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# FOREST MANAGEMENT PLAN IN DOMOGT SHARYN GOL, MONGOLIA IS ELABORATED ON ECOLOGICAL AND SUSTAINABLE PRINCIPLES

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## ABSTRACT

A forest management plan based on ecological principles and forest management sustainability was elaborated for the Domogt Sharyn Gol Company, Mongolia. We presented possibility of use of principles and methods traditionally utilized in forest management planning in the Czech Republic. A used methodology was adjusted for the forestry legislature in Mongolia.

A stratification of site characteristics and the forest development type concept was used as a framework for assessment of a forest property state via an operational forest inventory. A randomly generalized network of 354 inventory plots on the total area of 3 194 ha with spacing of 300 × 300 m was established for measurements of tree species, natural regeneration and a volume of lying deadwood.

We produced a text, table, graph, figure and map material consisted of areal, tree species and wood volume structuring including calculation of decenal logging, thinning treatments, plantation activities and natural regeneration support.

This 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. This way of management planning is also a save way towards mitigation of current environmental issues in a Mongolian forest landscape.

**Keywords:** Forest management plan; Mongolia; Forest classification; Sustainable management; Operational inventory.

## INTRODUCTION

Forestry reserves are in possession of the Mongolian state under the exclusive authority of the Mongolian people (The Constitution of Mongolia). A long-term rent of a forest property is allowed when a subject properly manages it (Mongolian Law on Forest, 2013). In Mongolia, controlled management of forests begun in 1960’s as planned logging of merchantable timber without an aimed natural and artificial regeneration/planting (personal communication with Arvindelger Dampil). An action plan of 2008 - 2012 obliged the Mongolian government to implement an ecological, socially oriented management policy with harmonized legislature in restauration and sustainable use of natural resources. The Mongolian public should be involved within this process (Nyam *et al*., 2009). The Mongolian Law on Forest is valid from 2007 and then, the other forest regulations and guidelines such as the Resolution by the Parliament of Mongolia No. 49 (2015) and Guidelines (Nyam *et al*., 2009) were approved. This new legislature tackles a mechanism of distribution of forests to forest user groups and additional subjects, and a form of management checking. This structure assumed elaboration of forest management plans (FMP) for different organization levels: forest user groups, regular management organizations, Soum (district), Aimag (province), and state general plan. At the beginning of forestry transitional period, FMPs were elaborated for 1, then for 3 years. Recently, they are produced for 10 years. A forest management plan definition is presented in the Section 3, Par. 3.1.6 of the Mongolian Law on Forest (2013). A FMP is defined as a complex summary of activities focused on conservation, rationale maintenance, use and regeneration of forests within a particular forest property.

A model FMP for a territory of Domogt Sharyn Gol Company Ltd. (Domogt) was elaborated on a mutual agreement of Czech and Mongolian side within a framework of the cooperation project: „Development of Forests and the Gene Pool of Local Forest Tree Ecotypes in Mongolia 2015–18“. On a particular forest property, we presented a possibility of use of principles and methods traditionally utilized in forest management planning in the Czech Republic. Used methods was adjusted to the existing legislature in Mongolia.

## MATERIAL AND METHODS

### Area of an interest

The forest property of Domogt is localized in Khongor Soum, Darkhan-Uul province near the city of Sharyn Gol. It encompasses plots in an area of 3 193.83 ha. The total forest area is divided into four compartments. A forest/land division (Mongolian Law on Forest, 2013) is showed in Table 1.

**Table 1: An actual area of the Domogt property divided by compartments and a kind of forest/land (forest categories)**

| | Commercial forest | | | | | Non-forested land | | | | | Protection forest | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Compartment | Natural forest | Planted forest | Thin forest | Forest free area | Total | Pastures/meadows | Treeless area | Burned area | Total | Total forest area | Exposed forest-steppe | Willow alluvium | Total | Property total |
| **Areas by the compartments (ha)** | | | | | | | | | | | | | | |
| 83 | 722.27 | 4.77 | 165.20 | 0 | 892.24 | 17.43 | 0 | 0 | 17.43 | 909.67 | 0 | 43.61 | 43.61 | 953.28 |
| 84 | 922.54 | 4.85 | 244.76 | 0 | 1172.15 | 18.92 | 0 | 0 | 18.92 | 1191.07 | 15.41 | 108.69 | 124.10 | 1315.17 |
| 89 | 526.41 | 3.16 | 169.89 | 0 | 699.46 | 20.16 | 0 | 0 | 20.16 | 719.62 | 0.22 | 9.61 | 9.83 | 729.45 |
| 90 | 181.98 | 0.00 | 10.09 | 0 | 192.07 | 2.41 | 0 | 0 | 2.41 | 194.48 | 1.45 | 0 | 1.45 | 195.93 |
| **Total** | **2353.20** | **12.78** | **589.94** | **0** | **2955.92** | **58.92** | **0** | **0** | **0** | **3014.84** | **17.08** | **161.91** | **178.99** | **3193.83** |

Compared to the former FMP, there was an addition of the Domogt forest area of ca 189 ha to the compartment No 90. Besides an area change, there was an increase of a forest category "a planted forest". This category includes plantations from 2016 through 2018, realized in the category of the commercial forests. Plantations out of the commercial forests encompasses 7.12 ha. Additionally, there was a change of an area of protection forests. In the former FMP, this category included only forests on steep slopes (> 30 %, according to the Law on Forest 2013). Based on forest classification (typological) survey, an exposed forest-steppe and willow alluvium was included into this category. The thin forest category (canopy cover < 30 %) was included into the commercial forests contrary to the former FMP.

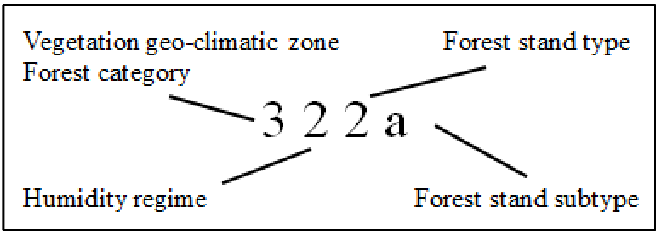
**Forest development type**

A forest development type (FDT) (Mikeska, 2013; Zahradníček *et al.*, 2010) is a forest management differentiation unit based on aggregation of sites with the same or similar potential natural vegetation sensu Tüxen (1956), i.e., with a similar successional trajectory. In the Domogt property, it serves as a framework for assessment of a state of forests via an operational forest inventory (Černý, 2004) and management planning (Kusbach *et al.*, 2019). For FDT structuring on the Domogt property, outputs of the project of the Czech Development Agency No. CzDA-RO-MN-2014-6-31210 „Development of Forests and the Gene Pool of Local Forest Tree Ecotypes in Mongolia 2015-18" were used. This structuring was based on:

- A framework delineation of FDTs that are characterized by natural/environmental conditions (vegetation geo-climatic zonation, site moisture regime),
- Functional structuring of forests based on public interests expressed via forest categories (commercial and protection forests; Mongolian Law on Forest, 2013),
- A state of forest stands defined by a dominant tree species and its successional stage and quality (Průša, 2001).

Site and stand characteristics were indicated by a three-digit and one letter designation (Fig. 1).

**Fig. 1: A digital and letter designation of site and stand characteristics**




*Vegetation geo-climatic coding (landscape zonation).* The first digit of a code of the FDT means two levels of information (i) Vegetation geo-climatic zone, expressing a macroclimatic conditions reflected by specific tree vegetation, (ii) forest category, an odd digit means commercial forests and 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 a forest area is greater than a steppe area, were chosen (Kusbach 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 another information for commercial and another 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 period),
2 – Fresh (mean moisture regime, later in a vegetation period, a soil profile may dry up),
3 – Moist (balanced moisture conditions in all vegetation period).

