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FOREST MANAGEMENT IN MONGOLIA – A REVIEW OF CHALLENGES AND LESSONS LEARNED WITH SPECIAL REFERENCE TO DEGRADATION AND DEFORESTATION

ABSTRACT. The natural conditions, climate change and socio-economic challenges related to the transformation from a socialistic society towards a market-driven system make the implementation of sustainable land management practices in Mongolia especially complicated. Forests play an important role in land management. In addition to providing resources and ecosystem functions, Mongolian forests protect against land degradation.

We conducted a literature review of the status of forest management in Mongolia and lessons learned, with special consideration to halting deforestation and degradation. We grouped our review into seven challenges relevant to developing regionally adapted forest management systems that both safeguard forest health and consider socio-economic needs. In our review, we found that current forest management in Mongolia is not always sustainable, and that some practices lack scientific grounding. An overwhelming number of sources noticed a decrease in forest area and quality during the last decades, although afforestation initiatives are reported to have increased. We found that they have had, with few exceptions, only limited success. During our review, however, we found a number of case studies that presented or proposed promising approaches to (re-)establishing and managing forests. These studies are further supported by a body of literature that examines how forest administration, and local participation can be modified to better support sustainable forestry. Based on our review, we conclude that it is necessary to integrate capacity development and forest research into holistic initiatives. A special focus should be given to the linkages between vegetation cover and the hydrological regime.

KEY WORDS: forest management, Mongolia, deforestation, degradation

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INTRODUCTION

The development and implementation of sustainable forest management strategies is a key environmental policy issue in Mongolia (Gerelbaatar et al. 2019a). The forests of northern Mongolia not only provide resources such as timber and firewood, but also ecosystem services that are relevant to the well-being of the whole country, such as water purification and retention, erosion control, and biodiversity (Krasnoshhekov 2001; Tsogt et al. 2018; Government of Mongolia 2018). However, nearly 80% of Mongolian territory is exposed to desertification and land degradation (Bulgan et al. 2013). With continuing forest loss and increasing utilization pressure (Tsogtbaatar 2004; Hansen et al. 2013; Government of Mongolia 2018), it is increasingly challenging to establish sustainable forest management practices in Mongolia. It is particularly problematic that forest management in Mongolia often fails to consider science-based standards (Oyunsanaa 2011). This is partly due to a lack of utilizing conclusions from research for regionally adapted management standards and the practical application of suitable management models. Further challenges are related to structural weaknesses in terms of implementation control and administrative oversight (Benneckendorf 2011). Despite nationally and internationally financed initiatives to improve the situation, the overall tendency of forest loss and degradation has been neither stopped nor reversed.

With regard to forest loss and degradation in Mongolia, the phenomena of deforestation and forest degradation need to be distinguished. Deforestation refers to a severe (>90% canopy cover loss) or total loss of forest cover (Government of Mongolia 2018). In contrast, degradation is characterized by a qualitative loss that affects forest ecosystem functions and is often triggered by specific disturbances. Such disturbances may include a decrease in stocking volume (Government of Mongolia 2018) or a shift toward broad-leaf pioneer tree species after intensive logging (Gerelbaatar et al. 2019a). Continuing degradation can eventually lead to complete deforestation (Government of Mongolia 2018; Gerelbaatar et al. 2019a) and even desertification (Khaulenbek and Kang 2017). Direct drivers of deforestation and forest degradation are disturbances such as fire, pests, unsustainable harvest practices, overexploitation of forest resources, mining activities, and overgrazing (Kondrashov et al., 2008; Ykhanbai 2010; Dulamsuren et al 2011; Khishigjargal et al., 2014; MET 2016; Government of Mongolia 2018; Khongor et al. 2018). Underlying drivers include climate change, which affects the frequency and severity of droughts (Davi et al. 2013) and factors related to socio-economic and political transformation processes in Mongolia (Saladyga et al. 2013), which encompass demographic factors, institutional organization, and the political and legal framework (Government of Mongolia 2018). On local scale permafrost degradation can also trigger forest degradation (Juřička et al. 2018). All of these aspects need to be understood in order to develop a sustainable forest management framework that can safeguard healthy ecosystem functions and resources, as well as halt or even reverse deforestation and degradation.

We conducted a literature review of the above-mentioned drivers of deforestation and degradation, as well as of the most important ecosystem functions and key socio-economic demands with the goal of identifying and outlining key challenges and lessons learned for forest management in Mongolia.

MATERIALS AND METHODS

We reviewed literature from the international scientific community, the Mongolian government, international projects, and other sources relevant to our objective of formulating the following key challenges for forest management in Mongolia: (1) *Adaptation to and mitigation of global warming-induced desertification; (2) Resilience against more frequent and severe natural disturbances; (3) Linking forest and water resources management; (4) Supporting forest regeneration against deforestation and degradation: Afforestation, reforestation, and underplanting; (5) Managing the conservation of nature, biodiversity, and wildlife; (6)Increased resource utilization and demand in forested areas; (7) Consideration of the social and political-cultural background*. In total, 155 publications were reviewed for this study. Of those, 125 sources are directly related to research, development work, or projects in Mongolia or its immediate neighbors, 21 provide a rather general global or theoretical background relevant to the challenges in Mongolia, and 9 provide specific insights from other regions of the world that may be transferable to Mongolia. For each challenge, we provide a short overview of the current situation and of lessons learned from recent studies or projects in the region.

Challenge 1: Adaptation to and mitigation of global warming-induced desertification

Central Asia is one of the global hotspots of climate change; over the past century, temperatures have risen faster than the world average. This trend is likely to continue in the future (Unger-Sayesteh et al. 2013; Mannig et al. 2013). According to Yu et al. (2003), "the center of the warming zone appears to lie just southeast of Lake Baikal, putting the drylands of northern China and Mongolia near the center of this hot spot".

In the Mongolian context climate change is usually expected to lead to overall warmer and drier conditions and more droughts (Batima et al. 2005, Dulamsuren and Hauck 2008, IWRM 2009). In general, the literature sources constitute that mean annual temperature has risen significantly during the last decades. However, because of different data material, time frames and methodologies the information differs, between rather low increase, for example of 0.4 °C between 1951 and 1990 (Yatagai and Yasurani 1995) to moderate, e.g. with a reconstructed increase of about 1.5 °C of growing season temperature compared to previous centuries (Davi et al. 2013), and even strong increase of 2.14 ° C during the last 70 years (Oyuntuya et al. 2015). According to Oyuntuya et al. (2015), precipitation has decreased in most regions by at least 0.1 mm/year. Sato et al. (2007) expects a further decrease of precipitation for some parts of northern Mongolia. With regard to future precipitation trends, there is a considerable model uncertainty for this region (Karthe et al. 2014).

A concern raised in many sources is that climate change may exacerbate desertification throughout the country. As northern Mongolia is an extreme and marginal habitat for trees, even minor changes in temperature and water availability may lead to significant changes in forest cover. For the Sibirian larch (*Larix sibirica* Ledeb.), which is the dominant tree species throughout most of the Mongolian taiga, Dulamsuren et al. (2011) and Kansaritoreh et al. (2018) observed growth declines since the 1950s and correlated them with increasing drought frequency during the growing period. Climate change impacts are likely to be most drastic in the forest steppe, where conditions may become unsuitable for tree growth (Angerer et al. 2008). Dulamsuren et al. (2010a) even suggested a supra–regional decline of certain tree species, specifically larch. However, not all studies predict such alarming scenarios. In their reconstruction and projection of past and future droughts, Hessl et al. (2018) conclude that the recent extreme drought (in 2000) and pluvial (in 1990) are very rare, but not without precedent in the last 2060 years. Based on comprehensive dendrochronological studies, Slemnev et al. (2012) concluded that spurts of forest regeneration in Mongolia coincide with especially moist periods that occur approximately every 40-100 years. Thus, climatic conditions and water availability in particular are the main factors shaping the distribution of the main vegetation zones in Mongolia.

From our literature review, we have identified three key areas of action to improve forest management in Mongolia. First, *forest management practices* need to adapt and be adaptable to changing climate conditions, which also includes special consideration of permafrost sites. Second, there needs to be a concerted effort to *combat desertification* along the forest-steppe border zone. Finally, Mongolia needs to assess and improve the *carbon sequestration capacity* of its forests to help offset greenhouse gas emissions.

