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DEFORESTATION AND DEGRADATION OF FORESTS IN THE KHUSTAI NURUU MOUNTAINS OF NORTHERN MONGOLIA

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Deforestation and forest degradation in the forest-steppe zone is one of the most pressing issues in the world, involving territory of southern boreal forests in Northern Mongolia. The changes in forest cover between 1999 and 2016 and driving factors to deforestation and forest degradation in the Khustai nuruu mountains of the Northern Mongolia were analyzed. Forest monitoring was carried out in mature and over-mature flat-leaved birch *Betula platyphilla* Sukacz. forests with an admixture of aspen *Populus tremula* L. using the combined method of remote sensing and ground based field measurements. We found an accelerated deforestation trend between 2006 and 2009, which amounted to 463 ha (23.2 %) since deforestation in the Khustai nuruu mountains was started. Overall 17-year forest monitoring revealed that a total of 675 ha of forests were completely converted to non-forest area. As urgent measures to mitigate the effects and limit rapid deforestation in study area, it is recommended to improve the sustainable forest management via establishing optimum head of livestock and wild animals, strengthening prevention and control measures against pests, and reforestation on deforested areas using seedling of native tree species taken from forest nurseries in the region.

Keywords: *reduction of forested area, remote sensing methods of forest environmental monitoring, flat-leaved birch Betula platyphylla Sukacz., aspen Populus tremula L., natural regeneration.*

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INTRODUCTION

The process of forest degradation associated with deforestation is currently one of the common phenomenon in the world, and is interpreted as being particularly important from a functional point of view for maintaining the ecological sustainability in forested regions (FAO, 2010; Gunin et al., 2017).

In a broad sense, forest degradation is not only the death of trees and the reduction of forest area, but also it includes an understanding of the deterioration of the vital state of forest vegetation, a decrease in growing stock, biological productivity and species diversity of forest ecosystems, and simplification of forest structure (Karkhova, Davydova, 2017). Deforestation is the process of replacement of sufficient forest landscapes with deforested areas due to natural and anthropogenic disturbance factors (Ekologicheskie terminy…, 2010). Forest degradation and rapid deforestation in boreal forests are becoming an urgent problem in the northern hemisphere, especially in Central, Northeast and Southeast Asia (Angerer et al., 2008; Wang et al., 2012; Bazha et al., 2019).

A number of researchers have found that accelerated global warming has a negative effect on tree growth, productivity, and vital state of trees and stands (Danilin, Tsogt, 2014; Sukhbaatar et al., 2020; Juřička et al., 2020). Scientists also noted the importance of forest ecosystem services for mitigating the effects of global warming by sequestrating of greenhouse gases, maintaining moisture in soils, and biodiversity (Baigal…, 2016; Sukhbaatar et al., 2018, 2019).

Among the countries of Northeast Asia, the rapid deforestation occurs in the boreal forests of Northern Mongolia, which attracts special attention of foresters, environmentalists, and a researchers (Bazha et al., 2019). Forest degradation is characterized by a qualitative loss that affects the functions of forest ecosystems and is often caused by specific disturbances. Such violations include, for example, a decrease in growing stocks (Danilin, Tsogt, 2014; Ministry…, 2018). Ongoing forest degradation may ultimately lead to complete deforestation and even desertification (Wang et al., 2012; Tsogtbaatar, 2013). According to D. Bulgan et al. (2013), about 80 % of Mongolia's territory is already subjected to desertification and land degradation.

Mongolia is located in the transition zone between the Siberian boreal forests and the Central Asian dry steppe landscapes. According to the latest National Forest Inventory (Baigal…, 2016, 2017), the boreal forests cover more than 9.1 million hectares (7-8 % of the territory of Mongolia). These forests play an important role not only in domestic wood supply, but also in maintaining the forest ecosystem services, which include soil protection, retention of soil moisture, and biodiversity conservation (Ministry…, 2018). In this regard, and the ongoing loss of forests, it is increasingly important to introduce sustainable forest management practices that are well-adopted to global warming (Sukhbaatar et al., 2020).

