Climate and timberline dynamics in the Carpathian Mountains during the XX century

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Introduction. The alpine forest-tundra ecotone, comprising the forest-meadow mosaic between timberline and treeline, is reported to have risen in elevation in many parts of the world as a result of global warming. However, in human-dominated mountain landscapes the effects of climate change on treeline position may be masked by historical and modern-day changes in land-use practices. The goal of this study was to analyze the changes in timberline position over the entire Carpathian mountain range with respect to concurrent changes in climate and land-use practices.

The warming rate in the Carpathians over the last century has been smaller than the global average (0.6 ± 0.2 °C [IPCC, 2001]) - approx. 0.2°C (Figure 1); significant warming has happened only in the last quarter of the XX ct. July temperature, important for trees at locations with a short growing period such as the timberline, shows two periods of warming in the XX ct: 1925-1965 and 1987-2000 (Figure 2).

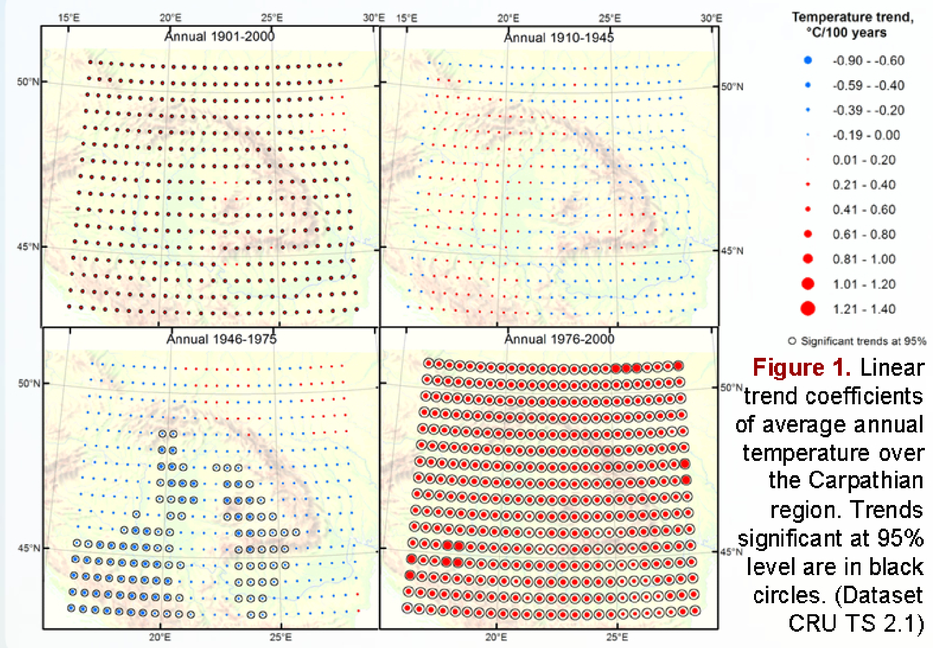
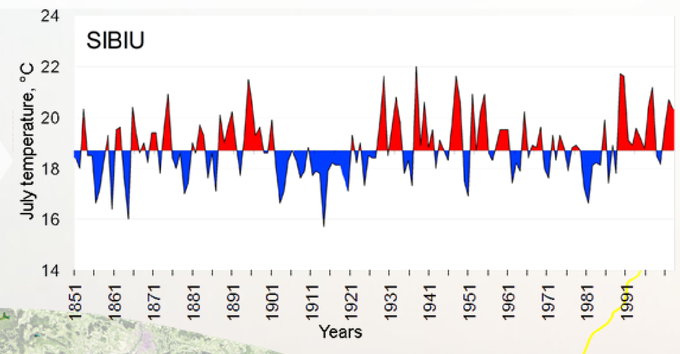


Figure 1. Linear trend coefficients of average annual temperature over the Carpathian region. Trends significant at 95% level are in black circles. (Dataset CRU TS 2.1)

Figure 2. Deviation of July temperature from the 1961-1990 mean on Sibiu weather station (Romania, 444 m a.s.l.).



