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MINING AS A CATALYST OF OVERGRAZING RESULTING IN RISK OF FOREST RETREAT, ERDENET MONGOLIA

ABSTRACT. This paper provides information on long-term suppression of natural forest regeneration due to the livestock grazing in the vicinity of one of the world largest open-pit ore mine close the city of Erdenet in Mongolia. The area is characterized by high concentration of herder's households where the 52% were found only up to 1 km distance from the forest edge. Forest grazing causes extensive damage to seedlings and significant reduction of their growth. Within the 30–99 cm height category, up to 61% *Larix sibirica,* 90% *Betula platyphylla* and 68% *Populus tremula* individuals are grazing-damaged. *L. sibirica* and *P. tremula* seedlings with heights over 99 cm were absent, and no individuals of any species were found within 136–200 cm height category. In addition to the seedlings, only 7 or more meters high *L. sibirica* individuals are found in the forest structure, which means the absence of successfully growing forest regeneration for at least 40 years. In 2017, the defoliation of *L. sibirica*, reaching locally up to 100%, occurred in the stands east of the mine. Total defoliation represents a high risk of mortality of affected individuals. The stands cannot be successfully regenerated under the conditions of current intensive grazing. Mine metal stocks are calculated to provide for at least another 25 years of mining. Over that time, neither significant population decline nor decreasing grazing pressure on forests can be expected. If effective protection measures are not implemented, there is a risk of transforming threatened forest into steppe.

KEY WORDS: overgrazing, forest regeneration, *Larix sibirica*, herders, defoliation, mining

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INTRODUCTION

Mongolian forests are located predominantly in the northern part of the country (between 47–52°N and 89–116°E.), on the southern border of the vast Siberian taiga and the Mongolian steppes with the total area over 19 million ha. (Ykhanbai et al. 2010; Batkhuu et al. 2011). The forests are mostly composed of *Larix sibirica* covering 60% of the forest territory. Another significant species are pines (*Pinus sylvestris* and *Pinus sibirica*) and *Picea sibirica* covering about 5 up to 8% of the forest area. Furthermore, a significant species proportion is represented by the *Betula* genus, occupying approximately 9% of the Mongolian forest territory (Batkhuu et al. 2011; MET 2019).

A very important part of Mongolian forest ecosystems are the extremely sensitive mountain forest-steppe ecosystems. They play an irreplaceable role for preventing soil erosion and desertification (James 2011; Priess 2015), they have a positive effect on the soil water regime, play an invaluable role for the regional hydrology (Menzel et al. 2011; Karthe et al. 2015; Batbayar et al. 2018), and serve as important biodiversity centres (Sankey et al. 2006).

Unfortunately, Mongolian forests have been subjected to strong negative impact of illegal timber logging, forest fires and overgrazing for a long time (Tsogtbaatar et al. 2004). The combination of anthropogenic disturbance and climate change (Sato et al. 2007; Marin 2010; Oyuntuya et al. 2015) causes serious change in moisture conditions of the ecosystems leading to deterioration of the forests health (Juřička et al. 2018). Weakened Mongolian forests are then exposed extensively to pests (Hauck et al. 2008; Dulamsuren et al. 2010a). A consequence of these factors can result in large-scale mortality of *L. sibirica* at affected sites (Juřička et al. 2018).

Above all, heavy grazing pressure poses a serious threat to tree regeneration and thereby to the long-term existence of Mongolian forests. The beginning of the primary anthropogenic degradation on the territory of Mongolia is connected especially with the onset of intensive grazing at the early of the second millennium (Saizen et al. 2010). Grazing livestock significantly disturbs forest ecosystems (Lkhagvadorj et al. 2013), causes reducing of litter, compacting and disturbing of soils, reducing water infiltration rates, soil erosion, and it also can be significant factor of species changes in forest vegetation (Belsky and Blumenthal 1997). The long-term intensive forest grazing changes quantity and height structure of seedlings and saplings. Thereby, it prevents successful forest regeneration for decades (Sankey et al. 2006; Khishigjargal et al. 2013). On the contrary, decrease in the number of grazing cattle in the forest leads to significant increase of number of seedlings and saplings (Buffum et al. 2009).