Besides climate change, accelerated forest loss in Mongolia is mainly caused by forest fires, pests and diseases, overexploitation, overgrazing and unsustainable forest management (Tsogtbaatar, 2004, 2013; Dulamsuren et al., 2010; Valendik et al., 2018; Ministry…, 2018; Juřička et al., 2020). Thus, the spatial and temporal patterns of deforestation and forest degradation in northern Mongolia have not been sufficiently studied, and the key factors contributing to deforestation along the southern border of boreal forests have not been identified.

The main objective of this study is to assess the current state of the forests in Khustai Nuruu, and to analyze the dynamics of the forest-cover and identify the main factors causing deforestation and forest degradation.

MATERIALS AND METHODS

Study area. This study was carried out in the forested areas of the Khustai-Nuruu National Park (KNP), which is part of the Khentii Mountains and located located 95 km west from the city of Ulaanbaatar, Mongolia. The KNP in the west includes the Mongolian steppe and is located on the territory of the Altanbulag, Argalant and Bayankhangai soums of the Tuv province. The Mongolian government declared the site a National park in 1993, one year after the start of the Przewalski's horse *Equus ferus przevalskii* Poliakov (Mong. «Takhi») reintroduction project and in connection with biodiversity conservation.

Permanent sample plots were selected and established for our study, and geographical coordinate, altitude, exposure and slope were recorded (Table 1).

According to botanical and geographical zoning (Grubov, 1982), the study area belongs to the western Mongolian Dahurian forest-steppe zone, and is located on the southern border of permafrost, which is interrupted in places between 1400 and 1842 m above sea level (Bayarsaikhan et al., 2009). Climate in the study area is semi-arid and sharp continental.

The average annual air temperature is 0.3 °C, and the annual precipitation ranges from 131.1 to 291.2 mm, with 80 % of which falling during the growing season. (Bugd Nairamdakh…, 1971). Dry-steppe vegetation and small-leaved birches were often the dominant types and life forms in plant community structure of KNP, and these forests were formed on dark brown soils, and mainly distributed on the north-facing slopes of the mountain. In species composition, a total of 450 species of vascular

Table 1. Geographical characteristics of permanent sample plots (SP) established at the KNP

SP No.	Tree species*	Geographical coordinates		Altitude, m a. s. l.	Exposition and slope
		Latitude, N	Longitude, E		
1	B	47°42′16.5″	105°51′25.6″	1782	NW 12º
2	B	47°42′12.8″	105°51′20.3″	1802	NE 4º
3	B	47°40′44.4″	105°51′12.7″	1652	NW 8º
4	B	47°41′00.8″	105°51′38.6″	1536	NE 7º
5	B, A	47°41′36.3″	105°51′39.2″	1618	N 12º
6	B, A	47°43′00.7″	105°49′58.0″	1619	NE 11º
7	B, A	47°42′50.3″	105°48′48.3″	1633	N 13º
8	B, A	47°47′37.5″	106°02′01.9″	1541	N 8º
9	B, A	47°48′50.3″	106°06′08.1″	1588	N 15º
10	B	47°48′16.8″	106°03′14.6″	1574	N 11º

Note. * B – birch; A – aspen; N – north; W – west; E – east.

plants from 236 genera, belonging to 63 families, were identified.

The selected forests were pure and mixed natural flat-leaved birch *Betula platyphylla* Sukacz. stands with an admixture of aspen *Populus trimula* L. in terms of forest structure, which have a number of standing dried and fallen trees.

Sampling design and measurements. Permanent sample plots were established considering OST 56-69-83 (1983). A total of ten 20 × 20 m sized sample plots were established using a completely randomized design for the selection of these plots. The tree health was determined in accordance with the developed rules (O pravilakh…, 2017). All trees on the SP were assigned to the following categories of health condition: I – healthy (no signs of weakening); II – weakened (drying of branches up to 50 %); III – strongly weakened (drying of branches up to 2/3 of the crown); IV – drying out (drying out more than 2/3 of the branches); V – fresh dead wood; Va – fresh windblow; Vb – fresh windbreak; VI – old dead wood; VIa – old windfall; VIb – old windbreak; VII – emergency trees.

