enviromental conditions caused by climate change promote the expansion of mountain pine and favour it in competition against alpine meadow communities.

5. Discussion

The interaction of individual components of the environment is an ongoing process. The result of this interaction as seen in our results, show an apparent shift of mountain pine to

higher altitudes. The expansion of mountain pine was confirmed by remote sensing. The precision of our results was limited by the fact that we performed a very fast automatic extraction of mountain pine fields. However, this analysis was repeated several times in order to avoid any errors during the extraction of mountain pine fields. We also recorded other factors which might affect the results of the distribution and growth of dwarf pine. This mainly relates to landslides, avlanches, snow cover and shadows from clouds or hills on the air photographs. Generally, a place where we have identified these problems, we excluded from the assessment in all of times periods. Due to aim of this study was not to highlight the processes that operate in the opposite direction to the expansion of mountain pine, so we did not dealt with this problem more. We had some problems in the lower parts of fields where the scrub of mountain pine interleaved with spruce forest. Analysis of this border and its response to climate change would be also interesting. We can assume, that spruce forest has pushed the lower limit of mountain pine to the higher altitudes (Mihai et al., 2007). But this process is slower than the expansion of mountain pine due to problems with the successful survival of spruce seedlings and seed production (Dullinger et al., 2005). Evidence of spruce forest move to higher altitudes was shown by Mihai et al. (2007) in the Southern Carpathians of Romania. In comparison to spruce stands the mountain pine cover in our study represented comparatively homogeneous areas easy to extract in our aerial images.

Similarly to other high mountains also the Carpathians show a trend of climate change and possibly the shift of vegetation types with altitude. Expected changes in tree line boundaries are evident in Carpathians but also other mountain ranges around the world, which could present a threat to the habitats of many rare species in the future. Over the last 50 years, summer temperatures in the Tatra Mountains summer temperatures have increased by 0.7 ° C at higher elevations, and 1.4 ° C at lower elevations. Winter temperatures have increased by 1.4 ° C at higher elevations, and 1.9 ° C at lower elevations (Melo, 2005). The temperature limit of the mountain pine zone is determined by the bio-temperature threshold in the range of 3.0 to 2.0 ° C (°C Max - Min ° C) (Miňdáš & Škvarenina, 2003). Considering the rate of current temperature changes (2-3 °C for 100 years) we can expect more turmoil changes to the growth within a single generation of woody plants. According to Miňdáš et al. (1996) a model scenario expects a complete extinction of conditions for alpine communities and their replacement by bioclimatic conditions for sub-alpine forest. The occurrence of mountain pine is subject to extreme habitat conditions, including soil. Mountain pine is a strongly heliophilic shrub. The most important factor of habitat which has a decisive role in the expansion of mountain pine is the light intensity. The spreading of mountain pine is conditioned mainly by altitude, slope, moisture conditions, but also the horizontal and vertical slope curvature. This can be seen in the fact that the mountain pine is spreading up along the ridges.

Minďáš et al. (2004) predict the following changes in an area of mountain pine zone timberline: (1) an increase in the abundance of tree species, (2) dominant representation of spruce, (3) a decrease of dwarf pine, and (4) an increase of general production and biomass of about 200–300%. These changes could also be contributed by the changes in phenological phases, which reflect the changing climate condtions. The onset of individual phenological stages and their proceeding is mainly influenced by air temperature, as well as temperature

and humidity of soil and other meteorological variables (Škvareninová, 2009). Development of climate can to some extent affect phenological trends (Bauer 2006; Škvareninová, 2008) and identyfying these relationships can help us use trees as bio-climatic indicators of climate change (Škvareninová, 2009). At high altitudes the vegetation is under constant environmental stress and thus abiotic conditions become more important for the community development than biotic relationships (Pauli et al., 1996).

The main results of our case study confirm the results of previous research on mountain vegetation zones in the Slovak Tatras. Boltižiar (2007) analyzed spatiotemporal landscape structure change in the alpine environment of the Tatra Mountains. The landscape structure in 1949 in the study area was dominated by grassland, which resulted mainly from human activity. Statistical analysis of thematic maps from 2003 suggests extension of mountain pine cover, advance of forest, and reduction of grassland areas. Martazinova et al. (2009) conducted research on grasslands above the upper forest limit in the Ukrainian Carpathians. Grass cover significantly decreased in the sites whit conifer presence. Spruce stands mainly on the northern slopes moved to higher altitudes, while the beech stands in the same area on the southern slopes did not show any significant movement. Apparently the greatest changes were recorded at those sites where upper forest limit was marked at higher elevations. In their study of alpine, subalpine, and forest landscapes in the Iezer Mountains (southern Carpathians), Mihai et al. (2007) described how mountain pine–subalpine associations developed and gradually covered subalpine meadows and barren land (between 1986 and 2002, colonization averaged 0.14 km2/y). This might be important in the context of the surface of the subalpine and alpine zones in the mountains. However, mountain pine area has lost some lower stands because of spruce forests, which increased in elevation. This is largely a feature of southern aspect slopes (sunny), where the natural timberline is under some local conditions higher. It is also related to shorter duration of snow cover on the southern slopes (Lapin et al., 2007). Peneuelas et al., (2007) also observed a shift and change in the distribution of species on the tree line in the Montseny Mountains (Span). As observed from historic photographs for the last 60 years, beech stands significantly increased in abundance, which is reflected in the shift of this species to higher altitudes by about 30-50 meters.

