BASICS OF FOREST ECOLOGY AND MANAGEMENT

TO SUSTAINABLE FOREST MANAGEMENT IN MONGOLIA

Edited by

Antonín Kusbach & Václav Pecina

Mendel University in Brno

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PROJECT

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ABSTRACT

Mongolian forests experience a unique transition between two biome extremes, the Gobi Desert and Siberian taiga. Moving from the south to the north, the journey is a spectacular mosaic of desert, semidesert, steppe landscapes and hemi-boreal forests. These slow growing forests are subject to harsh temperatures and some of the most rapidly warming climates on the planet. Compounding these natural factors, human-induced impacts are multiplying forest vulnerabilities. Climate change-accelerated disturbances, such as drought, wildfires, harmful insects, and tree diseases as well as logging, animal grazing, and mining activities are accelerating deforestation and land degradation. The extractive resource approaches of the past, in many cases recently increasing dramatically, are leading to additional problems. Relying on old practices with newer, higher rates of utilization is having tremendous negative socio-environmental impacts: desertification, permafrost melting, lack of water resources and pastures, nomadic migration, intensification of air pollution. Traditional Mongolian cultural practices rely on domestic animal grazing without responsibility and with little attention to forest stewardship. There is a need to build professional capacity with a credible forestry education program so that Mongolians can effectively manage the critical forest resource sustainably. Mongolian forest practices lack efficient tools and funding to shift towards sustainable forest protection, rehabilitation, regeneration, and a renewable forest value chain. Our intent was to fill a gap in the Mongolian forest ecology and sustainable forest management literature for today's practitioners as well as provide solid educational tools based on modern forestry practices for training tomorrow's forestry students and professionals.

Keywords: climate change; ecosystem; environment; forestry; permafrost; sustainability; taiga

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FOREWORD

Antonín Kusbach & Jan Šebesta

Mongolia is known as a country of steppes, semideserts, and deserts. Surprisingly, vast forests in the north convey a sense that Mongolians possess valuable natural resources and they do not have to be strict nomads.

The environmental protection of Bogd Khan Mountain dates back to the 13th century. Tooril Khan, the ruler of the Keraites, banned logging and hunting on the holy mountain with dense coniferous forests. Then, local people worshipped the mountain; they neither harvested timber nor hunted in the area. In 1783, the local government of the Qing dynasty declared Bogd Khan a preserved site for its beauty and value. By that, it is claimed to be the oldest "national park" in the world. Bogd Khan Mountain was designated as a UNESCO Biosphere Reserve in 1996. So, Mongolians have been worrying about their forests neighbouring steppes.

Mongolian forests present landscapes of striking beauty and rich resources. Forests are a multifaceted economic space, nevertheless, they were traditionally considered the seat of cults and gods. The vegetative cycle and succession are viewed as a symbol of renewing life. At the same time, the forests were sacred and mysterious areas, while serving as a refuge and resource of wood, fruits, animals, etc. Here, we would like to emphasize that caution is warranted where there is the potential to take these assets for granted. Following years of assessment of Mongolian forests, we present ecology basics with key concerns for facilitating intelligent stewardship of Mongolia's forests for the coming century.

Desertification is one of the most significant global environmental problems. It affects one-fifth of the world's population, which lives in arid lands. Approximately 90% of Mongolia is at risk of desertification; it is one of the hotspots of global desertification. Besides Mongolian steppes, semideserts, and deserts, even in the northern, forested part of the country, water resources are limited, donated mostly by permafrost. Here, the loss of forests strongly accelerates permafrost degradation and causes further landscape drying off. Hence, sustainable land use must be applied since healthy land is crucial for ongoing and future source water quality and accessibility. The degradation of forests and steppe ecosystems is caused by land use, for example, unregulated logging, overgrazing, and human-induced fires. One of the impacts of unfit land use is loss of water landscape retention capacity, which causes unprecedented drought that alternates with flash floods. Considering that fires are part of the natural process in forests, it is clear how sensitively these ecosystems could react to any changes. Combined with climate change effects, it all together results in a lack of water sources and pastures, leading to nomadic migration.

Regarding the interest of Mongolians in forests, it is fair to say that nowadays, they can see other ecological aspects, values, and functions of forests, not only logging and hunting. On the other hand, it is also necessary to say that the worrying of Mongolians about forests is limited simply because of the significant aspect of human beings, animal husbandry. That is why forestry has never been a keystone of the Mongolian economy. It also explains the relatively low forestry awareness of the public and the lack of experts in the country.

The Mongolian society has started to recognize the consequences of water scarcity and understood that the conservation of water resources is in balance with sustainable forest management; however, Mongolian forestry lacks tools for long-term planning and sustainable management. The sector is under development in Mongolia; it needs specialists. This publication should help with the education of a young generation of Mongolian experts at all levels of Mongolian forestry.

FOREST:

BASIC PRINCIPLES

1. FOREST – BASIC PRINCIPLES

1.1 Forest Definitions and Functions

Václav Pecina

Forest definitions

Forests are closely connected with the entire history of mankind. Every person on Earth can imagine what a forest is. But what does "a forest" mean? What exactly is a forest?

The perception of **forest** changes with the geographical location and society – for Indigenous peoples in the Amazon rainforest, a forest is something different than for a farmer from the African savannah, a forester from Central Europe, an official from a megacity or a shepherd from Mongolia (Figure 1). A forest can mean something different to everyone, but a clear definition is needed to assess it on a global scale. Further, it also simplifies all further education about a forest – its structure and components, ecological processes, interactions with the external environment or between internal components as well as forest management can be generally described so that the main principles are immutable and can be easily understood and applied if necessary.

The definition of forest, however, also often differs. The reason is different management objectives, which form the basis from which a forest is conceptualized, and definitions are created. Forests can be defined, for example, as **an ecosystem composed of trees** characterized by exceptional biological diversity, a source of wood products, a home for indigenous people, a source of ecosystem services or as social-ecological systems (Chazdon et al., 2016). The Mongolian definition says that "forest" means "***specific ecological-geographical conditions of a complex (in-situ) environment, where trees, bushes, shrubs and other plants, lichen, moss, wildlife and microorganisms naturally co-exist***" (Mongolian Law on Forest, 2012).

Although there are hundreds of definitions of forest, one of the most widely used is the definition by the Food and Agriculture Organization of the United Nations (FAO), which states that forest is "***land spanning more than 0.5 hectares with trees higher than 5 meters and a canopy cover of more than 10 percent, or trees able to reach these thresholds in situ. It does not include land that is predominantly under agricultural or urban land use.***" (FAO, 2020). Following the definition, forests are also windbreaks, shelterbelts and corridors of trees with an area of more than 0.5 hectares and a width of more than 20 m.

Figure 1. A mixed dark taiga forest in the Bugant area, Selenge, Mongolia (photo: Václav Pecina).

It is important to mention that areas with young trees that have not yet reached but are expected to reach a canopy cover of 10% and a tree height of 5 m are also considered forests according to the FAO definition. In addition, the forest definition also includes areas that are temporarily unstocked due to clear-cutting as part of a forest management practice or natural disasters (Figure 2), and which are expected to be regenerated within 5 years. Thus, **dynamics** is among the important characteristic features of a forest.

A good definition of forest can be crucial for forest land protection and management. Sasaki and Putz (2009) warned that some simple definitions based only on area, canopy cover and height may lead to the loss of environmental values of forests, because natural forests can be severely degraded by irresponsible logging or replaced by plantations but technically remain "forests." What's wrong with plantations and what's the difference?

If a natural forest is converted to a one tree species plantation, the loss of **species diversity** and overall degradation of the ecosystem related to intensive tree farming depletes soils and limits forest functions. Plantations, for example, have lower soil carbon and nitrogen concentration (Liao et al., 2010; Liao et al., 2012; Wang et al., 2021) and bacterial and fungal biomass (Wang et al., 2021) compared to natural forests. Such a conversion may increase CO_2

emission (Huang et al., 2019) and accelerate climate change. On the other hand, establishing plantations on formerly forested, currently agricultural, land can support biodiversity and contribute to carbon sequestration (Paquette et al., 2009; Pawson et al., 2013). Although plantations also provide a variety of forest functions, their range is limited, and the entire ecosystem is poorer, unstable and more susceptible to factors such as diseases and pests (Ghini et al., 2011; Pawson et al., 2013). Therefore, when defining forests, it is advisable not to forget the necessary related overall **diversity**, **natural processes** and acceptable level of **integrity**, which cannot be preserved, for example, during agricultural management with short rotation periods, which is typical for plantations. FAO (2020) defines plantation as a planted forest that is intensively managed and meets all the following criteria at planting and stand maturity: one or two species, even age class, and regular spacing. A key factor that should distinguish well-managed forests from plantations should be compliance with the principles of **sustainable forest management**.

In conclusion, comprehensive perception of forests is the key to healthy forests, **sustainability** in their protection, management and utilization and the full provision of **forest functions** ensuring the conditions for life on Earth.

Figure 2. An example of a forest – although the original forest stand was destroyed by fire, the area is regrown with hundreds of new trees through the process of natural regeneration (photo: Václav Pecina).

Forest functions

Forests are among the most studied and most important ecosystems, also regarding the number of services they provide to us. They are the driving force behind many global processes and play a vital role in the cycling of a number of elements; they produce oxygen, support nutrient cycling and filter pollutants from air. Through these processes, they influence the climate of the entire Earth. Their importance goes far beyond the local scale. Nevertheless, the local scale and importance of forests for people living in their proximity must not be forgotten.

Two designations are used for services provided by forests. The widely used term "**ecosystem services**" is perceived mainly ecologically, the term "**forest functions**" is more associated with forest management (Kindler, 2016). Despite the slightly different perception and approach, both terms well define the benefits that forests provide to us. With regard to the direction of the book's content to **sustainable forest management** in Mongolia, the designation "forest function" is used in the following text.

In the anthropocentric concept, forest functions can be divided into **production** (economic) and **non-production** (ecological and socio-cultural).

The production function includes forest products that can be economically valued as goods. This includes wood and non-wood products. Wood products are, for example:

- timber,
- firewood,
- fibres,
- woodchips,
- charcoal, etc.

Typical examples of non-wood products are:

- food crops,
- spices,
- fruits (berries, etc.),
- seeds (cedar nuts, etc.),
- mushrooms,
- medicinal plants,
- game from hunting, etc.

Ecological functions are represented by three main categories and related functions:

1. Climatic function:
   - oxygen production,
   - carbon storage,
   - regulation of air temperature and humidity,
   - wind speed regulation, etc.
2. Hydric function:
   - interception of precipitation,
   - water retention,
   - flood control,
   - purification and protection of water, etc.
3. Soil-protection function:
   - protection against landslides,
   - protection against soil erosion (Figure 3),
   - desertification control,
   - permafrost protection, etc.

A socio-cultural function is based especially on aesthetic, hygienic and recreational values of forests. Forest is a healthy environment for:

- spirituality and religion,
- folklore,
- artistic inspiration,
- tourism,
- sports,
- science,
- education,
- therapy, etc.

Human society relies on healthy forests to supply building materials, energy, and food and to continuously provide services such as hosting biodiversity and regulating climate and environment to achieve human welfare (Führer, 2000; Trumbore et al., 2015). To ensure their functions and health as part of landscape management, their categorization is appropriate.

***Figure 3**. Soil stabilization and protection from erosion by roots of trees. Tree roots also purify and crowns protect water from heating (photo: Václav Pecina).*

The categorization of forests according to these functions and the associated corresponding appropriate level of **protection** or **sustainable management** can be a way to protect forests while simultaneously obtain the required benefits.

Natural forests and planted forests can be classified into three main categories:

a) protection forests;
b) special-purpose or special-use forests;
c) production forests.

Both the ecological processes behind these benefits and the benefits themselves and how they can be achieved are described in more detail in the following chapters. The management recommendations (see chapter 4. FOREST MANAGEMENT) relate mostly to production forests.

REFERENCES

Chazdon, R.L., Brancalion, P.H., Laestadius, L., Bennett-Curry, A., Buckingham, K., Kumar, C., Moll-Rocek, J., Vieira, I.C.G. and Wilson, S.J., 2016. When is a forest a forest? Forest concepts and definitions in the era of forest and landscape restoration. Ambio, 45(5), pp.538-550. https://doi.org/10.1007/s13280-016-0772-y.

FAO, 2020. Global Forest Resources Assessment 2020: Terms and Definitions. Food and Agriculture Organization of the United Nations, Rome. Available at: https://www.fao.org/forest-resources-assessment/past-assessments/fra-2020/en/.

Führer, E., 2000. Forest functions, ecosystem stability and management. Forest Ecology and management, 132(1), pp.29-38. https://doi.org/10.1016/S0378-1127(00)00377-7.

Ghini, R., Bettiol, W. and Hamada, E., 2011. Diseases in tropical and plantation crops as affected by climate changes: current knowledge and perspectives. Plant pathology, 60(1), pp.122-132. https://doi.org/10.1111/j.1365-3059.2010.02403.x.

Huang, J., Lin, T.C., Xiong, D., Yang, Z., Liu, X., Chen, G., Xie, J., Li, Y. and Yang, Y., 2019. Organic carbon mineralization in soils of a natural forest and a forest plantation of southeastern China. Geoderma, 344, pp.119-126. https://doi.org/10.1016/j.geoderma.2019.03.012.

Kindler, E., 2016. A comparison of the concepts: Ecosystem services and forest functions to improve interdisciplinary exchange. Forest Policy and Economics, 67, pp.52-59. https://doi.org/10.1016/j.forpol.2016.03.011.

Liao, C., Luo, Y., Fang, C. and Li, B., 2010. Ecosystem carbon stock influenced by plantation practice: implications for planting forests as a measure of climate change mitigation. PloS one, 5(5), p.e10867. https://doi.org/10.1371/journal.pone.0010867.

Liao, C., Luo, Y., Fang, C., Chen, J. and Li, B., 2012. The effects of plantation practice on soil properties based on the comparison between natural and planted forests: a meta-analysis. Global ecology and biogeography, 21(3), pp.318-327. https://doi.org/10.1111/j.1466-8238.2011.00690.x.

Mongolian Law on Forest. Ministry of Environment and Green Development of Mongolia. A revised version. Government Bulletin No 22. Published on May 17, 2012, Ulaanbaatar. Available at: https://legalinfo.mn/mn/detail/15624.

Paquette, A., Hawryshyn, J., Senikas, A.V. and Potvin, C., 2009. Enrichment planting in secondary forests: a promising clean development mechanism to increase terrestrial carbon sinks. Ecology and Society, 14(1).

Pawson, S.M., Brin, A., Brockerhoff, E.G., Lamb, D., Payn, T.W., Paquette, A. and Parrotta, J.A., 2013. Plantation forests, climate change and biodiversity. Biodiversity and Conservation, 22, pp.1203-1227. https://doi.org/10.1007/s10531-013-0458-8.

Sasaki, N. and Putz, F.E., 2009. Critical need for new definitions of "forest" and "forest degradation" in global climate change agreements. Conservation Letters, 2(5), pp.226-232. https://doi.org/10.1111/j.1755-263X.2009.00067.x.

Trumbore, S., Brando, P. and Hartmann, H., 2015. Forest health and global change. Science, 349(6250), pp.814-818. https://doi.org/10.1126/science.aac6759.

Wang, Y., Chen, L., Xiang, W., Ouyang, S., Zhang, T., Zhang, X., Zeng, Y., Hu, Y., Luo, G. and Kuzyakov, Y., 2021. Forest conversion to plantations: A meta-analysis of consequences for soil and microbial properties and functions. Global Change Biology, 27(21), pp.5643-5656. https://doi.org/10.1111/gcb.15835.

1.2 Forest Dynamics and Process-Based Stewardship

Paul C. Rogers

Introduction

Mongolian forests, like those elsewhere, are likely to experience significant changes as the planet continues to warm. In particular, southern taiga and sub-taiga forests of Mongolia are located at a drought-induced frontier where temperature rises are expected to have dramatic impacts (Dulamsuren et al., 2010). Actions taken in the coming decades – **informed by science and implemented by agile practitioners** – will determine whether those forests will sustain human needs or follow a path of degradation. Fortunately, we possess the knowledge and skills now to bolster ecosystem resilience in the face of anticipated change. But can we match those abilities with a societal will to act on them?

Forested ecosystems in Mongolia are rich in natural resources. However, our challenge is to balance the use of those attributes with the need to preserve key ecological functions of these forests in perpetuity. About 9% of the total land area is covered by trees. However, theses ecosystems provide wood products, livestock forage, water retention, biodiversity, carbon sequestration, and aesthetic values for the countries citizens as well as foreign visitors. In fact, more attention is beginning to be devoted to future ecotourism values. While all of Mongolia's lands contribute important resources to the country's economy, the small percentage of forested lands provide more value than their land area may suggest.

The goal of this chapter is to understand the importance of **preserving ecosystem processes** to ensure Mongolia's forests maintain their resource attributes, as well as their hallmark calling as a source of national pride. Forest dynamics – growth, succession, damage/mortality, disturbance, rejuvenation, animal use, and others – comprise healthy ecosystem functions and understanding their role in maintaining system resilience can aid forest managers in implementing successful programs (Rogers, 1996; Bergeron and Harvey, 1997; Petrokas and Manton, 2023). A crucial tenant of process-based forest management, therefore, is working within a framework of understanding forest dynamics. In other words, work with forest systems rather than against them.

With that in mind, we will begin by gaining a basic understanding of process-based forest management (Holling and Meffe, 1996; Rogers, 1996; Franklin et al., 2002). Next, we will explore the most pressing contemporary issues facing Mongolia's forests. Having this context will allow us to then develop an implementation plan; plotting a course of action will entail examining strategies at very broad scales, as well as at the landscape level. Of course, any such approaches suggested here will need to undergo refinement for specific situations and be open to course-corrections where follow-up monitoring data dictate such needs. Ultimately, our aim is to ensure a keen knowledge of forest dynamics becomes a driver of forest management decision-making.

Process-based management

Ecosystem processes, whether in forests or other natural communities, provide a textbook of understanding and a menu for action should we take the time to read them carefully. For instance, understanding how tree species, in turn whole sub-taiga forests, respond to stress, competition, and disturbance informs **sustainable strategies** where multiple dominant cover species coexist (Petrokas and Manton, 2023). In the context of Mongolian forests, the dominant tree cover is comprised of *Larix sibirica*, *Pinus sylvestris*, *Pinus sibirica* and *Betula platyphylla* followed by less common *Picea obovata*, *Abies sibirica* and *Populus tremula* (Dulamsuren et al., 2005). **Process-based forest management** may be thought of as an informed bet on a certain outcome: if we understand key forest functions, such as disturbance intensity and periodicity, we take actions based on a certain probability of success. Bear in mind, this is only a probabilistic management decision; it does not imply a guarantee of success. The more we understand about these key processes, the higher the likelihood of gaining a result near what the ecosystem can tolerate and recover from.

Modern natural resource stewardship relies on working with nature rather than against it. In fact, centuries of human manipulations of forests took a 'command and control' tact that repeatedly proven to be unsustainable (Holling and Meffe, 1996). We have a long history of trying to bend natural systems – such as taiga and sub-taiga – toward our desires without considering how they might respond (Rogers, 1996). Thus, it is our task to intelligently note past errors, pairing these outcomes with our best understanding of contemporary ecological processes and their likely responses to changing climate conditions (Figure 4).

Mongolian forest issues

Taiga and sub-taiga forest complexes face a range of natural disturbances (Oyunsanaa, 2011; Mühlenberg et al., 2012). How they respond, meaning what follows the disruption, is a key to effective management. The task of contemporary forest stewardship is to **sustainably** blend human extraction with ecological disturbance (Esseen et al., 1997; Bergeron et al. 2002). Forest issues such as insect outbreaks or overharvesting can permanently deplete forested lands if they, for instance, the community is not able to effectively regenerate. Thus, an interdisciplinary understanding of multiple, often overlapping, forest issues is critical to effective process-based management.

Browsing by domestic livestock is likely the greatest limiting factor to healthy forest systems in Mongolia. At the southern edge of forest lands, along the forest-steppe ecotone, large increases in number of domestic herbivores have nearly eliminated successful *Larix sibirica* regeneration (Khishigjargal et al., 2013). Such intense browsing of juvenile seedlings and saplings can have long-term effects on forest dynamics, growth, regeneration, and disturbance interactions causing land stewards to alter their management prescriptions to account for lack of successful recruitment. Moreover, certain wildlife and domestic herbivores, such as moose and cattle, are known to target keystone aspen and birch suckers, thereby have indirect impacts on regional biodiversity (Myking et al., 2011; Rogers et al., 2020).

Understanding the impacts of climate change on Mongolian forests will be crucial to effective management and conservation over the next century (Furyaev et al., 2001). Unfortunately, there are a lot of unknown elements to contend with when predicting future conditions. One thing that managers can focus on is creating the most resilient forest ecosystems possible adhering to process-based management principles. First, it is crucial to ‘save all the parts,’ as the mid-20th century conservationist Aldo Leopold so famously extolled (Leopold, 1949); meaning to **preserve all native species** (especially keystone species) to the degree possible. Second, perhaps even more valuable, is to **maintain key ecosystem processes**, such as natural disturbances, predator-prey interactions, healthy soil functions, system nutrient cycles, and others. Third, process-based management requires vigilant monitoring of baseline forest conditions, but **site-specific monitoring following forest actions**. It is critical that resource managers implement credible monitoring protocols to check on whether expected outcomes are actually occurring. With these basic elements in place – while simultaneously doing all we can to reduce carbon in our atmosphere at all geographic scales – we can then develop plans for addressing impacts of climate warming on dynamic forest ecosystems.

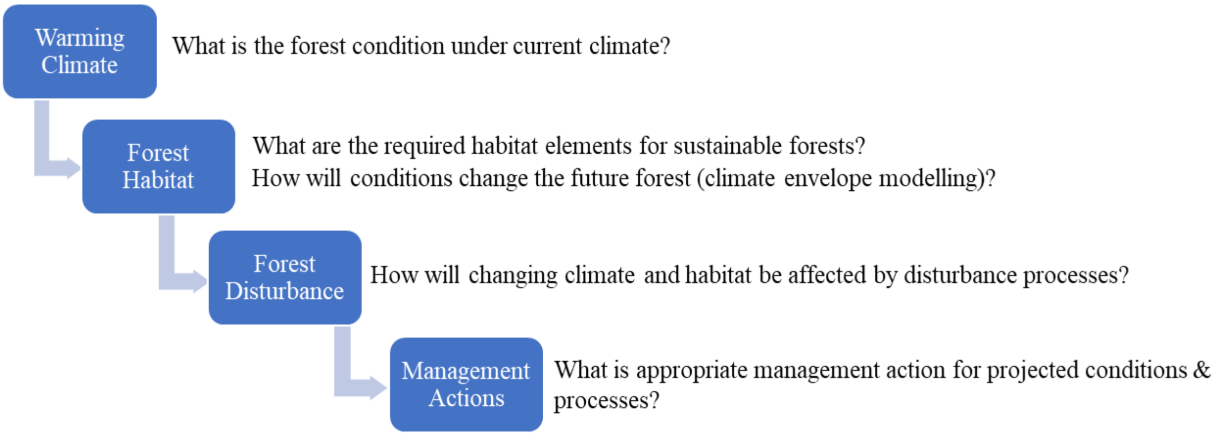

***Figure 4**. Incorporating forest dynamics into climate modelling and management actions.*

Figure 4 presents a schematic for understanding and addressing climate-change affected forest dynamics. Fully understanding impacts of management actions under warming climate conditions requires first, to the degree possible, fully understanding the state of contemporary Mongolian forests (i.e., baseline monitoring). Next, we will need to amass established science on individual forest types to determine their habitat requirements. Are these requirements being met? Are shortcomings related to climate change? Using reputable climate models, we can then project habitat requirements into the future to see conditions will expand, contract, or remain stable. Integral to these projections will be to interject key disturbances into mechanistic models (i.e., climate envelope model, plus incorporation of key disturbances). Finally, we can make forest management decisions and take actions based on modelled projections of ecosystems responses to these actions. Even with the finest models, these projections are really just informed guesses. We must vigilantly test models with real-world outcomes. In order to corroborate management actions with intended outcomes **regular monitoring** will be required. This protocol establishes a framework of adaptation; if unanticipated outcomes from management actions arise, then future land stewards will be empowered to adjust actions to correspond to current climate conditions (as well as other human impacts).

The adaptive monitoring cycle

Ecosystem monitoring is the cornerstone of sound forest management. To avoid common mistakes of past eras, we should implement a fail-safe system of before, after, and ongoing monitoring to check our assumptions about forest conditions (broadly) and responses to planned and unplanned disruptions. The Adaptive Monitoring Cycle (Figure 5) was first proposed for quaking aspen (*Populus tremuloides* Michx.) systems in North America (Rogers, 2017), but follows general principles that apply to ecosystem management in many community types.

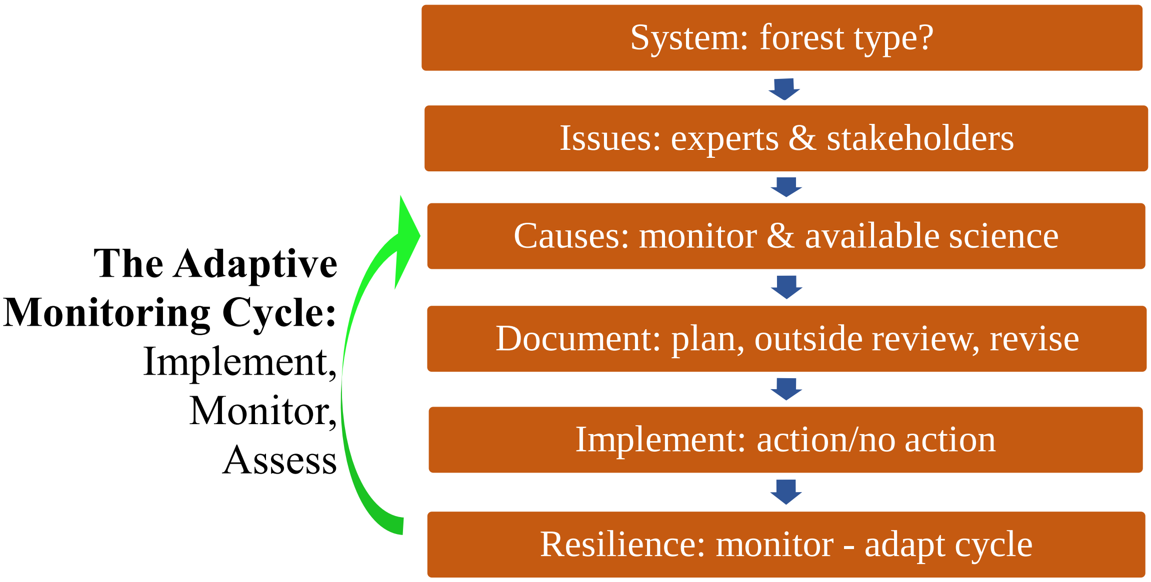

***Figure 5**. The Adaptive Monitoring Cycle determines future management actions.*

Of course, forest monitoring may take place at various scales. National and regional monitoring systems (see chapter 4.2 Forest Inventory) provide a starting point for understanding general patterns of forest status and trends. However, project- or landscape- based monitoring is useful for understanding specific local conditions and planned actions. While broadscale forest assessments help us identify distinct forest communities, landscape-level monitoring is useful for understanding particular issues of concern (i.e., What is the problem and what is the cause?). Once we know the forest type and related forest dynamics (see chapter 2.6 Forest Classification), we then want to involve various experts and user perspectives to fully understand the scope of the problem. This step should be followed by investigations of existing reports, scientific literature, and (ideally) some preliminary monitoring to gain a better sense of pertinent factors and on-the-ground conditions.

At this point, the principal team of investigators and field practitioners will develop a written **management plan**, considering the three previous stages of The Adaptive Monitoring Cycle. It is critical that any such plan gain at least two, ideally more, independent reviews of the situation and plan of action. While such reviews can be time consuming, they ultimately will help the team avoid overlooked missing elements or errors that often occur in small team environments.

Implementation is obviously a key step in this process. Once management actions are finalized – be they cutting, altering grazing, prescribed fire, or other measures – on-the-ground implementation should commence. As a caution, forest managers worldwide have a long history of rushing to this action stage without fully vetting intentions and possible outcomes. A concerted plan and follow through for monitoring should be in place even before these management actions are implemented. Sticking to a post-implementation monitoring schedules is key to systematically tracking regrowth and whether it is meeting desired outcomes. Building in the management agility to alter the course if unexpected or negative responses are documented is the "adaptive" part of this entire approach to a forest dynamics centred stewardship. As Figure 5 illustrates, altering the management regime requires continued and consistent repeat monitoring, as well as potentially revising the future plan of action.

Plotting a course of action

The current understanding of Mongolian forests is that they hold great promise in the form of physical, recreational, aesthetic, and spiritual resources. Mongolia's forests are a point of pride. But degradation in large areas of these forests threatens to reduce, and in some cases, eliminate these treasured assets. Thus, it is important that we take stock of what is there in as detailed a manner as is possible. Such a step entails not only documenting national forest cover and condition, but locating "reference forests" to present **targets** for **sustainable conditions**. A reference forest is a site that is fully functioning in terms of ecological processes and representative components (i.e., fauna and flora). Ideally, reference forests should be identified for each major forest type in the country. Following this course, forests identified to be poorly functioning can use conditions documented in reference forests as specific management goals. Setting goals based on functioning capacity is critical to successful process-based forest management. In the past, forest management goals were often grounded in resource outputs: amount of timber, number of (commercial) seedlings planted, water flow, livestock forage, or other resources harvested. Ultimately, such a tact, if not bounded by process-based restoration objectives, leads to resource depletion (e.g. soil erosion, substrate mineral, or mycorrhizal loss that negates future ecosystem function). Thus, process-based restoration goals should be based on **ecological** or **species indicators** (Langridge et al., 2023). For instance, if a forest lacks diverse tree assemblages or age classes, this will be reflected not only in an inventory of those specific conditions, but also in the understorey vegetation and lichen communities; both total species diversity and presence of key indicator species (Dufrêne and Legendre, 1997; Rogers and Ryel, 2008; Langridge et al., 2023). Selection of threshold values, based on fully functioning reference forests, for these indicators will provide a solid set of monitoring goals. In addition to reference forest-specific indicators, a national list of standardized goals for all forests should be identified to allow cross-forest type comparisons, as well as universal elements to report on the total stock of forest conditions in Mongolia.

After setting mutually agreed upon goals for forest conditions, implementation of a standardized monitoring system can take place. Such a national system should not preclude project-based monitoring in the Before-After-Control-Impact (BACI) format. Such BACI monitoring sets the course for objectively checking that the outcomes we desire related to locale forest treatments or policy implementation are truly measuring up to the expected conditions. Even with our best science and practice, responses following forest actions can take unpredictable trajectories. So, following through with standardized large-scale and project-specific monitoring is key to establishing an adaptive management framework for Mongolia's forests.

It is not uncommon for managers and policymakers to face difficult decisions where forests are dynamically altered by myriad human and natural disturbances. Rather than simply react to ongoing disruptions and resource depletions, it is best to have a strategic stance for the nation's total forest cover. For instance, what are our national forest priorities overall? How can we best meet our goals – forest products, livestock husbandry, biodiversity, tourism/recreation, and others – while retaining these important outcomes? Planning for disturbances with process-based management embraces forest dynamism within some natural ranges of variation (Landres et al., 1999).

Ultimately, **the goal of understanding forest dynamics and implementing process-based management is to provide healthy ecosystems for future generations of Mongolians**. This approach is sometimes thought of as 'paying it forward,' meaning what we do today will really benefit the coming generations of citizens, as well as the biosphere. So, one final consideration in a forest dynamics strategy is to set aside and use unmanaged forest reserves as benchmarks and laboratories to measure success in more actively managed sites. Taking such a scheme further, a legitimate use for such lands, in addition to their practicality as management targets, is use as ecotourism destinations. Such uses may raise revenues from passive, rather than active, forest management while still providing income for Mongolian residents at local-to-national levels. In the end, a diversity of forest uses implemented along a continuum of passive-to-active levels of alteration, firmly grounded in adaptive monitoring practices, provides a sound framework for guiding Mongolia's rich forest heritage into a bright future.

REFERENCES

Bergeron, Y. and Harvey, B., 1997. Basing silviculture on natural ecosystem dynamics: an approach applied to the southern boreal mixedwood forest of Quebec. Forest Ecology and Management, 92(1-3), pp.235-242. https://doi.org/10.1016/S0378-1127(96)03924-2.

Bergeron, Y., Leduc, A., Harvey, B. and Gauthier, S., 2002. Natural fire regime: a guide for sustainable management of the Canadian boreal forest. Silva fennica, 36(1). https://doi.org/10.14214/sf.553.

Dufrêne, M. and Legendre, P., 1997. Species assemblages and indicator species: the need for a flexible asymmetrical approach. Ecological monographs, 67(3), pp.345-366. https://doi.org/10.1890/0012-9615(1997)067[0345:SAAIST]2.0.CO;2.

Dulamsuren, C., Hauck, M., Khishigjargal, M., Leuschner, H.H. and Leuschner, C., 2010. Diverging climate trends in Mongolian taiga forests influence growth and regeneration of *Larix sibirica*. Oecologia, 163, pp.1091-1102. https://doi.org/10.1007/s00442-010-1689-y.

Dulamsuren, C., Hauck, M. and Mühlenberg, M., 2005. Vegetation at the taiga forest—steppe borderline in the western Khentey Mountains, northern Mongolia. Annales Botanici Fennici, 42(6), pp. 411-426.

Esseen, P.A., Ehnström, B., Ericson, L. and Sjöberg, K., 1997. Boreal forests. Ecological bulletins, pp.16-47.

Franklin, J.F., Spies, T.A., Van Pelt, R., Carey, A.B., Thornburgh, D.A., Berg, D.R., Lindenmayer, D.B., Harmon, M.E., Keeton, W.S., Shaw, D.C. and Bible, K., 2002. Disturbances and structural development of natural forest ecosystems with silvicultural implications, using Douglas-fir forests as an example. Forest ecology and management, 155(1-3), pp.399-423. https://doi.org/10.1016/S0378-1127(01)00575-8.

Furyaev, V.V., Vaganov, E.A., Tchebakova, N.M. and Valendik, E.N., 2001. Effects of fire and climate on successions and structural changes in the Siberian boreal forest. Eurasian Journal of Forest Research, 2, pp.1-15.

Holling, C.S. and Meffe, G.K., 1996. Command and control and the pathology of natural resource management. Conservation biology, 10(2), pp.328-337. https://doi.org/10.1046/j.1523-1739.1996.10020328.x.

Khishigjargal, M., Dulamsuren, C., Lkhagvadorj, D., Leuschner, C. and Hauck, M., 2013. Contrasting responses of seedling and sapling densities to livestock density in the Mongolian forest-steppe. Plant Ecology, 214, pp.1391-1403. https://doi.org/10.1007/s11258-013-0259-x.

Landres, P.B., Morgan, P. and Swanson, F.J., 1999. Overview of the use of natural variability concepts in managing ecological systems. Ecological applications, 9(4), pp.1179-1188. https://doi.org/10.1890/1051-0761(1999)009[1179:OOTUON]2.0.CO;2.

Langridge, J., Delabye, S., Gilg, O., Paillet, Y., Reyjol, Y., Sordello, R., Touroult, J. and Gosselin, F., 2023. Biodiversity responses to forest management abandonment in boreal and temperate forest ecosystems: A meta-analysis reveals an interactive effect of time since abandonment and climate. Biological Conservation, p.110296. https://doi.org/10.1016/j.biocon.2023.110296.

Leopold, A. 1949. A Sand County almanac, and Sketches here and there. Oxford University Press, New York.

Mühlenberg, M., Appelfelder, J., Hoffmann, H., Ayush, E. and Wilson, K.J., 2012. Structure of the montane taiga forests of West Khentii, Northern Mongolia. Journal of forest science, 58(2), pp. 45-56.

Myking, T., Bøhler, F., Austrheim, G. and Solberg, E.J., 2011. Life history strategies of aspen (*Populus tremula* L.) and browsing effects: a literature review. Forestry, 84(1), pp.61-71. https://doi.org/10.1093/forestry/cpq044.

Oyunsanaa, B., 2011. Fire and stand dynamics in different forest types of the West Khentey Mountains, Mongolia. Doctoral dissertation, Georg-August-Universität Göttingen, Göttingen. http://dx.doi.org/10.53846/goediss-515.

Petrokas, R. and Manton, M., 2023. Adaptive Relationships in Hemi-Boreal Forests: Tree Species Responses to Competition, Stress, and Disturbance. Plants, 12(18), p.3256. https://doi.org/10.3390/plants12183256.

Rogers, P., 1996. Disturbance ecology and forest management: a review of the literature. USDA Forest Service, Intermountain Research Station, General Technical Report, INT GTR-336.

Rogers, P.C., 2017. Guide to quaking aspen ecology and management. US Department of the Interior, Bureau of Land Management, Salt Lake City, Utah.

Rogers, P.C., Pinno, B.D., Šebesta, J., Albrectsen, B.R., Li, G., Ivanova, N., Kusbach, A., Kuuluvainen, T., Landhäusser, S.M., Liu, H. Myking, T., Pulkkinen, P., Wen, Z. and Kulakowski, D., 2020. A global view of aspen: Conservation science for widespread keystone systems. Global Ecology and Conservation, 21, p.e00828. https://doi.org/10.1016/j.gecco.2019.e00828.

Rogers, P.C. and Ryel, R.J., 2008. Lichen community change in response to succession in aspen forests of the southern Rocky Mountains. Forest Ecology and Management, 256(10), pp.1760-1770. https://doi.org/10.1016/j.foreco.2008.05.043.

1.3 Mongolian Forests

Khishigjargal Mookhor

Introduction

Northern Eurasia is covered by the belt of **boreal coniferous forests** (Siberian taiga). Eurasia's steppe grasslands are located south of it in continental Eurasia, i.e., eastern Siberia, Kazakhstan and Mongolia. Mongolia is the 19th largest country in the world with a surface area of 1,564,116 km^2 and an average altitude of 1,580 m above sea level. Half of its territory lies over 1,400 m above sea level and 81% over 1,000 m above sea level. Mountains cover the northern and western regions of the country and the Gobi Desert covers the southern part.

Precipitation is relatively low with an annual average of about 230 mm in the transition zone from the Siberian taiga forest in the north to the semi-arid steppe and desert in the south (Batjargal, 2007 in Goulden et al., 2016), ranging from <50 mm in the Gobi Desert to 300–400 mm in the northern mountain regions (Enebish et al., 2020). Mongolia's continental climate is much harsher than that in other countries of the same latitudes and is characterized by the extremes in both air temperature values and their fluctuations from about 42 °C to -46 °C in some regions (Oyunsanaa, 2011). Because of this, there is a very short growing season (Erdene-Ochir, 2006). These climatic factors are decisive for the vegetation of Mongolia in terms of its development, distribution and growth.

Following the overall natural conditions, six basic natural zones were distinguished in Mongolia – high mountains, taiga forest, mountain forest steppe, steppe, desert steppe, and desert – that are different in climate, landscape, soil, flora and fauna (Oyunsanaa, 2011). Major ecosystems of Mongolia follow a latitudinal zonation with forests in the most humid northern parts (Figure 6) and steppe, semi desert and desert in the centre and the south (Hilbig, 1995).

Mongolian forest ecosystems

With 14,172,780 ha of forests (FAO, 2020), Mongolia possesses a relatively low percentage of **forest cover (9.1%)** with a continuous decline over the past 30 years (The World Bank, 2024). Two major forest biomes are recognized in the country – boreal and saxaul forests (UN-REDD, 2018; FAO, 2020). According to the national definition, forests include both biomes with boreal forests covering approximately 14.2 million ha (87%) and saxaul forests approximately 2.0 million ha (13%). However, FAO (2020) defines saxaul forest as **other wooded land** and does not include it in the total forest area. This classification is more internationally acceptable and, therefore, the value of 14.2 million ha remains recognized. Other sources referring to the National Forest Inventory in Mongolia (2014–2017) findings indicate 11.3 million ha of boreal forests including 9.5 million ha of stocked ones (Altrell, 2019). The inconsistencies in values about Mongolian forests in different sources mainly stem from different approaches to inventory and mapping as well as different definitions of forest (see chapter 1.1 Forest Definitions and Functions).

The distribution of the Siberian taiga (boreal forest) extends into northern Mongolia from the Russian Federation (Figure 6) **following mostly permafrost distribution**. The boreal forests are reaching their southern limit in Mongolia; Mongolian forests are forming a transitional ecotone zone between the continuous Siberian taiga in the north and the grasslands in the south. This vegetation pattern is characterized by forests on north-facing slopes and grasslands on south-facing slopes in the mountains, often called hemi-boreal forests. These forests typically grow on mountain slopes that are situated between 800 and 2,500 m above sea level (Dulamsuren et al., 2005; UN-REDD, 2018).

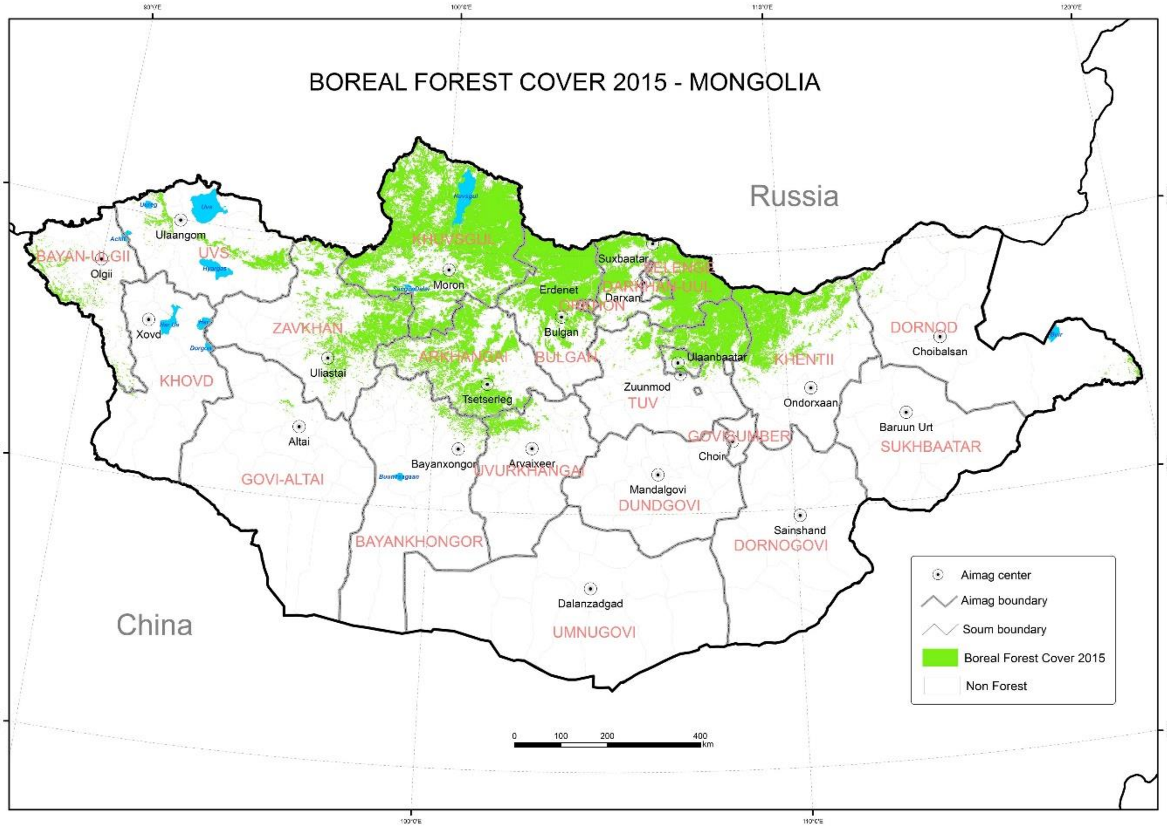

Figure 6. Boreal forest distribution in Mongolia in 2015 (MET, 2019).

Due to the geographic extent of forests in Mongolia (Figure 6), each of the major forested mountain systems in the country, primarily the Khentii, Khangai, Khuvsgul, and Altai regions, exhibits specific characteristics in terms of tree species, distribution range, productivity, vegetation structure, and composition (Tsedendash, 2000).

There is also high diversity within the mountain regions. Generally, the forest-vegetation altitudinal belt in mountain systems is divided into four main belts: subalpine (subgoltsy), mountain taiga, sub-taiga and forest-steppe. By way of illustration, in the Khentii Mountains, a continuous forest belt has a range of approximately 1650–2200 m above sea level (Dorjsuren et al., 2020). The lower part of the belt significantly differs from the upper part in vegetation structure and composition – the lower one is composed of **light taiga** species, while the upper one has dominating **dark taiga** species (Mühlenberg et al., 2012).

Forest-vegetation classification (zonation) was newly developed for Mongolia in 2020 following 11 basic criteria-requirements (Figure 7). These criteria are: (1) elevation, (2) dominant tree species, (3) forest soil type, (4) permafrost condition, (5) average mountain elevation, (6) indicator plant species, (7) dominant plant species, (8) succession type after disturbance, (9) ecology, economy, and social benefits, (10) required forestry activities, and (11) additional information on endemic species and genetic source. New forest-vegetation classification has four major provinces: (I) the Inner Baikal Forest Vegetation Region (seven sub-provinces), (II) the Khangai Forest Vegetation Region (four sub-provinces), (III) the Central Asian Forest Vegetation Region (one sub-province), (IV) the Central Asian Semi-Desert Steppe and Desert Region (three sub-provinces) (Dorjsuren et al., 2020).

Although the classification of forest ecosystems in Mongolia has been going on for a long time at several levels, there is still no uniform system that would be satisfactory for the needs of **sustainable forest management** (see chapter 2.6 Forest Classification).

Woody diversity of Mongolian forests

Mongolian forests comprise over 140 species of trees and shrubs (MET, 2016). These include both coniferous and deciduous tree species. The main coniferous tree species are **Siberian larch** (*Larix sibirica* Ledeb.) (Figure 8a), **Siberian pine** (*Pinus sibirica* Du Tour) (Figure 8b), **Scots pine** (*Pinus sylvestris* L.), Siberian spruce (*Picea obovata* Ledeb.) and Siberian fir (*Abies sibirica* Ledeb.). Deciduous tree species are mostly represented by **Asian white birch** (*Betula platyphylla* Sukaczev.) (Figure 8c) and aspen (*Populus tremula* L.). Dominant tree species are *Larix sibirica*, *Pinus sylvestris*, *Pinus sibirica* and *Betula platyphylla*.

The presence of *Picea obovata*, *Abies sibirica* and *Pinus sibirica* is typical for **dark Siberian taiga** while in **light taiga** there are mostly only *Larix sibirica*, *Betula platyphylla* and *Pinus sylvestris*. While light taiga has a wide distribution and is typical even in forest-steppe areas, dark taiga is tied to higher altitudes with better moisture conditions, often in the core parts of mountain ranges, and is considered a rather rare type of ecosystem.

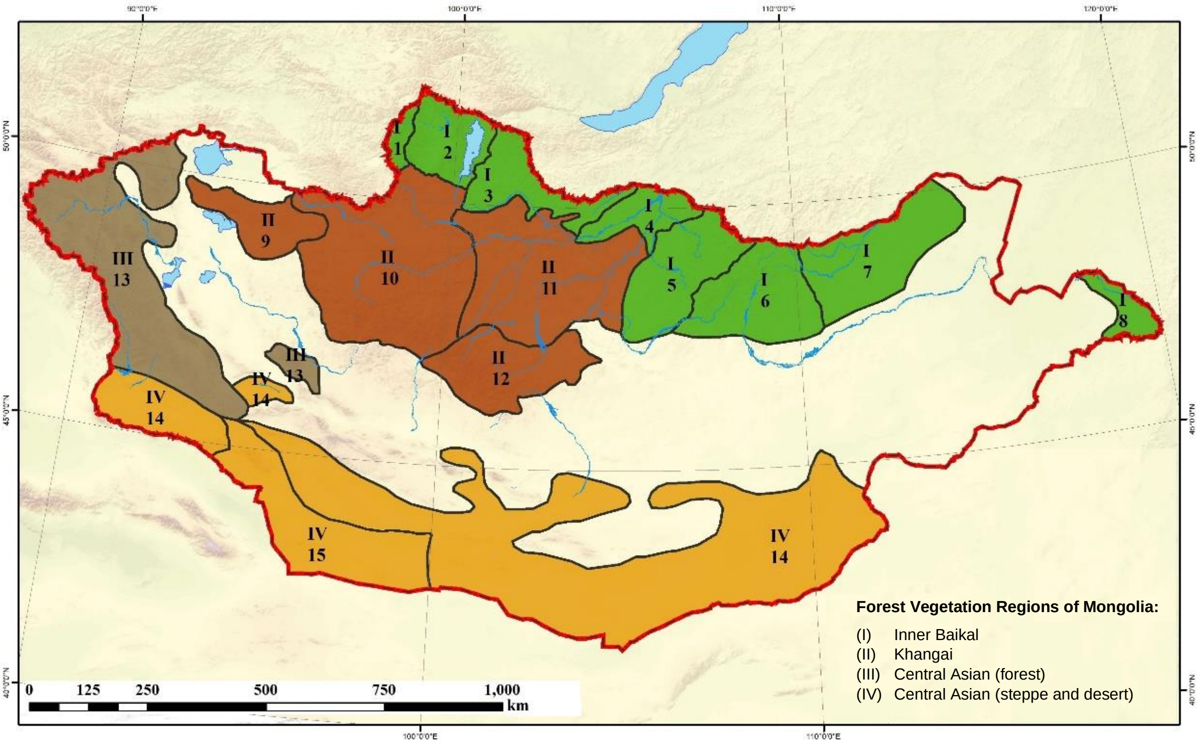

Figure 7. Forest-vegetation classification (zonation) (adapted after Dorjsuren et al., 2020). Colours and Roman numerals indicate major forest vegetation regions and Arabic numbers indicate sub-provinces in each region. For a more detailed description of the map, see the text above.

Figure 8. Typical stands of common species a) Siberian larch, b) Siberian pine and c) Asian white birch (photos: B. Batdemberel).

According to the forest taxation inventories conducted by the Forest Research and Development Center (FRDC), **Siberian larch** is the most common tree species, covering more than 60% of forest areas (UN-REDD, 2018) (Figure 9). For that reason, larch forests are crucial from the point of view of wood resources as well as providing other forest functions in Mongolia. Siberian larch has a strong adaptability and resistance to cold, drought and low soil nutrient conditions (Kalinina et al., 2019) which makes it a species capable of growing not only in a closed continuous taiga, but also forming forest fragments in a forest-steppe especially on the relatively moist north-facing slopes. It is often accompanied by pioneer **Asian white birch**, which accounts up to 10% of forest areas (UN-REDD, 2018).