Mongolia is one of the most overgrazed countries in the world (Asner et al. 2005). Nevertheless, grazing livestock does not long provide just food self-sufficiency for migrating nomads. Currently, it is an important factor of the Mongolian economy (Janzen 2005). Agriculture sector in Mongolia (livestock forms nearly 90%; FAO 2015) created 10.4% of GDP in 2017 (The World Bank 2019) although it was up to 41% in 1996 (The Global Economy 2019). Pastoralism presents not only production of meat and dairy products. There is a growing proportion and number of goats, which form the backbone of a dynamically growing and highly profitable cashmere industry (Berger et al. 2013). However, at the same time, they cause the most critical damage to seedlings (Fernández-Giménez et al. 2012; Lkhagvadorj et al. 2013). Goats make 41.2% in the total number of livestock (National Statistics Office of Mongolia 2019).

The situation got fundamentally worse after 1990´s with political and economic changes in Mongolia. The planned economy turned into market economy and, therefore, the number of livestock increased (Yoshihara et al. 2008; Saizen et al. 2010). In 1992, the number of livestock was 25.6 million in Mongolia. However, the number increased to 44.5 million in 2009 (Sankey et al. 2006; Maasri et al. 2011) and the number reached up to 66.2 million in 2019 (Mongolian Statistics Information Service 2019). Political changes and in some regions environmental deterioration have led to decline in nomad's migration. The herders concentrate around water resources, forests and large settlements. Therefore, the grazing pressure occurs for a longer time on a relatively smaller area (Sternberg 2008).

Our objectives were: (i) to provide information on long-term disturbance of forest regeneration in the vicinity of Erdenet city and to assess the role of mining in this unfavourable situation, (ii) to assess survival perspective of forest in the surrounding of Erdenet in the context of serious defoliation detected in 2017, (iii) to propose effective measures to ensure long-term survival of the forest.

MATERIALS AND METHODS

The study area

The research was conducted in forests in the vicinity of Erdenet city. The city is currently the second largest and populated in the Mongolia. The city began to grow in 1975 following the start of ore mining. Erdenet's population has increased from 29,100 inhabitants in 1979 (Quandal 2017) to current approximately 100,000 inhabitants (Enkhbayar 2019). It is a model example of population extension in Mongolia's mining areas.

In the centre of the area of interest there is a significant landscape element - a large Cu-Mo open-pit mine. The mine is surrounded by older urbanized area with block buildings in the north and younger yurt household area in the west. The central part of the locality around the mine consists of steppe (1,300 m a.s.l.), which turns into mountain with mountain forest-steppe ecosystem (max. 1,700 m a.s.l.) (Fig. 1). The warmest month is July with average temperature of 17 °C; the coldest month is January with -21 °C. The average annual precipitation is about 350 mm (TimeAndDate 2019).

To determine the amount of yurt households in the study area, actual satellite image (26 May 2016) was used from GoogleEarth. Positions of herder households was exported to ArcGIS 10.4.1. Distance of herder's households from forest edge was found using buffer-zones, which were established around the edge of forest stands by utilization multiple ring buffer analyses in ArcGIS 10.4.1.

Design of measurements

A total of 20 plots (1,376–1,653 m a.s.l.) of a size 10 x 10 m each were evaluated (Mühlenberg et al. 2012; Bellingham

