Timberline Changes in Relation to Summer Farming in the Western Chornohora (Ukrainian Carpathians)

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*Timberline changes in the Chornohora, the highest mountain range of the Ukrainian Carpathians, are related mainly to human activity. The most important factor influencing the timberline has been animal husbandry, with summer grazing on mountain pastures. Using historical maps and contemporary satellite data, we found that the timberline in the western Chornohora moved up by 80 m on average between 1933 and 2001, and the area of pastures (*polonynas*) shrank by one-third. The fastest advance of the timberline resulted from the expansion of spruce (*Picea abies*) and was detected far from working livestock farms. The smallest changes occurred in the case of deciduous (beech, ie* Fagus silvatica*, and sycamore, ie* Acer pseudoplatanus*) timberlines and near working farms.*

Keywords: *Timberline changes; animal grazing; land cover change; Chornohora; Eastern Carpathians; Ukraine.*

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Introduction

One of the most important environmental processes currently observed in European mountains is the rise of the upper timberline. The main reason for this is the decline of different types of traditional mountain farming (Holtmeier 2003), especially transhumance, which for centuries shaped mountain areas in Europe (Bunce et al 2004). The primary effect of summer farming was to lower timberline elevation by as much as several hundred meters (Miehe and Miehe 2000). Agricultural abandonment, a widespread phenomenon in European mountains (MacDonald et al 2000), initiated a secondary succession of forests and subalpine shrubs on formerly grazed areas. An increase of timberline elevations related to the abandonment of mountain pastures has been observed in many mountain regions of western and northern Europe (eg Hunziker 1995; Didier 2001; Motta and Nola 2001; Olsson 2004). Timberline changes, caused first by animal husbandry development and then by the collapse of mountain farming, have a wider context, as they contribute to the process of forest transition (Mather 1992). Positive effects of such a transition on hydrological cycles, soil conservation, and carbon sequestration (Rudel et al 2005) contrast with the disappearance of the semi-natural cultural landscape of mountain pasturelands. The transformation of mountain farming can also be observed in eastern Europe, although here there has been some delay compared to the rest of Europe (Lichtenberger 1978; Kozak 2003); the consequences of this land use change for the upper timberline remain relatively little understood.

The upper timberline in the Ukrainian Carpathians is mainly of anthropogenic origin, as the result of animal husbandry development (Środoń 1948; Malynovski 1985). Over the centuries, summer farming gave rise to large pasturelands, called *polonynas* in the Ukrainian Carpathians. Only a small proportion of the pastures are located in the vegetation belt of natural alpine meadows; the majority was created by clearing subalpine shrubs and forests. In the 20th century, shepherding collapsed in the Carpathians due to a decrease in the profitability of husbandry, the emergence of new, alternative sources of income, and finally nature protection restrictions implemented in the high-mountain areas. In the Ukrainian Carpathians, these processes were delayed, mainly by post-war collectivization of pastures (Troll and Sitko 2006). The slow but consistent decline of high-mountain animal husbandry in Europe during the 2nd half of the 20th century contrasted with the development of Soviet collective farms, called *kolhosps* in Ukraine. Most pastures located above the timberline in the Ukrainian Carpathians were used by *kolhosps* (Posysen' 1994), slowing timberline regeneration. In comparison, establishing protected areas in the Polish Carpathians after World War II eliminated animal grazing in the whole area above the timberline. Moreover, in the Ukrainian Carpathians, there were no alternative sources of income connected with tourism due to serious restrictions of tourist movement during the whole Soviet period. After the collapse of the Soviet Union in 1991, *kolhosps* stopped functioning, and huge stretches of *polonynas* were abandoned. At present, animals are the private property of nearby village inhabitants, and summer grazing still occurs on some *polonynas* (Chornohirs'kyi 2004). This is one of the ways for the local population to cope with high unemployment (Turnock 2002).

