Diploma

Analysis of selected silvicultural systems with regard to their economic efficiency and sustainability

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Analysis of selected silvicultural systems with regard to their economic efficiency and sustainability

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Objectives of thesis

The aim of this thesis is to analyze selected silvicultural systems (traditional based on the age class forests versus so called close-to-nature silviculture) with the aim to assess their economic efficiency and also the sustainability of forest management.

Methodology

Choice of comparative silvicultural systems in the variants of traditional clear cutting system versus close-to-nature silviculture.

The School Forest Enterprise in Kostelec nad Černými lesy will be used as a model area.

Silvicultural analysis of the selected methods (regeneration, tending, final cutting).

Assessment of the sustainability of the selected methods (stability, adaptability).

Identification of forestry activities (silvicultural and logging operations in technical units) of compared methods.

Calculation of economic indicators expressing technical (cost and revenue) units.

Expressing the economic efficiency of the compared silvicultural systems.

The proposed extent of the thesis

min. 40 pages

Keywords

silvicultural systems, sustainability, economic efficiency

Recommended information sources

HANEWINKEL, M., 2002: Comparative economic investigations of even-aged and uneven-aged silvicultural systems: a critical analysis of different methods. Forestry, 75(4): 473-481

JOHANSSON, P.O., LÖFGREN K.G., 1985: The Economics of Forestry and Natural Resources. Blackwell, Oxford, 292 s.

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DECLARATION

Hereby I declare that I have written Diploma thesis “Analysis of selected silvicultural systems with regard to their economic efficiency and sustainability” on my own under supervision of doc. Ing. Jiří Remeš and I have used only the sources which are marked in the bibliography.

I am aware that by releasing of this Diploma thesis I agree with its publication according to the law number 111/1998 Sb. about universities as amended regardless of the result of it defend.

In Prague on: …………….   Signature: ………………….

Abstract

This diploma thesis is based on the research of two types of forest management: Clear-cut and Shelterwood silvicultural systems, with two subtypes for each type. The major data source was provided by the Forest Enterprise in Kostelec nad Černými lesy. The study mainly includes data before the crisis (2005) and during the forest market crisis (2018-2019).

Key words: silvicultural systems, sustainability, economic efficiency

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Contents

Introduction

For many years now, the forest has been an ineligible part of the world economy, as well as part of the lives of ordinary people and even the entire ecosystem of the planet. Forests are an element of the development of peoples, their cultures and their relationship to nature. The forest has long been a source of resources for survival - food, water and shelter can be found here. As a consequence, forest life affects many factors of global importance and, as a logical result, people have begun to research forestry. If several hundred years ago the forest was cut down without thinking twice, now there are many rules how and where to do it, with a subsequent forest regeneration plan, which in turn significantly complicates the business process. It is based on the need for a competent approach to forest management that different types of forest management were created, which in turn raises a new question: which type of forest management is better, more efficient?

For modern man, the forest plays a big economic role. In the forests there is a growing wood, from which construction materials, paper, furniture, wood fuel, food, material and medicinal products are made. In addition, forests perform a number of natural tasks. One of them is the production and purification of oxygen. Also, forests serve as noise insulation, they are able to reduce the noise level from the road by 11 decibels, which is an important moment in the structure of human life.

In recent years, another question has emerged in the world, which is directly related to the forest sphere - global warming, climate change of the planet. If 20-30 years ago this aspect could have been missed, not included in the chain of events of production of the same forest, but now this problem is categorically impossible to avoid.

I chose this topic based on personal interest and global trends to maximize the efficiency of any business process, but with due regard to sustainable development. As the forest has long been an important area of business, any discoveries in management are 100% applicable. This research will investigate the characteristics of different approaches to forest management, with an analysis of the consequences, both economic and environmental.

The aim of this thesis is to analyze selected silvicultural systems (traditional based on the age class forests versus so called close-to-nature silviculture) with the aim to assess their economic efficiency and also the sustainability of forest management.

There are hundreds of factors proving the importance and necessity of forests. The products of the forest are very much demanded by mankind, so people use the forest for huge monetary benefits, but the forest is fossilized and therefore requires control and the right management approach.

The success of forestry depends on clearly defined management objectives. However, forestry is often confused with the management of stands and forests solely for the production of wood. The term "silviculture" is also used to manage forests for wildlife, water, recreation, aesthetics or any combination of these or other forest uses.

There are many forestry systems for managing forests, depending on the management objectives. These systems have been developed over several centuries as humans began managing forest plantations to restore beneficial species in ways that provide some long-term sustainability.

Silviculture system is a planned program of timber processing, aimed at achieving specific characteristics of the stand construction to perform the tasks of the site throughout the life of the stand.

This processing program combines special harvesting, regeneration and stand maintenance methods to achieve a predictable yield from a stand over time. The name of the harvesting system is based on the basic regeneration method and the desired age structure.

Forestry systems at most sites have been designed to maximize timber production. Non-harvesting objectives such as watershed improvement and wildlife rearing were less common. Environmental considerations and resource objectives have increased in recent times. Forestry systems tend to have the following main objectives:

- To ensure the availability of many forest resources (not just wood) through spatial and temporal distribution.
- Produce planned harvests of forest products in the long term.
- Meet biological/ecological and economic needs to ensure resource sustainability.
- Provides for regeneration and planned development of the mineralization phase.
- Make efficient use of growing space and productivity to produce desired goods, services and conditions.
- Consist with the landowner's goals and objectives at landscape and stand level (including consideration of different management options in the future).
- Take into account and try to minimize the risks associated with stand harmful substances such as insects, diseases and wind waves.

Below we will take a closer look at and compare two key approaches in forest management: Clear cut and the Shelterwood systems.

Forest management: history and development

The current use of the English word "forestry" indicates the management of forest resources to provide a satisfactory mix and quantity of social values for clients living, while protecting these values and use options for future generations (Kennedy in Paletto 2008). More specifically, in technical terms, "forest" is (FAO): "land with tree crown cover (or equivalent stocking level) of more than 10 percent and area of more than 0.5 hectares. The trees should be able to reach a minimum height of 5 m at maturity in situ". The origin of the term "forest" ("Forst" in German and "forêt" in French) lies in the Middle-Age Latin word "forestis" or "foresta" which indicated land, not necessary woodland, mainly used for hunting and secondly for the gathering of mushrooms, bark and other non-wood products (Helliwell; Fritzbøger & Søndergaard in Paletto 2008).

It is believed that Homo erectus used wood for fire at least 750,000 years ago. The oldest evidence of wood use for construction, found on a section of Kalambo Falls in Tanzania, dates from around 60,000 years ago. Early organized communities were located along waterways that ran through the arid regions of India, Pakistan, Egypt and Mesopotamia, where trees scattered along riverbanks were used, as today, for fuel, construction and tool pens. (Encyclopedia Britannica, 2020).

If to talk more about later time, the social perception of forest ecosystems has changed in line with people's interests and needs in using natural resources. In particular, three historical periods can be distinguished:

the pre-industrial period (from the Middle Ages to the mid-17th century);

the industrial period (from the mid-17th century to the mid-20th century);

and the post-industrial period (from the late 20th century to the present day) (Paletto 2008).

In all these periods, society has been working on new strategies and methods for the sustainable management of forest resources.

In medieval Europe, forest laws were originally aimed at protecting game and defining rights and obligations. Hunting rights belonged to the feudal lord, who owned this property and had the exclusive right to cut down trees and remove timber. Peasants were allowed to collect firewood, wood and litter for use on their lands and graze a certain number of animals (Encyclopedia Britannica, 2020).

In the Middle Ages, kings gradually lost their full control over forests, and noblemen, churches, monasteries and later local communities and communities began to develop their rights to them (Wickham, 1990). While early medieval laws tended to preserve social privileges rather than protect forests, later statutes demonstrated the growing concern of state authorities about the deterioration and disappearance of forest land. Late statutes therefore sought to protect forests by mimicking and controlling their exploitation.

Despite this new awareness of the danger of forest depletion, we cannot assume that people of the 13th, 14th and 15th centuries shared any real environmental consciousness (Ortalli in Paletto 2008).

In Modern Age, especially in the plains of Europe, integration into agricultural households contributes to the progressive growth of the agricultural economy, which is detrimental to other land uses. In particular, two main factors should be noted in this regard, namely, the increasing destruction of uncultivated land and the reduction of forests and wetlands. These events, which are of great importance for the development of the agrarian economy, have created some economic and environmental problems:

-Restriction of the forest-pastoral economy characteristic of the collective communities of the Middle Ages (restriction of rights to hunting and harvesting);

-Increased hydro-geological instability (protective function of the forest) in mountainous areas and flooding of plain zones (e.g.: flooding of the Tever River in Italy in 1495 and 1530); (Paletto 2008)

Thus, the Modern Era can be seen as an anthropocentric era in which people bend nature by their own will, and therefore forest management is determined on the basis of human needs. (Thomas, 1983).

New social needs and demands have emerged at the end of the Modern Era, and as a result, the management of natural resources has changed fundamentally. Industrial Revolution radically changed European economy of society, introducing innovations and technological progress, and above all a new philosophy of hedonistic ethics. Guillaume Thomas Reynal in Histoire des Deux Indes (1770): the search for happiness is extremely important in hedonistic ethics.

Production has increased significantly and technological efficiency has increased significantly. These factors have led to increased demand not only for raw materials (wood, cotton, iron, coal) but also for round wood for construction, fuel wood for household use, pole wood, charcoal and tannin. In this context, the concept of "modern" forestry was developed by Georg Ludwig Hartig and Heinrich von Kott. The old mixed forests were replaced by mono-specific forests managed by new technologies (fertilisation, individual exotic species, artificial regeneration) and clear-cut by continuous felling. In the Mediterranean region, scalding with a short rotation period of 3 to 10 years replaced high forests. The economic approach to forest management was imperative, and the need to achieve maximum revenues from forests coincided with the establishment of the timber market, industrial forestry and various forestry sectors (Agnoletti in Paletto 2008).

The growing demand for wood products and the resulting increase in human pressure on forest resources were the main reasons for the development of the following two forest management doctrines (Glück in Paletto 2008):

- Timber primacy doctrine;

- Sustained yield doctrine.

Timber primacy doctrine (TP) was born in the middle of the 19th century and was most important in Europe during the First and Second World Wars. This doctrine finds its ideological basis in the "wake theory" or "Kielwassertheorie theory" of forest management (Glüc; Pregernig & Weiss in Paletto 2008). In wake theory, proper management of wood production automatically ensures beneficial reusability values (Koch & Kennedy in Paletto 2008). The TP doctrine focuses on wood production management; in this doctrine one can find the origins of another theory, the Sustained Yield doctrine (SY). This doctrine pays special attention to the needs of future generations and therefore to sustainable resource management.

The term "sustainability" in forestry was first used in 1713 by Hans Karlvon Karlovitz in his book "Sylvicultura Oeconomica". In 1804, Georg Ludwig Hartigasser stated that sustainability is a priority in state forest management (Vehkamäki in Paletto 2008): " Forest mensuration and management planning, or the precise definition of current and future felling, or the creation of a reliable felling budget, is undoubtedly one of the most important responsibilities in any forestry" ... Every wise forest management must draw up sustainable forest management plans that allow for the highest possible percentage of forest use, taking into account that the administration takes care of the interests of future generations so that a fair distribution of interests between present and future generations becomes a reality". In this cultural context, the sustainable harvest doctrine was born in Germany and has been spreading throughout Europe since the mid-18th century (Paletto 2008).

After the industrial revolution, the social perception of forest resources changed as a result of the transition from rural to urban society. Two basic principles in forest management emerge in this cultural context: The concept of multifunctionality of forests was born in Germany with the development of the "Forest Function Theory", published in "Forstwirtschaftspolitik" (1953) by Professor Victor Dietrich from the University of Munich. In this theory, the concept of multi-purpose use, which is widespread in North America (Canada and the USA), has been developed and expanded through a less anthropocentric vision in which functions are intrinsically important (ecosystem vitality and health).

The first international definition of sustainable forest management emerged in the early 1990s in several important instruments: Agenda 21, the Rio Declaration on Environment and Development and the Statement of Principles for Sustainable Forest Management adopted by many Governments at the United Nations Conference on Environment and Development (UNCED), held in Rio de Janeiro, Brazil, from 3 to 14 June 1992: "Forest resources and forest land must be managed sustainably to meet the social, economic, environmental, cultural and spiritual needs of present and future generations.

These are needs for forest products and services such as timber and wood products, water, food, fodder, medicines, fuel, shelter, employment, recreation, wildlife habitats, landscape diversity, carbon sinks and reservoirs, and other forest products". (Paletto 2008).

A review of the results of these initiatives by FAO in 1994 showed a consensus on characterizing sustainable forest management based on six criteria, including older (although not always clearly defined) concerns such as biodiversity conservation and later priorities such as global carbon cycles and climate change. These can be summarized as follows:

- Three criteria regarding the quality and quantity of the forest ecosystem;
    - forest resource volume
    - biodiversity conservation (at ecosystem, species and intraspecific levels)
    - forest health and vitality

- Two criteria regarding the functions of the forest ecosystem:
    - forest productivity functions

    protective features of the forest (Lanly)

Development of the forest land in Czech Republic, specific emphasis on close to nature system

Close-to-nature forest management (CTNFM) is a production concept based on multifunctional forest management (Bauhus, 2013). It is an alternative to the forest management system based on clear-cutting and the cultivation of even-aged coniferous monocultures. Early attempts at sustainable forest management have been made on Czech lands, which in many aspects comply with the principles of close-to-nature silviculture. The most famous supporters of these efforts were Lebich, the first associate professor of the Department of Forestry at the Czech Technical University in Prague, who already in the first half of the 19th century drew attention to the harmful effects of overpopulation of forest monocultures. The most famous supporter of the alternative forest movement at the end of the 19th century was Tichý, who radically abandoned clear-cutting and promoted forest management according to the laws of nature. According to Tichý, this left a legacy only of individual or cluster forestry (Poleno in Remeš, 2018).

An important person in the first half of the 20th century was Konšel, who in his "Forestry on a biological basis" (Konšel in Remeš, 2018) presented and promoted principles of close to nature forest management. The first practical performer of the close to natural forest management in the Czech lands was Conias, the manager of the Opočno estate. During the 30 years after 1924 he continued to convert spruce and pine monocultures into mixed forests and later cut down forest types into selective forests (Konias in Remeš, 2018). In the first stage, Konias was engaged in the restoration of forest soil, as well as the preservation and strengthening of stands by the necessary transformation of the species composition into one that would correspond to the terrain conditions. In the second stage (in mixed stands) he promoted and created uneven stands by gradually changing the horizontal overhang to vertical and spatial.