The description of the vegetation coverage and the study of the dynamics of plant growth were carried out according to generally accepted methods (Sukachev, Zonn, 1961; Metody…, 2002). The height of growing trees and dead wood was measured using a Vertex IV/360, and the diameter at breast height was measured using a diameter type. The total height of stumps and length of fallen trees were measured with a measuring tape, and their diameter at mid-height was measured with a caliper.

On each SP, an assessment of natural regeneration was carried out according to A. V. Pobedinskiy (1966). The undergrowth of woody plants was divided into following height classes: Class I – 10 to 50 cm; Class II – 51 to 150 cm; Class III – 151 to 300 cm, respectively. The sources of remote sensing data for landscape analysis for 8 years of observations (1999, 2006, 2008, 2011, 2014–2016) were multispectral images obtained from Ladsat-8 satellites and data from global digital elevation models (Scientific data..., 2016; SRTM ..., 2016). To process satellite data, we used the ERDAS 9.1, ENVI 4.7, QGIS 2.8, eCognition Developer 8.7 image processing programs and the R Studio statistical program.

Sweeping, twig shaking, and light traps were used to collect samples. Insects were monitored throughout the growing season from May to September 2017.

RESULTS AND DISCUSSION

Distinctive features of forest characteristics. The main stand characteristics of growing stock of selected forests in KNP presented in Table 2.

Table 2 showed a high variation in the stand variables, which were considered in the studied SP. Our results indicated that all stands basically belonged to age classes from VI to VIII (on average (65 ± 10) years) and are classified as mature and overmature.

This pattern of the age structure in natural birch stands may be a consequence of unsustainable forest management and poor natural regeneration in the forests of KNP. The prevalence of mature and over-mature birch stands, and the absence of young and middle-aged trees in the stand age structure therefore indicated the existence of a potential risk of sufficient deforestation in the study region.

Table 2. Main stand characteristics of sampled forests in KNP

Variables	Sample plot number										Mean
	1	2	3	4	5	6	7	8	9	10	
Age, years	–	54	60	63	85	64	79	55	62	67	65 ± 10
Tree stand composition*	10B	10B	10B	10B	10B+A	10B single A	10B+A	10B+A	10B+A	10B+A	10B + A
Average diameter, cm	12.7	15	13.7	13.5	11	13.7	14.4	8.7	16.4	7.7	12.7 ± 2.6
Average height, m	1.1	4.2	7.3	6.7	6.6	7.9	10.4	5.9	8.5	6.5	6.5 ± 2.4
Density, stems per ha^{-1}	920	32	120	540	680	460	420	880	380	1400	583.2 ± ± 384.9
Basal area, m^2 per ha^{-1}	–	–	1.8	7.8	6.6	6.8	6.8	5.3	8	6.5	6.2 ± 1.8
Growing stock, m^3 per ha^{-1}	–	–	6.2	28.8	24.5	28.3	34.9	16.6	38.2	24	25.3 ± 9.5
Bonitet/site quality	Va	V	V	V	Va	V	V	Va	V	V	V

Note. Mean value is expressed by standard deviation. * B – birch; A – aspen.

The stand density w^{-1} as varied greatly (p = < 0.001) among SP, and averaged (583.2 ± ± 384.9) stems per ha^{-1}. However, the lowest stand density was observed in SP 2 (32 stems per ha^{-1}), and contrary, highest in SP 10 (1400 stems per ha^{-1}), respectively (Fig. 1, 2).

In terms of site quality, all of stands were belonged to lowest bonitet classes (V and Va), which confirms their low productivity and slow growth rate. The average growing stock was only (25.3 ± 9.5) m^3 per ha^{-1} with an average height and diameter of (6.5 ± 2.4) m and (12.7 ± 2.6) cm, respectively (see Table 2).