The consequences of 20th century land use transformation for the upper timberline in the Carpathians have been studied in different regions. The results of these studies highlight different aspects of current timberline changes. Increasing timberline elevation was detected in the Tatra Mountains in the Polish part of the Western Carpathians (Paterek and Olędzki 2005) and in the Iezer Mountains in the Romanian Southern Carpathians (Mihai et al 2007). In the Bieszczady Mountains, on the other hand, in the Polish part of the Eastern Carpathians, the timberline has remained stable since the mid-19th century (Kucharzyk 2004, 2006b). Disputable impact of global warming on the timberline has been analyzed for the Polish part of the Carpathians (Niemtur et al 2002), while for the Ukrainian Carpathians, forest succession in abandoned pastures has been studied a number of times (eg Malynovski 1985; Tsaryk and Malynovski 1997; Mróz 2006); according to the results, the diversity of vegetation in *polonynas* decreased after abandonment. The discussion of the impact of long-term animal grazing on the deformation of forest stands at the upper timberline and on subalpine vegetation was summarized by Kucharzyk (2006a). After catastrophic floods in the Ukrainian Transcarpathians in 1998 and 2001, plans for large-scale timberline restoration were elaborated by a team of Ukrainian experts (Kricsfalusy et al 2004). The contribution made by summer farming to conservation of the anthropogenic timberline as an important element of the cultural landscape of *polonynas* was also stressed (Troll and Sitko 2006). Unfortunately, the state of animal grazing and husbandry during the post-Soviet period and its role in timberline changes is not well known. Some data on this topic were collected for the two largest high-mountain pasturelands in the Ukrainian Carpathians, which are still grazed seasonally: Świdowiec (Gudowski 2001) and Chornohora (Troll and Sitko 2006).

In this paper, we assess the scale of timberline changes in the Chornohora and relate these changes to summer farming activities in the 20th and 21st centuries. Detected timberline changes are compared with livestock numbers and different types of pasture use. We assumed that the research results would indicate the impact of large-scale pasture abandonment on forest transition in the Ukrainian Carpathians. This could also help to improve the future management of cultural landscapes shaped in this region by shepherds.

Study area

The Chornohora is the highest range of the Ukrainian Carpathians (Howerla Mountain, 2061 m asl). The natural timberline, formed by spruce (*Picea abies*) with an admixture of stone pine (*Pinus cembra*), reaches 1650–1670 m asl (Środoń 1948; Malynovski 1985; Bajcar 2003). However, a large portion of the timberline was lowered by grazing: between 65–75% (Środoń 1948) and 80% (Bajcar 2003) or even 90% (Malynovski, in Nesteruk 2001) of its total length. The study area is located in the western part of the Chornohora, where the timberline was significantly lowered, probably along its whole length (Środoń 1948). Apart from spruce, the actual timberline is also formed by beech (*Fagus silvatica*) with an admixture of sycamore (*Acer pseudoplatanus*). Many botanists suppose that the spruce forest was totally removed during pastureland enlargement (Zapałowicz 1889; Środoń 1948; Komendar 1955; Malynovski 1985; Nesteruk 2001). The Krummholz zone (up to 1800–1850 m asl) is formed by shrubs of dwarf pine (*Pinus mugo*), dwarf juniper (*Juniperus communis* subsp. *nana*), and green alder (*Alnus viridis*) (Zapałowicz 1889; Stojko 2003). Natural alpine meadows cover only the highest peaks of the Chornohora range, above 1800–1850 m asl. The semi-natural landscape of the *polonynas* is currently protected in the Carpathian Biosphere Reserve (Hamor et al 2007), to which part of the study area belongs.

As part of Hutsulshchyna, a region specializing in sheep and cattle husbandry, the Chornohora was one of the most important centers of summer farming in the Eastern Carpathians (Posysen' 1994; Tyvodar 1994). Permanent use of mountain areas as pastures resulting in timberline lowering started no later than during the first phase of settlement in the 16th–18th centuries (Král 1923a; Jawor 2004). Summer sheep and cattle grazing has become an important element of animal husbandry; it is the primary occupation of the Hutsuls, the highlanders of Hutsulshchyna (Kubijovyč 1935). The importance of animal husbandry in the Hutsul economy is still reflected in the dominance of pastures and meadows, which together cover more than 90% of all agricultural land in Hutsulshchyna (Lavruk 2005).