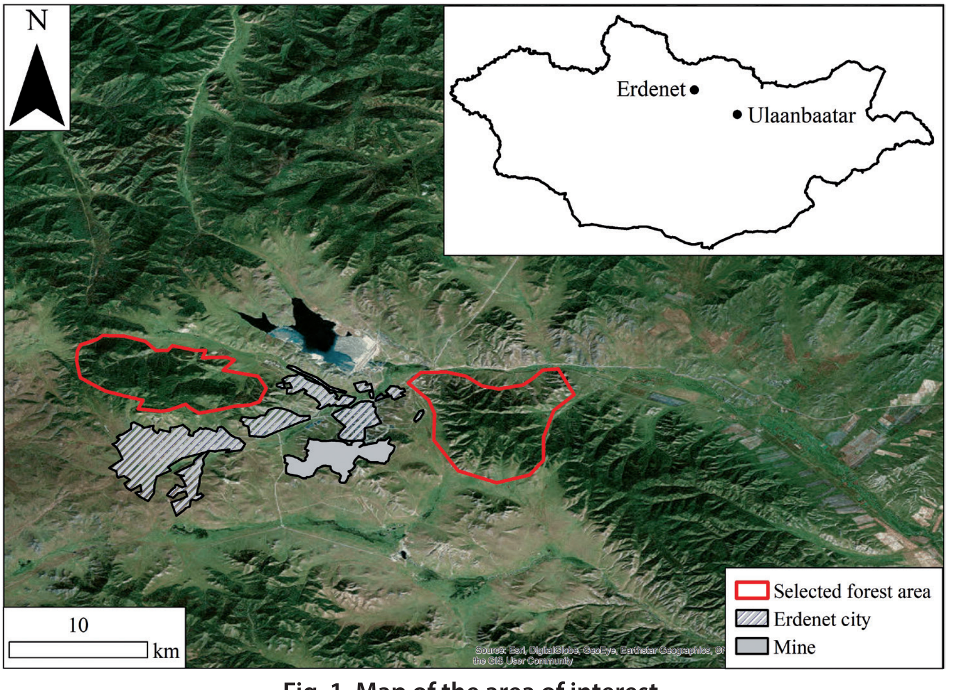

Fig. 1. Map of the area of interest

et al. 2016) in July 2016. The distance between individual sites is 0.7–2.2 km. Individual research plots were situated 0.1–2.5 km from forest edge. Each plot had been selected as a representative sample of local mature stands. We conducted grazing pressure evaluation, qualitative and quantitative evaluation of forest regeneration, dendrometric measurements and deadwood mapping. There were noted: position on the slope, altitude and slope aspect of each plot, as a background for evaluation of the influence of environmental factors.

Forest mapping

In the locality, there are goats, sheep, cattle, yaks and horses grazing. The overall grazing pressure on the site was evaluated through the Reimoser et al. (1999) (none to very heavy) and Ludwig et al. (2014) (degree 1–4) methodologies.

Forest regeneration evaluation included the measurement of the heights of the seedlings and saplings present and character of their damage (non-injured, lateral, terminal, lateral + terminal). Heights of forest regeneration of the individual species are classified into the categories <10, 10–29, 30–99, 100–136 cm and 136–200 cm (Acker et al. 2017). Summary of all plots was counted per 1 ha (individuals, ha^{-1}).

Species composition and number of individuals were determined within dendrometrics measurement. For each individual the height, girth, physiological vitality and biomechanical vitality were measured. Height of trees was measured using an altimeter Sylva CM-1015-2025 and a Nikon Laser Forestry rangefinder. Physiological vitality gauges tree health and cause of damage ranging from 1 to 5. Biomechanical vitality expresses the potential degree of reduced or threatened viability caused by mechanical failure of an individual, ranging from 1 to 5 (Pejchal and Šimek 2012, 2015). Stand basal area (SBA) was calculated by summing basal area (0.00007854 x diameter^2 at breast height) from all site locations and then converted to a one-hectare area (Hédl et al. 2009). The position of a tree, its altitude and slope exposure were recorded using the GPS (Garmin GPSMAP 62 st). Position on the slope was later determined in program ArcGIS 10.4.1. according to Ludwig et al. (2014).

In order to confirm the defoliation of the stands, recorded in the field in August 2017, and to determine its extent, satellite images by GoogleEarth from May 16, 2017 and September 7, 2018 were used. Images were exported to ArcGIS 10.4.1 where defoliation was marked by visual detection. The limited image size in 2018 allowed only a minority of Erdenet forest stands to be explored.

Data analyses

Relation of forest regeneration to environmental factors (position on the slope, altitude and slope aspect) has been tested using Monte Carlo test in the Canoco programme. The evaluation of the significance of single research plots distance from the edge of the forest was not made due to the high risk of results distortion due to the factor of "privileged cattle routes", which cannot be accurately evaluated from the satellite images. The horizontal distance between the plots and the forest edge is not a suitable variable.