Forest degradation and accumulation of dead aboveground biomass. Birch dominated small-leaved forests in KNP play an important not only in socio-economic development of the country, but also in maintaining of ecosystem sustainability, including water and soil protection, biodiversity conservation and nutrient cycling. The presence of numerous standing dead and fallen trees in the forests of KNP is an essential distinctive feature of this landscape. A large number of standing dead and fallen trees (birch and aspen) with varying degree of rotting were recorded in SP 5–8 (Fig. 3).

Meanwhile, the stocks of dead and fallen trees varied greatly (p = < 0.001) among studied stands. It should be noted that maximum amount of dead and fallen trees with high levels of rotting were recorded at SP 1, with single living birch trees, shoots, foliage and young growth of which are actively eaten by red deer (Fig. 4). The largest stock and density of dead wood observed in SP 3 and SP 6 (Table 3).

For example, a relatively high density of standing dead and fallen trees (560 stems per ha^{-1}) was observed in SP 1, and the stock was 24.5 m^3 per ha^{-1}. Such a picture, observed on over than 50 ha of area in the KNP, attracted special attention of researchers.

In general, it can be stated that a large accumulation of aboveground dead biomass with a high degree of decomposition, insignificant growing stock and density in the entire forest phytocenosis sufficiently confirm the real existence of forest degradation and the threat of complete deforestation in the study region.

Dynamics of forest cover and deforestation. Based on the 8-year use of the Landsat scenes and through visual deciphering of the boundaries of forest areas, multilayer cartographic images were formed, reflecting the dynamics of spatial and temporal patterns of forest cover change (Fig. 5).

At the beginning of growing season in 1999, the forests in the KNP were in a fairly healthy state with no signs of deforestation and forest degradation (see Fig. 5).

Comparative analysis of remote sensing images shows that the first significant reduction in forest cover occurred in an area of 226 hectares (11.4 % of the total forested area) in 2006 due to damage by a gypsy moth (see Fig. 5, 6). However, the dramatic reduction in forest cover occurred in the period between 2006 and 2009, and by the end of 2009, the forest cover had already decreased by 463 ha (23.2 %) of area.

We found that over a 17-year monitoring period, a total of 675 hectares (34 % of the total forested area) were completely replaced with non-forest eco-

Fig. 1. Weakened (category of health condition II) low density birch stand (SP 2) with grazing on the edge red deers *Cervus elaphus* Linnaeus (bottom, left) and Przewalski's horses (top, right).

Fig. 2. Weakened (category of health condition II) maximum density birch-aspen stand (SP 10).

systems. Overall, the annual loss in forest cover in the study area is 39.7 ha year^{-1}, and this rate of deforestation undoubtedly demonstrates that deforestation has become a real phenomenon in KNP area.

Thus, our findings revealed a tendency of intensifying deforestation in the study region, which tended to continue in the coming years. Thus, our conclusions revealed a tendency towards the intensification of the deforestation process in the studied region, which tends to continue in the coming years.

Factors affecting the natural regeneration and the vital state of forests. Natural regeneration is one of the main indicators of biological stability, productivity and reproduction of forest ecosystems.

Рис. 3. Heavily weakened (category of health condition III) birch stand (SP 6) with a significant amount of standing and fallen dead trees.

Fig. 4. Stand site with old wind-fallen trees and deadwood (category of health condition VIa) (SP 1) with grazing red deers, eating shoots, foliage, and young growth of the remaining single living birch trees and undergrowth.

The results of our study showed a relatively weak natural regeneration in the forests of KNP. This can be judged by the density of the young generation of the forest and its vital state. Our findings showed a high variation in undergrowth density thought sampled stands, ranging from 140 stems per ha^{-1} (SP 1) to 2570 stems per ha^{-1} (SP 5), and mean regeneration density was 1097 stems per ha^{-1} (Fig. 7).