Lessons learned

Climate effects on trees and climate-resilient forestry

A number of recent studies have evaluated the growth performance of tree species and their resilience to droughts and other climatic changes. There is a strong agreement that a minor temperature increase and/or a decrease in precipitation will have mostly negative effects on the growth of larch trees (Dulamsuren et al. 2011; James 2011; Khishigjargal et al. 2014), Scots pines (*Pinus sylvestris* L.; see Demina et al. 2017), Siberian stone pines (*Pinus sibirica* Du Tour; see De Grandpré et al. 2011), and especially spruce (*Picea obovata*, Ledeb.; see James 2011) and birch trees (*Betula platyphylla* Sukaczev; see Gradel et al. 2017a; Verhoeven et al. 2018). Studies that include dark coniferous trees are, compared to larch, rare for Mongolia. However, some authors have found indication of a potentially climate-induced decline in dark conifers in northern Mongolia (James 2011; Gradel et al. 2018). Overall decline of dark coniferous, for various reasons, is even more evident in neighboring southern Siberia (Kharuk et al. 2013). These conclusions are not yet final and specific long-term research protocols need to be implemented to shed more light. The species-specific demands of spruce and fir also indicate that stands at the southern distribution border may be more strongly affected by climate change. Dorjsuren (2014) has found that also the quality of larch seeds in Mongolia has decreased since 1980 due to drought. Similarly, Gao et al. (2017) conclude that birch seedlings are more sensitive to water deficit than larch seedlings, and Gradel et al. (2017a) have shown that younger trees are more susceptible to drought than older trees, most likely due to their less-developed root architecture and other factors. These findings indicate which species or development stages of trees may be especially affected if the climate gets drier.

Climate-resilient forestry depends also on the availability of suitable trees species and mechanisms that promote forest regeneration. Due to natural selection, certain provenances of one tree species can be especially valuable for climate-resilient forestry. Extensive research has been conducted on the genetic variation of Siberian tree species such as *Larix sibirica* (Semerikov et al. 2013; Krutovsky et al. 2014) and *Pinus sibirica* (Krutovsky et al. 2014). Research in the framework of the Czech – Mongolian forest cooperation also aims at understanding and improving tolerance to water scarcity (Kusbach et al. 2017). Based on recent research, adapted silvicultural measures for climate-resilient forest management have been proposed. These include analysis and establishment of specific selective harvesting measures and the development of adjusted regeneration and planting concepts (Gradel 2017; Gerelbaatar et al. 2019b). Some European studies, for example, have reported that thinning could be a measure for climate adaptation, since it has a positive impact on the amount of water available to the remaining trees (Gebhardt et al. 2014, Olivar et al. 2014). However, the effects of thinning can vary greatly, particularly when viewed from the level of a single tree to a stand to an entire site (Bolte et al. 2010). Studies that focus solely on the impact of thinning on the water balance in Mongolian forest stands are yet not available.

Combating desertification

Tree planting is frequently used as a tool for combating desertification at the forest steppe border and often focuses on the establishment or maintenance of scattered woodlands. The Korean-Mongolian *Center for Combating Desertification in Arid and Semi-arid Areas* (CCDASA) is a cooperation platform between key Korean and Mongolian institutions and explores solutions for the recovery of degraded deforested sites. Joint capacity-building measures are combined with field-based research in the southern part of the Bulgan province (see Fig. 1). Research includes the testing and selection of suitable clones (poplar species), agro-forestry experiments, testing of soil improvement and irrigation practices (especially drip irrigation for seedlings and saplings), studies of tree genetics and physiology, GIS analyses, and social-economic analyses (Khaulenbek and Kang 2017).

Planting methods that were adjusted to reduce earthwork costs and enhance tree growth were recently tested, after which the height and crown growth of *Populus sibirica* Tausch seedlings showed significant improvement (Jo and Park 2017a). The authors found that seedling survival rate and height growth improved with shorter irrigation intervals and denser planting (1.5 m spacing compared to 3 m spacing). The results for *Salix rorida* Lacksch., *Populus sibirica*, and *Ulmus pumila* L. were also promising, with *Salix rorida* showing the fastest growth (Khaulenbek and Kang 2017). Poplar and elm species are particularly suitable because they are relatively fast-growing and well-adapted to difficult environments. They therefore provide important wind-breaking benefits within a fairly short amount of time.

Silviculturists discuss the impact of plantations on groundwater in the desert. According to CCDASA scientists, it is very important to ensure that plantation species are chosen to suit the groundwater conditions at the plantation site. However, some trees, such as *Salix rorida,* can survive as shrubs on sand dunes without any irrigation at all. Planting trees specifically to create windbreaks has also been tested and found significantly increase crop yield (Jo and Park 2017b). On a larger scale, the "green belt" project in the south of the country was established in order to halt degradation and reduce dust and sand storms by establishing a belt of planted trees, such as Saxaul forest plantations in the Gobi Desert (Batkhuu et al. 2017a).

Carbon sequestration

Undisturbed boreal forests are considered to be carbon sinks. However, major disturbances that result in large-scale degradation can trigger continuous carbon emissions from these forests. Measures that reduce emissions from deforestation and degradation therefore go hand in hand with other objectives for stabilizing

(A) (B)

Fig. 1. Nurseries were established and sites afforested at the Elsentasarkhai Station in Bulgan Province by the ERCCD (Experimental Research Center to Combat Desertification) under the Institute of Geography and Geoecology (Mongolian Academy of Sciences). A) Irrigation system in a nursery with seedlings. B) A successful poplar nursery

forest cover. Sufficient inventory data are important for deriving country-wide information on the extent, density, and quality of forest resources. Dulamsuren et al. (2016) presented one of the earliest comprehensive studies of carbon pool densities in Mongolian forests. Mongolia is the only country with boreal forests under the UN REDD programme (UNFCCC 2019) and has recently submitted a national Forest Reference Level (Government of Mongolia 2018; Khongor et al. 2018). For the 2005-2015 period, carbon removals were much lower than emissions and no clear trend was detected, as emissions and removals varied significantly from year to year (Government of Mongolia 2018). The capacity for carbon sequestration may be improved through certain silvicultural practices (including reforestation). Unsustainable harvest practices and dead wood clearing can trigger negative long-term consequences for the forest carbon pool, for example by reducing the organic matter content of the soil (Gerelbaatar et al. 2019a). By reducing canopy cover, intensive logging and fire can trigger the melting of insular permafrost and the release of soil carbon (Juřička et al. 2018). Improved control of certain large-scale disturbances (e.g. fire) would also reduce direct carbon emissions. However, climate change is expected to trigger more frequent and severe disturbances, including fires and insect infestations (Ykhanbai 2010; Tchebakova et al. 2011, Dulamsuren et al. 2011). Such disturbances can lead to increased carbon emissions for years after the disturbance (Government of Mongolia 2018). Dulamsuren et al. (2016) predict that the carbon pool of Mongolia's forests will likely decrease further unless strong measures are taken at the national level.

Challenge 2: Resilience against more frequent and severe natural disturbances

In general, disturbances can be characterized by the following criteria (Pickett and White 1985; Puettmann and Ammer 2007): magnitude, intensity/severity, frequency and seasonality. Magnitude refers to the spatial extension (small scale or large scale). The severity of disturbance can be described by the degree of relative removal of basal area by considering all diameter classes, e.g. in form of an event analysis (see Gadow et al. 2005). Frequency refers to recurrence intervals and seasonality to the likelihood of occurrence of a disturbance during a certain time in the year (Sagwal 1991). Small and large scale disturbances by storms or certain weather events (e.g. snowbreak) are common during late spring and early autumn in Mongolia's mountain forests, but play a less significant role compared to the most eminent natural disturbances, which are fire and insect outbreaks (Tsogtbaatar 2004; Oyunsanaa 2011; Gradel 2017). Therefore, further contemplation in this review is on the latter two disturbances.

Lessons learned

Forest fires

Fire is the most common disturbance in Mongolia and is often related to dry weather conditions (Goldammer and Furyaev 1996; Kondrashov et al. 2008; Hessl et al. 2016). Approximately 95% of the forest fires in Mongolia are caused by humans; the remainder are largely due to lightning (MET 2017a; 2017b; Government of Mongolia 2018). Fires are most common during spring and to a lesser extent in autumn (Government of Mongolia 2018), when conditions are relatively dry. In Mongolia, heavy rains occur frequently during the summer months, which is the reason why fires do not usually spread at this time of year. Much of the outcome of a fire depends on its intensity. Surface and ground fires are less damaging than crown fires. Short return intervals between more intense fires can lead to the continuing reoccurrence of pioneer stages and prevent forest succession (Makoto et al. 2007; Gradel et al 2017b). Climate and fuel load are key determinants of the severity of a fire (Tanskanen and Venalainen 2008; Onderka and Melichercik 2010; Government of Mongolia 2018; Keane 2018): higher fuel loads and drier climates facilitate more severe fires.

