Forest management - silvicultural systems

Matjaž Čater, *Slovenian Forestry Institute,*
Jurij Diaci, *University of Ljubljana, Biotechnical Faculty, Department of Forestry and Renewable Forest Resources*

The crisis of the human natural environment, and particularly the change and exploitation of forests with increasing need for the provision of goods caused the development of silviculture (Eng.: silviculture, Ger.: Waldbau, It.: selvicoltura, Fr.: sylviculture). Forestry shifted during its development from deforestation and shifting agriculture in prehistoric times, through exploitation and mechanistic management towards the current sustainable, close-to-nature approach. The latter provides, along with the permanent and optimal yield, a number of ecological, social, nature-protection and other important forest functions, which are in harmony with the related requirements and environmental constraints.

Most of the world exploits forests, and due to pasturing, intensive agriculture and urbanization, the share of forests in tropical and developing countries is significantly decreasing, although in European countries the share is rising. Nevertheless, European forests are among the most changed ones due to the long-term prolonged cultivation of conifers at the expense of deciduous tree species, and promotion of fast-growing tree plantations with short-term benefits. Moreover, the economic importance of forests has recently started weakening in Europe, while the ecological and numerous intangible benefits are becoming more and more pronounced. This view of forests as a renewable source of raw materials and energy, a carbon sink and provider of ecological and social functions (Diaci 2006) is counterbalanced against increased wood consumption (UNECE - European Commission 2007), global scale deforestation and human population growth, as the differences in the silvicultural principles applied around the world are becoming greater than ever (Diaci and Golob, 2009). The situation is worsened by the increases in water and air pollution, and the increasing frequency and intensity of extreme weather events.

Planning represents silviculture's starting point. The basic purpose of planning – the determination of current conditions and defining practices to provide successful forest development – is divided into long-term, regulatory-forest management planning, and implementation, silvicultural planning. The regulatory plan outlines the framework guidelines and restrictions on forest intervention, while a detailed plan defines direct guidelines for the practical implementation of the regulatory plan.

Planning is crucial for sustainable forestry, and is based on a control method and the continuous verification of the forest's current state, and its responses and adaptation to the applied silvicultural measures (Diaci 2006).

Nearly 300 years ago the principle of sustainability was introduced in Central Europe and Slovenia, for which forest management planning was essential. Early examples are the Slovenian Idrija mining forests (the first established plan in 1724) and the Trnovo forest plan (the first plan of 1771), which supplied Trieste and Gorizia with wood – the first plan-regulated forest in the Austro-Hungarian empire was the Vienna Forest from 1720 (Gašperšič 2009). Forests were managed in the manner of old German clearcutting approach, applied in the Alpine and Pre-alpine region of Slovenia. The first deviation from this conservative approach was made during second half of the 19th century to avoid degradation of the sites in the high karst region of Kočevska by introducing plentering (Hufnagel) and a unique control method (Schollmayer) in the Notranjska region (Mlinšek, 1992). After World War II a widespread development programme was adopted due to the poor state of the forests and clear-felling was prohibited by law.

Today the development of forests is carried out in accordance with the natural site conditions by the measures of regeneration and tending. Tending represents all measures which aim to regulate the growth of individual trees and entire forest stands, provide the highest economic return and improve stand quality and stability (Leibundgut 1984). All development processes in forests are regulated and triggered by varying light conditions, which influence interspecific and intra specific competition, especially in low light environments. By eliminating competitors and helping quality trees, with tending measures for young stands and thinnings, we increase the share of quality assortments and provide a better quality of emerging stands, strengthening their mechanical and biotic stability and ensuring optimal quality yield.

In the north European countries clearcutting is the main silvicultural system, justified by the special ecological conditions and predominating tree species. Lower temperatures and a raw humus layer limit development of natural regeneration (Lafleur et al., 2018). The consequences of clearcutting may be reflected in many consequent forest generations in degraded sites, reduced production capacity, compromised mechanical and biotic stability of the stands, and consequently lower yield and reduced resilience (Diaci, 2006). The requirements for greater intensity and economic efficiency require an increasing mechanisation of work, the introduction of fast-growing species and the use of chemical preparations and fertilizers that are not allowed in Slovenia.

Forest management is now being abandoned on poor and less profitable sites, which do not meet the economic criteria. Governance follows the traditional concept, emphasizing the more natural tree species composition of altered forests (conversions) and preserving their healthy conditions. Around the wider world, but especially in Europe, there are growing efforts towards developing models of sustainable forest management.

Although Slovenia is known for its sustainable concept of management and a large share of preserved and protected forests compared to other European countries, the number of silvicultural problems is increasing; natural regeneration is hampered by overpopulated ungulates, there is an evident imbalance between developmental phases, forests are declining, and tending is performed insufficiently. Management costs are rising, as well as the pressure and demands for the increased protective and social functions of forests, while forestry as a field is being marginalized due to matters related to the state economy and political inconvenience. Noticeable deviations from planned and implemented silvicultural works compared to stable investments from the previous decades are increasingly evident. There are many challenges for the future, and one of the principal tasks is to preserve the active direction of sustainable forest development with an atmosphere of cooperation and the provision of adequate information to forest owners (Diaci and Golob, 2009).