However, there are interesting comparisons with studies from other European mountains. The results of the study conducted by Dirnböck et al. (2003) support earlier hypotheses that alpine plant species on mountain ranges with restricted habitat availability above the tree line will experience severe fragmentation and habitat loss, but only if the mean annual temperature increases by 2 °C or more. Even in temperate alpine regions, it is important to consider precipitation, in addition to temperature, when climate impacts are to be assessed. Another example from the Alps in Austria (Dullinger et al., 2004), after running a model for 1000 years, predicted that the area covered by pines will increase from 10% to between 24% and 59% of the studied landscape. The shape of the dispersal curve and spatial patterns of competitively controlled recruitment suppression affect range size dynamics at least as severely as does variation in assumed future mean annual temperature (between 0 and 2°C above the current mean). Moreover, invasibility and shape of the dispersal curve interacted with each other due

to the spatial patterns of vegetation cover in the region. Dullinger et al. (2003a) indicated that a shift of tree and shrub species caused by landuse and expected climate change can be expected in the European Alps. Abandonment of pasture will allow invasive expansion of *Pinus mugo* scrubs to new areas. In the peripheral areas this process will be dependent on the competitive struggle for light with abandoned grasslands after the grazing has ceased. Gehrig-Fasel et al. (2007) compared upward shifts to the potential regional tree line by calculating the difference in elevation of the respective pixels. The altitude of the potential regional tree line was considered as a reference. Upward shifts above the potential regional tree line were considered to be influenced primarily by climate change, while upward shifts below the potential regional tree line were interpreted as primarily influenced by land abandonment. Generally, dwarf pine forest lost a total surface area under pressure from lower vegetation communities and even secondary pastures (Mihai et al., 2007).

In addition to climate change, human land use may drive changes in tree line. Land use in subalpine and alpine areas (grazing and extraction) affects the distribution of flora just as much as climate. Since the 13th–14th century, anthropogenic land cover change has involved clearing mountain-pine thickets to obtain new pastures for sheep and cattle grazing, for extensive charcoal and oil production, and for copper and iron-ore mining, sometimes leading to degradation. Jodłowski (2007) described how establishing national parks in the Tatras—Babia Góra and Giant Mountains enabled secondary succession, which has led to colonization of previously abandoned habitats. However, these processes have been hampered by harsh edaphic and climatic conditions as well as by avalanches and debris flows. Extensive planting of mountain pine in former Czechoslovakia significantly facilitated the regeneration of mountain pine thickets. After the absolute restriction of grazing in some national parks, we observed progressive long-term trends in secondary succession and patterns of plant establishment driven by climate.

Closed mountain pine thickets stretch up to 300 m above timberline, reaching approximately 1600–1750 masl in the Tatras and encompassing the upper part of the forest-alpine tundra ecotone. Habitats in the peripheral or isolated mountain belts at or above the tree line are generally rich in diversity of endemic species. In these habitats, tree line expansion disproportionally reduces habitats of high-altitude species. Such legacies of climate history, which may aggravate extinction risks under future climate change, have to be expected for many temperate mountain ranges (Dirnböck et al., 2011). Minimizing greenhouse gas emissions effectively in order to reduce climate warming, and thus the expansion of tree line species to higher altitudes. Furthermore, slowing down forest expansion by land use. The maintenance of large summer farms may contribute to preventing the expected loss of nonforest habitats for alpine plant species and might provide additional refuges for those endemic species which can survive in managed habitats (Dirnböck et al., 2003).

6. Conclusion

Our study shows an apparent shift and densification of *Pinus mugo* scrubs at higher altitudes. This shift was shown to correlate with climate change. Longer growing seasons,

milder winters, shorter duration of snow cover create favourable conditions for the growth of mountain pine. This shift has not only had a devastating effect on alpine plant communities due to habitat loss, but also due to greater fragmentation, which ultimately will strongly affect the population of different animal species dependent on these habitats.

More research on vegetation dynamics in Slovakia's mountain areas is needed in light of the significance of vegetation in the context of global change. The results of our study can be used not only as a baseline for future research to test possible climate change influences (resulting upward shifts compared to a potential surface size and trends in approach of dwarf pine extension) but also to compare trends in other mountainous areas. Further understanding of dispersal, persistence, and survival strategies of mountain pine in the western Carpathians is also required. We will continue to monitor dispersal of *P. mugo* in Slovakia and extend our studies to the central Tatras. This workwill help to describe and evaluate the total tree surface area as a basis for the State Nature Conservancy's management of mountain national parks and protected areas in Slovakia.

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Acknowledgement

This research was partly supported by the European Economic Area and Norwegian financial mechanism grant SK-00061. We thank Dr L. Kňazovický for aerial photos from 1965. Let us also thank to authors Dr. J. Švajda, Prof. M. Janiga and M. Buliak who created the previous study entitled "Dwarf Pine (Pinus mugo) and Selected Habitat Abiotic Conditions in the Western Tatra Mountains" published in journal Mountain Research and Development 31/3 in the year 2011.

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