Oyunsanaa (2011) found that the average frequency of forest fires in the pine forests of the northwestern Khentii Mountains is quite short, with only 11.6 years on average. Hessl et al. (2016) concluded that although overall fire return intervals have not changed considerably since 1900, there has been a trend toward more fires and shorter fire return intervals since the 1500s. The same study concluded that limited fire activity over the last century may be due to the coincidence of drought and intensive grazing, which have reduced fuel continuity and fire spread. However, recent official data (MET 2013; 2017b) suggest that fire has become more frequent in the last two decades in Mongolia (see Fig. 2).

Fire often weakens the resilience of tree stands against secondary disturbances (Government of Mongolia 2018); for this reason, the prevention of forest and steppe fires is mentioned in the very first article in the Forest Law of Mongolia (MOLF 2015). Fire management activities should respect the timely perspective and intensity of the fire disturbance. In this context, some authors refer to three phases of the wildfire cycle: the pre-fire environment, the fire environment, and the post-fire environment. Each phase requires different management actions (Graham et al. 2004; Keane 2018). In Mongolia, the wooden debris is often removed after logging in form of cleanings. If the management goal is to increase stand resilience, silvicultural measures that take into account disturbance history and succession stage (e.g., burned/recently disturbed, early stage, mid-seral stage, late seral stage, and climax) need to be considered.

At the stand level, different silvicultural measures (thinning, prescribed burning) for increasing fire resilience in Mongolian forests are controversial. A study by Fischborn (2011), for example, did not find a relationship between stand density and fire susceptibility in the upper Eroo basin, and therefore did not support the hypothesis that selective cutting increases fire resistance at the stand level. Prescribed burning has been tested in Mongolia as one means of reducing the fuel load (Kondrashov et al. 2008). In neighboring Buryatia, prescribed burning is at some places practiced in order to reduce grass fuel load (Forestry Agency of Buryatia 2019). The immense input required to implement such a measure (e.g., planning, security, and personnel) also makes the application of, for example, prescribed burning at a broader scale prohibitive. Studies at a larger scale, however, indicate that there is indeed a connection between forest fire intensity and stand density (e.g., Kondrashov et al. 2008; Teusan 2018). The evidence suggests that this is due to higher fuel loads, as Teusan (2018) showed for the northern slopes in Selenge Aimag. For this reason, site-specific selective cutting practices should be evaluated further. As an alternative to prescribed burning, thinning of the larch and birch forests has been shown to have a positive short-term impact on the growth and vigor of the remaining trees, which may increase the resilience of individual trees (Gradel 2017).

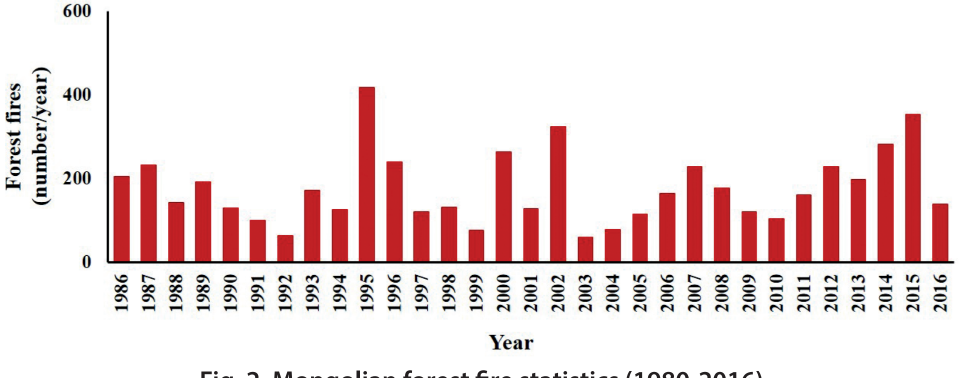

Fig. 2. Mongolian forest fire statistics (1980-2016)

It is important to note, however, that the reduction in canopy cover resulting from tree thinning measures may impact the permafrost; this potential consequence requires further study.

Thinning, however promotes diameter growth and usually bark thickness increases as stem diameter increases (Rosell et al. 2017); thick bark helps to protect the cambium of trees against fire. Recent studies have highlighted the close connection between fire-affected ecosystems and bark thickness, and shown that fire regimes influence whether and to what extent trees invest in bark thickness as a protection against fire (Pausas 2014; Pellegrini et al. 2017). In Mongolia fire frequency and intensity drive processes affecting tree species composition and competition. Recent results from the western Khentii Mountains indicate that fire intensity and frequency may control competition between thick-barked light coniferous trees and thin-barked birch; thus, the fire regime drives interspecific competition to some degree (Gradel et al. 2017b).

Beside intensive logging, fires are considered to be the main cause for the recent compositional shift from one tree species to another. In Mongolia and neighboring regions, this shift is often from coniferous to deciduous forests (Tikhonova et al. 2018; Gerelbaatar et al. 2019a). Birch often dominates after disturbances due to its sprouting ability (Otoda et al. 2013). To prevent the dominance of birch, low-intensity prescribed burning in birch-light coniferous forests may help promote the dominance of light coniferous trees (Gradel et al. 2017b), which may have more silvicultural value. Kondrashov et al. (2008) conclude that susceptibility to forest fires is related to ground vegetation (mainly grass fuel load), as is the resulting intensity of those fires. Thus, measures should focus on suppressing the ignition of fires.

With regard to suppression of an unintended fire outbreak, the intensity and magnitude are main parameter. During the active phase, weather conditions and fire suppression actions are decisive. Early suppression is reported to be especially successful (Keane 2018). In the Mongolian context, initial attacks on small fires with small groups of locals is one approach. Depending on the regional fire frequency of the respective forest area, the post-fire environment may endure for centuries. In this context, secondary disturbances and forest dynamics (short- and long-term response of the ecosystem) are relevant. The Mongolian government takes a number of forest fire preventing measures during the fire season (spring: late March – mid June, autumn: September – end October) by restricting activities including tourism, timber harvesting, and other silvicultural measures. In the forested regions, local administration pays special attention to firefighting capacities. Finally, restoration of forests after fire and other large scale disturbances is of special importance (Danilin and Tsogt 2012; 2014), which is part of another chapter.

Insects

Insects are an important part of healthy forest ecosystems. However, insect infestations often exacerbate previous damage (e.g. from fire) and are not uncommon in the boreal forests of northern Asia. Droughts and general forest degradation increase the frequency and severity of insect infestations because they weaken the resilience of the affected forest stands. This does not necessarily need to lead to significant forest dieback, however (Kharuk and Antamoshkina 2017). Important herbivorous insects in the region are currently *Lymantria dispar, Erannis jacobsoni,* and *Dendrolimus superans sibiricus* (Dulamsuren et al. 2010b; 2011; Gradel et al. 2017a). The invasive bark beetle (*Polygraphus proximus)* has recently been found in the fir forests of neighboring Siberia, but it has yet to be observed in Mongolia (Kharuk et al. 2017). However, official data show a clear increase in the area affected by insects and diseases in recent years. But the area where control measures are implemented stagnates, as shown by recent statistic data (MET (2017b). See Fig. 3.

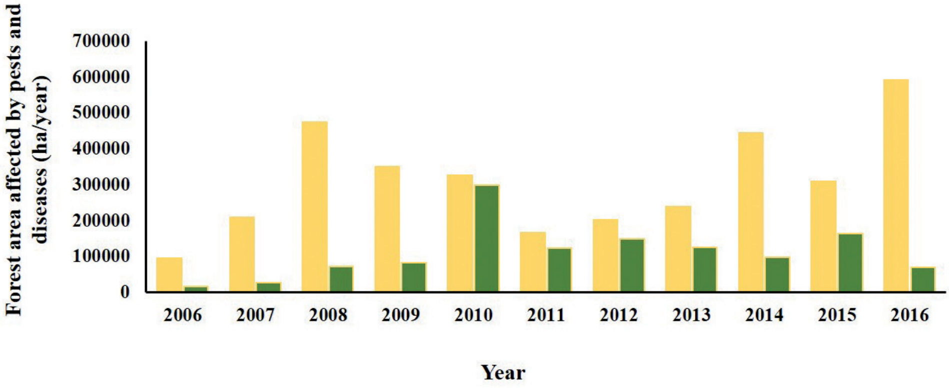

Fig. 3. Total forest area affected by pests and diseases in Mongolia (2006-2016). Light yellow: overall forest area affected by insects and diseases. Green: area where control measures have been implemented

Because winter temperatures and snow cover duration influence insect populations, they also (further) influence tree growth. The negative impact of higher mid-winter temperatures or the positive effect of above-average snow cover on insect populations is reflected in the growth rate of larch and birch during the subsequent vegetation period (Dulamsuren et al. 2011; Khishigjargal et al. 2014; Gradel et al. 2017a). Survival rates of eggs of *Lymantria dispar*, for example, can be related to threshold values of the surrounding air temperature (Waggoner 1985). Ongoing and projected climate warming will further exacerbate the current trend of increasing insect infestations. Options for increasing the resilience of forest stands against pests should therefore be considered in the development of Mongolian silviculture. Such options include more effective fire prevention and the regular removal of damaged and diseased trees.