The overall result of his efforts in both directions of management, Konias expected to increase and constantly increase (to a possible maximum) production, with special emphasis on improving and grading the quality of wood (Konias in Remeš, 2018). Indeed, his work resulted in mixed plantations that were fully suitable for the site, varied greatly in age, and were adapted to both natural and management requirements in terms of internal spatial distribution and regeneration period. He paid increased attention to the management of the stand stock (Poleno in Remeš, 2018).

The management policies of the main supporters of CTNFM have led to an emphasis on stability, productivity, diversity and continuity of the state of forests, which has led to attempts to integrate several forest management objectives on a small spatial scale, ideally within individual trees. This contrasts with a separate approach to forest management, such as the TRIAD concept, which includes separate areas of landscape for timber production and biodiversity conservation functions in addition to areas of less intensive multipurpose forestry (Seymour and Hunter, 1992). Attempting to simultaneously integrate multiple forest functions on a smaller scale, usually in the form of stands, has resulted in a focus on mixed and unevenly aged forests throughout the landscape as a way to ensure timber production, recreation, biodiversity conservation, aesthetic values, etc. (Bauhus, 2013)

Selective forest management gradually became the goal of Konias management. The findings of the assessment of transitions in individual habitats and stand types (Zakopal in Remeš, 2018) can be applied in other forms of management, in particular in the shelterwood system forests, which due to its variability has a much wider application. The management carried out by Konias was by no means unprofitable; the increase in quantitative production was not confirmed, but the qualitative superiority is undeniable (Souček in Remeš, 2018).

Selective management methods were widely used after 1951, and forest management plans were specifically developed between 1963 and 1972. However, Polanski's idea did not come true and after a critical evaluation of this approach in 1972, it was decided that MLUFE would abandon the application of selective principles and give preference to the shelterwood system forest (Truhlář; Souček in Remeš, 2018).

Other supporters of selective management were Kratochvil and Zakopál; the latter developed a concept for conversion of even-age forests into selective forests at the Kutná Hora FMU. On this basis, in the mid-1970s, Shah developed a Framework Guideline for Management of Plain Forest Conversion into Selective Forest at Kutná Hora FMU.

Especially thanks to Konias, the shelterwood system forests became widespread in Czech lands in the postwar period. It was characterized primarily by a shift away from clearcuts, relatively long reforestation periods and a desire for natural reforestation and gradual conversion of coniferous monocultures into locally suitable mixed stands (Čižek, Kratoch in Remeš, 2018).

The main advantage of this management method is the achievement of natural regeneration of the stand and all the benefits derived from it. The two-storey stand phase is in most cases only temporary (for the period of regeneration), and this management method is also applicable to trees with increased need for light. In addition to these two environmental benefits, a positive effect is expected from increasing the diameter of the top layer of trees that remain on the stand for different time periods depending on the landscape ecological and species composition of the site.

Another important source of natural forestry began with the ideas of Carl Gayer. (1822-1907), Professor of Forestry in Munich. At that time, organized forestry with continuous felling systems and the introduction of coniferous trees had already spread to large forest areas. Consequently, there were also outbreaks of soil, fungus and insect degradation as a result of this process, as wind waves were often observed in these areas. As a reaction, Geyer developed his idea of mixed forests, which was to be realized only through natural regeneration (Geyer in Larsen 2011), often in combination with irregular shelterwood system. The use of irregular regeneration over a longer period of time would thus provide different species to create and thus create mixed forest structures. His ideas were further developed in Switzerland. At the time, Swiss forests suffered greatly from currents, landslides and wind breaks, the result of spruce monocultures and clear management systems. Arnold Engler (1858-1923) succeeded in achieving a gradual change in the Swiss forestry paradigm, which was not linked to the reforestation scheme (Larsen 2011).

The third "wave" of logging on a natural basis developed in 1920 in northern Germany when Alfred Möller published the book "Der Dauerwaldgedanke" (Möller in Larsen 2011). His paradigm of continuous forest is significantly different from other concepts based on nature. Möller's approach is based on the organic and holistic concept of the forest and follows more stringent felling rules. His ideas have taken shape in forests that have been managed with care and continuity for many years (Berentoren in East Germany). Möller carries out various inventories and publishes his results in favour of continuous forest cover management (Dauerwald), which he believes offer improved forest areas, abundant regeneration as well as increased wood production. Möller's approach to forestry was met with great sympathy in the early years after the publication of his book. Dauerwald's concept was received with great enthusiasm throughout Germany. When Möller died shortly after the publication of his book and his ideas were unable to bring the desired success in this field, his approach became increasingly dubious, and in the end even doubts about his scientific credibility put an end to this chapter on forestry in Germany in the 1930s (Larsen 2011).

In the 1970s and 1980s, there was a significant decrease in the practical application of close to nature forestry methods in favour of felling in the Czech Republic. Only in the last 30 years there has been a renaissance of close to natural management ideas and a significant revival of the interest of foresters in more careful cultivation methods (Košulič in Remeš, 2018). An example of such activities in forest management practice is the forest district of Klokočná (e.g. Ferkl & Remeš). As far as forest management is concerned, recent attention has been paid to assessing the long-term transformation of coniferous monocultures into more structurally rich stands (Truhlář; Souček; Tesař et al.;Remeš & Kozel; Remeš et al.; Kučeravá et al.; Dobrovolný & Tesař; Dobrovolný in Remeš, 2018). Attention was also paid to objectivization of selection of individual trees for wood harvesting (Poleno; Remeš; Remeš & Bílek in Remeš, 2018).

In the late 1990s, Poleno was heavily involved in issues close to natural forest management. He carried out a comprehensive analysis of the logging system implemented by selecting individual trees in the originally flat forest. According to Poleno, this procedure is more convenient than continuous reforestation, as it allows individual assessment of the growth and development stage of each tree during the whole period of stand development. The genetic variability and the variability of the phenotype result in each tree showing more or less variability in its features and stages of development (Remeš, 2018).

Clear cut system

Since the 1960s, clear cutting has been one of the most controversial methods of logging in the logging industry. The felling system controls consecutive stands of uniform age by sawing all stands to plan. A new stand is then restored and maintained, not an old stand. The round billet system is the simplest and easiest to use system in the world.

A characteristic feature of clearcutting is the logging of mature forest stands from a particular area in one pass, resulting in open cuts. The influence of parental stands on the conditions of clearcutting is reduced to the border of one, and potential natural regeneration is limited only by light-demanding species of trees with flying seeds (pine, larch, birch, aspen, ash). The form of felling at clear-cut provides sufficient space for mechanized felling as well as for subsequent forest treatment of young stands (Bilek at all. 2016).

Kimmins defines clear-cut harvesting as the removal of all trees in a single felling in a forest area large enough to remove "forest impact" from most of the harvested area. (British Columbia 2003). Of all forestry terms, clear-cut harvesting should be the least ambiguous (Smith in Keenan 1993).

Picture 1.1: Clear cutting in the Bavarian Alps
(Teilzeittroll 2006)

The clear-cut form of forest management in the past started to reduce the risk of forest devastation by selective cutting, and facilitated promotion of sustainability principles but resulted in creating large unstable even-aged monocultures.

In contrast to the shelterwood system and seed trees, it is used by foresters to create certain types of forest ecosystems and to promote certain species (Merivale, 2013) that require abundant sunlight or grow in large, level stands (Bowyer, Fernholz 2009). Timber companies and timber trade unions in some countries support this practice for scientific, safe and economic reasons, while opponents see it as a form of deforestation that destroys natural habitats (U.S. Environmental Protection Agency 2011) and contributes to climate change. (Center for Biological Diversity, 2011)

Clear-cut is the most common and low-cost way to harvest timber. However, it also creates harmful side effects such as the loss of topsoil, the costs of which are intensively discussed by economic, environmental and other interests. In addition to the purpose of logging, it is used to create land for agriculture. Human consumption of wood and cropland as a result of unsustainable harvesting regimes, such as logging, has resulted in the loss of more than half of the world's tropical forests ("Rainforest Threats", 2015).

Clear-cut management in the past has begun to reduce the risk of forest devastation through selective logging and has promoted sustainability, but has created large unstable even-aged monocultures (Bilek at all. 2016).

While deforestation of both temperate and tropical forests through logging has attracted considerable media attention in recent years, other major forests in the world, such as taiga, also known as boreal forests, are also under threat of rapid development. In Russia, North America and Scandinavia, establishing protected areas and providing long-term leases for tree care and regeneration - that is, maximizing future yields - are some of the means used to limit the harmful effects of logging (Kunganavolok, 1998). Long-term logging studies, such as those of the Paso rainforest in Malaysia, are also important in providing insights into forest conservation around the world.

Clear-cuts are categorized into large clear-cuts (their short side is longer than the average height of a regenerated mature stand) and small area clear-cuts (their short side is shorter than the average height of a regenerated mature stand). The total area of clear-cuts in most cases is limited by the Forest Act to 1 hectare, but its shorter side should not exceed two heights of the stand being regenerated (the width of clear-cuts in open areas is limited to one height of the stand being regenerated). The exceptions are up to 2 ha of the area of clear-cuts on natural coniferous plots and natural alluvial plots on mountain ridges with poor accessibility (Bilek at all. 2016).

Advantages:

Supporters of clear cutting believe that it is good practice if the right conditions are met and the right harvesting methods are used. Conditions under which felling can be used as a harvesting tool are considered (Nix, Steve 2020):

- Regeneration of trees that need full sunlight to stimulate seed germination and seedling growth.
- Dealing with sparse, exposed, or shallow-rooted trees in danger of being damaged by wind.
- Trying to create an evenly aged tree.
- Restore growing stock of trees dependent on seeds blown by the wind, root suckers or cones that need fire to drop seeds.
- Rescue of over-mature trees and/or trees that have died of insects, disease or fire.
- Turning into another tree species by planting or sowing.

- Providing habitat for wildlife species that require edging, new soil and "high-density, evenly growing trees".
- Allow the creation of a more homogeneous culture (including the benefits of uniformity and uniformity in management).
- Allows for simpler and more efficient operations, as it is the simplest method.
- Reduces the cost of forest operations, including: planning, planning, supervision, harvesting, site preparation and intermediate treatment. Harvesting can be cheaper because of the larger volume/haul removal.
- It may be easier to place highly specialized equipment for logging and site preparation.
- Damage to regeneration is avoided, as felling and excavating is done before the harvest.
- Can provide the means to achieve free growth of plantations as quickly as possible in combination with logging technologies and fast-growing shade resistant shadow species. Note: Shadow species are often more desirable due to their growth and yields, as well as the quality of wood.
- This can facilitate insect control and solve problems related to disease:
  -Rot -Clean and remove stumps.
  -Dwarf mistletoe - Remove overhead sources of infection
  -Mountain pine beetle -remove susceptible struts.
- It may be easier to provide reclamation of the site/soil by preparing the site (although it can be argued that reclamation may not be necessary if another forestry system is used).
- Improve worker safety as most or all trees are removed.

Against or Disadvantages:

Opponents of clear cutting suggest that this is a destructive practice and should never be used. These are their reasons, although not all of them can be supported by modern scientific data (Nix, Steve 2020):

- Pure felling increases soil erosion, water degradation and siltation in streams, rivers and reservoirs.
- Old forests that have been systematically cleared are healthy ecosystems that have evolved over the centuries to be more resistant to insects and diseases.
- Continuous logging impedes the sustainability of healthy, holistic forest ecosystems.
- The aesthetics and quality of forest species are threatened by clear-cuttings.
- Deforestation and its associated removal of trees from felling leads to a "plantation mentality" and "environmental degradation".

- Sometimes it is negatively perceived as a system that fights against nature, regardless of environmental conditions, promoting uniformity, especially when agricultural methods such as site preparation and planting are used.
- May not be suitable for wildlife species that require an upper cover or more structurally diverse habitat at the stand level.
- Can lead to site erosion, especially if the soil is compacted and on steep slopes with a significant amount of exposed finely structured soil, there is a large amount of moisture contamination.
- Mass losses may increase on steep slopes with fine-grained soils and high humidity or with smooth geological planes of the underlying layer parallel to the ground surface.
- Adverse environmental conditions for regeneration, such as microclimate (frost, dry wind, extreme temperatures), soil moisture and possibly nutrients, competing vegetation, predators (insects/animals) may be exacerbated. This unfortunate situation occurs only in extreme places, where it is very difficult to restore trees.
- It may hinder full growth and yield potential of individual trees (as in the case of single selection). During a significant part of the crop rotation, the vegetation space is not fully occupied by planting trees.
- It may not be considered visually attractive.
- Not very good for shading species that grow slowly in young stages, even if they are planted.
  -Pioneer vegetation can have a big advantage and overlap with these trees.