Weak forest rehabilitation in our study was also confirmed by the health condition of undergrowth. Here, the dominant part (95.7 %) of undergrowth of white birch and aspen was classified as the category below 1.5 according to categories of health state (Fig. 7).

The existing relatively low density of regeneration and the serious health state of undergrowth in the study area emphasized the limited possibility of forming productive and full-fledged forests in the KNP. It is generally known that the forest is the optimal habitat for many species of mammals.

Table 3. Quantitative and qualitative characteristics of standing dead and fallen trees in the sampled stands

Variables	SP 1	SP 2	SP 3	SP 4	SP 5	SP 6	SP 7	SP 8	SP 9	SP 10
Dead standing birch trees										
Average height, m	–	4.5	2.9	4.2	3.6	5	3.3	3.9	3.6	3.4
Average diameter, cm	–	16	11.9	14.2	9	19.5	11	5.8	10.7	3.7
Density, stems per ha^{-1}	–	14	440	140	400	140	380	320	100	120
Basal area, m^2 per ha^{-1}	–	0.2	4.9	2.2	2.6	4.2	3.6	0.8	0.9	0.13
Timber stock, m^3 ha^{-1}	–	0.7	9.4	5.1	5.9	11.3	6.9	2.1	2.2	0.16
Dead standing aspen trees										
Average height, m	–	–	–	–	6	6.1	5.4	4.6	–	–
Average diameter, cm	–	–	–	–	14.2	11.5	10.8	5.8	–	–
Density, stems per ha^{-1}	–	–	–	–	180	100	80	1040	–	–
Basal area, m^2 per ha^{-1}	–	–	–	–	2.8	1	0.7	2.8	–	–
Timber stock, m^3 per ha^{-1}	–	–	–	–	8.5	3.3	1.8	8.5	–	–
Dead fallen birch trees										
Average height, m	7.8	–	4.7	3.8	4.6	3.5	5	–	5.7	–
Average diameter, cm	9.4	–	11.2	11	11.2	10.3	8.9	–	14	–
Density, stems per ha^{-1}	560	–	320	80	220	120	340	–	40	–
Basal area, m^2 per ha^{-1}	3.52	–	3.17	0.8	2.2	1.1	2.25	–	0.6	–
Timber stock, m^3 per ha^{-1}	24.5	–	6.5	9.2	4.3	1.9	5.8	–	1.84	–
Dead fallen aspen trees										
Average height, m	–	–	–	–	6.3	5.4	5.1	5.6	–	–
Average diameter, cm	–	–	–	–	11.2	11	9.2	5.3	–	–
Density, stems per ha^{-1}	–	–	–	–	260	400	100	60	–	–
Basal area, m^2 per ha^{-1}	–	–	–	–	2.6	23.6	0.72	0.7	–	–
Timber stock, m^3 per ha^{-1}	–	–	–	–	4.1	10.8	1.8	1.3	–	–