Intensification of summer farming in the western Chornohora started with Hungarian investments at the beginning of the 20th century and Czech investments after World War I (Král 1923b; Posysen' 1994; Tyvodar 1994). After World War II, Czech dairies were replaced by Soviet *kolhosps* (Figure 1). The largest number of livestock was kept in *kolhosps* between the 1960s and 1980s, but even at that time, only half of all livestock of Hutsulshchyna were collective property. After the disintegration of *kolhosps* in the 1990s, family enterprises came into existence. In the study area, pastures collectivized by the Soviets are currently in part property of the communities of nearby villages and in part managed by the Carpathian Biosphere Reserve. Distinctive features of Hutsulshchyna husbandry include a higher number of sheep than cattle and a large proportion of cows among the latter (about 80%, Lavruk 2005). The current livestock population in the study area is about 3000 sheep and 1300 cattle (mainly cows), grazed on pastures that cover about 2500 ha (Troll and Sitko 2006); this is probably relatively high in comparison to the rest of the Ukrainian Carpathians, but we could not find any relevant data on livestock grazed on other *polonynas*.

Materials and methods

We determined changes of the timberline by comparing a historical topographic map with contemporary satellite imagery. Old maps provide the only available infor-

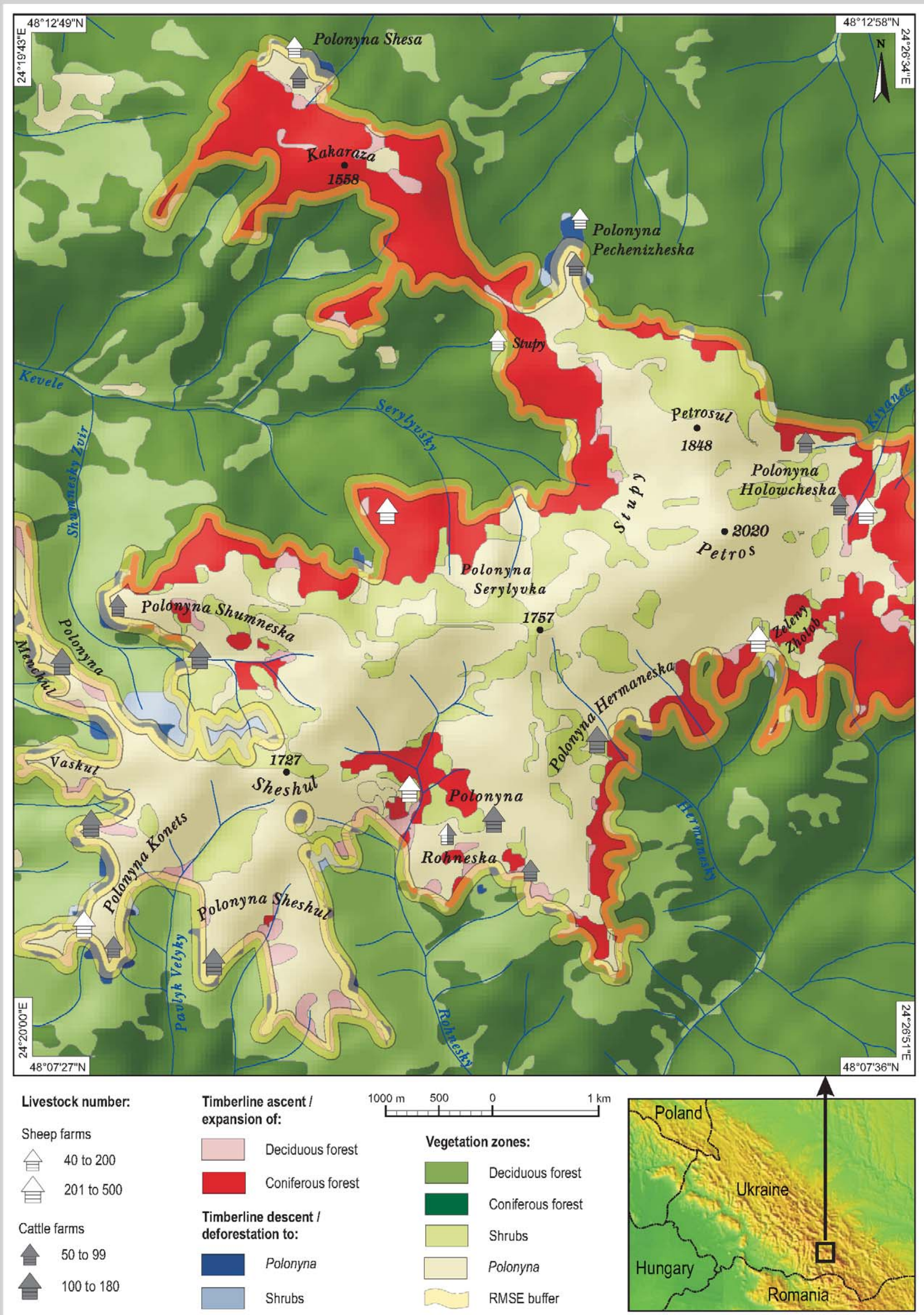
FIGURE 1 Cultural landscape with anthropogenic timberline: Hutsul pasture farm in an old Soviet *kolhosp*, built on the site of a former Czech farm (Menchul Kvasovsky Mountain). (Photo by Mateusz Troll)