Another clear-cut system variation

- ***Strip clear-cut system***
- ***Block clear-cut system.***

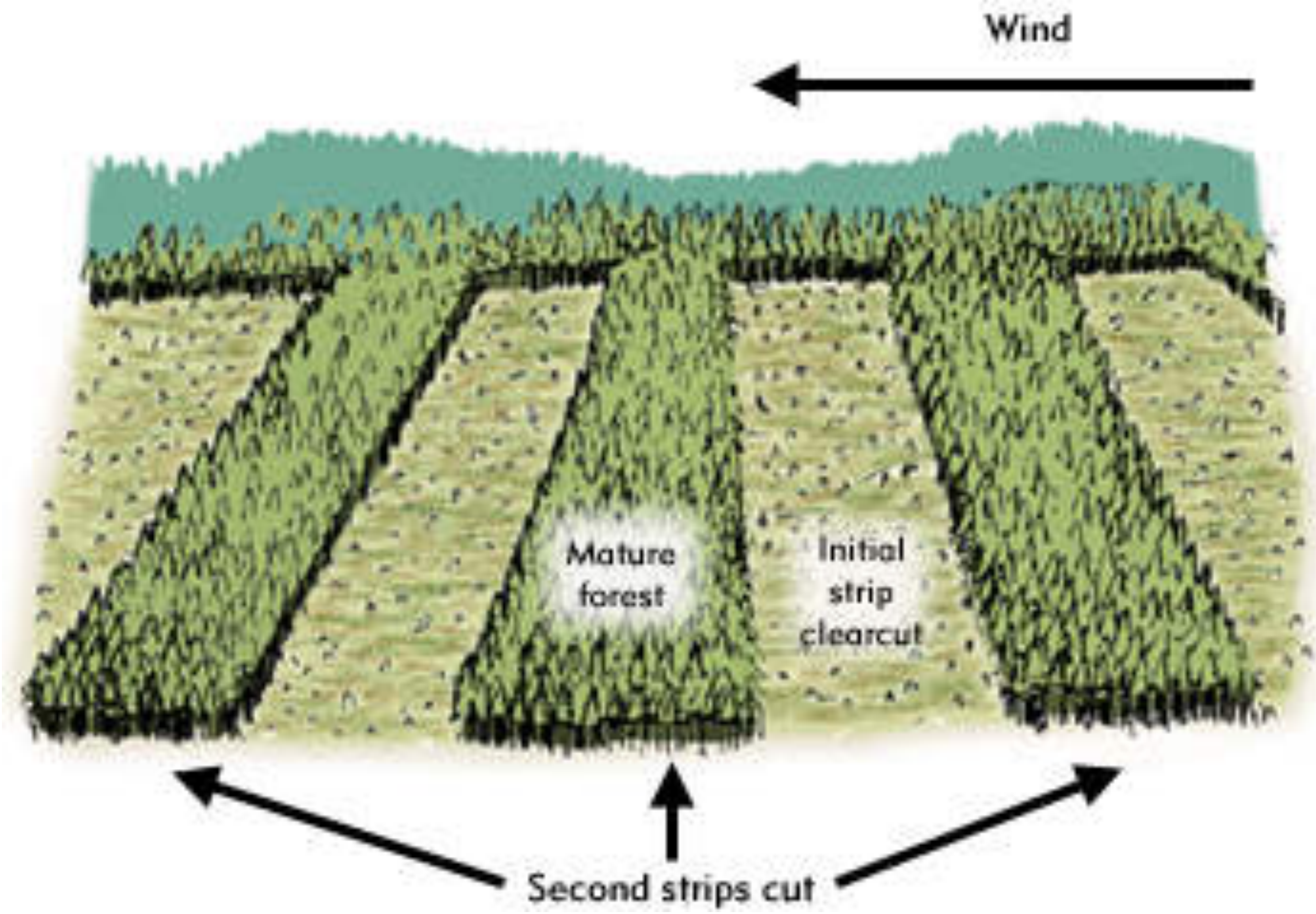
Strip cuts are used to harvest on a booth for three to seven years by removing several strips, instead of harvesting the entire booth at once. Strip cuts have been designed to take advantage of natural sowing from strips. In the pure sense, strip cuts were mainly used in Canada on new types of black spruce stands in boreal forests. This approach, along with striped shelter forests, has also been tried in boreal mixed tree types in northern Alberta.

The main problem associated with strip felling is wind damage, as logging strips expose much more edges within a short period of time than one large felling. To avoid excessive wind loads, at least 40 m wide strips should be used that are open at one end only and should be harvested immediately after regenerating the adjacent cleared strips, thus minimizing exposure time. In addition, the boundaries of the strips should be carefully placed in healthy plantings on deep, well-drained soils. The strips can be cleared in an alternative or progressive manner. (British Columbia 2003)

Alternative strip cutting

In alternative strip cutting systems, the cutter is cut in two stages. The initial cutting creates long narrow gaps between which the left strips are placed. More often than first pass strips, they are narrow because the strips are trimmed after regeneration has been set in the first pass strips. Therefore, cutting the second rung requires landing, but this requirement can be kept to a minimum.

Alternative or not, strip cuts are best oriented at right angles to prevailing winds. The width of the strips will depend on the distance to the planting material for the preferred species, wind hazard and other factors. (British Columbia 2003)



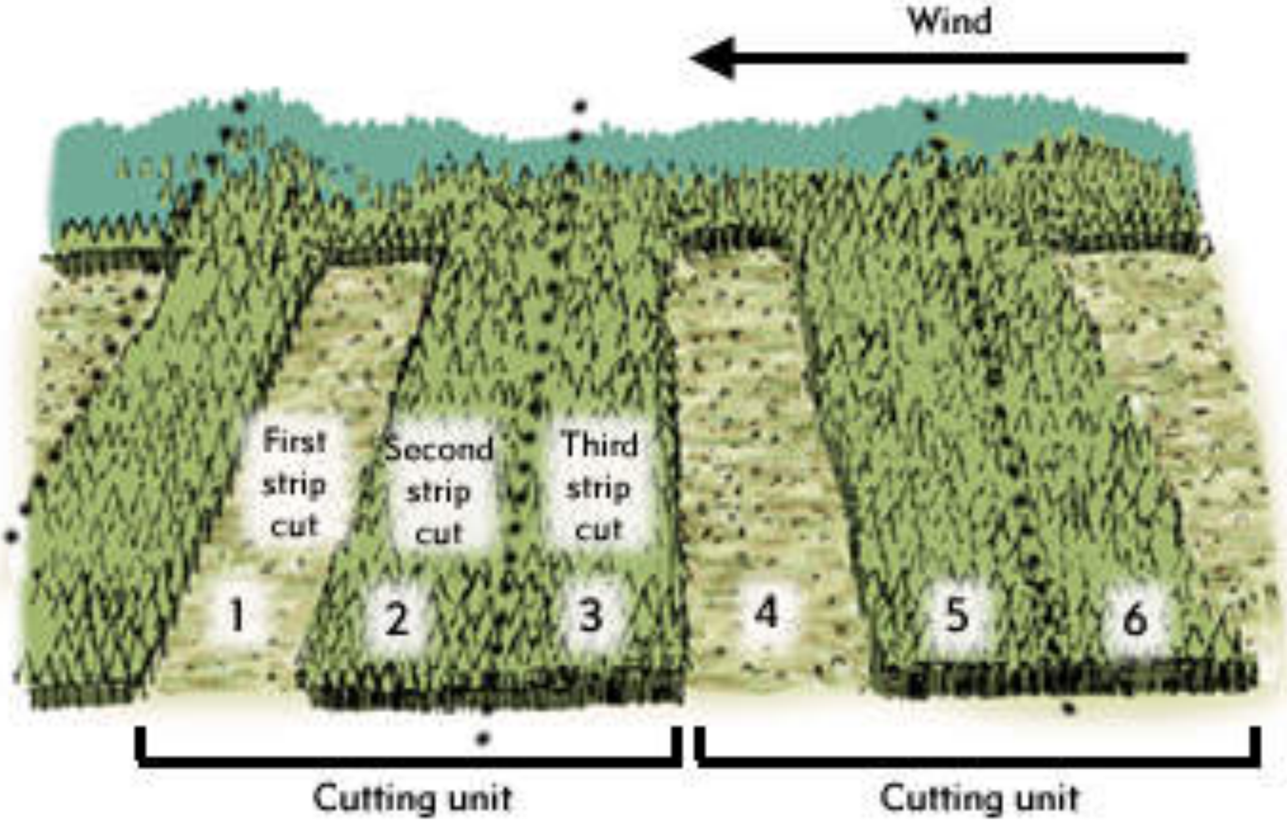
Picture 1.3: Alternative strip cleaning
(British Columbia: workbook "Introduction to Silvicultural Systems")

Progressive strip cleaning

The progressive strip clearing system achieves the same objectives as the alternative strip clearing, but in three or more passes rather than two.

The Progressive Strip Cleaning System has two advantages over the alternative strip clear system:

- The strips are gradually cut to the prevailing wind, reducing the open edge and shaft.
- A smaller area in the final pass requires landing.



Picture 1.4: Progressive strip cleaning
(British Columbia: workbook "Introduction to Silvicultural Systems")

Block clearcut systems

In block clear-cut system it is not necessary to rely on natural regeneration of wood from neighboring forests; on the contrary, other considerations dictate the size and shape of blocks. These considerations include unfinished timber, boundaries of forest types, topography, wind risk, and limitations on the harvesting equipment used.

Advantages of strip clear-cut system over block clear-cut system:

It relies mainly on natural regeneration, which reduces the cost of regeneration. May have less impact on the visual and other value of resources (temporary benefit) as the strips are smaller in scale than other clear systems.

Advantages of block clear-cut system over strip clear-cut system:

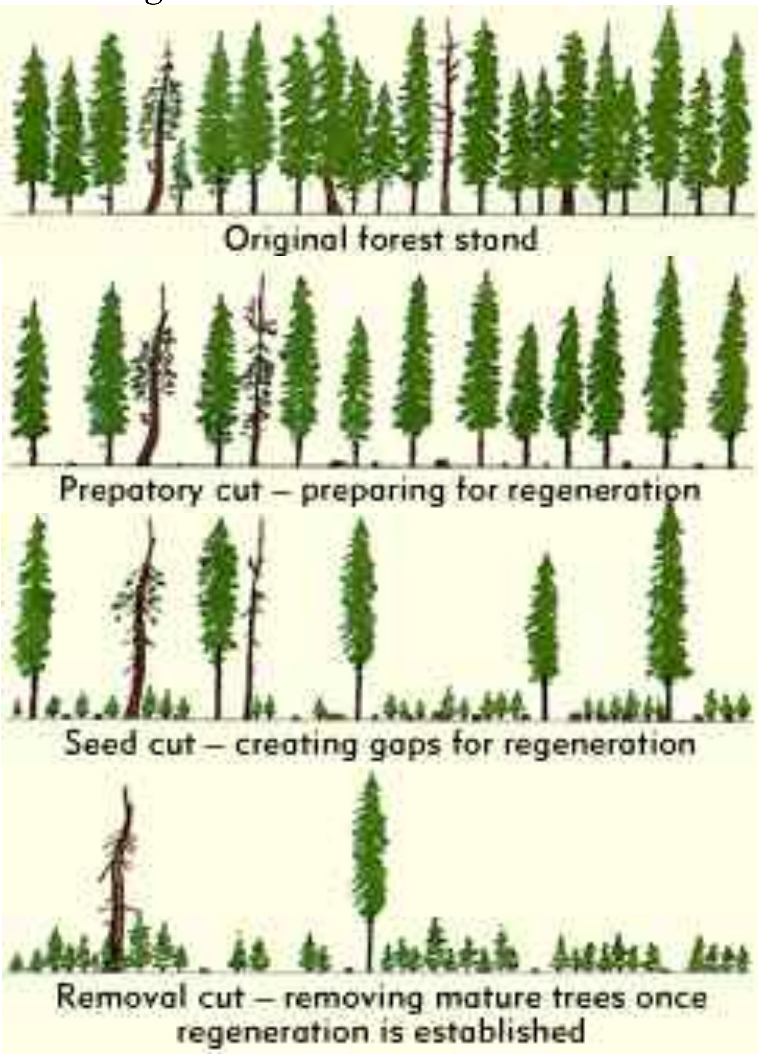
- It allows more flexibility to adapt to specific site conditions, as some plantings are often used and therefore boundaries can be defined for reasons other than seed dispersal.
- Larger aggregates can reduce administration, planning, layout and execution costs.
- More flexibility to deal with large-scale disasters (e.g. fires, insects and diseases). (British Columbia 2003)

Shelterwood System

Shelterwood system in forestry is understood as progressive cutting of the forest leading to the creation of a new generation of seedlings of a certain species or group of species without planting (Smith at all. 1997). This forest system is usually implemented in forests that are considered mature, often after several felling. The desired species is usually long-lived and their seedlings naturally begin their journey under partial shadow. Methods of shelterwood have the overall objective of providing reforestation under cover of an overhang or side shelter (Matthews in Raymond, Bedard 2009). The system provides enough light for the desired species, not giving enough light for weeds that are adapted to full sunlight. Once the desired species has taken root, the subsequent cuttings provide more light for the new seedlings and the space for the new generation to grow is completely taken over.

What sets the shelter cuttings apart from other regeneration systems, such as clear cutting or seed trees, is that the new seedlings are placed before the mature trees are completely (or mostly) removed. This gives the forester more control over the trees to be regenerated and forgives if the first attempt at regeneration fails. All mature trees can be removed, creating a young uniform forest, or a significant amount of reserves can be saved to provide a two-aged structure. Small logging site owners often prefer this method for the control it gives and also because the income from harvesting is distributed over a decade or more. On the managed land, applying ecosystem-based management principles is one way to achieve sustainable forest management goals (Galindo-Leal and Bunnell in Raymond, Bedard 2009).

During the harvesting of wood in the homestead lands a series of logging operations is used, each of which has its own specific objectives and characteristics. In order to fully understand the shelter system, it is important to understand the nature and purpose of these logging operations. Stand plantation systems may include *preparatory cuttings, seed cutting*, and one or more *overstory removal cuttings*:



Picture 2.1: Harvesting entries in a typical shelterwood (British Columbia: workbook "Introduction to Silvicultural Systems")

Preparatory cuttings are occasional but not always the first step in a canopy reforestation system. The purpose of such harvesting is a prerequisite for stand regeneration as it supports the production of seeds of existing tree species and creates suitable microclimatic and soil conditions for seed germination (Bilek at all. 2016). One or more preparatory slices can improve the vivacity of promising seed trees so that they can produce a healthy conical harvest and are windproof. Most of the preparatory cuts are concentrated in lower canopy classes; in fact, this harvest is similar to low commercial thinning.

If leaf trees can respond and improve growth and energy, this often-overlooked treatment can make the greatest contribution to a successful shelter forest system. In addition, it can provide harvesting from trees previously considered too young for harvesting.

One or more preparatory felling can improve the viability of promising seed trees so that they can produce a healthy cone harvest and are windproof. Most preparatory felling is concentrated in lower canopy classes; in fact, this harvest is similar to low commercial thinning. If leaf trees can respond and improve growth and energy, this often-overlooked treatment can make the greatest contribution to a successful shelter forest system. In addition, it can provide harvesting from trees previously considered too young for harvesting. (British Columbia 2003).

Seed cutting is aimed at ensuring recovery and is carried out in the year when the seed yield is good. The intention is to provide a certain amount of light, which is necessary to start the growth of new seedlings, but not necessarily that they grow freely. Such cutting increases the effect of preparatory cutting (Bilek at all. 2016). This trimming, which can be the first trim on some stands, is designed to provide space for regeneration to establish and provide shelter for young developing seedlings (British Columbia 2003).

Removal cut(s). Once regeneration has been completed, stocks are acceptable and shelter is no longer required, the excess shelter is usually removed. If left too long, excessive shelter can hamper regeneration due to excessive competition for light, moisture and/or nutrients. For shade-tolerant species, it may be desirable to gradually remove the surplus floor with several notches over a certain period of time. (British Columbia 2003). This type can be divided into two stepwise stages: release cutting and final cutting.