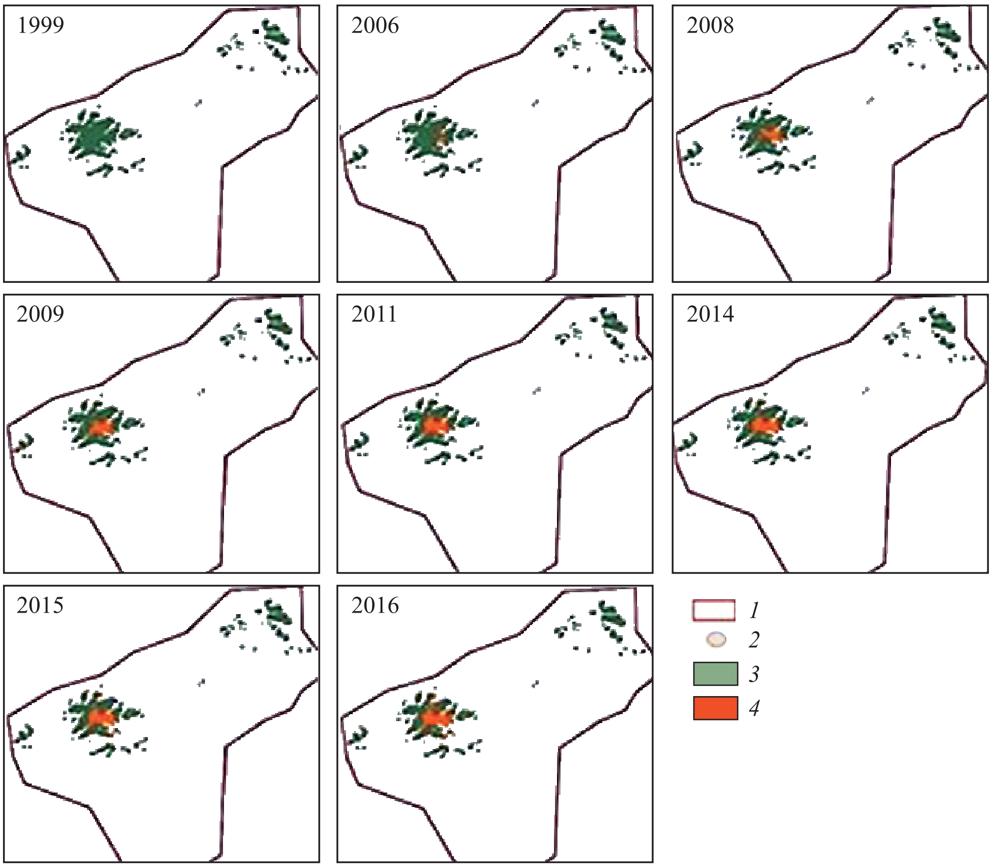

Fig. 5. Dynamics of spatial and temporal features of forest cover revealed by the Landsat scenes. Legend: *1* – border of the KNP; *2* – sample plots; *3* – forested area; *4* – deforested area.

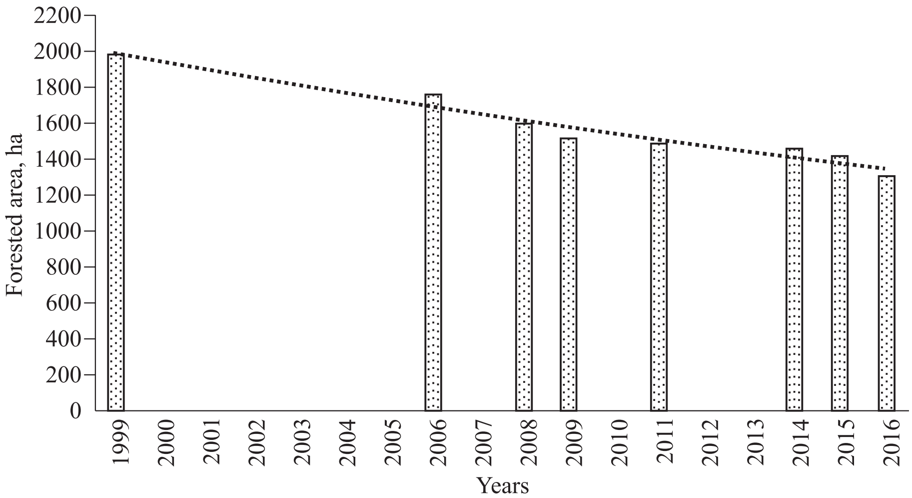

Fig. 6. The dynamics of the reduction in KNP forested area over the observation period 1999–2016.