*Protection forests*:
1 – Extremely dry (drought in all vegetation period)
2 – Fluctuating moisture up to wet (under influence of a seasonally fluctuating ground water table),
3 – Wet (a permanent ground water table presented).

*Forest development type coding* (Kusbach *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 (Fig. 1). Sites were aggregated according to similarity of potential natural vegetation and a related similar successional stage of a natural forest. FDT is named according to a dominant tree of potential natural vegetation or fundamental characteristics of a site, e.g., alluvium. In Domogt, these FDTs were indicated as:
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.* A stand type is a unit expressing an existing state of a forest stand and its remoteness from the target state defined by an owner's management and market strategy. Stand subtype is a part of the stand type different in composition, structure, potentially age from other parts of the stand type with the same or similar treatment. Depending on forest stand properties defined by a dominant tree species composition, structure, quality and its successional stage, three stand types (1–3) and two subtypes (a, b) may be differentiated:

1 – Target: a stand more or less 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, a spatial structure is not differentiated. Only one story is presented.

Subtype b) a structured stand, not reflecting natural composition (in Domogt, usually dominant birch or aspen is presented), a structure can be differentiated and also homogeneous (more than one story is presented),

3 – Distant: subtype a) a low quality stand with not demanding composition, a structure can be differentiated and also homogeneous.

Subtype b) a low canopy cover stand (usually < 0.3).

**Coding examples:**

1. 323a – a low quality stand type with not demanding composition relatively to a target stage, no respect to a stand structure, a fresh site within the montane zone,

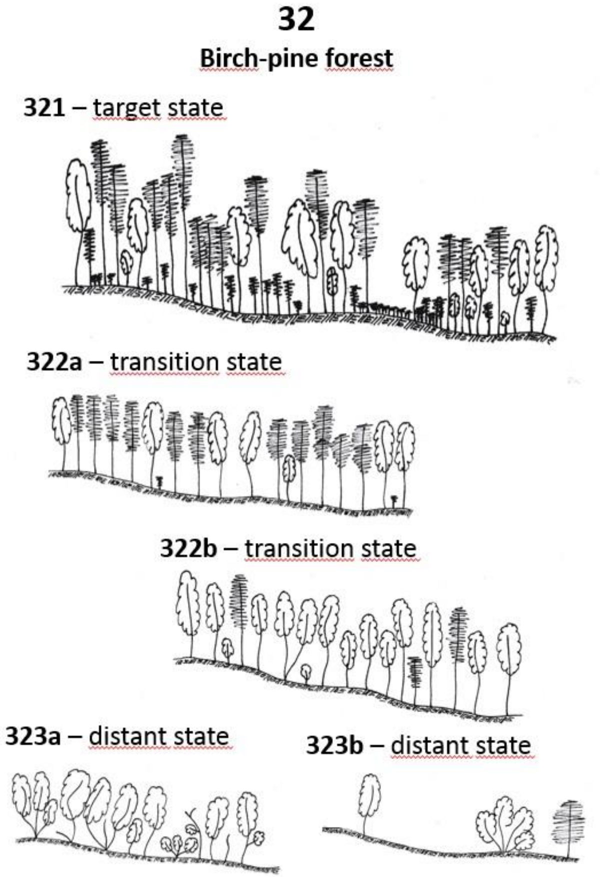
a commercial forest, Birch-pine forests FDT.

2. 323b – a distant stand type with a low canopy cover, a fresh site within the montane zone, a commercial forest, Birch-pine forests FDT (Fig. 2, Table 2).

**Statistical operational inventory**

A statistical operational inventory is one of basic methods for forest state assessment (Černý, 2004). It consists in a measurement of trees in a regular network of inventory plots and then, based on statistical calculations, results are relativized to broader areal units such as management complexes, summarized FDTs or summarized forest stand types. The lowest mandatory spatial framework for a statistical total allowable cut calculations is a summarized FDT (Zahradníček *et al*., 2010). A stratification (typification) of forest stands is a basic principle of the operational inventory. For this reason, FDT, stand types and stand subtypes were suggested. Field works and data gathering took placed in May – June 2018; an analysis and evaluation in October – December 2018.

**Fig. 2: Forest development type 32 Birch-pine forest with differentiation of stand types and subtypes**



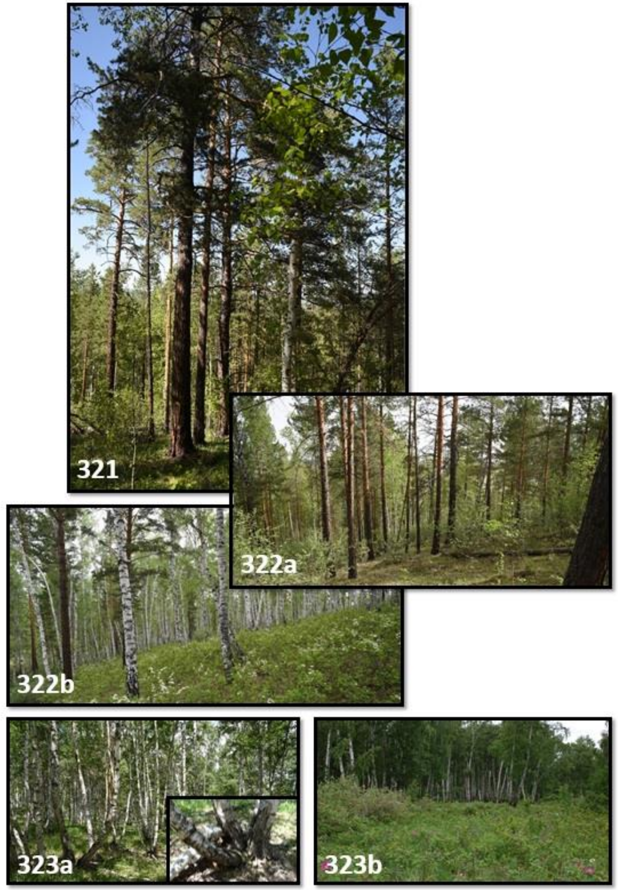
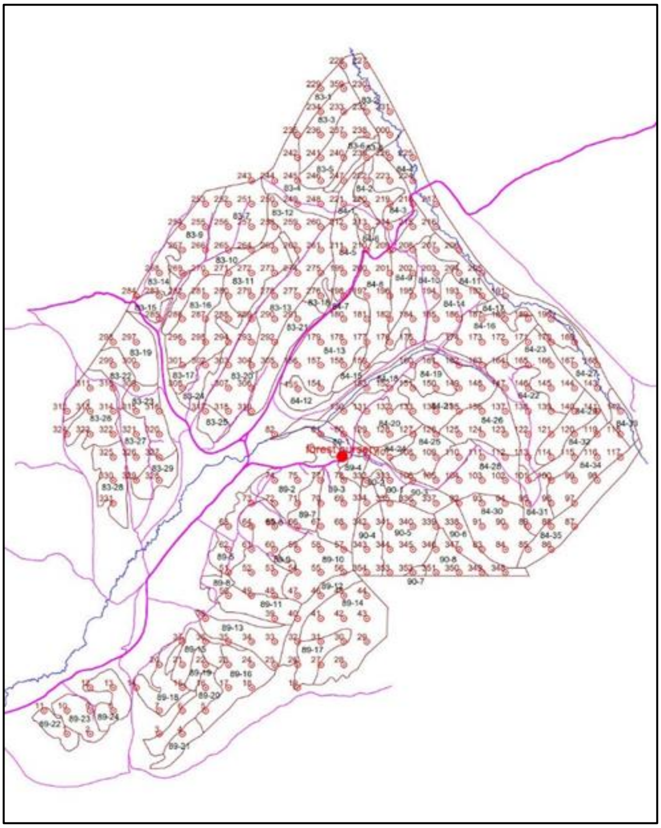