Release cutting further improves the conditions for crop and young growth. The application of the separating cuttings depends on the condition of the stand and the site. They should be repeated according to the requirements for young growth. Dense young growth and clean and dry soils require more frequent release cutting, while growth in rich and fertile areas should be released slower.

The final cut completes the natural regeneration process by removing residual parental stand and releasing young growth that does not need to be protected by mature stand (Bilek at all. 2016).

Also, can be a *Salvage cut.* This irregular commercial thinning removes felling, wood infected by insects or diseases, etc (British Columbia 2003).

Shelterwood vs. Seed-Tree

Often, we are making a wrong name for a forest system based on its appearance after harvesting. Even though the names of systems may contribute to some emphasis on harvesting (i.e., clarity), the real difference between systems is that each system is designed for stand regeneration and development.

While it is tempting to establish arbitrary densities that will distinguish between seed tree and shelter wood systems during the regeneration or felling phase, in fact such categories may overlook the intentions of systems. If the trees to be abandoned are to be maintained for their seeds only, the system should be called the seed tree system. If the intention is also to provide shelter, the system should be called the shelterwood. The area that distinguishes the shelter tree from the seed tree system has no magical number of trees left, as the shelter needs are determined by the climatic characteristics of the subzone and the species-specific regeneration needs. (British Columbia 2003) In shelterwood, trees will be removed at certain times under this method, but when using seed tree methods, there are so few trees that there is no need to cut them down just to remove them, they are more likely to be taken during a tree care, thinning or other felling operation than when removed (Nyland, 2002).

The shelterwood system should be the focus of the logger's efforts to determine the density and distribution of residual trees. For example, if a cooler seedbed temperature is required for germination, the number of shadows and the corresponding residues of non-compliant trees will depend on the species. In some cases, it may be sufficient to preserve 20-25% of the basal area to provide such shelter. If excessively large numbers of shelter trees (30 % or more of the original basal area) are required to maintain the moisture level in the seed bed, moderately large numbers may be required. Note: The leaf density of trees depends on the species and stand. If a shelter is required to protect regeneration from frost damage, high levels of moisture retention over a long period of time may also be required. The degree of moisture retention must match the conditions of the stand and the site. However, the seed-tree method is focused on very few trees that will be wind dispersed. So, for example red pine 25/ha, 7/ha for larch, 15-20/ha for Douglas fir.

For some species, such as the western larch in the western part of Kootenays, poor seed production can contribute to high residual leaf density even in seed tree systems. However, for hard pioneering species such as ponderosa pine shelterwood in harsh areas may look quite open. For this reason, you cannot distinguish between shelterwood and seed tree system only in appearance. (British Columbia 2003)

Material and methods

Forest Enterprise in Kostelec nad Černými lesy

The University Forestry Enterprise (UFE) was founded in 1935 as the building of the College of Agricultural and Forestry Engineering of the Czech Technical University in Prague. And for now, it is an important part of the Czech University of Life Sciences for over 80 years. It provides a basis for the practical training of university students, as well as conditions for research activities of faculty members.

The heart of this educational company was the state forest administration of Kostelec nad Černými lesy, which was established in 1933 on the Liechtenstein estate. The forests were selected for their diverse natural conditions and healthy forests (Šrámek in Remeš 2006).

This way, we will investigate all information on forest management with different methodologies, compare them and make conclusions about each. Thanks to the modern approaches of the university, based on the analysis and comparison of different theories, we have access to all necessary information and the main results of the work performed.

To begin with, it is worthwhile to tell about the study site: the forest area is 5,700 ha, located 30 km from Prague, at an altitude of 250 to 729 meters. The area is characterized as a warm climatic region (B), lightly warm, a slightly humid elevated climatic region, with soft winters (B3), with an average temperature of 8.5-9°C and an average annual precipitation of 650 mm. The vegetation season lasts 150-160 days. However, in recent years very dry periods have had a negative impact on the viability of forests. Annual rainfall has reached only 563 mm (2014), 451 mm (2015) and 509 mm (2016).

Geology in this region is a highly diverse one. Prevailing perm and carbon - conglomerates, arcos, sandstone, bone coal, shale, breccia. The soil is very diverse in its physical properties - from large boulder detritus to clayey sandy and clayey soils, mainly acidic, with a lower content of nutrients. The mesotrophic cambisol representing about 33.6 % of the forest soil is the most frequent type in the UFE, followed by oligotrophic cambisol (brown forest soil – 28.3 %), and pseudogley (15.2 %); whereas alluvial soils (3.0 %), eutrophic cambisol (2.6 %) and podzol (1.1 %) are less important. Other soil types represent less than 1 %.

The modern species composition of the trees is very different from that of natural trees. Over the past two centuries, forest management has influenced the composition of tree species in favour of the most productive tree species. This is a good indicator of the fact that the forest management of this area analyzes the scope of its work and is being upgraded to the most advantageous options.

In diagram 1 we can see the percentage of tree species in the plot under study.

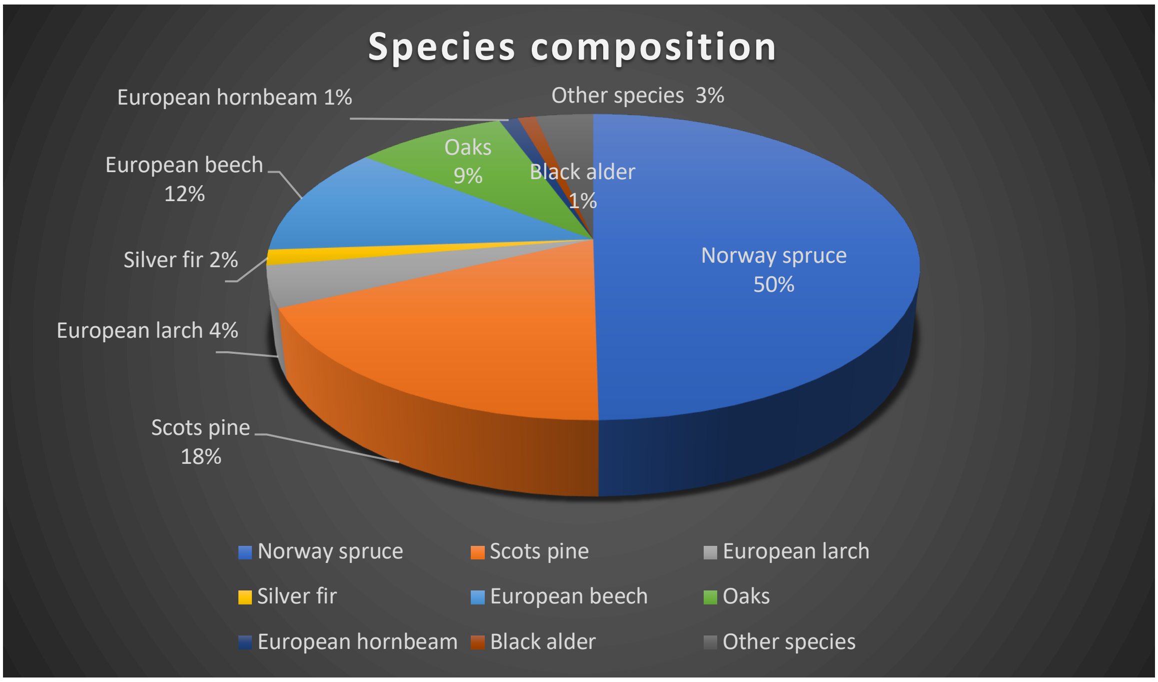


Diagram 1: Present species composition of the UFE forests

Natural conditions can be described by classifying forests by forest vegetation zones in table 1. Most of the plots belong to the second, third and fourth vegetation zones dominated by oak and beech. (Remeš 2006)

Table 1: The forest vegetation zones and their characteristics in the UFE forests (Remeš, J. The University Forest Enterprise in Kostelec nad Černými lesy)

No.	Name	Altitude m a. sea level	Average temperature	Annual precipitation	Growing season	Presence in the UFE (%)
1.	Pine					0.7
2.	Oak	<350m	>8°C	<600mm	> 165 days	0.3
3.	Beech-Oak	350-400	7.5-8 °C	600-650 mm	160-165	21
4.	Oak-Beech	400-550	6.5-7.5 °C	650-700 mm	150-160	53.8
5.	Beech	550-600	6.0-6.5 °C	700-800 mm	140-150	24.2
6.	Fir-Beech	600-700	5.5-6.0 °C	800- 900 mm	130-140	-
7.	Spruce-Beech	700-900	4.5-5.5 °C	900-1050 mm	115-130	-
8.	Beech-Spruce	900-1050	4.0-4.5 °C	1050-1200 mm	100-115	-
9.	Spruce	1050-1350	2.5-4.0 °C	1200-1500 mm	60-100	-
10.	Mountain Pine	> 1350	<2.5°C	> 1500 mm	< 60	-

Table 2: Forest operations in the UFE forests (according to Annual report for 2018)

Operation			technical unit	actuality	
				2018	2017
Regeneration	**TOTAL owned and leased**		ha	45,90	45,98
forests	Of which: on a clearing		ha	30,37	28,14
	improvements		ha	15,28	17,84
	natural regeneration		ha	0,25	9,04
	Total consumption of seedlings		ths. CZK	306,146	298
	Of which: coniferous		ths. CZK	169,309	150
	deciduous		ths. CZK	136,837	147
	average consumption of seedlings per ha		ths. CZK	6,706	6,5
	total leased forest restoration		ha	7,68	12,61
Clearing	Total		ha	94,08	71,64
trash	From that: mechanical		ha	39,11	24,47
Protection	**TOTAL own**		ha	485,6	455,17
forest	Of which: weeds	protection from weeds - moving	ha	240,70	245,08
Culture		weeds	ha	9,37	20,55
		chemical	ha	43,85	34,56
	game	repelents	ha	120,39	162,17
		Mechanical protection	ha	19,96	1,91
	other	Pine weevil	ha	51,33	69,04
	TOTAL rented		ha	112,02	121,71
Fences	TOTAL		km	13,203	12,510
			ha	6,00	8,98
Clearings	TOTAL		ha	15,46	48,08
	Of which: mechanical		ha	15,46	46,75
Soil preparation	TOTAL		ha	5,43	11,22
Forest protection	TOTAL costs		ths. CZK	5 703	5 351
Amelioration	TOTAL		ha	0,00	0,00
Pruning	TOTAL		ha	0,00	0,00
Oth. Sil.. Operat..	TOTAL costs		ths. CZK	2	28
CULTIVATION ACTIVITY	**TOTAL** *costs (table 8 total cultivation activity)*		ths. CZK	**11 103**	**11 622**
	of which wages		ths. CZK	**7 598**	**6 033**

By this informative table we can see amount of different operations in forest enterprise in 2017 and 2018. In both years we have 45,9 hectares of regenerated forest, from which: 30,3/28,1 ha based on clearing, 15,3/18,8 ha for improvements, and for natural regeneration only 0,25ha in 2018 and much bigger in 2017: 9 hectares. Total consumption of seedlings almost the same in 2018 and 2017: 306 000 and 298 000 Kr. The number of coniferous (169.3/150 thousand) slightly exceeds the number of deciduous (136.8/147 thousand). But at the same time, we see a significant decrease in expenses by 9 thousand CZK for deciduous in 2018 in 2018 (94.1 ha), an increase of 22.5 ha over the 2017 (71.6 ha) forest area was cleared. In 2018, 5.7 thousand CZK and 5.3 thousand CZK were spent on forest protection. About the same amount was spent on cultivation activity: 11,6 ths. (2017) and 11.1 thousand in 2018.

Table 3: Forest operations in the UFE forests (according to Annual report for 2018)

Operation		technical units	Actual in m3	
			2018	2017
Extraction	**annual plan total**	m^3	**50 000**	**50 000**
	total fact	m^3	**47 354**	**48 619**
	Of which: of timber from thinning	m^3	35	3
	intermediate felling in 40 years	m^3	350	1 372
	intermediate felling over 40 years	m^3	178	1 649
	intermediate felling random	m^3	6 262	8 832
	intentional nausea and clear - cut tolls	m^3	246	6 104
	intentional undergrowth and selective toll	m^3	351	13 985
	toll random	m^3	39 931	16 674
	in it: Extraordinary	m^3	0	0
	random bark beetle	m^3	2 310	1
	Salvage toll bark beetle	m^3	20 680	17
	wood production at OM	m^3	7 001	14 903
	total self-production:	m^3	**67**	**64**
	breakdown of self-production: roughs from prunings	m^3	18	3
	intermediate felling in 40 years	m^3	9	4
	intermediate felling over 40 years	m^3	3	0
	salvage	m^3	36	54
	regeneration	m^3	0	3
	extraordinary	m^3	0	0
	TOTAL mining	m^3	**47 354**	**48 619**
	Of which: coniferous	m^3	45 680	45 223
	deciduous	m^3	1 673	3 396
	(production + self-production) OSL	m^3	0	0
Tests	**TOTAL**	ha	**16,67**	**77,00**
	of which up to 40 years	ha	9,83	43,00

Table 3 gives us information about extraction in 2017 and 2018, and the difference between annual plan total and total fact. The difference was 1,4 and

2,6 thousand m3 respectively. We can clearly see that in these years toll random has the largest amount of wood produced, and in 2018 this type became much more dominant. The difference with 2017 was as much as 23 thousand m3. The reason for the so difference between the years was the invasion of bark beetles, which continues today. The dominant species of total mining is coniferous.

The methodology of economic analysis

The analyses the effectiveness of economically balanced forest units using the calculation of gross profit forest production. This approach can be applied to forest estates, which have sufficiently diversified age and spatial structure of forest stands that are able to achieve annually or at least periodically, in short time horizons similar economic results, therefore, the costs and revenues are relatively balanced (Pulkrab et al. 2014). The application of this approach is known in forestry economics as the school of net forest income.

An economically balanced forest unit is such a forest object (property), the management of which can be considered to be sufficiently balanced every year, ie. whose management on the basis of Forest management plan (FMP) and in accordance with the legal provisions on the forest generates similar revenues each year - revenues - at the current level of timber monetization and similar expenses - costs with an average profit rate in the usual way and technologies of management. Only large forest units and forest enterprises that have a sufficiently diversified age and spatial structure of forest stands can be economically independent - under normal economic conditions, with which a similar economic result can be achieved annually or at least in short several-year periods, ie whose costs and revenues are relatively balanced. Only these units, which are close to the so-called "normal forest" model, show lasting profitability and economic stability. In the case of developed close-to-nature forest management methods, the criterion of equilibrium is met if the structure of stands has reached the stage of continuous autoregulation and the balance of logging and increment has been achieved. In these cases, the forest area is not decisive and the balance of revenues and costs can be achieved even with a relatively very small area (Pulkrab et al. 2014).