Challenge 3: Linking forest and water resources management

Mongolia's climate is characterized by its high continentality, which results in limited water availability even in the relatively wettest mountain regions of Northern Mongolia. Consequently, there are strong and bidirectional links between forest cover and hydrology. On the one hand, northern Mongolia is a marginal habitat for trees, and small regional differences in water availability make the difference between closed taiga forest, open stands of trees or steppe as the dominant land cover (Dulamsuren et al. 2008; 2009). Therefore, any changes not only in precipitation but also in the regional hydrology (e.g. permafrost degradation, changes in the rates of evaporation, surface runoff and water infiltration into soils) are likely to have profound changes on the presence of trees. On the other hand, forest cover itself plays an important role for the regional hydrology – even more so because the headwater zones of all major river systems are located in forested mountain areas. Forest losses in these regions are therefore likely to have profound impacts on ground and surface water availability (Krasnoshhekov 2001; Kopp et al. 2017; Juřička et al. 2018). These linkages mean that forest and water management should be considered and implemented in an integrated way.

Lessons learned

Preservation of the mountain taiga is a prerequisite for ensuring water availability in lowlands

In a global perspective, Central Asia is one of the regions with the highest proportion of discharge formed in mountain areas (Viviroli and Weingartner 2004) which also contain a significant amount of the region's forest cover (Karthe et al. 2017a).

Mongolia is no exception to this, and the four forested mountain regions of Khentii, Khangai, Khuvsgul and Altai are the sources of the country's most important river and lake systems, comprising amongst others the Selenga and Lake Khuvsgul in Northern Mongolia, the Kherlen and Onon rivers in Eastern Mongolia, and the Khovd river and Valley of Great Lakes in Western Mongolia. For the Selenga, which is in terms of discharge the most important river system in Mongolia, forest cover in different subbasins ranges from a few percent (e.g. 5% in the subbasin of the Tuul river) to about two thirds (e.g. 66% in the subbasin of the Eroo river) and even more along some of its Russian tributaries (Karthe et al. 2017b). At the scale of such subbasins, contrasts become even more evident. For the Kharaa river system, for example, Menzel et al. (2011) showed that the specific runoff generated in forested mountainous headwater regions is about two to four times higher than in steppe-dominated regions. In this specific river basin, about two thirds of the total runoff is generated in those 20% of the catchment that are covered by mountain forests (Menzel et al. 2011).

Whereas the headwater regions are zones of surface runoff and groundwater formation, Mongolia's major water users are the urban and industrial centers of Ulaanbaatar, Erdenet and Darkhan and the agricultural and mining areas, many of which are located along the mid- and downstream sections of major rivers (Karthe et al. 2014; Kasimov et al. 2017). Rapid urbanization, a boom in mining and the intensification of agriculture (and increasing irrigation) have led to an ongoing trend of rising water consumption (Malsy et al. 2016; Park et al. 2017; Priess et al. 2011). In the end, this socio-economic development depends on water resources generated further upstream in the headwater regions of the major river systems which act as 'water towers' (Menzel et al. 2011; Karthe et al. 2015). However, these 'water towers' are under threat due to several pressures, including climate change, frequently recurring forest fires, illegal logging and the conversion of forest into pasture and agricultural land (Karthe et al. 2015; Priess et al. 2011; Tsogtbaatar 2004).

Even though the relevance of mountain forests for the regional hydrology is not fully understood, a field study in a burnt forest area in the eastern Kharaa river basin (Fig. 4) indicated that forest losses due to forest fires have several hydrologically relevant implications:

• mountain taiga, which typically covers northerly exposed mountain slopes underlain with permafrost soil, plays a key role for regional water availability (Minderlein and Menzel 2015); forest losses are thus likely to reduce freshwater availability in steppe areas further downstream;

• the loss of shading and thick, insulating organic layers contribute to permafrost melt (Lange et al. 2015), which in turn modifies infiltration pattern (for which permafrost acts as a natural barrier);

• losses of forest soils which typically have a high organic matter content and a high water retardation capacity lead to more pronounced hydrological extremes, particularly in case of stormwater flow (Kopp et al. 2017).

Degradation of floodplain forests affects water quality and aquatic ecology

Besides mountain taiga and forest steppe, over vast parts of Mongolia riparian floodplains constitute the only other areas dominated by woody vegetation. According to Minderlein and Menzel (2015), they contribute to regional freshwater availability at least temporarily during the rainy season, when precipitation exceeds the site-specific evapotranspiration. Even more importantly, woody vegetation in the floodplains plays an important role for erosion prevention and the stabilization of river banks. This is particularly important for the dryland rivers of Northern Mongolia where river bank erosion is the dominant source of fine sediment input into the river system (Theuring et al. 2015).

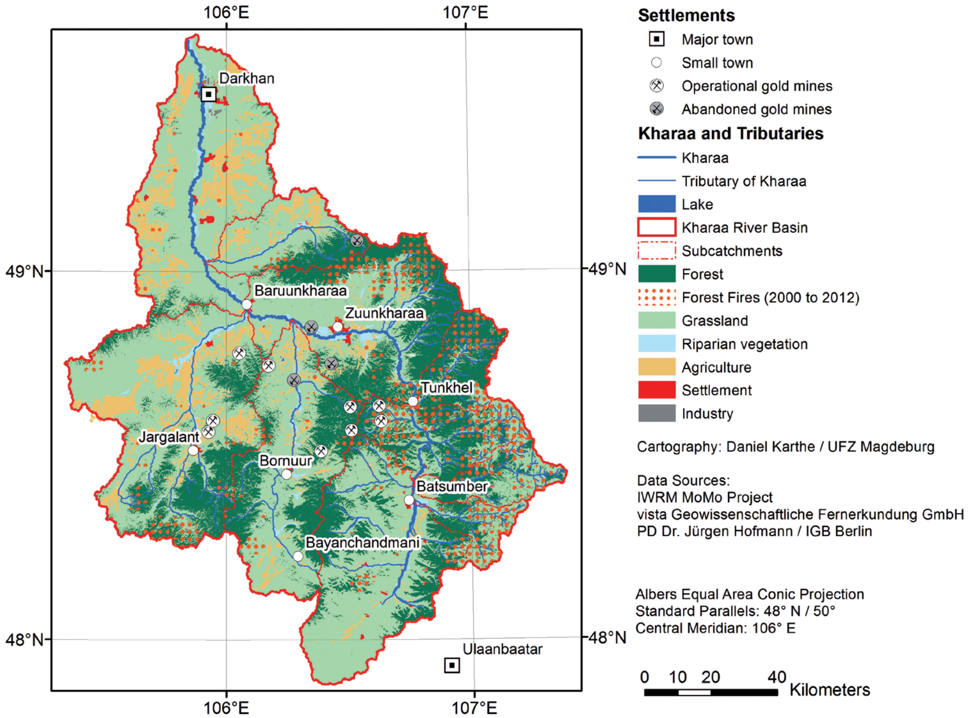

Fig. 4. Locations of forest fires in the Kharaa River Basin, 2000-2012

Increasing livestock densities are not only an important cause of grassland degradation (Tuvshintogtokh and Ariungerel 2012), but also puts river banks and their vegetation under growing pressure (Maasri and Gelhaus 2011). Since the 1990s, livestock numbers in Mongolia have increased drastically, reaching 33 million in 1999 (Rao et al. 2015), 44.5 million in 2009 (Maasri and Gelhaus 2011) and is now at the level between 60 and 70 million. Figure 5 illustrates the contrast between vegetated and degraded riverbanks and its relevance for erosion. Whereas dense shrubland (Fig. 5a) helps to prevent riverbank erosion, high livestock densities and vegetation-free riverbanks lead to significant sediment-input into the river system (Fig. 5b).