**Table 2: Forest types according to forest development types and actual/existing) vegetation (Kusbach *et al.*, 2019), see the text for forest development type coding (page 3)**

| Actual vegetation | Forest development type | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 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 | 311 | 312a | 313 | | | | 331 | 332a | | | | | | | | | | |
| *Pinus sylvestris* open forest | 311 | | | | | | | | | | | | | | | | | |
| *Pinus sylvestris* exposured forest-steppe | | | | | | | | | | | 41 | | | | | | | |
| *Betula platyphylla<Pinus sylvestris* hemiboreal forest | | 312a | | 321 | 322a | | | 332a | | | | | | | | | | |
| *Pinus sylvestris<Betula platyphylla* hemiboreal forest | | 312b | | | 322b | 323a | | 332b | 333a | | | | | | | | | |
| *Pinus sylvestris-Betula platyphylla* open forest | | | | | | 323b | | | 333b | | | | | | | | | |
| *Betula platyphylla* alluvial forest | | | | | | | | | | | | | 421 | 422 | 423 | | | |
| *Salix* spp.- *Betula platyphylla* alluvial forest | | | | | | | | | | | | | 421 | 422 | 423 | | | |
| *Salix* spp.- alluvial forest | | | | | | | | | | | | | | | | | 43 | |
| *Betula platyphylla* and/or *Populus tremula* young forest | | | 313 | | | 323a | | | 333a | | | | | | | | | |
| Meadow, pasture, clear-cut wetland without woody vegetation | | | | | | | | | | | | | | | | | | |

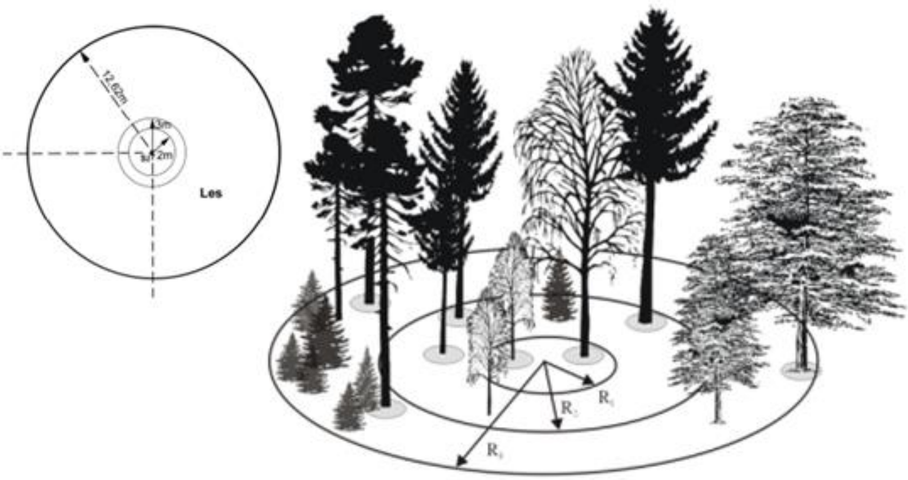
*Inventory plot network*. A randomly generalized backbone network of inventory plots with spacing of 300 x 300 m was established for Domogt (Fig. 3). The TopoL software (TopoL) was used for a random design.

**Fig. 3: Randomly generalized network of inventory plots in Domogt**



An inventory plot of two concentric circles was designed (Fig. 4). The smaller circle plot was used for regeneration assessment (Smola *et al*., 2018). The center of inventory plots was found with a GPS device.

**Fig. 4: The inventory plot schematic design (Černý, 2004), a Czech design from which a modification of two concentric circles with a radius of 12.62 m (area of 500 $m^2$) and 2 m (area of 12.5 $m^2$) was adopted for Mongolia**




**Data**

Field works were realized in May and June 2018 in two periods a 14 days. Two crews of 4 - 5 members were collected. The crews were equipped with Digitech Haglöf calipers and Vertex Laser hypsometers simultaneously used for the circle plot delineation. Data on 354 plots were measured within the time period. In the greater circle, diameters breast height (DBH) of all trees with DBH> 10 cm (for DBH > 15 cm two perpendicular measurements) were measured. We assessed a tree damage on a tree base, e.g., a fire scar, middle part and a tree crown. Snags (dry standing trees) were assessed separately. Five tree samples within a whole diameter range were selected for the height measurement and age assessment using an increment borer. In a smaller circle, a number of seedlings/saplings was calculated including damaged individuals in following height classes: 5–50 cm, 51–130 cm, 130 + cm up to 10 cm of DBH. Because of a high amount of dead wood (coarse woody debris) on a forest floor, a measurement of deadwood was included to the inventory. A database of measured items was created for a statistical calculation.

**Basic procedures**

1. Division of the Domogt area and classification of plots and trees according to FDTs.
2. Height graphs were constructed for pine, aspen and birch sample trees, the trees with an average DBH and a measured height. A height cloud was aligned with a functional equation for each tree species. Then, for each measured tree, a height was calculated.
3. Tree species composition calculation.
4. A tree volume derivation using measured diameter, calculated height and mensuration tables (Nyam, 2009). A mean tree volume derivation based on summarized tree of each plot by species. A real volume ($m^3$/ha) calculation by species.
5. A tree species age calculation.

6. Summarized database for each plot and tree species complemented by a table volume from the Table 6 of the mensuration tables (Nyam, 2009).

*7.* Forest cleaning. The deadwood measurement focused on pine wood due to its durability and potential use as firewood. We measured length and a central diameter (> 10 cm) of lying trunks and thick branches, then calculating a plot volume, we calculated a volume per a stand and hectare. A total volume was calculated from a hectare volume and the total stand area.

8. Logging, commercial use of forests. One of major FMP outputs is a total allowable cut (amount of logged wood) and its distribution within the forest area for 10 years. A total allowable cut in forests of an irregular structure is calculated with a formula:

$$TC_{LHC} = \sum TC_{TVL}$$

where $TC_{TVL}$:

$$TC_{TVL} = \left( CBP_{TVL} + \frac{Zs_{TVL} - Zc_{TVL}}{a_{TVL}} \right) t$$

$TC_{TVL}$ – total logging of a particular FDT for 10 years in $m^3$
$CBP_{TVL}$ – total current year increment of summarized FDT in $m^3$
$Zs_{TVL}$ – calculated stand volume of summarized FDT at the beginning of FMP in $m^3$
$Zc_{TVL}$ – target (example) stand volume of summarized FDT in $m^3$
$a_{TVL}$ – balancing period in years for summarized FDT needed for achievement of a target volume.
t – period of FMP validity (years)

Total current year (periodic) increment:

$$CBP_{TVL} = \left( \frac{Zs_{TVL} + Tt_{TVL} - Zp_{TVL} - D_{TVL}}{t} \right)$$

$Zs_{TVL}$ – inventory stand volume of summarized FDT at the beginning of FMP (current) in $m^3$
$Zp_{TVL}$ – inventory stand volume of summarized FDT from the former FMP in $m^3$
$Tt_{TVL}$ – logging in $m^3$ for an inventory period and summarized FDT, i. e., the period between this and former inventory.
$D_{TVL}$ – increment into a boles stage in $m^3$ of summarized FDT, which exceeded registered DBH during an inventory period
t – time interval between two inventories in years.

For statistical assessment, following items were used: mean, standard deviation, selection variability, and selection error. For each summarized level, volumes ($m^3$/1ha) for pine, aspen and birch were derived for FDT. As a graphical output, a map of actual forest stands, FDTs and stand types was produced using the TopoL software (TopoL).