The only objective evaluation criterion is the profit, defined as the difference between revenues and full own costs, which comes annually (so there is no need to consider the time factor as in the first option). The time level for this variant is therefore one year.

The gross profit of forest production can be calculated according to the model:$HZLV = Vu – Nu$

where

HZLV - gross profit of forest production,

Vu - revenues for the analyzed period,

Nu - costs for the analyzed period.

- The quality of the analysis depends, regardless of size, on the accuracy of the technical, biological and economic information used.
- The analysis requires the following assumptions to be met:
- All expected inputs and outputs must be described quantitatively.
- A time horizon must be defined for each input and output (it must be included in the period).
- Each input and output must also be expressed in value (monetary).
- The only suitable spatial unit of assessment is the set of forest types (SLT). This unit makes it possible to quantify ecological limits and economic parameters of management. This is especially important for comparing different farming methods (Pulkrab et al. 2014).

Model bases and typological limits

The diploma thesis analyzes potential differences, advantages and disadvantages of this systems, my diploma thesis includes cost of cultivation operations including repeated planting (especially now, when we have bad years, very dry spring so a lot of plants are destroyed. So, every year it is necessary to repeat some part, it can be for example 30%), also costs of protection of young stands. It is not always necessary for shelterwood system, especially when it is 100% nature regeneration. Opposite situation with artificial regenerated stands where we have ~40% of beech or fir. Without protection it is not possible to reach establishing of new stands. Protection can be from deer or pests, for example.

Also, some clearing operation must be included: clearing from logging residues, for example. In clear-cut we can use mechanical removing (cleaning) compare to shelterwood, where it should be done manually. Tending of the young stands is similar for the both systems, but for the shelterwood needs to remove higher number of trees, than in artificial, because there a lot of small trees. If we want to apply for estreatment and decrease number to 1 by 1 meter, we have to remove a lot of species and it is more expansive, comparing to artificial regeneration. So this operations are different for both systems. In the same way, we calculate direct costs for logging and transportation.

We have next proportions: nature regeneration in shelter wood system 100% in 1 variant and in second variant lower, according to proportion of ameliorative and stabilizing species: 40% of artificial regeneration and 60% of nature regeneration. And for clearcutting system it is artificial regeneration 100%, and second variant artificial regeneration 80% and nature regeneration-20%. Because sometimes it is possible to use nature regeneration in clear cut from the seeds from the neighboring stands. Now more detailed:

In our research we use next parameters: model bases for forest management **SLT 3K - acid oak-beech site, HS 43.** This site condition has been chosen because these sites are prevailing and probably the most important site condition in the University forest enterprise

1) Forest typological limits

Legislation (Act No. 289/95 Coll., including relevant decrees as amended) + ecosystem sustainability (Plíva 2000):

Rotation period (years): Norway spruce (SM), Scots pine (BO) 100 (90 - 130), European beech (BK) 120 (100 - 130),

Regeneration period (years): SM, BK 30-40, BO 20-30,

Min. proportion of stabilizing and ameliorative species (MZD): 35%, BK,

Included: Birch (BR), Silver fir (JD), Linden (LP), Pedunculate oak (DB), Sessile oak (DBZ), Rowan (JR), Sycamore maple (KL), Douglas fir (DG), European larch (MD).

Main species: SM, BO, BK, DB, DBZ, JD.

Target species composition, SM 30, BK 30, DB 20, JD 10, MD/DG 10.

2) Input parameters:

- Site index: SM 5/6, BK 6, DB 6/7, JD 5, MD 5 Plíva 2000),
- For individual species it is necessary to determine: mean height (m), mean diameter (cm), number of trees (inds/ha), volume stock with bark (growth and taxation tables of main tree species – SM,BO,BK,DB - Černý et al. 1996), mean volume per stem (volume stock/number of trees).

3) Variants of the Silviculture systems

A. Clear-cutting system

a) Proportion of artificial / natural regeneration 100 / 0 %

Target species composition: SM 40, BK 40, MD 20.

Rotation period: 95 years;

Regeneration period: 20 years;

% cutting used according to legislation (Annex No. 3 to Decree No. 298/2018 Coll., and Annex No. 5 to Decree No. 84/1996 Coll.).

Stocking: 0,88 (Report of the State of Forest)

b) Proportion of artificial / natural regeneration 80 / 20 %

Target species composition: SM 40, BK 40, MD 20.

Rotation period: 95 years;

Regeneration period: 20 years;

% cutting used according to legislation (Annex No. 3 to Decree No. 298/2018 Coll., and Annex No. 5 to Decree No. 84/1996 Coll.).

Stocking: 0,88 (Report of the State of Forest)

B. Shelterwood system

a) Proportion of artificial / natural regeneration 0 / 100 %

Target species composition: SM 30, BK 30, DB 20, JD 10, MD/DG 10.

Rotation period: 130 years;

Regeneration period: 50 years;

% cutting used according to legislation (Annex No. 3 to Decree No. 298/2018 Coll., and Annex No. 5 to Decree No. 84/1996 Coll.).

Stocking: 0,88 (Report of the State of Forest)

Light increment - determined on the basis of the adjusted Gehrahdt formula (adjusted for stock) the light increment in the first period of 13% - (SM, JD, BK) and 8% - (BO, DB) is used. In subsequent periods, the light increment decreases, it is not further calculated.

b) Proportion of artificial / natural regeneration 40 / 60 %

Target species composition: SM 30, BK 30, DB 20, JD 10, MD/DG 10.

Rotation period: 130 years;

Regeneration period: 50 years;

% cutting used according to legislation (Annex No. 3 to Decree No. 298/2018 Coll., and Annex No. 5 to Decree No. 84/1996 Coll.).

Stocking: 0,88 (Report of the State of Forest)

Light increment - determined on the basis of the adjusted Gehrahdt formula (adjusted for stock) the light increment in the first period of 13% - (SM, JD, BK) and 8% - (BO, DB) is used. In subsequent periods, the light increment decreases, it is not further calculated.

By the following two tables we can see direct costs on logging operation and on logging by harvesters:

Operation		CZK/m^3
Final harvest (clear cutting)	coniferous	120
Final harvest (clear cutting)	deciduous	145
Final harvest (shelterwood)	coniferous	165
Final harvest (shelterwood)	deciduous	180
Harvest (thinning)	coniferous	495
Harvest (thinning)	deciduous	285
Team skidding - direct		145
Team skidding - combination		100
Skidding UWT (P-OM)		137
Skidding UWT (VM-OM)		111
Manipulation		160

Table 4: Direct costs on logging operation

As we can see, final harvest with shelterwood system is slightly more expensive in comparison to clear cutting, for both types of trees.

Direct costs (CZK/m^3)	Tree mass (average volume m^3)						
	<0,19	0,29	0,39	0,49	0,69	1,2	>1,2
	480	446	440	385	363	358	375

Table 5: Direct costs on logging by harvesters

Data about growth, diameter, height, volume was arrived from the Growth table. And the data about costs of operations was arrived from Annual report about management of our university's forests and pieces with assortments was done from the assortment tables.

Results

Economics

In this chapter, I would like to show all costs belong to forest treatment in each type. Firstly, clear-cut system:

Set of forest types (SLT):	3K	3K
Management set of stands (HS):	43	43
Silvicultural system (HZ):	Clear cutting	Clear cutting
Species composition:	SM 40, BK 40 MD 20	SM 40, BK 40 MD 20
Rotation period:	95	95
Regeneration period:	20	20
Share of natural regeneration:	0	20

Table 6: Operation costs for clearcutting systems

Operation	Technical Units (t.u.)	Number t.u.	Number t.u.	Cost/ t.u.	Cost for 0%	Cost for 20%
Soil preparation:	ha		0,20	11936		2387,2
Natural regeneration	ha	0	0,20			
Artificial regeneration - planting						
- first planting	ha	1,0	0,8	65996	65996	52796,8
- repeated planting	ha	0,2	0,16	65996	13199,2	10559,36
Planting materiál:						
- first planting						
SM	ha/1000 ks	0,4/1,6	0,2/0,8			
JD	ha/1000 ks		0,1/0,4			
BK	ha/1000 ks	0,4/4	0,2/2			
DB	ha/1000 ks		0,2/2			
MD	ha/1000 ks	0,2/0,6	0,1/0,6			
- repeated planting						
SM	ha/1000 ks	0,1/0,4	0,07/0,28			
BK (JD)	ha/1000 ks	0,1/1	0,07/0,7			
Protection of young stands						
- protection form deer - chemical	ha	0,6 (*5)	0,4 (*5)	6733	**20199**	**13466**
- protection from deer - fencing	km	0,35	0,35	104017	36405,95	36405,95

- protection from weeds - moving	ha	1	0,8	6733	6733	5386,4
- protection from pine weevil	ha	0,3	0,3	3150	945	945
Other silvicultural operations						
- clearing from loppings	ha	1	1	31041	31041	31041
Forest protection	hour	20	20	130	2600	2600
Clearing						
- clearing of natural regeneration	ha		0,20	8900		1780
- clearing up to 4 m height	ha	0,50	0,50	5720	2860	2860
- clearing up over 4 m height	ha	0,4	0,4	14 176	5670,4	5670,4
Total sum					185649,55	163510,91
Per year					1954,2	1721,2

Table 6 display all necessary cost for clear-cut silvicultural management with two variants of share of natural regeneration: 0% and 20%, with their costs in result: 185649,55 Kč and 163510,91 Kč accordingly. Data show us, that 0% of share natural regeneration is more expensive than another variant. Half of the operations are more expensive for 10-20% for variant with 0% of share natural regeneration. In result, we have difference in price 22138,64 Kč. In next table we will see all cost of Shelterwood system.

Set of forest types (SLT):	3K	3K
Management set of stands (HS):	43	43
Silvicultural system (HZ):	Shelterwood	Shelterwood
Species composition:	SM 30, BK 30, DB 20, JD 10, MD 10	SM 30, BK 30, DB 20, JD 10, MD 10
Rotation period:	130	130
Regeneration period:	50	50
Share of natural regeneration:	100	60

Table 7: Operation costs for shelterwood systems

Operation	Techn. units	Number t.u.	Number t.u.	Cost/ t.u.	Cost for 100%	Cost for 60%
Soil preparation:	ha	1	0,60	11936	11936	7161,6
Natural regeneration	ha	1	0,60			
Artificial regeneration - planting						
- first planting	ha		0,4	65996		26398,4
- repeated planting	ha		0,08	65996		5279,68
Planting materiál:						
- first planting						
SM	ha/1000 ks					
JD	ha/1000 ks		0,1/0,4			
BK	ha/1000 ks		0,1/1			
DB	ha/1000 ks		0,2/2			
MD	ha/1000 ks					
- repeated planting						
JD	ha/1000 ks		0,08/0,32			
Protection of young stands						
- protection form deer - chemical	ha	0	0,4 (*5)			
- protection from deer - fencing	km		0,3	104017		31205,1
- protection from weeds - moving	ha		0,4	6733		2693,2
- protection from pine weevil	ha	0,3	0,3	3150	945	945
Other silv. operations						
- clearing from loppings	ha	1	1	31041	31041	31041
Forest protection	hour	20	20	130	2600	2600
Clearing						
- clearing of nat. regener.	ha	1	0,6	8900	8900	5340
- clearing up to 4 m height	ha	0,50	0,50	5720	2860	2860
- clearing up over 4 m height	ha	0,4	0,4	14176	5670,4	5670,4
Total sum					63952,4	121194,38
Per year					491,9	932,3

Table 7 shows all necessary expenses for shelterwood silvicultural management with two variants of share of natural regeneration: 100% and 60%, with their costs in result: 63952,4 Kč and 1121194,38 Kč accordingly. As we can see, cost of shelterwood system's operations with prevailing form of natural regeneration are lower, than clear-cut system with lower percentage of share of natural regeneration.

Clear cutting system SLT 3K Price 2015
Rotation period/regeneration period 95/20; zastoupení SM 40, BK 40, MD 20; stocking 0,88).

Table 8: Clear cutting system 2015 (short version, full version available in the Annex)

species (BS)	Age of stand (years)	average height (m)	average diameter (cm)	Tree number (ind.)	Volume stock with bark (m^3)	Volume stock without bark (m^3)	portion (%)	stocking (%)	notice	revenues (CZK)	costs (CZK)
SM	85,00	24,00	25,30	923	517,00	465,00	100,00	100,00	From growth tables		
					218	**197**				**357 966**	**82 153**
BK	85,00	23,40	25,50	641	385	347	100,00	100,00	From growth tables		
				225,79	**175**	**158**				**193 038**	**69 746**
MD	85,00	26,70	31,30	389	362	326	100,00	100,00	From growth tables		
				68,52	**73**	**65**				**93406,76**	**27145,45**
Total cutting:					**466**	**420**	**Total revenues/costs:**			**644410, 02**	**179044,89**
Total cutting for 1 year and 1 ha:					**4**	**4**	**Total revenues/costs for 1 year and 1 ha:**			**6783,26**	**1884,68**

Shelterwood system Price 2015
Rotation period/regeneration period 130/50; species composition SM 30, BK 30, DB 20, JD 10, MD 10; stocking 0,88).

Table 9: Shelterwood system 2015 (short version, full version available in the Annex)

species (BS)	Age of stand (years)	average height (m)	average diameter (cm)	Tree number (ind.)	Volume stock with bark (m^3)	Volume stock without bark (m^3)	stocking (%)	notice	revenues (CZK)	costs (CZK)
SM	95	25,1	27,2	816	547	492	100	From growth tables		
Total:					**229**	**207**			**396 592**	**95 791**
BK	95	24,5	28,4	528	412	371	100	From growth tables		
Total:					**186**	**168**			**215 645**	**80 311**
DB	95	19,6	25,5	560	285	257	100	From growth tables		
Total:					**84**	**76**			**137730**	**36054**
JD	95	27,7	32,4	625	699	629	100	From growth tables		
Total:					**118**	**107**			**208 126**	**49 220**
MD	95	27,6	33,5	345	376	338	100	From growth tables		
Total:					**52**	**45**			**69 709**	**21 839**
Total cutting:					**669**	**603**	**Total revenues/costs:**		**1 027 802**	**283 215**
Total cutting for 1 year and 1 ha:						**5**	**Total revenues/costs for 1 year and 1 ha:**		**7 906**	**2 179**

By tables 8 and 9 we can see expenses and profits for the year 2015. In those years most profitable species is spruce with revenue 396 thousand CZK in shelterwood system and almost 358 thousand with clear cut silvicultural system. The profit is CZK 300 801 and CZK 275,813 for shelterwood and clear-cutting systems respectively. The second most profitable species is Silver fir for shelterwood system with a profit of 158,906. For clear cut system the second most profitable is European larch with a profit of CZK 123,292.