Saxaul forests, formed mainly by salt tolerant and drought resistant saxaul (*Haloxylon ammodendron* (C.A. Mey) Bunge) (Batkhuu et al., 2011), are situated mainly in moist depressions, oases, and stream courses of the Gobi Desert. Saxaul, which was counted among forest species in the FRDC inventory, accounts for up to 15% of forest areas (UN-REDD, 2018). It can be accompanied, for example, by **Siberian elm** (*Ulmus pumila* L.), which is also well adapted to arid conditions and important from the point of view of providing ecological functions in the Mongolian landscape. Domestic tree species growing near rivers, such as various willows (*Salix* spp.) and poplars (*Populus* spp.), can be similarly significant in this regard.

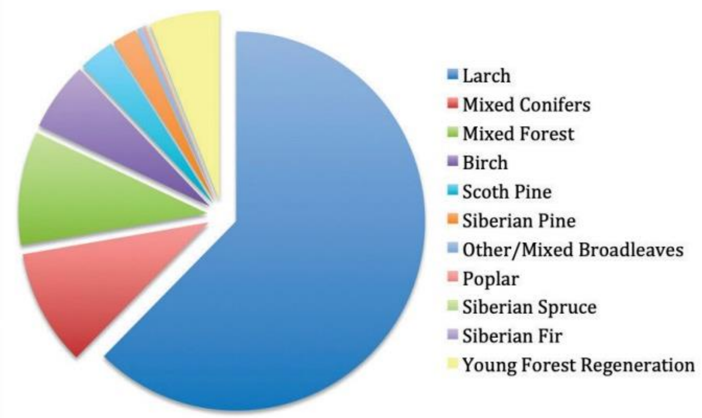

Figure 9. Distribution of boreal forest types according to tree species composition (Altrell, 2019).

Large mammals in Mongolian forests

The abundance of mammal species in Mongolia is highest in the northern regions with forests. Various large mammals, including ungulates, commonly found in forests such as Siberian roe deer (*Capreolus pygargus*), moose (*Alces alces),* musk deer (*Moschus moschiferus*) and elk (*Cervus canadensis*) may be important from the point of view of forestry, as they can harm forest regeneration, for example, by browsing seedlings. However, forest-dwelling predators including grey wolf (*Canis lupus*), brown bear (*Ursus arctos*) and Eurasian lynx (*Felis lynx*) as well as hunters regulate their numbers to a level that cannot threaten the growth of seedlings. On the other hand, rodents and wild boar (*Sus scrofa*) can pose a threat (Dulamsuren et al., 2008; Hauck et al., 2008). A serious threat is posed by domestic livestock, which is common in Mongolian forests.

Forest protection

Mongolian forests generally have **prevailing protection management** over human use. Legislatively, they are simply divided into utilization and protected zones. Protected zones are further divided according to the degree and reason for protection and include habitats for rare and endangered species of plants and animals. Utilization zones are further differentiated according to the nature of use taking logging or recreation into account. According to FAO (2020), only approximately 3.8 million ha of Mongolian forests are primarily designated for **production management** objectives and 0.2 million ha for **social services**. On the other hand, 9.2 million ha are primarily designated for protection of soil and water and 1 million ha for **conservation of biodiversity**. A characteristic feature important for forest protection as well as for management is their **100% public ownership**.

Forest resources

Due to the harsh continental climate and **short growing season**, Mongolian forests grow slowly with low productivity (Oyunsanaa, 2011; Dorjsuren et al., 2014; UN-REDD, 2018).

The boreal forest average growing stock volume is estimated to be 96.3 m^3/ha, excluding saxaul forest (MET, 2019 in FAO, 2020). The total growing stock of Mongolian boreal forests is 1,364.84 million m^3 (FAO, 2020). The non-protected stocked forests, i.e. **production forests** for production management objectives, have an average **growing stock** volume of 115 m^3/ha. That is twice less compared with an optimal growing stock volume of 237 m^3/ha in these forests. Additionally, there is about 46.5 m^3 of dead wood per hectare (Altrell, 2019). The results indicate that there is a **lack of tending** in production forests.

In terms of growing stock composition, *Larix sibirica* contributes approximately by 80% (Altrell, 2019; FAO, 2020). *Pinus sibirica* (7%), *Betula platyphylla* (6%) and *Pinus sylvestris* (5%) (Figure 10) are or may be additional economically important species of which all, except for *P. sibirica*, are legally harvestable species (Altrell, 2019). Although all Mongolian tree species can be classified as ecologically important, *Larix sibirica*, *Betula platyphylla* and *Pinus sylvestris* are especially important from an economic point of view. Ecological values must not be overlooked, and other tree species should therefore also be supported.

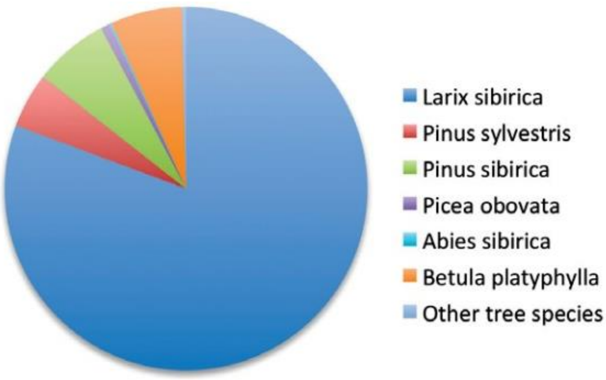

Figure 10. The average distribution of individual tree species in the stocked growing stock volume (Altrell, 2019).

Current state of Mongolian forests

Boreal ecosystems potentially constitute the largest terrestrial carbon source in the world (Bradshaw and Warkentin, 2015). However, the boreal forests in Mongolia are under serious threat. Due to the geographical position and associated climate, the ecosystems of Mongolia are among the most sensitive to climate change (Dorjsuren et al., 2014; Bao et al., 2020). The main driver of the reported **forest decline** is climate warming; in Mongolia, the mean annual air temperature has increased over 2 °C (Goulden et al., 2016). Other contributing factors include drought, forest fires, outbreaks of forest pest insects, an increase in livestock grazing pressure, a rise in the demand for fuel and wood, and various other land use activities (Dulamsuren et al., 2010; 2011; Batkhuu et al., 2011; Juřička et al., 2020).

Naturally slow growth of Mongolian forests (Oyunsanaa, 2011; Dorjsuren et al., 2014; UN-REDD, 2018) can be considered a weakness with regard to the resulting slow response to the impacts of climate change. At the same time their growth and health are increasingly limited by stress induced by these changes and related secondary or tertiary impacts (Dulamsuren et al., 2008; 2009; Hauck et al., 2008). For example, Siberian larch forest dieback may be directly linked to accelerated permafrost melting (Juřička et al., 2020). The loss of the forest allows the expansion of the desert and steppe zones.

Forest generation is the great challenge of the present time. Forest regeneration in Mongolia is challenging in itself in the forest-steppe transitions because of limited water supply and high soil temperatures (Hauck et al., 2008). In addition to climatic factors, pests such as insects, rodents (Dulamsuren et al., 2008) or livestock (see chapter 3.3 Forest Grazing) are also added.

In conclusion, Mongolian forests are not in a good shape in terms of health or production, especially in the marginal zones. Local boreal forests produce less than half of the biomass of well-managed boreal forests. Less than one fourth of the yearly biomass production is being cut, resulting in common self-thinning, represented by standing dead trees and over-aged trees, posing a potential risk for pest outbreaks and severe wildfires (Altrell, 2019). However, it is necessary to realize that possible strictly timber-oriented forest management does not adequately capture the complexity and diversity of provisioning necessary non-wood forest products or ecological functions (Sheppard et al., 2020).

Based on the aforementioned, there is a need to (I) **revise national forest policies** to address the overall suboptimal state of the boreal forest dedicated to production management objectives, and at the same time (II) change the under-utilisation of these forest by **sustainable forest management** for healthy green-wood production (Altrell, 2019).

At the same time, it is necessary to implement the **continuous restoration of degrading forests in places where the forest grows naturally or has recently grown**. Finances for restoration activities that will help to improve the overall environment in Mongolia can come from well-implemented sustainable forest management. This is in line with the government's commitments regarding the reduction of greenhouse gas emissions, as one of the goals is to create forest ecosystems well adapted to climate change and enhance carbon sink by implementing sustainable forest management (Government of Mongolia, 2020).

REFERENCES

Altrell, D., 2019. Multipurpose National Forest Inventory in Mongolia, 2014-2017-A tool to support sustainable forest management. Geography, Environment, Sustainability, 12(3), pp.167-183. https://doi.org/10.24057/2071-9388-2019-36.

Bao, G., Tuya, A., Bayarsaikhan, S., Dorjsuren, A., Mandakh, U., Bao, Y., Li, C. and Vanchindorj, B., 2020. Variations and climate constraints of terrestrial net primary productivity over Mongolia. Quaternary International, 537, pp.112-125. https://doi.org/10.1016/j.quaint.2019.06.017.

Batjargal, Z., 2007. Fragile environment, vulnerable people and sensitive society. Kaihatu-Sha Co., Ltd., Japan.

Batkhuu, N.O., Lee, D.K. and Tsogtbaatar, J., 2011. Forest and forestry research and education in Mongolia. Journal of sustainable forestry, 30(6), pp.600-617. https://doi.org/10.1080/10549811.2011.548761.

Bradshaw, C.J. and Warkentin, I.G., 2015. Global estimates of boreal forest carbon stocks and flux. Global and Planetary Change, 128, pp.24-30. https://doi.org/10.1016/j.gloplacha.2015.02.004.

Dorjsuren, Ch., 2014. Forest Ecosystems (in Climate change impact and exposure). In: Mongolia second assessment report on climate change - MARCC 2014. Ministry of Environment and Green Development of Mongolia, pp. 94-100. Available at: https://www.jcm-mongolia.com/wp-content/uploads/2015/11/MARCC-Final-Bk-2014-book-lst.9.17-ilovepdf-compressed.pdf.

Dorjsuren Ch., Dugarjav, Ch., Tsedendash, G., Tushigmaa, J. and Tungalag, M., 2020. Монгол орны ойн мужлал, хэвшинж [Forest status and patterns in Mongolia]. UB BCI [УБ Би Си Ай], Ulaanbaatar. (In Mongolian).

Dulamsuren, C., Hauck, M. and Leuschner, C., 2010. Recent drought stress leads to growth reductions in *Larix sibirica* in the western Khentey, Mongolia. Global change biology, 16(11), pp.3024-3035. https://doi.org/10.1111/j.1365-2486.2009.02147.x.

Dulamsuren, C., Hauck, M. and Mühlenberg, M., 2005. Vegetation at the taiga forest—steppe borderline in the western Khentey Mountains, northern Mongolia. Annales Botanici Fennici, 42(6), pp. 411-426.

Dulamsuren, C., Hauck, M. and Mühlenberg, M., 2008. Insect and small mammal herbivores limit tree establishment in northern Mongolian steppe. Plant Ecology, 195, pp.143-156. https://doi.org/10.1007/s11258-007-9311-z.

Dulamsuren, C., Hauck, M., Bader, M., Osokhjargal, D., Oyungerel, S., Nyambayar, S., Runge, M. and Leuschner, C., 2009. Water relations and photosynthetic performance in *Larix sibirica* growing in the forest-steppe ecotone of northern Mongolia. Tree physiology, 29(1), pp.99-110. https://doi.org/10.1093/treephys/tpn008.

Dulamsuren, C., Hauck, M., Leuschner, H.H. and Leuschner, C., 2011. Climate response of tree-ring width in *Larix sibirica* growing in the drought-stressed forest-steppe ecotone of northern Mongolia. Annals of Forest Science, 68, pp.275-282. https://doi.org/10.1007/s13595-011-0043-9.

Enebish, B., Dashkhuu, D., Renchin, M., Russell, M. and Singh, P., 2020. Impact of Climate on the NDVI of Northern Mongolia. Journal of the Indian Society of Remote Sensing, 48, pp.333-340. https://doi.org/10.1007/s12524-019-01080-9.

Erdene-Ochir, B., 2006. Mongolian third national report on implementation of convention on biological diversity. Ministry of Nature and Environment, Ulaanbaatar. Available at: https://www.cbd.int/doc/world/mn/mn-nr-03-en.pdf.

FAO, 2020. Global Forest Resources Assessment 2020: Report Mongolia. Food and Agriculture Organization of the United Nations, Rome. Available at: https://www.fao.org/forest-resources-assessment/fra-2020/country-reports/en/.

Goulden, C.E., Mead, J., Horwitz, R., Goulden, M., Nandintsetseg, B., McCormick, S., Boldgiv, B. and Petraitis, P.S., 2016. Interviews of Mongolian herders and high resolution precipitation data reveal an increase in short heavy rains and thunderstorm activity in semi-arid Mongolia. Climatic Change, 136, pp.281-295. https://doi.org/10.1007/s10584-016-1614-4.

Government of Mongolia, 2020. Mongolia’s Nationally Determined Contribution To the United Nations Framework Convention on Climate Change. UNFCCC, 407, pp.1–8. Available at: https://policy.asiapacificenergy.org/node/4485.

Hauck, M., Dulamsuren, C. and Heimes, C., 2008. Effects of insect herbivory on the performance of *Larix sibirica* in a forest-steppe ecotone. Environmental and Experimental Botany, 62(3), pp.351-356. https://doi.org/10.1016/j.envexpbot.2007.10.025.

Hilbig, H., 1995. The vegetation of Mongolia. SPB Academic Publishing, Amsterdam.

Juřička, D., Novotná, J., Houška, J., Pařílková, J., Hladký, J., Pecina, V., Cihlářová, H., Burnog, M., Elbl, J., Rosická, Z. and Brtnický, M., 2020. Large-scale permafrost degradation as a primary factor in *Larix sibirica* forest dieback in the Khentii massif, northern Mongolia. Journal of Forestry Research, 31, pp.197-208. https://doi.org/10.1007/s11676-018-0866-4.

Kalinina, E.V., Knorre, A.A., Fonti, M.V. and Vaganov, E.A., 2019. Seasonal formation of tree rings in Siberian larch and Scots pine in the southern taiga of Central Siberia. Russian Journal of Ecology, 50, pp.227-233. https://doi.org/10.1134/S1067413619030068.

MET, 2016. Mongolian Multipurpose National Forest Inventory (2014-2016). Ministry of Environment and Tourism (MET), Ulaanbaatar.

MET, 2019. Mongolian Multipurpose National Forest Inventory 2014-2018. 2nd edition. Ministry of Environment and Tourism (MET), Ulaanbaatar.

Mühlenberg, M., Appelfelder, J., Hoffmann, H., Ayush, E. and Wilson, K.J., 2012. Structure of the montane taiga forests of West Khentii, Northern Mongolia. Journal of Forest Science, 58(2), pp.45-56.

Sheppard, J.P., Chamberlain, J., Agúndez, D., Bhattacharya, P., Chirwa, P.W., Gontcharov, A., Sagona, W.C.J., Shen, H.L., Tadesse, W. and Mutke, S., 2020. Sustainable forest management beyond the timber-oriented status quo: transitioning to co-production of timber and non-wood forest products—a global perspective. Current Forestry Reports, 6(1), pp.26-40. https://doi.org/10.1007/s40725-019-00107-1.

The World Bank, 2024. Forest area (% of land area) – Mongolia. The World Bank Group. Available at: https://data.worldbank.org/indicator/AG.LND.FRST.ZS?locations=MN (accessed 6 December 2023).

Tsedendash, G., 2000. Хэнтэйн нурууны ойн хөгжлийн түүх, цаашдын хандлага (History and future trend of forest development in Khentii mountain range). Geoecology Institute Annual Scientific Journal Series, 1, pp.14-21.

UN-REDD, 2018. Mongolia's forest reference level submission to the UNFCCC. UN-REDD Mongolia National Programme, Ministry of Environment and Tourism, Ulaanbaatar. Available at: https://redd.unfccc.int/media/mongolia_2018_frl_submission_modified.pdf.

FOREST

ENVIRONMENT

2. FOREST ENVIRONMENT

2.1 Forest-Climate Interactions and Implications for the Hydrological Cycle

Jan Šebesta

Introduction

Forests have a unique role in contributing to the existence of diverse life on Earth. They **influence** and **regulate climate** through physical, chemical, and biological processes that affect planetary energetics, the hydrologic cycle, and atmospheric composition (Bonan, 2008; Anderson-Teixeira et al., 2012). Forests contribute significantly to the composition of the atmosphere and environmental quality by producing oxygen (O) and regulating carbon dioxide (CO_2) and potential air pollutants, such as ozone (O_3), particulate matter (PM), sulphur dioxide (SO_2), nitrogen dioxide (NO_2) and carbon monoxide (CO) (Nowak et al., 2007). The notion that forests, through transpiration, canopy shading, and surface albedo, can impact atmospheric moisture, heat, and circulation is not new (e.g. Forrester et al., 2018). Conversely, the biosphere determines the main flows and exchange of substances between the Earth's surface and the atmosphere and thus also contributes to the creation of the thermal structure of the atmosphere. Biogeophysical feedback can enhance or diminish this negative climate forcing (Bonan, 2008).

Forests contribution to climate change mitigation

Forests can significantly influence the climate and the course of climate change through the regulation of **greenhouse gases** in the atmosphere (Anderson-Teixeira et al., 2012). It is common knowledge that forests ecosystems contribute to climate change mitigation because of their capacity to remove carbon from the atmosphere and store it in plant tissues (Wei et al., 2018) and soils (Wang et al., 2023). Because of this, they are considered to be the major terrestrial carbon sink (Jandl et al., 2015).

Furthermore, several recent analyses of decarbonization pathways suggest that biomass energy could play a critical role in achieving global decarbonization targets (Favero et al., 2023). The potential of forest landscape restoration activities to remove CO_2 from the atmosphere and avoid emissions by reducing pressure on natural forests is becoming increasingly important as governments, civil society organisations and private sector players are looking for pathways to meeting the 1.5 °C goal formulated under the Paris Agreement (König et al., 2019). Proper forest management can be key to meeting climate commitments; therefore, adaptation to climate change should be one of the main priorities in forest management (Jandl et al., 2015).

In addition, forests and their contribution to **water balance** are increasingly mentioned concerning climate change and its mitigation (Bonan, 2008; Favero et al., 2023). The topic is especially relevant for ecosystems with a low amount of precipitation that is typical for the majority of Mongolia. On the one hand, forests are drying up, on the other hand, planting forests is considered a measure to retain water in the landscape or even attract precipitation.

Forest's role in the hydrological cycle

The **hydrological cycle** involves the continuous circulation of water in the Earth-atmosphere system with forests playing an important role there via soil stabilisation, reduction of runoff and erosion (the root system and the forest floor hold back and anchor soil against erosion), infiltration (the root system, fallen leaves and organic material on the forest floor slow down water), reduction of drought and floods events, etc. But the situation is complex and the relationship between forests, water, climate and landscape is not straightforward.

Single trees utilise and evaporate more water than understorey vegetation. But a forest complex shades the soil and thus reduces its **evaporation**. Moreover, forests also cool the air by evaporating water and by releasing large amounts of aerosols into the air, thereby contributing to the formation of nuclei and promoting rain. Forest and trees thus affect the water balance differently, it primarily depends on the landscape scale and environmental conditions. The trees dry out the landscape locally, but forests could increase precipitation elsewhere. The forest limits erosion and partially dampens hydrological extremes. Hence, when we ask about the water and temperature balance of the forest, it depends on whether we are talking about the local, regional or global scale.

One of the most interesting branches of atmospheric physics deals with the exchange of matter and energy at various atmospheric interfaces. The forest affects reactions near the Earth's surface and then on the so-called planetary boundary layer (PBL). The height of the PBL above the surface is controlled by surface temperature. The PBL is about 1000 m above sea level but around 4 km above deserts. It is important to mention that a lower PBL increases precipitation; this effect is also known as the "**small water cycle**" (Figure 11). Aerosols are carried out of the forest by turbulent flow, they form nuclei of water drops and it rains more easily there. Some of the precipitation gets caught in the tree crowns, evaporates, and consequently lowers the temperature, which lowers the PBL height. Studies (Berbet and Costa, 2003, Wei et al., 2018) suggest that widespread forest losses result in energy repartitioning and increased surface temperature, which may lead to unstable PBL, the lowest point of the troposphere still influenced by land surface moisture, energy, and roughness. Moreover, Forrester et al. (2018) described that the PBL is hotter, drier, and higher under infested forest conditions, which could have implications for atmosphere-vegetation feedback and forest drought stress. Finally, land-atmosphere coupling is sensitive to antecedent subsurface moisture.

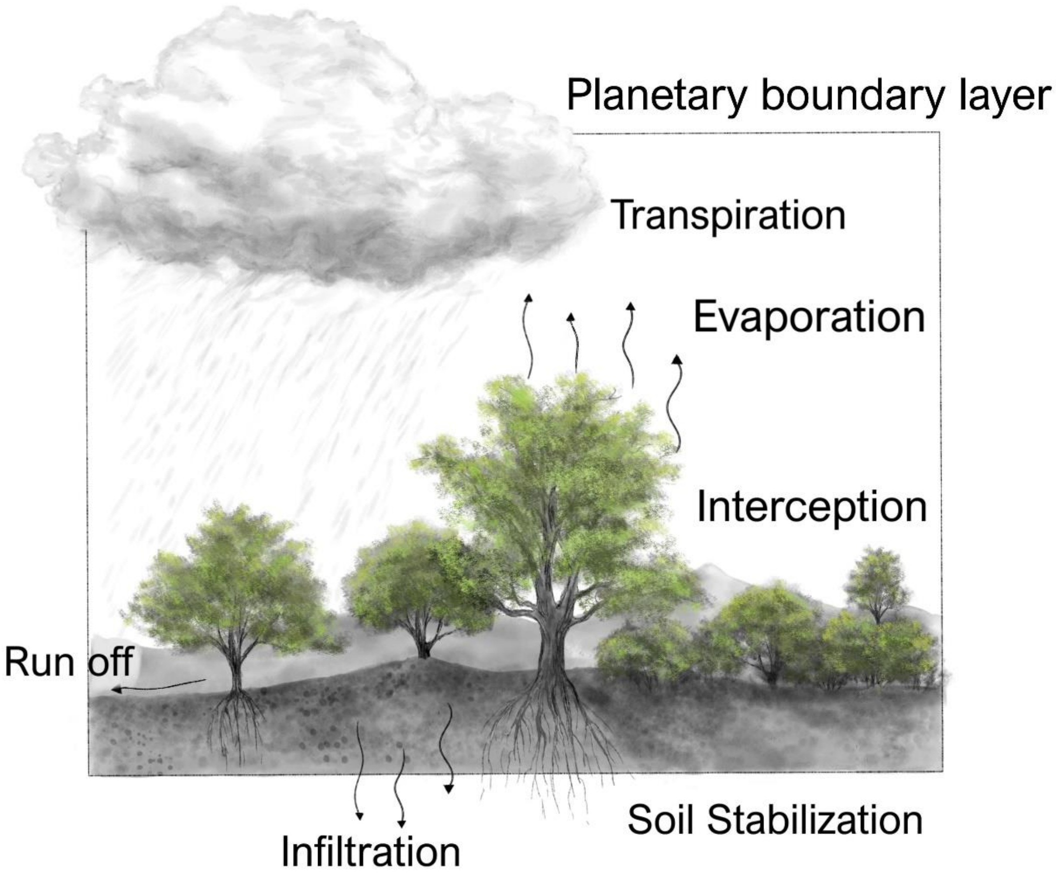

Figure 11. Role and benefits of the forest in the small hydrological cycle (authors: Jan Šebesta and Petra Barinová).

Above the forest complex, the PBL forms a continuous layer and is located below. But over a landscape with heat areas (e.g. cities, dunes, degraded grasslands, eroded slopes) and cooler areas of forest, the PBL "breaks up" into patches of varying height. As a result, the water vapor rises to a higher position where the winds blow it away. Then, the small water cycle (Figure 11) stops working. The thermal structure of the landscape thus influences local meteorological conditions.

Forest-climate interactions in Mongolia

Mongolia has a strongly continental climate, with highly fluctuating temperatures, low precipitation and marked regional variations depending on latitude and altitude. Average temperatures range between around -4 °C and -8 °C in mountain ranges, climbing to around 2 °C in the steppe desert region and up to around 6 °C in the southern desert. Annual precipitation rarely exceeds 400 mm and is typically much lower in the south and central desert and steppe regions. In the Gobi Desert, annual rainfall is only 40 mm (WBG and ADB, 2021). The already extreme conditions are becoming more intense due to the effects of **climate change** in Mongolia such as gradual increase in average annual temperatures, longer and more intense droughts and sandstorms (Marin, 2010; Khishigjargal et al., 2014; Juřička et al., 2020). Because of that, the forests are facing a serious threat (see chapter 1.3 Mongolian Forests).

Climate change is expected to exacerbate and reiterate regional drought events, especially mid-latitude aridity (Bonan, 2008). **Drought limitation** of tree growth and forest productivity has emerged as a key topic of forest health in boreal forests (Dulamsuren et al. 2023). For example, research suggests that increased summer drought reduces radial stem growth of Siberian larch (*Larix sibirica*) affecting especially latewood (Khishigjargal et al., 2014). Further, improper forest management can affect the structure of the water yield as Onuchin et al. (2017) recognized that forest cover changes led to the reduction of water yield in the continental climate of Siberia. Climate variability and change in forest cover are commonly viewed as two major drivers of runoff in large forested watersheds (Wei et al., 2018). As is evident in Mongolia in recent years, **drought events** and subsequent heavy rains cause local **flooding**.

Rising temperatures and drought are closely related to permafrost in Mongolia. The results suggest that climate change is having an impact on its functioning (see chapter 2.3 Permafrost as a Source of Water). In the northern part of Mongolia with discontinuous permafrost, the exposed steppe slopes are permafrost free and soil moisture is generally very low (Dulamsuren and Hauck 2008). In contrast, the northerly exposed slopes with a more favourable **microclimate** are vegetated with taiga forests which are provided with necessary water from melting permafrost during summer drought periods (Sugimoto et al. 2002). In summary, adverse changes in soil hydrological conditions following climate changed-induced permafrost melting likely regulate also associated CO_2, methane (CH_4) and nitrous oxide (N_2O) emissions (Ribeiro-Kumara et al., 2020).

A study by Minderlein and Menzel (2015) concludes that the highly continental climate of northern Mongolia results in water scarcity, which is particularly true for the lower river reaches in the steppe. High actual **evapotranspiration rates** were determined during fair weather periods with water unstressed conditions, suggesting evapotranspiration be the main branch of the hydrological cycle. At the shrubland site, the soil moisture dynamics differed. The water content remained almost constant at all depths with only small variations following precipitation events there.

After all, forests are under tremendous pressure from climate change (Bonan, 2008) which has been a key factor in the increasing risk and scope of **wildfires** worldwide (König et al., 2019), and also in Mongolia (Munkhjargal et al., 2020). This can further intensify the effects of climate change in the future, as wildfires strongly regulate carbon cycling and storage in boreal forests and account for almost 10% of global fire carbon emissions (Ribeiro-Kumara et al., 2020).

Forest dieback and **decline** in response to the above-mentioned extreme climate events can have long-term impacts on community dynamics and species interactions. The evapotranspiration in northern Mongolia is approximately equal to precipitation and the change of stored soil moisture. This results in negligible freshwater production at southerly exposed steppe slopes (Minderlein and Menzel, 2015). Models predict that Earth's surface temperatures will increase along with shifts in precipitation that result in greater drought severity and frequency in Mongolia (WBG and ADB, 2021). Thus, forest ecosystems in Mongolia will experience a combination of numerous **environmental stresses**. Small and isolated forest patches of Siberian larch appear to be far more sensitive to these changes than large continuous forests (Khansaritoreh et al., 2017). Considering the fundamental importance of these forests in the Mongolian landscape as **microclimate regulators**, it is possible to expect deterioration of living conditions for both people and animals.

The great and real threat is that decreases in precipitation and increased atmospheric dryness (together with increased temperature) can change climate from mesic to semi-arid or arid even in northern forested regions. Therefore, there is an urgent need for **long-term**

monitoring of the situation development, experimental studies on forest management and mitigation measures impacts and active **reforestation**.

REREFENCES

Anderson-Teixeira, K.J., Snyder, P.K., Twine, T.E., Cuadra, S.V., Costa, M.H. and DeLucia, E.H., 2012. Climate-regulation services of natural and agricultural ecoregions of the Americas. Nature Climate Change, 2(3), pp.177-181. https://doi.org/10.1038/nclimate1346.

Berbet, M.L. and Costa, M.H., 2003. Climate change after tropical deforestation: seasonal variability of surface albedo and its effects on precipitation change. Journal of Climate, 16(12), pp.2099-2104. https://doi.org/10.1175/1520-0442(2003)016<2099:CCATDS>2.0.CO;2.

Bonan, G.B., 2008. Forests and climate change: forcings, feedbacks, and the climate benefits of forests. science, 320(5882), pp.1444-1449. https://doi.org/10.1126/science.1155121.

Dulamsuren, C., Coners, H., Leuschner, C. and Hauck, M., 2023. Climatic control of high-resolution stem radius changes in a drought-limited southern boreal forest. Trees, pp.1-14. https://doi.org/10.1007/s00468-022-02384-z.

Dulamsuren, C. and Hauck, M., 2008. Spatial and seasonal variation of climate on steppe slopes of the northern Mongolian mountain taiga. Grassland science, 54(4), pp.217-230. https://doi.org/10.1111/j.1744-697X.2008.00128.x.

Favero, A., Daigneault, A., Sohngen, B. and Baker, J., 2023. A system-wide assessment of forest biomass production, markets, and carbon. GCB Bioenergy, 15(2), pp.154-165. https://doi.org/10.1111/gcbb.13013.

Forrester, M.M., Maxwell, R.M., Bearup, L.A. and Gochis, D.J., 2018. Forest disturbance feedbacks from bedrock to atmosphere using coupled hydrometeorological simulations over the Rocky Mountain headwaters. Journal of Geophysical Research: Atmospheres, 123(17), pp.9026-9046. https://doi.org/10.1029/2018JD028380.

Jandl, R., Bauhus, J., Bolte, A., Schindlbacher, A. and Schüler, S., 2015. Effect of climate-adapted forest management on carbon pools and greenhouse gas emissions. Current Forestry Reports, 1, pp.1-7. https://doi.org/10.1007/s40725-015-0006-8.

Juřička, D., Novotná, J., Houška, J., Pařílková, J., Hladký, J., Pecina, V., Cihlářová, H., Burnog, M., Elbl, J., Rosická, Z. and Brtnický, M., 2020. Large-scale permafrost degradation as a primary factor in *Larix sibirica* forest dieback in the Khentii massif, northern Mongolia. Journal of Forestry Research, 31, pp.197-208. https://doi.org/10.1007/s11676-018-0866-4.

Khansaritoreh, E., Dulamsuren, C., Klinge, M., Ariunbaatar, T., Bat-Enerel, B., Batsaikhan, G., Ganbaatar, K., Saindovdon, D., Yeruult, Y., Tsogtbaatar, J. and Tuya, D., 2017. Higher climate warming sensitivity of Siberian larch in small than large forest islands in the fragmented Mongolian forest steppe. Global change biology, 23(9), pp.3675-3689. https://doi.org/10.1111/gcb.13750.

Khishigjargal, M., Dulamsuren, C., Leuschner, H.H., Leuschner, C. and Hauck, M., 2014. Climate effects on inter-and intra-annual larch stemwood anomalies in the Mongolian forest-steppe. Acta Oecologica, 55, pp.113-121. https://doi.org/10.1016/j.actao.2013.12.003.

König, S., Matson, E.D., Krilasevic, E. and Espinosa, M.G., 2019. Estimating the mitigation potential of forest landscape restoration: Practical guidance to strengthen global climate commitments. Gland, Switzerland: IUCN.

Marin, A., 2010. Riders under storms: contributions of nomadic herders' observations to analysing climate change in Mongolia. Global Environmental Change, 20(1), pp.162-176. https://doi.org/10.1016/j.gloenvcha.2009.10.004.

Minderlein, S. and Menzel, L., 2015. Evapotranspiration and energy balance dynamics of a semi-arid mountainous steppe and shrubland site in Northern Mongolia. Environmental Earth Sciences, 73, pp.593-609. https://doi.org/10.1007/s12665-014-3335-1.

Munkhjargal, M., Yadamsuren, G., Yamkhin, J. and Menzel, L., 2020. The combination of wildfire and changing climate triggers permafrost degradation in the Khentii Mountains, northern Mongolia. Atmosphere, 11(2), p.155. https://doi.org/10.3390/atmos11020155.

Nowak, D.J., Hoehn, R. and Crane, D.E., 2007. Oxygen production by urban trees in the United States. Arboriculture and Urban Forestry, 33(3), p.220.

Onuchin, A., Burenina, T. and Pavlov, I., 2017. Hydrological consequences of timber harvesting in landscape zones of Siberia. Environments, 4(3), p.51. https://doi.org/10.3390/environments4030051.

Ribeiro-Kumara, C., Köster, E., Aaltonen, H. and Köster, K., 2020. How do forest fires affect soil greenhouse gas emissions in upland boreal forests? A review. Environmental Research, 184, p.109328.

Sugimoto, A., Yanagisawa, N., Naito, D., Fujita, N. and Maximov, T.C., 2002. Importance of permafrost as a source of water for plants in east Siberian taiga. Ecological Research, 17, pp.493-503. https://doi.org/10.1046/j.1440-1703.2002.00506.x.

Wang, S., Zhang, X., Adhikari, K., Wang, Z., Shi, D., Jin, X. and Qian, F., 2023. Impact of future climate warming on soil organic carbon stocks in Inner Mongolia, China. Ecological Indicators, 156, p.111208. https://doi.org/10.1016/j.ecolind.2023.111208.

WBG and ADB, 2021. Climate Risk Country Profile: Mongolia (2021). The World Bank Group (WBG) and the Asian Development Bank (ADB). Available at: https://www.adb.org/publications/climate-risk-country-profile-mongolia.

Wei, X., Li, Q., Zhang, M., Giles-Hansen, K., Liu, W., Fan, H., Wang, Y., Zhou, G., Piao, S. and Liu, S., 2018. Vegetation cover—another dominant factor in determining global water resources in forested regions. Global change biology, 24(2), pp.786-795. https://doi.org/10.1111/gcb.13983.

2.2 Herbaceous Vegetation: From Forests to Steppe

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Introduction

The central continental position of Mongolia, far from oceanic influences, defines its climate, and under such conditions, the spectrum of natural climate zones is rather uniform, typically with climate extremes. The flora of Mongolia reflects these conditions and is comprised of native species of different origins including boreal, steppe, desert and mountainous elements of vegetation (Gunin et al., 1999). Overall, the species richness of vascular plants in Mongolia is not particularly high, compared to other countries in Asia. The updated checklist of Mongolian flora comprises 3,041 native vascular plant taxa from 653 genera and 111 families (Baasanmunkh et al., 2022). Mongolia has the world's **largest intact grasslands** concerning biodiversity, which has great importance for the preservation of native vascular plants. While grassland vegetation is rather well explored, only a few studies focused on forest flora. For example, Bazarragchaa et al. (2022), who worked in Bogd Khan Mountain, stated that the number of species recorded in the forest area is more than 50% of the total vascular flora recorded (species pool) in the area of their interest.

In **temperate and boreal forests**, the tree layer frequently consists of a small number of tree species, while the herb layer is a major component of forest vegetation diversity. It averages more than 80% of the total plant species richness (Gilliam, 2007). The study of forests as ecological communities stresses their species composition, with a focus on the number of species and their relative importance, two variables that determine species diversity. The composition, diversity, and structure of vegetation are key factors for assessing the biological diversity of forest ecosystems. Generally, boreal and temperate forests contain fewer vascular plant species per small area than grasslands occurring in the same region (Chytrý et al., 2012). This is probably why the patterns of maximum species richness in boreal and temperate forests have not received much attention and remain poorly studied. However, Chytrý et al. (2012) discovered forests with a rich herb layer in southern Siberia. Some of the areas studied by the authors in Mongolia have a similar habitat and contain a large number of vascular species. In some of the plots, we found 35–45 species per plot (15×15 m). For example, in Bugant, the **light taiga** forest near the creek consists of Asian white birch (*Betula platyphylla*) and Scots pine (*Pinus sylvestris*), and also other wood species appear at the location, especially shrubs *Spiraea aquifolia, Rosa acicularis* and *Padus asiatica*. The **understorey vegetation** covers 50–70% of soil surface, grazing is quite sparse and occasional there. The vegetation is dominantly composed of *Carex lanceolata, Iris ruthenica* and *Maianthemum bifolium*. Yet, many other species occur there, of which these are more abundant *Vicia baikalensis, Vicia amoena, Viola biflora, Fragaria orientalis, Aegopodium alpestre, Anemone crinita, Trolius asiaticus, Geranium pseudosibiricum, Filipendula palmata* and *Poa sibirica* (Figure 12). However, mountainous and acidophilous species are also common (*Vaccinium vitis-idaea, Ledum palustre, Pyrola incarnata* and *Trientalus europaea*). Among rare species are the orchids *Cypripedium calceolus* and *C. guttatum*. The description of the vegetation unit is both a challenging adventure and an opportunity to reveal the relationship between vegetation and environmental factors in a regional context.

Figure 12. Hemi-boreal light taiga forest with an unusually high diversity of vascular plants per plot. The decorative flowers of Trollius asiaticus attract attention (photo: Václav Pecina).

Importance of vegetation

Vegetation is the source of **primary production**, controls the atmosphere gas exchanges playing a direct role in water and nutrient cycling, as well as climate and microclimate. It influences soil characteristics, and interacts strongly with other biotic components (insects, game, etc.), as it is a determinant habitat for many species. The study of forests as ecosystems takes a different perspective, emphasizing the intimate interlacing of the biotic community with its abiotic environment and focusing on how energy moves through the forest and how nutrients cycle within it. Despite the small stature of the **herbaceous layer** – its aboveground biomass is less than 1% of the forest as a whole – it has a quantifiable significance at the ecosystem level, mediating **carbon dynamics** and energy flow and influencing the cycling rates of essential nutrients, including nitrogen (N), phosphorus (P), potassium (K), and magnesium (Mg). Relative to the canopy layer, the herbaceous layer contributes little to the overall biomass of a forest, making up an average of 0.2% of the aboveground biomass of typical forests in the Northern Hemisphere (Gilliam, 2007). However, the herb layer provides approximately 4% of the net primary productivity in these forests, a 20-fold greater relative contribution to forest **net primary productivity** than to biomass. Summarizing several studies, Muller (2003) found that, on average, herbaceous litter typically decomposes more than twice as rapidly as tree litter. Thus, herb-layer species can contribute greatly to the litter component of the forest ecosystem, even though there may be relatively little herb-layer vegetation at any point in time. Because herb-layer species have high foliar concentrations of nutrients such as N, P, K, and Mg, the rapid decomposition and high turnover rate of herb-layer foliage facilitates efficient recycling of nutrients in the forest. The herbaceous layer is significant to the structure and function of forest ecosystems. It represents less than 1% of the biomass of the forest, yet can contain 90% or more of the plant species of the forest and contribute up to 20% of the foliar litter to the forest floor – litter that is generally of higher nutrient content than that of trees.

Vegetation has also been identified as a specific target for the calculation of critical loads/levels. The species composition and structure of vegetation can serve as bio-indicators for management treatments and environmental changes to ecosystems. Differences in vegetation composition can serve as **indicators** of the underlying environmental factors and status of other organisms. One of the important tasks for upcoming projects is to bring a list of indicator species for Mongolian forests.

Application for plant – herbivore interactions

Grazing is one of the factors that most affects the dynamics of vegetation in Mongolia. In the Mongolian landscape, the herds typically contain several herbivores; for various reasons the composition of livestock has changed in the last decades. The herbivores vary in body size and differ in their feeding strategies and selectivity. **A diversity of herbivores can have additive or complementary effects on plant species composition and diversity** (Sankaran and

McNaughton, 2013). The theoretical syntheses suggest that herbivore effects should vary predictably across soil fertility and moisture gradient (Ritchie and Olff, 1999). The underlying premise is that tissue nutrient concentrations and palatability of dominant species differ depending on the particular limiting resource. Where dominant plant species tend to be palatable (have high tissue nutrient concentrations), multiple herbivores can consume the same species in an additive fashion.

Plants deal with herbivory in two basic ways: they try to avoid it, or they tolerate it. Avoidance of herbivore damage can be achieved through investment in mechanical defences, production of secondary compounds or by escape in space and time (Sankaran and McNaughton, 2013). As it is typical in Mongolian grasslands and other grazed ecosystems, where herbivory is inevitable, plants instead **tolerate herbivory** through adaptations that maintain growth and reproduction following damage.

Among the principal variables affecting a plant's susceptibility to herbivory is the presence of "secondary" chemicals. Plant secondary compounds repel herbivores, inhibit their feeding, mask a plant's nutritional suitability, reduce digestibility of plant tissue or can be toxic. The high probability of herbivore attack is the driving force behind investment in constitutive defences. In communities characterized by abundant low-quality plants and rare high-quality plants, the effects of multiple herbivores can lead to compensatory effects. Herbivores also influence successional rates and trajectories of communities. Plants are vulnerable to tissue loss and even if herbivory does not result in mortality, it can reduce seedling vigour thereby influencing its competitive ability and chances of long-term survival. However, as we can often see in the species-rich forests of Mongolia, herbivore effects on seedling establishment need not always be harmful. Besides direct negative effects on vulnerable species, herbivores can also have indirect positive effects on seedling establishment of other species, which may be favoured when herbivores enhance microsite suitability through disturbances or open up canopy, reduce competition and increase light availability at the soil surface.

Nutrient and water availability, and the evolutionary history of grazing are some of the variables hypothesized to have a regulatory effect on herbivore mediation of plant richness and species composition. Herbivores have varied effects on **plant richness** of communities. Richness often declines with grazing in nutrient-poor ecosystems, while the outcome is reversed in nutrient-rich ecosystems (Sankaran and McNaughton, 2013). When grazed, species intolerant of herbivory are removed from the community (Figure 13). Since few species remain in the pool tolerant to both herbivory and low-nutrient conditions, colonization is low and species diversity declines under grazing. In nutrient-rich ecosystems, grazing on competitive dominants controls competitive interactions and diversity increases with grazing. However, increases in grazing intensity beyond a critical threshold (**overgrazing**), even in nutrient-rich ecosystems, can cause diversity to decline.

Loss of **biodiversity** is occurring on a global scale and at an ever-increasing rate. This is especially true for forest ecosystems, which often are near areas of high human population density (Gilliam, 2016) and exceedingly used landscapes. The resultant land use (including forest use, pasture, urban development, and conversion to agriculture) can exacerbate the loss of native species through habitat destruction or alteration and the introduction of invasive species. Plant species richness is higher in the herbaceous layer than in any other forest stratum, thus, threats to forest biodiversity are most often a function of threats to herbaceous layer species. On the other hand, grazing-based vegetation and its genetic diversity is a valuable resource for Mongolia (Gunin et al., 1999).

> The herb-layer composition can influence overstory **seedling dynamics** and **overstory composition**. Conversely, the composition of the overstory can influence the dynamics of herbaceous species on the forest floor by altering light availability and enhancing the spatial heterogeneity of soil fertility (Muller, 2003).

Above such broad generalizations, herbivore effects are likely to be specific to spatial scales. In Mongolian traditionally man-made landscapes, herds of domestic livestock migrated over large distances from summer to winter pastures and back. In the study by Fischer et al. (1996) on cattle and sheep, it was shown that more than 50% of local flora was transported either ecto- or endozoochorously. They also showed that dispersal distances are a function of migration speed and retention time, which for mammals is between 6 hours and 10 days (a maximum of 70 days). At small scales, herbivore mediation of competitive interactions may be the dominant process influencing species diversity, while colonization-extinction dynamics may be more important at larger scales.

At small scales, herbivores can enhance plant diversity by:

i) Selectively consuming competitive dominants, permitting the establishment of inferior species.

ii) Increasing heterogeneity through soil disturbances and permitting species co-existence.

iii) Reducing individual plant size and allowing for greater species covering within a given area.

In the absence of grazing, dominants can grow bigger, exclude sub-dominants and lower plant diversity at small scales. However, if overall rates of colonization and extinction are not altered, such differences may not be evident at large scales (Stohlgren et al., 1999). Species excluded by grazers at small scales may persist in "grazing-safe sites" at larger scales. However, as we recognized in steppe locations with strong grazing and trampling intensity, if grazing pressure is strong enough, intolerant species may be weeded out altogether from the regional species pool, lowering diversity at larger scales.

Figure 13. Intensively grazed and trampled steppe grassland with a few dominant herb species (Carex duriuscula vegetation type) and low cover (photo: Jan Šebesta).

The low-productivity steppe near the village of Javkhlant is dominated by the tussock-forming short grasses. The cover of vegetation is quite variable, ranging from 30 to 80%. Common species of the herb layer are species adapted to grazing pressure, disturbance and intensive solar radiation. The matrix comprises *Carex duriuscula*, hard and durable sedge of low growth. Other dominant species include grasses *Elymus sibirica*, *Poa pratensis, Achnateron splendens* and the dicot herbs *Plantago major, Potentilla tanacetifolia, P. acaulis, Rumex pulchellus, Artemisisa* spp., *Heteropapus hispidus, Schisonepeta annua* etc. Some of the dominant plants are nutrient demanding – *Chenopodium album*, *Medicago lupulina, Taraxacum* spp. and *Urtica cannabina* – which is another consequence of grazing. Besides, some of the species are halophytes (salt meadow plants) e.g. *Potentilla anserina*, *Glaux maritima* and *Saussera davurica*; saline grasslands are quite common in the surrounding habitats. After all, the diversity is still high. Probably the bunchy hard grass such as *Achnateron splendens* creates micro-habitats where some species find their niche. Besides, even a small difference of geomorphology like the terrain depression hosts other types of species: *Schizonepeta annua*, *Potentilla bifurca, Iris lactea* and others.

Forest ecosystems harbour the majority of **terrestrial biodiversity** and are a key to maintaining multiple ecosystem services. Our studies demonstrate unique forest and non-forest vegetation with a rich herb layer containing many rare plants. However, **forest biodiversity** in Mongolia is increasingly affected by global changes, including climate change, land-use change together with unregulated grazing. Comprehension of temporal changes in understory diversity and its responses to changes in environmental conditions is essential for **forest conservation** and **sustainable management**. In summary, understanding these natural relations and the dynamics of herbaceous vegetation is important for **setting up sustainable forest and landscape management while maintaining species diversity**.

REFERENCES

Baasanmunkh, S., Urgamal, M., Oyuntsetseg, B., Sukhorukov, A.P., Tsegmed, Z., Son, D.C., Erst, A., Oyundelger, K., Kechaykin, A.A., Norris, J. and Kosachev, P., 2022. Flora of Mongolia: annotated checklist of native vascular plants. PhytoKeys, 192, p.63. https://doi.org/10.3897/phytokeys.192.79702.

Bazarragchaa, B., Kim, H.S., Batdelger, G., Batkhuu, M., Lee, S.M., Yang, S., Peak, W.K. and Lee, J., 2022. Forest vegetation structure of the Bogd Khan Mountain: A strictly protected area in Mongolia. Journal of Asia-Pacific Biodiversity, 15(2), pp.267-279. https://doi.org/10.1016/j.japb.2022.04.001.

Chytrý, M., Ermakov, N., Danihelka, J., Hajek, M., Hájková, P., Horsák, M., Kočí, M., Kubešová, S., Lustyk, P., Otýpková, Z. and Peláneková, B., 2012. High species richness in hemiboreal forests of the northern Russian Altai, southern Siberia. Journal of Vegetation Science, 23(4), pp.605-616. https://doi.org/10.1111/j.1654-1103.2011.01383.x.

Fischer, S.F., Poschlod, P. and Beinlich, B., 1996. Experimental studies on the dispersal of plants and animals on sheep in calcareous grasslands. Journal of Applied Ecology, pp.1206-1222. https://doi.org/10.2307/2404699.

Gilliam, F.S., 2016. Forest ecosystems of temperate climatic regions: from ancient use to climate change. New Phytologist, 212(4), pp.871-887. https://doi.org/10.1111/nph.14255.

Gilliam, F.S., 2007. The ecological significance of the herbaceous layer in temperate forest ecosystems. BioScience, 57(10), pp.845-858. https://doi.org/10.1641/B571007.

Gunin, P.D., Vostokova, E.A., Dorofeyuk, N.I., Tarasov, P.E. and Black, C.C. (eds.), 1999. Vegetation Dynamics of Mongolia. Boston, London Kluwer Academics.

Muller, R.N., 2003. Nutrient relations of the herbaceous layer in deciduous forest ecosystems. In: Gilliam, F.S. and Roberts M.R. (eds.). The herbaceous layer in Forests of Eastern North America. 1st edition. Oxford University Press, New York.

Ritchie, M.E. and Olff, H., 1999. Herbivore diversity and plant dynamics: compensatory and additive effects. Herbivores: between plants and predators, pp.175-204.

Sankaran, M. and McNaughton, S.J., 2013. Terrestrial Plant-Herbivore Interactions: Integrating Across Multiple Determinants and Trophic Levels. In: Van der Maarel, E. and Franklin, J. (eds.). Vegetation ecology. 2nd edition. John Wiley & Sons, Ltd. https://doi.org/10.1002/9781118452592.ch8.

Stohlgren, T.J., Schell, L.D. and Vanden Heuvel, B., 1999. How grazing and soil quality affect native and exotic plant diversity in Rocky Mountain grasslands. Ecological applications, 9(1), pp.45-64. https://doi.org/10.1890/1051-0761(1999)009[0045:HGASQA]2.0.CO;2.

2.3 Permafrost as a Source of Water

David Juřička

What is permafrost?

Permafrost is the ground frozen for at least two years continuously (FAO, 2015). Permafrost occurs almost exclusively in the northern hemisphere where it covers up to 25% of its area (Anisimov, 2007), approximately 23 million km^2 (Figure 14). Frozen ground can reach a depth of up to 1,450 m. The extension of permafrost is conditioned by the long-term cold climate with a mean annual air temperature below 0 °C. Most of the existing permafrost was formed in the Holocene approximately 10,000 years ago. Permafrost is divided according to the degree of fragmentation into **continuous** (coverage 90–100%), **discontinuous** (coverage 50–90%), sporadic (coverage 10–50%) and **isolated** (coverage 0–10%) (Dobinski, 2011).