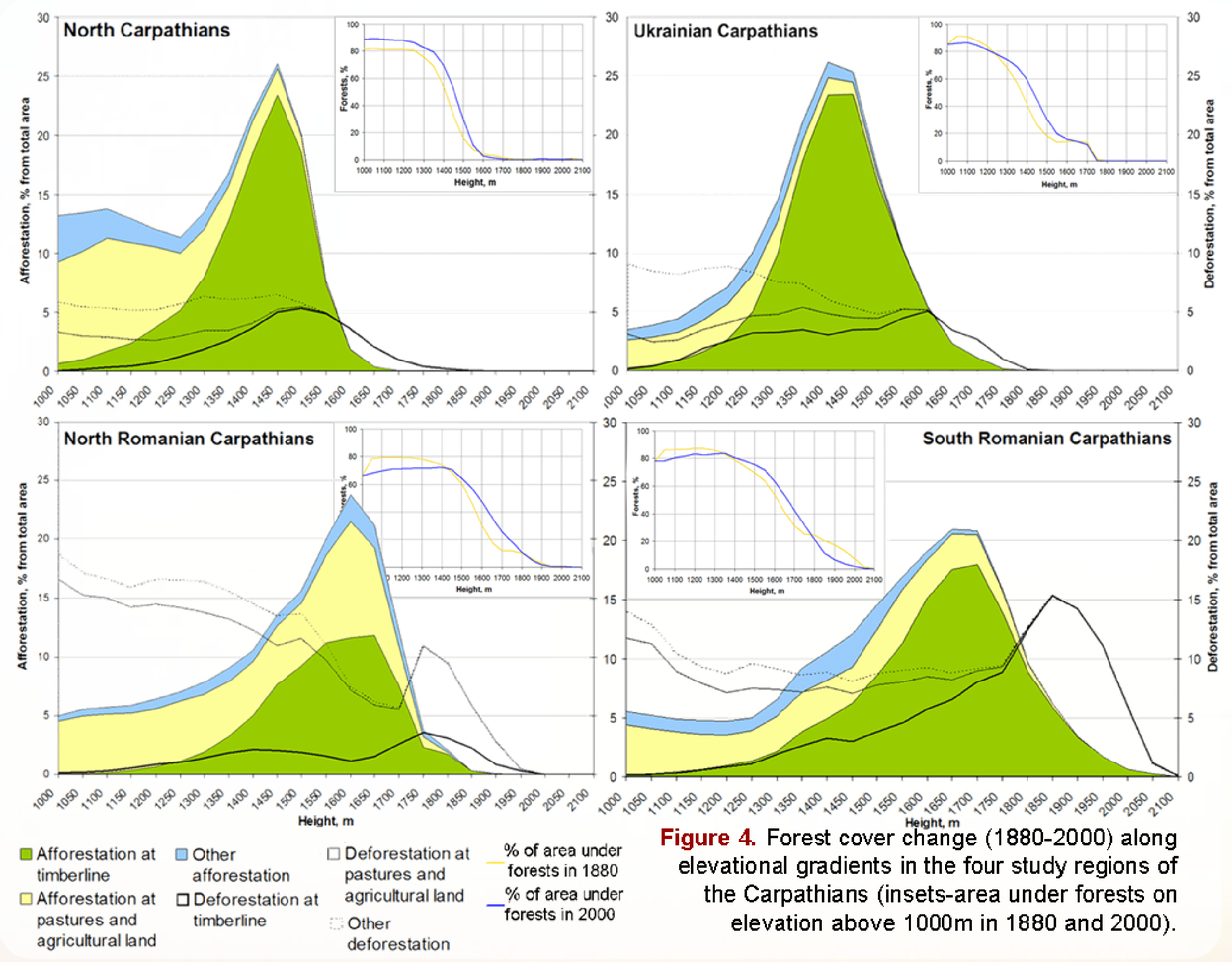


Figure 4. Forest cover change (1880-2000) along elevational gradients in the four study regions of the Carpathians (insets-area under forests on elevation above 1000m in 1880 and 2000).