Silvicultural systems

All measures for achieving the targeted goal of managed forests in a given time and space are defined by the silvicultural system. It represents the planning directions and all the required direct measures in the individual spatial forest units to permanently achieve the targeted/ final state, the defined goal with tending methods and information about the method of regeneration (forest restoration).

The first systems from the early ancient periods would be hard to characterize as silvicultural due to the lack of timber (the Mediterranean). They were designed for smaller areas than systems applied later in the 19th century. Lack of timber and increasing demands caused a crisis which encouraged the development of the sustainability principle – the permanent provision of timber and the definition of the smallest area that would provide such a concept. The first forms followed design from agriculture, where each year the same area of harvested forest was planted with young trees. The number of all such parcels represented the area of the forest, which consistently provided a permanent yield. The strict spatial order allowed control and the first such transparent management was established in Central Europe, which became later known as the German forestry school.

In the middle of the 19th century, the fragments of a different, selective silvicultural approach in France, Switzerland and Slovenia were established. Due to unregulated primitive plentering, which left behind depleted forests, the system gradually proved its efficiency and benefits, as developed in opposition to the former clearcutting system of the German forestry school, especially after World War II. Today this approach is acquiring international recognition for obtaining other, also protective and social forest functions.

Silvicultural systems can be classified according to their historical development and application, from the early cultivation types like clearcutting, the shelterwood system and edge-shelterwood system, to modern approaches based on tending that include the irregular shelterwood method, selection system and free silvicultural technique.

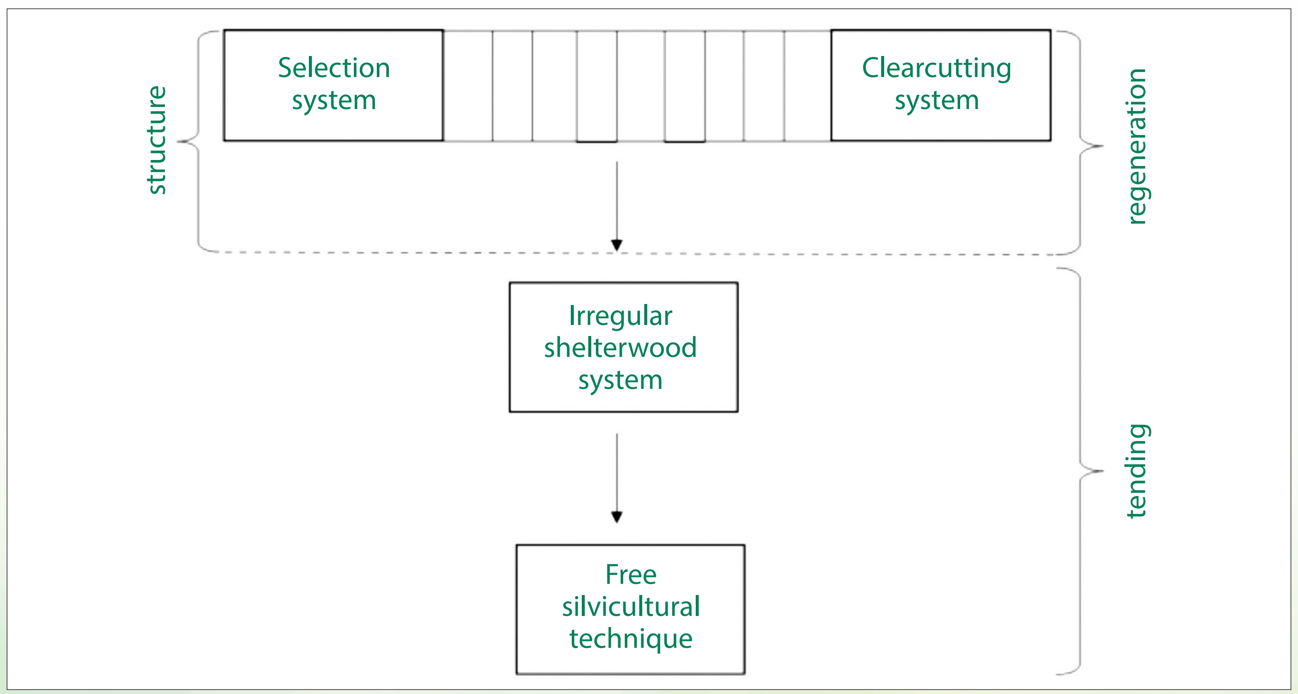

Figure 9: Silvicultural systems according to their leading or governing principles: regeneration, structure and tending (after Mlinšek 1968).