## RESULTS AND DISCUSSION

In following tables and graphs, selected characteristics of Domogt forest stands were presented as results of operational statistical inventory.

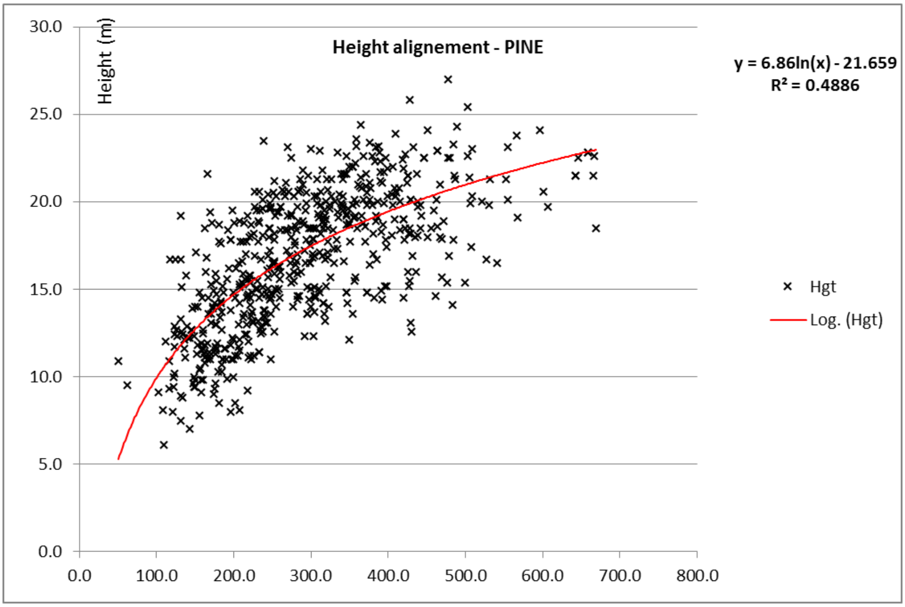
1. Division of the Domogt area according to FDTs is showed in Table 3 and on the map of FDT (Appendix A).

**Table 3: The Domogt property divided by forest development types**

| Forest development type | Area (ha) | Share (%) |
|---|---|---|
| 31 Pine forest | 838.87 | 26.27 |
| 32 Birch-pine forest | 1390.65 | 43.54 |
| 33 Larch-birch-pine forest | 639.63 | 20.03 |
| 41 Exposed forest-steppe | 17.08 | 0.53 |
| 42 Birch alluvium and spring areas | 98.62 | 3.09 |
| 43 Willow alluvium | 140.46 | 4.40 |
| 0 Meadow and pasture | 68.52 | 2.15 |
| **Total** | **3193.83** | **100.00** |

2. An example of the height graph for pine. A height cloud was aligned with a functional equation (Fig. 5).

**Fig. 5: An aligned height cloud of pine**




3. Main tree species composition calculated for defined FDTs (Table 4). A dominant tree species in Domogt is birch (*Betula platyphylla* Sukacz.) and pine (*Pinus sylvestris* L.)

with willow (*Salix caprea* L.) and aspen (*Populus tremula* L.) as codominants. Other tree species such as Siberian larch (*Larix sibirica* Ldb.), Siberian elm (*Ulmus pumila* L.), Asian cherry (*Padus asiatica* Kom.) with a composition less than 2 % do not have commercial importance.

**Table 4: Main tree species composition (ha)**

| Forest development type | Birch | Pine | Aspen | Willow | Non-forest | Total |
|---|---|---|---|---|---|---|
| 31 | 330.9 | 494.1 | 12.7 | 0.0 | | 837.7 |
| 32 | 1006.8 | 308.7 | 80.4 | 0.0 | | 1395.9 |
| 33 | 371.7 | 223.5 | 49.6 | 0.0 | | 644.8 |
| 41 | 4.0 | 10.6 | 2.5 | 0.0 | | 17.1 |
| 42 | 68.1 | 10.2 | 0.5 | 0.0 | | 78.8 |
| 43 | 0.0 | 0.0 | 0.0 | 161.9 | | 161.9 |
| Non-forest | 0.0 | 0.0 | 0.0 | 0.0 | 57.6 | 57.6 |
| **Total sum** | **1781.6** | **1047.0** | **145.7** | **161.9** | **57.6** | **3193.8** |
| **Tree spp. composition %** | **55.8** | **32.8** | **4.6** | **5.1** | **1.8** | **100.0** |

4. Mean and total volume estimates by FDT, stand types and species in Appendix B.
5. Tree species age calculation (Table 5).

**Table 5: Age of tree species by forest development type**

| **Forest development type** | **Tree spp.** | **Mean age** | **Min age** | **Max age** |
|---|---|---|---|---|
| 31 Pine forest | pine | 55 | 16 | 153 |
| | birch | 43 | 16 | 92 |
| | aspen | 28 | 24 | 35 |
| 32 Birch-pine forest | pine | 59 | 24 | 201 |
| | birch | 52 | 17 | 120 |
| | aspen | 46 | 18 | 79 |
| 33 Larch-birch-pine forest | pine | 75 | 17 | 300 |
| | birch | 54 | 18 | 118 |
| | aspen | 41 | 30 | 65 |

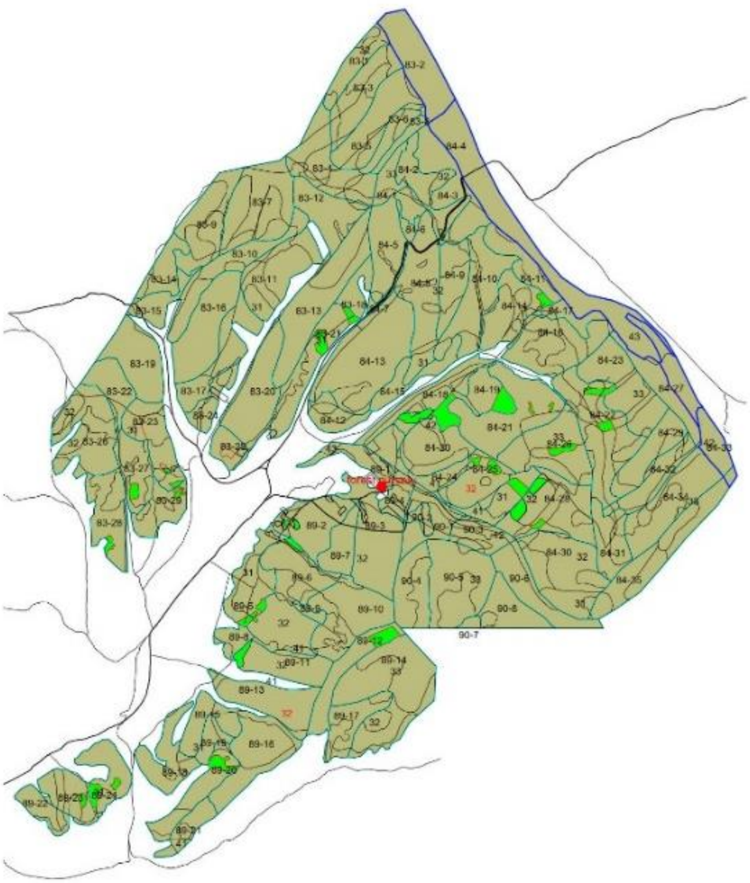
**Proposal of management treatments of FMP**

This FMP respects natural conditions and an actual state of the Domogt forests reflected by FDTs, stand types and subtypes (Table 2). Model management guidelines were elaborated following this stratification. For each level and further for five age phases, we recommended a proper silviculture system, management treatment with protection and possible technology. See an example for the FDT 31 - Pine forest in Appendix D.