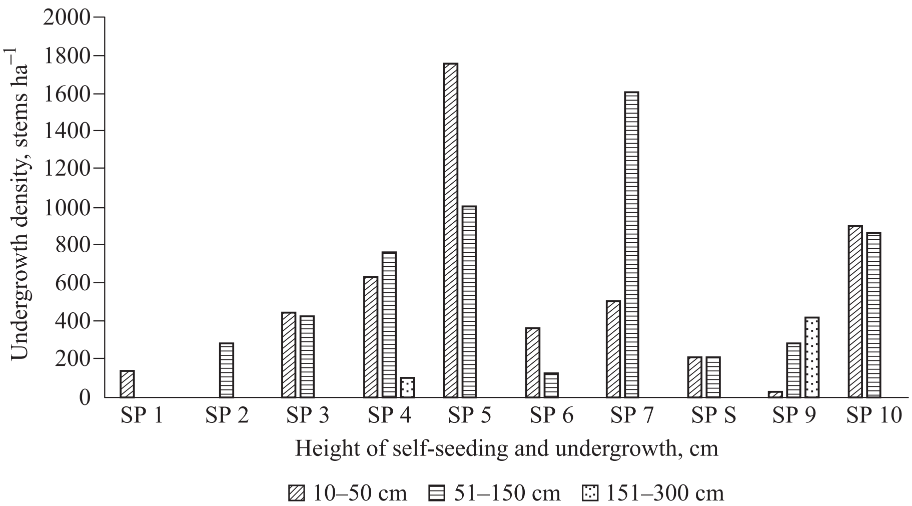

Fig. 7. Distribution of birch and aspen self-seeding and undergrowth densities by height categories on the sample plots.

According to biodiversity studies carried out in the KNP area, there are 55 species of mammals from 18 genera and 8 families were recorded (Hustai…, 2020).

The latest field inventories showed that more than 1300 red deers, 500 Mongolian gazelle *Procapra gutturosa* Pallas, and 330 Przewalski's horses live permanently on the territory of the KNP. Red deer and horses, especially in winter, as observations have shown, often feed on lower branches and bark of the trees, which leads to physiological stress and scars in young individuals. In particular, large mammals cause serious damage to the natural regeneration by eating and damaging undergrowth.

We found that the forest degradation and deforestation in the KNP are closely related to frequent pest outbreaks, and their destructive effect on tree health and wood properties. A total of 3417 individuals belonging to 37 species from 31 genera and 4 families were recorded in our forest pathological survey. Among them, 4 species of moths and 29 species of beetles were noted, which have a harmful effect on woody plants, reducing the processes of photosynthesis and damaging their above- and belowground organs. Especially, the gypsy moth *Lymantria dispar* Linnaeus, whose caterpillars eat up the foliage, has a detrimental effect on healthy birch and aspen trees.

According to U. Bayarsaikhan et al. (2009), a strong outbreak of the gypsy moth in the KNP territory was noted during the growing season of 1999, which caused significant damage to the forest resources. A few years later, J. Tsogtbaatar et al. (2004) reported that due to gypsy moth outbreak, 31 % of the forest cover was severely, 26.6 % moderately and 39.4 % slightly defoliated in the KNP.

Table 4. Survival of gypsy moth eggs in laboratory conditions

Plot No.	Number of egg, pcs	Number of eggs, pcs		Survival rate, %
		without larvae	with larvae	
1	310	181	129	42
2	560	204	356	64
3	275	203	72	26
4	140	135	5	4
5	650	415	235	36
Total	1935	1138	797	41

To determine the survival of gypsy moth eggs in laboratory conditions, a special experiment was carried out using 1935 samples collected (5 different parts) from eggs placed on stones and tree barks. The results of the laboratory tests on survival presented in Table 4.

The average survival rate was (34.2 ± 9.8) % and varied greatly ($p < 0.0001$) among the selected parts, ranging from 3.5 to 63.5 % (see Table 4). Such high rate of egg survival indicates existing potential risks of pest infestation and possible outbreak in the study area.

Suggested forest management solutions to limit forest degradation and deforestation. Several studies (Tsogtbaatar et al., 2004; Bayarsaikhan et al., 2009) have devoted to the forest degradation and deforestation, and importance of forest landscape restoration in Mongolia. Particularly, they noted that the current accelerated process of deforestation, which can ultimately lead to a complete loss of forest resources, requires the development and implementation of sustainable forest management in the coming years.