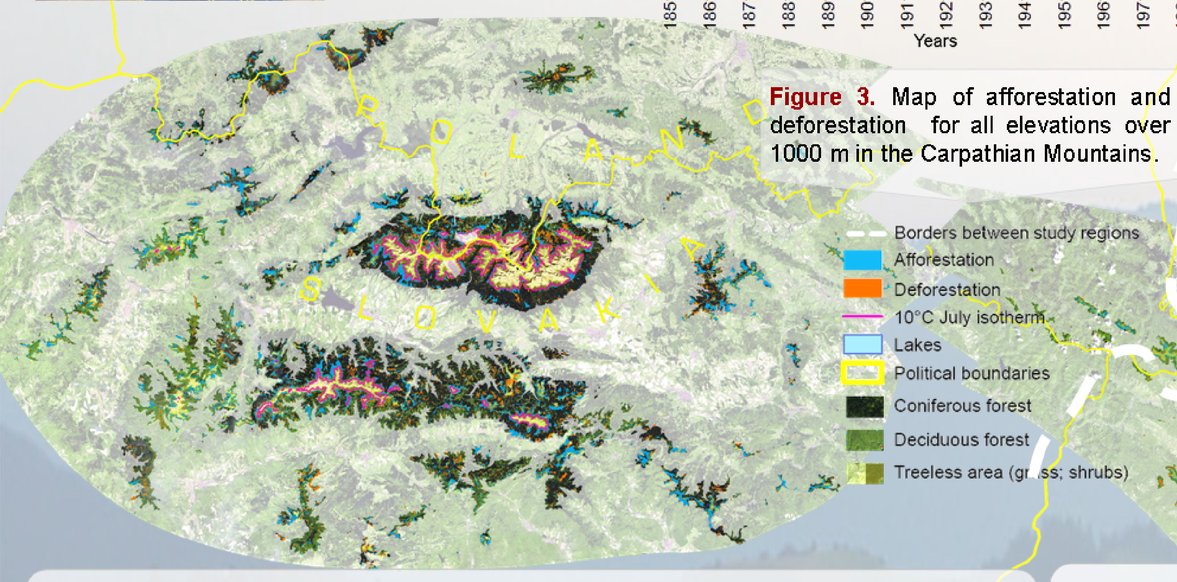


Figure 3. Map of afforestation and deforestation for all elevations over 1000 m in the Carpathian Mountains.

Table 1. Statistics of forest cover change over the whole study area and within the four study regions.

	All Carpathians	North Carpathians	Ukrainian Carpathians	North Romanian Carpathians	South Romanian Carpathians
Forest cover in 1880, %	73.2	64.8	77.1	74.6	71.5
Forest cover in 2000, %	70.6	75.9	77.9	68.3	69.3
Difference, %	-2.6	11.1	0.8	-6.3	-2.2
Afforestation, %	9.6	12.1	8.3	7.4	8.3
Deforestation, %	12.0	5.0	8.0	16.1	10.1

Materials and Methods. We georeferenced maps from the Third Military Survey of the Austro-Hungarian empire (circa 1880) and digitized the position of the timberline at elevations above 1000 m. The position of the modern timberline was obtained by mosaicking and classifying Landsat ETM imagery (March-August 2000-2002). Due to high shrub/mixed forest misclassification, the position of the timberline was manually verified using Google Earth high-resolution imagery and Tiles-on-line Instrument. Analysis was conducted in Envi and ArcGIS software.

Vector layers of afforestation and deforestation were generated over the study area. Based on visual interpretation of satellite imagery and topographic maps, deforestation and afforestation were classified into categories of timberline, pastures and agriculture below timberline, and other. The SRTM dataset from CGIAR-CSI was used as a digital elevation model (DEM).

We used detrended ordinary kriging to interpolate average July temperature (1961-1990) from 48 weather stations in order to establish the position of the 10°C July isotherm, considered to represent the climatic timberline limit in continental regions. We used climatic grids from the CRU TS 2.1 dataset to map temperature trends over the Carpathian region for different periods of the XX ct.

Results and Discussion.