**Forest regeneration**

Based on the field survey, and realized model plantation in 2016 and 2017, a proposal of areas suitable for reforestation and underplanting was undertaken (Fig. 6).

**Fig. 6: Proposed locations of reforestation and underplantings in light green color**



Forest natural regeneration of *Pinus sylvestris* is very perspective according to operational inventory in the Domogt property. The field survey was recalculated for stands and tree species as numbers of individuals per hectare. Natural regeneration was classified into four classes:

| No/ha | Regeneration class |
|---|---|
| 1 - 500 | weak regeneration |
| 501 – 1500 | good regeneration |
| 1501 – 5000 | very good regeneration |
| 5001+ | excellent regeneration |

It is obvious that in the area of 63 % of the property, very good and excellent potential of natural regeneration may be achieved when one applies a proper regeneration management such as a type of thinning (e.g., Ulbrychová *et al*., 2018) support and protection (Table 6).

**Table 6: Class and distribution of natural regeneration**

| Class of natural regeneration | Area (ha) | Class share % |
|---|---|---|
| Weak | 239.02 | 5 |
| Good | 493.41 | 11 |
| Very good | 1069.67 | 27 |
| Excellent | 959 | 36 |
| No | 375.13 | 12 |
| Non-forest | 57.57 | 9 |
| Total sum | 3193.8 | 100 |

### Tending/pre-commercial thinning

Tending in Mongolian forests is solved in the Appendix 1 of the regulation No 190 of the Ministry of Environment and Tourism 2009. The Guideliness No. 88 „The Technical instruction of tending realization“ specifies four types of pre-commercial thinning: a) cleaning, b) increment thinning, c) weak thinning, d) mechanical thinning.

There was no target tending treatment on a majority of the Domogt property so far. Only some tending/shelterwood, probably towards support of pine, was realized on the compartments 83-23, 83-26, 83-27, 83-28, 83-29 and 89-24 (Fig.6). In the Domogt FMP, thinning treatments were specified according to urgency of a treatment: a) urgent thinning with priority realization (usually in the first half of the FMP validity), and b) thinning without priority with realization anytime during the decennium, usually within the second half of FMP.

### Forest cleaning

Results and an image of lying dead wood are showed in Table 7, Fig. 7.

**Table 7: A volume of lying dead pine wood according to the Domogt compartments**

| Compartment | Mean volume of lying pine wood ($m^3$/ha) | Total volume of lying pine wood ($m^3$) |
|---|---:|---:|
| 83 | 7 | 5 249 |
| 84 | 7 | 7 965 |
| 89 | 3 | 2 903 |
| 90 | 3 | 984 |
| **Total sum** | **6** | **17 101** |

**Fig. 7: Lying pine dead wood, logging slash**

**Logging, commercial use of forests.**

A current tree species composition and spatial structure of Domogt forests are a result of combined influence of growth conditions with disturbances including a former forest use. The former management was focused only on selection logging of thick trunks. Table 8 displays a total volume of forest stands with a volume of lying dead wood structured by tree species.

**Table 8: A total volume of wood on the Domogt property structured by species and forest development types**

| **Forest development type** | **Total volume m$^3$ with bark** | | | |
|---|---|---|---|---|
| | Birch | Pine | Aspen | Total |
| 31 Pine forest | 15305.0 | 51049.0 | 43.0 | 66397 |
| 32 Birch-pine forest | 90037.0 | 19192.0 | 660.0 | 109889 |
| 33 Larch-birch-pine forest | 23844.0 | 22016.0 | 852.0 | 46712 |
| 41 Exposed forest-steppe | 0.0 | 0.0 | 0.0 | 0 |
| 42 Birch alluvium and spring areas | 5897.0 | 174.0 | 0.0 | 6071 |
| 43 Willow alluvium | 0.0 | 0.0 | 0.0 | 0 |
| **Total sum** | **135083.0** | **92431.0** | **1555.0** | **229069.0** |

A total allowable cut (a logging volume for a period of 10 years) was suggested in following categories:

- Individual selection focused on broadleaved trees over 61 years and pine trees over 121 years,
- Shelterwood selection in two - four phases in already managed stands,
- Support of natural regeneration as a form of an individual selection. It is possible to combine this treatment with thinning from above to get timber quality (Ulbrychová *et al.*, 2018, Table 9).

**Table 9: Total allowable cut divided by categories and tree species for the Domogt property**

| Management treatment | Logging volume/thinning $m^3$ with bark | | | |
|---|---|---|---|---|
| | Birch | Pine | Aspen | Total |
| Shelterwood 4-phases | 49 | 81 | 0 | 130 |
| Shelterwood 2-phases | 44 | 34 | 0 | 78 |
| Support of natural regeneration | 409 | 0 | 0 | 409 |
| Thinning urgent | 383 | 221 | 0 | 604 |
| Thinning regular | 1523 | 591 | 0 | 2114 |
| Thinning/cleaning | 24 | 315 | 0 | 339 |
| Cleaning | 0 | 0 | 0 | 0 |
| Selection logging | 1167 | 316 | 0 | 1483 |
| Total sum | 3599 | 1558 | 0 | 5157 |

The total allowable cut was suggested inductively, i.e., treatments were placed into particular stands and drawn down in the map of management treatments (technology map) (Appendix C). A total amount of wood represents 13% of a decenal increment on the Domogt property. However, it is possible to increase the total cut up to 8 246 $m^3$, it means 20 % of the increment. This threshold was suggested with regards on an actual condition of the Domogt forest stands and technological possibilities of the Domogt.

Birch is the most representative tree species on the Domogt (55.8 %), following by pine (32.8 %). Other tree species without commercial importance do not exceed 5 %. Tree species composition is also obvious from suggested FDTs. A distance of an existing forest stand from a target state is a very important indicator. Only 10 % of stands are close to the target state. Transitional stands are the most prevailing (67 %), a distant state is characteristic for 21% of stands. A mean stand stocking is 0.58, which indicates a relatively thin, open forest, an indicator of not a very good condition of the Domogt forests resulting from natural and human-induced disturbances and mainly forest management (improper former logging) (Gerelbaatar *et al*., 2019).

Domogt FMP based on ecological principles and forest management sustainability provides a feasible prescription of treatments not only towards immediate commercial benefits but also towards sustainability in forest yield and other ecological forest functions. This way of management planning is also save towards mitigation of current environmental issues such as global climate change (Čermák *et al*., 2019) in a Mongolian forest landscape.

## CONCLUSIONS

A forest management plan based on ecological principles and forest management sustainability was elaborated for the Domogt Sharyn Gol Company, Mongolia. On this forest property, we presented possibility of use of principles and methods traditionally utilized in forest management planning in the Czech Republic. A used methodology was adjusted for the forestry legislature of Mongolia.

Forest management plans so far were oriented on logging activities. Forest regeneration was neglected, areas after logging were left to natural succession. This elaborated FMP respects natural conditions and the actual state of the forests reflected by FDTs, stand types and subtypes, which model management guidelines were elaborated for. Additionally, FMP is coming from statistical operational inventory that provides objective mensurational items and then information on a volume of forest stands. These properties enable objectification of logging possibilities via the total allowable cut. FMP solves forest regeneration and tending with a clearly located treatment including urgency prescription for 10 years. If this FMP will be realized a state of the Domogt forests should not worsen.

This FMP is to our best knowledge, the first plan in Mongolia, elaborated on ecological principles. It provides a feasible prescription of treatments not only towards immediate commercial benefits but also towards sustainability in forest yield and other ecological forest functions. This way of management planning is also save towards mitigation of current environmental issues in a Mongolian forest landscape.