Clear-felling

Despite its rigidity, clear-felling is still present in most European countries: it prevails for example in Austria, Scandinavia and a large part of Russia due to specific environmental conditions, and as a form of exploitation in the tropical and subtropical belt on a global scale (Diaci, 2006). The remains of this type of management in Slovenia are still visible today in Pohorje and Alpine spruce forests, where ironworks or glassworks were set in the past. Trees grown under this system are more susceptible to mechanical damage (windthrows), insect attacks, and so on (Diaci, 2006). However, shifting from clear-felling to a different system represents long term and expensive process. The system in Slovenia is prohibited by the law: it is characterized by short-term advantages, such as large quantities of equal assortments, the possibility of machine-felling, low costs of tending and harvesting, simple planning and the possibility of mechanised tree planting. However, the long-term weaknesses outweigh these short-term benefits (Bormann and Likens, 1986), and these include depletion of site conditions, problematic natural regeneration and lower stand stability of larger areas, which are present for generations after their establishment, preventing the natural balance from being re-established. Moreover, the resulting increased risk of erosion, changes in energy flow and matter cycling due to increased solar radiation (Mayer, 1981; Flemming, 1968; Holstener-Joergensen, 1967) and increased exposure to temperature and precipitation extremes (Mitscherlisch et al., 1966; Hibbert, 1967) are processes that are far from natural. Accelerated mineralization of the soil and loss of nutrients also have negative effect on water quality, while the presence of pioneer species may inhibit the establishment of climax tree species for a longer time period due to altered site conditions (Irrgang, 1990; Diaci, 2006).

Despite criticism and numerous shortcomings, the clear-felling system may be applied on small surfaces in direct conversions – in cases of the compromised health of a certain stand which threatens the adjacent stands. After the conversion, intensive investment in the restoration and protection of such stands is required.

Figure 10: Clearcutting in Slovenia is prohibited by law since 1949 (Photo: M. Čater)

Shelterwood method

The shelterwood system is composed of various cutting forms of cutting – preparatory, regeneration, light and final or only light and final logging. By progressively loosening the mature canopy over time the intensive development of the ground vegetation is controlled, which would otherwise prevent successful regeneration. Light conditions allow the emergence of natural saplings under mature canopy stand, especially in the case of broadleaves. Preparatory logging stimulates floor activity due to less dense canopy cover and releases adult quality trees; regeneration logging allows the emergence of saplings in mast years. The measure intensity reaches up to 30% of the growing stock, but not more, otherwise emerging species would suppress sapling development. This is followed by one or several light cuts, which are carefully planned to cause as little damage and injuries to the remaining regeneration as possible. Light conditions are adapted to the regenerated species. With the last, final logging we remove the remaining trees of the mature stand, usually when the younger phase does not require further protection from the mature stand. The time from the beginning of the light cuts to the final cut is the regeneration period, and this mainly depends on the light requirements of the species and the size of the stand. For light demanding species the regeneration period is shorter than for shade tolerant species.

This system was created as a response to the clearcutting system in Central Europe and, has been established mainly in broadleaf and mixed forest stands. In Slovenia, it was present at the time of glassworks and ironworks in Carinthia, Pohorje, and Idrija, and represented a qualitative improvement in the direction of forest soil conservation and the protection of the newly emerging stands. The regeneration process was also more transparent and faster compared to the previous one. The main disadvantages of the system are the dependence on the mast years of the old stand, and the susceptibility of the young stand to later interventions. This system is still in use in some pure and mixed beech stands of Central Europe (Diaci 2006).

Strip-shelterwood system

The more favourable conditions at the forest edge and more successful regeneration compared to the conditions under shelter promoted development of the next system, known as the strip-shelterwood approach. The forest edge was shifted by harvesting, and by cutting belts the width of the tree height along the forest edge favourable conditions for the emergence of various types of young trees were established. The edges were initially straight and with development they adapted to the ground conditions (exposition, slope) or prevailing winds that influenced the microclimate. The distinction among cutting, harvesting and transporting areas was clearer than in shelterwood light logging. By determination of the bandwidth, the method allows the cultivation of species with different ecological light requirements. Like the shelterwood method, this system introduced a rigid and strictly defined spatial order to ensure an annual harvest and successful natural regeneration. Unfortunately, the system does not consider the forest as a whole system or does not respect individual trees and microsites that require an individual approach. Tending is not anticipated, the mechanical stability of the forest stands created in this way is questionable, and they are often damaged by the wind. Rapid regeneration leads to uniform forms or stand shapes that are unstable on large areas.

Figure 11: Strip-shelterwood system (Photo: M. Čater)

Irregular shelterwood system

Large-sized forest stands created by the clearcutting or shelterwood system did not provide sufficient stability against the natural disturbances. The search for better possibilities, with regeneration in the openings and gaps, led to the development of so-called regeneration cores, where young trees emerged under the shelter and protection of the mature canopy stand. Later, the cores were merged, and each forest stand acquired the new form with a multidimensional structure. The original form was limited only to the regeneration of the oldest parts of the stands with the smallest scale logging (Germany), while a later system relied heavily on the tending principle (Switzerland) and gained its present value. For the first time in history, the harvesting system adapted and followed the tending principles of the adult stand, to both the site conditions and the ecology of the entire forest. The new system required close cooperation with silvicultural planning, and no longer followed a strict spatial order.