The basin of the Kharaa river, just north of Ulaanbaatar, is exemplary for the impacts of high livestock densities on the river system. Based on geochemical and isotope-based fingerprinting techniques, it could be demonstrated that elevated fine sediment loads predominantly originate from riverbank erosion. Moreover, it could be shown that the fine sediments clog the hyporheic interstitial, the ecologically

(A) (B)

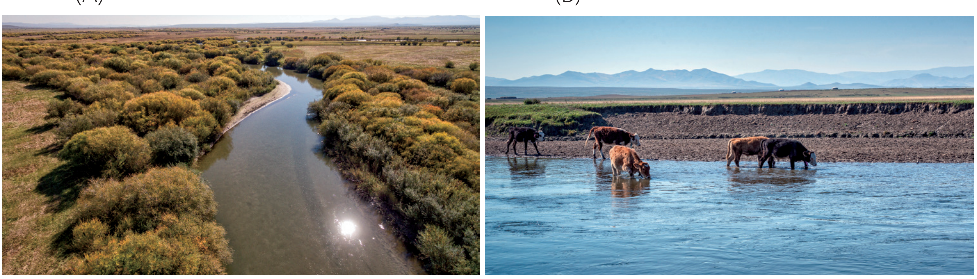

Fig. 5. A) Natural floodplain vegetation around a tributary to the Kharaa. Photo: André Künzelmann, UFZ. B) Cattle in the Kharaa river

highly relevant interface zone between surface and groundwater zones. Amongst other problems, this leads to a reduced aquatic macroinvertebrate biodiversity, which coincides with an increased proportion of fine-sediment colonizers (Hartwig and Borchardt 2014). From a management perspective, the stabilization of river banks (which is best achieved by the preservation and restoration of floodplain shrubland) is therefore a high priority (Hartwig et al. 2016).

Climate has significant impacts on regional forest cover and hydrology

For the regional hydrology, climate change has both direct and indirect impacts. In the recent past, several streams in North Mongolia have desiccated and runoff even in major rivers has decreased (Angerer et al. 2008; Batimaa et al. 2008; Karthe et al. 2015). Since the observed and predicted temperature rise is particularly marked for the winter months, sublimation which already equals about 80 % of the total snowfall may increase even further (Wimmer et al. 2009). Even though snowmelt only contributes a small percentage of the annual water supply, reductions in snow water storage affect not only river hydrographs (weaker spring floods) but also plant water availability at the start of the growing season (Hülsmann et al. 2015; Menzel et al. 2011). Similarly, reductions in glaciation of Mongolia's high mountain zones are likely to negatively impact future water availability during the summer months. Even though systematic studies of Mongolia's glaciers are relatively rare, studies from the Altai (Kamp and Pan 2014) and the Tavan Bogd massif (Syromyatina et al. 2015) have shown a considerable shrinkage of glacier areas and volumes. Moreover, it has already been argued that climate change is also likely to have indirect effects on the regional hydrology by leading to changes in forest cover.

Regarding precipitation, global climate models are known to perform rather poorly in the region, leading to considerable uncertainties about future trends (Malsy et al. 2013; Mannig et al. 2013; Bring et al. 2015). In Mongolia, temperatures have increased by more than 2K since the 1940s, leading to increasing evaporation rates (Karthe et al. 2015) and the thawing of permafrost soils (Sharkhuu et al. 2007; Törnqvist et al. 2014). Even though some models predict a slight increase in future precipitation, it is important to note that changes in rainfall pattern have been observed that are likely to be ecologically relevant. All over Mongolia, a transition from stratiform (moderate but long-lasting) to convective (short but very intensive) rainfall has been observed. Because short and intensive rain showers tend to create more surface runoff, they result in a reduced soil infiltration and therefore plant water availability (Vandandorj et al. 2017).

Challenge 4: Supporting forest regeneration against deforestation and degradation: Afforestation, reforestation, and underplanting

Today, remote sensing and large-scale inventories support the monitoring of deforestation on regional (Teusan 2018), national (MET 2016), or even global levels (Hansen et al. 2013). Depending on the source and methodology, the annual reduction in Mongolian forest area in the first decade of the new millennium was reported to range between 0.21% and 0.7% (FAO 2011; Dorjsuren 2014). The most important and recent baseline data on boreal forest cover southern saxaul forest area are provided by the national forest inventory (MET 2016). A basic question for reforestation initiatives was to what extend the Mountain forest steppe is of natural origin or a product of nomadic pastoralism as touched by Hilbig (2000). Studies showed that the mixture of open grassland and forests, the Mountain forest steppe, with a range of fluctuation over time, is predominantly of natural origin (Zhukov et al. 1978; Dulamsuren et al. 2005).

Lessons learned

Afforestation initiatives

Despite increasing reforestation efforts (see Fig. 6), forest quality in terms of species composition, density, and stand health are decreasing, particularly since the 1990s (Tsogtbaatar 2004; Ykhanbai 2010; Hansen et al. 2013; Khishigjargal 2014). In a study financed by GTZ, the proportion of degraded forest land was estimated to be 25% for the whole country (Kondrashov et al. 2008). This is especially noteworthy since reforestation efforts have increased constantly over the last four decades (see Fig. 6). Although reforestation has been practiced since the 1970s, forest rehabilitation has had relatively limited success around the country (Mühlenberg et al. 2006; MET 2017b). A World Bank study on reforestation in Mongolia found that low survival rates are due to fire, livestock grazing, and water shortages (Mühlenberg et al. 2006).

Species selection depends on a number of factors, such as seed provenance (see also Batkhuu et al. 2010), site conditions, region, and quality of planting materials and their adaptation. Appropriate species selection and soil treatments in reforestation activities facilitate the restoration of land, as shown by Ganchudur (2019) in Bulgan province. Park et al. (2016) found that indigenous Siberian elm trees (*Ulmus pumila*) growing in arid areas are able to substantially alter their morphological and physiological characteristics to avoid heat stress and increase water conservation. Tree height, leaf size, and stomatal area per unit area decreased with increasing site aridity, while leaf mass per unit leaf area and water-use efficiency increased.

Scots pine (*Pinus sylvestris* L.) and Siberian larch (*Larix sibirica* Ledeb.) are commonly used for boreal conifer forest rehabilitation in Mongolia. This is especially the case in Selenge, Bulgan, and Khentii provinces, where most of the forest timber harvesting and overexploitation has taken place in recent decades. However, these species are also particularly robust, seedlings are readily available, and the mature trees have industrial value. Both species are usually planted as monocultures from two-year old seedlings (Gerelbaatar et al. 2019b). A successful example of reforestation activities are the Scots pine plantations in the Tujyin Nars Special Protected Area (Gerelbaatar et al. 2019b). The forests of Tujyin Nars were depleted sharply during 1960-2000.

On a national level, over 19 thousand hectares of degraded forests have been restored and successfully reforested between 1971 to 2011 (Batkhuu et al. 2017b). In 2005, the Government of Mongolia initiated the National "Green Belt" Programme with the goal of reducing desertification, sand movement, and dust and sand storms caused by climate change and improper land management in the steppe-desert border region.

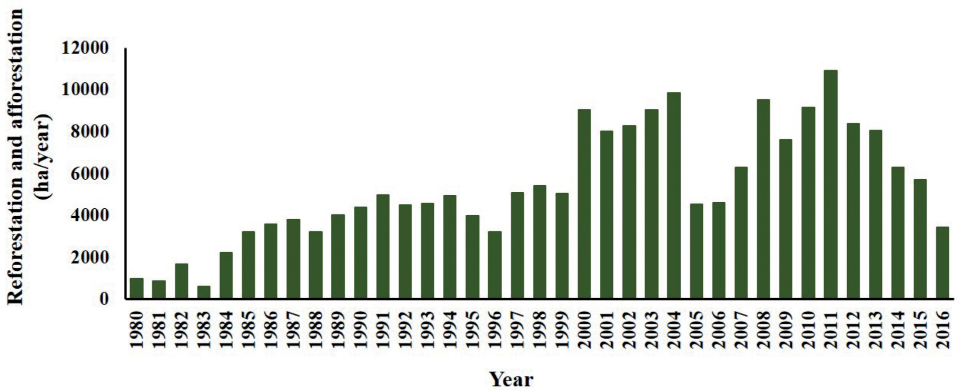

Fig. 6. Reforestation and afforestation in Mongolia between 1980 and 2016 (data source: MET (2017b)

Species were especially selected with respect to tolerance to drought, cold, and salt (Batkhuu et al. 2017b).