Table 10: Light increment for 2015

specie	age	increment (m3)	volume (m3)	DBH (cm)	portion %	stocking	cutting (m3)	cutting (m3)	notice	tariff (CZK)	revenues (CZK)
SM	85 - 95	100	0,56	26,3	100	100			G. Tables		
			0,56		**50**	**88**	**44**	**40**	**cutting**	1272	55 968
BK	85 - 95	120	0,6	27	100	100			G. Tables		
			0,6		**30**	**88**	**31**	**28**	**cutting**	1732	53 692
DB	85 - 95	60	0,41	24,4	100	100			G. Tables		
			0,41		**5**	**88**	**3**	**3**	**cutting**	1494	4 482
JD	85 - 95	130	0,91	29,3	100	100			G. Tables		
			0,91		**10**	**88**	**11**	**10**	**cutting**	1183	13 013
MD	85 - 95	50	0,93	32,4	100	100			G. Tables		
			0,91		**10**	**0,88**	**4**	**4**	**cutting**	1417	5 668
Total light increment							**93**	**84**			**132 823,00**
Total light increments for 1 ha and 1 year								**0,64**			**1 022,00**
Total shelterwood system + Light increment								**5,94**			**8 928,00**

Light increment is a result of reaction of individual trees on releasing of their crowns. This happening by partial cutting. In this type we must reduce stand density by taking out some trees (bad trees, for example) and the reaction of the trees which are left in the stand is that they enlarge crowns and more cover of crowns is expose to direct sun radiation. So, this trees are able to produce more increment, more wood.

In fact, these years are an example in general, as in 2018 there began a crisis and the situation changed. We will be able to see if there any difference in detail by analyzing the same two tables for the year 2018. In both situations, profit means as result of revenue minus costs, that mentioned in analyzed tables. Total profit will be calculated later for all variants and years.

Clear cutting system SLT 3K Price 2018

Rotation period/regeneration period 95/20; zastoupení SM 40, BK 40, MD 20; stocking 0,88)

Table 11: Clear cutting system 2018 (short version, full version available in the Annex)

species (BS)	Age of stand (years)	average height	average diameter	Tree number (ind.)	Volume stock with bark	Volume stock without bark	portion (%)	stocking (%)	notice	revenues	costs
		(m)	(cm)		(m^3)	(m^3)				(CZK)	(CZK)
SM	85,00	24,00	25,30	923	517,00	465,00	100,00	100,00	From growth tables		
					218	**197**				**301 926**	**82 153**
BK	85,00	23,40	25,50	641	385	347	100,00	100,00	From growth tables		
				225,79	**175**	**158**				**217 151**	**69 746**
MD	85,00	26,70	31,30	389	362	326	100,00	100,00	From growth tables		
				68,52	**73**	**65**				**107988,48**	**27145,45**
Total cutting:					**466**	**420**	**Total revenues/costs:**			**627064,64**	**179044,89**
Total cutting for 1 year and 1 ha:					**4**	**4**	**Total revenues/costs for 1 year and 1 ha:**			**6600,68**	**1884,68**

Shelterwood system Price 2018

Rotation period/regeneration period 130/50; species composition SM 30, BK 30, DB 20, JD 10, MD 10; stocking 0,88)

Table 12: Shelterwood system 2018 (short version, full version available in the Annex)

species (BS)	Age of stand (years)	average height (m)	average diameter (cm)	Tree number (ind.)	Volume stock with bark (m^3)	Volume stock without bark (m^3)	portion (%)	stocking (%)	notice	revenues (CZK)	costs (CZK)
SM	95	25,1	27,2	816	547	492	100	100	From growth tables		
Total:					**229**	**207**				**331 388**	**95 791**
BK	95	24,5	28,4	528	412	371	100	100	From growth tables		
Total:					**186**	**168**				**256 525**	**80 311**
DB	95	19,6	25,5	560	285	257	100	100	From growth tables		
Total:					**84**	**76**				**194000**	**36054**
JD	95	27,7	32,4	625	699	629	100	100	From growth tables		
Total:					**118**	**107**				**174 909**	**49 220**
MD	95	27,6	33,5	345	376	338	100	100	From growth tables		
Total:					**52**	**45**				**80 298**	**21 839**
Total cutting:					**669**	**603**	**Total revenues/costs:**			**1 037 119**	**283 215**
Total cutting for 1 year and 1 ha:						**5**	**Total revenues/costs for 1 year and 1 ha:**			**7 978**	**2 179**

By tables 11 and 12 we can see expenses and revenues for the year 2018. In those years prevailing species is also spruce with revenue 331 thousand CZK in shelterwood system and almost 302 thousand with clear cut silvicultural system. The profit is CZK 235 597 and CZK 219 773 respectively. The second in the revenue list of species is European beech for shelterwood system with a profit of 158,906. For clear cut system the second most profitable is also European beech with a profit of CZK 219 773.

Table 13: Light increment for 2018

specie	age	increment (m3)	volume (m3)	DBH (cm)	portion %	stocking	cutting (m3)	cutting (m3)	poznámka	tarif (CZK)	revenues (CZK)
SM	85 - 95	100	0,56	26,3	100	100			G. Tables		
			0,56		**50**	**88**	**44**	**40**	**cutting**	1272	55 968
BK	85 - 95	120	0,6	27	100	100			G. Tables		
			0,6		**30**	**88**	**31**	**28**	**cutting**	1732	53 692
DB	85 - 95	60	0,41	24,4	100	100			G. Tables		
			0,41		**5**	**88**	**3**	**3**	**cutting**	1494	4 482
JD	85 - 95	130	0,91	29,3	100	100			G. Tables		
			0,91		**10**	**88**	**11**	**10**	**cutting**	1183	13 013
MD	85 - 95	50	0,93	32,4	100	100			G. Tables		
			0,91		**10**	**0,88**	**4**	**4**	**cutting**	1417	5 668
Total light increment							**93**	**84**			**132 823,00**
Total light increment for 1 ha and 1 year								**0,64**			**1 022,00**
Total shelterwood sytem + Light increment								**5,94**			**9 000,00**

In 2018, we clearly see changes in volumes and revenues. The first strand is spruce, but its volumes are already much smaller compared to other species. And the second place is now taken by European beech. At a time when the crisis is beginning, the diversification of species is beginning. (profit means as result of revenue minus costs, that mentioned in analyzed tables. Total profit will be calculated later for all variants and years)

Final table: Economic efficiency of different silvicultural systems

Type of system	**Share of natural regeneration %**	**Year**	**Profit**
Clear cutting	0	2015	2944,38
Clear cutting	20	2015	3177,38
Clear cutting	0	2018	2761,8
Clear cutting	20	2018	2994,8
Shelterwood	100	2015	5235,1
Shelterwood	60	2015	4794,7
Shelterwood	100	2018	5307,1
Shelterwood	60	2018	4866,7

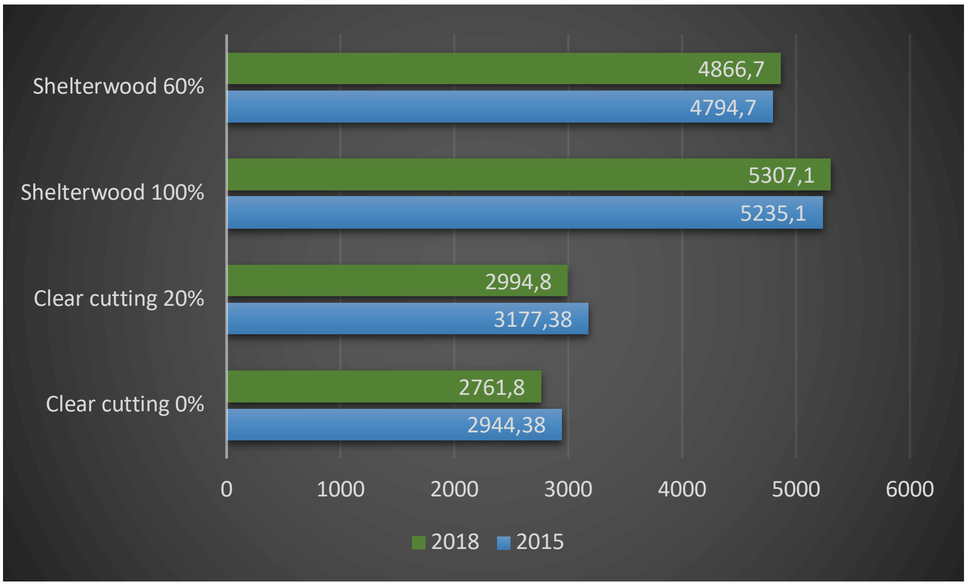


Diagram 2: final revenue table

A final table was created with all the variations that have been studied before, as well as different years: before and during the crisis. The numbers are based on net profit, minus all the actions that we have examined before. For better understanding, was created a histogram based on the data from this table. As we can see, even during a crisis, the most effective is a shelter wood silvicultural system with 100% of share nature regeneration.

Discussion

Hanewinkel based on the findings of the study, which reveal fundamental difficulties in comparing even-aged and uneven-aged management systems from an economic point of view, states that most unlikely that even technical improvements of model studies or new empirical studies with a broader data base can lead to critical improvements in such comparative economic studies. Given the fact that shelterwood system with 50 years of regeneration period is in the transition between even-aged and uneven-aged management system, because age difference can to be 50 years in the new stand- we can object, as the technical improvements in forest management gives positive results based on data from recent years. This is how we see the difference between the research in 2002 and 2020. But still, the data from the diploma thesis rely on the recommendations of that 2002 work.

In far 2002, Marc Hanewinkel's investigation comparative economic studies of even-aged and uneven-aged silvicultural systems concluded with a suggestion that the results of economic studies - either empirical or model studies - could be used to help evaluate different management systems, made by Hanewinkel (2001). In this case, instead of using arbitrary comparisons, a benchmarking approach is proposed. Benchmarking is a process used to identify best business practices. Applying it to the problem of finding the best management system in forestry would require that we have to look for typical forest enterprises practising even-aged or uneven-aged management that deliver the maximum economic output of all forest enterprises that have been investigated so far. The absolute value of the maximum under given production conditions (site index, species composition, etc.) is then an indicator of the economic productivity of the management system. This approach would allow to partially avoid the main drawbacks of empirical studies (flawed comparability) as well as model studies (unfair assumptions) (Hanewinkel 2002).

That's how this thesis was written. Real data from one area, completely equal to the evaluation criteria. Two management systems with several subsystems. All data are given above, and the result of the comparison showed a clear advantage of Shelter wood system, due to the cost of logging and silvicultural operations.

An important point of the diploma thesis is the time of its writing, as we are now in a crisis situation caused by the bark beetle invasion a few years ago. For comparison, was used data from 2015, when the market was stable, and data from 2018, when the crisis has already started to change the wood market and forest management. As the market changes, it is necessary to analyse how the price of different types of wood changes.

Table 14: Average prices of raw timber in the Czech Republic in 2015/2019 (CZK/m3) (Český statistický úřad 2020)

			Average for 2015	Average for 2019
Coniferous assortments	I. quality class	spruce	**2 597**	---
		pine	**1 731**	---
		larch	**2 958**	---
	II. quality class	spruce	**2 933**	**2 654**
		pine	**2 367**	**2 604**
		larch	**3 759**	**4 318**
	III. A/B quality class	spruce	**2 256**	**1 550**
		pine	**1 743**	**1 480**
		larch	**2 451**	**2 446**
	III. C quality class	spruce	**1 996**	**1 252**
		pine	**1 568**	**1 269**
		larch	**2 113**	**2 155**
	III. D quality class	spruce	**1 688**	**880**
		pine	**1 381**	**866**
		larch	**1 549**	**1 333**
	IV. quality class for groundwood pulp		**1 239**	**841**
	V. quality class for pulp production	spruce	**992**	**509**
		pine	**973**	**544**
	VI. quality class - fire wood		**812**	**587**
Deciduous assortments	I. quality class	oak	**13 068**	**17 424**
		beech	---	---
	II. quality class	oak	**5 280**	**9 318**
		beech	**2 255**	**2 802**
		birch	---	
	III. A/B quality class	oak	**2 990**	**4 208**
		beech	**1 605**	**1 905**
		birch	**1 375**	
	III. C quality class	oak	**2 447**	**3 495**
		beech	**1 447**	**1 641**
		birch	**1 119**	
	III. D quality class	oak	**1 681**	**2 407**
		beech	**1 267**	**1 412**
		birch	**1 123**	
	V. quality class for pulp production	oak	**1 049**	**1 254**
		beech	**1 149**	**1 246**
	VI. quality class - fire wood		**1 111**	**1 108**