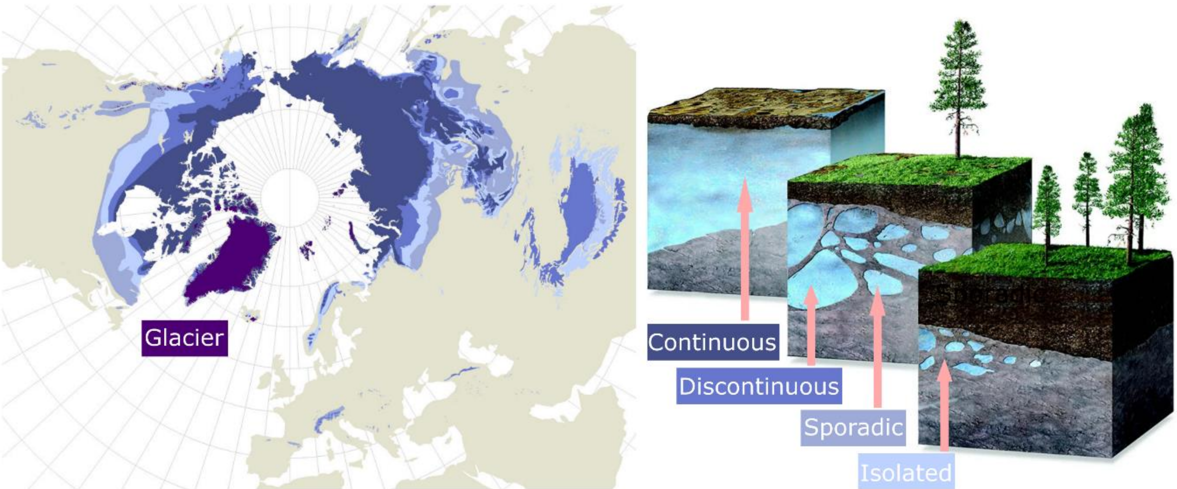


Figure 14. Permafrost in the North Hemisphere (modified according to National Geographic, 2023).

The uppermost layer of permafrost is called the **active layer**. The active layer naturally melts in summer and freezes in autumn again (Davis, 2001). Seasonal melting of the active layer is an important natural process when the frozen water is becoming available for environment and vegetation (Figure 15).

Figure 15. *The active layer of permafrost at different places in Mongolia (photos: David Juřička).*

Permafrost in Mongolia

Permafrost covers up to 67% of Mongolia's territory (Figure 16). The lower boundary of continuous and discontinuous permafrost is at 1,400 m above sea level and 600–700 m above sea level, respectively. The average depth of permafrost is 100–250 m in mountains and 50–100 m in valleys and lower altitudes. The active layer of permafrost reaches 4–6 m in a consistent subsoil and in 1–3 m in fine-grained soils (Sharkhuu, 2003).

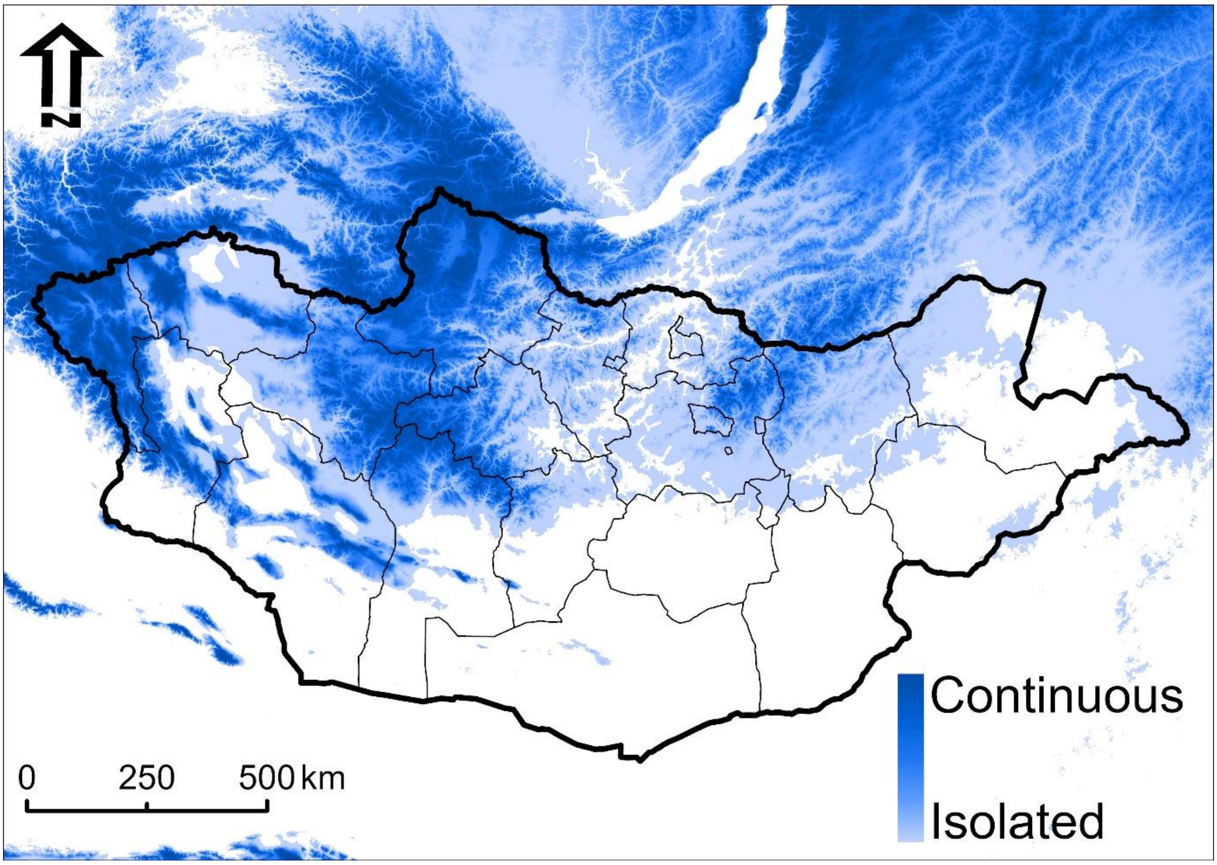


Figure 16. *Extension of permafrost in Mongolia (author: David Juřička).*

Why is permafrost so important?

Natural seasonal melting of permafrost active layer supplies the environment with water and significantly contributes to soil moisture. Due to the low annual amount of precipitation (less than 400 mm in the north) occurring mostly between June and August (85–90% of precipitation) most forests in Mongolia are strictly dependent on water supply from the natural seasonal melting of the active layer. **The occurrence of forest in Mongolia is almost exclusively linked to permafrost occurrence** (Figure 17).

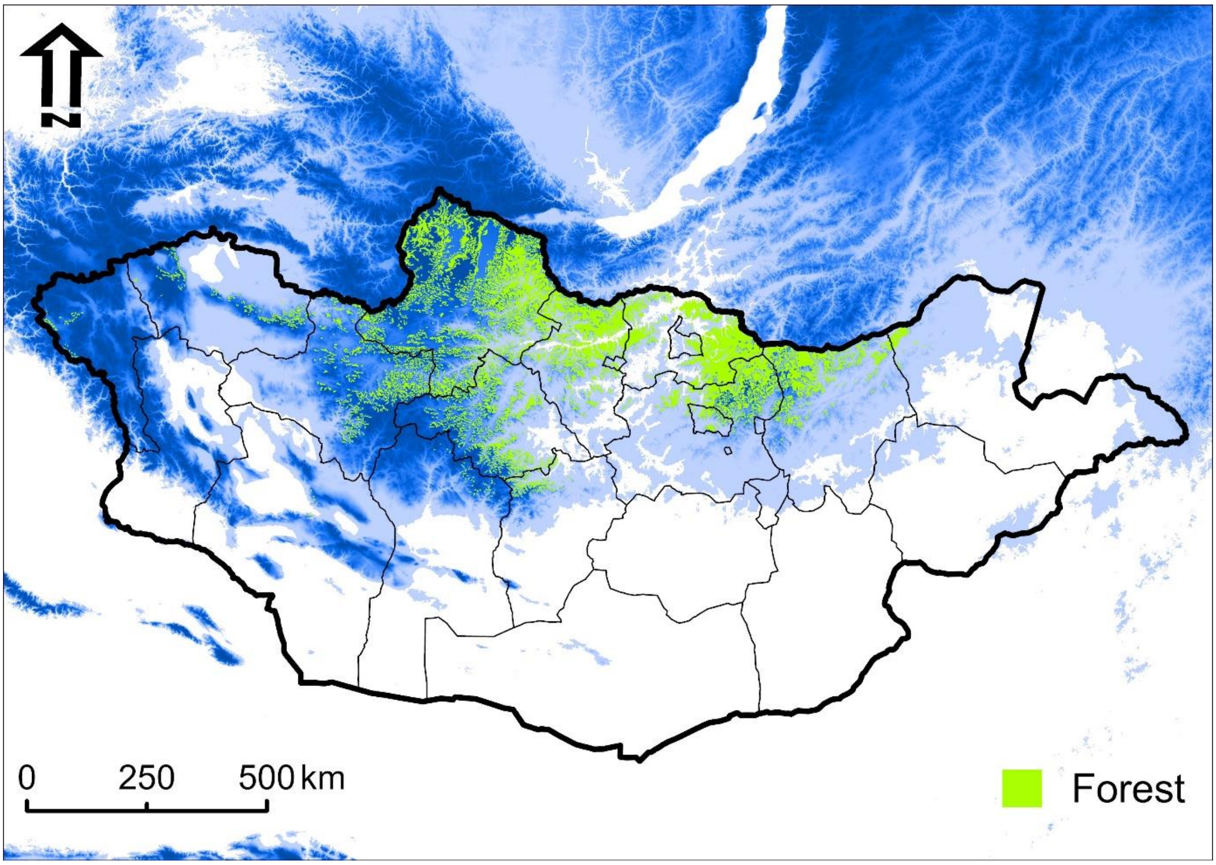


Figure 17. Occurrence of forest in Mongolia (author: David Juřička).

Permafrost has an important socio-economic value when significantly it influences the quality and accessibility of **drinking water**. Water from natural seasonal active layer melting contributes to recharge of ground water sources both in situ and in the remote areas of Mongolia far from permafrost occurrence. Active layer melting is also an important source of water for many Mongolia's rivers.

Mutual interaction between forest and permafrost

Permafrost and forest are under strong **mutual interaction**. Forest protects soil surface against sun radiation and prevents excessive melting of frozen ground (Kokelj et al., 2010). Then the natural seasonal melting of the active layer increases soil moisture (Osawa et al., 2010) and thus compensates for the lack of precipitation. A problem will arise when this sensitive balance is disturbed. When the forest is affected by some large-scale disturbance, it causes the canopy cover reduction and the bare soil is more exposed to the sun and becomes warmer. Increasing soil temperature causes excessive permafrost melting and massive development of the active layer. This leads to significant changes in soil moisture and water balance of landscape.

In first stage of **permafrost degradation**, a huge amount of water frozen for many decades becomes available. Soil moisture increases dramatically and the soil above the permafrost is becoming waterlogged. Unfortunately, the conifers are not able to tolerate waterlogged soils with a lack of oxygen for a long time. The roots of trees are rotting, which makes the trees weak and an easy target for a pest invasion. This results in the spiral of degradation when the retreat of forest is increasing soil heating, which accelerates permafrost melting and vice versa. In the second stage of permafrost degradation, the frozen ground is deeper, and water is becoming unavailable for plants (Juřička et al., 2020; Figure 18). The degradation process leads to aridization and desertification of the landscape.

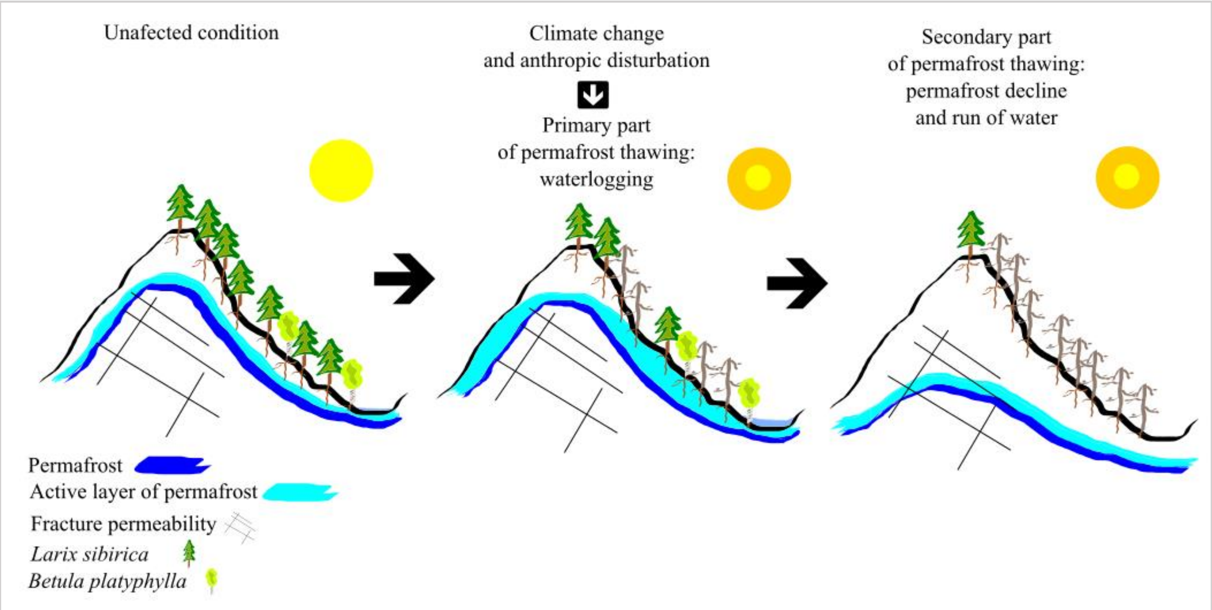


***Figure 18**. Permafrost degradation (Juřička et al., 2020).*

REFERENCES

Anisimov, O.A., 2007. Potential feedback of thawing permafrost to the global climate system through methane emission. Environmental Research Letters, 2(4), p.045016. https://doi.org/10.1088/1748-9326/2/4/045016.

Davis, N., 2001. Permafrost: A Guide to Frozen Ground in Transition. University of Alaska Press, Fairbanks.

Dobinski, W., 2011. Permafrost. Earth-Science Reviews, 108(3-4), pp.158-169. https://doi.org/10.1016/j.earscirev.2011.06.007.

FAO, 2015. World reference base for soil resources 2014: International soil classification system for naming soils and creating legends for soil maps. Food and Agriculture Organization of the United Nations, Rome. Available at: http://www.fao.org/3/i3794en/I3794en.pdf.

Juřička, D., Novotná, J., Houška, J., Pařílková, J., Hladký, J., Pecina, V., Cihlářová, H., Burnog, M., Elbl, J., Rosická, Z. and Brtnický, M., 2020. Large-scale permafrost degradation as a primary factor in *Larix sibirica* forest dieback in the Khentii massif, northern Mongolia. Journal of Forestry Research, 31, pp.197-208. https://doi.org/10.1007/s11676-018-0866-4.

Kokelj, S.V., Riseborough, D., Coutts, R. and Kanigan, J.C.N., 2010. Permafrost and terrain conditions at northern drilling-mud sumps: Impacts of vegetation and climate change and the management implications. Cold Regions Science and Technology, 64 (1), 46–56. https://doi.org/10.1016/j.coldregions.2010.04.009

Osawa, A., Zyryanova, O.A., Matsuura, Y., Kajimoto, T. and Wein, R.W. (eds.), 2010. Permafrost ecosystems: Siberian Larch Forests, Springer, Dordrecht. https://doi.org/10.1007/978-1-4020-9693-8.

Sharkhuu, N., 2003. Recent changes in the permafrost of Mongolia. In: Proceedings of the 8th International Conference on Permafrost, 21-25 July 2003, Zurich, Switzerland (1029–1034). AA Balkema, Lisse, the Netherlands. Available at: https://www.arlis.org/docs/vol1/ICOP/55700698/Pdf/Chapter_180.pdf.

2.4 Soil Properties and Nutrient Cycling

Martin Valtera & Douglas L. Godbold

Introduction

From the physical point of view, soil consists of three phases: solid, liquid, and gaseous (Lukac and Godbold, 2011). The solid phase consists of **soil organic matter** and **mineral particles** of various shapes and sizes and is responsible for the long-term fertility of a soil. The liquid phase is usually represented by **soil water** with varying concentrations of dissolved compounds (soil solution), which is the medium of nutrient exchange between the solid phase, microorganisms, and plant roots. Finally, the gaseous phase represents soil '**air**' and is mostly responsible for soil exchange with the atmosphere.

Understanding soil conditions is key to **classifying forests** and setting up proper **sustainable forest management**, which must be based on the **natural potential** of the site.

Soil texture

Soil composition strongly influences its mechanical and hydrological properties, and the surface area available for mineral weathering, ion and water exchange. **Soil texture** describes the soil solid phase by the relative proportions of mineral constituents smaller than 2 mm (fine earth). These constituents are classified as **sand** (2.000–63 μm), **silt** (63–2 μm), and **clay** (< 2 μm) and their relative proportions determine the soil textural class (Figure 19). Coarse particles larger than 2 mm are called gravel (< 60 mm), stones (< 200 mm), and boulders. After removal of coarse particles, soil texture can be analysed in a laboratory or estimated using various field tests (IUSS Working Group WRB, 2022).

Sand and coarser particles make soil more easily permeable for water and air, which enables the roots to grow deep (Figure 20). The contents of sand and coarse particles also make soil more resistant to mechanical compaction. On the other hand, high contents of sand and coarse particles lower the water-holding and cation-exchange capacities of a soil, which can limit plant access to key resources. Moreover, soils with high contents of sand and coarse particles can be highly permeable for percolating water, which increases the risk of nutrient loss by leaching (e.g. with excessive rainfall, snow melt, or irrigation). Dry sand is particularly prone to water and wind erosion (the latter can form sand dunes). In such cases, reforestation can be considered as a kind of conservation or **restoration management**.

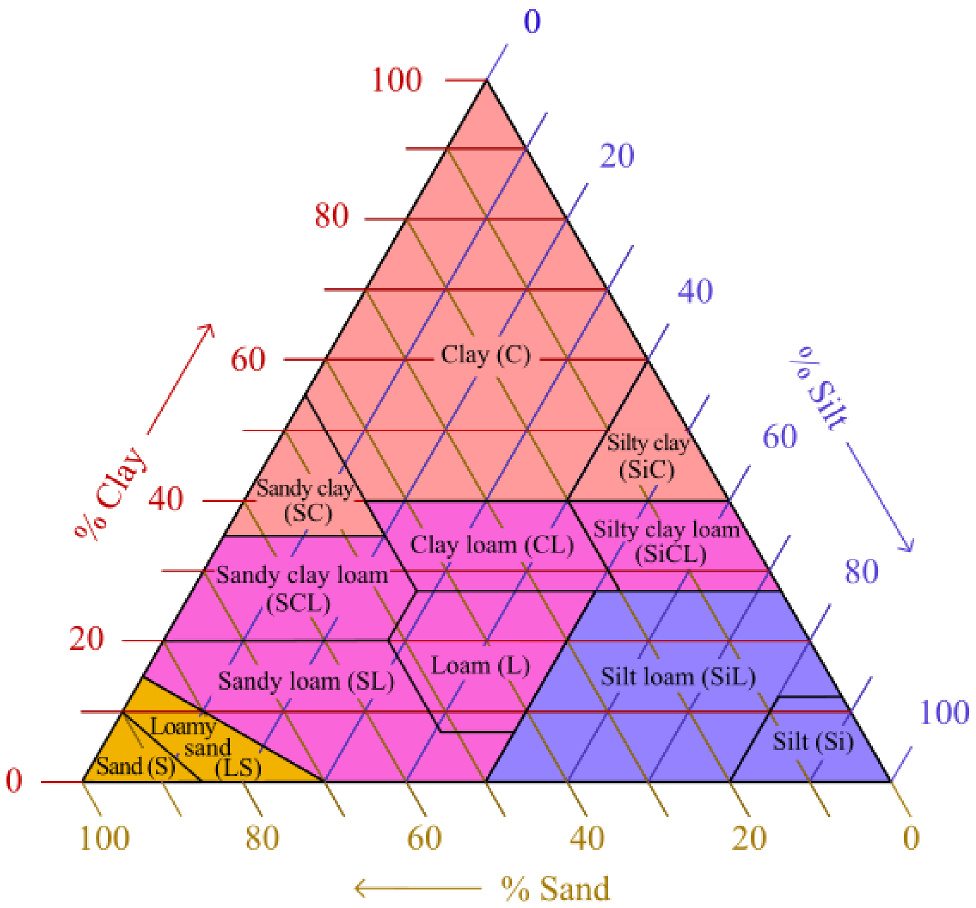


Figure 19. Soil textural classes and the general definitions of sandy (yellow), silty (blue), clayey (orange), and loamy (purple) soils based on the sand, silt, and clay contents in the fine earth (IUSS Working Group WRB, 2022).

Silt has somewhat higher surface area compared to sand and a high affinity with clay particles and organic matter (OM), which promotes the development of soil aggregates and an excellent soil structure. Therefore, soils rich in silt make some of the most fertile soils on Earth (IUSS Working Group WRB, 2015). Such soils are often formed on loess (Figure 21), which is the relic post-glacial wind deposit common in many temperate and boreal landscapes. Loess material is particularly vulnerable to wind erosion when dry (e.g. dust storms), which poses a severe risk to some agricultural and steppe ecosystems. A silty soil is also prone to water erosion, which may contribute to the fast formation of deep rills and gullies as the result of a heavy rainfall.

Figure 20. The profile of a sandy soil (Eutric Arenosol) in a pine forest near Bayan-Adarga. The mineral topsoil was loamy sand with a high density of fine roots and an old burrow at the centre of the profile; the subsoil (40–70 cm depth) and substrate (70+ cm depth) were medium sand; note the sinker roots that occur below the transition from subsoil into substrate (photo: Martin Valtera).

Figure 21. The profile of a silty soil (Calcic Kastanozem) in a pine forest near Sharin-Gol. A thin forest floor overlaid the thick and dark mineral topsoil (a mollic horizon). The subsoil (40–70 cm depth) was slightly calcareous and the substrate loess (70+ cm depth) strongly calcareous (field test with 10% $CaCl_2$) silt loam (photo: Martin Valtera).

Clay particles belong to a group of secondary minerals known as alumino-silicates that are formed as the products of weathering. The small size of clay particles makes an enormous surface area for water and ion exchange. Moreover, clay particles have usually a negative electric charge on their surfaces, which attracts cations present in soil solution. Therefore, clay content strongly increases soil cation exchange capacity. In addition, clays have the typical layered structure, which enables the absorption of water and dissolved compounds in high volumes. In clayey soils, this property may result in swelling when wet and cracking when dry, which can cause a mechanical damage to plant roots. The excess of water in some clayey soils may also limit the access of oxygen to plant roots. Under certain condition, clay particles can migrate through a soil profile with percolating water to develop distinct textural differentiation of soil horizons (Figure 22).

Loam occupies a central location in any soil texture diagram. As noted by Lukac and Godbold (2011), this is a texture class that contains the balanced proportion of sand, silt and clay. Therefore, a loamy soil typically stores more nutrients than pure sand, is better drained and aerated than pure clay, and provides better mechanical stability than pure silt. This all can make loamy soils the optimal choice for a productive and **sustainable forest management** (Figure 23).

Figure 22. The profile of a soil with the vertical translocation of clay (Luvic Phaeozem) in a mixed birch forest near Sharin-Gol. Underneath the loamy mineral topsoil (10–40 cm depth) a bleached silt loam has developed. The subsoil (70–90 cm depth) silty clay loam had clay-humus coatings on soil aggregates and transitioned to the slightly calcareous silt loam substrate loess (photo: Martin Valtera).

Figure 23. The profile of a loamy soil (Eutric Cambisol) in a larch forest near Burkhan Khaldun. A thin (0–10 cm depth) silt loam topsoil overlies the thick (10–55 cm depth) subsoil (a cambic horizon), loam to sandy loam with gravel and stones; the rock content was around 35% by volume (field estimate) down to the 65-cm depth (photo: Martin Valtera).

Soil organisms

Living organisms are the essential part of any soil (Osman, 2013), which differentiates it from a sterile substrate. The living constituents of soil are typically represented by plant roots, fungal mycelia, and other micro- and macro-organisms. Soil organisms continuously influence and modify their physical environment, for which they are often called "ecosystem engineers". The activity of soil microorganisms is critical for plant access to water and mineral nutrients.

Soil organic matter

Soil organic matter (SOM) comprises the sum of all organic substances in soil, which come from plant, animal, and microbial bodies and products at various stages of decomposition (Lal, 2017). **SOM is essential to soil fertility**, and its content is high particularly in cool environments such as those in Mongolia. Erosion by water and wind preferentially removes SOM from the soil surface due to its low density. Fortunately, there are several stabilization mechanisms that preserve SOM in soil, including the physical protection (e.g. aggregation), interaction with mineral surfaces (particularly fine silt and clay), and the complexation with metals such as calcium (Ca), or aluminium (Al) and iron (Fe), depending on soil pH (Cronan, 2018).

Soil pH

Soil pH can be defined as the negative logarithm of the activity of H^+ in a soil solution and is used as the relative measure of soil acidity or alkalinity. Soil pH ≤ 5.5 indicates strongly acidic soils, while pH ≥ 8.5 indicates strongly alkaline soils. Soils with pH 6.6–7.3 are considered pH neutral and soil pH range between 5.5 and 7.5 is considered optimum for most plants. Soil pH has strong consequences for many bio-chemical processes in soil, including the **accessibility of mineral nutrients** to plants and microorganisms. The pool of H^+ in soil solution is typically small as any inputs of H^+ are strongly buffered by complex interactions with the ion exchange processes at soil colloids (Cronan, 2018). Therefore, changes in soil pH are strongly linked to the cycles of OM and plant nutrients such as nitrogen and base cations (Binkley and Fisher, 2020).

Plant nutrients

Based on their contribution to plant biomass, chemical elements can be divided into plant **macro and micronutrients**. The so-called “macro” nutrients build up together around 95% of plant biomass and can be somewhat casually divided into the following three groups: (i) carbon (C), oxygen (O), and hydrogen (H) are coming from atmosphere in the forms of water (H_2O) and carbon dioxide (CO_2), which plants can directly utilise in photosynthesis. In contrast, (ii) potassium (K), calcium (Ca), and magnesium (Mg) are mostly released by weathering and are together with sodium (Na) known as the base cations. Base cations are easily retained on the negatively charged surfaces of inorganic particles or SOM, which form the soil cation exchange complex. Finally, the key nutrients with mixed origin include nitrogen (N), sulphur (S), and phosphorus (P), which are being largely accumulated in SOM and their release for plant uptake is strongly controlled through the activity of soil microorganisms.

Nutrient cycling

All essential elements are more or less tightly **recycled** in the ecosystem through various processes and mechanisms (Figure 24). This nutrient cycling enables nutrient accumulation in the system, if the nutrient budget is positive (inputs > outputs), or results in nutrient depletion, if the nutrient budget is negative (inputs < outputs).

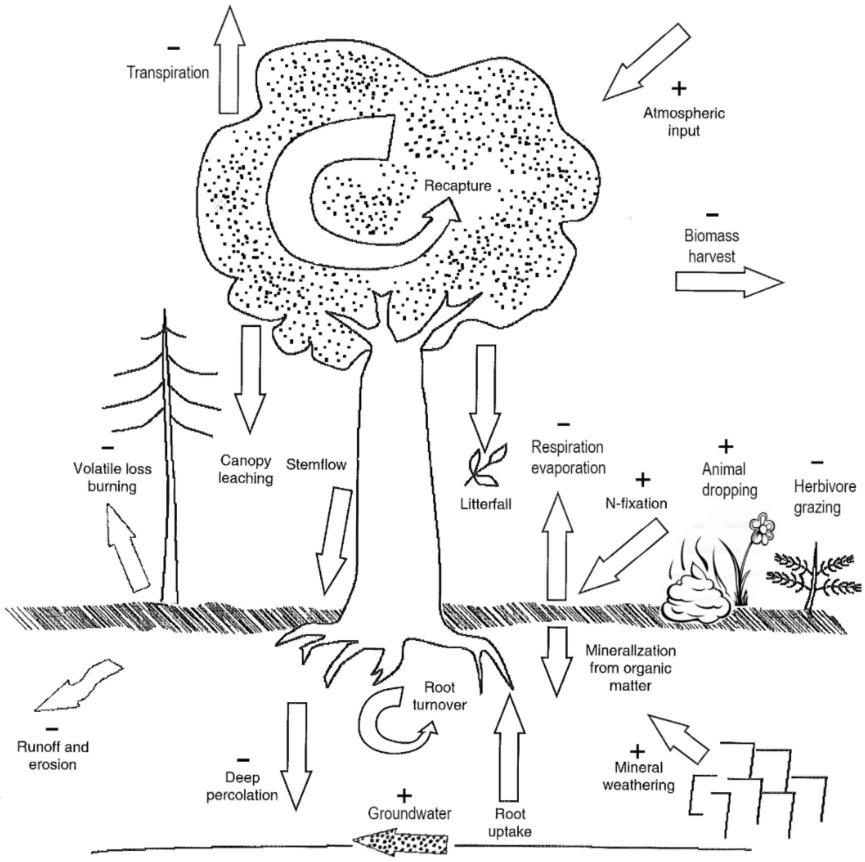


Figure 24. Potential processes of nutrient fluxes in a forest ecosystem; the symbols indicate inputs (+) and outputs (-) of the plant–soil subsystem. Adapted after Morris (2004).

Soil carbon cycle

Soil organic matter is the main pool of soil organic carbon (SOC). The SOC stocks can be equal or higher than the C stock in the aboveground biomass. For example, Dulamsuren et al. (2019) found the belowground C stocks down to 1-m depth between 134 and 181 Mg/ha in *Larix sibirica* forests near Tunkhel. Compared to other biomes, boreal forests soils have the highest SOC stock down to 1-m depth, particularly in peat and organic soils (Lorenz and Lal, 2010). Plant litter and root exudation support a complex food web of soil organisms, which results in the transformation of SOM into various products with different stability at every step of the food chain (Lukac and Godbold, 2011). The final product of decomposition can be either dissolved organic matter (the most labile form) or soil humus (a general term for the stable SOC pool). Soil respiration is one of the main processes of soil C release to the atmosphere, which is strongly intensified by the **climate change** and increases after **forest harvest** (Binkley and

Fisher, 2020). This results in the typical temporary decrease of SOC pools after forest disturbance, particularly in the forest floor (Figure 25). On the other hand, the rapid combustion and mineralization of SOC pools during and after a forest fire is partly compensated for by the transformation of some improperly burned biomass into the biochemically recalcitrant char (or "black C"), whose residence time in a soil ranges from decades to millenia (Lorenz and Lal, 2010).

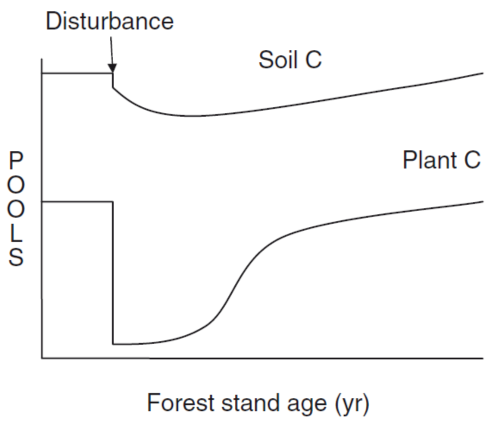


Figure 25. Idealized patterns of changes in soil and plant carbon pools during the secondary succession following forest disturbance (modified from Lorenz and Lal, 2010).

Soil nitrogen cycle

Soil N is usually the main mineral nutrient limiting plant growth in boreal forests. Although the atmosphere comprises > 78% N_2, this molecular form is not accessible to plants. Therefore, plants rely on the soil N pool, which is strongly controlled by the activity of soil microorganisms (Figure 26). In boreal forests with low N inputs, organic N plays a prominent role in the N cycle. The availability of N is regulated by recycling of OM and the release of N during decomposition. The breakdown of OM is regulated by saprotrophic and mycorrhizal fungi, but also by bacteria. The provision of mineral forms of N as NH_4 and NO_3 occurs in sequential steps, in which the availability of the product of the previous reaction limits the subsequent reaction. The rates of the different reaction steps are regulated by soil temperate and moisture. After depolymerisation of organic N, the monomers such as amino acids are rapidly taken up by ectomycorrhizal fungi and plant roots, limiting the substrate availability for ammonification, and subsequent nitrification. As a consequence, only low levels of NH_4 and particularly NO_3 are found in the soil solution of these soils (Table 1). This is strong contrast to tropical forest soil or fertilized agricultural soils where NH_4 and NO_3 dominate. This tight N cycling may shift significantly, however, as the result of forest grazing or forest disturbance such as fire (Cronan, 2018).

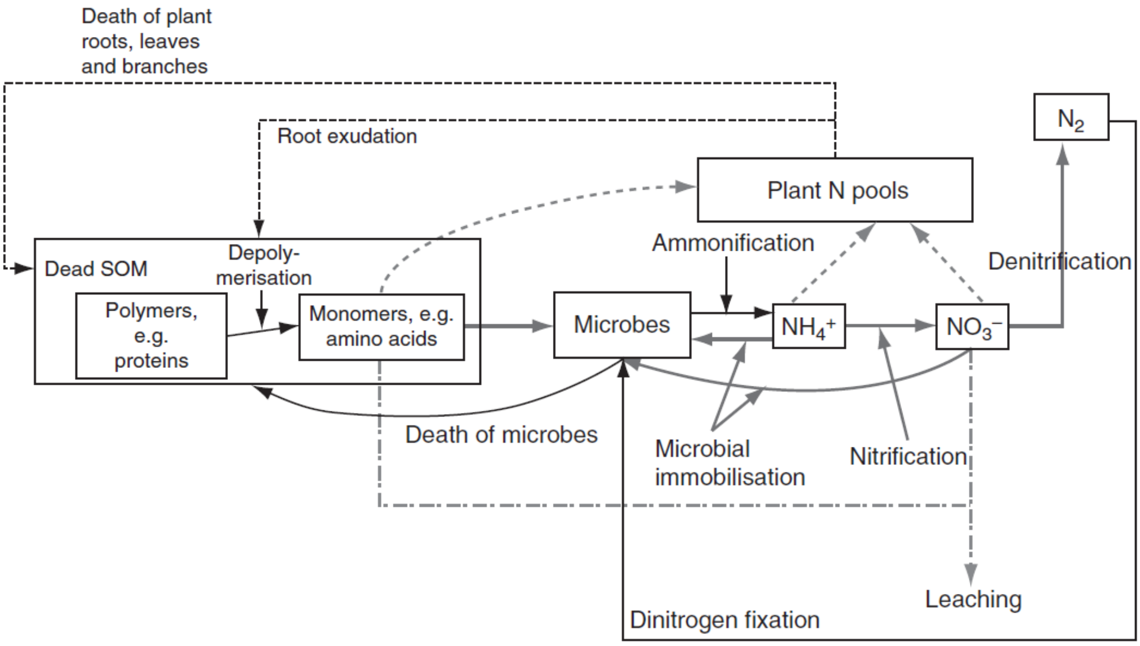


Figure 26. N cycling in a low N input forest ecosystem (Lukac and Godbold, 2011): dashed lines, plant processes; solid lines, microbial processes; grey dashed lines, competitive processes between plants and microorganisms; dot–dashed lines, hydrological transport pathways; SOM, soil organic matter.

Table 1. Levels of ammonium (NH_4+), nitrate (NO_3-) and dissolved organic N (DON) in soils of a high-elevation pine forest; the same letters indicate no differences between the tree species (Otgonsuren et al., 2020).

Tree species	NH_4^+	NO_3^- (mg/kg)	DON
Pinus sibirica	24.6±2.0ᵃ	2.2±0.8ᵃ	37.6±7.8ᵃ
Pinus sylvestris	24.0±2.9ᵃ	1.9±0.3ᵃ	43.2±8.9ᵃ

REFERENCES

Binkley, D., Fisher, R.F., 2020. Ecology and Management of Forest Soils, 5th edition. John Wiley & Sons, Ltd. https://doi.org/10.1002/9781119455745

Cronan, C.S., 2018. Ecosystem Biogeochemistry: Element Cycling in the Forest Landscape. Springer Nature, Cham. https://doi.org/10.1007/978-3-319-66444-6

Dulamsuren, C., Klinge, M., Bat-Enerel, B., Ariunbaatar, T., Tuya, D., 2019. Effects of forest fragmentation on organic carbon pool densities in the Mongolian forest-steppe. Forest Ecology and Management 433, 780–788. https://doi.org/10.1016/j.foreco.2018.10.054

IUSS Working Group, W., 2022. World Reference Base for Soil Resources: International soil classification system for naming soils and creating legends for soil maps, 4th edition. International Union of Soil Sciences (IUSS), Vienna.

IUSS Working Group WRB, 2015. World Reference Base for Soil Resources 2014, update 2015, World Soil Resources Reports No. 106. FAO, Rome.

Lal, R., 2017. Encyclopedia of Soil Science, 3rd edition. CRC Press, Boca Raton.

Lorenz, K., Lal, R., 2010. Carbon Sequestration in Forest Ecosystems. Springer, Dordrecht. https://doi.org/10.1007/978-90-481-3266-9

Lukac, M., Godbold, D.L., 2011. Soil Ecology in Northern Forests: A Belowground View of a Changing World. Cambridge University Press, New York.

Morris, L.A., 2004. Soil Development and Properties: Nutrient Cycling. In: Burley, J. (ed.). Encyclopedia of Forest Sciences. Elsevier Ltd., Oxford, pp. 1227–1235. https://doi.org/10.1016/B0-12-145160-7/00242-8

Osman, K.T., 2013. Forest soils: Properties and Management. Springer, Cham. https://doi.org/10.1007/978-3-319-02541-4

Otgonsuren, B., Rosinger, C., Wang, L., Godbold, D.L., 2020. Winter soils of Mongolian forests have viable ectomycorrhizas and soil enzymatic activity. Soil Biology and Biochemistry 148, 107914. https://doi.org/10.1016/j.soilbio.2020.107914

2.5 Mycorrhiza for Healthy Forest Communities

Burenjargal Otgonsuren, Enkhtuya Batkhuu, Douglas L. Godbold

Introduction

Mycorrhizas are a highly evolved, **mutualistic association between soil fungi and plant roots**. In this association, the fungus acts as an extension of the root system. Mycorrhizas improve the growth and survival of plants by enhancing the uptake of nutrients, especially that of phosphate and nitrogen (Smith and Read, 1997). In return, mycorrhizas receive from the host plant carbohydrates from photosynthesis necessary for their own growth. The movement of carbohydrates into the root system and mycorrhizal hyphae is a major pathway for the flow of carbon (C) from leaves to soils. **Mycorrhizal fungi** also have the potential to affect host plant quality and alter C allocation to defence responses above ground, thus providing protection against herbivores and tolerance to biotic and abiotic stresses. Mycorrhizal fungi have also been linked to increasing host tree resistance to soil pathogens.

Mycorrhizal fungi form a range of types of mycorrhizas on roots of plants, the most common mycorrhizal associations are (Brundrett et al., 1996):

1. Arbuscular mycorrhizas (AM) – in which zygomycete fungi produce arbuscules, hyphae, and vesicles within root cortex cells.
2. Ectomycorrhizas (EM) – where mainly basidiomycetes and ascomycete fungi form a mantle around roots and a Hartig net between root cells.
3. Ericoid mycorrhizas – involving hyphal coils in outer cells of the fine 'hair roots' of plants in the plant order *Ericales*.
4. Orchid mycorrhizas – where fungi produce coils of hyphae within roots (or stems) of orchidaceous plants,
5. Ectendo-, arbutoid and monotropoid mycorrhizas associations which are similar to ectomycorrhizal associations but have specialized anatomical features (Figure 27).

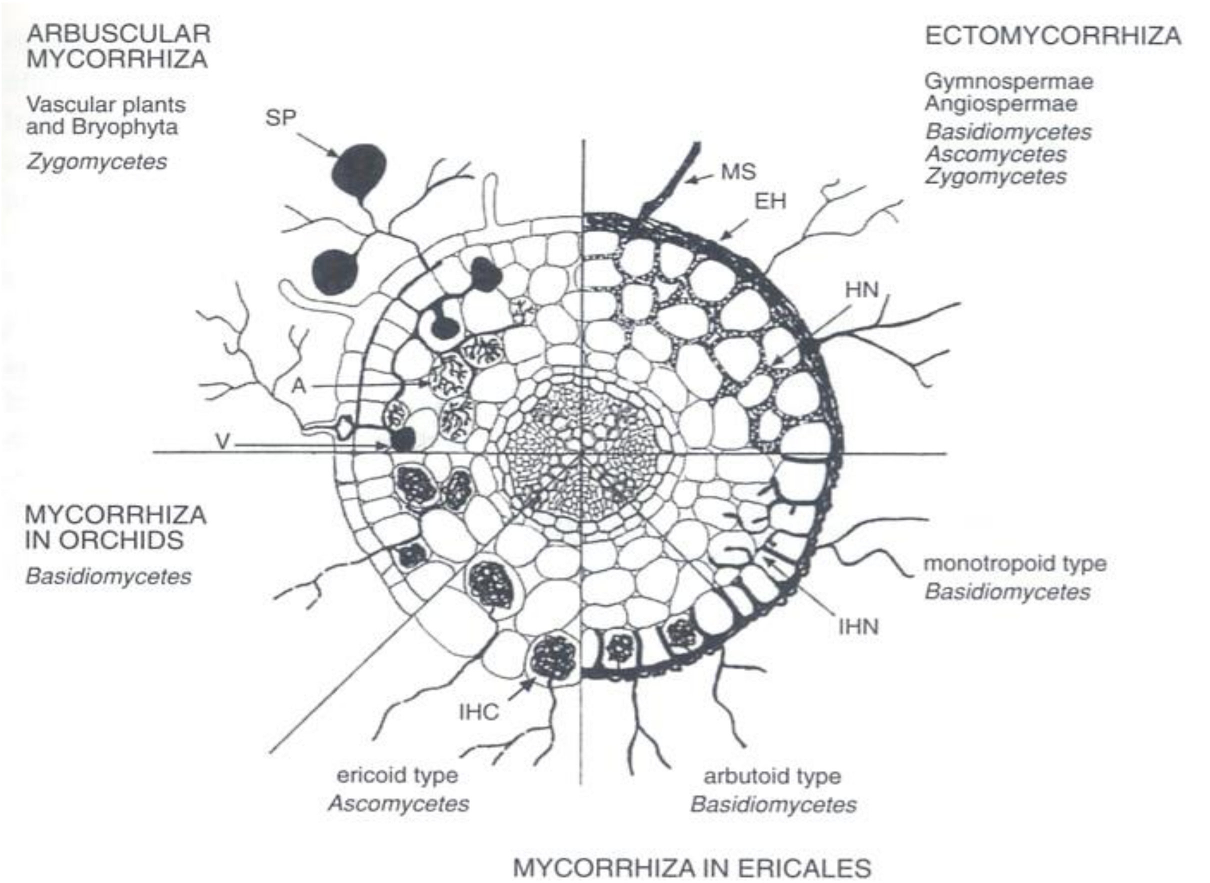


Figure 27. Morphology of typical mycorrhizas (Larcher, 2003). SP - spore, A - arbuscule, V - vesicle, HN - Hartig net, MS - mycelial strands, EH - external hyphal mantle, IHN - intercellular hyphal net, INC - intercellular hyphal complexes.

Ectomycorrhizas (EM)

Ectomycorrhizas are formed by most of the woody plants and trees in boreal and temperate forests, and by some tree species in tropical forests. The fungi are predominantly from the Basidiomycota and Ascomycota and globally as many as 27 000 fungal species and 8000 plant species form this type of symbiosis. Ectomycorrhizas are characterized by the presence of a fungal mantle or sheath around the short roots, as well as a network of intercellular hyphae penetrating between the epidermal and cortical cells, forming the Hartig net (Figure 28). Unlike arbuscular and ericoid mycorrhizas, the fungi do not penetrate the cell walls of the cortex cells. The Hartig net was first described over 100 years ago by German botanist Robert Hartig in the 1890s. In ectomycorrhizas, the Hartig net forms the contact zone between the cells of the cortex and the fungal hyphae. The mantle is usually connected to a more or less well-developed extramatrical mycelium, which may extend for many centimetres from the root into the soil (Figure 29).

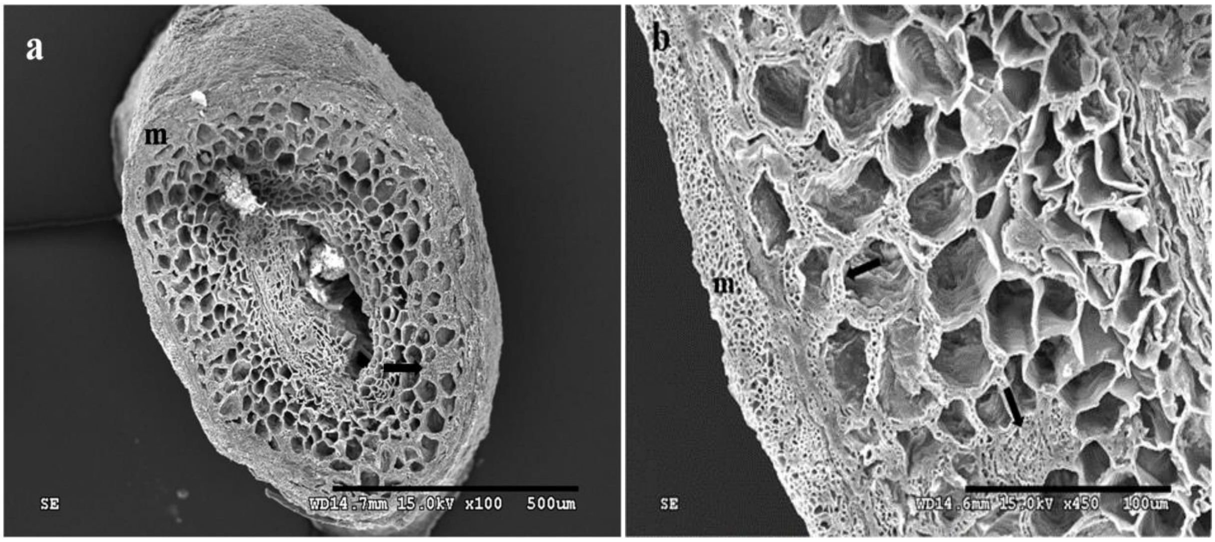


Figure 28. Ultrastructure of ectomycorrhizal roots of Scots pine from Bogd Khan Mountain, Mongolia (Otgonsuren and Lee, 2012). Arrow indicates Hartig net; m indicates mantle.

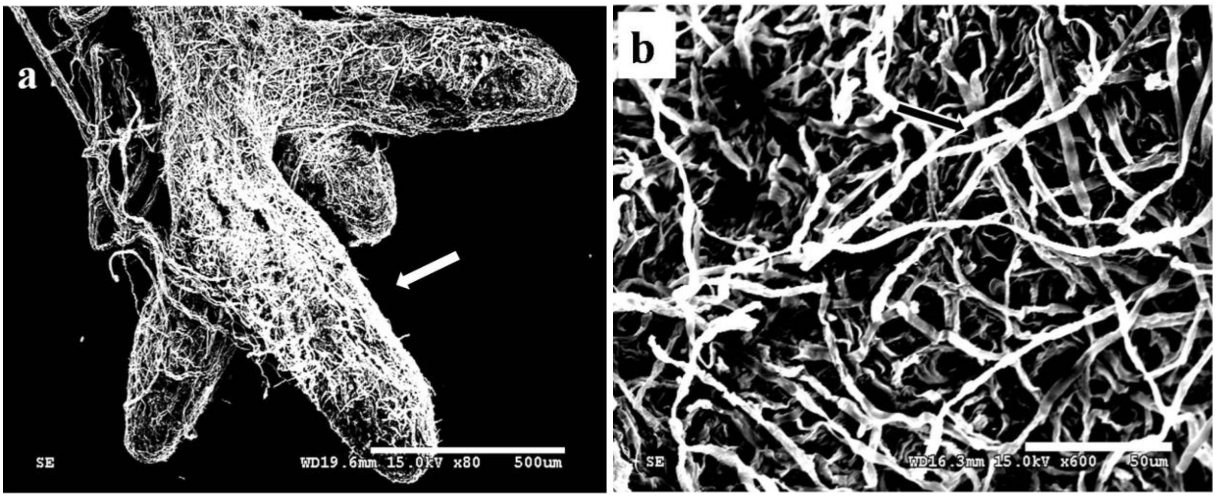


Figure 29. Ectomycorrhizal roots of Scots pine seedling (Otgonsuren and Lee, 2012). a, b) Dichotomous root tips of Scots pine colonized by ECM. Arrow indicates outer mantle structure with intertwined hyphae.

Many EM fungi produce sexual fruiting structures: epigeous aboveground structures commonly referred to as mushrooms, toadstools, coral fungi or puffballs, but also belowground or hypogeous structures commonly referred to as truffles. The production of fruiting bodies is dependent upon environmental conditions such as moisture and temperature, and thus fungi do not produce fruiting bodies every year.

Arbuscular mycorrhiza (AM)

Arbuscular mycorrhiza is the most ancient and widespread form of mycorrhizas forming symbiosis with both woody plants and herbaceous plants. Arbuscular mycorrhizal fungi form associations with a very wide range of plant species, as many as 250 000 globally. In contrast, only 150–200 species of AM fungi have so far been distinguished on the basis of morphology, but DNA-based studies suggest that the true diversity of these symbionts may be very much higher. The fungi forming AM are *Glomeromycota* and include the families *Glomalecea Acaulosporaceae* and *Gigasporacea*. Paleobotanical and molecular sequence data suggest that the first land plants formed associations with Glomalean fungi about 460 million years ago. The symbiosis is characterized by highly branched fungal structures called arbuscules, which grow intracellularly without penetrating the host plasmalemma (Figure 30). These mycorrhizas also have intra-cellular hyphae, vesicles and external emanating hyphae forming an extra-radical mycelium (Figure 30 and Figure 31). Replication of these fungi occurs via spores in the soil, examples are shown in Figure 32.