RESULTS

In the area around the mine, 126 herder households were counted and mapped in 2016. 52% of them have been found to be located in distance from forest edge less than 1 km (Fig. 2).

The assessment of the grazing intensity has confirmed that forests around Erdenet city are under heavy grazing pressure (Fig 3). The level of grazing pressure at research plots have been indicated as *"very heavy"* according Reimoser et al. (1999) and *"degree 4"* as reported by Ludwig et al. (2014). Both authors report it as a maximum level of grazing pressure on a locality.

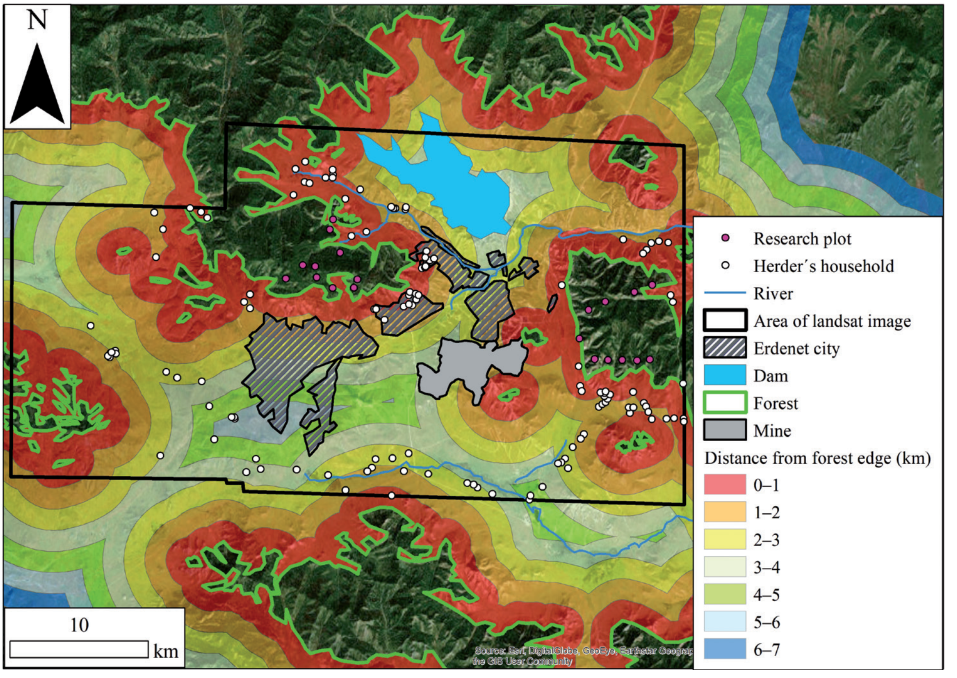

Fig. 2. Distribution of herder households depending on the forest stands distance

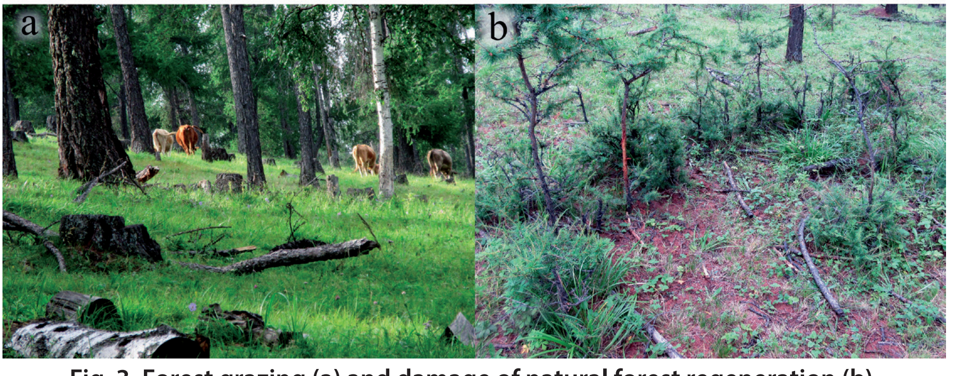

Fig. 3. Forest grazing (a) and damage of natural forest regeneration (b)

The occurrence of seedlings was sporadic in the stands. Tree seedlings were found in 8 of the 20 sites. *L. sibirica* was regenerated only in 4 sites, *B. platyphylla* in 3 sites and *P. tremula* in 4 sites out of 20. The most regenerated tree species is the main late successional species of the local forest, *L. sibirica*, forming 69% of the total counts of 2,190 individuals, ha^{-1} higher than 10 cm.