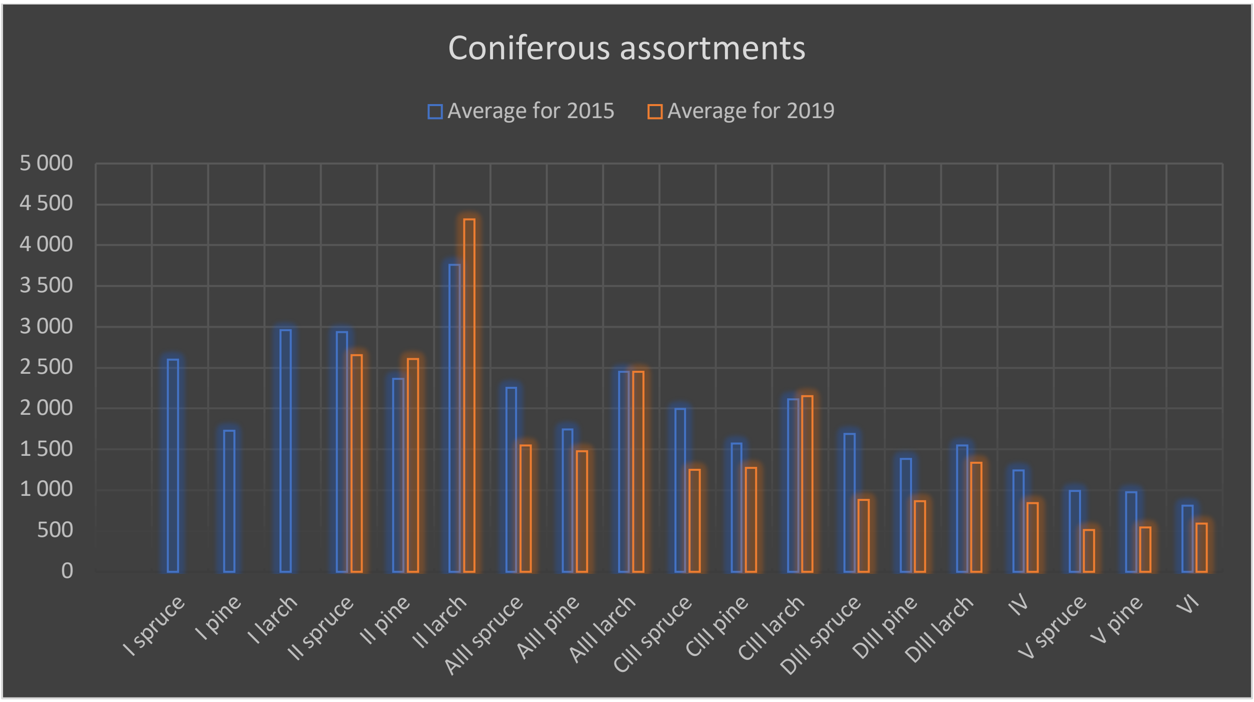


Diagram 3: Average prices of raw timber in the Czech Republic in 2015/2019 (CZK/m3) (Český statistický úřad 2020)

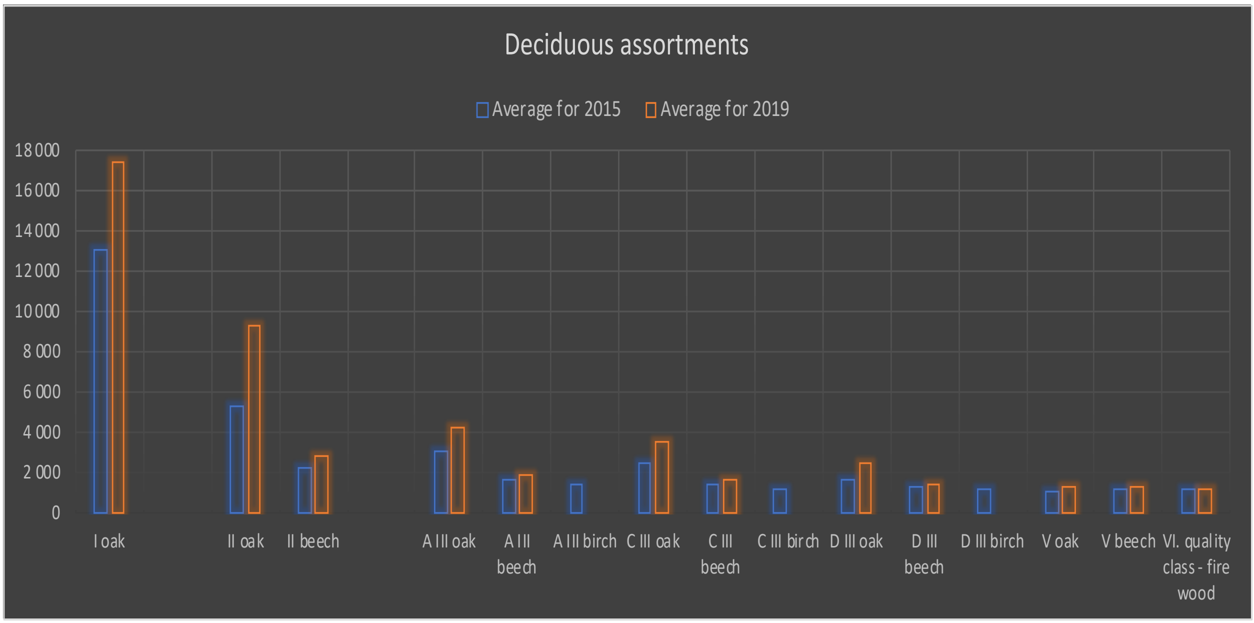


Diagram 4: Average prices of raw timber in the Czech Republic in 2015/2019 (CZK/m3) (Český statistický úřad 2020)

This table and its subsequent illustration in the form of two diagrams shows the main tree species sold on the market, divided into 6 wood quality classes. As we can see, prices and demand for certain types of trees have changed dramatically with the arrival of the Bark beetle.

Thus, there are no data on the first quality class of conifers for 2019 at all. In general, there is a prevailing decline in prices for conifers, except for a few species. The demand for larch 3 quality category has particularly increased. And spruce has fallen in price across all quality categories.

In deciduous assortments, we see the opposite statistics: prices rise during times of crisis, especially in the demand of oak 1 and 2 classes. Now let's take a look on average profit by years:

Table 15: Economics of the forest management in the Czech Republic (Ministerstvo zemědělství ČR 2019)

Profit before taxation (excl. subsidies) Kč/ha	2008	2010	2011	2014	2018
State forests	520	2311	3714	5765	69
Private forests	1077	1974	2026	1247	803
Communal forests	612	1051	1281	2133	661
Average	667	2031	2922	4119	364

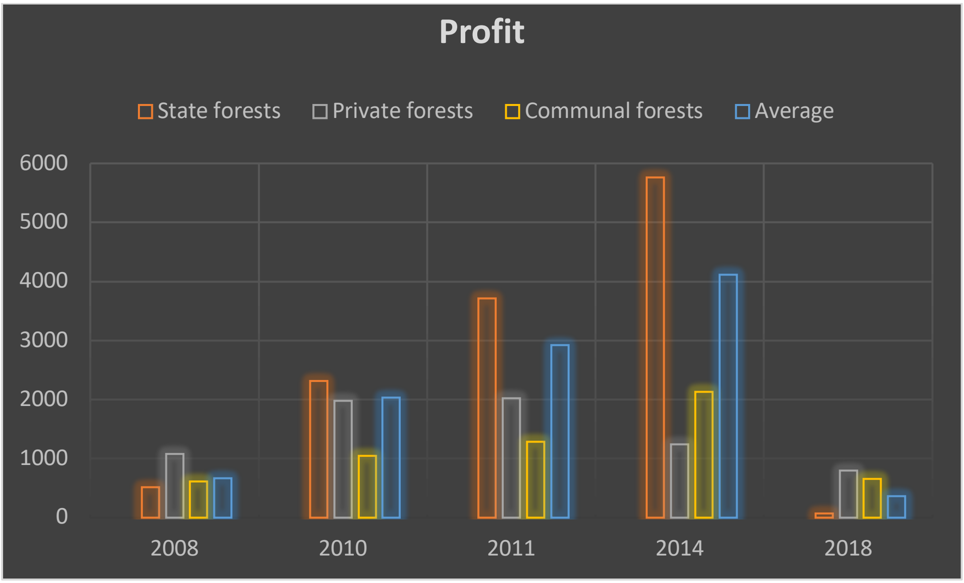


Diagram 5: Economics of the forest management in the Czech Republic (Ministerstvo zemědělství ČR 2019)

Table 15 and its subsequent illustration show the level of the crisis since 2018. If we take the last years (2014 and 2018) the income fell by ~90%. This means that in order for a business to survive, it is necessary to adopt market changes and adjust to demand and again analyse management approaches and choose the most effective ones.

The final table showed us the main results. They will be described in detail in the next chapter, but it is worth to mention some several important reasons for the advantages of the Shelter wood system: light increment and longer regeneration period. light increment it a saving of costs and bigger number of species. Longer regeneration period of 50 years (instead of only 20 years) allows longer growth for highest quality trees and as a result- to produce more and more wood.

Conclusion

My diploma thesis focused on the analysis of selected silvicultural systems (traditional based on the age class forests versus so called close-to-nature silviculture) with the aim to assess their economic efficiency and also the sustainability of forest management.

Two types of management were taken for the main types: shelter wood and clear-cutting silvicultural systems. They and their subtypes were described in detail both in theory and analyzed data from real life. The main source of field information was the Forest Enterprise in Kostelec nad Černými lesy. Also used were the data from official sources, about volumes, revenues and prices of wood.

By analyzing and comparing all available information in detail, we can draw several fundamental conclusions that can be used in the forest business to improve productivity. First, we can confidently state that the shelter wood silvicultural system has been found to be more effective than the clear-cut system. Especially the more efficient type with 100% share of natural regeneration. The visual difference can be clearly seen in diagram 2.

An important point is that the time of crisis and current data are different from usual times. It is difficult to predict when the crisis will end, but risks can be reduced. By analyzing the new data in detail, it can be argued that risks can be reduced by cultivation of mix stands with lower proportion of the main species. We can see how much spruce has fallen in price, but prices for some other tree species have risen. Thus, with a large variety of trees species, you can cover losses from one species, by another tree species that has increased in price. It is more and more important to save costs for regeneration and shelter wood system is effective in this way.

It is also important to choose suitable species, for example price for larch, row timber is very stable when we compare years 2015 and 2019, and also oak. The result of oak is much better than beech. When we make decision about target species composition, we not only taking into consideration ecological demand of the species and the site conditions, but sometimes we have more choice and we include price as one more factor. For example, beech or oak, and oak is much better regarding to price. Also, accordance to the climate change, if here will be more and more warm temperature so oak will have advantage compared to beech. Oak is better adopted in warmer climate than beech.

Thus, based on the diploma thesis, we can confidently recommend to apply shelterwood system with cultivation of mix stands with lower proportion of main species up to 30%. And to use the following principles: on the one hand - to save costs, to use nature processes instead of artificial regeneration / tending, and on the other - to choose the optimal species and reduce the risks. This way of management will increase total profit by lower costs for logging and silvicultural operations and decrease risk of losses from price declines of main species.

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Annex

Clear cutting system SLT 3K,

Rotation period/regeneration period 95/20; zastoupení SM 40, BK 40, MD 20; stocking 0,88), **prices 2015**

species (BS)	Age of stand (years)	average height (m)	average diameter (cm)	Tree number (ind.)	Volume stock with bark (m^3)	Volume stock without bark (m^3)	Average volumet (m^3/ks)	portion (%)	stocking (%)	cutting percentage	notice	tariff (CZK/m3)	revenues (CZK)	costs (CZK)
SM	85,00	24,00	25,30	923	517,00	465,00		100,00	100,00		From growth tables			
				325	181,98	163,68		40,00	88,00		correction accord.. portion and stocking			
				81	**45**	**41**	**0,51**			**25,00**	**cutting**	1 783	72 960	17 064
	95,00	25,10	27,20	244	163	147					after 10 years			
				163	**109**	**98**	**0,60**			**67,00**	**cutting**	1 820	179 252	41 070
	105,00	25,80	29,00	80	64	58					after 10 years			
				80	**64**	**58**	**0,69**			**100,00**	**cutting**	1 836	105 754	24 019
					218	**197**							**357 966**	**82 153**
BK	85,00	23,40	25,50	641	385	347		100,00	100,00		From growth tables			
				226	136	122		40,00	88,00		correction accord.. portion and stocking			
				56	**34**	**31**	**0,54**			**25,00**	**cutting**	1 210	36 949	13 497

	95,00	24,50	28,40	169	131	118					after 10 years			
				113	**88**	**79**	**0,70**			**67,00**	**cutting**	1 222	96 857	35 033
	105,00	25,30	30,90	56	53	48					after 10 years			
				56	**53**	**48**	**0,86**			**100,00**	**cutting**	1 234	59 232	21 216
				225,79	**175**	**158**							**193 038**	**69 746**
MD	85,00	26,70	31,30	389	362	326		100,00	100,00		From growth tables			
				68	64	57		20,00	88,00		correction accord.. portion and stocking			
				17	**16**	**14**	**0,79**			**25,00**	**cutting**	1 417	20 325	5 981
	95,00	27,60	33,50	51	51	46					after 10 years			
				34	**34**	**31**	**0,90**			**67,00**	**cutting**	1 436	44 161	12 824
	105,00	28,40	35,40	17	23	20					after 10 years			
				17	**23**	**20**	**1,20**			**100,00**	**cutting**	1 446	28 920	8 340
				68,52	**73**	**65**							**93406,76**	**27145,45**
Total cutting:					**466**	**420**			**Total revenues/costs:**				**644410,02**	**179044,89**
Total cutting for 1 year and 1 ha:					**4**	**4**			**Total revenues/costs for 1 year and 1 ha:**				**6783,26**	**1884,68**

Shelterwood system

Rotation period/regeneration period 130/50; species composition SM 30, BK 30, DB 20, JD 10, MD 10; stocking 0,88), **prices 2015**

species (BS)	Age of stand (years)	average height (m)	average diameter (cm)	Tree number (ind.)	Volume stock with bark (m^3)	Volume stock without bark (m^3)	Average volume (m^3/ks)	portion (%)	stocking (%)	cutting percentage	notice	tariff (CZK/m3)	revenues (CZK)	costs (CZK)
SM	95	25,1	27,2	816	547	492		100	100		From growth tables			
				215	144	130		30	88		correction accord.. portion and stocking			
				4	**3**	**3**	**0,6**			**2**	**cutting**	1820	4 728	1200
	105	26,3	32,7	211	184	167					after 10 years			
				38	**33**	**30**	**0,79**			**18**	**cutting**	1876	56 288	13862
	115		33,9	173	166	151					after 10 years			
				43	**42**	**38**	**0,87**			**25**	**cutting**	1900	71 492	17384
	125		35,6	130	139	126					after 10 years			
				43	**46**	**42**	**0,97**			**33**	**cutting**	1914	79 647	19225
	135		37,1	87	102	92					after 10 years			
				43	**51**	**46**	**1,06**			**50**	**cutting**	1931	89 038	21303
	145		38,5	43	54	49					after 10 years			