## ACKNOWLEDGEMENTS

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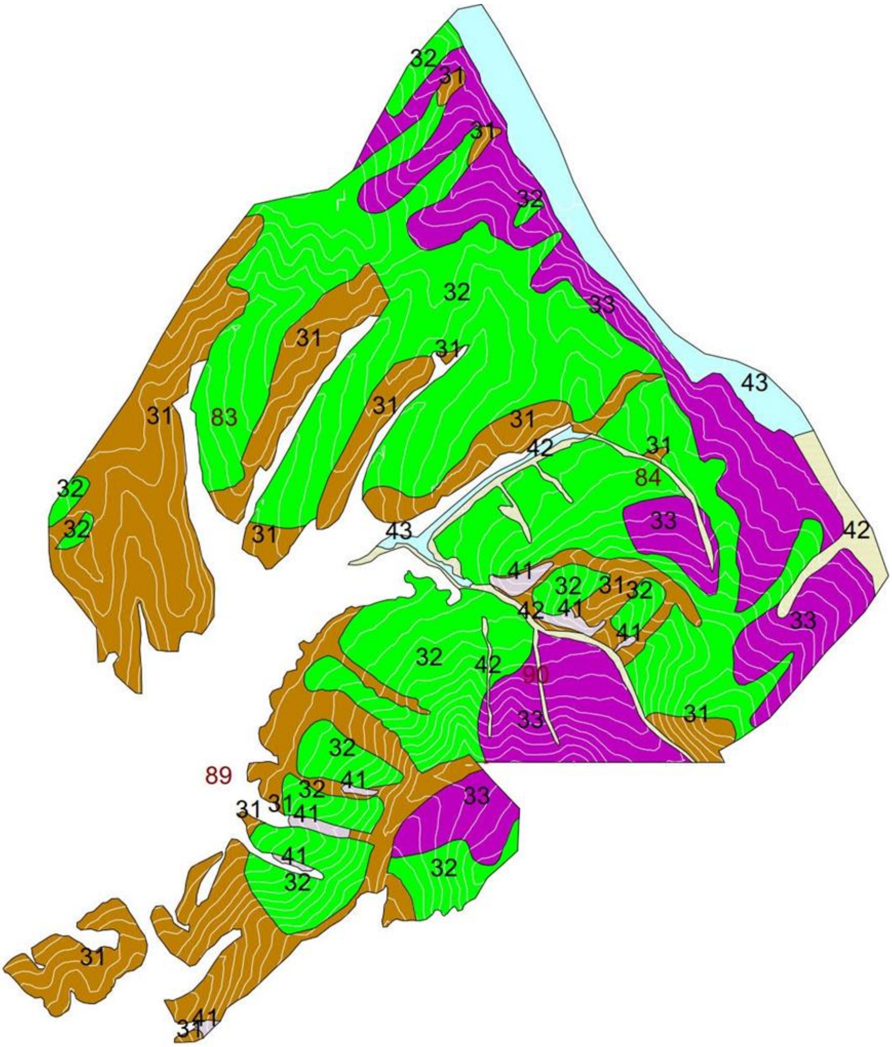
## APPENDIX

### Appendix A: Map of forest development types




**Forest development types 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

## Appendix B: Volume estimates by forest development types (FDT), stand types (ST) and species

| FDT | ST | Species | Mean volume $m^3$/ha | Mean volume error $m^3$/ha | Mean volume used $m^3$/ha | Plot number | Tree species area ha | Total volume $m^3$ |
|---|---|---|---|---|---|---|---|---|
| 31 | 311 | Pine | 143.67 | 40.50 | 184.17 | 4 | 32.70 | 6 022.0 |
| 31 | 312a | Pine | 129.62 | 16.56 | 146.18 | 25 | 146.90 | 21 474.0 |
| 31 | 312b | Pine | 64.53 | 14.82 | 79.35 | 24 | 62.70 | 4 975.0 |
| 31 | 313 | Pine | 62.22 | 11.68 | 73.90 | 31 | 251.40 | 18 578.0 |
| 32 | 321 | Pine | 77.48 | 18.63 | 96.11 | 7 | 10.20 | 980.0 |
| 32 | 322a | Pine | 101.00 | 11.50 | 112.50 | 31 | 85.00 | 9 563.0 |
| 32 | 322b | Pine | 38.91 | 4.44 | 43.35 | 94 | 187.90 | 8 145.0 |
| 32 | 323a | Pine | 2.11 | 1.20 | 3.31 | 11 | 2.10 | 7.0 |
| 32 | 323b | Pine | 14.19 | 8.19 | 22.38 | 8 | 22.20 | 497.0 |
| 33 | 331 | Pine | 105.09 | 20.83 | 125.92 | 10 | 24.60 | 3 098.0 |
| 33 | 332a | Pine | 101.38 | 23.55 | 124.93 | 11 | 129.70 | 16 203.0 |
| 33 | 332b | Pine | 35.75 | 6.09 | 41.84 | 36 | 52.10 | 2 180.0 |
| 33 | 333a | Pine | 10.47 | 10.47 | 20.94 | 3 | 4.10 | 86.0 |
| 33 | 333b | Pine | 23.56 | 12.09 | 35.65 | 7 | 12.60 | 449.0 |
| 42 | 421 | Pine | 21.16 | 16.86 | 38.02 | 7 | 2.90 | 110.0 |
| 42 | 422 | Pine | 5.07 | 3.75 | 8.82 | 3 | 7.30 | 64.0 |
| 31 | 311 | Birch | 4.47 | 2.61 | 7.08 | 4 | 6.40 | 45.0 |
| 31 | 312a | Birch | 25.01 | 5.79 | 30.80 | 25 | 50.20 | 1 546.0 |
| 31 | 312b | Birch | 64.95 | 8.43 | 73.38 | 24 | 164.20 | 12 049.0 |
| 31 | 313 | Birch | 11.67 | 3.47 | 15.14 | 31 | 110.00 | 1 665.0 |
| 32 | 321 | Birch | 85.88 | 11.51 | 97.39 | 7 | 14.50 | 1 412.0 |
| 32 | 322a | Birch | 82.14 | 9.43 | 91.57 | 31 | 98.10 | 8 983.0 |
| 32 | 322b | Birch | 92.35 | 5.47 | 97.82 | 94 | 727.40 | 71 154.0 |
| 32 | 323a | Birch | 53.93 | 10.45 | 64.38 | 11 | 31.80 | 2 047.0 |
| 32 | 323b | Birch | 35.72 | 12.35 | 48.07 | 8 | 134.00 | 6 441.0 |
| 33 | 331 | Birch | 58.16 | 12.75 | 70.91 | 10 | 22.40 | 1 588.0 |
| 33 | 332a | Birch | 30.77 | 7.01 | 37.78 | 11 | 77.70 | 2 936.0 |
| 33 | 332b | Birch | 66.59 | 5.88 | 72.47 | 36 | 199.70 | 14 472.0 |
| 33 | 333a | Birch | 66.73 | 34.59 | 101.32 | 3 | 33.40 | 3 384.0 |
| 33 | 333b | Birch | 28.41 | 10.02 | 38.43 | 7 | 38.10 | 1 464.0 |
| 42 | 421 | Birch | 55.34 | 20.08 | 75.42 | 7 | 32.10 | 2 421.0 |
| 42 | 422 | Birch | 70.07 | 26.22 | 96.29 | 3 | 36.10 | 3 476.0 |
| 31 | 311 | Aspen | 0.00 | 0.00 | 0.00 | 4 | 0.00 | 0.0 |
| 31 | 312a | Aspen | 0.38 | 0.35 | 0.73 | 25 | 0.61 | 0.0 |
| 31 | 312b | Aspen | 2.79 | 1.58 | 4.37 | 24 | 6.60 | 29.0 |
| 31 | 313 | Aspen | 1.28 | 1.23 | 2.51 | 31 | 5.40 | 14.0 |
| 32 | 321 | Aspen | 7.33 | 3.49 | 10.82 | 7 | 1.90 | 21.0 |
| 32 | 322a | Aspen | 8.92 | 3.88 | 12.80 | 31 | 6.60 | 84.0 |
| 32 | 322b | Aspen | 4.33 | 1.51 | 5.84 | 94 | 55.30 | 323.0 |
| 32 | 323a | Aspen | 19.42 | 11.48 | 30.90 | 11 | 6.90 | 213.0 |
| 32 | 323b | Aspen | 0.97 | 0.97 | 1.94 | 8 | 9.70 | 19.0 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 33 | 331 | Aspen | 4.28 | 3.87 | 8.15 | 10 | 5.20 | 42.0 |
| 33 | 332a | Aspen | 5.54 | 4.04 | 9.58 | 11 | 16.80 | 161.0 |
| 33 | 332b | Aspen | 5.05 | 2.47 | 7.52 | 36 | 13.20 | 99.0 |
| 33 | 333a | Aspen | 23.40 | 23.40 | 46.80 | 3 | 8.90 | 417.0 |
| 33 | 333b | Aspen | 12.34 | 12.34 | 24.68 | 7 | 5.40 | 133.0 |
| 42 | 421 | Aspen | 0.31 | 0.31 | 0.62 | 7 | 0.50 | 0.0 |
| 42 | 422 | Aspen | 0.00 | 0.00 | 0.00 | 3 | 0.00 | 0.0 |
| | | | Total | | | | 2953.51 | 229 069.0 |