Height category of 10–29 cm prevails in terms of *L. sibirica* and *P. tremula* height structure. Only 13% of the individuals of *L. sibirica* and 16% of *P. tremula* were found within 30–99 cm height category. No individuals of these two species were found in higher height categories. *B. platyphylla* was found mostly in the 30–99 cm height category in a number of 165 individuals, ha^{-1}. In the 100–136 cm height category, there were only 10 individuals, ha^{-1} of *B. platyphylla* and no individuals in 136–200 cm height category.

The structure of damage to individuals is shown in Fig. 4. Individuals in 30–99 cm height category are damaged significantly more than those in category of 10–29 cm. Within 10–29 cm height category, only 8% of *L. sibirica* individuals are damaged; within 30–99 cm height category, 61% of *L. sibirica* individuals are already damaged. In total, 14% of *L. sibirica* individuals are damaged. Deciduous trees show distinctly higher damage in all height categories than *L. sibirica*. 90% of *B. platyphylla* individuals in 30–99 cm height category are damaged. In total, 88% of the individuals are damaged. *P. tremula* showed a total damage in 66% of individuals: 65% within 10–29 cm height category and 68% within 30–99 cm height category. The characteristics is similar in all species; terminal damage was the most frequent.

The influence of environmental factors on data variability was excluded. Monte Carlo test did not confirm any correlation between the environmental factors with number, tree species and type of regeneration seedlings damage in the locality.

The observed stands were mainly composed of larch with sporadic occurrence of birch. Their predominant status was assessed as satisfactory on the basis of parameters evaluated in 2016 (Table 1). Physiological vitality at level 2 of *L. sibirica* showed slight deviations from the optimum and the assumption of possible long-term existence. The biomechanical vitality of *L. sibirica* at level 2 was only slightly reduced, with the assumption of a long-term existence. The dead individuals of *L. sibirica* occupied only 15% of the total number of living and dead trees. There was recorded occurrence of gypsy moth (*Lymantria dispar*) as a potential risk factor, which sporadically caused different degrees of crown defoliation. There was also visible evidence of timber logging throughout the area with a character of either selection harvesting in the stand (Fig. 3a) or clearcutting (Fig. 5). Efforts of targeted forest management with its sustainability

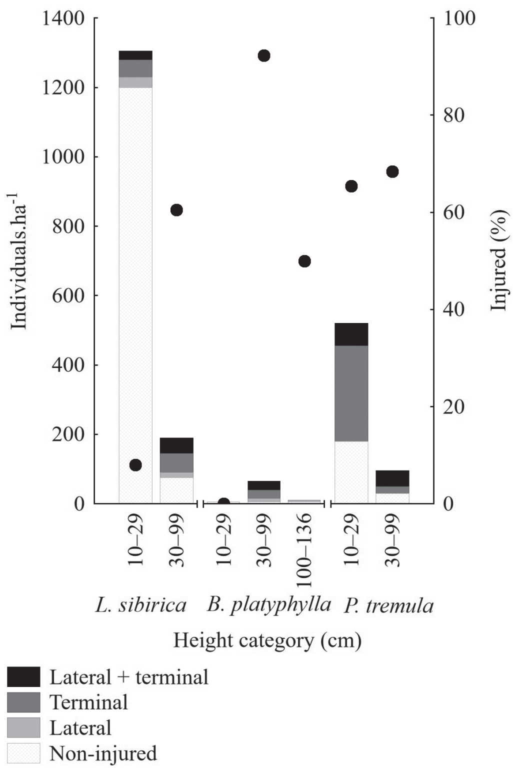

Fig. 4. Numbers (individuals, ha^{-1}) and structure of damage (%) of the seedlings