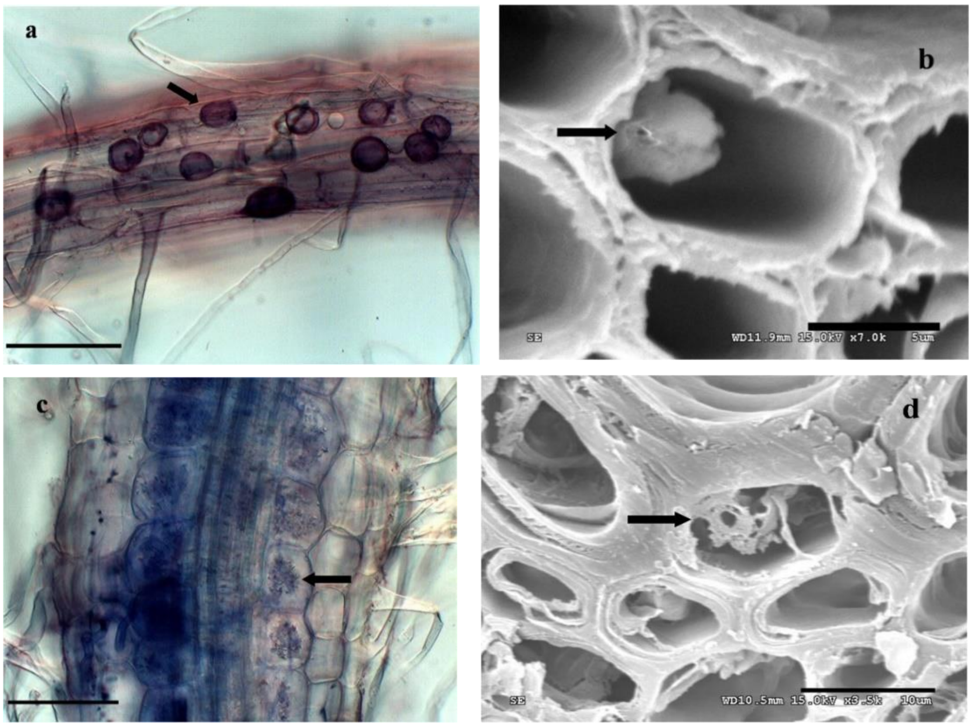


Figure 30. Morphology of the root of crested wheatgrass inoculated with AM (Otgonsuren and Lee, 2011). a) structure of the root with vesicles (arrowhead); b) ultrastructure of the root with vesicle (arrowhead); c) arbuscules (arrowhead) in root cortical cells; d) ultrastructure of the root with arbuscules (arrowhead).

The relationships between plants, AM fungi, and soils may be helpful in the revegetation of disturbed areas. Especially the extraradical mycelium links between the plants may also serve as an energy and nutrients pathway as it affects the coexistence of different species in the plant community and greatly supports the growth of slow-growing woody plants (Enkhtuya et al., 2005).

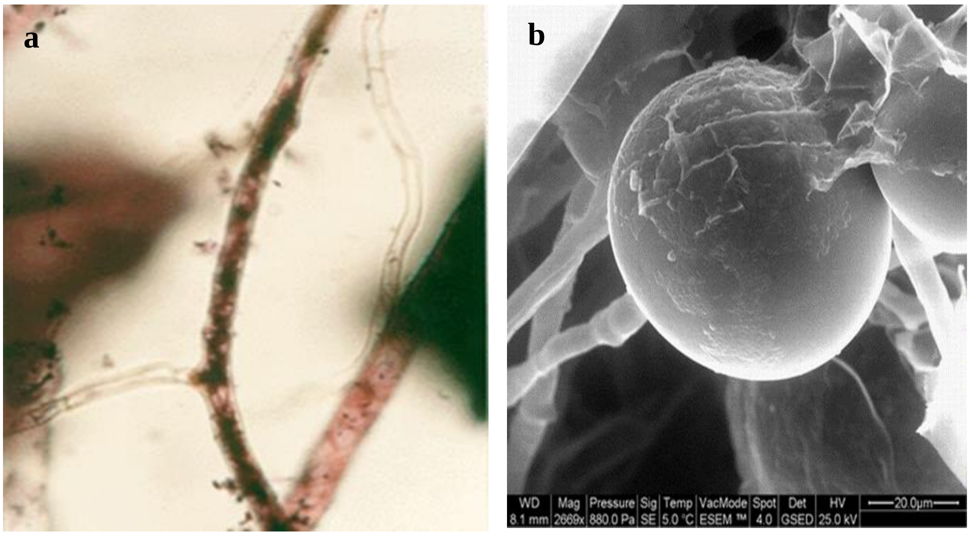


Figure 31. a) Extraradical mycelium of Glomus mosseae with part of black stained hyphae showing alkaline phosphatase activity. Colourless part is inactive. Magnification is 200x. Light microscopy: bright field, the whole-mount object. b) Arbuscular mycorrhizal spores and their mycelium, Glomus spp. Electron microscope, Magnification is 2669x. (photos: Enkhtuya Batkhuu)

There are also specific data for Mongolia. For example, Enkhtuya B. (2005) isolated AM spores from Mongolian grassland soils (Figure 32) and registered them in the International Bank for the Glomeromycota (Table 2).

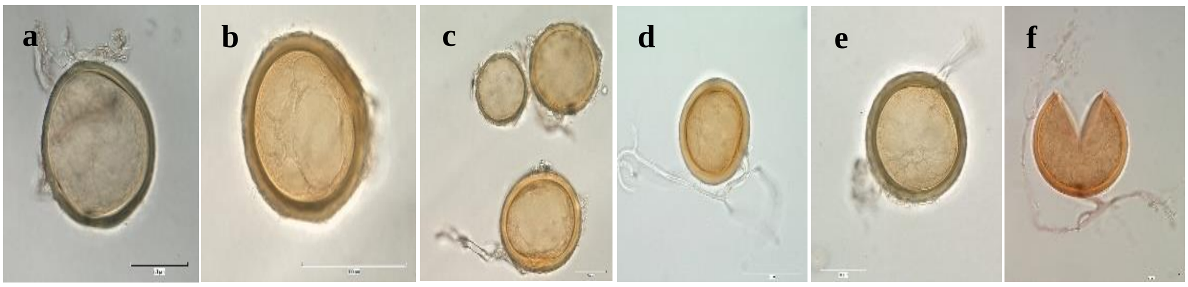


Figure 32. AM spores from Mongolian grassland soils. a) BEG200 Acaulospora morrowiae, b and c) BEG 201 Glomus etunicatum, d) BEG203 Glomus claroideum, e) BEG 204 Glomus claroideum, f) BEG205 Glomus claroideum (photos: Enkhtuya Batkhuu).

A lack of AM among the community of microorganisms may lead to problems in establishing plants in the disturbed soils. As a consequence, additions of AM spores are used in the remediation of such soils (Enkhtuya et al., 2000; 2004).

Table 2. AM fungi isolates from the Mongolian soils, unpublished data. For more information search the genetic archive for BEG (La Banque Européenne des Glomales) number.

BEG number	Species name	Biome and Longitude, Latitude	Soil pH
BEG 200	*Acaulospora morrowiae*	Arid Grassland, 102.510E, 49.120N	7.00
BEG 201	*Glomus etunicatum*	Arid Grassland, 106.5910E, 47.5410N	6.80
BEG 202	*Archaeospora trappei*	Arid Grassland, 115.31266E, 48.24975N	7.10
BEG 203	*Glomus claroideum*	Arid Grassland, 115.31266E, 48.24975N	7.10
BEG 204	*Glomus claroideum*	Arid Grassland, Zavkhan, Aldarkhaan sum	7.50
BEG 205	*Glomus claroideum*	Arid Grassland, 102.510E, 49.120N	7.00
BEG 206	*Glomus claroideum*	Arid Grassland, 106.5910E, 47.5410N	6.80

Ericoid mycorrhiza (EcM)

Ericoid mycorrhizas are formed by around 3400 plant species from three plant families, the *Ericaceae*, *Empetraceae*, and *Epacridaceae*, all belonging to the order *Ericales*. In forests, these plants form the **understorey** and include genera such as *Vaccinium* and *Erica*. Ericoid mycorrhizas also occur in warm Mediterranean climate zones in chaparral vegetation systems throughout the world, suggesting that nutritional rather than climatic factors determine their distribution. The fungi forming ericoid mycorrhizas are *Ascomycota*, and several species are known to form EcM, however only one species *Rhizoscyphus ericae* (formally *Hymenoscyphus ericae*) has been studied in detail. However, recent evidence also suggests that some species of Basidiomycota that normally form ectomycorrhizas also form ericoid mycorrhizas with the *Ericales*. Similar to arbuscular mycorrhizal structures, in ericoid mycorrhizas the fungus penetrates the cell walls of roots without penetrating the host plasmalemma. But instead of forming arbuscules, the fungus forms coiled structures within each cell (Figure 33), mainly in the fine hair roots of ericaceous plants. Similar to the arbuscules in arbuscular mycorrhiza, the coils of ericoid mycorrhizas are an effective way of increasing the surface area of contact between the fungus and the root cells of the host plant. In addition, ericoid mycorrhizas also have extensive emanating hyphae forming an extra-radical mycelium.

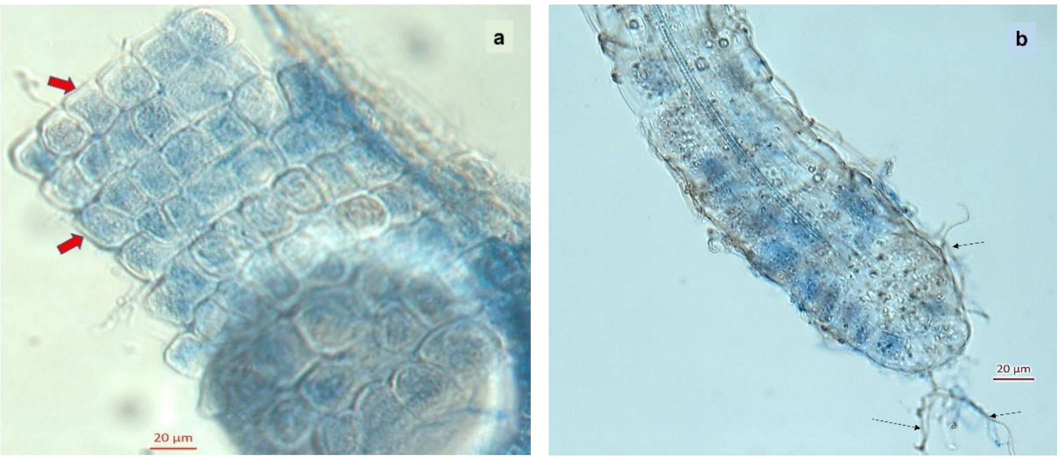


Figure 33. *Morphology of ericoid mycorrhizas. a) Intracellular fungal coils in the roots of Vaccinium vitis-idaea (arrows) and b) stained root tip of Vaccinium vitis-idaea counterstained with alcian blue showing the root cap and fungal hyphae of ericoid mycorrhizas (arrows) (Wang et al., 2018).*

Mycorrhizal communities and soil freezing

The climate of Mongolia is characterized by large fluctuations in annual temperatures and precipitation. Extreme minimum temperatures of -50 °C in January and extreme maximum temperatures of over +40 °C in July have been recorded. In boreal forests, low winter temperatures result in **soil freezing** down to 1 m or more, depending on snow depth. Due to the low precipitation in Mongolia especially during winter, snow cover outside the high mountains is rarely deep and thus soils freeze. Soil freezing has been shown to damage fine roots of trees (Tierney et al., 2001), and winter hardiness of roots is considered to be a critical factor for **winter survival** (Sakai and Larcher, 2012). Fine roots of *Picea abies* and *Pinus sylvestris* have been shown to be damaged between -10 and -20 °C. Ectomycorrhizal fungi associated with the roots must also be adapted to cope with the worst-case low soil temperatures to survive in cold-susceptible ecosystems. Moser (1958) found that several species of ectomycorrhizal fungi had the ability to survive periods of up to 3 months of freezing (-5 °C). More recent studies have shown survival at lower temperatures of between -7.6 and -13.7 °C (Ma et al., 2011). In Mongolia, ectomycorrhizas on roots of *Pinus sibirica* and *Pinus sylvestris* were shown to be viable and active after intense soil freezing (Figure 34; Otgonsuren et al., 2020). **In addition, ectomycorrhizas may improve the freezing tolerance of the host tree.** Otgonsuren and Lee (2013) showed that an isolate of *Phialocephala fortinii* from Nuhkt in Mongolia increased the freezing tolerance LT_{50} of *Pinus sylvestris* from -14 to -18 °C. However, Korhonen et al. (2013) did not find increased frost hardiness of *Pinus sylvestris* seedlings supported by EM fungal symbionts.

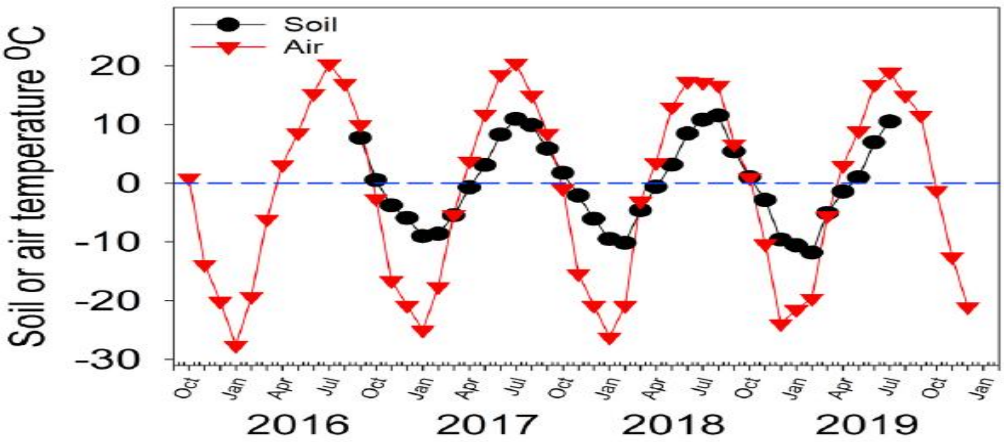


Figure 34. Average monthly soil temperature at 10 cm depth, at Nukht in the Bogd-Khan National Reserve, Mongolia, and air temperature measured at weather station ZMUB 44290 located at Chinggis Khaan International airport approx. 7 km from the Nukht site (Otgonsuren et al., 2020).

Forest trees are colonized by a number of species of ectomycorrhizal fungi to form a community (Rosinger et al., 2018). A host genus has been shown to be one of the most important factors determining the ectomycorrhizal community composition. Typically, these communities are composed of a few taxa with high abundance and a high number of taxa with low abundance. An example of this is shown in Figure 35 for *Pinus sylvestris* and *Pinus sibirica* in Mongolia. In these communities, only three taxa were common to both tree species: *Lactarius luculentus*, *Helotiales* sp. and *Russula nauseosa*, which is an unusually high host specificity. For example, co-existing *Pinus ponderosa* and *Pinus contorta* trees in the western USA showed a similar community composition (Garcia et al., 2016). Of the 26 taxa detected at Nukht, 11 were dark brown to black in colour, representing 37% and 33% of all mycorrhizal root tips in *Pinus sibirica* and in *Pinus sylvestris*, respectively. Black melanised ectomycorrhizas are associated with harsh environments (Trappe, 1964) and are known to be highly **drought tolerant**. The drought tolerance of *Cenococcum geophilum* has been suggested to be due to the mechanical stiffness of the thick-walled hyphae and the ridged hyphae mantel structure. Strong mechanical stability may also be an important but un-investigated factor in freezing tolerance.

Beneficial relationships between ectomycorrhizal fungi and trees can also be used in forestry by **artificial application** (**inoculation**) of appropriate ectomycorrhizal fungi to the root system of seedlings to increase their **survival rate** and subsequent successful growth after reforestation or afforestation.

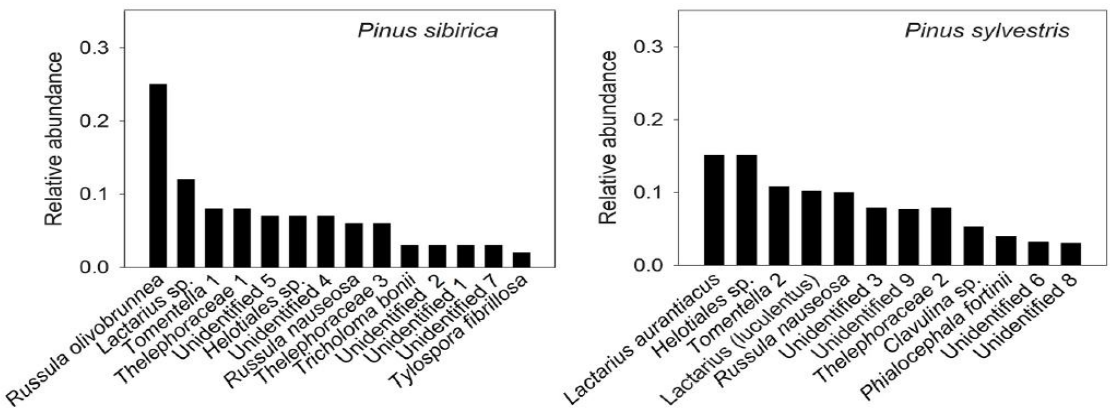


Figure 35. Relative abundance of ectomycorrhizal taxa on fine roots of Pinus sibirica and Pinus sylvestris collected at 1530 m and 1600 m elevations in Nukht in the Bogd- Khan National Reserve, Mongolia, in April 2016. From Otgonsuren et al., (2020).

REFERENCES

Brundrett, M., Bougher, N., Dell, B., Grove, T. and Malajczuk, N., 1996. Working with mycorrhizas in forestry and agriculture (Vol. 32, p. 374). Canberra: Australian Centre for International Agricultural Research.

Enkhtuya, B., Rydlová, J. and Vosátka, M., 2000. Effectiveness of indigenous and non-indigenous isolates of arbuscular mycorrhizal fungi in soils from degraded ecosystems and man-made habitats. Applied Soil Ecology, 14(3), pp.201-211. https://doi.org/10.1016/S0929-1393(00)00057-3.

Enkhtuya, B., Rydlová, J. and Vosátka, M., 2004. Occurrence and ecology of arbuscular mycorrhizal fungi in substrates of abandoned industrial sedimentation basins. In: Kovář, P. (ed.). Natural recovery of man-made deposits in landscape (Biotic interactions and ore/ash-slag artificial ecosystems). Academia, Praha., pp. 98-120.

Enkhtuya, B., Pöschl, M. and Vosátka, M., 2005. Native grass facilitates mycorrhizal colonisation and P uptake of tree seedlings in two anthropogenic substrates. Water, air, and soil pollution, 166, pp.217-236. https://doi.org/10.1007/s11270-005-7273-0.

Garcia, M.O., Smith, J.E., Luoma, D.L. and Jones, M.D., 2016. Ectomycorrhizal communities of ponderosa pine and lodgepole pine in the south-central Oregon pumice zone. Mycorrhiza, 26, pp.275-286. https://doi.org/10.1007/s00572-015-0668-x.

Korhonen, A., Lehto, T. and Repo, T., 2013. Frost hardiness of mycorrhizal (*Hebeloma* sp.) and non-mycorrhizal Scots pine roots. Mycorrhiza, 23(7), pp.551-559. https://doi.org/10.1007/s00572-013-0497-8.

Larcher, W., 2003. Physiological plant ecology: ecophysiology and stress physiology of functional groups. Springer Science & Business Media.

Moser, M., 1958. Der Einfluß tiefer Temperaturen auf das Wachstum und die Lebenstätigkeit höherer Pilze mit spezieller Berücksichtigung von Mykorrhizapilzen. Sydowia, 7, pp.386-399.

Otgonsuren, B. and Lee, M.J., 2010. A native arbuscular mycorrhizal fungus, *Acaulospora scrobiculata* stimulated growth of Mongolian crested wheatgrass (*Agropyron cristatum* (L.) Gaertn.). Mongolian Journal of Biological Sciences, 8(2), pp.33-41.

Otgonsuren, B. and Lee, M.J., 2011. Arbuscular Mycorrhizal Fungus *Diversispora spurcum* Improved the Growth and Freeze Tolerance of Mongolian Crested Wheatgrass (*Agropyron cristatum*). Taiwan Journal of Forest Science, 26(2), pp.179-192.

Otgonsuren, B. and Lee, M.J., 2012. *Pinus sylvestris* can form ectomycorrhiza with *Phialocephala fortinii*. Taiwan Journal of Forest Science, 27, pp.265-281.

Otgonsuren, B. and Lee, M.J., 2013. Ectomycorrhiza enhanced the cold-acclimation growth and freeze tolerance of Scots pine (*Pinus sylvestris* L.). Taiwan Journal of Forest Science, 28(2), pp.97-111.

Otgonsuren, B., Rosinger, C., Wang, L. and Godbold, D.L., 2020. Winter soils of Mongolian forests have viable ectomycorrhizas and soil enzymatic activity. Soil Biology and Biochemistry, 148, p.107914. https://doi.org/10.1016/j.soilbio.2020.107914.

Rosinger, C., Sandén, H., Matthews, B., Mayer, M. and Godbold, D.L., 2018. Patterns in ectomycorrhizal diversity, community composition, and exploration types in European beech, pine, and spruce forests. Forests, 9(8), p.445. https://doi.org/10.3390/f9080445.

Sakai, A. and Larcher, W., 2012. Frost survival of plants: responses and adaptation to freezing stress (Vol. 62). Springer Science & Business Media.

Smith, S.E. and Read, D.J., 2010. Mycorrhizal symbiosis. Academic Press, London.

Tierney, G.L., Fahey, T.J., Groffman, P.M., Hardy, J.P., Fitzhugh, R.D. and Driscoll, C.T., 2001. Soil freezing alters fine root dynamics in a northern hardwood forest. Biogeochemistry, 56, pp.175-190. https://doi.org/10.1023/A:1013072519889.

Trappe, J.M., 1964. Mycorrhizal hosts and distribution of *Cenococcum graniforme*. Lloydia 27, pp.100-106.

Wang, L., Otgonsuren, B., Duan, W. and Godbold, D., 2018. Comparison of Root Surface Enzyme Activity of Ericaceous Plants and *Picea abies* Growing at the Tree Line in the Austrian Alps. Forests, 9(9), p.575. https://doi.org/10.3390/f9090575.

2.6 Forest Classification

Antonín Kusbach & František Máliš

Introduction

Plants like all other living organisms have certain requirements for the environment. Some grow on sites which are nutrients rich, others tolerate low levels of nutrients in soil, some are drought tolerant, others require high amounts of moisture. And on the other hand, there are many plants with similar requirements for the environment and thus occur at the same sites, usually together, creating specific species assemblages, which are called **plant communities**. It is therefore possible to classify vegetation into **vegetation units**, which are categories with typical species composition. At a very rough scale these could be birch forests, larch forests or spruce forests, but, of course, classification is usually much more detailed, depending on the purpose. Classifying forests into vegetation units (e.g. **forest types**) is particularly useful for forestry and nature conservation practice. Forest types differ in many aspects, for example wood production, resilience to harmful agents, biodiversity or provisioning of ecosystem services.

Ecological classifications

Traditional ecological classifications in the world were constructed on **species composition** (Daubenmire, 1943). "Eastern" and "Western" classifications of forests incorporated concepts such as forest type (Cajander, 1926), phytosociology (Braun-Blanquet, 1928), ecosystem, polyclimax (Tansley, 1935), and biogeocoenology (Sukachev and Dylis, 1968). These classifications were established throughout Europe for purposes of landscape-non-forest/forest management, for example, Zlatník (1959) in Slovakia, Kilian et al. (1994) in Austria, Dahdouh-Guebas et al. (1998) in Belgium, Blasi et al. (2005) in Italy, Gauer and Aldinger (2005) in Germany, and also in North America (Pojar et al., 1987; Bailey, 1998) and Russian Asia (Sukachev and Dylis, 1968; Kolesnikov, 1974; Melekhov, 1959). The idea of "forest type" was generalized in the Czech Forest Ecosystem Classification (CFEC) (Plíva, 1971).

Importantly, ecological classifications could be divided into two types. The first applies the approach of creating units of real (existing or actual) vegetation, the second creates units of potential (natural) vegetation. **Real vegetation** is vegetation which is present on the site in reality, **potential vegetation** occurs there naturally as a final phase of forest development. A typical example is a meadow (not a natural grassland such as a steppe in Mongolia, but a meadow maintained, regularly cut by people). Within a classification system reflecting real vegetation, this meadow would be classified as a certain type of grassland vegetation unit, but within a system of potential vegetation, it would be classified as a forest, which naturally grows on this site without cutting. Both approaches have advantages and are used for different purposes. In nature conservation, the real vegetation concept is frequently applied because the aim is to protect and conserve also semi-natural (human made) habitats, while in forestry, the potential vegetation concept could be better since it defines the **forest type** which is natural on the site and thus provides the forest **ecosystems services** at the maximum.

Ecological classification as a forestry tool

In addition to providing helpful information, classification systems have served as significant communication tools for an interested audience and provide **an underlying framework for forest policy, decision-making, and practice** (e.g. Kotar, 1988). For instance, in the Czech Republic, Regional Plans of Forest Development (RPFD) serve as a framework for forestry planning and legislation, practical management, nature protection and conservation, forested land evaluation, tax calculation, subsidies, etc. The plans have been developed for natural forest areas, regional units homogeneous in natural conditions (Plíva and Žlábek, 1986). For the last approximately 30 years, these plans have been conveying a unique conversion of ecological information, provided by the CFEC, to management units facilitating **sustainable management**, supporting national forestry policy and nature conservation based on fine-scale terrestrial mapping and **forest management planning** (Kusbach et al., 2023). The management information includes a vegetation dynamic/historic component by existing vegetation "**stand types**" (characterized by dominant tree species) for the management complex (Kusbach et al., 2017). While based on the recent history of commercially driven forest management (Vrška et al., 2019), existing stand types reflect recent anthropogenic changes towards the cultivation of valuable timber. The use of this approach has been shown on the forestry-pastoral cooperative farm (3600 ha) in the extreme interior of Mongolia (Smola et al., 2019).

Sustainability is a widely accepted principle in forest ecosystem management (e.g. Barbati et al., 2007; chapter 4.1 Sustainable Forest Management). **Forest managers need an ecological classification system to manage forests efficiently.** Traditionally, the sustainability principle has been applied through ecological classifications based on knowledge of natural vegetation (supported by advanced paleoecological findings, see chapter 2.7 Pedoanthracology for Forest Reconstructions), and environmental conditions (usually defined by important environmental parameters) of a particular area or region (Pojar et al., 1987; Viewegh et al., 2003; Kusbach et al., 2017).

The situation in Mongolia

In Mongolia, a great amount of work was done from 1970 during the Joint Russian/Soviet-Mongolian Complex Biological Expeditions and further surveys of forest ecosystem classification and mapping (e.g. Lavrenko and Sokolov, 1978; Vostokova and Gunin, 2005). However, coarse-scale outputs such as units of ecosystem surveys and maps (scales 1:1.5–12 000 000; Vostokova and Gunin, 2005) and recent forest-vegetation zonation (Dorjsuren et al., 2020) do not provide sufficient environmental stratification (at least in climate scaling) for the definition of detailed forest classification units. Additionally, there is no mapping of localities, no site-specific information and data except a general soil description (Nogina et al., 1980) used in the phytocoenological typology by Lavrenko and Sokolov (1978) with a brief description of basic forest types. These typological structures used, e.g. in Nyam et al. (2009), are obsolete and broad.

The forestry sector, especially forestry legislation, planning, education and extension is under development in Mongolia (Tsogtbaatar, 2007). There is no framework and tools analogical to the CFEC and RPFD in Mongolian territory. Since there are no legal spatial units similar to the Czech natural forest areas and forest vegetation zones and a sufficient tool (a classification system), it is not possible to recommend forest management reflecting environmental conditions and implement political decisions systematically (Kusbach et al., 2017). Therefore, it is necessary to build a **formal framework** (forest classification with management structures such as e.g. the RPFD management complexes) besides monitoring activities as National Forest Inventory (Altrell and Erdenebat, 2016).

Recently, experience from the CFEC, where various vegetation, environmental, soil properties, and forest management data are available, was taken, and a basic structure/framework for Mongolian forests was suggested. Available vegetation, environmental, and soil data were used to assess the geo-vegetation zones (Figure 36) and identify their **environment thresholds** (Table 3). Then, it is possible to set up lower-level units and appropriate management for relevant forest sites/stands (Kusbach et al., 2019). This geo-vegetation zonation is the first attempt at quantifying vegetation along with the environment at a macroclimatic level in Mongolia. It provides a framework for building a comprehensive ecological classification, a background for **sustainable forest management**, which is currently unavailable in Mongolia and many Central Asian countries. It offers a roadmap for an ecosystem survey and may act as an information platform and reference for current environmental issues, e.g. forest degradation across Mongolian landscapes (Kusbach et al., 2019).

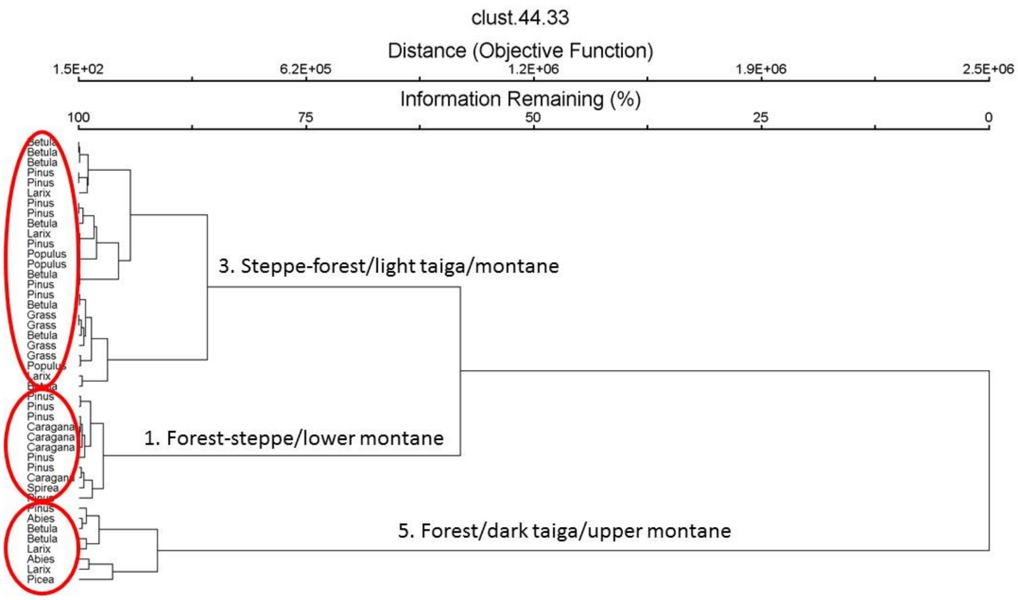


Figure 36. Delineation of the geo-vegetation zones using the cluster analysis. Zones 1, 3, 5, represented by clusters of sample plots, highlighted in red, are represented by a dominant plant (woody or non woody species).

Table 3. Statistically significant environmental characteristics/thresholds of the geo-vegetation zones for the study area (Kusbach et al., 2019). C/N – carbon, nitrogen ratio in the upper soil part (0–30 cm), T_{summer} – main summer temperature.

Geo-vegetation zone	Altitude	Latitude	C/N	T_{summer}	Soil group[1]
	m	degrees		°C	
1. Forest-steppe/lower montane	750–900	49.5–49.6	0.4–49.6	17–17.7	Phaeozem Kastanozem
3. Steppe-forest/light taiga/montane	900–1300	48.7–49.4	11.7–41.4	15.6–17.5	Phaeozem Cambisol, Luvisol
5. Forest/dark taiga/upper montane	1300–1800	48.6–49.1	3.8–48.4	14.6–16.5	Cambisol, Luvisol Umbrisol

[1] IUSS Working Group WRB (2015)

REFERENCES

Altrell D., Erdenebat E., 2016. Mongolian Multipurpose National Forest Inventory 2014–2016. 1st edition. Ministry of Environment and Tourism, Ulaanbaatar.

Barbati, A., Corona, P. and Marchetti, M., 2007. A forest typology for monitoring sustainable forest management: the case of European forest types. Plant Biosystems, 141(1), pp.93-103. https://doi.org/10.1080/11263500601153842.

Bailey, R.G., Pfister, R.D. and Henderson, J.A., 1978. Nature of land and resource classification--a review. Journal of Forestry, 76(10), pp.650-655. https://doi.org/10.1093/jof/76.10.650.

Blasi, C., Capotorti, G. and Frondoni, R., 2005. Defining and mapping typological models at the landscape scale. Plant Biosystems-An International Journal Dealing with all Aspects of Plant Biology, 139(2), pp.155-163. https://doi.org/10.1080/11263500500163629.

Braun-Blanquet, J., 1928. Pflanzensoziologie: Grundzüge der Vegetationskunde. 1st edition. Julius Springer, Berlin.

Cajander, A.K., 1926. The theory of forest types. Acta Forestalia Fennica, 29, pp.1913-1929.

Dahdouh-Guebas, F., Triest, L. and Verneirt, M., 1998. The importance of a hierarchical ecosystem classification for the biological evaluation and selection of least valuable sites. Impact assessment and project appraisal, 16(3), pp.185-194. https://doi.org/10.1080/14615517.1998.10590207.

Daubenmire, R.F., 1943. Vegetational zonation in the Rocky Mountains. The Botanical Review, 9(6), pp.325-393.

Dorjsuren Ch., Dugarjav, Ch., Tsedendash, G., Tushigmaa, J. and Tungalag, M., 2020. Монгол орны ойн мужлал, хэвшинж [Forest status and patterns in Mongolia]. UB BCI [УБ Би Си Ай], Ulaanbaatar. (In Mongolian).

Gauer, H.V.J. and Aldinger, E., 2005. Forest ecologically-based nature areas in Germany. Forest growth regions and growth districts with a 1:1 000 000 map. Mitteilungen des Vereins für Forstliche Standortskunde und Forstpflanzenzüchtung, Freiburg.

Kilian, W., Müller, F. and Starlinger, F., 1994. The Forest Growth Regions of Austria a Land Classification Based on Forest Ecology. FBVA Berichte, Wien.

Kolesnikov, B.P., 1974. Geneticheskiy etap v lesnoy tipologii i ego zadachi [Genetic Stage in the Forest Typology and Its Objectives]. Lesovedenie, 2, pp.3-20.

Kotar, J., 1988. Ecological land classification: the first step in forest resource management. In: Johnson, J.E. (ed.). Proceedings of the fourth Society of American Foresters Region V Technical Conference, Duluth, Minnesota. Managing North Central forests for non-timber values. SAF publication 88-04, Bethesda, Maryland, USA.

Kusbach, A., Friedl, M., Zouhar, V., Mikita, T. and Šebesta, J., 2017. Assessing forest classification in a landscape-level framework: an example from Central European forests. Forests, 8(12), p.461. https://doi.org/10.3390/f8120461.

Kusbach, A., Štěrba, T., Šebesta, J., Mikita, T., Bazarradnaa, E., Dambadarjaa, S. and Smola, M., 2019. Ecological zonation as a tool for restoration of degraded forests in northern Mongolia. Geography, Environment, Sustainability, 12(3), pp.98-116. https://doi.org/10.24057/2071-9388-2019-31.

Kusbach, A., Dujka, P., Šebesta, J., Lukeš, P., DeRose, R.J. and Maděra, P., 2023. Ecological classification can help with assisted plant migration in forestry, nature conservation, and landscape planning. Forest Ecology and Management, 546, p.121349. https://doi.org/10.1016/j.foreco.2023.121349.

Lavrenko E.M. and Sokolov V.E., 1978. Forests of Mongolia - Geography and Typology. Academy of Science of USSR, Nauka, Moscow. (In Russian).

Melekhov, I.S., 1959. Basics of felling typology. Foundations of Felling Typology and Its Significance in Forestry; Academy of Sciences of the USSR: Arkhangelsk, Russia, pp.5-34.

Nogina N.A. et al., 1980. Pocvennaya karta Mongolskoy narodnoy respubliky [Soil map of Mongolia] 1: 2 500 000. Commom Soviet-Mongolian expedition, Pocvennyy institut V. V. Dokuchaeva VASCHNIL [V.V. Dokuchaev Soil Science Institute VASCHNIL], Moscow. (In Russian).

Nyam L., Otgonsuren B., Ganbaatar CH., Dashdorj N., Saule A., Tsogbaatar A. and Enkhjargal D., 2009. Guidelines for forestry workers in Mongolia. The Forest Agency (Implementing Agency for Government of Mongolia), Ulaanbaatar.

Plíva, K. and Žlábek, I., 1986. Přírodní lesní oblasti ČSR [Natural Forest Areas in the Czech Republic]. Státní Zemědělské Nakladatelství Praha: Praha. (In Czech).

Plíva, K., 1971. Typologický Systém ÚHÚL [Forest Classification System of the FMI]. Ústav pro Hospodářskou Úpravu lesů Brandýs nad Labem: Brandýs nad Labem. (In Czech).

Pojar, J., Klinka, K. and Meidinger, D.V., 1987. Biogeoclimatic ecosystem classification in British Columbia. Forest Ecology and Management, 22(1-2), pp.119-154. https://doi.org/10.1016/0378-1127(87)90100-9.

Smola, M., Kusbach, A., Štěrba, T., Adolt, R. and Nečas, M., 2019. Forest Management Plan in Domogt Sharyn Gol, Mongolia is Elaborated on Ecological and Sustainable Principles. Journal of Landscape Ecology, 12(2), pp.92-115. https://doi.org/10.2478/jlecol-2019-0012.

Sukachev, V. and Dylis, N., 1968. Fundamentals of Forest Biogeocoenology: Translated from Russian Edition (Moscow, 1964). Oliver & Boyd.

Viewegh, J., Kusbach, A. and Mikeska, M., 2003. Czech forest ecosystem classification. Journal of Forest Science, 49(2), pp.74-82.

Vostokova, E.A. and Gunin, P.D., 2005. Ecosystems of Mongolia: Atlas. General Scientific Edition. Institute of Ecology and Evolution, Russian Academy of Science, Moscow.

Tansley, A.G., 1935. The use and abuse of vegetational concepts and terms. Ecology, 16(3), pp.284-307. https://doi.org/10.2307/1930070.

Tsogtbaatar J., 2007. Forest Rehabilitation in Mongolia. In: Lee, D.K. (ed.). Keep Asia Green, Volume II, “Northeast Asia”. IUFRO World Series Vol. 20-II. IUFRO, Vienna.

Vrška, T., Hort, L., Janík, D., Adam, D., Šamonil, P., Unar, P., Král, K., Modlinger, R. and Liška, J., 2019. Rok českých pralesů VI. Jaké poučení nám pralesy přinášejí pro praxi? (Year of Czech forests VI.). Živa, 1, pp.21-24. (In Czech).

IUSS Working Group WRB, 2015. World Reference Base for Soil Resources 2014, update 2015, World Soil Resources Reports No. 106. FAO, Rome.

Zlatník, A., 1959. Přehled slovenských lesů podle skupin lesních typů [An Overview of Slovak Forests by Forest Types Groups]. Spisy vědecké laboratoře biogeocenologie a typologie lesa Lesnické fakulty Vysoké školy zemědělské v Brně, Brno. (In Czech).

2.7 Pedoanthracology for Forest Reconstructions

Pavel Peška & Jan Novák

Introduction

Forest fires are a common and frequent disturbance factor in Mongolian forests (Kazato and Soyollham, 2022). Wildfires have been part of the dynamics of boreal forest for thousands of years (Kelly et al., 2016) and **charcoal** assemblages in the soil (Figure 37a) bring preserved information about the forests of that time. The method that deals with the reconstruction of woody composition of forest using macrocharcoal fragments is called **pedoanthracology**.

Pedoanthracology allows the investigation of **forest dynamics** (Robin et al., 2013). It makes it possible to obtain information about forest stands that grew hundreds to thousands of years ago. It can reconstruct the species composition of the forests of that time, the intensity of the fire, and under certain conditions, the age of the forest at the time it burned down. The analysis takes advantage of the woods ability to retain its microanatomical structure even though it has already been burned. Thanks to this, it is possible to microscopically determine the species, or at least the genus, of the tree from which the charcoal comes. Samples are determined by observing characteristic anatomical elements (rays, vessel perforation, etc.) (Figure 37b).

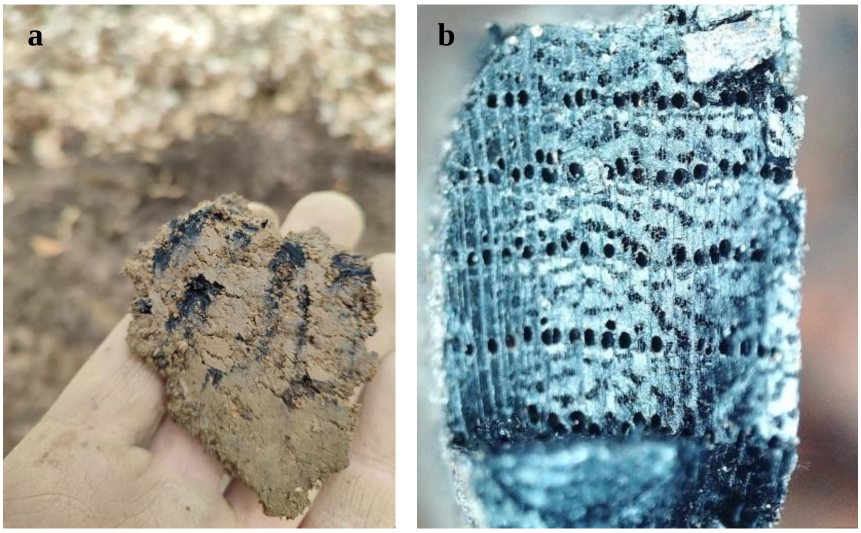


Figure 37. a) Charcoal pieces in soil profile and b) Ulmus spp. charcoal piece detail (photos: Pavel Peška).

Methods of pedoanthracology

Charcoal can be transported down-slope by surface runoff soon after a fire event or once embedded in the soil matrix, so the palaeo-signal of charcoal in soil depends on the topography of the catchment area (Novák et al., 2018; Novák et al., 2019). This needs to be considered when taking soil samples. Soil samples are taken in subsequent layers (10 cm) in a known volume (usually 10 l of fine soil from one layer). The separation of charcoal takes place by the method of soft sieving and subsequent manual selection of individual charcoal fragments (Figure 38). Individual pieces of charcoal are subsequently subjected to laboratory analysis, which determines the tree species from which they originate (Figure 39).

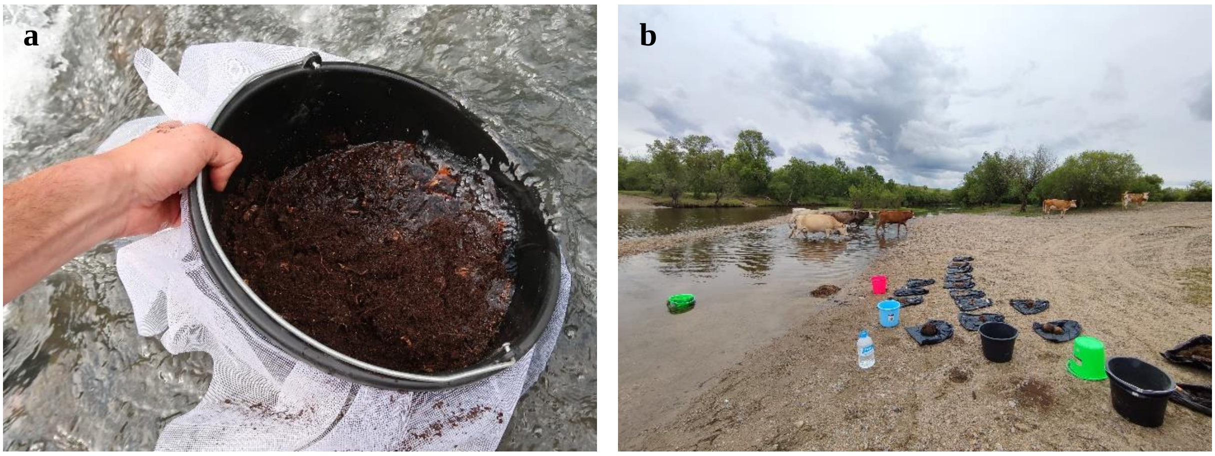


***Figure 38**. a) Sifting and b) drying of soil samples, the first step of separation (photos: Pavel Peška).*

The mass of pure charcoal is referred to as anthracomass. From the weight of the anthracomass from one entire layer, it is possible to get information about the intensity of the fire. One hundred pieces of charcoal are usually determined from an anthracomass sample. The species composition of the community at that time is subsequently estimated from the weight of anthracomass for individual tree species. Together with the use of the radiocarbon method (C14), it is also possible to find out the exact age when the fire took place in a forest stand. This makes it possible to achieve a relatively detailed description of the historical forest and its gradual development over time.

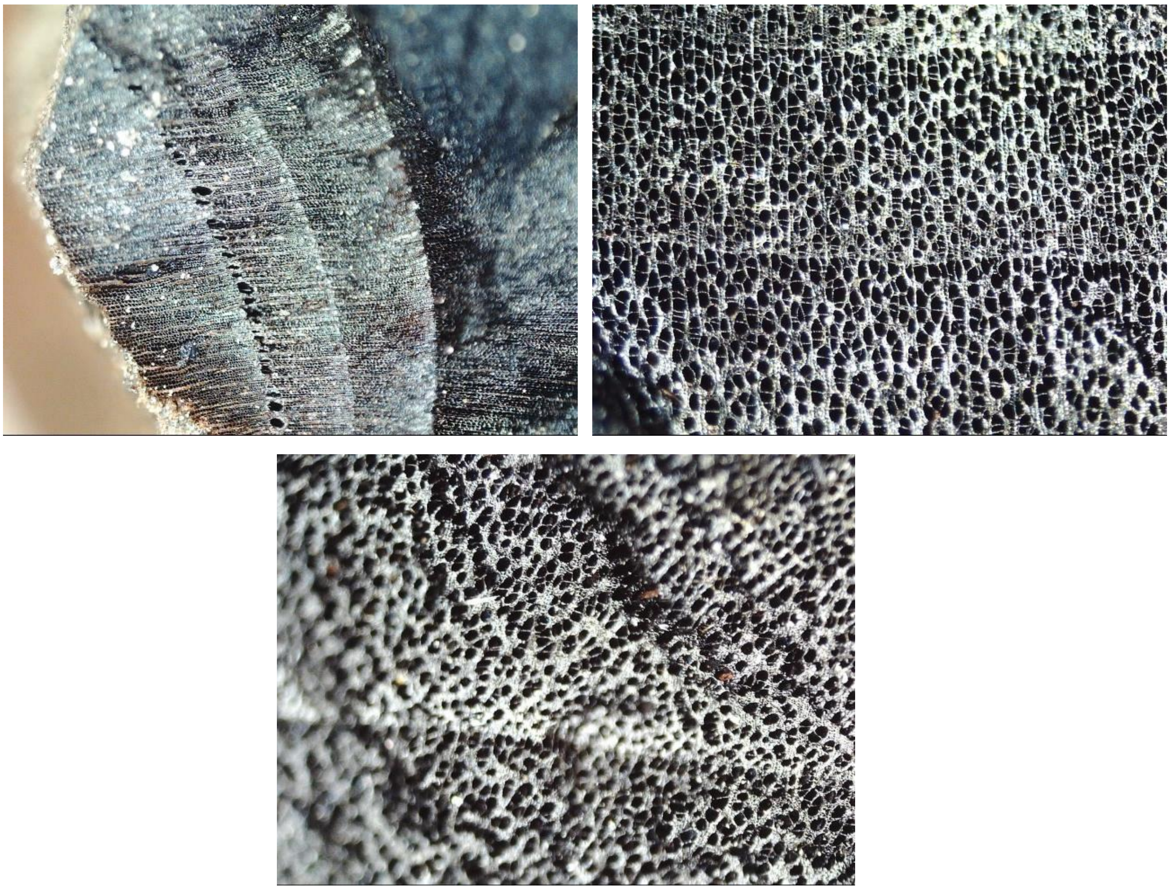


Figure 39. Final charcoal samples for laboratory determination – The determination showed that it is a) Pinus spp., b) Populus spp. and c) Salix spp. (photos: Pavel Peška).

Implementation of pedoanthracology

The pedoanthracological approach is especially necessary in countries where forests have been intensively managed for tens to hundreds of years, and the current tree species composition can therefore differ significantly from the original one (Robin et al., 2013; Feiss et al., 2024). Although intensive forestry like that in Central Europe has not been practised in Mongolia for a long time, pedoanthracological results allow local foresters to obtain other important data. The first pedoanthracological results for Mongolia already exist. For example, Novák et al. (2019) found that forest vegetation on the edge of the Khan Khentii Mountain range has been more influenced by human activities than vegetation in the core area of the mountains. Ongoing research can significantly help **to return forest to the landscape where it naturally belongs**; nowadays also following the challenging "One Billion Trees" national movement.

Results of the laboratory and radiocarbon analysis help to understand the dynamics of Mongolian forests (Figure 40, Figure 41). The results can (and should) be considered in **forestry planning** when we confront the historical (closer to nature and potential, Figure 41) with planned (sometimes called actual) species composition introduced by management interventions. When returning forest stands to their potential, natural species composition, the pedoanthracology method provides valuable information. More importantly, considering climate change, these interventions can be realized as a type of assisted migration using the historic knowledge and recent climatic modelling to get “safe” **sustainable forest management**.