**Appendix C: Map of management treatments (technology map)**

**Legend:**

00 No treatment-natural forest regeneration

01 Planting

02 Underplanting

03 Selection logging

04 Shelterwood 2-phases

05 Shelterwood 4-phases

09 Cleaning

26 Thinning/cleaning

10 Urgent thinning (age of 21–60 years)

11 Thinning regular (age of 21–60 years)

12 Pasture, meadow

13 Support of natural regeneration

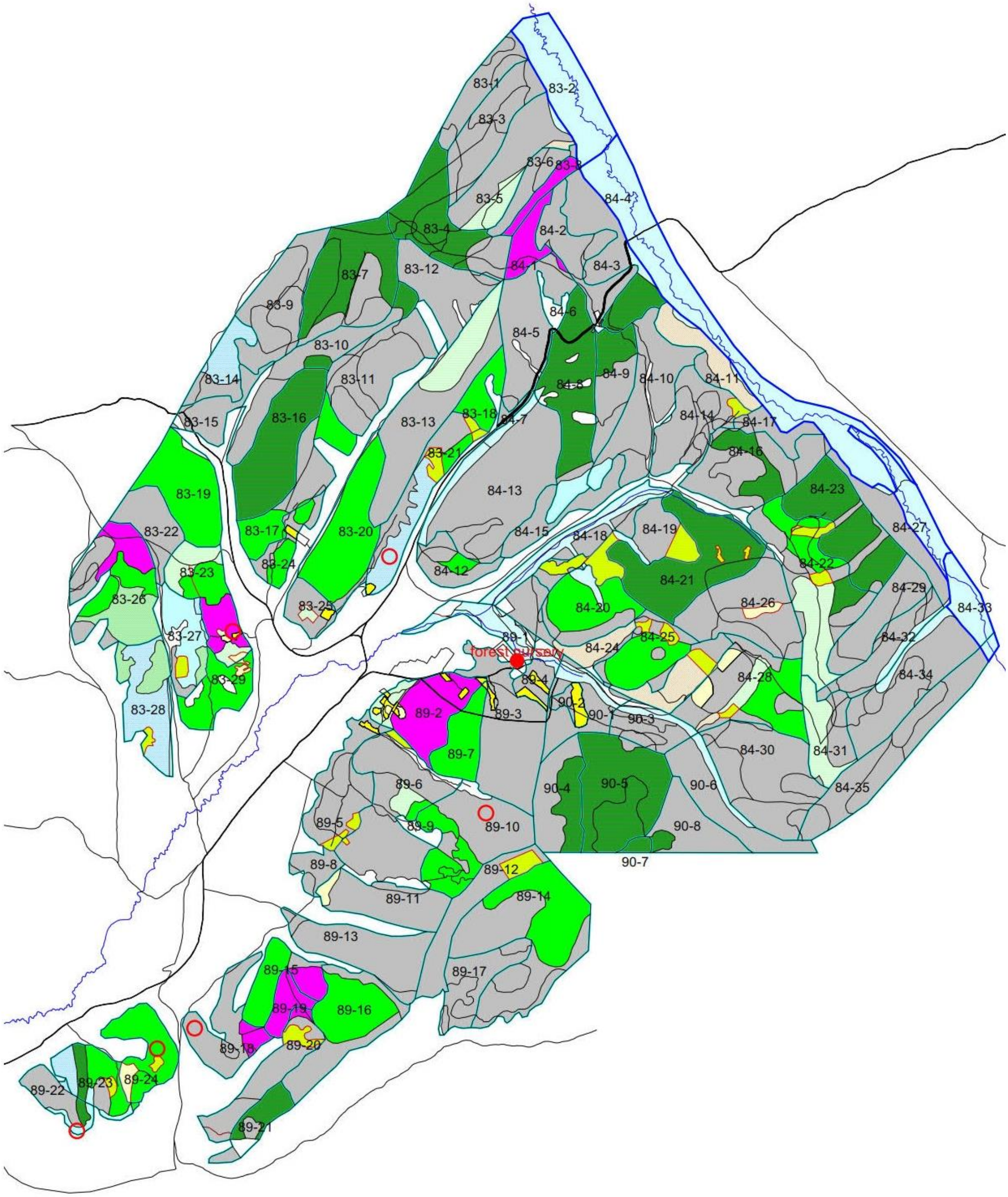
15 Reforestation/afforestation (proposal)