Our findings demonstrated that, besides of global warming, the pest outbreaks, overgrazing and high density of livestock and wild mammals are the main drivers of forest degradation and deforestation in KNP. To limit this processes, the following measures should be applied. Here, effective protection of forests from forest insect pests should be carried out through regular monitoring and operational control in the event of a massive outbreak. Moreover, to ensure successful natural regeneration and sustaining of forest ecosystems, there is a need to maintain an optimal population density of livestock and wild mammals grazing in the forests of KNP. Finally, to restore deforested areas, it is necessary to carry out drought-resistant reforestation (Wang et al., 2012) using seedlings of native tree species grown in a forest nursery (Sukhbaatar et al., 2018).

CONCLUSION

Based on results obtained from this study, it should be recognized that the problem of landscape deforestation and degradation in the boreal forests of Mongolia still remains unresolved, including deciduous forests in the KNP. Analysis of forest cover using satellite imagery showed that over the past 17 years, about 34 % of forested area has been converted to non-forest ecosystems. These data undoubtedly demonstrate the real processes of deforestation, which, due to the negative climate trend and other factors, will continue in the coming years. Deforestation was facilitated in the KNP by a complex of jointly acting factors: the predominance of mature and over-mature trees in the forest age structure, weak regeneration, excessively high population density of livestock and wild animals, pest outbreak and frequent droughts. To limit the real degradation of forests and deforestation in KNP, following urgent measures should be taken such as the implementation of sustainable forest management; determination of the optimal density of livestock and wild animals suitable for grazing; strengthening preventive and timely pest control measures and landscape restoration of deforested areas with native tree species. The implementation of the recommended measures is aimed at mitigating the rate of deforestation and forest degradation, while maintaining environmental functions of forest ecosystems, ensuring the ecological balance and biological diversity of the territory.

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ОБЕЗЛЕСЕНИЕ И ДЕГРАДАЦИЯ ЛЕСОВ В ГОРАХ ХУСТАЙ НУРУУ СЕВЕРНОЙ МОНГОЛИИ

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Обезлесение ландшафтов и деградация лесов в лесостепной зоне – одна из важнейших экологических проблем в планетарном масштабе, в том числе в Северной Монголии – на южной границе бореальных лесов. На основе анализа динамики лесопокрытой площади за 1999–2016 гг., проведенного на постоянных пробных площадях в горных лесах хр. Хустай нуруу Северной Монголии, выявлены ключевые факторы, ведущие к обезлесению ландшафтов и деградации лесов. Мониторинг лесопокрытой площади разреженных спелых и перестойных мелколиственных лесов с участием в составе древостоев березы плосколистной *Betula platyphilla* Sukaczev и частично осины обыкновенной *Populus tremula* L. проводился комбинированным методом. В районе исследований процессы обезлесения и деградации лесов только нарастали и наиболее активно протекали в период с 2006 по 2009 г., когда лесопокрытая площадь с начала процесса обезлесения (1999 г.) снизилась на 463 га, или на 23.2 %. В ходе 17-летних мониторинговых наблюдений установлено, что в общей сложности 675 га (34 %) утратило лесной покров. В качестве неотложных мер для смягчения последствий и сдерживания процессов обезлесения и деградации лесов рекомендуется совершенствование системы устойчивого управления лесами, установление оптимальной численности выпасаемых домашних и обитающих диких животных, усиление профилактики и мер борьбы с насекомыми-вредителями, проведение лесовосстановительных работ на утративших лесной покров площадях с применением крупномерного посадочного материала из местных древесных пород.

Ключевые слова: *сокращение покрытой лесом площади, дистанционные методы лесоэкологического мониторинга, береза плосколистная Betula platyphylla Sukacz., осина обыкновенная Populus tremula L., естественное возобновление.*