mation on land cover patterns before World War II; Kozak et al (2007) used a similar dataset and approach to detect forest cover changes in the Northern Carpathians. Satellite and aerial imagery has been used in studies of Carpathian timberline changes (eg Wężyk and Guzik 2004; Paterek and Olędzki 2005; Mihai et al 2007), but not for the Ukrainian Carpathians.

The current position of the timberline was obtained from a Terra ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) satellite image acquired on 28 October 2001. We used visible and near-infrared bands with a spatial resolution of 15 m. The historical timberline position was determined from a Polish WIG (*Wojskowy Instytut Geograficzny* [Military Geographical Institute]) topographic map at a scale of 1:100,000. This map was produced in 1932–1933 on the basis of two older maps: an Austrian one at a scale of 1:25,000, dating to 1874, and a Czech one (1:75,000, 1924). Information about elevation was obtained using the Shuttle Radar Topography Mission (SRTM) model, version 2. The present state of animal farming was assessed in the field in 2003 and 2004. Farm locations were measured using the Global Positioning System. Data about the number and type of grazed animals and the grazing period were collected using questionnaires among shepherds (Troll and Sitko 2006). Historical statistics about livestock were obtained from relatively scarce literature (Posysen' 1994; Tyvodar 1994).

ASTER image digital numbers (DNs) were calibrated to at-sensor radiance using metadata to eliminate striping. Using the stereo pair in the near-infrared range, an orthorectified image in the Universal Transverse Mercator projection (UTM, zone 35N) was generated with the reference points collected from a Russian topographic map at 1:100,000. Further processing included a combination of visual interpretation and segment-based land cover classification. Image segments derived based on a region-growing algorithm (Baatz et al 2004) were interpreted visually using field expertise; they were divided into segments located above and below the timberline. This allowed us to determine the timberline position. For an explanation of timberline dynamics (eg which forest type was expanding), additional discrimination of land cover types along the timberline was needed. Using the minimum distance classifier, segments below the timberline were classified as deciduous or coniferous forests, and segments above the timberline as *polonynas* or subalpine shrubs. The signatures were determined using ground truth and photo documentation of the study area. Overall classification accuracy calculated for 38 randomly sampled points verified in the field was 79%. Nevertheless, visual assessment of classification results indicated that, in the most important part of the study area (along the timberline), the accuracy was much higher.