Timing of reforestation

The effect of timing of reforestation success has recently been scrutinized by Gerelbaatar et al. (2019b), who found that the survival rate of seedlings in Scots pine plantations is a linear function of the number of dry days (days with air humidity below 30%) during the common planting period in May. The same authors elaborated threshold values of air humidity for the dieback of planted Scots pine seedlings in the Selenge Aimag. Survival rate and relative growth are also the main control parameters regarding reforestation for combating desertification in the frame of the above-mentioned CCDASA initiative (Khaulenbek and Kang 2017). Gerelbaatar et al. (2018a; 2019b) recommended the development of climate-resilient reforestation guidelines, and to test planting during autumn, depending on site conditions possible to consider also other tree species where possible. This includes also underplanting in degraded stands, which so far is not happening. The spectrum of available tree species planting methods and conditions needs to be enlarged (Gerelbaatar et al. 2019b).

Examples of natural reforestation after stopping grazing

Although the overall trend in Mongolia is one of deforestation, there are some local examples of natural reforestation or potentially even forest expansion. There are places, where livestock grazing is the only factor that keeps grasslands open. Small-scale natural forest expansion has been reported following the reduction of livestock pressure in valleys in the eastern Khentii Mountains (Hartwig 2007) and in the Altansumber region, west of Darkhan (Gradel 2017).

Challenge 5: Managing the conservation of nature, biodiversity, and wildlife

The most important criteria for conservation planning are diversity, naturalness, area size and rarity (Spellerberg 1992). Compared to other biomes in the world boreal forests exhibit rather low biodiversity per area unit, but have a relatively high proportion of natural, untouched forest areas (Potapov et al. 2008). In northern Mongolia the boreal forest biome transitions into the open steppe biome (Balandin et al. 2000). This creates a mosaic of different habitats. Therefore, several literature sources value the biodiversity and naturalness of Northern Mongolian forests, especially of the Mountain forest steppe (Dulamsuren et al. 2005; Mühlenberg 2012; Mühlenberg et al. 2012). The studies of Grubov (2001) and Dulamsuren (2004) provide an overview of botany, species and plant communities in the taiga zone and mountain forest steppe. First forest ecological descriptions and botanical studies of the Khangai and Khentii regions were subject of several joint Soviet-Mongolian biological expeditions (e.g. Savin et al. 1983; Savin et al. 1988) and German - Mongolian cooperation (Hilbig and Mirkin 1983).

Lesson learned

High biodiversity in the Mountain forest steppe

Research at the German-Mongolian research station Khonin Nuga showed that biodiversity is especially high in the Mountain forest steppe. Since the mid 90ies researchers conducted comprehensive interdisciplinary field work in international teams (Mühlenberg 2012), which lead in some cases even to the validation of new species for Mongolia or even new to science (see for example Bayartogtokh (2000). It also provided comprehensive basic descriptions and classification of botanical description and of western Khentii Mountains (Dulamsuren 2004). The naturally fragmented Mountain forest steppe landscape (Dulamsuren et al 2005) is likely to also contain higher biodiversity.

Undisturbed forests contain also higher biodiversity compared to frequently disturbed forests as indicated by studies focusing on forest structure in disturbed light taiga and undisturbed dark taiga forest stands (Gradel and Mühlenberg 2011; Mühlenberg et al. 2012). These forests are also more productive in terms of basal area and volume (Mühlenberg 2012), which is in compliance with recent conclusions about a diversity-productivity relation on global level (Liang et al. 2016). Naturalness and area size are also often connected in Mongolia. Due to its low population density and accessibility 'untouched, natural' forests can still be found in Northern Mongolia. Based on criteria related to human alteration, remoteness and the level of fragmentation the remote sensing based worldwide intact forest landscape mapping and monitoring (Potapov et al. 2008; 2017) indicated that in Mongolia especially the Khentii Mountains have still a considerable portion of untouched, so called intact forest landscapes, which is however, constantly decreasing, especially due to fire impact (Potapov et al. 2017). Forest types that are often mentioned as valuable for different conservation reasons are especially types of riparian forests (Bei et al. 2003; Mühlenberg et al. 2004) and types of dark conifer forests (Dulamsuren 2004; Gradel and Mühlenberg 2011; Mühlenberg et al. 2012). *Abies sibirica* is naturally rare and limited to the two main forest regions in Northern Mongolia, namely around Lake Khuvsgul and the Khentii Mountain range (Dulamsuren 2004). *Pinus sibirica* is mentioned as a species with high ecological importance for wildlife (Dulamsuren 2004; Oyunsanaa 2011; Mühlenberg et al. 2012). The nuts of this tree species are an important energy source for wildlife in autumn (Dulamsuren 2004).

Approaches of forest conservation

With regard to realization of forest conservation objectives, two basic approaches exist: segregation and integration. According to the Mongolian law on forests (MOLF 2015), forests are divided into protection and production forests, which is typical for countries with large forest areas and low population density (e.g. countries of the former Soviet Union, but also North America). Protected forests (such as strictly protected areas, national parks, natural reserves and cultural monuments and local protected areas, where limited use is permitted for the local use of firewood and NTFPs, and other forest areas along rivers, for example) account for approximately 31% of the forest area (MET 2016). The integration of different objectives (e.g. conservation and utilization) in one management unit, often covered under the umbrella term "multifunctional forestry" is another approach developed and applied in Europe and incorporates a wider set of functions (often also recreation) in one forest area. The current approach of segregation (e.g. strictly protected areas for conserving natural landscapes and production forests) allows to protect very large pristine areas. In Mongolia remoteness can be considered as best form of protection of larger natural areas. Clear cuts are forbidden, but some authors suggested considering the integration of ecological values into management practices to some degree (Mühlenberg 2012; Gradel 2017). The review of forest scientific and biological studies indicated that diversity in terms of life forms and forest structure to a considerable extend depend on the amount of overall volume and certain dimensions of dead wood, sufficient number of large sized trees (DBH> 50 cm), certain species (especially Stone Pine), the forest type, amount of dead wood and the succession stage. The disturbance history plays a role in that way, that higher later succession stages with long term undisturbed development consequently lead to higher values of typical old-growth attributes and even diversity levels (Bei et al. 2003; Mühlenberg et al. 2004; Gradel and Mühlenberg 2011; Meyer and Schmidt 2011; Mühlenberg et al. 2012). Certain management practices, such as salvage cutting, which may be useful for other purposes, are considered negative from an ecological viewpoint (Lindenmayer and Noss 2005). Natural regeneration was found to grow sufficiently in many closed forests (MET 2016) and in some regions, for example around Bugant, even after intensive logging activities and fires (Gradel 2017). However, successful reforestation activities in Mongolia are active measure against degradation and desertification (Ganchudur 2019). In such cases native tree species and if possible local provenances should be given priority. Gerelbaatar et al. (2018b) compared ground vegetation in Scots pine plantations of different age classes with natural stands and found that young plantations were most diverse in terms of species diversity, but lacked certain typical forest species. Recently in a preliminary study Jamyansuren et al. (2018) identified seed regions for the important tree species: 19 regions for Siberian larch, 12 regions for Scots pine, 9 for Siberian pine, 6 for Siberian fir and 9 for Siberian spruce. The same authors recommend that seeds from higher elevated mountainous regions should only be used in a range of about 200-400 m of the original altitude.

Challenge 6: Increased resource utilization and demand in forested areas

Various sources report a recent increase in forest resource utilization, especially with respect to wood (Tsogtbaatar 2004; Hartwig 2007; UNREDD 2013), but NTFPs are also shown to be under increased pressure (Sepp and Schüler 2016). The extent, intensity, and frequency of logging-induced degradation is greatest in the most accessible areas, especially in the vicinity of populated and developed regions. These areas are largely dominated by light coniferous trees and now, increasingly, deciduous tree species (Gerelbaatar et al. 2019a). At a regional level, the pressure on forest products is greatest in the more densely populated regions north of Ulaanbaatar, especially in Selenge Aimag (Teusan 2018). Local overuse is one of the reasons why a particularly large number of forest stands grow from birch-rich succession forests in this region. Scots pine and larch (Dugarzhav 1996) are the most preferred species due to their rapid growth, wood quality, and broad distribution in rather accessible areas.