Today's irregular shelterwood approach involves assessing the responses of adult stands and creating a favourable climate for successful regeneration by constant evaluation of the tree responses to the silvicultural measures applied (i.e., the control method). The resulting measures dynamically adjust to the goals. Both care and tending are used at the same time in all development phases, which are present on a small surface and provide with their diversity a greater stability of the stand. Cutting is adapted and more detailed and, more frequent than in the previously described systems, with a lower intensity. Regeneration is carefully planned on location, where other measures would not damage or compromise its emergence. Logging is carefully planned to provide minimal injuries.

Figure 12: Irregular shelterwood system (Photo: M. Čater)

Natural regeneration of tree species is constantly present in all older development phases of the forest. Depending on the ecological conditions, they can always be included for stand renewal or the admixture regulation of tree species, if necessary. If problems arise with regeneration, the vitality of the stand is compromised. Following all the tending measures, however, ensures sustainability. The rotation period introduced by the previous systems is defined individually and refers primarily to the dynamics of the rise in value, which indicates the economic suitability of the stand regeneration, and thus the cutting of adult trees, which is species and site specific. The share of development phases is balanced, towards the permanent provision of silvicultural and other objectives and functions of the stand on small surface areas. In Slovenia this is the predominating system.

Plenter / selection system

The original form of plentering had a different character from today's selection system, as the forests were extensively exploited in a way that enabled negative selection, leaving behind fewer valuable individuals. The forests were not tended, and the yield was modest. The selection structure may be presented as a natural reaction of forests, especially at extreme sites, and as a transient and short-term process in the old growth forests reserves.

The advanced system was first presented in France during the middle of the 19th century and in Switzerland at the end of the 20th. At the same time, on Slovenian territory, selective large-scale Kočevje forests were established, while in Postojna, in addition to the established selection system the control method was also applied, which included repeated forest inventories. The first approach was numerical and individual – all felling trees were chosen by measuring the threshold of the diameter at breast height. The forests of the high karst would soon be devastated by the clear-felling method, since the soil would not favour regeneration on larger areas, so the management consequently focused on plentering and natural regeneration under the cover of mature forest stands.

In the selection method forest trees of all dimensions are represented on a small surface area, ensuring sustainable production and conservation of the site's potential. Regeneration is continuous, and the growth and development of trees are more individualized compared to the previous systems. The canopy cover is not continuous, but variable, multi-layered and following a stepwise structure. A tree's status can only be determined by its social position in relation to the neighbouring trees.

In the social ascent of trees, the overgrowing of individual trees appears when the light conditions or the release of competitors allows the passage from one to the other layer. In the selection stands we may define the various stand positions of the forest trees as follows:

1 **the position of suppressed, waiting individuals** is characterized by shady microsites, where height growth is supressed, and only the most vigorous individuals survive. Shade tolerant species like silver fir (*Abies alba* Mill.) could dwell in this position for more than a hundred years. Growth is plagiotropic, due to modest light-intensity conditions.

2 **the position of runners** is indicated by smaller gaps and light shafts, where height growth is rapidly increased due to the increased light environment or release of the competitors. Mechanically, these trees are not very stable due to high slenderness ratio.

3 **the position of winners or carriers**; the social ascent is completed; despite slow initial radial growth a long period of stable, unsuppressed height and radial growth is followed.

The social ascent of trees is not strictly increasing, and the reverse path is also possible, from runners to the suppressed position of waiters. In plenter forest with the advanced selection technique, regeneration, regulating of competitors (waiters, runners, winners), tending and exploitation are performed with one single measure. This usually refers to clusters of an individual position rather than to individual trees (like in the case of numerical plentering), so the efficiency is greater. Objectives are defined by the equilibrium state (continuous production by preserving natural processes), where self-regulating mechanisms of care and tending are most emphasized and expressed. The measure of balance represents the size of the growing stock, the representation of tree species in the growing stock and their radial increment. The control method checks the forest response after silvicultural measures have been performed and adjusts them in the most favoured direction with regard to achieving a balanced state with total inventory or, if the costs of this are too great, using sampling methods.

The selection system is of course not suitable for all tree species and all sites; it is more adapted to shade tolerant species that can thrive in modest light conditions – especially for conifers (spruce and fir). The selection method is more demanding in the case of broadleaves (beech), especially due to unwanted forms of growth and, consequently, poor assortment quality if the light is not sufficient. Where regeneration is compromised due to overpopulation with herbivores, the preservation of the selection method is associated with high costs.

Of all the presented systems, the selection system is closest to natural processes, which can also be observed in virgin forests and old growth reserves (Diaci 2006, Schütz et al. 2016, Adamič et al. 2017). The cost of tending and regeneration is low compared to other systems; indirect care and tending prevail with self-regulating mechanisms performed by selection cutting. Due to individual tree growth, the stability of the stands is better and also better able to adapt to environmental changes. Assortment structure and yields are constant, focused primarily towards the quality of native, autochthonous species. The more even distribution of target trees – carriers – along the entire surface consequently means less accumulated harvesting intensities, dispersed throughout the whole stand. In the case of larger assortments, harvesting is more demanding due to the increased injuries of loggers or damage to regeneration and remaining stand. This is also true for the regeneration phase, which is less abundant, but spatially dispersed throughout the stands. Due to the complexity of the work, the planning is more difficult, aimed at combining stands with similar structure and silvicultural goals.