- The timberline in the Carpathians is significantly lower than the climatic limit as approximated by the 10°C July isotherm. Only 4.6% of the actual timberline length overlaps this climatic limit, and 11% is within 200 m (Figure 3). This suggests that timberline position may be strongly influenced by land-use practices, and therefore that mountain forest responses to land-use change may to some degree obscure potential responses to climate change.
- There is net forest increase near the timberline (Figure 3). The elevational peak of afforestation varies across the four study regions: 1450 m in the North and Ukrainian Carpathians, 1600 m in the North Romanian Carpathians and 1700 in the South Romanian Carpathians (Figure 4). This difference in elevation of maximum afforestation is probably caused by latitudinal, and therefore temperature differences of the study regions.
- In all, the forest cover in 2000 decreased by 2.6% over the whole region relative to 1880 (Table 1). There has been a significant increase in forest cover over the North Carpathians (11.1%), a minor increase in the Ukrainian Carpathians (0.8%), and a decrease in the North and South Romanian Carpathians (6.3 and 2.2% respectively). The Ukrainian Carpathians remain the most forested region in the Carpathians in 2000, as they were in 1880.
- At the highest elevations, deforestation values exceed afforestation (Figure 4). This is especially pronounced in the South Romanian Carpathians. Deforestation in the Tatra Mountains of Slovakia is also noteworthy (Figure 3). Possible explanations for these phenomena include: intensification of debris flows and avalanches (which is especially relevant for rugged mountains such as the Tatras); artificial clearance of forests at high elevations; and, possible mistakes of the Austro-Hungarian surveyors.
- The majority of afforestation and deforestation (52% and 68%, respectively) is caused by ingrowth or clearance of pastures or other agricultural land, reflecting a high intensity of historical and modern-day land use in the study region (Figure 5).
- Land is being mainly afforested by coniferous and mixed forest (44% each); deforested land is currently covered by shrubs and grass (47 and 49% respectively). The dominance of conifers in recently afforested areas may indicate an advantage of the evergreen growth habit under the current timberline climatic regime, or may result from prior selective deforestation of coniferous forest. The high percent of shrubs in deforested areas reflects the expected, old-field successional processes occurring at abandoned pastures.
- Greater proportions of afforestation areas on south and southwestern slope aspects may reflect afforestation of previously cleared pastures, given that forest clearing for pastures is favored on warmer, sunnier slopes (Figure 6). A higher percentage of deforested area on more gradual slopes reflects easier accessibility to human influence (Figure 7).
- There is clear evidence of timberline rise and forest cover increase only in the Northern Carpathians. In the Ukrainian Carpathians, much apparent treeline change represents a shift from traditional highland pasturing to other forms of forest resource utilization, such as logging ("other" deforestation class in Figure 4). The North and South Romanian Carpathians are the most human-influenced regions and have experienced a net decrease in timberline forests, with creation and abandonment of mountain farmlands accounting for much of the observed afforestation and deforestation.

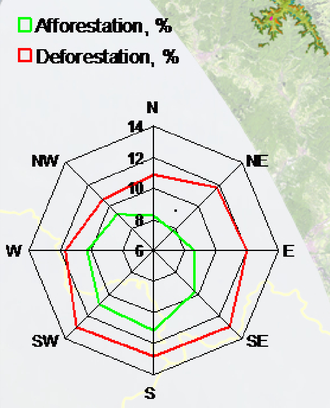


Figure 6. Percent of area with afforestation/deforestation (1880-2000) according to slope aspect. Afforestation has occurred primarily on more southwesterly slopes, whereas deforestation has been relatively rare on the more northerly slopes.

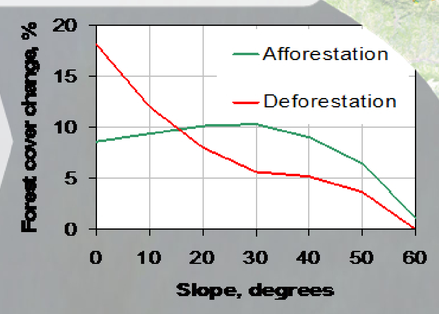
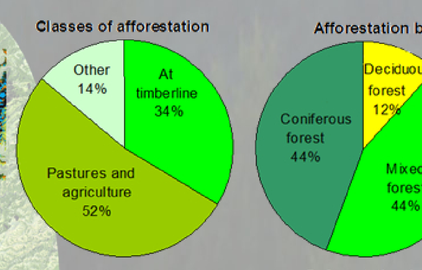


Figure 7. Afforestation and deforestation over the Carpathians (1880-2000) as a function of slope steepness. Deforestation exceeds afforestation on gradual slopes, whereas the converse is true for steeper slopes.



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Conclusions

1. Regional variation in forest cover change at timberline obscures climate change responses and can be attributed to sociopolitical differences in land-use practices over time, including logging, sheep and cattle pastures, and subsequent abandonment of pastures.
2. The forest-tundra ecotone of the Carpathians represents a patchwork of forests that have variously expanded and declined in extent and elevational range, highlighting the complex nature of mountain forest responses to climate change in the context of rapidly evolving land-use practices.
3. Improved understanding of timberline response to changing land-use practices, as these have varied regionally and across topographic gradients, will improve our ability to isolate past effects of climate change on timberline dynamics, and to predict timberline response to future climate change.

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