Lessons Learned

Management practices, including NTFP collection

Despite the increasing amount of research concerning forest management in Mongolia, the literature review shows that current practices are largely deemed inadequate. Oyunsanaa (2011), for example, doubts that Mongolian forests have ever been subject to science-based sustainable forest management. Inadequate forest management is frequently mentioned as a driver of forest degradation (UNREDD 2017; Government of Mongolia 2018; Khongor et al. 2018). Although silvicultural guidelines are hardly implemented (Gerelbaatar et al. 2019a), cutting often takes place nowadays as some kind of selective logging. Soum and Aimag authorities typically determine the amount of dead wood to be extracted during a cleaning. The Ministry of Environment and Tourism finally sets an annual quota, which is implemented at the regional level (Sepp and Schüler 2016). In dark taiga forests logging is largely prohibited. Dark coniferous grow also in higher and remote locations, which are more difficult to reach (Gradel et al. 2018).

Commercial forests are managed by private logging companies or with considerable limitations also by forest user groups (FUG), which represent a kind of community forestry. Logging of living trees is carried out only by private companies holding special logging licenses (Gradel and Petrow 2014). FUGs mostly conduct cleanings, collect fuelwood from dead trees and collect NTFPs (MET 2016). These are the most common forest products for local inhabitants of the forested regions; they are also collected by non-FUG members with the respective permissions. NTFP collection is especially practiced at the accessible edge of the forests (e.g. dogroses) or for longer trips in the remote dark taiga areas, especially for stone pine nuts, different berries and herbs. Stone pine nuts are considered to be the most important NTFP. According to a study by Sepp and Schüler (2016), the world market price for shelled pine nuts increased by 600% between 2006 and 2014. However, the prevailing method of collection of pine nuts is seriously damaging the stone pine trees. Trees are hit with huge hammers that destroy the bark.

Logging – scale and practices

Logging data vary widely and are difficult to obtain due to unlicensed (illegal) logging. Since 2000, the FAO has provided estimates of the annual legal production of firewood and industrial round and sawn timber in Mongolia. For 2010, this number was about 974,000 m^3 (FAO 2011). However, especially since the end of the last century, logging has been largely uncontrolled (Tsogtbaatar 2004; UNREDD 2017). Based on the evaluation of additional sources, Gradel and Petrow (2014) estimated an annual fluctuating range of 1 to 4 million m^3. This number includes an unlicensed logging of between 345,000 and 2 million m^3. However, the utilization is unregular distributed over the country and a lot of forest stands are actually over-aged (MET 2016). A further increase in the utilization pressure on forests is projected (Ykhanbai 2010).

Most of the harvested timber comes from forest cleanings. According to official sources, about 86.3% of the harvest volume comes from cleaning and sanitation cutting. An additional 4.6% results from thinning, and 9.1% from final harvests (Government of Mongolia 2018). Forest cleaning refers to salvage and sanitation cuttings and consists of the removal of dead trees and fallen limbs (MET 2014). See Fig. 7 for official Mongolian statistics on legally harvested timber through forest cleanings between 2011 and 2014.

According to official sources, only about a fifth of the harvest volume (18.8%) is comprised of commercial timber harvest, whereas about 81.2% is fuelwood. However, fuelwood collection is not usually perceived as a driver of forest degradation. Rather, it is seen as a secondary activity and one that is mostly part of cleanings by forest user groups and locals. For this reason, fuelwood collection is not taxed (Government of Mongolia 2018).

Some sources discuss potential measures to prevent illegal logging. Teusan (2018) reported at least short-term success in working with local people to control illegal logging in the area around Bugant. This is somewhat similar to the basic assumptions of participatory forestry initiatives and forest user groups (e.g. as recommended by FAO, GIZ), which consider participation of local forest users as a prerequisite for protection against illegal logging by

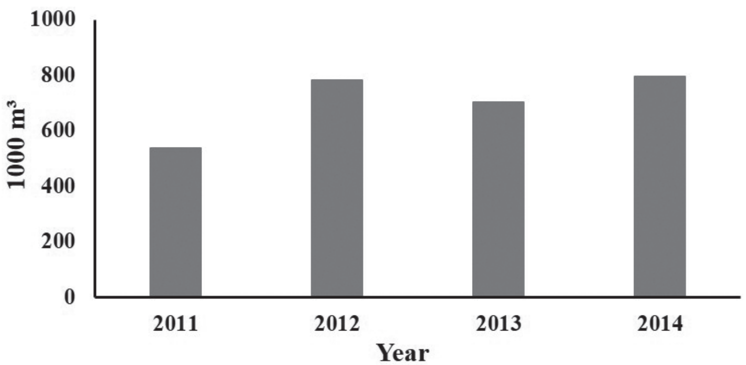

Fig. 7. Official statistic on legally harvested timber through forest cleaning between 2011 and 2014 (MET 2014)

externals (Gradel 2017). In other studies, about Siberian larch, Siberian Pine and Scots Pine it has been shown that genetic timber tracking with molecular markers is possible at regional scale and therefore has been suggested as tool for clarifying illegal logging (Putintseva et al. 2018; Blanc-Jolivet et al. 2018).

Already in the second half of the 20th century, research trials for the evaluation of logging impact concluded that in Mongolia the impact of selective logging is ecologically more positive than clear-cutting (Savin et al. 1988). The short-term effects of thinning from below on individual tree growth was recently studied in larch and birch stands near the steppe border (Gradel et al. 2017c). The authors found that the growth response of the remaining trees was significantly positive and directly related to the reduction of surrounding competitor trees. Interestingly, even medium-aged trees also responded immediately with significant growth increases. These results indicate that in terms of growth reaction and regeneration, low to medium intensity selective logging regimes may be sustainable. The long-term effects of different logging intensities on soil capacity and regeneration in Mongolian Scots pine stands in Selenge province were also recently examined (Gerelbaatar et al. 2019a). The final conclusion was that low intensity (around 25% removal) and, to a lesser extent, even medium intensity (around 50% removal) selective logging triggered regeneration of the main conifer species. The same authors showed that especially high intensity selective logging (around 75% removal) and clear cuts (100% removal) lead to significant decreases in regeneration (especially of the conifer species) and degradation of physical soil properties. However, physical and chemical soil properties indicated that soil capacity was best maintained without any logging at all.

Several authors (Benneckendorf 2011; Schmidt-Corsitto 2014) call for the research and design of improved instruments to promote sustainable forestry, e.g. regionally adapted silvicultural guidelines. Similarly, measures related to fostering markets for certain products (e.g. charcoal from birch thinning residuals and cleanings) may create incentives for financing silvicultural practices that help promote continuous cover forestry (Gradel 2017). To some degree, this may also shift current utilization away from cutting conifer trees and larger diameters toward harvesting more deciduous trees and trees with smaller diameters. This would help shift utilization to secondary growth succession forests, thereby protecting the remaining old growth forests. The voluntary certification of forest management and NTFPs may also promote a more sustainable utilization. These processes are, however, only in the initial stages in Mongolia; as yet, little regional knowledge is available.

Other relevant forest utilization practices

On a regional scale, the grazing of cattle can be an important utilization factor (MET 2016). Grazing affects the contact zone between forest and steppe, but mainly plays a role in open forests (UNREDD 2017) with sufficient grass cover. Grazing is reported to play a minor role in more closed forests (MET 2016). In the mountain forest steppe, dense grass layers are common and may hinder forest regeneration (Gradel 2017). Therefore, under certain circumstances grazing could potentially even have a slightly positive impact, if timed properly and managed for the right intensity. On the other hand, grazing in the forest area has most often an adverse effect on the success of forest reproduction and forest establishment when cattle eat or trample seedlings. While the effects of forest fires and logging are relatively clear, the introduction of livestock into forest fringe areas is less well understood in Mongolia. Nevertheless, there are many examples that show, that increasing livestock densities has an adverse effect on the survival of young tree saplings and can totally stop successful forest regeneration (Khishigjargal 2013). There are also examples of natural reforestation after grazing was stopped (see challenge 4 of this review).

Finally, mining also affects forest area. The impact is significant where practiced, but the area in the forested region is in absolute terms relatively little, compared to the area sizes affected by grazing or logging.