FIGURE 2 Changes in land cover and timberline position for the period 1933–2001, in relation to the current distribution of livestock farms. (Map by Izabela Sitko)



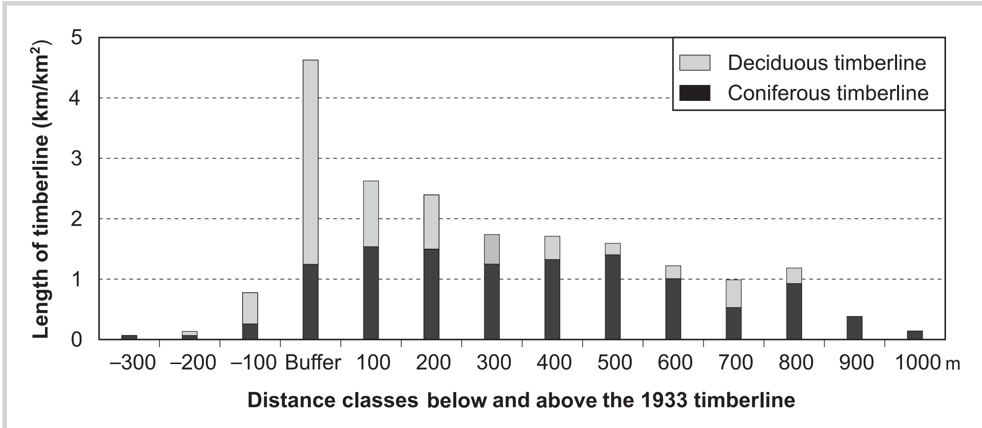


FIGURE 3 Length of the 2001 timberline calculated within distance classes below and above the 1933 timberline; values normalized by distance class area.

The topographic map was scanned with a resolution of 300 dpi and co-registered to the ASTER orthoimage with 47 reference points and the first-order polynomial function. A root mean square error (RMSE) of 68 m was calculated. This error is principally a result of the generally poor geometric accuracy of the WIG map itself; it is equal to a 0.68 mm distance on the map's scale on paper, and it is comparable to values determined in other studies (Kozak et al 2007). Next, the timberline was digitized. Only *polonynas* and forests could be distinguished. Differentiation between coniferous and deciduous forests and delimitation of subalpine shrubs were not possible on the topographic map.

The maps were overlaid with elevation data to analyze changes in the position and elevation of the timberline together with related land cover changes. To minimize the impact of inaccuracy of topographic map rectification, we eliminated a buffer of one RMSE value (68 m) above and below the historical timberline from land cover change analysis. To analyze the distance between two timberline stages, the length of the 2001 timberline was calculated within the distance classes from the RMSE buffer above and below the 1933 timberline. Values were normalized by the area of the particular distance class. Finally, analysis of animal farm distributions in relation to timberline changes was done visually using the map overlay. The distance between farms and the 2001 timberline was also calculated.

Results

In 1933, timberline elevation in the western Chornohora was 1329 m asl on average and ranged from 1126 to 1604 m asl. In 2001, average timberline elevation was 47 m higher (1376 m asl). Its maximum elevation changed by a similar value (1670 m asl), while the minimum elevation (1116 m asl) remained comparable to that of 1933. In 2001, the timberline was formed by spruce and beech forests in almost equal proportions (52% and 48%, respectively). The deciduous timberline occurred mostly in the western part of the study area (Figure 2). Spruce forests reached, on average, 80 m higher than beech forests. Forest bordered *polonynas* along 72% of the timberline. The boundary between forest and shrubs was much shorter (28%), but it was, on average, 59 m higher.

The distance between the 1933 and 2001 positions of the timberline reached a maximum of 1000 m for coniferous and 800 m for deciduous forests (Figure 3). More than 50% of the 2001 deciduous timberline fell into the RMSE distance buffer; this value was much lower for the coniferous timberline.

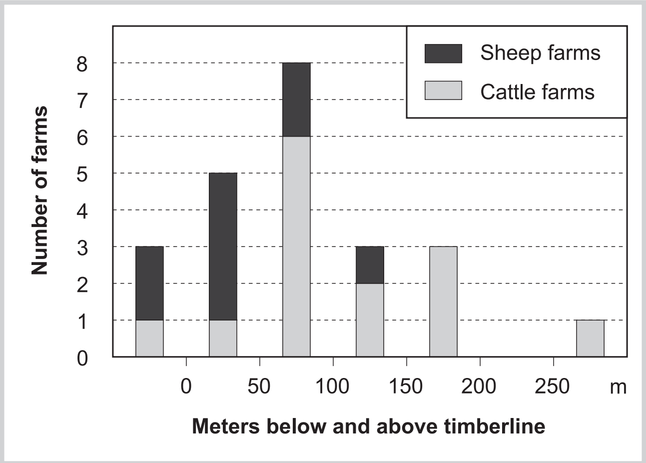
The area above the timberline decreased from almost 32 km^2 in 1933 to about 22.5 km^2 in 2001. Of the 1933 *polonynas*, 26% (7 km^2) were overgrown by forest by 2001, mostly (88%) with conifers. The main regions of forest expansion and timberline advance were the northern and eastern parts of the study area. In the Kakaraza massif, historical *polonynas* had become almost completely forested. The opposite type of land cover change (deforestation) was of marginal importance and only occurred on an area of 0.4 km^2.