Free silvicultural method

Of all the techniques reviewed here, the free silvicultural approach is the youngest and includes principles of the plentering, selection and irregular shelterwood systems. It is characterized by the free choice of silvicultural measures but requires a lot of professional competence and consistency. It is suitable for all types of sites and stands, but most of all in cases where we can not only consider the principles of irregular shelterwood or plentering alone: it may be applied on degraded and changed stands, where there are problems associated with inappropriate former management (litter-gathering forests, coppice forests) or in degraded or declining forests, where site and stand conditions require great flexibility with regard to the silvicultural approaches adopted. Due to its adaptation to the specific site conditions and problems, the free silvicultural technique combines elements of various approaches on small surface areas. It requires careful and demanding planning according to the established management objectives.

The principles of the free silvicultural technique combine the preservation of natural site fertility, the nursing of young forests and tending of the adult stand, preserving and respecting individuality, attention being paid to function holders, natural regeneration, natural governance of the site factors, silvicultural planning and great alignment with natural processes (Mlinšek 1968). The measures should mimic natural conditions and cause as little disturbance to the forest as possible (Mlinšek 1968).

Figure 13: 95% of Slovenian forests are regenerated naturally (Photo: M. Čater)

Tending measures are applied in all stand development phases. Setting clear and realistic goals represents the most demanding part of the process; it is a prerequisite for determining the type and extent of the necessary tending measures to reach the defined goal (function). The goal of each development phase is its next stage, where their characteristics and properties are described in detail – the quality, the structure and the possible peculiarities of the site. Direct or indirect tending should provide protection against adverse conditions (weather, mechanical, biotic) and enable the selection of quality individuals and promote the desired positive properties.

- In the youngest development stage direct tending is performed to protect saplings in the herbal layer by regulating the species admixture (the relationship between tree species, taking into account their competitive power) and cleaning (removing herbs and shrubs that inhibit the growth of the young and the removal of diseased specimens). We exploit the influence of an adult stand, providing indirect care for protection against weather extremes and protection against wild animals. The stability design and quality of the next developmental stage depends on the proper timing of the performance and quality of the work, which should be strictly maintained.

- By cleaning of the dense young forest (with a height up to 2-3 m) a mass of quality individuals is selected and the conditions for social ascent are provided. Future quality is increased by removal of overgrown and branched trees, and by thus reducing the density greater mechanical stability is provided. The density of conifers may be smaller than in broadleaves but depends on the individual tree species. Large-scale tending with negative selection becomes positive in the later development stages, when individual positive qualities are recognized.

- After stratification in the former stage is finished and the economically interesting properties of individuals begin to appear, we start to perform selective thinning to stimulate growth, as the growing space is restricted. Resistance, mechanical stand stability and above all value all significantly increase at this stage. The former mass selection progressively transforms to selected groups and/or responsive individuals. Thinning is constantly present until the stands are introduced to the regeneration phase. The optimal growing conditions of the selected individuals provide better quality and yield of the stands. **Thinning intensity** indicates the time when tending begins and determines the amount of the harvested wood volume according to the living stock in the stand. The **frequency** of thinning is species and site specific: in younger stands and on good sites, interventions are more frequent due to faster stand response, while on more modest, depleted and older stands, where interactions between selected individuals/groups and their competitors is declining out because of their age, thinning becomes less and less frequent.

An important silvicultural tool is the filling layer – the remainder of the lower pole stand layer that disappears in time and is difficult to maintain in pure stands; usually it is composed of ecologically complementary tree species. It provides more favourable soil conditions and a stand microclimate even at its higher age, favourable natural regeneration and the possibility of regulating light in both stand layers. The value of the upper layer should not suffer from this, however, otherwise the nourishing role of the filling layer is missed. Measures within filling layer (light intensity, shaping) are separated from the thinning in the upper layer.

Silvicultural planning

Forest management could not be imagined without silvicultural planning due to the complexity of processes and constantly changing state of forest ecosystems. A silvicultural plan includes a set of all the necessary measures and actions in time and space to ensure optimal success by following the natural processes and at the same time considering the requirements for the permanent and multipurpose role of the forest stands. A silvicultural plan is a tool for finding optimal solutions, as well as a document for verifying the state and success of previous decision-making processes (Mlinšek 1968, Diaci 2006). It is crucial to closely integrate silvicultural planning and forest operations.

A forest management plan defines the main guidelines to ensure sustainability at the spatial and content level of forest management districts and units; it is more strategic and refers to general orientations and the coordination of interests. Silvicultural planning derives a more detailed set of direct, implementing measures with specific tasks in the content of completed works. Successful silvicultural planning requires key knowledge of the stands, sites and their origin, with clear, realistic and defined objectives (and measures) to achieve defined goals. All parts of the forest stand with the same long-term forest management goals on similar sites are classified into permanent silvicultural planning units. Smaller, tending units are defined by the short-term or stage silvicultural goals, and relate to the same developmental stages within the silvicultural-planning units.