Challenge 7: Consideration of the social and political-cultural background

Mongolia currently faces the simultaneous challenges of transforming from traditional nomadic herding practices to increasingly urban lifestyles, as well as adapting to climate change and increasing utilization pressures. Socio-economic and demographic factors are considered to be indirect drivers of deforestation (Government of Mongolia 2018). We therefore consider the social and political-cultural context as an additional challenge affecting forest management. Factors include population growth, urbanization, and economic growth, all of which lead to more activity in the increasingly accessible forests and a growing demand for wood for construction. At the same time, increasing rural poverty drives unsustainable forest management (Government of Mongolia 2018). These drivers increasingly influence the provision of ecosystem services and management decisions in Mongolia. A schematic presentation of the interdependencies between the forest ecosystem and the social system is presented in Fig. 8.

Overview of forest historical background in Mongolia

To better understand the relationship between social-political factors and the challenges the forestry sector faces, some historical context is needed. For a long time, the core element of the Mongolian economy was livestock farming in the form of nomadism in the steppe and forest steppe. Both steppe and forest have played a decisive role in the cultural identity of Mongolia and neighboring regions (Filep and Bichsel 2018). For Mongolia, one can argue that steppe-based, subsistence-oriented nomadic pastoralism represents the origin of the Mongolian cultural identity. In this context, forests were perceived as places of shelter, as reported in the national epic from the 13th century, the Secret *History*, as well as places for hunting and gathering (Taube 2005; Hartwig 2007).

The background of present-day forest institutions, however, was laid during the socialist period. Although there were early forest use regulations, institutionalization of the forestry sector only took place after the establishment of the Socialist People's Republic of Mongolia in the 1920s. In 1924, the first forestry division was formed in the Ministry of Economic Affairs, and in 1931, the first forest law was passed (Tsogtbaatar 2008). The first national forest inventory took place between 1956 and 1957 (MET 2016). Sovereign rights over forestry and the timber industry

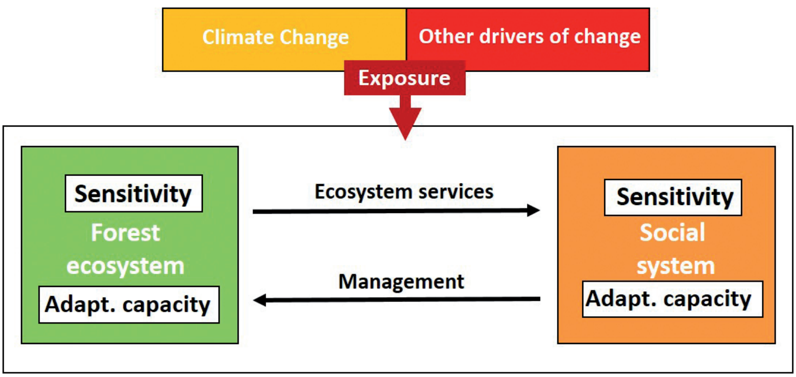

Fig. 8. The interdependencies between managed forest ecosystems and the social system. Both systems are exposed to climate change and other drivers of change (based on a general figure from Locatelli et al. 2008)

were consolidated during socialist times in one ministry. Land and forest were state-owned and the Mongolian timber industry was dominated by state-owned enterprises and joint ventures with COMECON members (Council for Mutual Economic Assistance), in particular the USSR, but also Poland and Romania (Gradel and Petrow 2014). The peak of timber use was achieved in the 1980s with a total of sixty sawmills. According to Tsogtbaatar (2008), the total annual volume of timber reached about 2.2 million m^3. At that time, timber accounted for 4 to 14% of national GDP (Bastian 2000), and several thousand people were employed in the wood combines (Ammann 2002). According to Ykhanbai (2010), the relative share of the forest industry in the GNP was still about 4.1% in 1990, compared with only 0.26% in 2010. With the supply and funding constraints and difficulties faced by COMECON members, the political changes in 1990 brought about drastic changes in the Mongolian forestry sector. Regional forestry units were initially dissolved or integrated into more general environmental authorities (Gradel and Petrow 2014), and a considerable number of sawmill workers lost their jobs. Official annual logging fell significantly (Tsogtbaatar 2008) and unlicensed, illegal logging increased.

Lessons learned

Bridging gaps between different stakeholders, levels and hierarchies

Today, as in socialist times, woodland remains exclusively in public ownership, while its utilization has been reformed through various models. According to Saladyga et al. (2013), the greatest evidence for an anthropogenic fire regime was found following the transition to a free market economy during the early 1990s, when land-use intensification near the capital city of Ulaanbaatar took place. This indicates the importance of considering increasingly socio-political aspects in the transformation process of land-use management. The Mongolian forest policy sector has been under constant reform. This ongoing transformation process of the law reflects, to a certain degree, perceived needs, for example putting emphasis on the protection function of forests. Over the last two decades, forest policy has shown the potential for development, such as when a reformed edition of the Forest Act was issued in 2007. Subsequently, a forestry agency was established that was later integrated into the Ministry of Environment as a forestry department. This integration was suggested to give the forestry sector a new framework, to stop the progressive degradation of the forest, and to bring order to the timber business. At regional and local levels, forestry has been re-established to some degree. However, the transfer of policy objectives, formulated for example in the law on forests, into concrete objectives with related implementation guidelines (e.g., guidelines for ecologically adapted silviculture) has not been sufficiently realized yet. There is a gap between policy frameworks, law reformation, and actual implementation and monitoring. Benneckendorf (2011) emphasizes that there is still a need for policy adjustments and capacity buildup within the administrative system. Especially at the local level (soum forest unit), capacities for controlling proper implementation are still lacking.

Some recent initiatives emphasize participatory forestry, especially with regard to the establishment and training of forest user groups (Evans 2008). The introduction of rights and obligations in the context of participatory forest management by forest user groups has been a particular reform approach used in Mongolia. Since the new Forestry Act of 2007, forest user groups (FUG/Nukhurlul), which are mostly associations of local nomads, can acquire usage rights within the scope of approved management plans. Usage is most often related to firewood and NTFPs (Sepp and Schüler 2016). Internationally funded projects have been tailored to facilitate further reforms and capacity development of FUGs. The performance of user groups during a recent FAO project was largely assessed through methods that involved the participation of all group members (Gradel 2017). This assessment was based on instruments that help to develop group capacities, group identity, and personal ownership (e.g., see Lynam et al. 2007). Local usage rights are combined with duties to protect the forest areas, e.g. from fire and external illegal users. This mechanism should function on the basis of the common interests of the state and the local population. For many forest user groups, staking areas to secure pasture areas plays just as important a role as securing their forest areas. According to recent data presented by UNREDD (2017), a total of 1179 FUGs manage 3,119,635 ha in Mongolia, whereas 83 private forest entities manage about 681,378 ha. In practice, the management impact of these groups varies widely and is not always effective. Community participation and capacity development for agroforestry initiatives for combating desertification are also relevant within the Korean-Mongolian CCDASA initiative (Khaulenbek and Kang 2017). The involvement of locals, e.g. with different user group and community participation approaches, usually has several objectives. These can include balancing the very uneven management impact on a regional scale, protecting and enhancing the protection functions of the ecosystems (e.g., with regard to soil and water), and reducing rural unemployment and poverty by improving or even creating income opportunities. However, the official harvesting of industrial wood continues to be carried out by private companies under concessions acquired by the state (Gradel and Petrow 2014). According to national experts from leading universities in Ulaanbaatar, the establishment of infrastructure for private timber enterprises (e.g., roads and electricity) could also reduce rural unemployment and poverty and balance uneven forest management intensity at the country level.

CONCLUSIONS

Because forest management in Mongolia faces numerous related and unrelated challenges, integrated and scientifically-based approaches are urgently needed. These complex problems cannot be solved by focusing on a single topic; rather, synergies need to be identified and utilized to set priorities and guide actions. In Mongolia, the relationship between vegetation cover and the water balance is a particularly urgent issue in the face of advancing climate change and land degradation. The forests and hydrology of a region are connected in manifold ways. The survival or re-establishment of forests requires sufficient water supply, especially in a country like Mongolia where water availability is the most critical factor limiting forest distribution. At the same time, forests play a crucial role in maintaining the hydrological balance and preventing desertification. Forest cover is essential for preventing the loss of permafrost, for example, but this protective function can only be maintained when low-intensity logging practices are used. We therefore recommend that future initiatives emphasize synergetic cross-sectoral approaches that consider the different challenges to forest management, especially with respect to the impact on the hydrological regime. To achieve this, integrated capacity development, forest research, and rehabilitation is needed that works across disciplines and at landscape scales. At the same time, capacity development and legislation need to take into account the specific socio-economic backgrounds of the target regions, and work with local communities, regional and national administrations.

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