The distribution of livestock farms was clearly related to the course of the timberline (Figure 4). In all, 16 of 23 seasonal settlements located in the study area were within 100 m from the 2001 timberline (see also Troll and Sitko 2006). Only in one case out of 13 was the change of timberline position large enough for the settlement location to change from *polonyna* to forest. As regards sheep farms, only 3 out of 10 were situated below the timberline.

Discussion

In the western part of the highest Ukrainian mountain range, the timberline moved up during the 20th century despite persistent seasonal animal farming. While

FIGURE 4 Horizontal distance between livestock farms (represented by farmsteads) and the 2001 timberline. (Source: Troll and Sitko 2006, p 115, modified)



before World War II the timberline in that region was lowered by shepherds along its whole length (Środoń 1948), we can currently observe its re-naturalization. On some peaks lower than the climatic timberline, the former anthropogenic timberline has disappeared. Nevertheless, there is still a forestless area below the climatic timberline, where forest expansion may continue depending on the rate of decline of animal farming.

The smallest changes in the timberline position occurred in areas where the forest boundary was formed by deciduous trees, mostly in the western and southwestern parts of the study area. The changes there did not exceed the RMSE of map rectification and may be due to errors of map overlay. The largest changes took place in the northern and eastern parts of the region, where *polonynas* were mostly surrounded by coniferous forests (pure spruce stands).

The magnitude of timberline changes is related to animal farming. Seasonal grazing of sheep and cows, for 3–4 months per year, has taken place continuously on most of the western Chornohora pastures for centuries (Troll and Sitko 2006). Timberline changes were much smaller near farms, and the majority of farms still remain above the timberline. Cattle farms had a greater influence on timberline stability than sheep farms because of their stable locations during the 20th century and more intensive grazing around farm buildings and thus near the timberline. Sheep farms often changed their location, some even every year. Moreover, sheep herds migrate quite far from farms, so pressure on the direct farm neighborhood was lower and varied more in time than in the case of cattle grazing. Animal grazing is not restricted to pastures only; it occurs in the timberline zone as well or even within the forest, despite legal prohibition (Troll and Sitko 2006).

Another important factor preventing secondary forest succession on *polonynas* is scorching. Scorching was common in the past and was recently prohibited, but it has not been eliminated. We noticed burned areas of juniper and spruce in the western Chornohora during field trips between 2000 and 2006 (Troll and Sitko 2006). Scorching of dwarf pine shrubs in the Chornohora was confirmed by Nesteruk (2001), though some fires may be caused by lightning or tourist activity. Some of the pastures were cleared legally under the supervision of the Carpathian Biosphere Reserve. Such activity agrees with the principle of 'conservation and maintenance of the national traditions' in the anthropogenic landscape zone of the reserve (Hamor et al 2007). Overall, in the study area we found several practices supporting the conservation of the anthropogenic timberline. However, these occurred only locally and very irregularly.