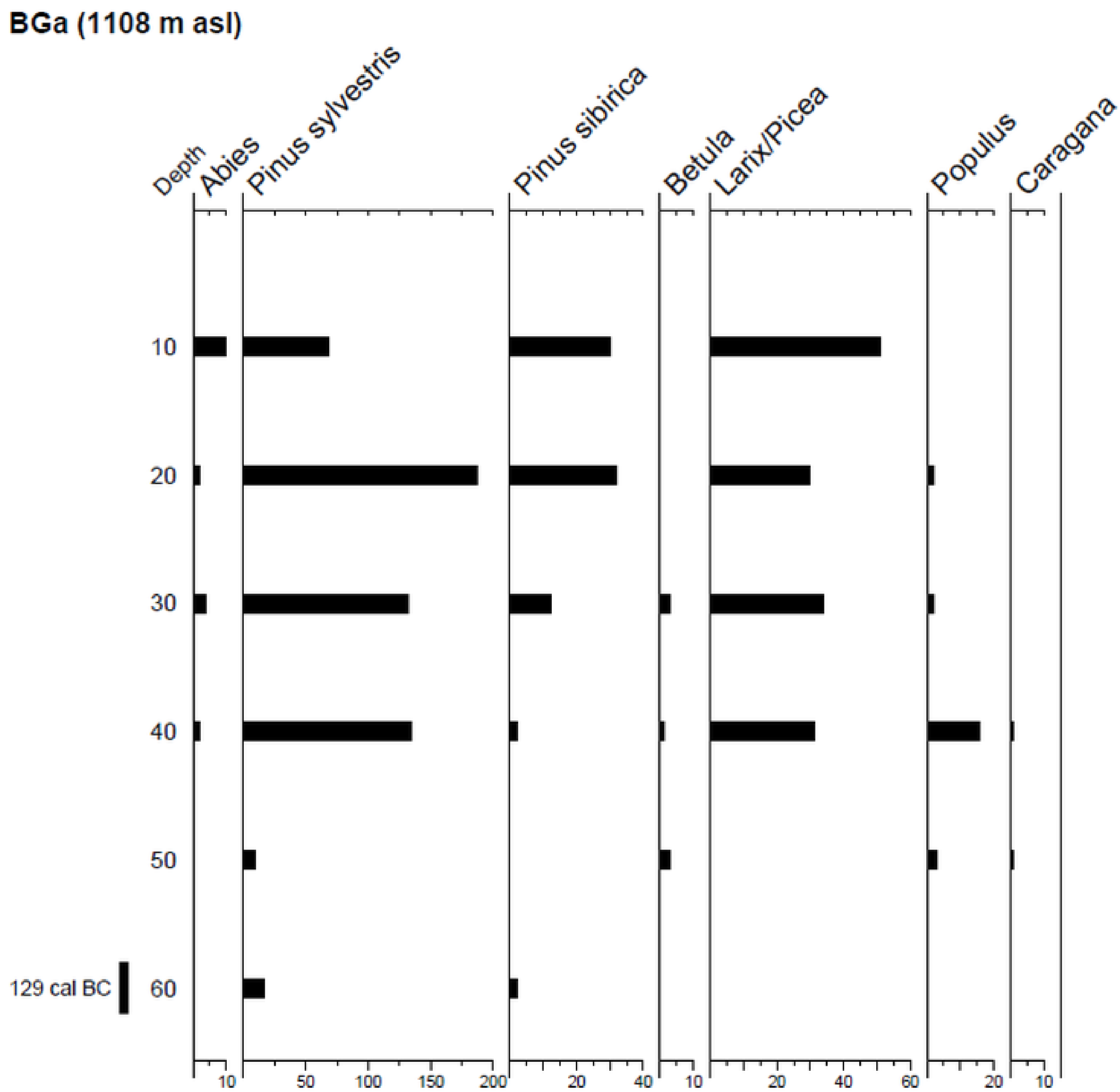


Figure 40. An example of results obtained by pedoanthracological analysis. The top of the graph shows the historic tree species composition of the dark taiga in Northern Mongolia. At the bottom left of the graph is the result of the radiocarbon dating, so at a depth of 60 cm, the chosen charcoal sample was dated to 129 calibrated years before Christ (BC). The bottom x-axis shows the anthracomass in micrograms (authors: Jan Novák, Pavel Peška, unpublished data).

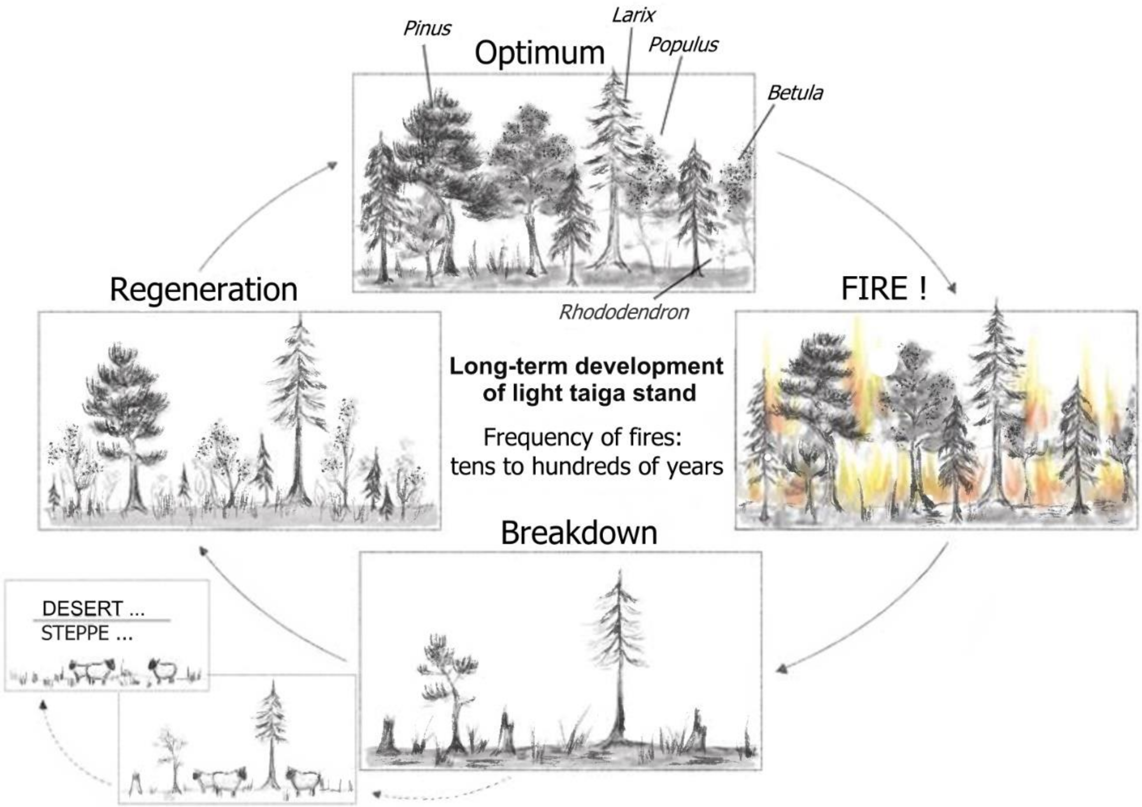


Figure 41. Light taiga developmental cycle based on pedoanthracological data from northern Mongolia (authors: Pavel Peška and Petra Barinová).

REFERENCES

Feiss, T., Robin, V., Aran, D., Levillain, J., Paul, T. and Dupouey, J.L., 2024. Are western European oak forests man-made constructs? The pedoanthracological perspective. Forest Ecology and Management, 552, p.121588. https://doi.org/10.1016/j.foreco.2023.121588.

Kazato, M. and Soyollham, B., 2022. Forest-steppe fires as moving disasters in the Mongolia-Russian borderland. Journal of Contemporary East Asia Studies, 11(1), pp.22-45. https://doi.org/10.1080/24761028.2022.2113493.

Kelly, R., Genet, H., McGuire, A.D. and Hu, F.S., 2016. Palaeodata-informed modelling of large carbon losses from recent burning of boreal forests. Nature Climate Change, 6(1), pp.79-82. https://doi.org/10.1038/nclimate2832.

Novák, J., Abraham, V., Houfková, P., Kočár, P., Vaněček, Z. and Peška, J., 2018. History of the Litovelské Pomoraví woodland (NE Czech Republic): A comparison of archaeoanthracological, pedoanthracological, and pollen data. Quaternary International, 463, pp.352-362. https://doi.org/10.1016/j.quaint.2016.11.020.

Novák, J., Kusbach, A., Abrahám, V. and Štěrba, T., Pedoanthracological records as tools for revelation of the forest history in the Khan Khentii Mts., northern Mongolia. EuroDendro 2019, p.38. ISBN 978-80-7509-676-0.

Robin, V., Talon, B. and Nelle, O., 2013. Pedoanthracological contribution to forest naturalness assessment. Quaternary International, 289, pp.5-15. https://doi.org/10.1016/j.quaint.2012.02.023.

FOREST DISTURBANCES

3. FOREST DISTURBANCES

Václav Pecina

Introduction

Forest dynamics is closely related to forest disturbances. FAO (2020a) defines disturbance as a "***damage caused by any factor (biotic or abiotic) that adversely affects the vigor and productivity of the forest and which is not a direct result of human activities***". This definition is, however, strongly forestry-oriented. If we look at forest disturbances from an ecological point of view, we can simply say that forest disturbance is an event that causes change in the structure and composition of a forest ecosystem. This includes both natural and anthropogenic events such as fires, wind, flooding, insect outbreaks, fungi, grazing, logging, or pollution.

Forest disturbances create space for **succession** – new forest development – and are a natural part of the forest development cycle. Critical are their frequency and intensity. These determine the visual appearance and functioning of the forest and its chance to reach the final stage of succession – the **climax** – which represents the shift from dynamism to stability. Even in the case of leaving the forest untouched and excluding major anthropogenic disturbances such as logging, human impact on the frequency and intensity of natural disturbances can still be noticeable. In Mongolian forests, it is responsible for the critical intensification of several natural disturbances. Most of them are linked to climate change.

Mongolian forests are adapted to extreme environmental conditions, however, their capacity for **resilience** and **resistance** can be severely limited by climate change and unsustainable landscape management. As a result of the semi-arid to arid climate, forests are particularly threatened by fires. Common monocenosis (natural single-species stands) facilitate pest outbreaks and disease vulnerability. Both disturbances are intensifying with climate change-related longer periods of drought and rising temperatures. In addition, illegal and unprofessional logging contribute to forest degradation and forest grazing to forest loss in Mongolia. A combination of these disturbances together with climate change-related permafrost melting may result in desertification and forest retreat. Restoring the functions of Mongolian forest ecosystems can take up to 60–100 years (Gunin et al., 1999). Therefore, understanding forest disturbances and succession is key to proper **sustainable forest management** as well as forest protection.

3.1 Forest Fires

Forest fires are the most important natural ecological factor in the dynamics of taiga ecosystems (Kharuk et al., 2021) and one of the main landscape-forming factors in the taiga zone (Petrov et al., 2022). Although forest fires are viewed by society in an entirely negative way, they are dynamic ecological forces driving many necessary ecological processes and ecosystem characteristics. These include, for example, the regulation of carbon and nutrient cycling, population sizes, species interactions, community composition and ecosystem functions (McLauchlan et al., 2020). Basically, they support ecosystem health and biodiversity. Their **periodicity** does not have to be a problem either, periodic forest fires decrease the danger of catastrophic forest fires (Kharuk et al., 2021). To distinguish and characterize such forest fires, a fire regime assessment is used. It has six components: **fire frequency**, **size**, **intensity** (Figure 42), **seasonality**, **type** and **severity** (Flannigan et al., 2000).

Figure 42. Limited periodic fire damage with low intensity – a stronger fire effect is visible around lying deadwood. Bugant area, Selenge, Mongolia (photo: Václav Pecina).

The **fire regime** influences forest structure and composition in both the long and the short term (Flannigan et al., 2000). Siberian larch (*Larix sibirica* Ledeb.) and Scots pine (*Pinus sylvestris* L.) have evolved under conditions of periodic forest fires as pyrophytic species.

This gave them a competitive advantage over non-fire-adapted species for regeneration and growing in burned areas. Consequently, periodic fires are a prerequisite for the dominance of larch in the permafrost zone (Kharuk et al., 2021). These species are especially in the dark taiga in the first phase after the fire accompanied by primary establishing pioneer species – aspen (*Populus tremula* L.) and birch (*Betula* spp.) (Figure 43). Forest composition change therefore occurs in favour of short-lived, photophilous, fast-growing species.

The mature larch- and pine- dominated stands of the continuous northern taiga forests have a closed canopy structure. Therefore, grass is less abundant in the understorey and fires are not as common as in the less dense southern forest-steppe stands (Johnson et al., 2009; Kazato and Soyollham, 2022). On the contrary, towards the north, ground fires are generally more intense (Kharuk et al., 2021).

Forest fires are an important part of natural landscape management in Mongolia due to harsh climate. The average fire return interval is >100 years and is of mixed severity, with an important role of weather (Johnson et al., 2009). However**, human activities have disturbed the natural fire dynamics** especially by influencing fire frequency. Nowadays, they are one of the main causes of a drastic degradation of Mongolian forest resources (Oyunsanaa, 2011) having adverse impacts on both ecosystems and economy (Kazato and Soyollham, 2022).

Figure 43. The development of a new forest with birch domination under the old pine trees that survived the fire due to thick bark. Bugant area, Selenge, Mongolia (photo: Václav Pecina).

The most common natural cause of forest fires in the taiga ecosystems is lightning. However, natural causes of fires are less common nowadays. **Approximately 95% of forest fires in Mongolia are man-made** (UN-REDD, 2018) and are both directly or indirectly linked to activities such as logging, hunting, collecting pine nuts, herbs and berries, mostly in the spring and autumn months (Johnson et al., 2009; Oyunsanaa, 2011; UN-REDD, 2018).

Since the beginning of the 1990s, the duration, frequency and intensity of forest fires have increased significantly in Mongolia (Oyunsanaa, 2011). At that time, about 6.47 million ha of forest have been damaged by fire (Ykhanbai, 2010). Between 2000–2008, an average of 188 fires per year were recorded (Johnson et al., 2009). From 2000 to 2019, approximately 2,650 forest-steppe fires occurred in Mongolia (Figure 44). Despite the frequency of fires, the total forest land area affected by fire has significantly decreased since 2010 compared to the previous two decades. Even so, between 2010 and 2016, an average of approximately 83,000 ha of forest was damaged each year (FAO, 2020b).

The extent of the impacts can be observed in the order of several decades. Forest fires burn seedlings and consume live foliage thereby reduce affected tree growth and survival (Bachelet et al., 2000). Due to the dependence of most Mongolian forests on natural regeneration, the high frequency of fires can ruin successful forest regeneration over large areas. It is difficult to estimate the overall impact of fires on the ecosystem services of forests in Mongolia, but it is already certain that they have a significant impact on wood production and water management in the landscape.

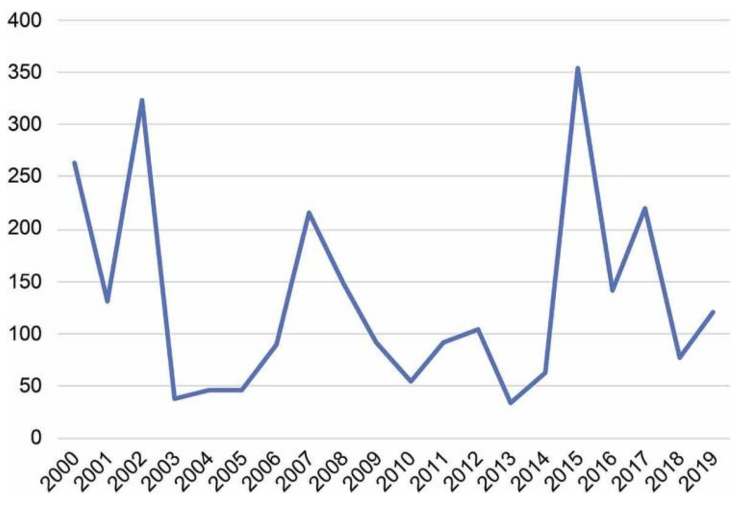


Figure 44. Number of forest-steppe fires between 2000–2019 (Kazato and Soyollham, 2022).

The threat associated with forest fires is not only the death of trees and temporary forest loss. There is a great potential for natural regeneration considering the evolutionary adaptations of taiga tree species. Even with soil damage (e.g. plant root and forest floor microbial populations) (Flannigan et al., 2000) and related permafrost damage, the ecosystem can regenerate in good conditions in approximately seven years, including the re-stabilization of the permafrost (Petrov et al., 2022). However, the related impacts of forest fires, especially in the forest-steppe transition zones, may be critical at present in Mongolia as forests are being opened for logging and livestock grazing (UN-REDD, 2018). Natural regeneration of these forests is improbable, and forest fire can thus contribute to **forest retreat**.

3.2 Forest Pests

Insect pests and **pathogens** are among the most important disturbance factors in forests (Canelles et al., 2021). They are integral components of forest ecosystems, and they have considerable influence on forest health. Insect pests and pathogens can adversely affect tree growth, vitality and survival, wildlife habitat, aesthetics and cultural values of forests (FAO, 2009). For example, insects alone can damage up to 1.6% of the global forested area annually (Fischbein and Corley, 2022). However, like most disturbances, they also open space for species community change accompanied by the potential for biodiversity growth. Nevertheless, their influence is perceived primarily as negative not only from the point of view of forestry.

Although forest diseases are also a hot topic worldwide, the ecologically and economically more important topic in Mongolia is insects. **Forest pests** are insects which can cause significant damage in forest stands, up to the mortality of entire forests. Most of them are of cyclical occurrence (Wagner, 2013) commonly including polyphagous species (FAO, 2009). However, the critical pests are usually tied to one host tree species. By decimating it, forest pests can alter natural forest landscapes (FAO, 2009; Canelles et al., 2021) (Figure 45).

Mongolian forests are vulnerable to pests. It is one of the main drivers of deforestation and forest degradation in Mongolia (UN-REDD, 2018). The reason is the frequent occurrence of fire-related even-aged monocenoses or monocultures composed mainly of Siberian larch or Scots pine. Such an environment creates favourable conditions for **pest outbreaks** (Figure 46).

Among the most dangerous Mongolian forest pests are especially defoliators (FAO, 2009) such as Gypsy moth (*Lymantria dispar* L.) (Figure 47a), Siberian moth (*Dendrolimus superans sibiricus* Tschetw.), Vapourer moth (*Orgyia antiqua* L.) and Jacobson's spanworm (*Erannis jacobsoni* Djak.), which are jointly responsible for extensive outbreaks reaching hundreds of thousands of hectares annually (FAO, 2014). It is important to mention that forest pests in Mongolia are reported equally in naturally regenerated and planted forests (FAO, 2009); therefore, changing the management system may not be the way to reduce damage. Although the major Mongolian pests damage especially needles and leaves, there are also important pests attacking phloem or wood (Figure 47b,c), e.g. six-spined engraver beetle (*Ips sexdentatus* Boerner), larch bark beetle, (*Ips subelongatus* Motschulsky) and lesser pine shoot beetle (*Tomicus minor* Hartig) (FAO, 2009).

Figure 45. *Damage to the forest by pests leading to the gradual disappearance of forest fragments from the landscape. Gorkhi-Terelj area, Töv, Mongolia (photo: Václav Pecina).*

Figure 46. *Damage to the Siberian larch forest by pests – no tree survived the outbreak. Gorkhi-Terelj area, Töv, Mongolia (photo: Václav Pecina).*

Figure 47. a) Lymantria dispar caterpillar on larch, b) larch damaged by the bark beetle and c) birch damaged by Scolytus sp. Gorkhi-Terelj area, Töv, Mongolia (photos: Václav Pecina).

Many countries face devastating pest outbreaks mainly due to several pest generations per year. However, the climatic conditions of Mongolia, with its short growing season and long frosts, offer natural protection as insects have a short time to develop. Despite this and annual oscillations, pest problems are becoming more common in Mongolia. While approximately 28,000 ha of forest land were damaged in 1990 (FAO, 2009), the number increased to 32,500 ha in 2003, and it was even 173,400 ha in 2013 (FAO, 2014). The reason may be **climate change** as rising temperatures limit this natural time-related protection and stress the trees. In addition, **forests weakened by long periods of drought are unable to resist pest attacks** (Jactel et al., 2019).

The latest results show that interactions between pests and other forest disturbances play critical roles in driving forest dynamics and their effects are likely to increase because of climate change (UN-REDD, 2018; Canelles et al., 2021). In conclusion, the combination of rising temperatures, melting permafrost and more frequent fires may accelerate the impacts of pests on forest ecosystems in Mongolia.

3.3 Forest Grazing

Vegetation composition, structure and dynamics of many terrestrial ecosystems are shaped by extensive grazing and browsing of domestic and wild herbivores (Gordon and Prins, 2008).

These also include forest-steppe landscapes. Large herbivores are among **key controlling factors** there (Erdős et al., 2022) because of their long-term and large-scale influence on ecological functioning (Öllerer et al., 2019). Forest-steppe ecosystems are species-adapted to this type of disturbance with an interesting diversity of these species. Herbivore grazing can be a tool to maintain or restore the biodiversity of such landscapes, contribute to their aesthetic and leisure value, and thus has cultural and recreational significance (Metera et al., 2010). In some ecosystems, it can also be a critical tool for biodiversity conservation (Bernes et al., 2018). In addition, as it reduces grass biomass and fuel loads including forest understorey, grazing can have an important role in fire mitigation (Öllerer et al., 2019) and enhance the expansion of forests or woodlands (Bachelet et al., 2000).

In summary, grazing herbivores influence the extent of forests, their structure, openness, composition and dynamics (Hester et al., 2000; Öllerer et al., 2019). However, this influence may not always be positive. With excessive grazing pressure (**overgrazing**), grazing can have harmful effects on forests. These include soil erosion, compacting and disturbing of soils, and reducing of litter and water infiltration rates (Belsky and Blumenthal, 1997). Forest woody understorey abundance and richness decrease with increasing grazing and **browsing** duration and intensity, respectively, with livestock playing a more significant role compared to native ungulates (Bernes et al., 2018). A closer analysis of this finding shows that the long-term intensive forest grazing may cause changes in quantity and height structure of seedlings and saplings (Sankey et al., 2006; Khishigjargal et al., 2013; Juřička et al., 2019, 2020) and changes in tree species composition (Belsky and Blumenthal, 1997). From the woody understorey, saplings are the most vulnerable to grazing (Bernes et al., 2018). In summary, it is important to realize that impacts are highly contextual (Öllerer et al., 2019).

In Mongolia, population increase, nomadic migration stagnation and abandoning the nomadic life due to social-economic and climatic changes resulted in the concentration of herders and their livestock in limited areas (Juřička et al., 2019). In recent years, the number of livestock including mostly sheep, cattle, horses and goats has also continued to rise (Juřička et al., 2020). Because of the related increasing pressure on the landscape resources, the overgrazing arises, leading to **landscape degradation**, soil erosion and desertification.

Overgrazing is common nowadays in Mongolian forest-steppes with negative impacts on forest regeneration, as was already documented in several locations (Sankey et al. 2006; Khishigjargal et al., 2013; Juřička et al., 2019, 2020) (Figure 48, Figure 49). Although grazing is not considered a driver of forest change in Mongolia, along with other factors it **contributes significantly to deforestation through continued site degradation** (UN-REDD, 2018).

However, the fact that current grazing pressure may inhibit or even stop successful forest regeneration for decades (Juřička et al., 2019) suggests that the importance of grazing may be reconsidered as a **critical forest disturbance** in Mongolian forest-steppe areas in the future.

Figure 48. *Regular long-term browsing led to the modelling of a small bush from birch saplings. Gorkhi-Terelj area, Töv, Mongolia (photo: Václav Pecina).*

Figure 49. *Terminal-browsing of Siberian larch – typical damage to most seedlings and saplings in Mongolian forest edges. Binder area, Khentii, Mongolia (photo: Václav Pecina).*

REFERENCES

Bachelet, D., Lenihan, J.M., Daly, C. and Neilson, R.P., 2000. Interactions between fire, grazing and climate change at Wind Cave National Park, SD. Ecological modelling, 134(2-3), pp.229-244. https://doi.org/10.1016/S0304-3800(00)00343-4.

Bernes, C., Macura, B., Jonsson, B.G., Junninen, K., Müller, J., Sandström, J., Lõhmus, A. and Macdonald, E., 2018. Manipulating ungulate herbivory in temperate and boreal forests: effects on vegetation and invertebrates. A systematic review. Environmental Evidence, 7(1), pp.1-32. https://doi.org/10.1186/s13750-018-0125-3.

Belsky, A.J. and Blumenthal, D.M., 1997. Effects of Livestock Grazing on Stand Dynamics and Soils in Upland Forests of the Interior West. Conservation Biology, 11(2), pp.315-327 https://doi.org/10.1046/j.1523-1739.1997.95405.x.

Canelles, Q., Aquilué, N., James, P.M., Lawler, J. and Brotons, L., 2021. Global review on interactions between insect pests and other forest disturbances. Landscape Ecology, 36, pp.945-972. https://doi.org/10.1007/s10980-021-01209-7.

Erdős, L., Török, P., Veldman, J.W., Bátori, Z., Bede-Fazekas, Á., Magnes, M., Kröel-Dulay, G. and Tölgyesi, C., 2022. How climate, topography, soils, herbivores, and fire control forest–grassland coexistence in the Eurasian forest-steppe. Biological Reviews, 97(6), pp.2195-2208. https://doi.org/10.1111/brv.12889.

FAO, 2009. Global review of forest pests and diseases Food and Agriculture Organization of the United Nations, Rome. Available at: https://www.fao.org/3/i0640e/i0640e.pdf.

FAO, 2014. Global Forest Resources Assessment 2015: Country Report: Mongolia. Food and Agriculture Organization of the United Nations, Rome. Available at: http://www.fao.org/3/a-az278e.pdf.

FAO, 2020a. Global Forest Resources Assessment 2020: Terms and Definitions. Food and Agriculture Organization of the United Nations, Rome. Available at: https://www.fao.org/forest-resources-assessment/past-assessments/fra-2020/en/.

FAO, 2020b. Global Forest Resources Assessment 2020: Report Mongolia. Food and Agriculture Organization of the United Nations, Rome. Available at: https://www.fao.org/3/cb0031en/cb0031en.pdf.

Fischbein, D. and Corley, J.C., 2022. Population ecology and classical biological control of forest insect pests in a changing world. Forest Ecology and Management, 520, p.120400. https://doi.org/10.1016/j.foreco.2022.120400.

Flannigan, M.D., Stocks, B.J. and Wotton, B.M., 2000. Climate change and forest fires. Science of the total environment, 262(3), pp.221-229. https://doi.org/10.1016/S0048-9697(00)00524-6.

Gordon, I.J. and Prins, H.H., 2008. The ecology of browsing and grazing. Springer Berlin, Heidelberg. https://doi.org/10.1007/978-3-540-72422-3.

Gunin, P.D., Vostokova, E.A., Dorofeyuk, N.I., Tarasov, P.E. and Black, C.C., 1999. Assessing Present-Day Plant Cover Dynamics. In: Gunin, P.D., Vostokova, E.A., Dorofeyuk, N.I., Tarasov, P.E. and Black, C.C. (eds.). Vegetation Dynamics of Mongolia. Boston, London Kluwer Academics.

Hester, A.J., Edenius, L., Buttenschøn, R.M. and Kuiters, A.T., 2000. Interactions between forests and herbivores: the role of controlled grazing experiments. Forestry, 73(4), pp.381-391. https://doi.org/10.1093/forestry/73.4.381.

Jactel, H., Koricheva, J. and Castagneyrol, B., 2019. Responses of forest insect pests to climate change: not so simple. Current opinion in insect science, 35, pp.103-108. https://doi.org/10.1016/j.cois.2019.07.010.

Johnson, D., Oyunsanaa, B., Myers, R.L. and Babler, M., 2009. Fire management assessment of the eastern steppe, Mongolia. GFI technical report. The Nature Conservancy, Arlington. Available at: https://www.conservationgateway.org/Documents/mongolia-fire-assessment-english.pdf.

Juřička, D., Kusbach, A., Pařílková, J., Houška, J., Ambrožová, P., Pecina, V., Rosická, Z., Brtnický, M. and Kynický, J., 2020. Evaluation of natural forest regeneration as a part of land restoration in the Khentii massif, Mongolia. Journal of Forestry Research, 31, pp.1773-1786. https://doi.org/10.1007/s11676-019-00962-5.

Juřička, D., Pecina, V., Brtnický, M. and Kynický, J., 2019. Mining as a catalyst of overgrazing resulting in risk of forest retreat, Erdenet Mongolia. Geography, Environment, Sustainability, 12(3), pp.184-198. https://doi.org/10.24057/2071-9388-2019-23.

Kazato, M. and Soyollham, B., 2022. Forest-steppe fires as moving disasters in the Mongolia-Russian borderland. Journal of Contemporary East Asia Studies, 11(1), pp.22-45. https://doi.org/10.1080/24761028.2022.2113493.

Kharuk, V.I., Ponomarev, E.I., Ivanova, G.A., Dvinskaya, M.L., Coogan, S.C. and Flannigan, M.D., 2021. Wildfires in the Siberian taiga. Ambio, pp.1-22. https://doi.org/10.1007/s13280-020-01490-x.

Khishigjargal, M., Dulamsuren, C., Lkhagvadorj, D., Leuschner, C. and Hauck, M., 2013. Contrasting responses of seedling and sapling densities to livestock density in the Mongolian forest-steppe. Plant Ecology, 214, pp.1391-1403. https://doi.org/10.1007/s11258-013-0259-x.

McLauchlan, K.K., Higuera, P.E., Miesel, J., Rogers, B.M., Schweitzer, J., Shuman, J.K., Tepley, A.J., Varner, J.M., Veblen, T.T., Adalsteinsson, S.A. and Balch, J.K., 2020. Fire as a fundamental ecological process: Research advances and frontiers. Journal of Ecology, 108(5), pp.2047-2069. https://doi.org/10.1111/1365-2745.13403.

Metera, E., Sakowski, T., Słoniewski, K. and Romanowicz, B., 2010. Grazing as a tool to maintain biodiversity of grassland-a review. Animal Science Papers and Reports, 28(4), pp.315-334.

Oyunsanaa, B., 2011. Fire and stand dynamics in different forest types of the West Khentey Mountains, Mongolia. Doctoral dissertation, Georg-August-Universität Göttingen, Göttingen. http://dx.doi.org/10.53846/goediss-515.

Öllerer, K., Varga, A., Kirby, K., Demeter, L., Biró, M., Bölöni, J. and Molnár, Z., 2019. Beyond the obvious impact of domestic livestock grazing on temperate forest vegetation–A global review. Biological Conservation, 237, pp.209-219. https://doi.org/10.1016/j.biocon.2019.07.007.

Petrov, M.I., Fedorov, A.N., Konstantinov, P.Y. and Argunov, R.N., 2022. Variability of permafrost and landscape conditions following forest fires in the central Yakutian taiga zone. Land, 11(4), p.496. https://doi.org/10.3390/land11040496.

Sankey, T.T., Montagne, C., Graumlich, L., Lawrence, R. and Nielsen, J., 2006. Lower forest–grassland ecotones and 20th century livestock herbivory effects in northern Mongolia. Forest Ecology and Management, 233(1), pp.36-44. https://doi.org/10.1016/j.foreco.2006.05.070.

UN-REDD, 2018. Mongolia's forest reference level submission to the UNFCCC. UN-REDD Mongolia National Programme, Ministry of Environment and Tourism, Ulaanbaatar. Available at: https://redd.unfccc.int/media/mongolia_2018_frl_submission_modified.pdf.

Wagner, L.D., 2013. Moths. In: Levin, S.A. (ed.). Encyclopedia of Biodiversity. 2nd edition. Elsevier Science.

Ykhanbai, H., 2010. Mongolia forestry outlook study. Food and Agriculture Organization of the United Nations Regional Office for Asia and the Pacific, Bangkok. Available at: http://www.fao.org/3/a-am616e.pdf.

FOREST MANAGEMENT

4. FOREST MANAGEMENT

4.1 Sustainable Forest Management

Václav Pecina

Introduction

In recent years, one key word has become a buzzword through the forestry sector – **sustainability**. It is part of academic and political discussions, education, reports, legislative documents and is slowly starting to be implemented in practice as well. **Sustainable forest management** is a forest management concept that is becoming an integral and essential part of forest land management worldwide as part of the fight against forest degradation and deforestation. The situation in Mongolia is in line with that trend, as the "sustainable use" of forests resonates in the Mongolian Law on Forest (2012). However, current practice is not always what it should be, and foresters are often not sure what sustainable forest management means.

What is sustainable forest management?

Sustainable forest management has a number of definitions, however, probably the most important and most frequently used is that it is: "***The stewardship and use of forests and forest lands in a way, and at a rate, that maintains their biodiversity, productivity, regeneration capacity, vitality and their potential to fulfil, now and in the future, relevant ecological, economic and social functions, at local, national, and global levels, and that does not cause damage to other ecosystems.***" This is the definition of Forest Europe, previously called Ministerial Conference on the Protection of Forests in Europe (MCPFE), from 1993, adopted by FAO (Forest Europe, 2023).

Another well-formulated and commonly used definition is the one from the International Tropical Timber Organization (ITTO) which says: "*The process of managing forest to achieve one or more clearly specified objectives of management with regard to the production of a continuous flow of desired forest products and services without undue reduction of its inherent values and future productivity and without undue undesirable effects on the physical and social environment*" (ITTO, 2023).

The key feature of sustainable forest management is that the **ecological, economic** and **social-cultural values** of forests are at the same level and create the three pillars of sustainability.

Sustainable forest management principles

What to imagine under these definitions? Several **criteria and indicators** (C&I) contribute to the definition of sustainable forest management principles. Their conceptualization started in the 90s. The first C&I for sustainable forest management were formally developed by the ITTO, resulting in the "Criteria for the Measurement of Sustainable Tropical Forest Management" (1992), and were focused primarily on sustainable tropical forest management for timber production (Zhu et al., 2000).

A very important milestone was also the so-called "**Montréal Process**" (1994), which dealt with criteria and indicators for sustainable forest management in temperate and boreal forests in 12 countries (e.g. Canada, the Russian Federation, the United States of America and China). These countries together represent about 90% of the world's temperate and boreal forests and about 49% of all forests (Montréal Process, 2015; Gilani and Innes, 2020). The member countries have agreed on a set of non-legally binding C&I for sustainable forest management for implementation at a national level. The current set of the C&I includes seven criteria and 54 indicators.

The criteria are as follows (Montréal Process, 2015):

1) Conservation of biological diversity.
2) Maintenance of productive capacity of forest ecosystems.
3) Maintenance of forest ecosystem health and vitality.
4) Conservation and maintenance of soil and water resources.
5) Maintenance of forest contribution to global carbon cycles.
6) Maintenance and enhancement of long-term multiple socio-economic benefits to meet the needs of societies.
7) Legal, institutional and economic framework for forest conservation and sustainable management.

Similarly, C&I were defined and adopted by Forest Europe for Pan-European countries, gradually at conferences in 1993 (Helsinki) and in 1998 (Lisbon). The updated version (2015, Madrid) of these C&I includes the following Pan-European criteria that define and describe various aspects of sustainable forest management in the pan-European region (Forest Europe, 2015; Forest Europe, 2023):

1) **Maintenance and appropriate enhancement of forest resources and their contribution to global carbon cycles.**
2) **Maintenance of forest ecosystems' health and vitality.**
3) **Maintenance and encouragement of productive functions of forests (wood and non-wood).**
4) **Maintenance, conservation and appropriate enhancement of biological diversity in forest ecosystems.**
5) **Maintenance and appropriate enhancement of protective functions in forest management (notably soil and water).**
6) **Maintenance of other socio-economic functions and conditions.**

There is also the set of National Level C&I for sustainable forest management in Mongolia with the following criteria (+ 51 indicators) (Tsogtbaatar, 2008):

1) Increase in the extent of forest and tree cover.
2) Increase in the extent of forest and tree cover criterion.
3) Conservation and maintenance of soil and water resources.
4) Maintenance and enhancement of ecosystem function and vitality.
5) Maintenance and enhancement of forest productivity.
6) Optimization of forest resource utilization.
7) Maintenance and enhancement of social, cultural and spiritual benefits.
8) Adequacy of policy, legal and institutional framework.

A set of quantitative and qualitative indicators characterize each criterion to provide a way to measure or describe the criterion. Through periodic measurement, their monitoring can indicate change in trends in conditions relevant to sustainable forest management, including environmental, social, economic, and political conditions. Although the resulting reports may not be considered important by foresters, their conclusions are essential for political decisions and related legislation (Forest Europe, 2015), which in turn has direct implications for forestry.

Although the principles of sustainability along with some definitions are recognized worldwide (Montréal Process, 2015; Forest Europe, 2023), not every C&I system is suitable to be blindly followed. This is because inappropriately defined C&I may be misunderstood. For example, in the first point of the Mongolian system (Increase in the extent of forest and tree cover), there is often an inappropriate application in the form of planting a forest on the steppe or in the desert and its artificial irrigation, because the forest would not survive there otherwise. Afforestation in conditions where forests have not grown naturally for hundreds of years is not sustainable and such management can, on the contrary, lead to landscape degradation due to groundwater depletion. On the path to sustainability, respecting natural conditions is essential.

The situation of sustainable forest management in Mongolia

Mongolian forests face many threats (see chapter 3. FOREST DISTURBANCES). As has been known for several years, the solution to many of them may be to promote the introduction of an integrated sustainable forest management system that takes into consideration ecological, economic, and social consequences (Tsogtbaatar, 2008). The situation is gradually improving, but the process is very slow. The Multipurpose National Forest Inventory took place between 2014–2017, the aim of which was to promote sustainable management of forestry resources in Mongolia (Altrell, 2019). Although it brought interesting and important results for the forestry sector, their implementation in practice is limited.

The reason is also **insufficient human resources** and **expertise of foresters**. Despite the progress in higher education (Burmaa et al., 2021), there is a lack of real experienced forestry practitioners and graduates for work in forests. Therefore, important investment areas for approaching sustainable forest management in Mongolia include forestry education at the high school level in direct cooperation with forestry practice and the introduction of new forestry technologies. However, the problem is more complex and needs a comprehensive solution (Burmaa et al., 2021). In conclusion, Tsogtbaatar's (2008) fifteen-year-old opinion that investments in the forestry sector will initially face low return rates, but are essential for introducing the concepts of sustainable forest management, is still current.

REFERENCES

Altrell, D., 2019. Multipurpose National Forest Inventory in Mongolia, 2014-2017-A tool to support sustainable forest management. Geography, Environment, Sustainability, 12(3), pp.167-183. https://doi.org/10.24057/2071-9388-2019-36.

Burmaa, N., Ganchimeg, T. and Baasanjav, G., 2021. Sustainable forest management: current situation and certain challenges of the forest sector of Mongolia. GIS Odyssey Journal, 1(2). https://doi.org/10.57599/gisoj.2021.1.2.47.

Forest Europe, 2015. Madrid Ministerial Declaration. 7th Ministerial Conference on the Protection of Forests in Europe. October 20–21, 2015, Madrid, Spain. Available at: https://foresteurope.org/wp-content/uploads/2016/11/III.-ELM_7MC_2_2015_MinisterialDeclaration_adopted-2.pdf#page=5.

Forest Europe, 2023. Sustainable Forest Management. Forest Europe. Available at: https://foresteurope.org/workstreams/sustainable-forest-management/ (accessed 1 December 2023).

Gilani, H.R. and Innes, J.L., 2020. The state of Canada's forests: A global comparison of the performance on Montréal Process Criteria and Indicators. Forest Policy and Economics, 118, p.102234. https://doi.org/10.1016/j.forpol.2020.102234.

ITTO, 2023. Sustainable forest management. International Tropical Timber Organization (ITTO). Available at: https://www.itto.int/sustainable_forest_management/ (accessed 1 December 2023).

Mongolian Law on Forest. Ministry of Environment and Green Development of Mongolia. A revised version. Government Bulletin No 22. Published on May 17, 2012, Ulaanbaatar. Available at: https://legalinfo.mn/mn/detail/15624.

Montréal Process, 2015. The Montréal Process: Criteria and Indicators for the Conservation and Sustainable Management of Temperate and Boreal Forests. 5th edition, September 2015. Available at: https://www.montreal-process.org/The_Montreal_Process/Criteria_and_Indicators/index.shtml (accessed 1 December 2023).

Tsogtbaatar, J., 2008. Mongolia: Study work report methodologies and tools for harmonized Monitoring assessment, In: Dorjsuren, C. Global FRA 2010: Mongolia Country Progress Report: Recommendation for Harmonization and Standardization of MAR, Terms. FAO, Ulaanbaatar, 15–21. Available at: http://www.fao.org/forestry/18245-08434bb1070bfb2b014426d6d2c76f987.pdf.

Zhu, C., Zhang, S., Shi, Z. and Jiang, Z., 2000. Criteria and indicators for sustainable forest management in Bhutan, Mongolia, Nepal and China. FAO. Available at: http://www.fao.org/3/x6895e/x6895e05.htm.

4.2 Forest Inventory

Martin Smola

Introduction

Inventory is one of the basic methods of finding out **information** about forests (Figure 50) through the **systematic collection** of data and forest information for subsequent analysis and evaluation. Forest inventory is defined as the independent examination of forest lands and their development describing mainly the quantity and quality of trees (Černý, 2004). Depending on the purpose of the inventory, the **national forest inventory** (Altrell and Erdenebat, 2016) and the **operational forest inventory** are distinguished.

The main objectives of national forest inventories are:

1. To provide complete information on the state of the forest and its development in the country for the needs of the state administration.
2. To verify the development of growing stock in relation to growth or decrease in felling.
3. To evaluate the fulfilment of basic forest management criteria (the preservation of health and vitality of forest stands, forest production functions and the biological diversity of forest ecosystems) as well as to reach the strategic targets of forest management (the preservation of forests as sustainable and renewable natural resources, the application of principles of sustainable forest management).
4. To use data for developing the state's long-term forest and grant policy and its impact on the state of the forests.

Figure 50. Tree diameter measurement and age determination (photo: Martin Smola).

Statistical operational inventory

In the statistical operational inventory (Černý, 2004), live and dead trees are measured in a regular network of inventory plots (Smola et al., 2019) and then, by means of statistical calculations, generalized on a scale of forest stands using similar characteristics. The results are transferred to broader areal units such as management complexes, summarized **forest development types** or summarized forest **stand types**. This stratification of forest stands is a basic principle of the operational inventory.

Methods and data of statistical operational inventory

There are several different methods of forest inventory. As an example, it is valuable to cite here one of the applications that were implemented to create a **forest management plan** for forests near Shariin Gol town, Mongolia (Smola et al., 2019).

A randomly generalized network (300×300 m) of **inventory plots** (Figure 51) and the TopoL software (TopoL, 2013) were used for a digital measurement technology. The centre of inventory plots (Figure 52), randomly determined, was found with a GPS device. The inventory crews were equipped with Digitech Haglöf callipers and Vertex Laser hypsometers simultaneously used for the two concentric circle plot delineation (Zahradníček et al., 2010). The smaller circle plot was used for regeneration assessment (Smola et al., 2019). In the larger circle, the **diameter at breast height (DBH)** of all trees with DBH >10 cm (for DBH >15 cm two perpendicular measurements) was measured. DBH is one of the most important dendrometric measurements; it is a diameter of a tree at a height of 1.3 m (about breast height). DBH is used for the calculation of the volume of a single tree and forest stand.

Tree damage at base (e.g. a fire scar), mid tree damage and tree crown damage were assessed. Snags (dry standing trees) were assessed separately. Five exemplary tree individuals within a whole diameter range were selected for **height** measurement and **age** assessment using an increment borer. The height of trees is important for calculating the tree volume. The age of trees is important for subsequent forestry planning.

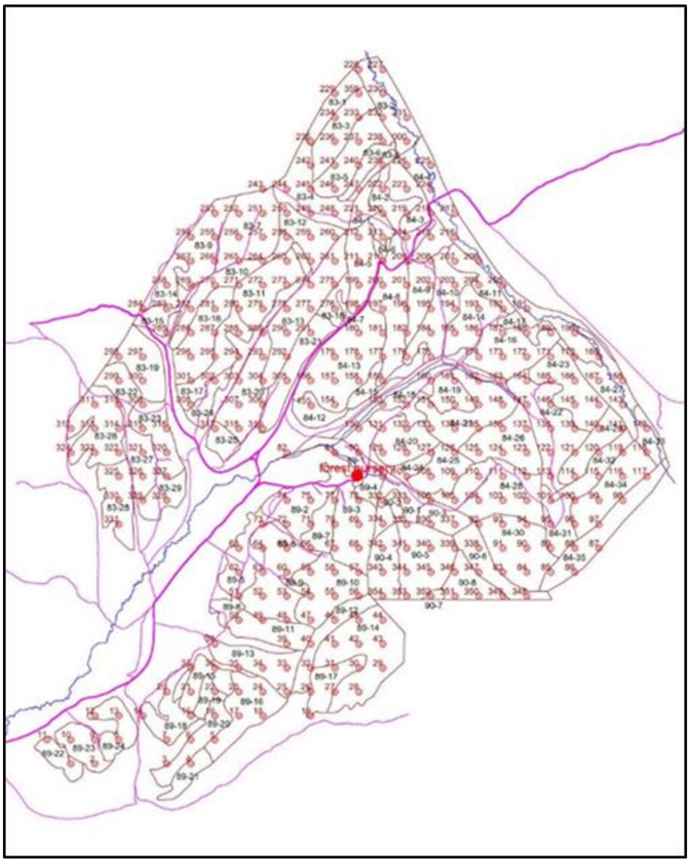


Figure 51. An example of randomly generalized network of inventory plots in the Domogt locality (Smola et al., 2019).

In a smaller circle, the number of **seedlings/saplings** was manually calculated including damaged individuals in the following height classes: 5–50 cm, 51–130 cm, 130+ cm up to 10 cm of DBH. These characteristics are important for describing the regeneration and development of the stand as well as game or livestock pressure. Because of a high amount of **deadwood** (coarse woody debris) on a forest floor, deadwood measurement was included in the inventory (Smola et al., 2019). Deadwood has positive benefits for the forest environment and biodiversity (e.g. habitat for many organisms, carbon storage), but it can also constitute threats (e.g. fire hazard, obstacles for the movement of forest machinery). The knowledge of its volume is therefore important both for forest management and for calculating carbon stocks.

Such a detailed description of the forest stand environment, summarizing its basic characteristics, makes it possible to evaluate its current state and predict future development. Then, a database of the measured items is created for a statistical calculation and for the **forest management planning**. Based on the calculations, the number of trees per hectare, stand **basal area**, can be added to the already mentioned volume of trees or forest stand. A forest management plan, including **sustainable forest measures** and other related forestry activities, is subsequently set.

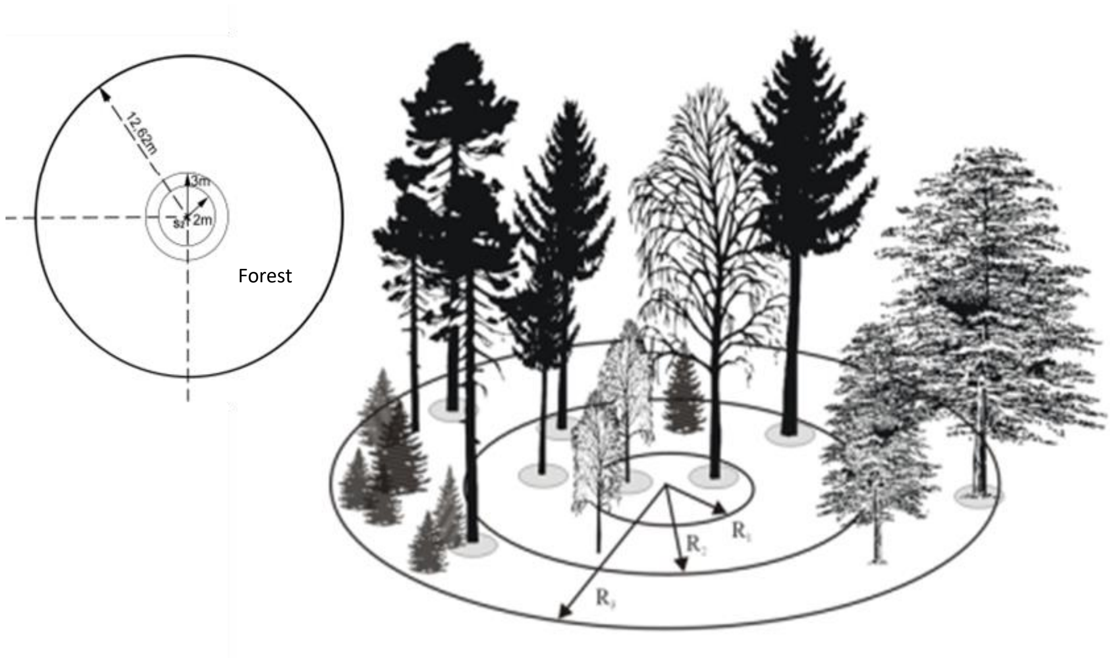


Figure 52. The inventory plot schematic design (Černý, 2004).

REFERENCES

Altrell D., Erdenebat E., 2016. Mongolian Multipurpose National Forest Inventory 2014–2016. 1st edition. Ministry of Environment and Tourism, Ulaanbaatar.

Černý M., 2004. Metodika tvorby lesního hospodářského plánu na podkladě provozní inventarizace [Methodology of Forest Management Plan Elaboration Based on an Operational Inventory]. Ministerstvo životního prostředí, Praha. (In Czech).

Smola, M., Kusbach, A., Štěrba, T., Adolt, R. and Nečas, M., 2019. Forest Management Plan in Domogt Sharyn Gol, Mongolia is Elaborated on Ecological and Sustainable Principles. Journal of Landscape Ecology, 12(2), pp.92-115. https://doi.org/10.2478/jlecol-2019-0012.

TopoL, 2013. TopoL software ver. TopoL xTBasic10.0.19.0. TopoL Software, s.r.o., Prague.

Zahradníček J., Hron M. and Ferkl L., 2010. Methodology of Management of Noncompartment Commercial Logged Forests. Ministerstvo životního prostředí, Praha. (In Czech).

4.3 Forest Management Planning

Martin Smola

Introduction

The **forest management plan** is the main work of forest management and is primarily an owner's tool for forest management. However, it is also the state's tool for **preserving the nature of the forest, its functioning as an ecosystem and, last but not least, for maintaining the sustainability of timber production** as a strategic renewable raw material. It is the state's indispensable role to create a legislative framework for the management and protection of forest resources that will ensure the continued existence of the forest ecosystem. The state defends its interests in forests through its participation in the process of elaboration and approval of the forest management plan. The forest management plan provides an overview of the natural, technical and economic conditions of management and the current state of the forest and proposes basic management measures. It consists of a **text section**, a **management book** and **forestry maps**.

In the modern concept of forest management, the proposed management measures are based on **respect for natural conditions** and the use of **nature-based forest management**.

The general principles of nature-friendly forest management include:

- To establish and maintain an optimal species, age and spatial composition of trees in forests fully suited to the habitat and the stated management objective.
- To use productive potential of the site through active forest management aimed at not only optimizing timber production, but also supporting the ecological stability of the forest ecosystem.
- To avoid large-scale clear cutting.
- To exploit the dynamics of the natural forest in regeneration, especially natural regeneration.

Silviculture and **management** via forest management plans in Mongolia (if any available) have been oriented to logging activities so far. Forest regeneration development has been neglected and often overlooked, large clearcuts after logging were left to natural succession.

A model forest management plan for the territory of Domogt Shariin Gol based on the statistical operational inventory was elaborated. On a particular forest property, the possibilities of using the principles and methods traditionally utilized in forest management planning in the Czech Republic were presented. The methods were adjusted to the existing legislation in Mongolia (Smola et al., 2019).

The forest management plan elaborated for Domogt Company Ltd. is based on **ecological** and **sustainable principles**. It respects natural conditions and the actual state of the forests reflected by forest development types, stand types and subtypes, for which model management guidelines were elaborated. A stratification of site characteristics using the forest classification framework (Kusbach et al., 2017a) and the forest development type concept (Zahradníček et al., 2010) was used as a framework for the assessment of a forest property state.