Fig. 5. Patch cutting without natural or artificial regeneration

Table 1. Forest characteristics. Growing stock SBA (m^3, ha^{-1}), number of trees (individuals, ha^{-1}), height (m): median (min–max), physiological and biomechanical vitality (degree), deadwood (individuals, ha^{-1}) in 2016

	L. sibirica	*B. platyphylla*
Growing stock SBA	33.25	0.33
Number of trees	405	10
Height	21 (7–35)	16 (9–23)
Physiological vitality (1–5)	2	1
Biomechanical vitality (1–5)	2	1
Standing deadwood Ø 10–50 cm	15	0
Standing deadwood Ø > 50 cm	5	0
Fallen deadwood Ø 10–50 cm	20	0
Fallen deadwood Ø > 50 cm	30	0

principles in the study area can be ruled out, because no artificial regeneration of forests was found and the protection of forests practically does not exist there.

In August 2017, 100% defoliation of *L. sibirica* was detected with focal area character east from the mine (Fig. 6a). Large-scale extend was confirmed by the analysis of satellite images (Fig. 6b).

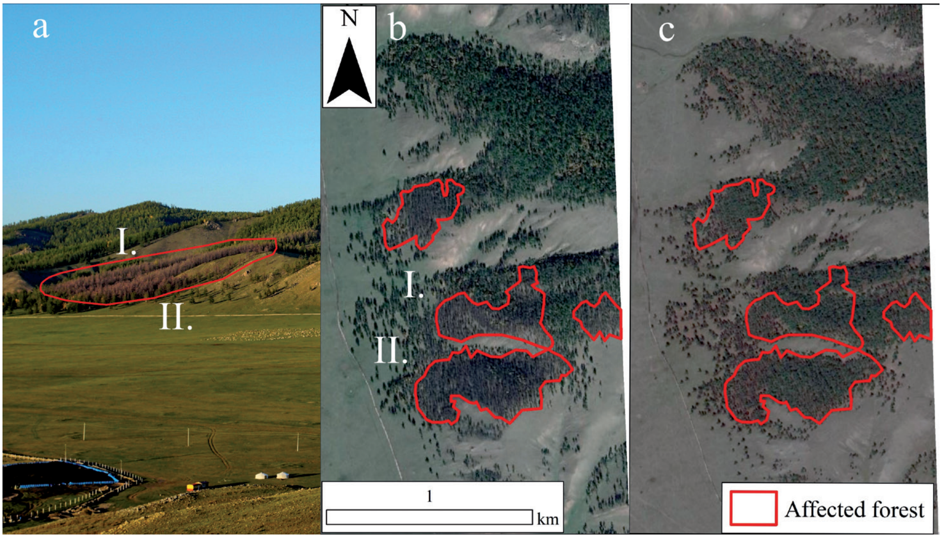

Fig. 6. Defoliation of forest near the mine. (a) situation from terrain 08.2017, (b) situation 09.2018, (c) situation 05.2017

The defoliation occurred between May (Fig. 6c) to August 2017. There were only standing individuals; no fallen timber was found. These stands did not show any damage caused by fire. Individual focal areas were of size 6–18 ha.

DISCUSSION

The city of Erdenet is the second most populated city in Mongolia (Enkhbayar 2019). As such, it represents an important market of livestock products and resources for herders, which is used by herders as they concentrate (Fig. 2) in large quantities around the city. However, this is a serious problem for local forest ecosystems as they are subjected to heavy grazing pressure.

The yurt household factor is also presented as significant by Sankey et al. (2006), as they found a lower grazing intensity in sites with lower number of yurt households. Very heavy grazing pressure, as it is described by Reimoser et al. (1999), was found in the whole study area. Local opening of stands by selection harvesting and clearcutting (Fig 3a, 5) simulates natural disturbances and processes typical for boreal forest, as Bondarev (1997) describes them. This creates ideal conditions for forest regeneration, but long-term intensive grazing around Erdenet has not allowed the successful growth of seedlings and thereby prevented the natural forest regeneration in the area. Poor condition of the seedlings is reflected in particular by low count of *L. sibirica*, *B. platyphylla* and *P. tremula* seedlings in height category of 30–99 cm and by the absence of these species in height categories over 99 cm. Similar situation is also described by Sankey et al. (2006), who indicate the absence of forest regeneration within the intensively grazed forest-steppe ecotones in Darhad Valley for the period of up to 30 years. Khishigjargal et al. (2013) also states the absence of *L. sibirica* saplings in excessively grazed forest of Altai Tavan Bogd National Park since the late 1970's. This observation is further confirmed by Hauck and Lkhagvadorj (2013) who report that long-term grazing pressure can totally stop successful forest regeneration for decades.