Silvicultural goals

Silvicultural goals are defined by the prevailing ecological, economic and social conditions. With regard to the temporal scale, we define long-term goals as those affected predominantly by site fertility, and short-term goals as those defined by the growth characteristics of forest stands. Preservation of **site productivity** (site-production capacity) is only possible with a good understanding and proper selection of suitable tree species. The starting conditions listed in the forest management plans of forest units serve as a reference here. Long-term silvicultural goals define and characterize the forest management, and the final silvicultural image of the forest stand with its defined structure, tree species admixture, quality and targeted living stock (Mlinšek 1968). As a measure of site fertility we consider the maximal possible yield (of mass or value) achieved by the ideal silvicultural treatment (Kotar 2005), by the peak of the average volume or increase in value. Natural site fertility may be reduced (Karst) or preserved (Dinaric region).

Stand growth potential is defined by the development of stand value: if the growth potential and site productivity are consistent and optimally exploited, the peak of the average value increment achieves site fertility. The culmination itself is prolonged, giving the silviculturist wider space to manoeuvre for the final measures and regeneration of the stand. If the growth potential is large and the site productivity is small (e.g. in case of allochtonous species), current tree species deplete and degrade site conditions, as their nutritional demands are too great. The introduction of regeneration is appropriate when the average value increment begins to decline. Due to the incorrect selection of tree species, however, the situation could also occur when the average increment does not reach the level of site productivity, and thus it is reasonable to introduce the regeneration process without delay. This is because the loss of stand value increases over time.

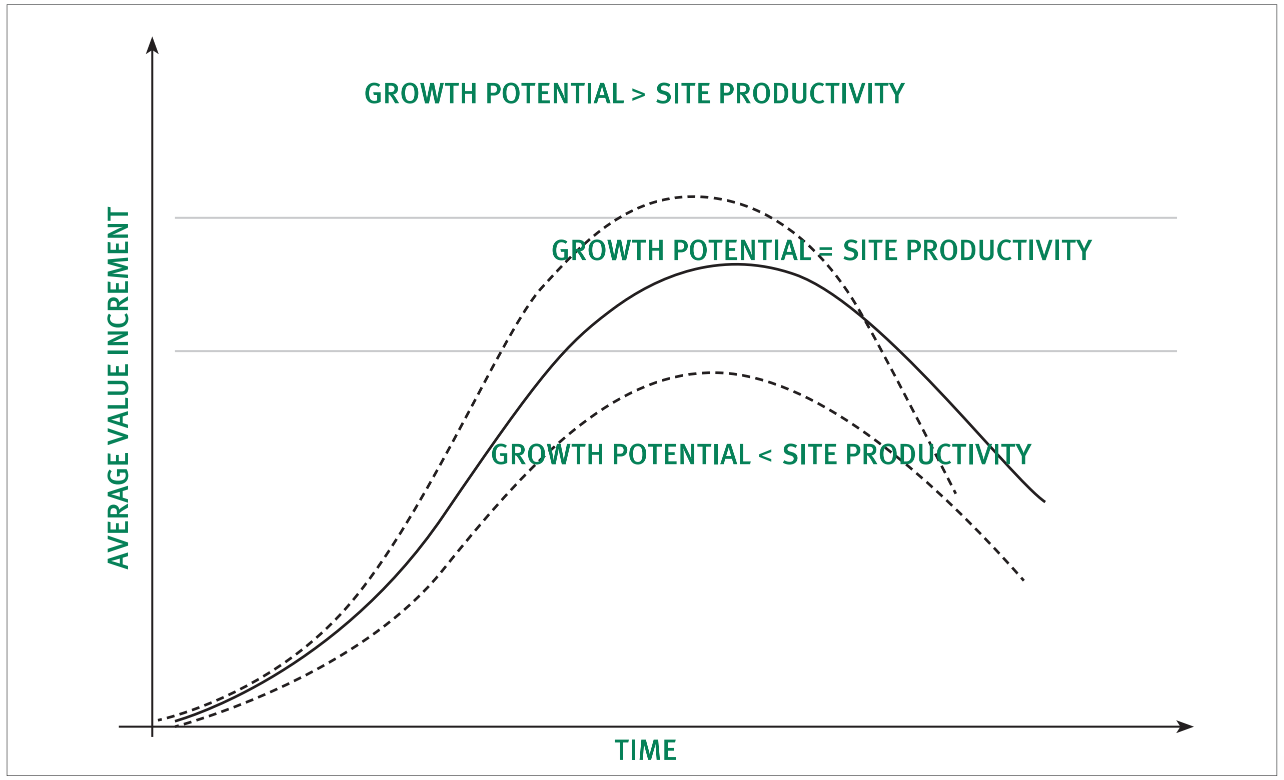

Figure 14: Growth potential and site productivity

Silvicultural measures

Silvicultural measures represent the best solution for achieving the goal of a certain final value of the stands, with many possible routes and given schedules. Targets can be achieved faster with more intensive measures or over a longer time period with lower intensity. We adapt measures to the condition of the forest, the available material resources and experience, such as the knowledge of the forest owner. The measures in tending units relate to the development stages of the stands, considering the overall image of the stand. The specific area and normative standards are also considered when planning and calculating costs.