Forest development type

A forest development type (Zahradníček et al., 2010; Mikeska 2013) is a forest management differentiation unit based on the aggregation of sites with the same or similar potential natural vegetation sensu Tüxen (1956), i.e., with a similar successional trajectory. On the Domogt property, it served as a framework for the assessment of the state of forests via an operational forest inventory (Černý, 2004) and management planning (Kusbach et al., 2017b). For forest development type structuring on the Domogt property, the outputs of the project were used. This structuring was based on:

1. Framework delineation of **forest development types** that are characterized by natural/environmental conditions (**vegetation geo-climatic zonation, site moisture regime**).
2. Functional structuring of forests based on public interests expressed via forest categories (commercial and protection forests, Mongolian Law on Forest 2012).
3. State of forest stands defined by a dominant tree species and its successional stage and quality (Průša, 2001).

Vegetation geo-climatic coding (landscape zonation; Figure 53)

The first digit of the code of the forest development type means two levels of information (i) vegetation geo-climatic zone, expressing macroclimatic conditions reflected by the specific tree vegetation and (ii) forest category. The odd digit means commercial forests and the even digit protection forests. Thus, for one vegetation geo-climatic zone, two digits (odd and even) are reserved. For Domogt, 3 (4) – montane zone (*Pinus sylvestris* light taiga) where the forest area is larger than the steppe area were chosen (Kusbach et al., 2017a).

Site and stand characteristics were indicated by a three-digit and one-letter designation (Figure 53).

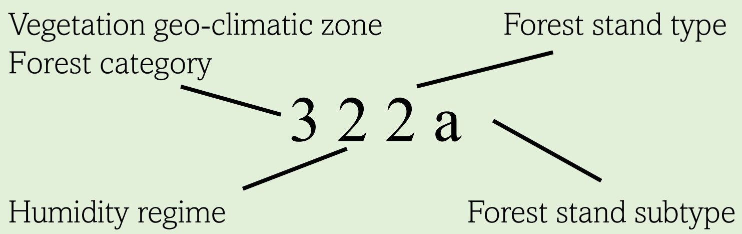


Figure 53. A digit and letter designation of site and stand characteristics (Smola et al., 2019).

Site moisture regime coding

Besides climate, soil moisture and nutrient regimes have a fundamental effect on vegetation (e.g. Pojar et al., 1987; Viewegh et al., 2003). With respect to a relatively small area of Domogt and homogeneous site conditions, only a gradient of soil moisture was considered.

The second digit gives information for commercial and for protection forests. Always, it follows a soil moisture gradient from the driest (1) up to moist/wet (3).

Commercial forests:

1 – Dry (moisture deficit is distinct in all vegetation periods),

2 – Fresh (mean moisture regime, later in a vegetation period, a soil profile may dry up),

3 – Moist (balanced moisture conditions in all vegetation periods).

Protection forests:

1 – Extremely dry (drought in all vegetation periods)

2 – Fluctuating moisture up to wet (under the influence of a seasonally fluctuating ground water table),

3 – Wet (a permanent ground water table present).

Forest development type coding (Kusbach et al., 2017a; Smola et al., 2019)

A forest development type was designated by a combination of the first two digits of the 4-digit code within a given vegetation geo-climatic zone (Figure 53). Sites were aggregated according to the similarity of potential natural vegetation and the related similar successional stage of a natural forest. The forest development type was named according to the dominant tree potential natural vegetation or fundamental characteristics of a site, e.g. alluvium. In Domogt, these forest development types were indicated:

31 – Pine forest (dry sites within the montane zone),

32 – Birch-pine forest (fresh sites within the montane zone),

33 – Larch-birch-pine forest (moist sites within the montane zone),

41 – Exposed forest-steppe (extremely dry sites within the montane zone),

42 – Birch alluvium and springs (fluctuating moist up to wet sites within the montane zone),

43 – Willow alluvium (wet sites within the montane zone).

Stand type and subtype coding (Figure 54)

Depending on forest stand properties defined by dominant tree species composition, structure, quality and its successional stage, three stand types/subtypes (a, b) may be distinguished:

1 – Target:

- a stand close to a natural (demanding target) state with respect to composition and structure.

2 – Transition:

- Subtype a) a homogeneous stand close to a natural target state by composition, spatial structure is not differentiated. Only one storey is present.
- Subtype b) a structured stand, not reflecting natural composition (in Domogt, usually dominant birch or aspen is present), structure can be differentiated and homogeneous (more than one storey is present),

3 – Distant:

- Subtype a) a low-quality stand of not demanding composition, structure can be differentiated and homogeneous.
- Subtype b) a low canopy cover stand (usually < 0.3).

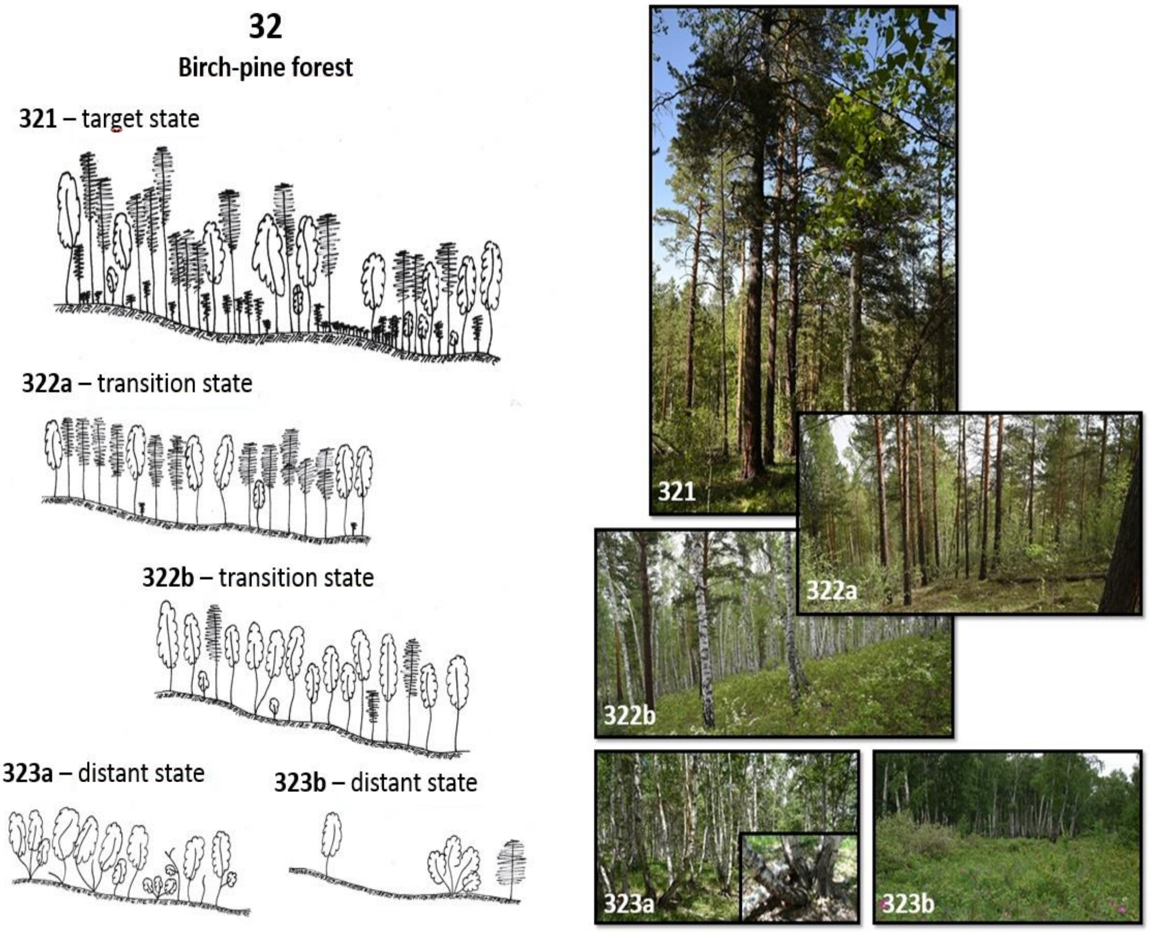


Figure 54. Birch-pine forest development type with stand types and subtypes (Smola et al., 2019; photos: Martin Smola).

Coding examples:

1. 323a – a low quality stand type of not demanding composition in relation to a target stage, no respect to stand structure, a fresh site within the montane zone, a commercial forest, birch-pine forest development type.
2. 323b – a distant stand type with a low canopy cover, a fresh site within the montane zone, a commercial forest, birch-pine forest development type (Figure 54, Figure 55).

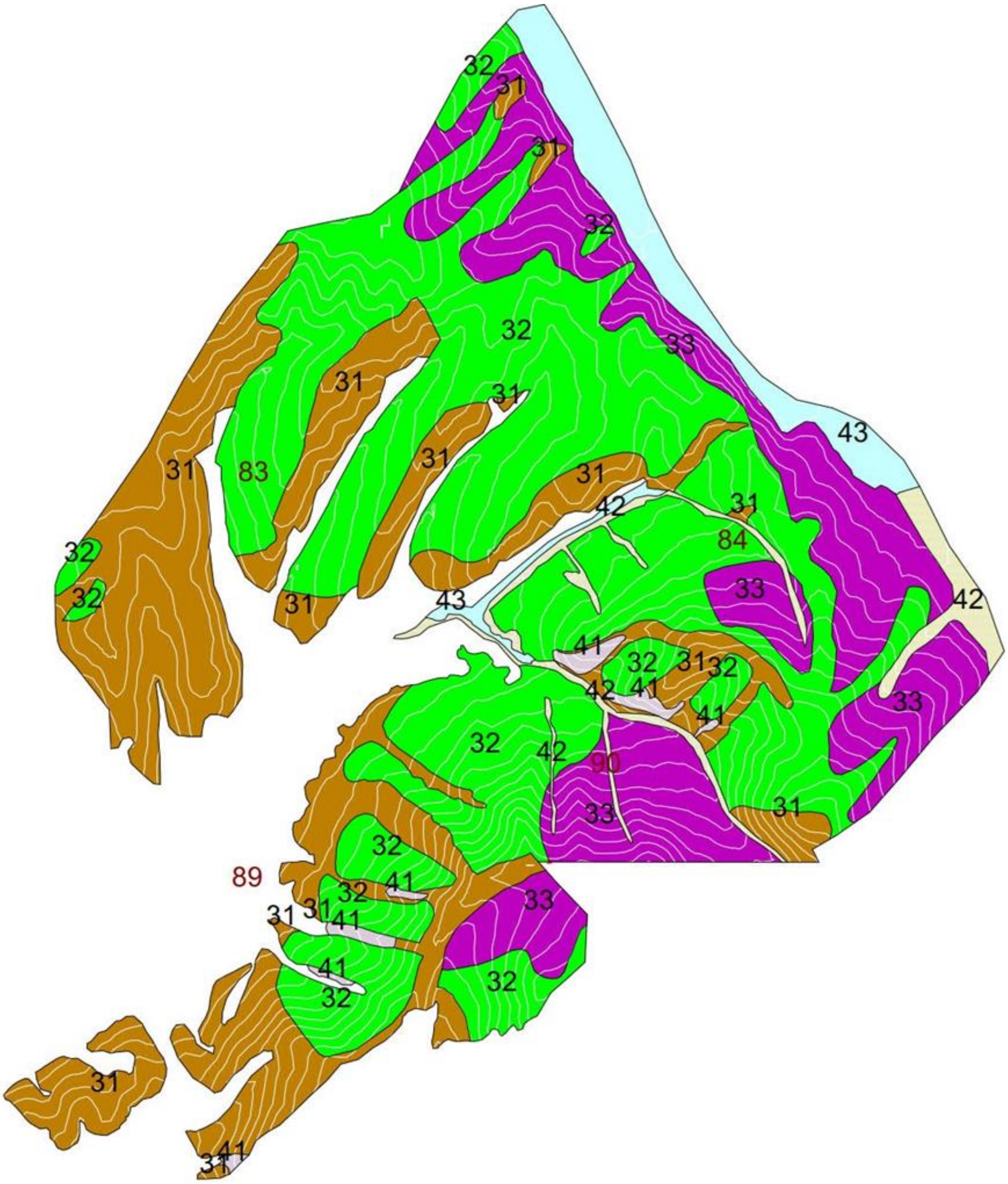
Current vegetation	Code	FTP																	
		31			32			33			41			42			43		
		target state	transition state	distant state	target state	transition state	distant state	target state	transition state	distant state	target state	transition state	distant state	target state	transition state	distant state	target state	transition state	distant state
Pinus sylvestris hemiboreal forest	1	311	312a	313				331	332a										
Pinus sylvestris open forest	2	311																	
Pinus sylvestris exposure-related forest-steppe	3											41							
Betula platyphylla<Pinus sylvestris hemiboreal forest	4		312a		321	322a			332a										
Pinus sylvestris<Betula platyphylla hemiboreal forest	5		312b			322b	323a		332b	333a									
Pinus sylvestris-Betula platyphylla open forest	6						323b			333b									
Betula platyphylla alluvial forest	7													421	422	423			
Salix spp.-Betula platyphylla alluvial forest	8													421	422	423			
Salix spp.- alluvial forest	9																	43	
Betula platyphylla and/or Populus tremula young forest	10			313			323a			333a									
Meadow, pasture, clear-cut wetland without woody vegetation	11																		

Figure 55. Forest types according to forest development types (FTP) and actual/existing vegetation (Kusbach et al., 2017a; Smola et al., 2019); see the text for forest development type coding.

The Domogt forest management plan comes from a statistical operational inventory that provides objective measurable items and information on a **volume of forest stands** (more in chapter 4.2 Forest Inventory). These properties enable generalization of logging possibilities via the **total allowable cut**. Forest management plan solves forest regeneration and tending with a clearly located treatment including urgency prescription for **10 years**.

Text, table, graph, figure and map materials were produced in forest management plan. These text, table, graph, figure and map outputs (Figure 56, Figure 57) consisted of areal, tree species and wood volume structuring, including the calculation of decennial logging, thinning treatments, plantation activities and natural regeneration support. The forest management plan provides a feasible perspective not only towards immediate commercial benefits but also towards **sustainability** of forest yield and other **ecological forest functions**. If this forest management plan is implemented, the state of the Domogt forests should not worsen and the company must get a profit from its own forests (Smola et al., 2019). This way of management planning follows demands for the mitigation of the current environmental issues in a Mongolian forest landscape.

Main **silvicultural** and **management treatments** were demonstrated on 13 demonstration plots in close surroundings of the forest nursery (Smola et al., 2019) with site-specific examples of thinning, afforestation, reforestation, and natural regeneration support. These demonstration plots include all major forest development types and cover all prevailing natural conditions (wet/dry, rich/poor sites) within the Domogt property.



Forest development type legend:

31 Pine forest
32 Birch-pine forest
33 Larch-birch-pine forest
41 Exposed forest-steppe
42 Birch alluvium and spring areas
43 Willow alluvium

Figure 56. Forest management plan – Map of forest development types (Smola et al., 2019).

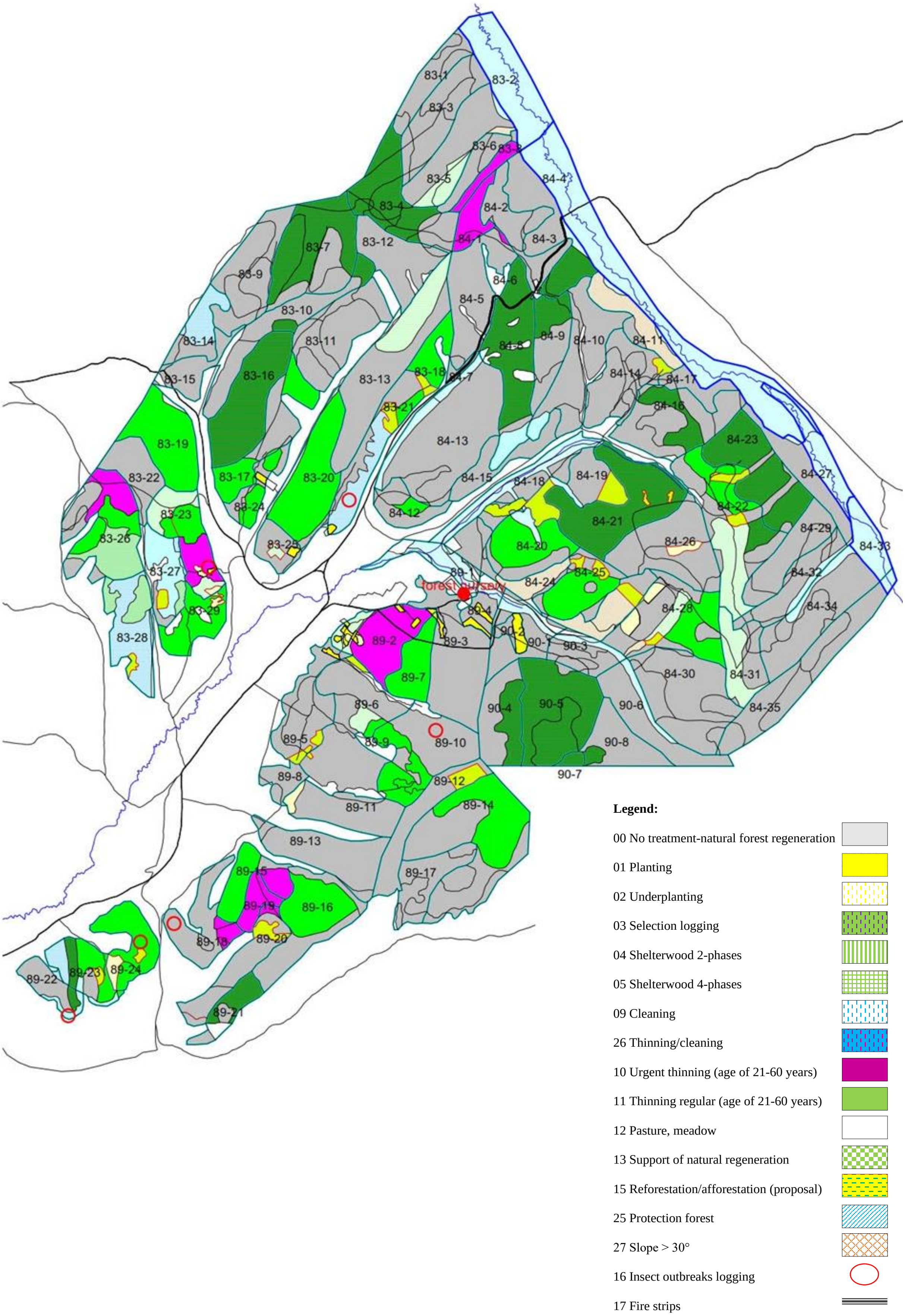


Figure 57. *Forest management plan – Map of management treatments (technology map) (Smola et al., 2019).*

REFERENCES

Černý M., 2004. Metodika tvorby lesního hospodářského plánu na podkladě provozní inventarizace [Methodology of Forest Management Plan Elaboration Based on an Operational Inventory]. Ministerstvo životního prostředí, Praha. (In Czech).

Kusbach A., Štěrba T., Smola M., Novák J., Lukeš P., Strejček R., Škoda A., Bažant V. and Pondělíčková A., 2017a. Development of Forests and the Gene Pool of Local Forest Tree Ecotypes in Mongolia. Part III.: Development of Forests and Landscape in Mongolia, Silviculture, Urban Forestry, Public Relations. Proceedings of the seminar, Sharyn Gol/Darkhan, Mongolia, September 2017. ÚHÚL Brandýs nad Labem. (In Czech and Mongolian).

Kusbach, A., Friedl, M., Zouhar, V., Mikita, T. and Šebesta, J., 2017b. Assessing forest classification in a landscape-level framework: an example from Central European forests. Forests, 8(12), p.461. https://doi.org/10.3390/f8120461.

Mongolian Law on Forest. Ministry of Environment and Green Development of Mongolia. A revised version. Government Bulletin No 22. Published on May 17, 2012, Ulaanbaatar. Available at: https://legalinfo.mn/mn/detail/15624.

Mikeska M., 2013. Cílový hospodářský soubor versus typ vývoje lesa [Target Management Series vs. Forest Development Type]. Lesnická práce, 92(10). (In Czech).

Pojar, J., Klinka, K. and Meidinger, D.V., 1987. Biogeoclimatic ecosystem classification in British Columbia. Forest Ecology and Management, 22(1-2), pp.119-154. https://doi.org/10.1016/0378-1127(87)90100-9.

Průša E., 2001. Pěstování lesů na typologických základech [Cultivation of Forests Based on Forest Classification]. 1st edition. Lesnická Práce, Kostelec nad Černými Lesy. (In Czech).

Smola, M., Kusbach, A., Štěrba, T., Adolt, R. and Nečas, M., 2019. Forest Management Plan in Domogt Sharyn Gol, Mongolia is Elaborated on Ecological and Sustainable Principles. Journal of Landscape Ecology, 12(2), pp.92-115. https://doi.org/10.2478/jlecol-2019-0012.

Tsedendash G., 1998. Forest Ecological Features of Mongolia. Paper presented at the Open Parliamentary Forum (April 28, 1998), Ulaanbaatar. (In Mongolian).

Tüxen R., 1956. Die Heutige Potentielle Natürliche Vegetation als Gegenstand der Vegetationskartierung; Angewandte Pflanzensoziologie 13. Bundesanstalt (Zentralstelle) für Vegetationskartierung, Stolzenau. (In German).

Viewegh, J., Kusbach, A. and Mikeska, M., 2003. Czech forest ecosystem classification. Journal of Forest Science, 49(2), pp.74-82.

Zahradníček J., Hron M. and Ferkl L., 2010. Methodology of Management of Noncompartment Commercial Logged Forests. Ministerstvo životního prostředí, Praha. (In Czech).

4.4 Forest Tending

Aleš Škoda

Introduction

Forest tending is one of the basic silvicultural treatments. **Silviculture** is forest management controlling the establishment, growth, composition, health, and quality of forests so that they provide forest functions to meet the diverse needs and values of landowners and society on a **sustainable** basis (Brüllhardt et al., 2022; USDA Forest Service, 2024). It is a critical element of forestry, which ensures long-term continuity of essential forest functions and health and productivity of managed forest ecosystems (Nyland, 2016). Silviculture applies different types of treatments, which can be simply categorized under forest regeneration, tending and harvesting. These treatments should be planned and included in **forest management plans** and should be part of **sustainable forest management**.

Tending is represented by operations and activities which should ensure stand stability and timber improvement. Targeted cultivation care should be in accordance with the transport and economic possibilities in the specified locations. Mongolian forests are mainly located in inaccessible areas. It is not economically sustainable to manage these areas. On the other hand, the accessible sites are often without the necessary care and the potential to produce high quality wood raw material is not exploited.

The main objectives of tending in forest stands are (Škoda and Pecina, 2024):

- Increasing forest stability.
- Adjustment of species composition.
- Accelerating stem volume growth.
- Improving the quality of the timber grown.
- Improving the accessibility of forest complexes.
- Fire safety.

Artificial forest tending includes especially:

a) Release operations
b) Pruning
c) Thinning

Release operations

Release operations are carried out to regulate species composition and improve very young stands. These interventions in young stands are aimed at releasing the trees from the pressure of unwanted woody and herbaceous vegetation (Figure 58). They are suitable on fertile, mineral-rich soils where competition from other vegetation is high. The whole area can be released (cleaned) or only a partial release can be done. In places where young forest stands are structurally rich and have already exceeded the height of herbaceous vegetation (weeds), this intervention is no longer necessary.

Figure 58. *Release operation with a brush cutter (photo: Václav Pecina).*

Pruning

Compared to other tending operations, **pruning** involves only the branches of trees. It is based on manual removal of the lower tree branches to a predetermined height to produce knot-free wood and improve stand environment conditions. This treatment further reduces the risk of crown fires and makes treated forests more transparent and accessible. Pruning can be carried out up to a height of 2.5 m (low pruning) (Figure 59a) or up to a height of 5–6 m (high pruning) (Figure 59b). At least 1/3 of the tree crown length must always remain intact. The measure is usually carried out using hand tools with an extended telescopic pole.

Figure 59. a) An example of low pruning (Scots pine) at a site with a loose canopy and b) an example of high pruning (Siberian larch) (photos: Václav Pecina).

Pruning should be carried out after the thinning intervention; then shape-high-quality individuals can be pruned in the number of about 100–500 individuals/ha. In open stands, pruning can replace thinning interventions.

Pruning is particularly important in sparser parts of stand groups where natural pruning due to competition does not occur. The trees present would be extremely branched without pruning and the possibility of future sawmill use of their wood would be limited.

Thinning

Thinning is an intermediate treatment **designed primarily to enhance growth, quality, stability, and composition of the forest stand** after its establishment and prior to its final harvest. In addition, thinning is considered a suitable approach to improve the growth response of post-thinning residual trees in a forest stand to drought in both conifers and broadleaves (Sohn et al., 2016). Similarly, del Campo el. (2022) found that thinning mitigates the effects of drought through increasing water use efficiency. According to Kang et al. (2014), thinning can also positively affect soil moisture content in forests and available moisture. Such an advantage may be decisive in view of the advancing impacts of climate change in Mongolia.

Thinning is crucial for the development of the young stand (Marchi et al., 2014) and cannot be skipped. It fundamentally improves the stability of the trees and the economic quality of the future forest. There are two types of thinning based on the age of the stand:

a) Thinning of young growth and thickets (**precommercial thinning**) which is oriented to the youngest stands where mostly unmarketable trees are felled and usually not removed from a stand. However, they should be concentrated to prevent risks of ground fires.
b) Thinning of older stands (**commercial thinning**) which is leading to some additional production of wood products and therefore these treatments are planned and controlled.

Precommercial thinning

This measure does not bring immediate financial benefits; on the contrary, it requires financial support. However, it can significantly increase the benefits from future forest stands. Precommercial thinning can be carried out in all young forest stand types (Figure 60, Figure 61, Figure 62, Figure 63, Figure 64, Figure 65). The first thinning is carried out at a stand height of about 5–7 m in order to sufficiently release selected tree species and high-quality individuals in the stand. The main principles are to maintain a diverse species composition of the forest and to maintain a good quality deep canopy of the remaining trees. At these stages of forest management, it is advisable to establish a road network designed to improve access to the forest stand. It is also possible to promote the quality of selected stems by pruning.

***Figure 60**. Asian white birch stand formed by stump clearance in a very dense patch. Without thinning intervention, these forest stands are at high risk of collapsing (photo: Václav Pecina).*

***Figure 61**. Asian white birch stand after the intervention, in which about 1000 best individuals/ha with a straight trunk and well-formed crown were released. The trees released in this way will grow rapidly in the coming years. The stability of the whole stand will be significantly increased. The opening of the canopy in the birch stand will allow a rapid establishment of natural regeneration of the main economic tree species under the stand protection (photo: Václav Pecina).*

Figure 62. An example of high intensity precommercial thinning in young Siberian larch stand. The aim of the intervention was to release the best quality larches at the upper height of the stand of 5–7 m. Spacing of individuals is about 3–4 m. The intervention will accelerate the growth of quality individuals and will result in earlier growth of harvestable dimensions of the trunks, which will be harvested in the following commercial thinning in about 15–20 years (photo: Václav Pecina).

Figure 63. An example of structural precommercial thinning (medium intensity), in which the best quality trees were marked at a spacing of about 2–3 m and these individuals were released from competing trees in the canopy space. A useful understorey remains in the stand. Vertically structured forests are being formed (photo: Václav Pecina).

Figure 64. *An example of precommercial thinning in a young Scots pine stand (photo: Nikola Jurczková).*

Figure 65. *An example of the management of mixed forest stands. These stands often arise as a result of successional development on disturbed sites. The main principle in the management of these stands is to maintain species diversity and to positively promote high-quality economic tree species. Selection in these stands can be carried out at a higher age (photo: Václav Pecina).*

Commercial thinning

This measure can be performed in a **positive** (support to the target trees by removing of restraining individuals) or **negative** (removing of individuals of lower quality or individuals not appropriate from the viewpoint of planned forest management) selection. Commercial thinning is carried out from a trunk diameter at breast height (DBH) of 10–15 cm and the harvested wood mass can already be used economically. From the first commercial thinning, wood for poles, weak sawmill roundwood and fuelwood, for example, can be obtained. The main factors which determine the profitability of first commercial harvesting are the availability of transport equipment, **accessibility** of the terrain (Figure 66, Figure 67) and the **transport distance** to the processing site.

Figure 66. *An example of a well-accessible Scots pine forest that is ready for a medium-intensity thinning (photo: Václav Pecina).*

Figure 67. *An example of an accessible mixed (Scots pine and Asian white birch) forest that is ready for a medium-intensity thinning (photo: Václav Pecina).*

REFERENCES

Brüllhardt, M., Rotach, P., Forrester, D.I. and Bugmann, H., 2022. Sustainable regeneration in uneven-aged mixed deciduous forests managed by selection silviculture: the role of demographic structure. Forestry, 95(2), pp.201-214. https://doi.org/10.1093/forestry/cpab041.

del Campo, A.D., Otsuki, K., Serengil, Y., Blanco, J.A., Yousefpour, R. and Wei, X., 2022. A global synthesis on the effects of thinning on hydrological processes: Implications for forest management. Forest Ecology and Management, 519, p.120324. https://doi.org/10.1016/j.foreco.2022.120324.

Kang, J.S., Shibuya, M. and Shin, C.S., 2014. The effect of forest-thinning works on tree growth and forest environment. Forest science and technology, 10(1), pp.33-39. https://doi.org/10.1080/21580103.2013.821958.

Marchi, E., Picchio, R., Spinelli, R., Verani, S., Venanzi, R. and Certini, G., 2014. Environmental impact assessment of different logging methods in pine forests thinning. Ecological Engineering, 70, pp.429-436. https://doi.org/10.1016/j.ecoleng.2014.06.019.

Nyland, R.D., 2016. Silviculture: Concepts and Applications. 3rd edition. Waveland Press.

Sohn, J.A., Saha, S. and Bauhus, J., 2016. Potential of forest thinning to mitigate drought stress: A meta-analysis. Forest Ecology and Management, 380, pp.261-273. https://doi.org/10.1016/j.foreco.2016.07.046.

Škoda, A. and Pecina, V., 2024. Sustainable forest management silviculture basics: Forest regeneration, protection and tending in Mongolian light taiga forests. 1st edition. Mendel University in Brno, Brno. https://doi.org/10.11118/978-80-7509-972-3.

USDA Forest Service, 2024. Forest Service Silviculture. Available at: https://www.fs.usda.gov/forestmanagement/vegetation-management/silviculture/index.shtml (accessed 6 December 2023).

4.5 Forest Regeneration Methods

Aleš Škoda

Introduction

Forest regeneration is a key activity in achieving **sustainable forest management** (Montoro Girona et al., 2018). In well-managed forests, **harvesting** is a kind of regeneration treatment, and it is applied to mature stands in order to establish a new age class of trees on a forest land. In addition to the **principles of sustainability**, activities related to logging should also follow the Mongolian Law on Forest (Mongolian Law on Forest, 2012).

Regeneration methods usable in Mongolian high forest can be grouped by the type of forest structure after initial harvest:

a) clearcutting,

b) seed tree,

c) shelterwood and

d) selection.

Clearcutting method

The **clearcutting method** establishes a new forest stand by **complete removing of the original mature stand by one cutting**. Clearcutting causes sudden environmental changes with resulting extreme conditions and intensified permafrost melting. The nature of the changes and their extent is strongly site-specific, especially influenced by the water regime of the site and its microclimatic parameters (Dymov, 2017). However, the method is a cheap and relatively easy and fast way of new stand establishment. In addition, it follows the natural large-scale disturbances inherent to boreal forests and light-demanding light taiga species such as *Larix sibirica* and *Pinus sylvestris*. In a sustainable forestry system, the size of clearings must be limited to mitigate extreme conditions and simplify forest regeneration. Following new even-aged stand establishment can be done artificially or from seeds germinating after clearing operations. A suitable measure supporting natural regeneration is a soil scarification by rotary tillers or appropriate ploughs (Figure 68). If the natural regeneration of a forest is not successful, an artificial one must be used (Figure 69).

Figure 68. *Scarification of soil in places with open canopy space. Soil surface is already covered with dense herbaceous vegetation. Rapid development of natural regeneration is impossible without natural or mechanical disturbance of soil surface (photo: Václav Pecina).*

Figure 69. *If natural regeneration does not occur, or if the mother trees are distant from the site of the groves, it is necessary to use artificial reforestation and to plant tree seedlings evenly throughout the area (photo: Nikola Jurczková).*

Seed tree method

The **seed tree method** is based on the **removal of the mature stand in one cutting event** similarly as in the case of the clearcutting method. The difference is that with this method, **several seed (mother) trees remain** after cutting to provide seeds for natural regeneration (Figure 70). The remaining seed trees must be genetically superior trees of the selected species able to survive exposure and wind and produce enough seeds. In addition to larch, this method can also be suitable, for example, for various pine species to obtain successful natural regeneration (Rodríguez-García et al., 2010). Also in this case, the success rate of natural regeneration in boreal (taiga) forests can be significantly increased by soil scarification (Montoro Girona et al., 2018).

Figure 70*. An example of pine tree left in the clearing (unstocked area) after logging (photo: Aleš Škoda).*

Shelterwood method

The **shelterwood method** is removal of the original mature stand in a **series of cuttings which extend over a relatively short time**, by means of which the establishment of the first generation of regeneration under the partial shelter of remaining trees is encouraged.

This method involves the removal of the majority of the original mature stand at the end of the **rotation**, but a part of the mature stand is left. It is a suitable method for taiga forests as a viable silvicultural alternative to clearcutting (Montoro Girona et al., 2018).

This method involves four basic phases:

1. ***Preparatory phase*** – the first cutting; it is carried out at the age of 60–80 years. Stand density is reduced in the canopy by 30%. Removing non-vital trees and trees of unwanted species and poor quality (Figure 71).
2. ***Seed phase*** – this cut is made when the trees are 80–100 years old. Good quality and well-fruiting trees remain in the stand, the canopy cover is about 50%. This phase can be combined with the preparation phase for light-demanding tree species (*Pinus sylvestris, Larix sibirica*).
3. ***First removal*** – when a dense "carpet" of new seedlings has become established (Figure 72), about 50% of remaining trees are removed. This creates suitable light conditions required for seedlings growth and development.
4. ***Final removal*** – most of the remaining mature trees are removed to release the young trees that have become established.

Figure 71*. Forest stand after preparatory cutting (photo: Antonín Kusbach).*

Figure 72. Forest stand after establishment cutting with mature trees and dense natural regeneration (photo: Antonín Kusbach).

Selection method

The **selection method** is **continual maintenance of uneven-aged forest stands** by means of occasional replacement of single trees or their small groups (Figure 73), usually throughout natural regeneration following selective cutting. Cutting is focused on mature trees at relatively short intervals. This method should not significantly alter the species composition of logged stands. Soil disturbances caused during selective cutting by this method can enhance natural understory regeneration (Noguchi and Yoshida, 2007).

The selection method simulates natural conditions in a **small development cycle** and continuously provides forest functions. Therefore, it can be considered close-to-nature with minimal impacts on the forest ecosystem. However, it is an expensive and difficult method requiring skilled workers and adequate logging technology and mechanization. Due to the permanent canopy cover, natural regeneration of shade-tolerant species is at an advantage over shade-intolerant species (Brüllhardt et al., 2022). This makes the method more suitable for shade-tolerant dark taiga (Figure 74) species such as *Abies sibirica*, *Picea obovata*, and possibly *Pinus sibirica*.

Figure 73. *A view of a part of the multi-level creative forest with selective forms of management (photo: Aleš Škoda).*

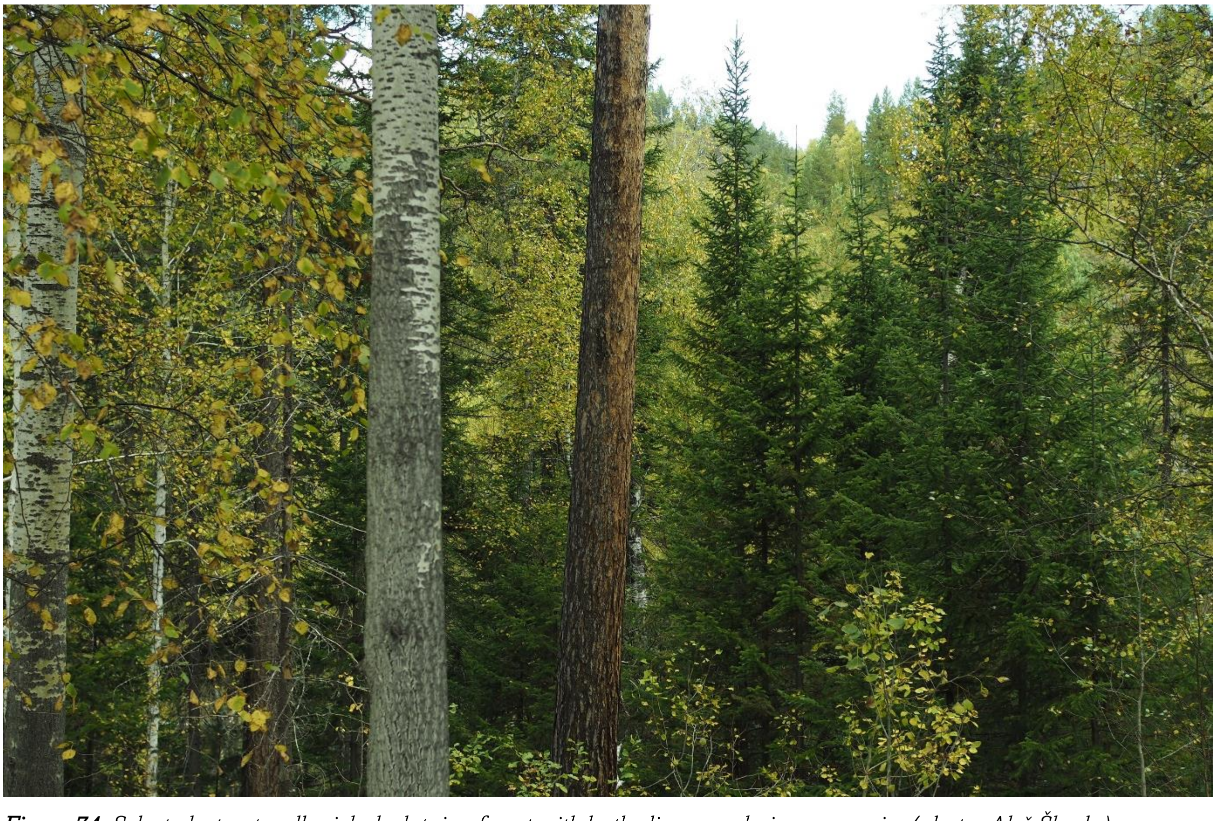


Figure 74. *Selected, structurally rich dark taiga forest with both climax and pioneer species (photo: Aleš Škoda).*

REFERENCES

Brüllhardt, M., Rotach, P., Forrester, D.I. and Bugmann, H., 2022. Sustainable regeneration in uneven-aged mixed deciduous forests managed by selection silviculture: the role of demographic structure. Forestry, 95(2), pp.201-214. https://doi.org/10.1093/forestry/cpab041.

Dymov, A.A., 2017. The impact of clearcutting in boreal forests of Russia on soils: a review. Eurasian Soil Science, 50, pp.780-790. https://doi.org/10.1134/S106422931707002X.

Mongolian Law on Forest. Ministry of Environment and Green Development of Mongolia. A revised version. Government Bulletin No 22. Published on May 17, 2012, Ulaanbaatar. Available at: https://legalinfo.mn/mn/detail/15624.

Montoro Girona, M., Lussier, J.M., Morin, H. and Thiffault, N., 2018. Conifer regeneration after experimental shelterwood and seed-tree treatments in boreal forests: finding silvicultural alternatives. Frontiers in Plant Science, 9, p.1145. https://doi.org/10.3389/fpls.2018.01145.

Noguchi, M. and Yoshida, T., 2007. Regeneration responses influenced by single-tree selection harvesting in a mixed-species tree community in northern Japan. Canadian journal of forest research, 37(9), pp.1554-1562. https://doi.org/10.1139/X07-103.

Rodríguez-García, E., Juez, L. and Bravo, F., 2010. Environmental influences on post-harvest natural regeneration of Pinus pinaster Ait. in Mediterranean forest stands submitted to the seed-tree selection method. European journal of forest research, 129, pp.1119-1128. https://doi.org/10.1007/s10342-010-0399-7.

FOREST TECHNOLOGY

5. FOREST TECHNOLOGY

5.1 Technologies for Forest Tending and Logging

Tomáš Zemánek

Introduction

Technologies and machinery in the forestry sector are insufficiently developed and implemented in Mongolia. Basically, they are focused only on felling trees. However, this approach is wasteful, unprofitable and unsustainable. Implementation of new technologies in tending and logging therefore represents a necessary part of the development of the sector.

Machines for cleaning or precommercial thinning

Tending of young stands by precommercial thinning (juvenile thinning) or cleaning is considerably important for achieving target species and spatial stand composition and elimination of low-grade, dead and sick individuals. The aim is to create preconditions for enhanced timber quality and stand stability in its further development. In terms of technology, cleaning or precommercial thinning is the removal of young trees by felling. The product can be felled young trees left in whole lengths or cross-cut and chipped young trees. However, high harvesting costs are a critical problem in first thinning. Therefore, the search and use of machines with lower operating costs can be a potential solution towards cost-efficiency (Kärhä et al., 2004).

Manual tools for precommercial thinning are appropriate in moderately sized stands of lower diameters. Tools whose performance can be compared with mechanized means are pulling knives on the handle, choppers, machetes and hand saws of various designs. Their use takes into account stem diameter at the cutting point, which should not be of more than 2.5–3.5 cm in pulling knives and 2.5–4.5 cm in choppers and machetes. Strangulation saws with the flexible multi-cut saw chain represent a special type of tool. Stem surface is cut through and water-conducting tissues are broken off (strangulation cut) as a result of pulling on the handrails of chain wrapped around the stem. Performance is about one tree per minute. Although the tree dies after the treatment, it acts supportively to adjacent trees in the stand before it perishes.

Portable means of mechanization for precommercial thinning most widely used nowadays are **power saws** and brush cutters. With respect to material dimensions and character of work in cleaning operations, it is advised to use power saws of lower performance classes with a short saw blade: saws of up to 7 kg, engine capacity of up to 60 cm^3 and performance of up to 2.6 kW.

Brush cutters are portable machines used for more purposes such as the mowing of herbaceous vegetation, elimination of undesirable advance growth of both herbaceous and shrubby vegetation (weeding) (Figure 75) and felling of trees. The brush cutter normally forms a rigid unit which is carried at work on the operator's side, hung on straps. Some types have the engine part coupled with the protective tube via a flexible shaft (bowden), the engine is carried on the operator's back and the tube is held by the handles.

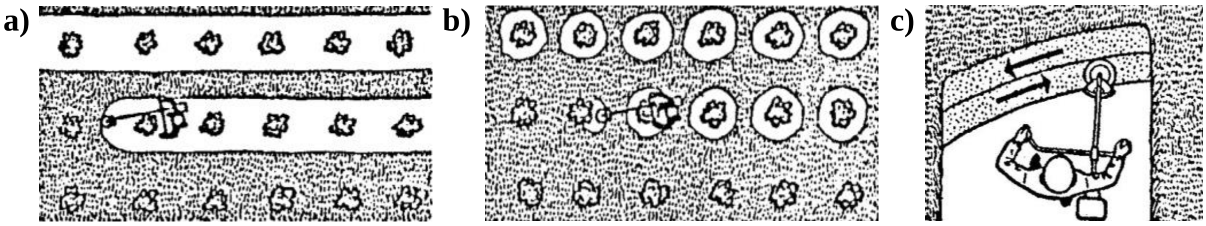


Figure 75. Mowing (weeding) with a brush cutter: a) strip mowing, b) mowing of spots and c) whole-area mowing (authors: Department of Engineering, Faculty of Forestry and Wood Technology (FFWT), Mendel University in Brno (MENDELU)).

Working tools of brush cutters are divided into three groups:

- Cutting tools for soft herbaceous vegetation (cord mowing heads, plastic cutting bodies, metal knives with 2, 3, 4 and 8 blades) (Figure 76a, b).
- Cutting tools (saw blades) for felling trees of up to 100 mm in diameter on stump (Figure 76c).
- Other working tools (herbicide applicators, adapters for soil preparation, pruning, etc.).

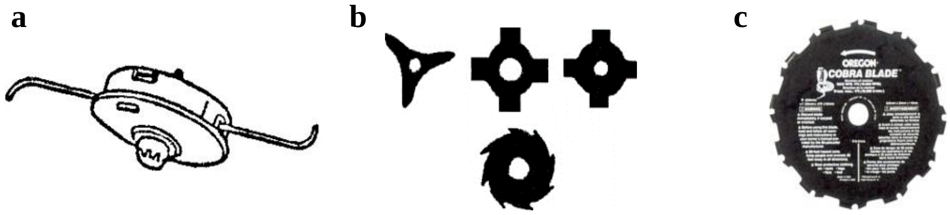


Figure 76. Working tools of brush cutters: a) cord mowing head, b) tools for soft weeds and c) saw blade (authors: Department of Engineering, FFWT MENDELU).

At felling, blade diameter must be taken into account: blades appropriate for felling trees of up to 30 mm in diameter are those with a diameter of 200 mm; blades appropriate for trees of larger diameters have diameters of min. 225 mm; however, these can be used only on brush cutters with engine capacities of over 35 cm^3.

The method of working with the brush cutter during felling depends mainly on the thickness of the trees at the place of cutting. When cutting, different parts of the disc circumference can be used, depending on which side the fall of the tree should be directed (Figure 77). Trees of over 60 mm are felled with a brush cutter in two cuts, with the first cut serving as a directional cut, the second cut being similar to the main cut. When working, the engine of the brush cutter must work at a maximum speed.

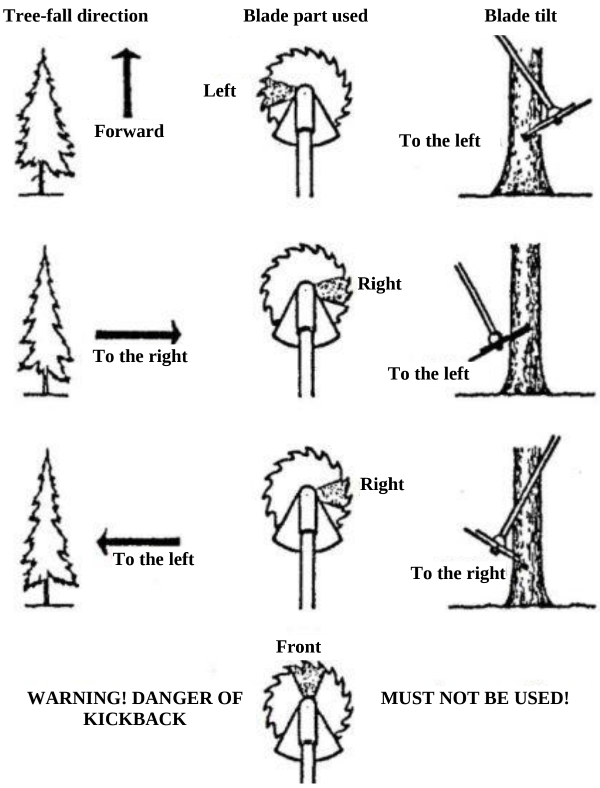


Figure 77. Directional tree felling with a brush cutter (authors: Department of Engineering, FFWT MENDELU).

Machines for tree pruning

Pruning in premature stands is a silvicultural measure implemented in order to achieve a greater share of valuable assortments and higher value of production. However, it may also have other objectives (collection of decorative slash, enhancement of passable road profile). Pruning is profitable only at good sites; in stands endangered by wind and snow, investment into pruning is risky and in stands infested by rots it is useless. On the other hand, early and intense pruning can be an effective component of the management system, for example, in larch stands (Takiya et al., 2010). In areas endangered by deer barking, pruned trees must be protected against bark scaling.

On average, the number of trees selected for pruning is 200–300 individuals/ha with a diameter at breast height (DBH) of about 12–15 cm so that the target DBH is at least a triple of DBH at the beginning of pruning. The pruning should ideally start at a diameter of branches of up to 2 cm so that the cut is quickly healed. The cut must be clean, smooth and close to the trunk, stubs after branches must not be left behind (Figure 78). Pruning can be made by hand tools, motor-manual machines and machines (Figure 79).

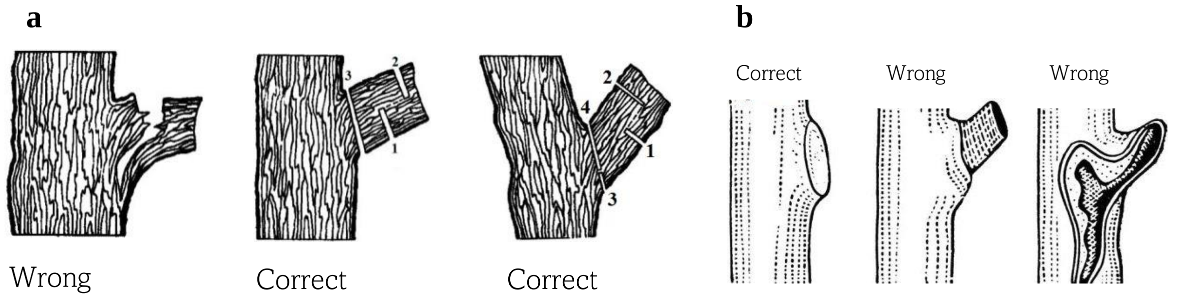


Figure 78. a) Cutting off large-diameter branches (the sequence of cuts is indicated by a number) and b) results of pruning (authors: Department of Engineering, FFWT MENDELU).

Hand tools for pruning include frame saws, hacksaws, or special V-shaped twin saws with internal teeth (shark jaw). Manual scissors and disc blades are manufactured, too. Working tools for pruning are placed on a handle several meters long (even telescopic) allowing to cut branches at heights. Pruning saws have fine teeth (for smooth cut) and they are operated similarly as saws on short handles. In addition to working from the ground, pruning can be carried out from ladders and retractable platforms.

Motor-manual machines are designed as pneumatic or hydraulic scissors; chain, linear or circular saws fixed on telescopic rods; climbing chain saws and climbing knife branch trimmers.

Pruning chain saws are placed on telescopic tubes up to 6 m long, blade length is 200–300 mm, and they are usually driven mechanically by an engine via a PTO shaft similarly as in brush cutters, with the engine and PTO shaft forming one unit together with the tube.