				38	**48**	**43**	**1,14**			**88**	**cutting**	1931	83 299	19930
	155		39,6	5	7	6					after 10 years			
				5	**7**	**6**	**1,24**			**100**	**cutting**	1936	12 100	2888
Total:					**229**	**207**							**396 592**	**95 791**
BK	95	24,5	28,4	528	412	371		100	100		From growth tables			
				140	109	98		30	88		correction accord.. portion and stocking			
				3	**2**	**2**	**0,7**			**2**	**cutting**	1259	2 468	935
	105		34,9	137	121	110					after 10 years			
				25	**22**	**20**	**0,8**			**18**	**cutting**	1259	24 838	9410
	115		37	113	120	108					after 10 years			
				28	**30**	**27**	**0,96**			**25**	**cutting**	1273	34 524	12936
	125		38,9	84	119	108					after 10 years			
				28	**39**	**35**	**1,28**			**33**	**cutting**	1277	45 310	16925
	135		40,7	57	90	82					after 10 years			
				28	**45**	**41**	**1,43**			**50**	**cutting**	1285	52 370	19440
	145		42,3	28	48	43					after 10 years			
				25	**42**	**38**	**1,55**			**88**	**cutting**	1294	49 420	18218
	155		45,1	3	6	5					after 10 years			
				3	**6**	**5**	**1,71**			**100**	**cutting**	1309	6 715	2447
Total:					**186**	**168**							**215 645**	**80 311**

DB	95	19,6	25,5	560	285	257		100	100		From growth tables			
				99	50	45		20	88		correction accord.. portion and stocking			
				2	**1**	**1**				**2**	**cutting**	1676	1 516	432
	105		29,8	97	64	58					after 10 years			
				17	**12**	**10**	**0,6**			**18**	**cutting**	1726	18 082	4997
	115	20,1	31,5	79	59	54					after 10 years			
				20	**15**	**13**	**0,68**			**25**	**cutting**	1780	23 905	6406
	125		33,1	59	49	44					after 10 years			
				20	**16**	**15**	**0,75**			**33**	**cutting**	1836	26 810	6965
	135		34,5	40	40	36					after 10 years			
				20	**20**	**18**	**0,9**			**50**	**cutting**	1836	33 048	8586
	145		35,7	20	20	18					after 10 years			
				18	**18**	**16**	**0,9**			**88**	**cutting**	1887	30 025	7590
	155		37	2	2	2					after 10 years			
				2	**2**	**2**	**1,13**			**100**	**cutting**	1922	4 344	1078
Total:					**84**	**76**							**137730**	**36054**
JD	95	27,7	32,4	625	699	629		100	100		From growth tables			
				57	64	58		10	88		correction accord.. portion and stocking			

				1	**1**	**1**				**2**	**cutting**	1880	2 181	536
	105		39,1	56	89	81					after 10 years			
				10	**16**	**15**	**1,44**			**18**	**cutting**	1936	28 101	6706
	115		41,6	46	82	75					after 10 years			
				11	**21**	**19**	**1,62**			**25**	**cutting**	1943	36 198	8607
	125		43,9	34	71	64					after 10 years			
				11	**23**	**21**	**1,88**			**33**	**cutting**	1951	41 154	9745
	135		46	23	53	48					after 10 years			
				12	**27**	**24**	**2,1**			**50**	**cutting**	1961	47 358	11157
	145		48,1	12	31	28					after 10 years			
				10	**27**	**24**	**2,3**			**88**	**cutting**	1968	47 799	11221
	155		50,1	1	3	3					after 10 years			
				9	**3**	**3**	**2,7**			**100**	**cutting**	1976	5 335	1247
Total:					**118**	**107**							**208 126**	**49 220**
MD	95	27,6	33,5	345	376	338		100	100		From growth tables			
				30	33	30		10	88		correction accord.. portion and stocking			
				1	**1**	**1**	**0,9**			**2**	**cutting**	1436	854	275
	105		38,2	29	43	39					after 10 years			
				5	**8**	**7**	**1,35**			**18**	**cutting**	1456	10 260	3256
	115		41	24	36	32					after 10 years			

				6	**9**	**8**	**1,35**			**25**	**cutting**	1468	11 891	3742
	125		43,4	18	30	27					after 10 years			
				6	**10**	**9**	**1,5**			**33**	**cutting**	1476	13 151	4116
	135		45,5	12	22	20					after 10 years			
				6	**11**	**10**	**1,65**			**50**	**cutting**	1481	14 662	4574
	145		47,3	6	13	12					after 10 years			
				5	**12**	**11**	**2,03**			**88**	**cutting**	1485	15 917	4952
	155		49	1	2	2					after 10 years			
				1	**2**	**2**	**1,8**			**100**	**cutting**	1487	2 974	924
Total:					**52**	**45**							**69 709**	**21 839**
Total cutting:					**669**	**603**			**Total revenues/costs:**				**1 027 802**	**283 215**
Celkem těžba na 1 rok a 1 ha:						**5**			**Total revenues/costs for 1 year and 1 ha:**				**7 906**	**2 179**

Light increment

specie	age	increment (m3)	volume (m3)	DBH (cm)	portion %	stocking	cutting (m3)	cutting (m3)	poznámka	tarif (CZK)	revenues (CZK)
SM	85 - 95	100	0,56	26,3	100	100			G. Tables		
			0,56		**50**	**88**	**44**	**40**	**cutting**	1272	55 968

BK	85 - 95	120	0,6	27	100	100			G. Tables		
			0,6		**30**	**88**	**31**	**28**	**cutting**	1732	53 692
DB	85 - 95	60	0,41	24,4	100	100			G. Tables		
			0,41		**5**	**88**	**3**	**3**	**cutting**	1494	4 482
JD	85 - 95	130	0,91	29,3	100	100			G. Tables		
			0,91		**10**	**88**	**11**	**10**	**cutting**	1183	13 013
MD	85 - 95	50	0,93	32,4	100	100			G. Tables		
			0,91		**10**	**0,88**	**4**	**4**	**cutting**	1417	5 668
Total light increment							**93**	**84**			**132 823,00**
Total light increment for 1 ha and 1 year								**0,64**			**1 022,00**
Total shelterwood sytem + Light increment								**5,94**			**8 928,00**

Clear cutting system SLT 3K **Price 2018**

Rotation period/regeneration period 95/20; zastoupení SM 40, BK 40, MD 20; stocking 0,88)

species (BS)	Age of stand (years)	average height (m)	average diameter (cm)	Tree number (ind.)	Volume stock with bark (m^3)	Volume stock without bark (m^3)	Average volumet (m^3/ks)	portion (%)	stocking (%)	cutting percentage	notice	tariff (CZK/m3)	revenues (CZK)	costs (CZK)
SM	85,00	24,00	25,30	923	517,00	465,00		100,00	100,00		From growth tables			

				325	181,98	163,68		40,00	88,00		correction accord.. portion and stocking			
				81	**45**	**41**	**0,51**			**25,00**	**cutting**	1 494	61 134	17 064
	95,00	25,10	27,20	244	163	147					after 10 years			
				163	**109**	**98**	**0,60**			**67,00**	**cutting**	1 536	151 281	41 070
	105,00	25,80	29,00	80	64	58					after 10 years			
				80	**64**	**58**	**0,69**			**100,00**	**cutting**	1 554	89 510	24 019
					218	**197**							**301 926**	**82 153**
BK	85,00	23,40	25,50	641	385	347		100,00	100,00		From growth tables			
				226	136	122		40,00	88,00		correction accord.. portion and stocking			
				56	**34**	**31**	**0,54**			**25,00**	**cutting**	1 361	41 559	13 497
	95,00	24,50	28,40	169	131	118					after 10 years			
				113	**88**	**79**	**0,70**			**67,00**	**cutting**	1 376	109 063	35 033
	105,00	25,30	30,90	56	53	48					after 10 years			
				56	**53**	**48**	**0,86**			**100,00**	**cutting**	1 386	66 528	21 216
				225,79	**175**	**158**							**217 151**	**69 746**

MD	85,00	26,70	31,30	389	362	326		100,00	100,00		From growth tables			
				68	64	57		20,00	88,00		correction accord.. portion and stocking			
				17	**16**	**14**	**0,79**			**25,00**	**cutting**	1 641	23 539	5 981
	95,00	27,60	33,50	51	51	46					after 10 years			
				34	**34**	**31**	**0,90**			**67,00**	**cutting**	1 660	51 050	12 824
	105,00	28,40	35,40	17	23	20					after 10 years			
				17	**23**	**20**	**1,20**			**100,00**	**cutting**	1 670	33 400	8 340
				68,52	**73**	**65**							**107988,48**	**27145,45**
Total cutting:					**466**	**420**			**Total revenues/costs:**				**627064,64**	**179044,89**
Total cutting for 1 year and 1 ha:					**4**	**4**			**Total revenues/costs for 1 year and 1 ha:**				**6600,68**	**1884,68**

Shelterwood system **Price 2018**

Rotation period/regeneration period 130/50; species composition SM 30, BK 30, DB 20, JD 10, MD 10; stocking 0,88)

species (BS)	Age of stand (years)	average height (m)	average diameter (cm)	Tree number (ind.)	Volume stock with bark (m^3)	Volume stock without bark (m^3)	Average volume (m^3/ks)	portion (%)	stocking (%)	cutting percentage	notice	tariff (CZK/m3)	revenues (CZK)	costs (CZK)
SM	95	25,1	27,2	816	547	492		100	100		From growth tables			

				215	144	130		30	88		correction accord.. portion and stocking			
				4	**3**	**3**	**0,6**			**2**	**cutting**	1536	3 990	1200
	105	26,3	32,7	211	184	167					after 10 years			
				38	**33**	**30**	**0,79**			**18**	**cutting**	1567	47 017	13862
	115		33,9	173	166	151					after 10 years			
				43	**42**	**38**	**0,87**			**25**	**cutting**	1593	59 941	17384
	125		35,6	130	139	126					after 10 years			
				43	**46**	**42**	**0,97**			**33**	**cutting**	1602	66 664	19225
	135		37,1	87	102	92					after 10 years			
				43	**51**	**46**	**1,06**			**50**	**cutting**	1610	74 237	21303
	145		38,5	43	54	49					after 10 years			
				38	**48**	**43**	**1,14**			**88**	**cutting**	1610	69 452	19930
	155		39,6	5	7	6					after 10 years			
				5	**7**	**6**	**1,24**			**100**	**cutting**	1614	10 088	2888
Total:					**229**	**207**							**331 388**	**95 791**
BK	95	24,5	28,4	528	412	371		100	100		From growth tables			
				140	109	98		30	88		correction accord.. portion and stocking			
				3	**2**	**2**	**0,7**			**2**	**cutting**	1376	2 697	935

	105		34,9	137	121	110					after 10 years			
				25	**22**	**20**	**0,8**			**18**	**cutting**	1494	29 474	9410
	115		37	113	120	108					after 10 years			
				28	**30**	**27**	**0,96**			**25**	**cutting**	1516	41 114	12936
	125		38,9	84	119	108					after 10 years			
				28	**39**	**35**	**1,28**			**33**	**cutting**	1523	54 038	16925
	135		40,7	57	90	82					after 10 years			
				28	**45**	**41**	**1,43**			**50**	**cutting**	1527	62 233	19440
	145		42,3	28	48	43					after 10 years			
				25	**42**	**38**	**1,55**			**88**	**cutting**	1543	58 930	18218
	155		45,1	3	6	5					after 10 years			
				3	**6**	**5**	**1,71**			**100**	**cutting**	1567	8 039	2447
Total:					**186**	**168**							**256 525**	**80 311**
DB	95	19,6	25,5	560	285	257		100	100		From growth tables			
				99	50	45		20	88		correction accord.. portion and stocking			
				2	**1**	**1**				**2**	**cutting**	2039	1 845	432
	105		29,8	97	64	58					after 10 years			
				17	**12**	**10**	**0,6**			**18**	**cutting**	2161	22 639	4997
	115	20,1	31,5	79	59	54					after 10 years			

				20	**15**	**13**	**0,68**			**25**	**cutting**	2351	31 574	6406
	125		33,1	59	49	44					after 10 years			
				20	**16**	**15**	**0,75**			**33**	**cutting**	2677	39 091	6965
	135		34,5	40	40	36					after 10 years			
				20	**20**	**18**	**0,9**			**50**	**cutting**	2677	48 186	8586
	145		35,7	20	20	18					after 10 years			
				18	**18**	**16**	**0,9**			**88**	**cutting**	2784	44 297	7590
	155		37	2	2	2					after 10 years			
				2	**2**	**2**	**1,13**			**100**	**cutting**	2818	6 369	1078
Total:					**84**	**76**							**194000**	**36054**
JD	95	27,7	32,4	625	699	629		100	100		From growth tables			
				57	64	58		10	88		correction accord.. portion and stocking			
				1	**1**	**1**				**2**	**cutting**	1567	1 818	536
	105		39,1	56	89	81					after 10 years			
				10	**16**	**15**	**1,44**			**18**	**cutting**	1615	23 442	6706
	115		41,6	46	82	75					after 10 years			

				11	**21**	**19**	**1,62**			**25**	**cutting**	1620	30 181	8607
	125		43,9	34	71	64					after 10 years			
				11	**23**	**21**	**1,88**			**33**	**cutting**	1643	34 657	9745
	135		46	23	53	48					after 10 years			
				12	**27**	**24**	**2,1**			**50**	**cutting**	1654	39 944	11157
	145		48,1	12	31	28					after 10 years			
				10	**27**	**24**	**2,3**			**88**	**cutting**	1662	40 367	11221
	155		50,1	1	3	3					after 10 years			
				9	**3**	**3**	**2,7**			**100**	**cutting**	1667	4 501	1247
Total:					**118**	**107**							**174 909**	**49 220**
MD	95	27,6	33,5	345	376	338		100	100		From growth tables			
				30	33	30		10	88		correction accord.. portion and stocking			
				1	**1**	**1**	**0,9**			**2**	**cutting**	1660	988	275
	105		38,2	29	43	39					after 10 years			
				5	**8**	**7**	**1,35**			**18**	**cutting**	1680	11 839	3256
	115		41	24	36	32					after 10 years			
				6	**9**	**8**	**1,35**			**25**	**cutting**	1692	13 705	3742
	125		43,4	18	30	27					after 10 years			

				6	**10**	**9**	**1,5**			**33**	**cutting**	1700	15 147	4116
	135		45,5	12	22	20					after 10 years			
				6	**11**	**10**	**1,65**			**50**	**cutting**	1705	16 880	4574
	145		47,3	6	13	12					after 10 years			
				5	**12**	**11**	**2,03**			**88**	**cutting**	1709	18 318	4952
	155		49	1	2	2					after 10 years			
				1	**2**	**2**	**1,8**			**100**	**cutting**	1711	3 422	924
Total:					**52**	**45**							**80 298**	**21 839**
Total cutting:					**669**	**603**			**Total revenues/costs:**				**1 037 119**	**283 215**
Celkem těžba na 1 rok a 1 ha:						**5**			**Total revenues/costs for 1 year and 1 ha:**				**7 978**	**2 179**