Silvicultural plan

A silvicultural plan is needed to document various decisions in the process of reaching the final, targeted state of the forest. The initiation of a plan may be based on either a completed planning period with realized objectives, or different circumstances that require the adjustment of an existing plan by obtaining new, updated information for its actualization. For many factors that influence such decisions, it is sensible that the current and former planner are the same person, because valuable experience is transferred to the next planning period (lasting five to 15 years).

- The current forest management plan, the course of the current management (silvicultural plans) and maps represent starting points for the definition of the situation, which is verified in the field. The assessment of the measures required to achieve goals relates to individual development phases, where development trends should be identified (Diaci 2006). Special features are parts of stands, where no measures will be performed.

- The stage of gathering information is followed by drawing up and assembling a plan, defined by the objectives and multifunctional target forest image. Long-term goals are set for planning units, followed by the stage objectives and general orientations (tending, regeneration, logging). The general part of the plan defines the state of the forest, the long-term objectives and guidelines for the planned units, while the special part of the plan defines the current condition, stage goals and measures for each tending unit. An essential supplement is a map of sites showing the planning and tending units along with all the required details. Once the stage goals of tending units have been achieved, the plan is updated. It is complemented according to the stand development and management intensity, with preference given to more demanding interventions.

- Implementation is closely related to tree marking, logging and harvesting; the thoughtful spatial order and rational time sequence of such measures can reduce costs and increase the work quality. After performing the work and protection measures, the planner and forest owner compare the plan with what has been realized (Diaci 2006). Organization of the planning in Slovenia is separated from the implementation (logging, harvesting).

- The control of the forest response to tending measures triggers corrections and an assessment of the quality of the past planning period. Adjustment corrections could be performed with additional silvicultural measures or tending, which are reasonably combined with regular interventions or logging measures in order to lower costs.

Involving forest owners in the planning process is sensible for assessing the cost of tending measures. The plan should rely on the decisions and orientations of the owners, and less on detailed stand description. If developed with the participation of forest owners, such a plan is a good tool for finding the optimal solutions for the future forest conditions.

Regeneration

The first cultivation systems had difficulties with regeneration because of their strict spatial order, and therefore artificial regeneration was necessary. Professional observations recognized benefits of **natural regeneration**, which is today encouraged due to the lower costs, existing microsite adaptation of the young forest and free choice among numerous autochthonous species. Regeneration under adult stand canopy cover provides better protection and benefits with regard to future stand quality. In vital stands natural regeneration is constantly present, but only a few trees reach the final stage of an adult, dominant position in a constantly changing cycle of replacing generations. Physiological ageing, which dictates regeneration cycles, is accelerated by disease, while shading in younger stages of development causes a slowing down of the processes and indirectly prolongs lifespan. It also depends on the site and composition of tree species. Forest ecology and respecting economic frames are starting points which can help to determine the time and duration of the regeneration in an individual stand.

In cases of altered tree species composition (spruce, pine plantations), on degraded stands, in the extreme conditions or after large scale natural disturbances, regeneration with sowing or planting, known as **artificial regeneration**, is applied. The areas for regeneration are prepared by manual arrangement of residuals after harvesting. In limited quantities, these increase the circulation of soil nutrients and favourably affect soil conditions. The competitive ability of the introduced seedlings is also improved by the mechanical removal of ground vegetation.

Soil preparation (where required) represents a more demanding and expensive task and influences the structure and release of soil nutrients; it also includes preparation for mechanical sowing or planting. However, the value of this approach is questionable on sensitive soils, which could be easily damaged and compressed by heavy machinery. Species selection must be in line with site conditions and numerous ecological factors. Due to the many advantages, planting predominates before sowing. Seedlings are planted on average on 500 ha per year, while sowing is performed on average 10 ha. Seedlings and seed of up to 35 tree species are used for artificial regeneration although Norway spruce still predominates and is followed by European beech, noble hardwoods such as maple and cherry and oaks. Enrichment planting is needed if natural or artificial restoration is not successful and regeneration on larger scales is compromised. The success of planting decreases with the age of seedlings, as the demands of young trees progressively increase and consequently the transplant shock is also greater. Such enrichment planting also provides an opportunity for adaptation to climate change by utilising seedlings and seed from forest stands adapted to warmer and/or dryer conditions.

Based on ecological regions, Slovenia is divided into seven provenance regions with further sub-regions and four altitudinal belts. The legislation requires the use of seed and seedlings in the same altitudinal belt as the forest reproductive material was collected, while it encourages its use within the same provenance region. Unfortunately, there is only a limited number of forest nurseries in Slovenia and seedlings that would fit the planting site best are not always readily available. This is amplified as most seedlings used for artificial regeneration are bareroot seedlings.