Climbing chain saws consist of a tubular frame with folding arms, on which 4 drive wheels and 4 guide tire wheel or belt traction device are attached. The cutting part is a chain blade or delimbing knives. The arc-shaped knives copy the trunk surface. The saw is powered by an internal combustion engine or an electric motor. At work, the saw is put on the trunk along which it proceeds in spiral or rectilinear motion to a set-up height while tree branches are being cut off. The diameter of cut-off branches is 50 mm. Compared with manual work; the machine output is about three- to four-times higher.

Pruning is a good **investment into future**. Nevertheless, a considerable delay in its benefits from the time when the pruning measure is implemented and the costs incurred are challenges that discourage many foresters.

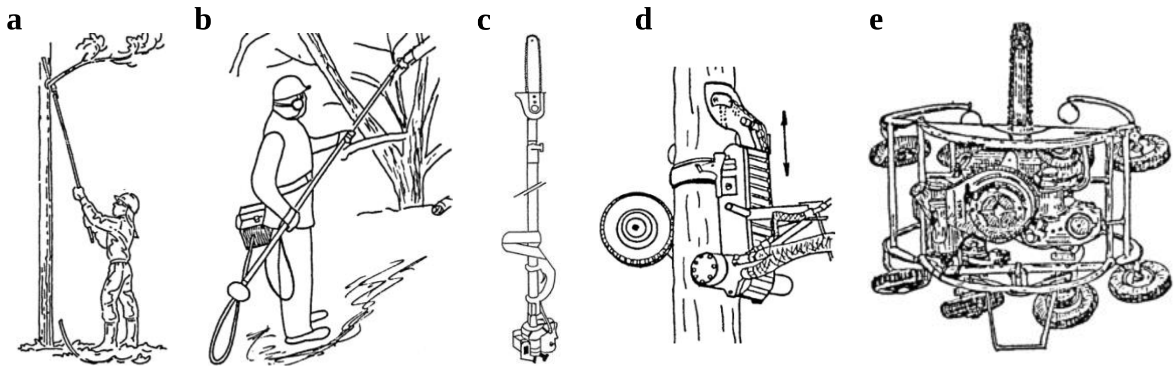


Figure 79. Machines for pruning: a) Hand-held pruning saw, b) Husqvarna Highcutter PS 50, c) Oregon Power Pruner, d) Climbing hydraulic delimbing unit Baumhexe and e) Climbing saw KS 31 (authors: Department of Engineering, FFWT MENDELU).

Machines for timber logging

Timber logging is the forestry term including the preparation of logging activities, felling and delimbing of trees, and log-making in the stand or at a timber yard. The form of timber was taken as a basis for the systematics of logging methods, in which the raw timber is transported to the roadside landing. According to this criterion, three basic logging methods can be distinguished: assortment method, whole stem method and whole tree method.

Timber logging technologies differ in their proportion of manual and machine work, according to which they are divided into manual (manual work), moto-manual (using hand-held machines – power saws and brush cutters) and mechanized (using machines). Fully mechanized technologies are those in which the human hand does not touch the produced wood (using felling machines, processors and harvesters), and partly mechanized technologies are those in which a certain share of manual work is necessary.

Moto-manual logging implements – power chain saws

The **power chain saw** is the most widely used implement in logging. The predominant type of drive-in power saws is a combustion, ignition two-stroke engine whose crank shaft is directly (without transmission) coupled with the driving mechanism of the saw chain through the centrifugal automatic clutch. Depending on the nature of the work, it is possible to choose chainsaws from several classes (Table 4).

Table 4. Division of saws into classes according to weight and engine performance.

Class	Weight (kg)	Displacement (cm^3)	Engine power (kW)
I. very light	4–5	30–40	1.1–1.9
II. light	6–7	50–60	1.9–2.6
III. moderate	8–10	60–80	2.6–3.4
IV. heavy	11–12	90–100	3.7–4.8
V. very heavy	>13	120–140	5.2–6.6

When felling trees with a chainsaw, several steps must be followed:

1) Determining the direction of the tree's fall.
2) Adaptation of the workplace.
3) Adjustment of the lower part of the trunk.
4) Felling a tree: making a notch, performing the main cut, deflecting the tree in the direction of fall, adjusting the front of the trunk, or the stump.
5) After felling a tree, it is usually followed by its delimbing and cross cutting into logs.

The procedures for working with a chainsaw in Mongolian conditions have already been described in detail by Bayartsetseg et al. (2018).

Fully mechanized logging technologies

Main reasons for their development are high performance, improved safety and ergonomics of work, reduced dependence of logging on climatic conditions, and in the case of correct deployment of machines and correct working procedures also friendliness to the environment.

The cost-effectiveness of introducing fully mechanized logging technologies in the forestry practice represents another important reason. At the same time, however, they impose high requirements on work preparation, management and organization both for the suppliers of logging works and the contracting authorities.

Harvesters are multi-operational machines intended for work in the forest, which can fell, cross-cut, delimb, cube and register in one work cycle (Figure 80). According to their design parameters, they are designed for a wide spectrum of conditions from thinning, through main felling up to calamities. Harvesters are deployed in the line system of production, and together with forwarders or tractor and trailer units they create the so-called harvester nodes.

***Figure 80**. Wheeled harvester and forwarder John Deere (photo: John Deere Forestry).*

Harvesters can be effectively and cheaply used for **thinning** (Sirén and Aaltio, 2003). The skidding line must be felled first. The trees on it must be delimbed so that the carriageway can be covered with slash to protect the soil. The tree buttresses and easy to damage roots must be overlaid with cut branches by means of a harvester head. The skidding line width should be about 3.5–4.0 m (Figure 81). The trunks are processed on the skidding line. The trees can be felled alternately on the right and left side. Prior to felling, grading of logs should be considered as well as their subsequent loading on the forwarder (Figure 80).

Harvesters can also be used in the **main felling**. A principle in the regeneration felling (if the terrain allows) is to harvest and process a strip 8–12 m wide in one travel. In the main felling, mostly conventional felling on both sides is used (Figure 82), which avoids useless movements of hydraulic crane. In this method, logging residues remain on the hauling line and enhance its bearing capacity. Felling in one direction can be used, for example, in high density stands. In addition, it can be used in the presence of natural regeneration, exclosures, power lines or with the prevailing unfavourable wind direction.

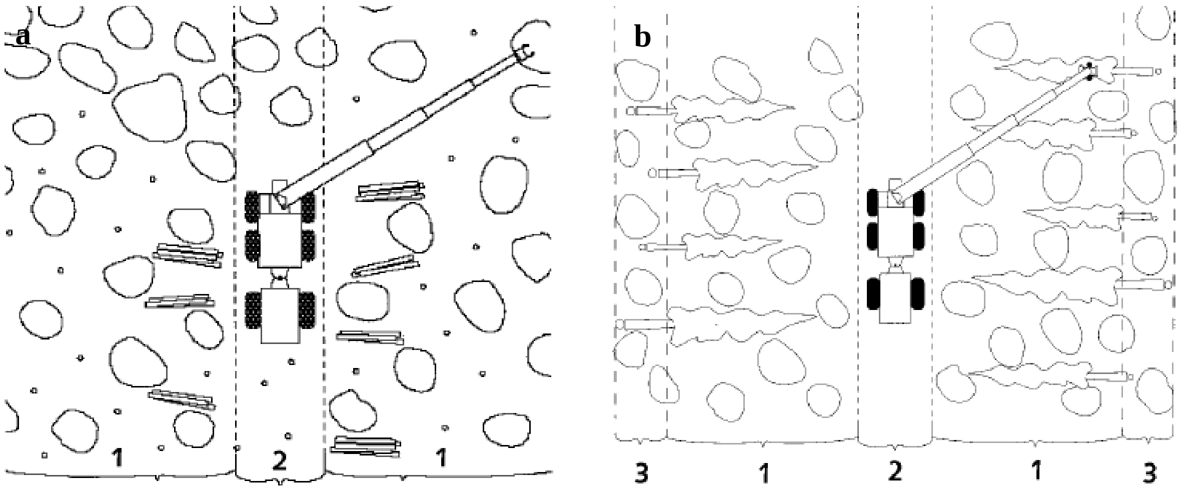


Figure 81. Work procedure at thinning a) by a harvester where 1) means hydraulic boom reach and 2) means line width 3.5–4.0 m and b) by a harvester and a power saw where 1) means harvester reach, 2) means line width 4.0 m and 3) means an area of manual logging (authors: John Deere Forestry).

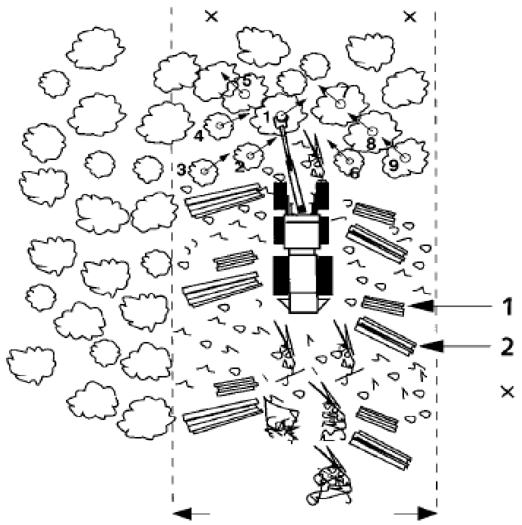


Figure 82. Bidirectional felling with a harvester in main felling where: 1) means pulpwood and 2) means roundwood (authors: John Deere Forestry).

A processor is a machine that is unable to fell but can delimb and cross-cut felled trees (Figure 83). Boom processors carry the processor unit "on them", in which the boom with grapples serves only for the insertion of trees into the processor unit. There are two manual operations needed in processing a tree: guiding the grapples to the butt of the felled tree and its gripping, and then the insertion of the tree butt into the delimbing and cross-cutting device.

***Figure 83**. Two-phase processor (photo: HYPRO).*

REFERENCES

Bayartsetseg, B., Chuluuntsetseg, D., Ganzorig, B. and Gerelbaatar S., 2018. The Forestry Professional: A Handbook (Ойн мэргэжлийн ажилтан: Гарын авлага). UB BCI (УБ Би Си Ай), Ulaanbaatar. (In Mongolian).

Kärhä, K., Rönkkö, E. and Gumse, S.I., 2004. Productivity and cutting costs of thinning harvesters. International Journal of Forest Engineering, 15(2), pp.43-56. https://doi.org/10.1080/14942119.2004.10702496.

Sirén, M. and Aaltio, H., 2003. Productivity and costs of thinning harvesters and harvester-forwarders. International Journal of Forest Engineering, 14(1), pp.39-48. https://doi.org/10.1080/14942119.2003.10702468.

Takiya, M., Koyama, H., Umeki, K., Yasaka, M., Ohno, Y., Watanabe, I. and Terazawa, K., 2010. The effects of early and intense pruning on light penetration, tree growth, and epicormic shoot dynamics in a young hybrid larch stand. Journal of forest research, 15(3), pp.149-160. https://doi.org/10.1007/s10310-009-0167-z.

5.2 Technologies for Timber Transportation

Tomáš Zemánek

Introduction

Logging operations are followed by **timber transportation**. In Mongolia, this is a critical factor with regard to the absence of appropriate technologies, machinery, and a sufficient road network. In addition to skidding, timber transportation from forests to sawmills is challenging. Currently, there is a need to find and introduce acceptable technologies adapted to local conditions. In view of the challenges and threats associated with logging and skidding such as soil compaction (Jamshidi et al., 2008; Zemánek and Neruda, 2021) and rut formation (Toivio et al., 2017), it is also necessary to observe the restrictions set by the law (Mongolian Law on Forest, 2012).

Systematics of timber skidding

Each method of timber skidding is characterized by a certain level of productivity, culture, occupational safety and hygiene, with the sorting character being the share of manual and animal work according to which the following are distinguished:

1) manual timber skidding
2) gravitational timber skidding
3) animal timber skidding
4) mechanized timber skidding

Mechanized timber skidding can be further divided into:

- Integrated mechanized (chokerless) timber skidding, implemented without the touch of a human hand using truck-and-trailer units and forwarders when the load is assembled by the hydraulic crane equipped with a grapple or by tractors with claw grapples.
- Partly mechanized (choker) timber skidding with a share of manual work at pulling the winch cable into the forest stand and tying of chokers.

Considering the environmental conditions of Mongolia, **gravitational** and **mechanized** timber skidding in particular have great potential for development.

Gravitational timber skidding

Modern facilities for gravitational log sliding are **mobile chutes** made of metal sheet or plastic material (Figure 84). They are referred to as "Log-Lines" although the name was originally used as a type designation of one specific product. Chute sections are shaped as troughs and are 5 m long, with an inner diameter of 350 mm. They are mutually connected by stainless steel screws or wedge clips. In the terrain, the assembled track is fixed by ropes and anchor pins to trees and stumps. The lower end of the track is somewhat lifted to create space for the slid timber and thus to prevent discontinuation of sliding due to insufficient capacity of the deck. On the deck, the timber accumulates chaotically and hand tools are used in order to reduce the risk of injuries (hookaroons, wood cutter's pliers and hooks).

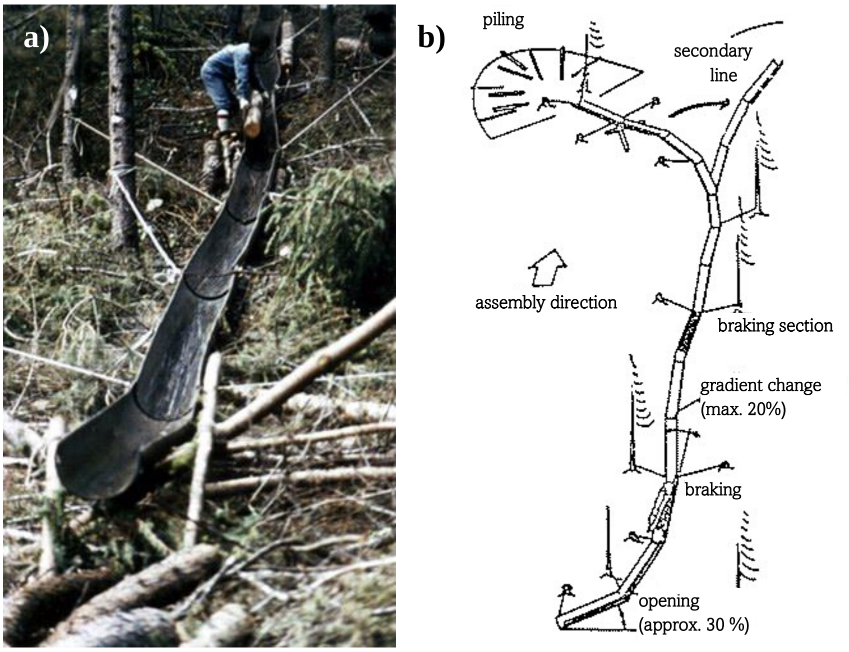


Figure 84. a) Log-Line and b) mobile trough chute Log Line (authors: Department of Engineering, FFWT MENDELU).

The optimum track gradient when transporting timber in bark is 25–35%; with the use of braking sections, the possible gradient is up to 60%. Track length is unlimited, but the usual length is 150–200 m. The possibility of smaller direction deflections in assembling the sections allows mild directional turns. Working field width is 35–50 m in the continual working method (felling, delimbing, cross-cutting, piling, sliding) and can increase to 60 m when the logs are brought to the chute track before the chute installation; the disadvantage is that the timber must be handled by hand twice. The width of lane for the chute track is up to 2 m. The harvested timber is brought to the track along the contour; this is why the size of timber is limited by its physical maneuverability. Theoretically, transported logs can be up to 6 m long and up to 32 cm wide.

Chutes are recommended at sites where they can be an alternative to cableway or manual piling. The advantage of trough chutes is their suitability for regions with unqualified labour force, practical indestructibility, minimum maintenance, unnecessary spare parts, zero fuel consumption, minimum dependence on weather and environment-friendly operation.

Mechanized ground-based timber skidding

Small machines for timber skidding

Recently, interest in **small production technologies** became more popular. They combine motor-manual procedures (Figure 85) and machines of lower performance usable for lower work volumes, often in terrains with difficult access (low bearing capacity, steep slope). The machines can be used in improvement felling, only exceptionally in main felling assuming that volumes of produced logs can be managed by the limit traction power of these machines. Their operating costs are low, and they are environmentally friendly. For example, in the production of cross-cut timber, the danger of damage to trees by dragged timber is reduced.

Wheeled and tracked self-propelled winches extract timber in improvement felling to the line (bundling, bunching); some of them can skid timber by dragging. Traction of winch is 30 kN, cable Ø 8.0 mm and winding speed 0.3 m/s. A version with the two-drum winch is also supplied to create a simple cable system. Both the winch and the machine have a remote control. Its travel speed is 4 km/h. The machine can skid both long and short assortments, max. volume of towed log is 1 m^3.

Figure 85. A small skidding tracked machine MK-18 and its use (photos: Engineering Blatná s.r.o.).

Tractors and prime movers for choker timber skidding

Tractors and prime movers (**skidders**) have the dominant position in ground-based timber skidding (Shegelman et al., 2019). They primarily operate in tractor terrains (slope up to 40%). Tractors are used at choker timber skidding for primary extraction of timber by a winch cable from working fields, for dragging timber load by a tractor (skidding) and for work on timber landings (grading, decking). Other uses for tractors in logging are power stations of cable transport installations or basic machines of some timber transport units.

Tractors for ground-based choker timber skidding must have special equipment which allows the use of classic **farm tractors**. This can be an effective and relatively cheap option for Mongolian conditions. The modification of a farm tractor for timber skidding has two levels: A) **professional completion** (Figure 86a) or B) **farm equipment** (Figure 86b).

A) Professional completion

It is farm tractor reconstruction into a special forest machine for timber skidding after which the machine is unable to perform farm and other works without rebuilding. The advantage is complete tractor equipment with components needed for skidding (a winch – usually remote controlled; a complete skidder shield, a pusher) as well as the fact that the winch is situated as close to the rear axle as possible, by which a shift of gravity centre towards the rear axle due to loading with the winch and the towed burden is minimized. The modification of a farm tractor for use as a forest tractor should further include:

- Modification of an engine vat by fitting it with a deeper sump for lubrication oil (to ensure engine lubrication when working on slopes).
- Selection of proper transmission – 2 × 4 (5) gears are enough, at the best with a reverse and drive inverter.
- Undercarriage protected with a vat and reinforced, wheel rims should be reinforced with a steel bar welded along the circumference and the valve should be protected by steel cover.
- The cab should meet international standards: ROPS Protection at tractor overturning, FOPS – Protection against a falling object, and OPS – Protection against penetration of objects from sides.

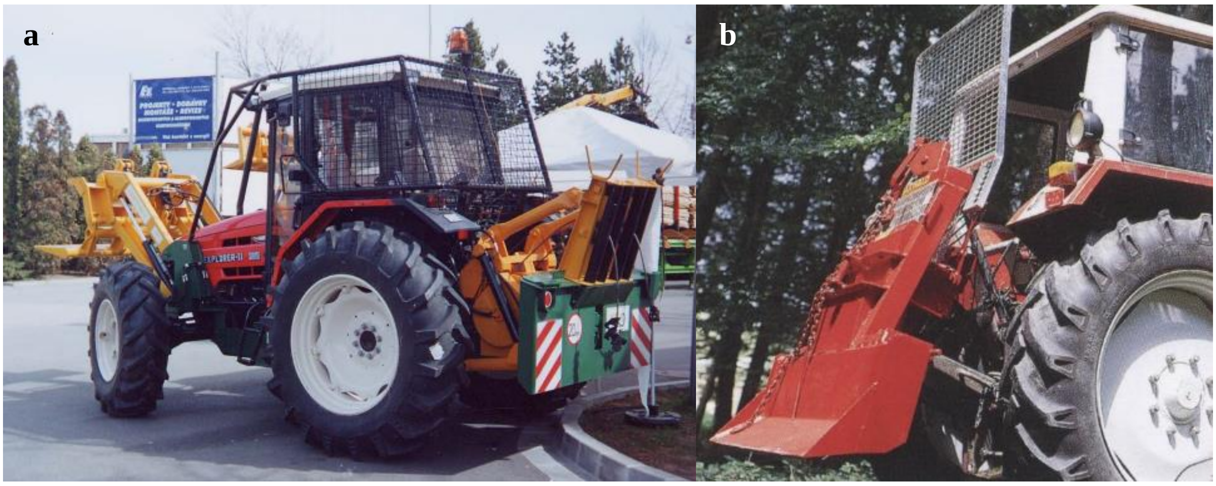


Figure 86. Different levels of equipment for skidding by farm tractors: a) professional completion and b) farm equipment (photos: Department of Engineering, FFWT MENDELU).

B) Farm equipment

Farm equipment of a farm tractor is simple, fast to mount and dismount by a winch suspended on the three-point linkage of hydraulics, i.e. the tractor is not blocked by logging equipment for other purposes. A winch is usually a one-drum type, with lower traction, without remote control (or with a simple control by a stranded wire only), and usually forms one whole with the skidder shield and protective net. A tractor is usually not equipped with a pusher, reinforced undercarriage, or complementary protective elements in the cab. Winch suspension on the 3-point linkage shifts the machine gravity centre backwards, which becomes even more evident with the load; this is how the relieved front axle may result in lost controllability of the machine. Load capacity of rear axle is by 30% lower than in the professional completion (load weight must be proportionally lower), and thus the efficiency of a farm tractor with farm equipment is lower in comparable conditions than that of professional completion. A positive parameter of a farm tractor with the farm equipment is the purchasing price which is considerably lower than that of professional completion.

The key element of this type of skidding are **chokers.** Chokers serve to tie the load (tree, trunk, log) and to attach it to the winch drag line. There are three basic types of chokers: cable and chain chokers are used to drag timber, and textile chokers are used for low-damage fastening of directional pulleys on standing trees.

Cable chokers (Figure 87a) are useful in conditions when the choker is permanently pulled to prevent its release and slipping from the trunk. Permanent tension of chokers can be best ensured by skidding in semi-suspension or up the slope in favourable terrain conditions (chokers are loosened by load hitting against obstacles), on non-abrasive grounds and dragged over shorter distances. A sufficient choker length for thinning is 1 m, a choker length of 1.5–2 m is used for main felling. On one end of the choker, there is usually a hook, sliding hook or cylindrical sleeve; on the other end, there is a spliced eye, metal eye, etc. so that a self-locking loop can be created for fastening the load. Chokers with the cylindrical sleeve are provided with a sliding block (Figure 87b) into which the sleeve is slid, and they are used in the method of choker line.

Chain chokers (Figure 87c) are heavier than cable chokers but can be used in stony terrains, on tracks with counter-gradients (do not tend to loosen) and over larger distances. On one end of the chain choker, there is an eye, on the other end, there is a hook or a profiled eye which is narrowed on one end to at least the length of chain width. The profiled eye is usually slid on the terminal eye. Length/weight of chokers is 1.6 m/3.5 kg; 2.0 m/4.2 kg; 2.5 m/5.1 kg. The advantages of chain chokers include the tight gripping of the trunk (with the chain link slotting into the profiled eye so that the choker cannot slip even at released tension), they can be simply shortened using a profiled eye or a hole on the sulky or tractor and at skidding down the slope the chain chokers act as brakes.

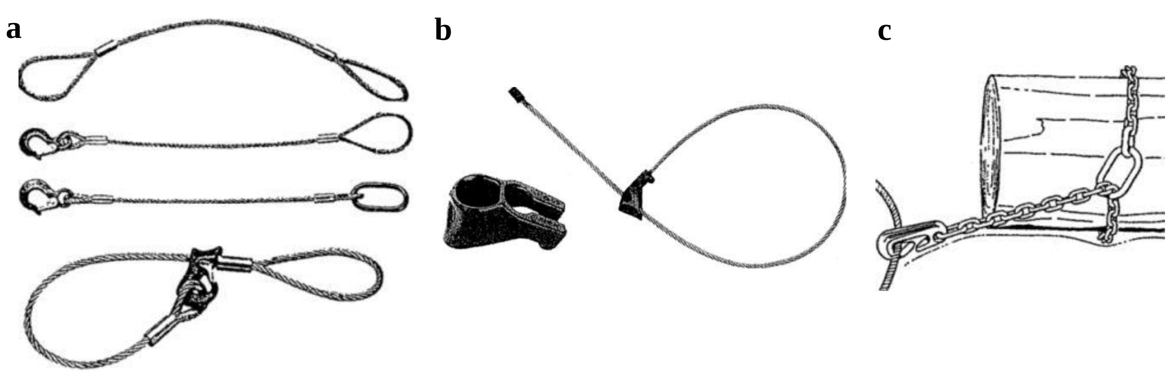


Figure 87. Chokers: a) different types of cable chokers, b) a cable choker with a cylindrical sleeve and sliding buckle and c) chain choker (authors: Department of Engineering, FFWT MENDELU).

Textile chokers (Figure 88) are made from an endless bundle of high-strength polyester or another type of fibre, enclosed in protective cover. They are light; their load capacity is high;

the range of working temperatures is wide (from -40 to +100 °C); they protect the surface of trees onto which they are fastened; they are supplied as endless or with eyes; their basic load capacity is 500–30,000 kg and can be increased by the mode of binding (simple, loop, parallel – twinned). The length of an endless choker = circumference; commonly supplied lengths are 1.0 m, 2.0 m, 3.0 m to 20 m. The load capacity of chokers is expressed by colour and inscription on the choker packaging. They are useful for fastening pulleys and guy lines of cable transport installations onto trees, however, inappropriate for dragging timber.

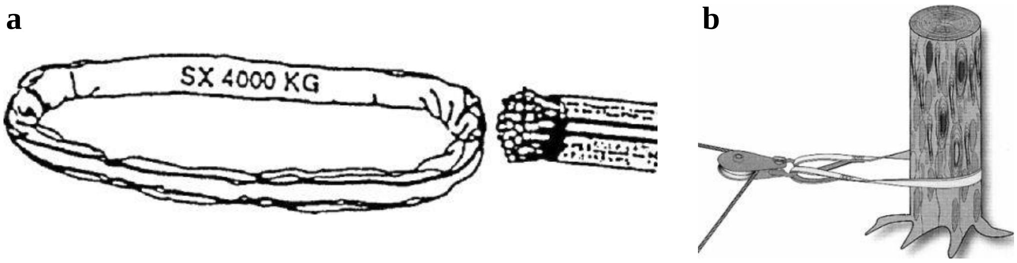


Figure 88. a) A textile choker and b) its use at binding a directional pulley onto the tree (authors: Department of Engineering, FFWT MENDELU).

The way of **tying chokers** (Figure 89) depends on the technological and work procedure used and to some extent also on local traditions. Chokers are fastened approx. 0.5 m from the stem (log) end. Tying on the swing bearing is used for avoiding obstacles and rolling onto decks. The number of simultaneously skidded stems (logs) is limited by friendliness to the standing stand and by the stem volume of timber skidded (by pulling force).

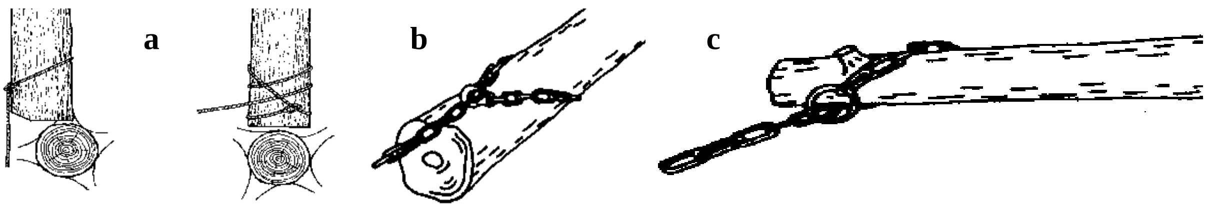


Figure 89. Ways of tying chokers: a) choker „ on the swing bearing " at avoiding an obstacle, b) simple loop and c) choker secured with a branch stub (authors: Department of Engineering, FFWT MENDELU).

<u>**Machines for chokerless skidding of timber by dragging**</u>

The main principle of chokerless timber skidding by dragging is grabbing and gripping timber by a tongs-shaped tool that may be a **grapple** (Figure 90a) or a **clam bunk** (Figure 90b). Both are equipped with hydraulically controlled **jaws** which grip the timber. A difference between them is in the position of jaws that point downwards in the grapple and upwards in the clam bunk. Directional felling is an important factor in efficient chokerless timber skidding; in the case of bundling, another important factor is the placement of stems with butt ends in the skidding direction, on sides of the line, in longitudinal or slightly slant position. The disadvantages of this skidding method include travelling across the whole logging site as the tractor with the boom has to travel to each piece and worse usability in challenging terrains. The advantage can be higher work performance, as the worker does not leave the cabin.

Figure 90. Skidder with a) a grapple and b) a clam bunk (photos: John Deere Forestry and HSM).

<u>Timber forwarding machines</u>

At **forwarding**, the load of timber dwells on the cargo area of the machine, placed between the stanchions. Timber is extracted from the stand by the hydraulic boom within a distance given by its reach (6–10 m), and the load is assembled continually onto the cargo area. Benefits of skidding timber by forwarding include reduced physical effort of workers as compared with the binding of chokers, lower dependence on the weather, elimination of some unpleasant operations (e.g. tying and untying of chokers in mud or snow), reduced risk of injuries (most accidents happen at choker skidding of timber by a damaged – frayed rope); increased daily performance of workers and the soil surface does not get disturbed by log butt ends. As to customer-supplier relations, it is important that timber is not being damaged or polluted by dragging on the ground. The disadvantage of the forwarding units and forwarders is their limited employment in difficult field conditions and a higher purchase price.

The semantic difference between the tractor and trailer unit (timber transport unit) (Figure 91a) and the forwarder (Figure 91b) is of essential character as it directly relates to the technological possibilities of these machines. **The forwarder** is a special compact machine determined for timber loading, forwarding and stacking; it consists of an engine part and a cargo part, which are on two semi-frames connected by a joint (axial or central); machine control is articulated by means of a hydraulic system, all wheels are driven and load carrying capacity is usually markedly higher than that of tractor and trailer units. **The tractor and trailer** are two separate units connected by a temporary connection; each can be used separately for different purposes. Simple units have a tractor and a trailer coupled with a firm shaft, a drive of trailer wheels is not available, or there is only a hydraulically driven pinion between the wheels of a double (bogie) axle. More advanced trailer designs include hydraulically articulated shafts facilitating and improving the guidance of the trailer by the tractor when driving (reversing). In favourable conditions, they can be a purposeful alternative (the purchasing cost lower by up to 50%) to forwarders, and their performance in favourable conditions can be up to 90% of that of forwarders (this is however not the rule). Annual timber volume forwarded by tractor and trailer units is 2,000–8,000 m^3.

Figure 91*. Timber forwarding machines: a) tractor and trailer unit and b) forwarder (photos: AGAMA a.s. and Rottne).*

Timber skidding by cable transport installations

The foundation machine of **cable transport installations** (CTIs), their drive station, does not drive into the stand (logging site); this is why CTIs are used even where steep slopes, terrain obstacles, and grounds of low bearing capacity do not allow ground-based timber yarding. CTIs do not require such a dense forest road pattern as yarding by tractors, which results in lower (i) disturbance to the geomorphology of the area and (ii) removal of timber land from production. CTI advantage is friendliness to the transported timber as well as to the environment – the soil is not compacted and the soil surface disturbance is reduced (Harrill et al., 2019). The scope and cost of post-production workplace treatment tend to be significantly lower than after timber yarding by tractors. In terms of production preparation and control, timber hauling by cable transport installations (Figure 92a) is the most demanding of all timber yarding methods. Therefore, attempts to introduce this technology must be supported by a strong training effort to achieve success (Spinelli et al., 2023).

The adapter (short tractor) cable system (Figure 92b) is a modification of a double-drum tractor winch that works with or without the skyline, with or without the high outlet of cables (tower). In the simplest variant without the skyline, one cable (acting as a haul-back line) retracts the other cable (acting as a mainline) over the block back to the stand so that it is not necessary to retract the mainline to the stand manually. It must be borne in mind when using this system that an effective route length may be only one half of haul-back line length. The range of these systems is up to 150 m because the drum sizes of the tractor winch are limited.

Figure 92. Examples of cable systems: a) cable transport installations and b) adapter (short tractor) cable system (photos: University Enterprise MFK MENDELU).

Loading of timber on transport units

Some timber **hauling technologies** are characterized by the fact that a loading device (winch, hydraulic crane, container loading equipment) is permanently transported on the hauling vehicle for its operability. The advantage is that the wood can be loaded and unloaded anywhere. The disadvantages are a higher price of the hauling vehicle (by the price of the loading equipment and its assembly) and lower utilization of the load capacity of the vehicle for the load itself (by the weight of the loading equipment).

Manual loading and unloading of wood are an integral part of small-scale production technologies. Long wood is loaded from the back of the vehicle by pushing wood between the stakes (Figure 93a) where one worker stays next to the vehicle and the other one behind the vehicle. Only low-weight wood can be loaded this way. Heavier timber is rolled manually onto the loading area of the vehicle using the skids. Heavier pieces must be rolled only from the sides (from butt ends) to avoid injuries in case of accidental backward movement of the timber (Figure 93b). The rolling height should not exceed 1 m, and the angle of skid inclination should not exceed 30%. When loading timber to be stacked manually, loading is performed from the ground as long as it is physically manageable. Then one worker enters the loading area of the vehicle and the other one hands the logs to him. Logs may not be thrown onto the loading area to avoid injuries.

a b

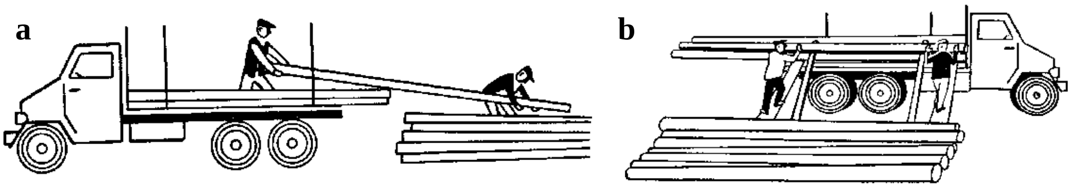


Figure 93. *Manual loading of long wood by a) pushing it between the stakes and b) rolling it on the skids (authors: Department of Engineering, FFWT MENDELU).*

Loading by **twin drum winches** (Figure 94a) consists of the creation of two independent rope loops, which are shortened – with the rope ends firmly anchored to the vehicle – by winding on the winch drums. It is advantageous that the winch is driven by the vehicle engine and the weight of the whole loading equipment is low. The winch brake must be dimensioned to be able to brake the load in any position. The stakes of the vehicles equipped with the loading winches are usually half-length foldable so that one part of the load can be secured by erecting parts of the stakes. The tilted part of the stake serves as a rolling unit. The vehicle crew must have more members (1 + 1, 1 + 2), because rope movement by the operator is time and physically demanding. Heavier pieces are loaded by dragging on the rolling units (skids) so that the necessary traction force may be lower that the lifting force. To load the timber by winches, the timber must be placed in parallel to the vehicle axis, and the distance of the landing from the vehicle is limited by the length of the ropes. The same principle is applied during timber unloading (Figure 94b), except the fact that the ends of the ropes and pulleys are anchored to the fixed points behind the landing.

a b

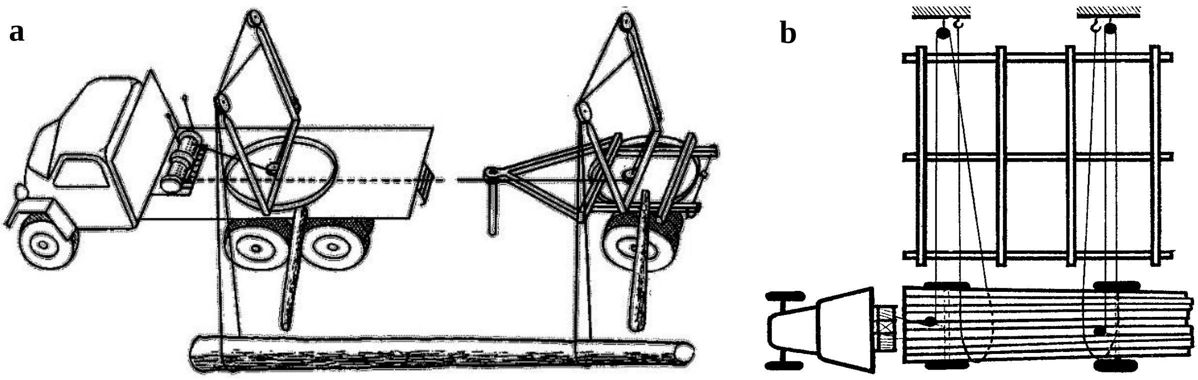


Figure 94. *a) Loading of long wood by a twin drum winch on the vehicle and b) unloading of long wood from the vehicle by a twin drum winch on the vehicle (authors: Department of Engineering, FFWT MENDELU).*

Wood loading and unloading with a hydraulic crane has quickly replaced the loading winches. The specific features of hydraulic cranes are that they can also serve as separate equipment (unloading and dosing equipment in warehouses) or they can carry other equipment (loading tongs; felling, processor and harvester heads; grab saws; lifting platforms; trimmers). When used for timber hauling, their advantage consists in loading as a one-man operation, in loading speed, as well as in the fact that timber to be hauled can be stored at any angle to the hauling road. A hydraulic crane is controlled by changing the supplied amount of fluid and its pressure, thus regulating speed (revolutions), load, direction of movement, change of the rotary motion to rectilinear and vice versa. Their disadvantage is the sensitivity of the hydraulic fluid to dirt, presence of air and water vapour. By changing the temperature of the fluid, its viscosity and thus the flow rate and efficiency of the drive are changed. Therefore, the hydraulic circuit has not only a cooler, but also a device for heating the liquid at low temperatures.

As elsewhere in the world, hydraulic cranes should also undergo rapid development in Mongolia. In view of the higher initial and related costs, however, in the transition stage, at least a greater use of loading by twin drum winches is appropriate compared to the current predominant manual loading.

REFERENCES

Harrill, H., Visser, R. and Raymond, K., 2019. New Zealand cable logging 2008–2018: a period of change. Current Forestry Reports, 5, pp.114-123. https://doi.org/10.1007/s40725-019-00092-5.

Jamshidi, R., Jaeger, D., Raafatnia, N. and Tabari, M., 2008. Influence of two ground-based skidding systems on soil compaction under different slope and gradient conditions. International journal of forest engineering, 19(1), pp.9-16. https://doi.org/10.1080/14942119.2008.10702554.

Mongolian Law on Forest. Ministry of Environment and Green Development of Mongolia. A revised version. Government Bulletin No 22. Published on May 17, 2012, Ulaanbaatar. Available at: https://legalinfo.mn/mn/detail/15624.

Shegelman, I.R., Budnik, P.V. and Baklagin, V.N., 2019. Simulation modeling of truck load of skidding tractors with a grapple for chokerless skidding. Croatian Journal of Forest

Engineering: Journal for Theory and Application of Forestry Engineering, 40(2), pp.297-310. https://doi.org/10.5552/crojfe.2019.567.

Spinelli, R., Magagnotti, N. and Cosola, G., 2023. Characterizing cable-logging enterprises in Italy: production, workforce, equipment and potential for growth. International Journal of Forest Engineering, 34(2), pp.254-266. https://doi.org/10.1080/14942119.2022.2153321.

Toivio, J., Helmisaari, H.S., Palviainen, M., Lindeman, H., Ala-Ilomäki, J., Sirén, M. and Uusitalo, J., 2017. Impacts of timber forwarding on physical properties of forest soils in southern Finland. Forest ecology and management, 405, pp.22-30. https://doi.org/10.1016/j.foreco.2017.09.022.

Zemánek, T. and Neruda, J., 2021. Impact on the operation of a forwarder with the wheeled, tracked-wheel or tracked chassis on the soil surface. Forests, 12(3), p.336. https://doi.org/10.3390/f12030336.

5.3 Potential of Remote Sensing Satellite Data and ERA5 Climate Data for Studying Forest Ecosystems

Petr Lukeš

Satellite **remote sensing** methods have an indispensable place in forestry (Lechner et al., 2020) because they allow **systematic and repeated observation** of the Earth's surface, which can conveniently complement or even completely replace some laborious and expensive ground-based surveys (White et al., 2016). These methods are particularly suited to areas that are difficult to access, such as the forests of Mongolia. At the same time, however, it is important to be aware of the limitations of these methods in forestry, in terms of the level of detail that can be captured given the spatial resolution of the data and the forest parameters that can be mapped by these methods.

The ability to extract forest parameters depends on the type of remote sensing sensors. In practice, the most common are passive optical remote sensing data (Figure 95), which capture the energy of solar radiation reflected from the upper part of the canopy in several spectral bands, or active remote sensing data – LiDAR or RADAR – which capture the change in energy of the signal emitted by the sensor after passing through the forest stand (Elachi and Van Zyl, 2021). This fundamental difference in the way the signal is processed determines its suitability for the acquisition of forest parameters – while passive optical data are suitable for assessing landscape cover type, classifying forest species composition or assessing forest health, for example. Active LiDAR and RADAR data, on the other hand, are used to assess forest taxation parameters or timber stocks (Lehmann et al., 2015).

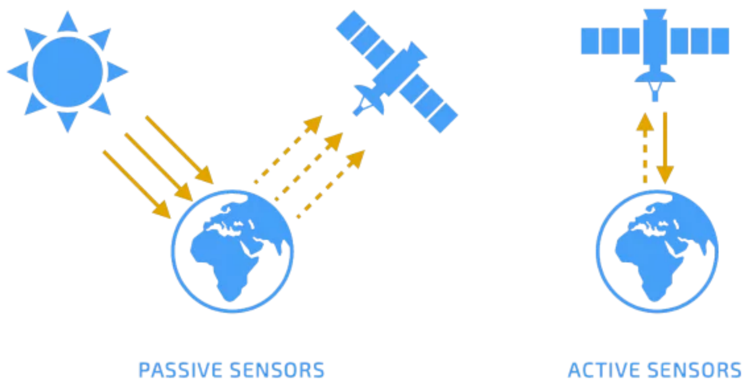


Figure 95. The difference between a passive sensor, which detects the energy of reflected solar radiation (left), and an active sensor, which detects the change in the signals sent by the sensor after interaction with the surface (right) (https://www.skyrora.com/remote-sensing/).

A distinct advantage of satellite remote sensing systems is the possibility of **frequent updates** depending on sensor characteristics (e.g. spatial and temporal resolution), the construction of time series of observations (Figure 96), and the possibility of retrospective analysis of historical imagery (Lambert et al., 2013). While remote sensing is not a complete replacement for field surveys, when combined with traditional field surveys, researchers and forest managers can gain a more complete understanding of forest ecosystems and **improve forest management practices**. The ability to update forest information frequently is particularly important for forest management during crisis events, such as forest fires, outbreaks of wood-boring insects or windstorms (Senf et al., 2017).

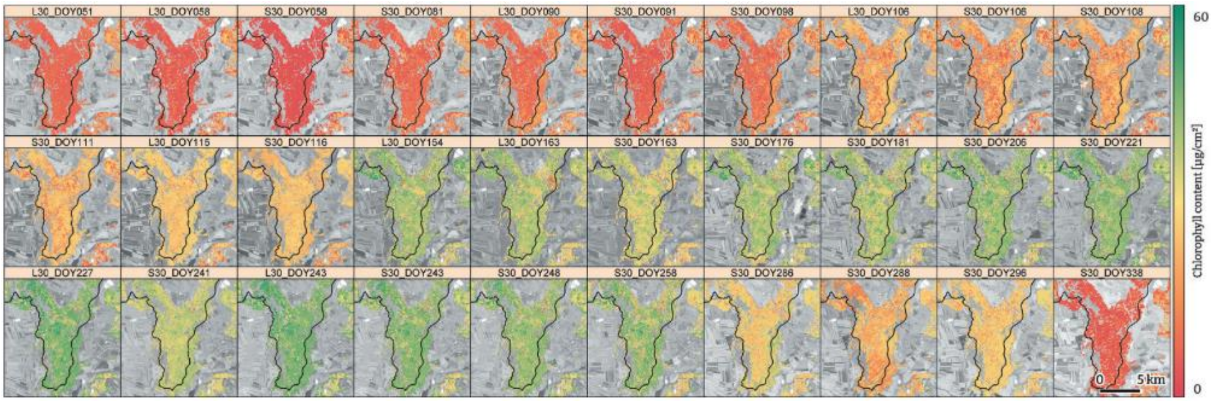


Figure 96. Interpretation of Sentinel-2 satellite sensor data time series as maps of chlorophyll content change in riparian broadleaf forest between DOY 51 (February) and DOY 338 (December). This allows us to study specific phenological trends in vegetation associated with changes in pigment content at different phenophases (Švik et al., 2023).

Passive optical data can capture the energy of reflected solar radiation in several separate regions of the electromagnetic spectrum, known as multispectral data, or continuously capture the entire region in hundreds of spectral channels, known as hyperspectral data (Ghiyamat and Shafri, 2010). By evaluating information in regions of the electromagnetic spectrum that are invisible to the human eye, it is possible to obtain information about the landscape that is otherwise hidden by conventional terrestrial surveys (Figure 97). The advantage of hyperspectral data is that it captures a 'spectral fingerprint' of the landscape that is unique to a particular surface type and condition. By creating databases of the spectral behaviour of different materials, we can do things like classify mineral composition and detect different targets (Van der Meer et al., 2012). Hyperspectral data is an emerging technology in satellite optical remote sensing that will allow us to further refine some of the retrievals of forest parameters in the future, particularly in terms of species composition classification (He et al., 2011) (Figure 98) and health assessment (Terentev et al., 2022).

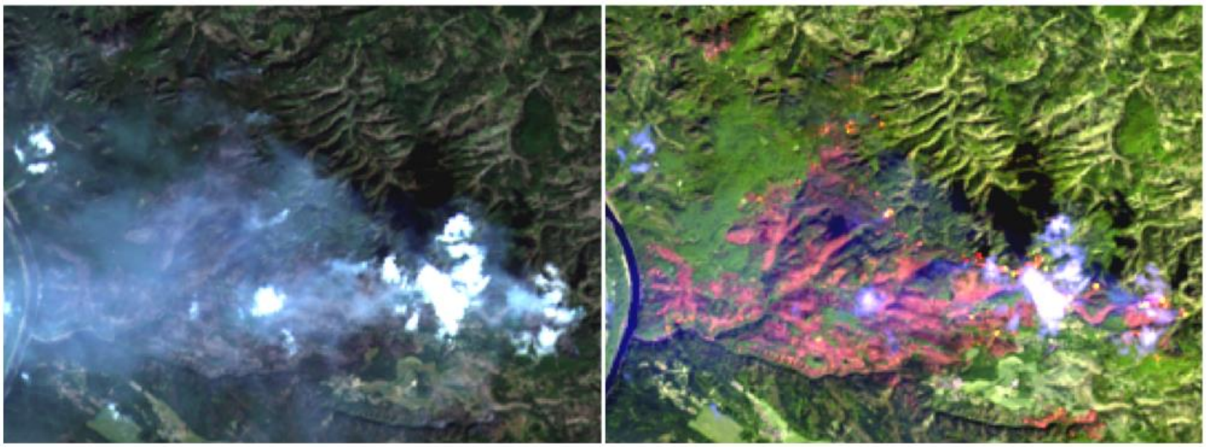


Figure 97. *Image of an area of active forest fire (Bohemian Switzerland National Park, Czech Republic, 28 July 2022) in the visible spectrum (left) and as a "false colour" colour composition using the mid-infrared wavelength bands SWIR2, SWIR1 and RED (right) of the Landsat-9 multispectral satellite. Red highlights burned vegetation, and yellow dots show areas of active fire. By using SWIR wavelengths, it is possible to interpret even areas obscured by smoke that are impenetrable to the human eye (Landsat-9 data).*

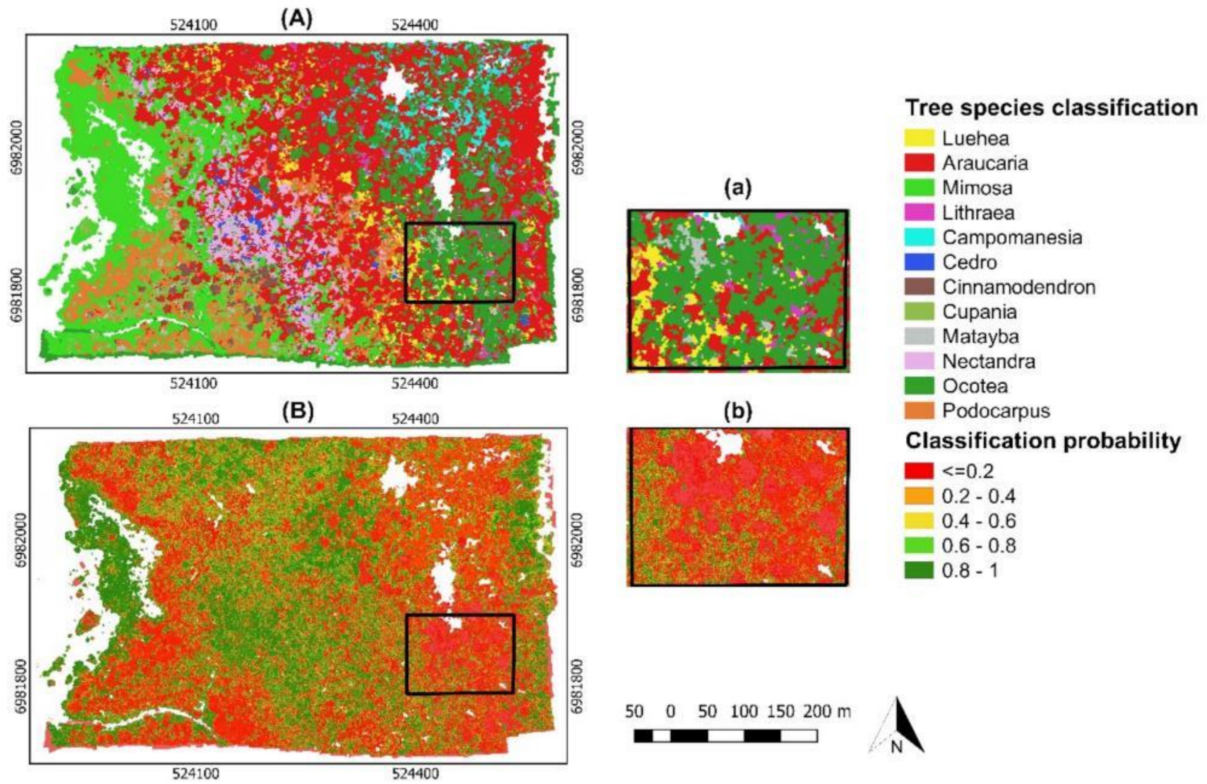


Figure 98. *An example of classification of heterogeneous forest species composition using high spatial resolution hyperspectral data (Sothe et al., 2019).*

A major advantage of satellite multispectral data is its **global availability**, thanks to the NASA-operated Landsat (Wulder et al., 2019) and COPERNICUS-operated Sentinel-2 (Drusch et al., 2012) Earth observation systems. These systems provide free global coverage of the land surface and selected islands at regular intervals, and the data are also archived and published in publicly available databases. Operational hyperspectral satellite missions such as NASA's Surface Biology Geology (SBG) (Cawse-Nicholson et al., 2021) and ESA's CHIME (Nieke and Rast, 2018) are planned for the near future, which will add hyperspectral data to our suite of global, systematically acquired and freely available remotely sensed data.