In contrast to the low number of seedlings in height category above 99 cm, there is a high number of *L. sibirica* seedlings within 10–29 cm height category (Fig. 4). This can point to suitable conditions for regeneration through opening of crown canopy, but it is also a direct consequence of overgrazing. In the affected forest, there is very low internal species competition (Khishigjargal et al. 2013), where 100–

200 cm height category individuals are missing and only mature trees are present. Therefore, seedlings have enough light: *L. sibirica* seedlings have extremely high light demand (Abaimov 2010). Only 8% of damage of 10–29 cm height *L. sibirica* seedlings is due to the fact that livestock do not prefer small seedlings, as it focuses on taller individuals (Khishigjargal et al. 2013). However, 61% was damaged within 30–99 cm height category.

The beginning of intensive grazing in the locality of Erdenet can be approximately deduced from height structure of the stand (Khishigjargal et al. 2013), because typically there is very common multi-aged tree age pattern for Siberian larch forests (Bondarev 1997), and in the studied stands next to Erdenet trees 1–7 m high are missing (Fig. 4, 7; Tab 1). From initial mapping of *L. sibirica* held in similar natural conditions of southern Khentii (unpublished data), cambial age of trees 8–13 m high was determined to be 36–52 years (true age plus 10–20 years, Dulamsuren et al. 2010). Even Koizumi et al. (2003) state age of *L. sibirica* individuals high 12.3–20.4 m in south Siberia to be in rage of 40–80 years. Kharuk et al. (2018) report age of *L. sibirica* high 9.8 ± 0.6 m 46 ± 3 years in the same area. From already mentioned, it can be assumed that the last generation of *L. sibirica* in the Erdenet locality has exceeded height 1 m approximately in 1980s, i.e. at the beginning of ore mining in Erdenet mine. In this southern part of boreal forests, age distribution can be a result of periodic catastrophic fires (Bondarev 1997). This fact can be avoided due to distribution of the plots and absence of fire damage of the remaining trees.

During 2017–2018, east from the mine, there has been noticed *L. sibirica* defoliation of focal area character confirmed by landsat image. Defoliation of larch can cause significant tree mortality in the dry sites (Jardon et al. 1994), thus, we assume there will be massive mortality of the stands in future years. Meanwhile, the confirmed scale of such damaged stands is more than 49 ha. Based on occurrence of gypsy moth, detected in 2016, we suggest that defoliation of *L.*