It is difficult to assess the relation between timberline changes and livestock numbers on the Chornohora pastures, due to the lack of available data for the first half of the 20th century, as well as for the period after the collapse of the Soviet *kolhosps* at the beginning of the 1990s (Gudowski 2001). In the Shumneska summer farm, one of the largest in the region, the number of cows before World War I was 260 (Tyvodar 1994), while in 2004, it was only 100–180 (Troll and Sitko 2006). Timberline changes detected in the pastures used by this farm were very large. In another pasture farm (Menchul Kvasovsky, see Figure 1), the number of cows at the end of the 1920s was 120 (Tyvodar 1994), the same as at present (Troll and Sitko 2006). Similarly, in three farms on the Sheshul and Konets *polonynas*, the livestock number (320–330 cows) did not change from 1945 (Posysen' 1994) to 2004 (Troll and Sitko 2006). Near farms that maintained similar livestock numbers over time, the timberline was relatively stable, in contrast to farms where livestock numbers were decreasing. Although we could not find any reliable data on the overall number of animals in the western Chornohora before World War II, we suspect that livestock numbers were much higher than currently, especially for sheep (Troll and Sitko 2006).

The faster advance of the coniferous timberline compared to that of the deciduous timberline can be explained by two factors: feeding preferences of sheep and cattle, and seed dispersion mode. Deciduous trees are several times more susceptible to gnawing (Gąsiorek 2002). In addition, European beech is a shadow-tolerant species, and its reproduction near the timberline is often vegetative (Kucharzyk 2006b), so regeneration of the timberline is relatively slow and only occurs near the timberline. Spruce, on the other hand, has very light wind-dispersed seeds, so overgrowing of pastures surrounded by conifers is favored by high availability of seeds. We found that spruce often expands above an anthropogenic beech timberline,

FIGURE 5 Spruce succession on abandoned pastures surrounded by anthropogenic beech and sycamore timberline (Sheshul *polonyna*). (Photo by Izabela Sitko)

either as single trees, as tree clusters, or as small spruce forests (Figure 5). Spruce succession usually occurs over huge areas of pastures simultaneously, not only gradually from the forest edge. On lower ridges, this process may lead to a complete elimination of the former anthropogenic timberline (eg Kakaraza, 1558 m asl). The large scale of spruce succession on the *polonynas* of the western Chornohora confirms general tendencies observed in the Eastern Carpathians as a whole (Tsaryk and Malynovski 1997). The faster advance of the coniferous timberline and contemporary spruce expansion may be considered a regeneration of the former spruce forests removed during farming and forestry development (Środoń 1948; Tsaryk and Malynovski 1997). However, according to Holubets (1978) and Kucharzyk (2006a), the natural timberline on the southwestern slopes of the Eastern Carpathians was formed by deciduous forest; in this case, contemporary spruce succession on abandoned pastures might be a consequence of forest management in the past, which favored spruce and increased the availability of spruce seeds close to the lowered timberline. Small changes in the beech timberline, even after very long periods of pasture abandonment, have been detected in the Polish Eastern Carpathians—the rate of beech timberline succession was about 10 m per 40–50 years (Kucharzyk 2004).

Global climate warming can be considered to be an additional factor sustaining the advance of the timberline. Its influence on the progress of forest succession has been observed in many regions, eg in the Alps (Motta and Nola 2001) and the Himalayas (Nautiyal et al 2004). We are not familiar with similar studies in the Chornohora, but, in our opinion, its impact can be determined only for the climatic upper timberline, which is very rare in the Ukrainian Carpathians. In the case of the anthropogenic timberline, the role of pasture abandonment is probably much more important than global warming due to the scale of previous timberline lowering.

Timberline changes are linked to a gradual decrease in pasture area, even in regions where animal farming is still present. This, in turn, leads to slow vanishing of the semi-natural and cultural *polonyna* landscapes. Our observations show that forest expansion on former pastures, and the resulting disappearance of the timberline on low ridges, is ongoing in other regions of the Eastern Carpathians, not only in sparsely inhabited ones (eg the Chyvchyny Mountains) but also in quite densely populated ones (eg Skolivsky Beskydy Mountains). Forest expansion on agricultural land located below the timberline is common in the Ukrainian Carpathians as well (Kuemmerle et al 2006; Kozak et al 2007). Thus, less than 20 years after the collapse of the USSR, the Ukrainian Carpathians show distinct signs of agricultural abandonment processes that are well known in other European mountains. One of the reasons for this might be the development of new, alternative sources of income, such as tourism. In general, changes of this type may be the beginning of a forest transition process in the Ukraine.

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