Active remote sensing data includes primarily LiDAR laser scanning data (Wulder et al., 2013). These are typically airborne, in UAV systems (Kellner et al., 2019) or terrestrially operated (Dassot et al., 2011). Systematic LiDAR data acquired at high point densities and globally from space are not yet available. Therefore, these methods are currently limited by the availability of airborne datasets, which are typically only available locally and on a one-off basis. Nevertheless, these data are very useful for obtaining key taxonomic parameters such as tree height, diameter at breast height and volume of growing stock, with a precision similar to ground-based surveys (Figure 99). For systematic monitoring of forest stands, these data have been used with great success in the Scandinavian countries due to the regular acquisition of aerial LiDAR data (Shendryk et al., 2014); in other areas we are limited by locally available data.

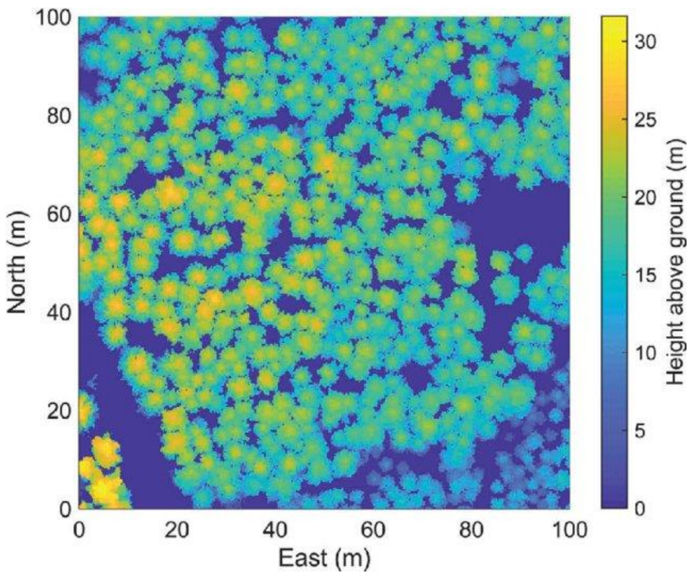


Figure 99. Digital model of tree height created by interpreting a point cloud from an airborne LiDAR sensor (Holmgren and Lindberg, 2019).

Several types of publicly available satellite data and derived products useful for the monitoring of Mongolian forests are freely available (Figure 100). Those used here included:

- Very high-resolution satellite imagery from Maxar's WorldView satellites, available on the Google Maps and Bing maps platforms. These images, with a resolution of 0.5–1 m per pixel, provide excellent background imagery for basic terrain navigation and visual interpretation of the area's surroundings.
- Multispectral Sentinel-2 satellite imagery acquired by ESA as part of the COPERNICUS system. These images are acquired at regular intervals of 5 days in several spectral channels of the visible and infrared spectrum with a spatial resolution of 10 m and 20 m per pixel. From these data we can derive information on landscape cover or even quantitative vegetation parameters such as canopy cover and species composition. By analysing time series of these satellite images, it is possible to detect forest cover loss and attribute it to a specific year (Hansen et al., 2013) or, in combination with thermal data, to assess the probability of forest loss due to fire (Tyukavina et al., 2022).

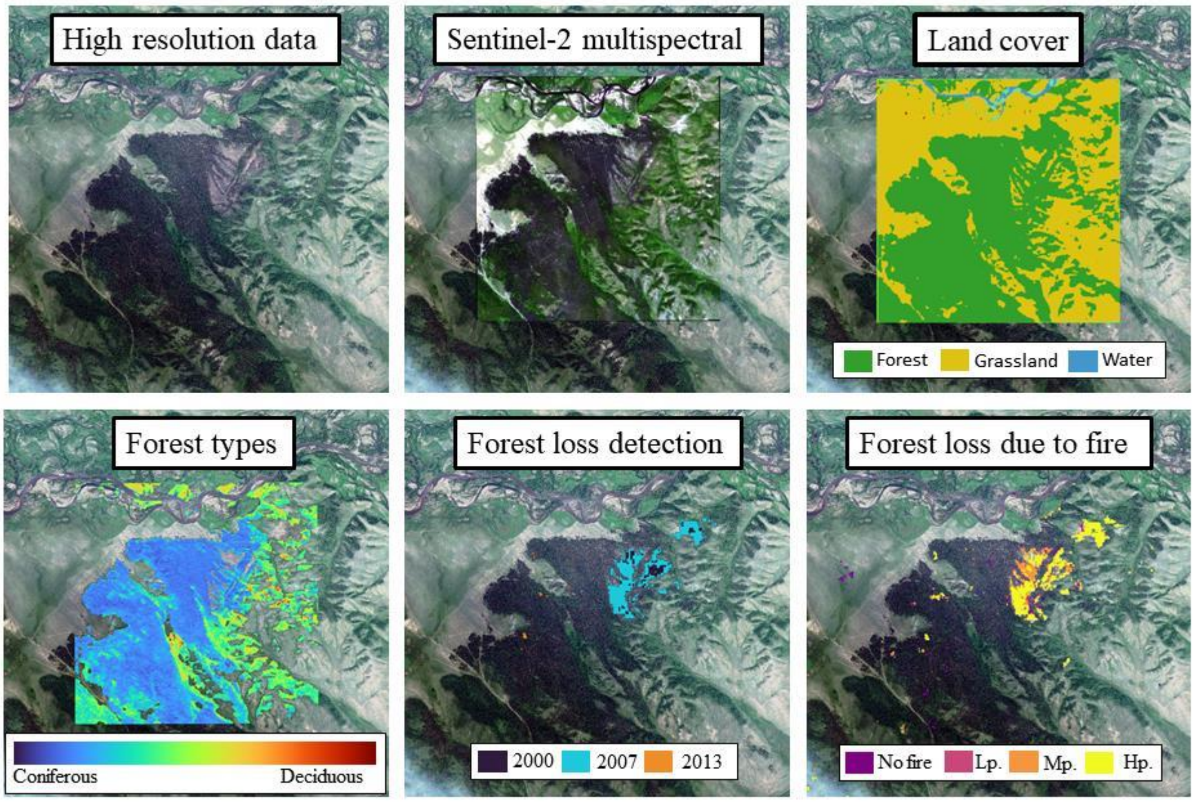


Figure 100. Example datasets recently supporting forestry activities in Mongolia – WorldView very high spatial resolution imagery, Sentinel-2 multispectral imagery and derived landscape cover products, dominant forest types, forest loss detection and forest loss attribution due to forest fires (author: Petr Lukeš).

The ERA5 dataset from the European Centre for Medium-Range Weather Forecasts (Muñoz-Sabater et al., 2021) also has great potential for ecological studies with implications for forestry and landscape management. This dataset provides hourly estimates of meteorological variables such as temperature, humidity and precipitation at a moderate spatial resolution of 30 × 30 km (ERA5) and 9 × 9 km (ERA5-Land) from 1950 to the present day. This allows us to assess not only the current state of the climate, but also its trends over the last 70 years at a relatively high spatial resolution. In combination with the in-situ instrumental data, we are thus able to locally validate the results of the ERA5-Land model reanalyses and, in turn, to use longer time series data to extrapolate beyond the period covered by the sensor measurements. In addition to information on air temperature and precipitation patterns, the ERA5-Land data also provide valuable information on e.g. evapotranspiration, runoff, irradiance or soil temperature at several depth profiles.

ERA-5 land data were used recently by forestry experts in Mongolia to provide a basic meteorological description of individual areas by interpreting the **time series** of available model outputs – daily temperature and precipitation or soil temperature. In this way, the instrumental measurements were complemented and **long-term trends were calculated to describe the changing climate of Mongolia** in terms of temperature and precipitation trends. The assessment of mean annual soil temperature also helped us to map the presence of permafrost, an important factor influencing the conditions for forest growth in the area (Figure 101).

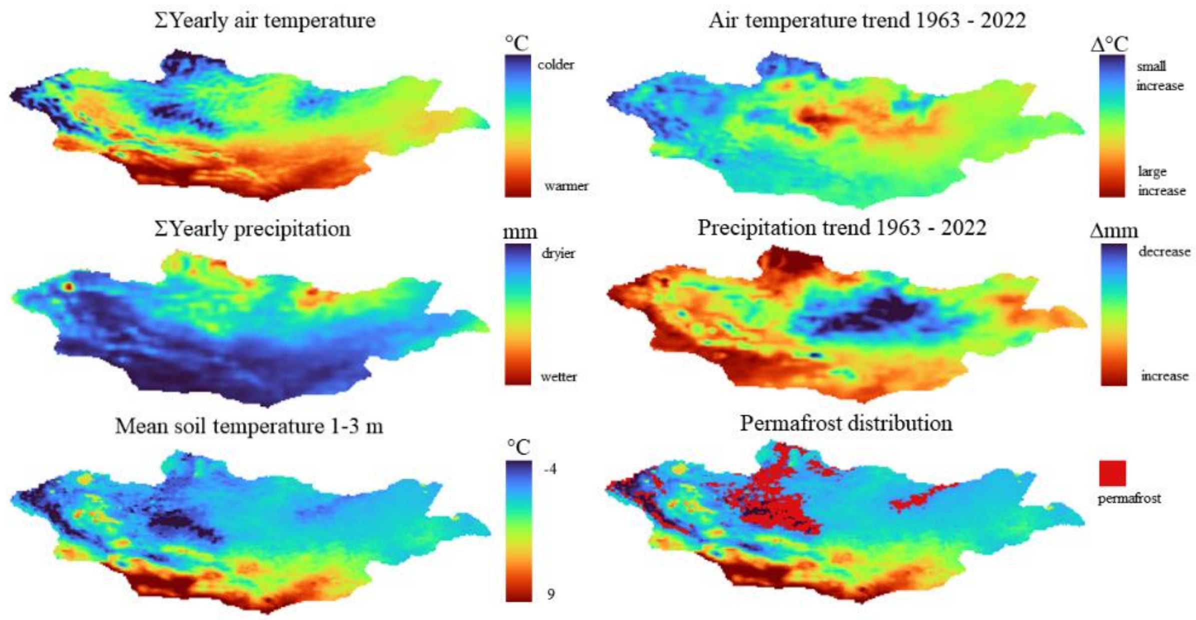


Figure 101. Example interpretation of time series of ERA5-Land model output for Mongolia in terms of annual sum of temperature and precipitation and mean annual soil temperature at 1-3 m depth (left), trends in temperature and precipitation change between 1963 and 2022, and permafrost occurrence (right) (author: Petr Lukeš).

REFERENCES

Cawse-Nicholson, K., Townsend, P.A., Schimel, D., Assiri, A.M., Blake, P.L., Buongiorno, M.F., Campbell, P., Carmon, N., Casey, K.A., Correa-Pabón, R.E. and Dahlin, K.M., 2021. NASA's surface biology and geology designated observable: A perspective on surface imaging algorithms. Remote Sensing of Environment, 257, p.112349. https://doi.org/10.1016/j.rse.2021.112349.

Dassot, M., Constant, T. and Fournier, M., 2011. The use of terrestrial LiDAR technology in forest science: application fields, benefits and challenges. Annals of forest science, 68, pp.959-974. https://doi.org/10.1007/s13595-011-0102-2.

Drusch, M., Del Bello, U., Carlier, S., Colin, O., Fernandez, V., Gascon, F., Hoersch, B., Isola, C., Laberinti, P., Martimort, P. and Meygret, A., 2012. Sentinel-2: ESA's optical high-resolution mission for GMES operational services. Remote sensing of Environment, 120, pp.25-36. https://doi.org/10.1016/j.rse.2011.11.026.

Elachi, C. and Van Zyl, J.J., 2021. Introduction to the physics and techniques of remote sensing. John Wiley & Sons, Ltd.

Ghiyamat, A. and Shafri, H.Z., 2010. A review on hyperspectral remote sensing for homogeneous and heterogeneous forest biodiversity assessment. International Journal of Remote Sensing, 31(7), pp.1837-1856. https://doi.org/10.1080/01431160902926681.

Hansen, M.C., Potapov, P.V., Moore, R., Hancher, M., Turubanova, S.A., Tyukavina, A., Thau, D., Stehman, S.V., Goetz, S.J., Loveland, T.R. and Kommareddy, A., 2013. High-resolution global maps of 21st-century forest cover change. science, 342(6160), pp.850-853. https://doi.org/10.1126/science.124469.

He, K.S., Rocchini, D., Neteler, M. and Nagendra, H., 2011. Benefits of hyperspectral remote sensing for tracking plant invasions. Diversity and Distributions, 17(3), pp.381-392. https://doi.org/10.1111/j.1472-4642.2011.00761.x.

Holmgren, J. and Lindberg, E., 2019. Tree crown segmentation based on a tree crown density model derived from Airborne Laser Scanning. Remote Sensing Letters, 10(12), pp.1143-1152. https://doi.org/10.1080/2150704X.2019.1658237.

Kellner, J.R., Armston, J., Birrer, M., Cushman, K.C., Duncanson, L., Eck, C., Falleger, C., Imbach, B., Král, K., Krůček, M. and Trochta, J., 2019. New opportunities for forest remote sensing through ultra-high-density drone lidar. Surveys in Geophysics, 40, pp.959-977. https://doi.org/10.1007/s10712-019-09529-9.

Lambert, J., Drenou, C., Denux, J.P., Balent, G. and Cheret, V., 2013. Monitoring forest decline through remote sensing time series analysis. GIScience & Remote Sensing, 50(4), pp.437-457. https://doi.org/10.1080/15481603.2013.820070.

Lechner, A.M., Foody, G.M. and Boyd, D.S., 2020. Applications in remote sensing to forest ecology and management. One Earth, 2(5), pp.405-412. https://doi.org/10.1016/j.oneear.2020.05.001.

Lehmann, E.A., Caccetta, P., Lowell, K., Mitchell, A., Zhou, Z.S., Held, A., Milne, T. and Tapley, I., 2015. SAR and optical remote sensing: Assessment of complementarity and interoperability in the context of a large-scale operational forest monitoring system. Remote Sensing of Environment, 156, pp.335-348. https://doi.org/10.1016/j.rse.2014.09.034.

Muñoz-Sabater, J., Dutra, E., Agustí-Panareda, A., Albergel, C., Arduini, G., Balsamo, G., Boussetta, S., Choulga, M., Harrigan, S., Hersbach, H. and Martens, B., 2021. ERA5-Land: A state-of-the-art global reanalysis dataset for land applications. Earth system science data, 13(9), pp.4349-4383. https://doi.org/10.5194/essd-13-4349-2021.

Nieke, J. and Rast, M., 2018, July. Towards the copernicus hyperspectral imaging mission for the environment (CHIME). In: Igarss 2018-2018 IEEE international geoscience and remote sensing symposium. IEEE. https://doi.org/10.1109/IGARSS.2018.8518384.

Senf, C., Seidl, R. and Hostert, P., 2017. Remote sensing of forest insect disturbances: Current state and future directions. International Journal of Applied Earth Observation and Geoinformation, 60, pp.49-60. https://doi.org/10.1016/j.jag.2017.04.004.

Shendryk, I., Hellström, M., Klemedtsson, L. and Kljun, N., 2014. Low-density LiDAR and optical imagery for biomass estimation over boreal forest in Sweden. Forests, 5(5), pp.992-1010. https://doi.org/10.3390/f5050992.

Sothe, C., Dalponte, M., Almeida, C.M.D., Schimalski, M.B., Lima, C.L., Liesenberg, V., Miyoshi, G.T. and Tommaselli, A.M.G., 2019. Tree species classification in a highly diverse subtropical forest integrating UAV-based photogrammetric point cloud and hyperspectral data. Remote Sensing, 11(11), p.1338. https://doi.org/10.3390/rs11111338.

Švik, M., Lukeš, P., Lhotáková, Z., Neuwirthová, E., Albrechtová, J., Campbell, P.E. and Homolová, L., 2023. Retrieving plant functional traits through time series analysis of satellite observations using machine learning methods. International Journal of Remote Sensing, 44(10), pp.3083-3105. https://doi.org/10.1080/01431161.2023.2216847.

Terentev, A., Dolzhenko, V., Fedotov, A. and Eremenko, D., 2022. Current state of hyperspectral remote sensing for early plant disease detection: A review. Sensors, 22(3), p.757. https://doi.org/10.3390/s22030757.

Tyukavina, A., Potapov, P., Hansen, M.C., Pickens, A.H., Stehman, S.V., Turubanova, S., Parker, D., Zalles, V., Lima, A., Kommareddy, I. and Song, X.P., 2022. Global trends of forest loss due to fire from 2001 to 2019. Frontiers in Remote Sensing, 3, p.825190. https://doi.org/10.3389/frsen.2022.825190.

Van der Meer, F.D., Van der Werff, H.M., Van Ruitenbeek, F.J., Hecker, C.A., Bakker, W.H., Noomen, M.F., Van Der Meijde, M., Carranza, E.J.M., De Smeth, J.B. and Woldai, T., 2012. Multi-and hyperspectral geologic remote sensing: A review. International Journal of Applied Earth Observation and Geoinformation, 14(1), pp.112-128. https://doi.org/10.1016/j.jag.2011.08.002.

White, J.C., Coops, N.C., Wulder, M.A., Vastaranta, M., Hilker, T. and Tompalski, P., 2016. Remote sensing technologies for enhancing forest inventories: A review. Canadian Journal of Remote Sensing, 42(5), pp.619-641. https://doi.org/10.1080/07038992.2016.1207484.

Wulder, M.A., Coops, N.C., Hudak, A.T., Morsdorf, F., Nelson, R., Newnham, G. and Vastaranta, M., 2013. Status and prospects for LiDAR remote sensing of forested ecosystems. Canadian Journal of Remote Sensing, 39(sup1), pp.S1-S5. https://doi.org/10.5589/m13-051.

Wulder, M.A., Loveland, T.R., Roy, D.P., Crawford, C.J., Masek, J.G., Woodcock, C.E., Allen, R.G., Anderson, M.C., Belward, A.S., Cohen, W.B. and Dwyer, J., 2019. Current status of Landsat program, science, and applications. Remote sensing of environment, 225, pp.127-147. https://doi.org/10.1016/j.rse.2019.02.015.

FOREST

ECONOMY

6. FOREST ECONOMY

6.1 Basic Concepts and Challenges for the Mongolian Forest Economy

Ján Parobek

Introduction

Forests store a significant amount of carbon and methane in their plants and soils. They also prevent erosion on steep mountainsides and act as a natural barrier to deserts expansion. In addition, they provide plenty of goods, namely fuelwood, charcoal, timber, nuts, berries, and honey, as well as a variety of other benefits to rural communities' lives.

Basic information about Mongolian **forests production** is presented in Figure 102. According to Evans (2018), timber and fuelwood harvested from Mongolian boreal forests annually is worth an estimated $142 million. Unfortunately, unlicensed operators harvest more than half of it. Further, collection of forest products like berries, pine nuts, and medicinal plants is estimated to be worth $12 million annually. Furthermore, at least 35% of Mongolia's livestock graze in or near forest areas. The role of supporting grazing is worth an estimated $25 million per year. Together with forest fires, which up to 95% are estimated to be caused by human activities, we can consider these human impacts as the most significant negative impacts causing changes in the area and quality of forest stands. In this sense, more than 52 thousand hectares of Mongolian forests were lost and almost 1.4 million hectares degraded between 2005 and 2015. Forest degradation and deforestation have been estimated to emit more than 3.5 million tonnes of carbon dioxide equivalents each year, but much more (about 29 million tonnes) is removed from atmosphere by natural growth and planted forests. Moreover, because of the climate change, some species of trees grow slowly and are vulnerable to fire, pest outbreaks and droughts.

Sustainable forest management is an important aspect of combating climate change ensuring that future generations can benefit from what forests offer. Moreover, a sustainable approach to forest management can provide environmental, social, and economic advantages to people. From this perspective, management steps focused on sustainable utilisation of wood resources should be supported by crucial information provided by **forest economics**.

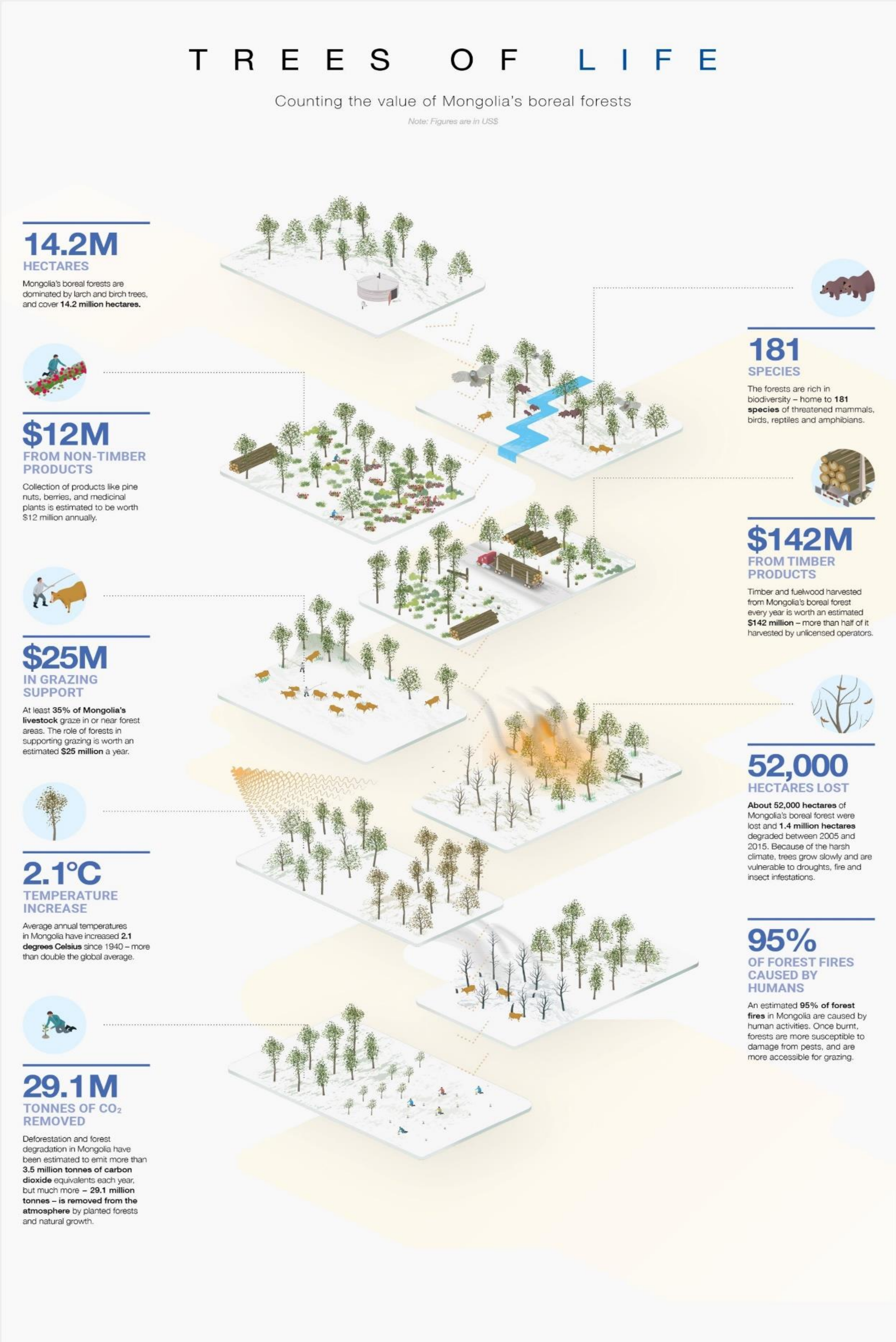


Figure 102. *Counting the value of Mongolia's forest ecosystems (Evans, 2018).*

Economic resources can be divided into four categories: labour, land or natural resources, capital, and entrepreneurship (entrepreneurial ability). Natural resources are capitals, such as wood, land, oil, and water. From this point of view, forest and wood represent a significant economic source. Sustainably managed forests are able to provide **services and goods for long term consumption** (construction wood, furniture (Figure 103), etc.). Forest economic resources are considered as the inputs we utilise to produce goods and services from forest.

Figure 103. Traditional Mongolian furniture for nomadic families is elegantly created for Mongolian gers and tailored to the nomadic lifestyle. Most of the furnishings in a ger is box-shaped, making it easy to transport. The conventional ger furniture consists of two single beds, a table with four chairs, a cupboard and a closet (author: Ján Parobek).

Historically, forest economics only addressed the timber producing process. Currently, its purview has broadened to include the multipurpose role that forests play in benefiting society not just economically but also in terms of the environment, society, and culture (see chapter 1.1 Forest Definitions and Functions). The value of the public benefits that forestry provides, such as carbon sequestration, protecting biodiversity, maintaining water quality, providing recreational opportunities and adding value to landscapes, is currently being evaluated by forest economics. Compared with the other sectors, a fuller picture of the economic benefit that forests bring to society and the net public benefit of forestry in general can be obtained by assigning a monetary value to these **public goods**.

Economic situation in Mongolia

From the economic point of view, Mongolia is a **resource-rich**, landlocked, lower-middle-income and open economy. It is still in the transition process. These factors, together with the country's history, have defined its economic present, as well as future. Mongolia's economic development outcomes are shaped by natural resources such as forest resources, mining and geographical endowments. Mongolia is the world's least densely populated country, with a population of 3.35 million people (2021) and an area of 1.56 million km^2. As a result, its resource-based enterprises have a great potential comparative advantage.

Mongolia has an unusual economic structure dominated by the **capital city** and **mining**, which accounted for about 65% and 20%, respectively, of gross domestic product (GDP) in 2018 (Helble et al., 2020). On the other hand, the share of agriculture, forestry, and fishing was low with a share of about 11% of GDP in that time (The World Bank, 2024a), whereas the largest part of the mentioned division was made up of agriculture (Helble et al., 2020). The centralization of the national economy in the capital city and around the mining industry points to a weakly economically developed countryside that is focused on traditional agricultural production, which is, however, becoming unsustainable with changing environmental conditions due to climate change. Sustainable forest management, on the other hand, can represent future job opportunities for local people and the associated development of poor and remote countryside areas.

The GDP of this small, dualistic economy was just about $13 billion in 2018 (Helble et al., 2020). In 2022, the value of GDP reached $17.15 billion (The World Bank, 2024b) with a major contribution by mining (Figure 104). **The economy is also significantly reliant on international trade with its neighbours.** Mongolia imports 95% of its petroleum products, and a significant portion of its electricity comes from Russia, making it vulnerable to price increases. Business with China accounts for more than half of Mongolia's foreign trade. Approximately 84% of Mongolian export flows to China.

Mongolia has undertaken significant reforms of its economic system over the last decade in order to transit to an open, dynamic market economy. Recently, improvements have been made to its mining and investment legislation to provide stability for foreign investors. Mongolia attained a real GDP growth of 4.8% in 2022. Among the economic sectors, the services, agriculture and net taxes on products were the major contributors to the growth (Invest Mongolia, 2024).

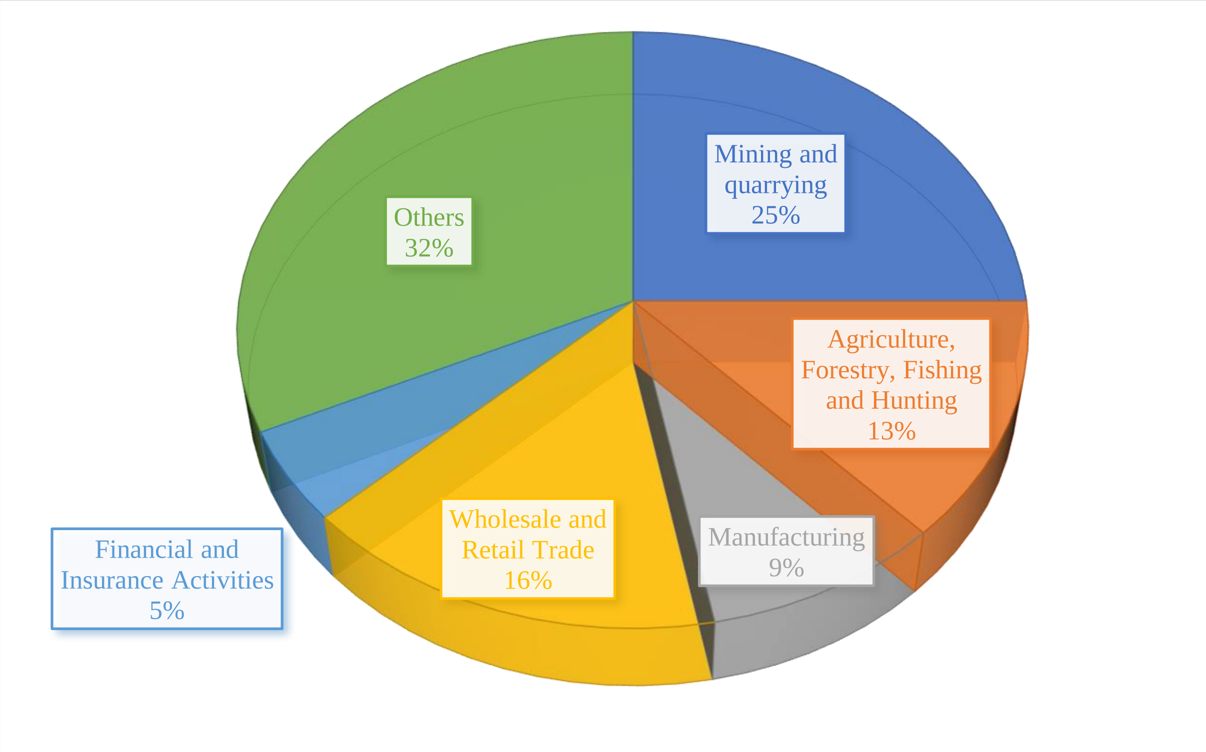


Figure 104. Distribution of GPD by sectors in 2022 (National Statistics Office, 2023).

Economic contributions of forests

Forests play a crucial role in **supporting the livelihoods of rural communities** in Mongolia (Development Asia, 2022) as they are used extensively to support household demands for **wood** and **non-wood forest products** (Ykhanbai, 2010). Generally, poorer households in upland communities heavily depend on forest resources for income and subsistence with forests providing a source of food, fuelwood, and other essential materials (Rawlins et al., 2017). The sustainable management and conservation of these forests are therefore critical for ensuring the continued well-being of these communities. By recognizing the importance of forests in supporting local livelihoods, Mongolia is taking important steps towards achieving sustainable development. In recent years, Mongolia has made significant efforts towards building resilient forests, restoring and conserving forest resources, and developing economic opportunities (AFoCO, 2021; ADB, 2022). However, changes may take several years to become apparent.

Forests in Mongolia have significant economic value, both in terms of **timber** and **non-timber forest products** (Nelson et al., 2011), as indicated by the national forest inventory results (Altrell, 2019). In connection with that, they should also meet demands for wood from economic sectors (Ykhanbai, 2010).

Timber forest production

Timber is the most important source of income for artificial maintaining forest functions and employment in the forestry sector and timber processing industry. Therefore, it is almost impossible to manage forests profitably without logging and subsequent wood processing.

The establishment of the Forest Division in the Ministry of Economy in 1924 marked the beginning of organised forest production in Mongolia. A focus on the sustainable use of timber resources began to be implemented into the national forest policy at the turn of the millennium (Tsogtbaatar, 2002).

There are two different ways of assessing the importance of the forestry sector to the national economy. The first approach is represented by **annual wood production**. Over the past twenty years, roundwood production in Mongolia has been almost on the same level with a slight increase. Currently, the total volume of harvested roundwood is almost 0.9 million m^3 annually (Figure 105).

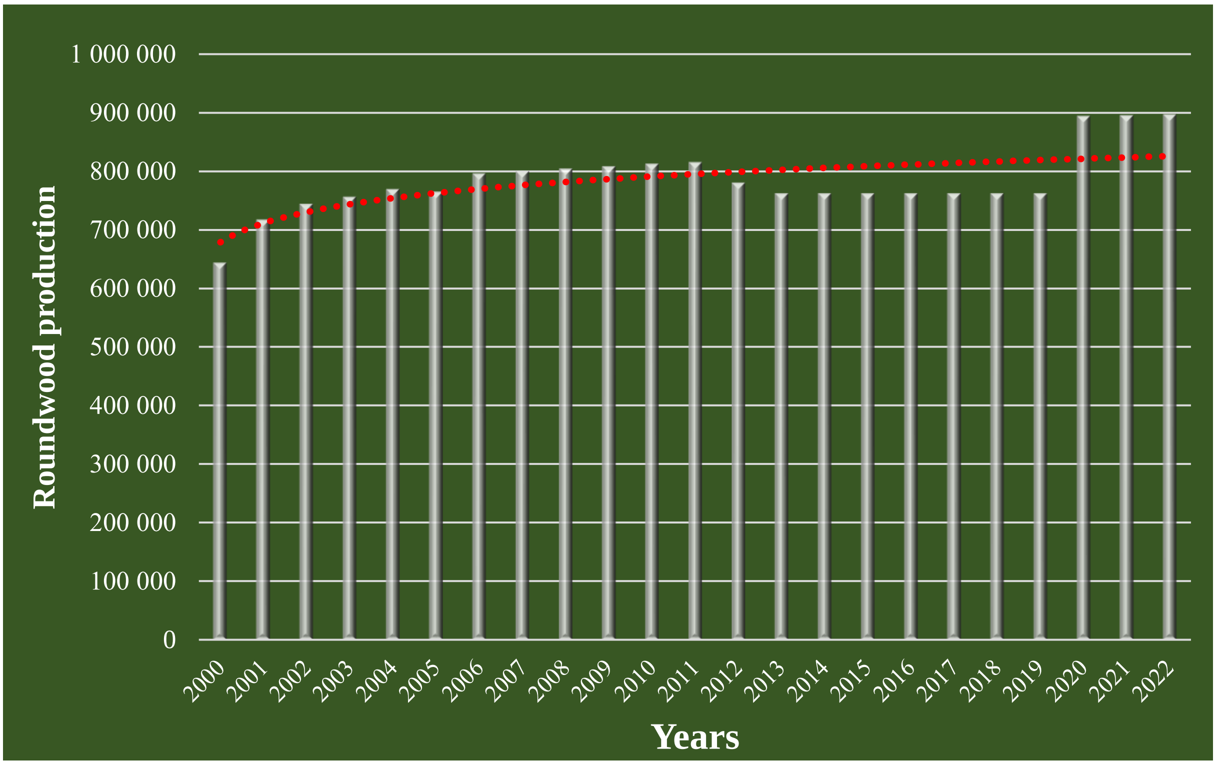


Figure 105. Development of forest harvest volume (estimated values in m^3) in Mongolia in recent years (FAOSTAT, 2023).

Unfortunately, even with the low production of roundwood in acceptable quality, its use is predominantly as not very profitable **wood fuel**. One of the reasons is that the majority of it comes from dead trees. The production of fuelwood amounts to 734 thousand m^3 (Table). It means that almost 80% of all harvested wood is utilised for energy purposes. Low profit of wood is unfavourable not only from an economic but also from an ecological point of view. The use of renewable wood fuel as an environmentally friendly substitute for the non-renewable coal that critically pollutes the Mongolian air (Guttikunda et al., 2013) is a step forward, however, it should also be accompanied by sustainable increased production of roundwood for further profitable wood processing and carbon storage in harvested wood products to make sustainable forestry meaningful for forest managers and truly sustainable. The potential of a sustainable green wood harvest based on the annual wood increment is unfulfilled and shows the need for change. In addition, a suitable alternative for fuelwood can be the implementation of forest **tending** including **thinning** and the use of wood thus obtained as fuel.

Table 5. Development of forest harvest volume (estimated values in m^3) in Mongolia in recent years (FAOSTAT, 2023).

Year	Industrial roundwood (coniferous)	Industrial roundwood (non-coniferous)	Wood fuel
2010	47,000	2,000	763,361
2011	47,000	2,000	766,334
2012	177,000	3,000	600,000
2013	160,000	2,000	600,000
2014	160,000	2,000	600,000
2015	160,000	2,000	600,000
2016	160,000	2,000	600,000
2017	160,000	2,000	600,000
2018	160,000	2,000	600,000
2019	160,000	2,000	600,000
2020	160,000	2,000	731,867
2021	160,000	2,000	733,137
2022	160,000	2,000	734,414

The new approach could result in lower production of fuelwood due to a shift of its portion to the category of industrial wood (primarily sawlog). This will have a positive effect on the production of longer half-life products. The longevity and recycling rate have significant influence on the carbon stock in wood products. Furthermore, the carbon stock increases linearly in wood products when increasing the average lifespan of wood products.

Among the production of wood-based products, sawnwood is the most important product with a total production volume of almost 20 thousand m^3 (Table 6).

Table 6. Estimated forestry production and trade (values in m³) in Mongolia in 2022 (FAOSTAT, 2023).

	Production	Export	Import	Consumption
Sawlogs and veneer logs	43,000	N/A	N/A	43,000
Sawnwood	19,400	50	109	19,459
Wood-based panels	1,000	15[1]	178,140	179,125
Chemical wood pulp[2]	N/A	165	515	350

[1] Rounded value.

[2] The values given are in tonnes.

The second approach to assessing the importance of the forestry sector to the national economy is the calculation method, and it is focused on the **share of the forestry sector in GDP**. GDP is the sum of value added by all economic activities produced within a country's territory during the course of one year. GDP can be measured in three ways:

1) The production approach consists of adding the gross value added by all industries and subtracting intermediate consumption.
2) The expenditure approach is the value of final consumption expenditure, gross capital formation and net exports of goods and services (exports minus imports).
3) And finally, the income approach consists of adding the compensation of employees, consumption of fixed capital, net taxes on production and imports (taxes minus subsidies on production and imports) and net operating surplus or mixed income during the accounting period.

Recent development of the significance of the agricultural and forestry sectors in GDP is described in Table 7. It shows the positive development of the share of agriculture and related industries in GDP. However, the actual growth of the forestry sector is questionable.

Table 7. Share (%) of economic sectors in GDP in Mongolia (The World Bank, 2024a, 2024c, 2024d).

	2018	2019	2020	2021	2022
Agriculture, forestry, and fishing	11.4	11.6	13.0	13.2	13.0
Industry (including construction)	38.0	38.1	37.0	37.1	35.3
Services	39.8	39.7	40.5	39.6	41.0

Non-timber forest production

Non-timber or non-wood forest products such as pine nuts (Figure 106), berries, herbs and mushrooms also play an important role in the economy, with the development of the non-timber forest products industry promoting both **ecological** and **economic benefits** (Dou et al., 2023). The sustainable management of these resources can provide a significant **source of income** for communities and contribute to the overall economic growth of the country (Wu et al., 2023; ADB, 2024). At the local level, non-timber forest products can contribute to human nutrition, cultural and experiential services, as well as create income and job opportunities (Weiss et al., 2020). For low-income households, they can represent 10–60% of their income and in Europe, the total value of non-wood forest products collected each year can reach up to 71% of the value of annual roundwood production (Lovrić et al., 2020). Therefore, their importance cannot be overlooked.

It must not be forgotten that forests in Mongolia also have the potential to generate revenue through **ecotourism**. The extreme continental climate of Mongolia, with long, dry, and harsh winters (UNDP, 2023), shaping the landscape and forest ecosystems, makes forests an attractive destination for local as well as foreign seasonal tourists seeking unique experiences in nature. The development of ecotourism, for example, in relation to hiking, biking and climbing (Santarem et al., 2015) in forested areas can provide additional income for local communities while promoting the conservation of these vital ecosystems. However, it is crucial to balance the economic potential of ecotourism with sustainable forest management practices to ensure the long-term preservation of these ecosystems. By recognizing the economic potential of ecotourism, Mongolia can continue to develop its forest resources while preserving its natural heritage.

Figure 106. Pine nuts and cones contain high levels of oil, protein and minerals. Pine nuts are generally added to meals and can be consumed raw or roasted. Due to their beneficial effects on human health, they are one of the most attractive non-wood forest products in Mongolia (author: Ján Parobek).

Because non-wood forest products open **new market fields**, there is a need for cross-sectoral thinking or connecting across societal groups (Weiss et al., 2020). This brings accompanying development in other sectors (services) besides forestry as a primary source of products and can, therefore, have a multiple positive impact.

Challenges

Mongolia has about 12.4 million ha of forests which could be utilized for wood and mainly non-wood production with regard to the prevailing forest protection (see chapter 1.3 Mongolian Forests). Reforestation increases very slowly, which shows the need to implement a new approach to reduce the degradation of wood resources by applying modern system of forest resources management. According to the national targets that directly support forest restoration, the Mongolian government focused on increasing the area of forest cover and sustainable forest management will be introduced to the forestry sector. Moreover, the rate of usage of primary wooden materials will be increased up to 80% and fully meet people's demand for wood and wooden products (AFoCO, 2021). However, there are several related challenges.

It is mainly a **conflict between pastoralism and forest management**, which is increasing due to the enormous increase in the number of livestock. The significant impact of agriculture, especially excessive goat, cattle and horses breeding (Figure 107), limits maintaining forests in their current extent or even expanding to places where they have recently disappeared (see chapter 3.3 Forest Grazing). Pastoralism at its current level can therefore bring an increase in additional costs to the forestry sector, especially due to the **high costs of protecting planted seedlings and natural forest regeneration**.

Figure 107. Horses are an important part of Mongolian culture and have a long history of being used for transportation, agriculture, and in traditional nomadic lifestyle. The significant impact of horse breeding limits the preservation and quality of forests in their current extent and leads to economic losses and increased costs in forest protection (author: Ján Parobek).

Further, several studies have shown that the value of non-timber forest products can vary depending on land tenure conditions and change of climate (Zhu et al., 2017). Wood production may also be limited due to the impacts of climate change. In addition, associated forest fires can have fatal economic consequences. The resulting financial losses associated with the **loss of timber** as well as the **costs of forest restoration can be critical**.

Even the way of life and the dwellings of Mongols living in the countryside differ from those who live in the cities. Private land is often enclosed with high and dense fences made of larch logs/sawn timber. Considering the nature of the fence and related buildings and their use, this is often a very **wasteful way of using valuable wood** raw material. Large economic losses and the deterioration of valuable wood raw material also occur due to inappropriate cutting of timber associated with insufficient transport capacities (Figure 108).

Figure 108. The ZIL-131 is a general purpose 3.5 tonne 6×6 army truck designed in the Soviet Union by ZIL. The basic model is a general cargo truck and local people in Mongolia often use the truck to transport wood (author: Ján Parobek).

Currently, due to efforts to stop **illegal logging**, the limited production of high-quality wood assortments was almost zero. On the other hand, there is a clear increase in demand for wood and wood products from locals. There is a great opportunity to bridge the gap and prepare some ideas and strategies for policy makers to change this situation, i.e. to **reduce the import** of wood products from China and to **promote the domestic use of renewable resources**.

Specifically, there is the possibility of developing a project as a case study in a small local area that has the potential to sustainably produce industrial wood. The locality should have the possibility of making money in the woodworking industry (e.g. simple furniture production, or by-product for wood fences, constructions, etc). This idea (or project) should be interlinked with government according to state policy. Using such a functional example from Mongolian conditions, it is possible to further develop and present the importance of forestry value chains, forest industry and wood manufacturing industry for the economic development of the forestry sector. The economic potential of forests must be further developed because of their importance to the national economy and society.

Main findings about wood utilization in Mongolia are as follows:

- Conservation of forest remains the priority for Mongolia, which points in particular to efforts to stop the loss of forests.
- There is little interest by local communities in using wood with high added production value.
- There is little functioning wood processing industry.
- There is a gap between wood-based products demand and production.
- There is a weak link between policy makers and reality = weak support for the wood processing industry.

Based on the findings, the identification of forests suitable for sustainable wood production can be recommended as the first step towards further economic development and growth of the forestry sector.

REFERENCES

ADB, 2022. Saving Mongolian Forests with Finnish Expertise. Asian Development Bank (ADB). Available at: https://rksi.adb.org/publications/saving-mongolian-forests-with-finnish-expertise/ (accessed 27 November 2023).

ADB, 2024. Mongolia: Forest Sector Development Program (Completion Report). Asian Development Bank (ADB). Available at: https://www.adb.org/projects/documents/mon-52022-002-tcr.

AFoCO, 2021. Mongolian forestry in a changing environment. Asian Forest Cooperation Organization (AFoCO). Available at: https://afocosec.org/newsroom/news/forestry-news/focus-mongolian-forestry-in-a-changing-environment/ (accessed 27 November 2023).

Altrell, D., 2019. Multipurpose National Forest Inventory in Mongolia, 2014-2017-A tool to support sustainable forest management. Geography, Environment, Sustainability, 12(3), pp.167-183. https://doi.org/10.24057/2071-9388-2019-36.

Development Asia, 2022. Mongolia Protects Its Boreal Forests by Improving Local Livelihoods. Asian Development Bank. Available at: https://development.asia/case-study/mongolia-protects-its-boreal-forests-improving-local-livelihoods (accessed 27 November 2023).

Dou, Y., Wu, J., Li, Y., Chen, X. and Zhao, X., 2023. Has the Development of the Non-Timber Forest Products Industry Achieved Poverty Alleviation? Evidence from Lower-Income Forest Areas in Yunnan Province. Forests, 14(4), p.776. https://doi.org/10.3390/f14040776.

Evans, K., 2018. The Changing World of Mongolia's Boreal Forests. The Mongolia National UN-REDD Programme. Available at: http://stories.unep-wcmc.org/borealforestsmongolia/index.html#group-top-pkQbXgi9sx (accessed 12 January 2024).

FAOSTAT, 2023. Forestry Production and Trade. Food and Agriculture Organization of the United Nations. Available at: https://www.fao.org/faostat/en/#data/FO (accessed 21 November 2023).

Guttikunda, S.K., Lodoysamba, S., Bulgansaikhan, B. and Dashdondog, B., 2013. Particulate pollution in Ulaanbaatar, Mongolia. Air Quality, Atmosphere & Health, 6, pp.589-601. https://doi.org/10.1007/s11869-013-0198-7.

Helble, M., Hill, H. and Magee, D. (eds.), 2020. Mongolia's Economic Prospects: Resource-rich and Landlocked Between Two Giants. Asian Development Bank. http://dx.doi.org/10.22617/SGP200172-2.

Invest Mongolia, 2024. Economy: Diversified and Growing Market Exists in Mongolia. Investment and Trade Agency. Available at: https://investmongolia.gov.mn/economy/ (accessed 12 January 2024).

Lovrić, M., Da Re, R., Vidale, E., Prokofieva, I., Wong, J., Pettenella, D., Verkerk, P.J. and Mavsar, R., 2020. Non-wood forest products in Europe–A quantitative overview. Forest Policy and Economics, 116, p.102175. https://doi.org/10.1016/j.forpol.2020.102175.

National Statistics Office, 2023. Mongolian Statistical Information Service. Available at: https://www.1212.mn/en/statistic/statcate/573052/report/573052 (accessed 17 December 2023).

Nelson, E., Montgomery, C., Conte, M. and Polasky, S., 2011. The provisioning value of timber and non-timber forest products. In: Kareiva, P. (ed.). Natural Capital: Theory and Practice of

Mapping Ecosystem Services, pp.129-149. https://doi.org/10.1093/acprof:oso/9780199588992.003.0008.

Rawlins, M.A., Aggabao, L.F., Araza, A., Calderon, M., Elomina, J., Ignacio, G.B. and Soyosa, E., 2017. Understanding the Role of Forests in Supporting Livelihoods and Climate Resilience: Case Studies in the Philippines. World Bank: Manila, Philippines. Available at: https://www.profor.info/content/understanding-role-forests-supporting-livelihoods-and-climate-resilience.

Santarem, F., Silva, R. and Santos, P., 2015. Assessing ecotourism potential of hiking trails: A framework to incorporate ecological and cultural features and seasonality. Tourism Management Perspectives, 16, pp.190-206. https://doi.org/10.1016/j.tmp.2015.07.019.

Tsogtbaatar, J., 2002, July. Forest policy development in Mongolia. In: Policy Trend Report 2004. Institute for Global Environmental Strategies. https://www.jstor.org/stable/resrep00866.9.

The World Bank, 2024a. Agriculture, forestry, and fishing, value added (% of GDP) - Mongolia. The World Bank Group. Available at: https://data.worldbank.org/indicator/NV.AGR.TOTL.ZS?locations=MN (accessed 21 November 2023).

The World Bank, 2024b. GDP (current US$) - Mongolia. The World Bank Group. Available at: https://data.worldbank.org/indicator/NY.GDP.MKTP.CD?locations=MN (accessed 21 November 2023).

The World Bank, 2024c. Industry (including construction), value added (% of GDP) - Mongolia. The World Bank Group. Available at: https://data.worldbank.org/indicator/NV.IND.TOTL.ZS?locations=MN (accessed 21 November 2023).

The World Bank, 2024d. Services, value added (% of GDP) - Mongolia. The World Bank Group. Available at: https://data.worldbank.org/indicator/NV.SRV.TOTL.ZS?locations=MN (accessed 21 November 2023).

UNDP, 2023. SDG Partnership with Mongolia on Sustainable Forestry: Preventing illegal logging through innovative digital tools. United Nations Development Programme (UNDP). Available at: https://www.undp.org/policy-centre/seoul/news/sdg-partnership-mongolia-sustainable-forestry-preventing-illegal-logging-through-innovative-digital-tools (accessed 27 November 2023).

Weiss, G., Emery, M.R., Corradini, G. and Živojinović, I., 2020. New values of non-wood forest products. Forests, 11(2), p.165. https://doi.org/10.3390/f11020165.

Wu, X., Liu, G. and Bao, Q., 2023. Impact of economic growth on the changes in forest resources in Inner Mongolia of China. Frontiers in Environmental Science, 11. https://doi.org/10.3389/fenvs.2023.1241703.

Ykhanbai, H., 2010. Mongolia forestry outlook study. Food and Agriculture Organization of the United Nations. Bangkok, Thailand. Available at: http://www.fao.org/3/a-am616e.pdf.

Zhu, H., Hu, S., Ren, Y., Ma, X. and Cao, Y., 2017. Determinants of engagement in non-timber forest products (NTFPs) business activities: A study on worker households in the forest areas of Daxinganling and Xiaoxinganling Mountains, northeastern China. Forest Policy and Economics, 80, pp.125-132. https://doi.org/10.1016/j.forpol.2017.03.019.

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