Realization of silvicultural work is the responsibility of the owner. Among the most important activities of a district forester is thus co-operation with forest owners in the form of advising, educating, and training for carrying out the professional work of silviculture and forest protection. The most effective approach is through direct contacts with owners, and more than 100 seminars and workshops are organized by the Slovenia Forest Service annually to educate forest owners when this is not possible. Nature and administrative procedures are two different notions, but nevertheless for all activities of silviculture (including the selection of trees for possible felling) and forest protection, the Slovenia Forest Service issues administrative decrees for forest owners. The work and financial resources intended for the forest are an investment that they mostly will not benefit from themselves. Because of this, and also due to the public interest in the generally useful roles of the forest, a system of financing and co-financing investments in forests has been established from the budget of the Republic of Slovenia and European funds, which enables forest owners who manage their forests according to such plans to obtain some resources once their work is finished.

Literature

Adamic, M., Diaci, J., Rozman, A., Hladnik, D., 2017. Long-term use of uneven-aged silviculture in mixed mountain Dinaric forests: a comparison of old-growth and managed stands, Forestry: An International Journal of Forest Research, Volume 90, Issue 2, 279–291.

Bončina, A., Kadunc, A., Robič, D., 2007. Effects of selective thinning on growth and development of beech (Fagus sylvatica L.) forest stands in south-eastern Slovenia. Annals of Forest Science 64, 47-57.

Bormann, F.H., Likens, G.E., 1986. Pattern and Processes in a Forested Ecosystem. Springer, New York.

Božič, G., Kraigher, H. 2012. Kdaj je naravna obnova alfa in ne tudi omega: tehnične smernice za ohranjanje in rabo genskih virov: Slovenija. Gozdarski vestnik, 70: 141.

Flemming, G., 1968. The wind speed on clear cut areas within forest stands. Archiv.f.Forstw.: 5-16 (in German).

Diaci, J. 2006. Silviculture: primeval forests, forest stands, systems, planning, selected chapters. University textbook, University of Ljubljana, Biotechnical Faculty, Department of Forestry and Renewable Forest Resources, 348 p (in Slovene).

Diaci, J., Golob, A., 2009. Slovenian Forestry Meeting the 21st Century Challenges. Gozdarski vestnik 67, 307-316 (in Slovene).

Diaci, J., Kerr, G., O'Hara, K., 2011. Twenty-first century forestry: integrating ecologically based, uneven-aged silviculture with increased demands on forests. Forestry 84, 463-465.

Gašperšič, F. 2009. Forests and Forestry in Slovenia, Discussion on Forum 21, Cankarjev dom, Ljubljana, October 2009.

Hibbert, A.H., 1976. Forest treatment effects on water yield. In: Sopper, W.E., Lull, H.W. (Eds.) Intern. Symp. On Forest Hydrology. Oxford: 527-550.

Holstener-Joergensen H., 1967. Influences of Forest management and drainage on groundwater fluctuations. In: Sopper, W.E., Lull, H.W. (Eds.) Intern. Symp. On Forest Hydrology. Oxford: 325-333.

Irrgang, S., 1990. Dynamics of the species structure as well as biomass production and accumulation in the first year following clear cut. Arch. Nat. schutz Landsch. Forch. 30.: 231-252 (in German).

Kotar, M. 2005. Forest structure, growth and yield on ecological and physiological foundations. Zveza gozdarskih društev Slovenije, ZGS, Ljubljana (in Slovene).

Lafleur, B., Fenton, N.J., Simard, M., Leduc, A., Paré, D., Valeria, O., Bergeron, Y., 2018. Ecosystem management in paludified boreal forests: enhancing wood production, biodiversity, and carbon sequestration at the landscape level. Forest Ecosystems 5, 27.

Leibundgut H., 1984. Forest tending. Paul Haupt, Bern, Stuttgart (in German).

Mayer, H., 1981. Global radiation in the mixed mountain forest of East Bavaria. Arch. Met. Geo. Biokl. Ser. B.:283-292.

Mitscherlisch, G., Moll, W., Künstle, E., Maurer, P., 1966. Growth and yield and ecological research in pure and mixed stands. Allg. Forest- u. Jagdztg.:25-33, 72-90, 101-115 (in German).

Mlinšek, D. 1968. Free-style silvicultural technique based on tending. Poslovno združenje gozdnogospodarskih organizacij, Ljubljana, 117 p (in Slovene).

Mlinšek, D. 1992(a). Silviculture I., BF, Oddelek za gozdarstvo, textbook (in Slovene).

Mlinšek, D. 1992(b). Silviculture II., BF, Oddelek za gozdarstvo, textbook (in Slovene).

Mlinšek, D. 1995. Silviculture in Slovenia is based on biodiversity. Tempus, Proceedings of the international colloquium on bioindication of forest site pollution: Development of methodology and training, p. 311-314.

Schütz, J., Saniga, M., Diaci, J., Vrška, T., 2016. Comparing close-to-nature silviculture with processes in pristine forests: lessons from Central Europe. Annals of Forest Science 73, 911–921.

UNECE - FAO - University Hamburg - European Commission, 2007. Wood resources availability and demands - implications of renewable energy policies, 74 p.