25 Protection forest

27 Slope > 30°

16 Insect outbreaks logging

17 Fire strips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## Appendix D. Forest management guidelines

| **Forest development type** | **31 – Pine forests** | | | |
|---|---|---|---|---|
| **Commercial composition (%)** | pine 95, birch 5 | | | |
| **Stand type/subtype** | **311 – Target** | **312 – Transition** | | **313 – Distant** |
| | Pine structured | **a** – Pine homogeneous | **b** – Pine-birch homogeneous and structured | **a** - Poorly stocked areas |
| **Stand characteristics** | Strongly differentiated stands by structure with dominant pine and admixture of birch and/or aspen (<5%). Minimally two-story stands. Spontaneous regeneration of pine supported by target logging/thinning treatments A mosaic of two/three-story stands is optimal. | Simple stands by structure with a full - very thin canopy. Stands with one distinct story, others are indistinctive. | Simple - differentiated stands by structure with more than 30% of birch (aspen). | Very thin stands for a long time, also with only scattered trees. Clear cut vegetation is fully developed, natural regeneration is impossible in a short time period. |
| **Minimal number of seedlings/saplings for planting (pieces/ha)** | 1500 | 1500 | 2500 | 2500 |
| **Silviculture system** | Selective or shelterwood system. A vertical structure of stands by individual/group selection of ripe trees (>121 years) is a goal. | Shelterwood system oriented on development of a lower story. Gradual effort towards transition to a selective system individual/group. Alternatively, transition to two-story stands with 2-4-phase shelterwood. | Group shelterwood in pine spots focused on increase of target quality pine. Reduction of low quality and damaged birch and aspen in thinning. | To leave to natural succession. In larger, more homogeneous spots and proper sites (soil moisture), support of natural regeneration is demanding (shelterwood is possible). |
| **Forest regeneration / reforestation** | Natural regeneration under an old stand is preferential. Artificial regeneration is exceptional. Clear cut only in a case of disaster. Snags (standing dead trees) kept for shading on exposed south-facing slopes. | Natural regeneration under an old stand is preferential. Artificial regeneration is exceptional. Clear cut only in a case of disaster. Snags (standing dead trees) kept for shading on exposed south-facing slopes. | Natural regeneration under an old stand is preferential. Artificial regeneration is exceptional. Clear cut only in a case of disaster. In a case of clear cuts over 1 ha, artificial planting of pine is possible. | To leave to natural succession. Proper clear cuts over 1 ha can be artificially planted by pine is possible. on exposed clearings under overgrazing, protection of regeneration and plantations is necessary (repellent painting, spraying, fencing etc.) |
| **Young phase up to 20 years (broadleaved up to 10 years)** | **Clearing** in dense stands (stocking over 1.0) after natural regeneration, reduction of numbers of individuals, growth support of a dominant species by light access. | **Clearing** in dense stands (stocking over 1.0) after natural regeneration, reduction of numbers of individuals, growth support of a dominant species by light access. Sanitary selection. | **Clearing** only in case of lower story presence. | **Clearing** only in case of extremely dense groups of birch and aspen. A goal is adjustment of numbers and support of light increment. Sanitary selection. |
| **Middle phase 21–40 years (broadleaved 11–20 years)** | **Thinning** aiming to quality and health. Stand stability, spatial and growth (light) adjustment. | **Thinning** aiming to quality and health. Stand stability, spatial and growth (light) adjustment. | **Thinning** focusing quality and health selection. Stand stability, spatial and growth (light) adjustment. | **Thinning** only in case of extremely dense groups of birch and aspen. Reduction of individuals numbers, support of target pine. |
| **Premature phase 41–60 let (broadleaved 21–40 years)** | **Thinning** aiming to quality and health. Stand stability, spatial and growth adjustment mainly in a main crown level. Possible release of a younger lower story. | **Thinning** aiming to quality and health. Stand stability, spatial and growth adjustment mainly in a main crown level. Possible release of a younger lower story. | **Thinning** aiming to quality and health. Stand stability, spatial and growth adjustment mainly in a main crown level. Possible release of n younger lower story. | |
| **Mature phase 61–110 let (broadleaved 41–60 let)** | **Thinning** aiming to space arrangement towards light increment increase and optimization of light conditions of a lower story. | **Thinning** aiming to space arrangement towards light increment increase and optimization of light conditions of a lower story. | **Thinning** aiming to adjustment of stand spacing (reduction of individuals' numbers), set up a proper microclimate for establishment of a lower story. This establishment is possible in a natural way (regeneration) or artificial way (underplanting). | |

| | | | | |
|---|---|---|---|---|
| **Final phase 121+ years (broadleaved 61+ )** | **Logging of ripe individuals, release of a lower story.** Treatment iteration after 10 - 20 years in broadleaved species, 20 - 40 years in conifers. | **Logging of ripe individuals,** (conifers over 121 years, broadleaved over 61 years), release of a lower independent story. A final stage of shelterwood. Treatment iteration after 10 - 20 years in broadleaved species, 20 - 40 years in conifers. | **Logging of ripe individuals,** (conifers over 121 years, broadleaved over 61 years), release of a lower independent story. A final stage of shelterwood. Treatment iteration after 10 - 20 years in broadleaved species, 20 - 40 years in conifers. | |
| **Poorly stocked area/Clear cut** | - | Treatments toward support of natural regeneration, reduction of dead wood, scarification of a ground surface on a bare mineral horizon (soil cutter, "iron horse"). The soil treatment realization in a seed year. Spot without natural regeneration should be planted artificially. | Treatments toward support of natural regeneration, reduction of dead wood, scarification of a ground surface on a bare mineral horizon (soil cutter, "iron horse"). The soil treatment realization in a seed year. Spot without natural regeneration should be planted artificially. | Treatments toward support of natural regeneration, reduction of dead wood, scarification of a ground surface on a bare mineral horizon (soil cutter, "iron horse"). The soil treatment realization in a seed year. Spot without natural regeneration should be planted artificially. |
| **Dead wood** | Lying dead wood to process for firewood (forest cleaning) or chips. Other useless slash should be piled. | Lying dead wood to process for firewood (forest cleaning) or chips. Other useless slash should be piled. | Lying dead wood to process for firewood (forest cleaning) or chips. Other useless slash should be piled. | Lying dead wood to process for firewood (forest cleaning) or chips. Other useless slash should be piled. |
| **Forest protection treatment** | **Regeneration:** fencing of planted areas and natural regeneration is necessary in stands in contact with pastures. Repellents can be used for older regeneration as protection against wildlife browsing. | **Regeneration:** fencing of planted areas and natural regeneration is necessary in stands in contact with pastures. Repellents can be used for older regeneration as protection against wildlife browsing. | **Regeneration:** fencing of planted areas and natural regeneration is necessary in stands in contact with pastures. Repellents can be used for older regeneration as protection against wildlife browsing. | **Regeneration:** fencing of planted areas and natural regeneration is necessary in stands in contact with pastures. Repellents can be used for older regeneration as protection against wildlife browsing. |
| | **Young, mid-age and mature stands:** fast processing of trees killed by a bark beetle *Ips subelongatus*, when clearcut appears, protection of natural regeneration or artificial planting is necessary. To minimize deadwood and a slash volume. Transport lines linked to a forest road network are necessary for protection treatments of natural regeneration and plantations. 30 % of snags (standing dead trees) left for microclimate improvement. Logging on slopes over 30°should be avoided except salvage logging. | **Young, mid-age and mature stands:** fast processing of trees killed by a bark beetle *Ips subelongatus*, when clearcut appears, protection of natural regeneration or artificial planting is necessary. To minimize deadwood and a slash volume. Transport lines linked to a forest road network are necessary for protection treatments of natural regeneration and plantations. 30 % of snags (standing dead trees) left for microclimate improvement. Logging on slopes over 30°should be avoided except salvage logging. | **Young, mid-age and mature stands:** fast processing of trees killed by a bark beetle *Ips subelongatus*, when clearcut appears, protection of natural regeneration or artificial planting is necessary. To minimize deadwood and a slash volume. Transport lines linked to a forest road network are necessary for protection treatments of natural regeneration and plantations. 30 % of snags (standing dead trees) left for microclimate improvement. Logging on slopes over 30°should be avoided except salvage logging. | **Young, mid-age and mature stands:** fast processing of trees killed by a bark beetle *Ips subelongatus*, when clearcut appears, protection of natural regeneration or artificial planting is necessary. To minimize deadwood and a slash volume. Transport lines linked to a forest road network are necessary for protection treatments of natural regeneration and plantations. 30 % of snags (standing dead trees) left for microclimate improvement. Logging on slopes over 30°should be avoided except salvage logging. |
| **Technology** | To minimize damages of natural regeneration, directional felling is necessary. Skidding on marked transport lines and a forest road network. Low stumps should be left for additional machinery for soil preparation (soil cutter, scarifier). | To minimize damages of natural regeneration, directional felling is necessary. Skidding on marked transport lines and a forest road network. Low stumps should be left for additional machinery for soil preparation (soil cutter, scarifier). | To minimize damages of natural regeneration, directional felling is necessary. Skidding on marked transport lines and a forest road network. Low stumps should be left for additional machinery for soil preparation (soil cutter, scarifier). | Hand hole planting using a hoe-axe or spade. Brush-cutter for preparing of planting lines, weed protection for five years. |