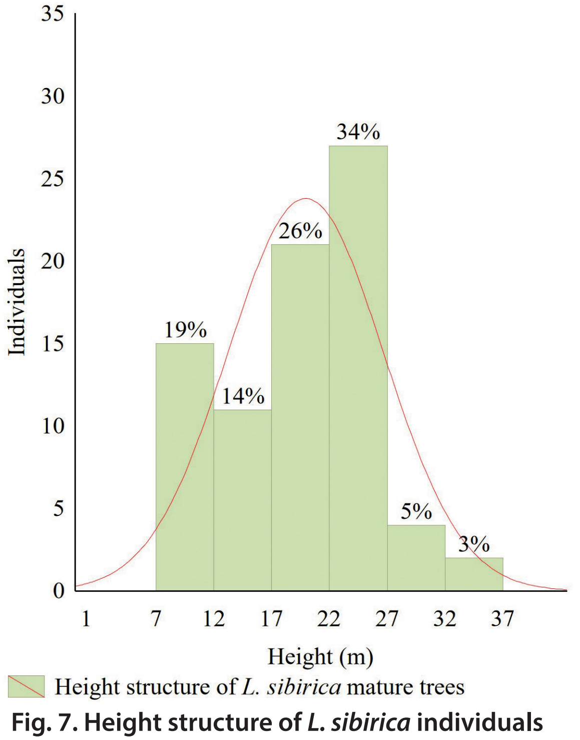

Fig. 7. Height structure of *L. sibirica* individuals

sibirica individuals is caused by increasing numbers of the pest. It can indicate influence of another stress factor, which has caused primary weakening of the stands, e.g. drought stress (Dulamsuren et al. 2010). Outbreak of gypsy moth causing extensive mortality of *L. sibirica* is described by Hauck et al. (2008) and Dulamsuren et al. (2010a) in the Khentii Mountains in the north of the Mongolia. Due to intensive grazing, there are not young individuals in the locality which would fill an ecological niche. Systematic artificial restoration of the stands cannot be expected as it is only very limited in Mongolia (FAO 2015) and it is very inefficient (Ykhanbai et al. 2010).

We assume that the current negative trend of forest regeneration inhibition due to overgrazing will further continue depending on the Cu-Mo mining in the Erdenet Ovoo mine. Mine metal stocks are calculated to provide for another 25 years of mining, at minimum until 2040 (Seltmann et al. 2004). Over that period, there is no assumption of significant population decline, and therefore no foreseen reduction in grazing livestock, which is needed to reduce the pressure on the overgrazed forests.

Herders do not respect forest grazing prohibition, neither in strictly protected area (our experience). Therefore, it is imperative to ensure the protection of the affected forest stands from further grazing, e.g. by fencing. It is currently the only truly effective measure, which is verified in the Mongolian environment at the stands of Domog Sharin Goll in the Khentii Mountains (Kusbach et al. 2017). Fencing physically prevents access of livestock to selected forest stands and thus protects them from further damage. Assuming that protective measures are implemented, the natural restoration of the heavily affected areas can also be realized by pioneer species of *B. platyphylla* and *P. tremulla*. Pioneer species will prepare the habitat for the growth of the late successional species of *L. sibirica*, as it happens in conditions of natural succession, such as in the case of habitats affected by the fire (Abaimov 2010). If no action is taken, there will be a risk of cutting dead trees after forest dieback in the short term, and since the defoliation of *L. sibirica* affects mainly forest edge, an immediate shift of the tree line will occur there. In the degraded stands, there will be a gradual change of environmental conditions (James 2011), which in the background of the Mongolian climate changes (Sato et al. 2007; Marin 2010; Oyuntuya et al. 2015) in synergy of intensive grazing, can represent a real threat of transformation of the affected forest ecosystems into steppe.

CONCLUSIONS

Erdenet city has become aim of the urbanization process due to ore mining. We assume that the high number of yurt households in Erdenet surroundings results from socioeconomic reasons, because the city presents a constant market for herder's products. Herders in the city surroundings prefer sites located close the forest: 52% yurt households were found within 1 km distance from the forest edge. As a result of their accumulation, an intensive overgrazing of larch forest occurs in the vicinity of the city.

Very heavy grazing pressure prevents successful growing of *L. sibirica* seedlings as the late succession tree species. *L. sibirica* individuals within 99–200 cm height category are completely missing in the stands. Further, seedling of pioneer tree species *B. platyphylla* and *P. tremula* do not grow well as no individuals were found in 137–200 cm height category. Individuals within 10–29 cm height category were found in large quantities and are generally less damaged, as livestock doesn’t prefer to feed on very small seedlings. High amount of lower seedlings was also allowed by increasing resource availability resulting from absence of intraspecific competition for light through the timber logging and by the absence of a higher height category seedlings. Disturbed height structure of mature trees indicates the beginning of the intensive grazing from 1980s.

In the forests located east of the mine, extensive defoliation of *L. sibirica* was found on more than 49 ha. Under current grazing pressure there will not be any natural regeneration to maintain actual tree line of threatened forest. The grazing pressure will not drop for at least 25 years, which is the remaining time of mining operation according to current plans. If the measures for the physical protection of natural forest regeneration against livestock grazing, such as forest fence, are not implemented, there is a real threat of forest transforming into steppe. Such a change would be difficult to reverse due to the resulting alterations of microclimate and soil hydrology.

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