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The most discussed logging method in Swedish forest history

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Cover: View over a clear-cut in state-owned forest in the county of Jämtland in 1917. Sowing and planting, conducted in 1911 and 1912, are described as successful.
(Source: SLU, Forest library)

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Clear-cutting. The most discussed logging method in Swedish forest history

Abstract

Clear-cutting has been applied in Sweden for nearly 200 years. To understand the history of this method, the ongoing discussion about logging methods, and the current debate about clear-cutting, an analysis of the forestry history is needed. This thesis presents a historical analysis of the development of the clear-cutting system in central and northern Sweden from the early 1800s to the 1950s. A variety of forest historical records were analysed, including journals, management plans and maps, and aerial images.

Clear-cutting was introduced into central Sweden in the early 1800s, due to concerns about deforestation. This new approach to forestry originated in Germany, where clear-cutting was applied very early and considered to be a method that would ensure regrowth. In the late 1800s, the increased need for timber in Europe made it possible to introduce clear-cutting in northern Sweden. Its adoption was driven by industrialization, the desire for sustainable forestry, inspiration from Germany, new forest research, and favourable economic conditions. As a result, by the early 1900s, clear-cutting was widely and systematically used in parts of northern Sweden, in both state-owned and private forests.

In the early 1900s, clear-cutting was developed side by side with selective cutting. However, selective cutting was gradually phased out and almost completely abandoned in northern Sweden during the 1950s. Until recently, it was believed that clear-cutting was first introduced into northern Sweden in the 1950s. However, this is a myth because clear-cutting occurred to a large extent in the early 1900s. In the late 1940s, two-fifths of the study area in Västernorrland County had been clear-cut. The myth was created to make a clear break between old traditions and new forest management based on science.

These results were obtained by combined analysis of complementary historical records using a variety of methods. This allows a subject to be approached from multiple angles, giving a holistic perspective on the studied issue. In this thesis, the journals present the ideas of clear-cutting, the management plans show the implementation of the ideas and the aerial images give an indication of the extent of the clear-cutting in the early 1900s. The aerial images were especially informative, providing information that would have been difficult to obtain from any other source. This thesis reveals the history of the most common and debated forestry method in Sweden. By looking into the past, we can better understand the current situation and maybe avoid future mistakes.

Keywords: clear-cutting, selective cutting, forest history, forest management, forestry, forestry journal, forest management plan, forest map, aerial image, historical records

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Kalhuggning. Den mest diskuterade avverkningsmetoden i svensk skogshistoria

Sammanfattning

Kalhyggesbruket har tillämpats i Sverige i nästan 200 år. För att förstå historiken bakom metoden, den pågående diskussionen om avverkningsmetoder och den aktuella debatten om kalhuggning behövs en analys av skogshistorien. Denna avhandling presenterar en historisk analys av kalhyggesbrukets utveckling och tillämpning i mellersta och norra Sverige från tidigt 1800-tal fram till 1950-talet. Flera olika skogshistoriska källor har analyserats, såsom tidskrifter, skogsbruksplaner och flygfoton.

I mellersta Sverige introducerades kalhuggning i början av 1800-talet när rädslan för skogsbrist blev alltmer påtaglig. Idéerna till det nya skogsbruket kom från Tyskland, där kalhyggesbruket tillämpades mycket tidigt och ansågs vara en metod som kunde säkerställa föryngringen. I slutet av 1800-talet gjorde det ökande virkesbehovet i Europa det möjligt att introducera kalhyggesbruket även i norra Sverige. Drivkrafterna bakom introduktionen var industrialiseringen, behov av hållbart skogsbruk, inspiration från Tyskland, ny skoglig forskning och gynnsamma ekonomiska förhållanden. Detta ledde till att kalhuggning tillämpades systematiskt i stor skala redan i början av 1900-talet i delar av norra Sverige, i både statligt ägd och privat skog.

I början av 1900-talet utvecklades kalhuggning sida vid sida med blädning, men gradvis fasades blädning ut och övergavs i stort sett helt i Norrland på 1950-talet. Tills nyligen har 1950-talet setts som den tidpunkt då kalhyggesbruket introducerades i norra Sverige. Detta är dock en myt eftersom kalhyggen förekom i stor utsträckning redan i början av 1900-talet. I slutet av 1940-talet hade två femtedelar av studieområdet i Västernorrland kalhuggits. Myten skapades för att upprätta en tydlig gräns mellan gamla traditioner och den nya skogsskötseln baserad på vetenskap.

Resultaten erhölls genom kombinerad analys av kompletterande historiska källor och flera metoder. Då angrips ämnet från flera vinklar och ger ett helhetsperspektiv. I avhandlingen representerar tidskriften idéerna bakom kalhyggesbruket, skogsbruksplanerna visar implementeringen och flygbilderna indikerar omfattningen av kalhyggesbruket i början av 1900-talet. Flygbilderna var särskilt viktiga eftersom de gav information som skulle varit svår att få på annat sätt. Denna avhandling avslöjar historien om den vanligaste och mest debatterade avverkningsmetoden i Sverige. Genom att se till det förflutna kan vi förstå dagens situation bättre och kanske undvika framtida misstag.

Nyckelord: kalhuggning, blädning, skogshistoria, skogsskötsel, skogsbruk, skogliga tidskrifter, skogsbruksplaner, skogskartor, flygbilder, historiskt källmaterial

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Dedikation

Till mina trogna supportrar; Jonas, Ebbe och Lo.

A generation which ignores history has no past and no future.
Robert Heinlein

Contents

List of publications

This thesis is based on the work contained in the following papers, referred to by Roman numerals in the text:

I Lundmark, H.*, Josefsson, T. & Östlund, L. (2013). The history of clear-cutting in northern Sweden – Driving forces and myths in boreal silviculture. *Forest Ecology and Management*, 307, pp. 112-122. © 2013 Published by Elsevier B.V.

II Lundmark, H.*, Josefsson, T. & Östlund, L. (2017). The introduction of modern forest management and clear-cutting in Sweden: Ridö State Forest 1832-2014. *European Journal of Forest Research*, 136 (2), pp. 269-285. Available from: https://link.springer.com/article/10.1007/s10342-017-1027-6

III Lundmark, H., Östlund, L. & Josefsson, T*. Continuity forest or second-generation forest? Historic aerial photos provide evidence of clear-cutting in northern Sweden. (*Submitted manuscript*)

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Paper II was published with Open Access.

* Corresponding author.

The contribution of Hanna Lundmark to the papers included in this thesis was as follows:

I My contribution corresponds to about 80% of the work. I have discussed the idea and design of the study with Lars Östlund and Torbjörn Josefsson. I have carried out the research in the library and analysed the historical records with support by Lars Östlund. I have had the main responsibility for writing the paper, with comments and editing by Lars Östlund and Torbjörn Josefsson. I am corresponding author and I have revised the paper after comments by editors and reviewers.

II My contribution corresponds to about 75% of the work. I have discussed the idea and design of the study, carried out the research in the archive and analysed the historical records with support by Lars Östlund. I have had the main responsibility for writing the paper, with comments and editing by Lars Östlund and Torbjörn Josefsson. I am corresponding author and I have revised the paper after comments by editors and reviewers.

III My contribution corresponds to about 60% of the work. I have discussed the idea and design of the study with Lars Östlund and Torbjörn Josefsson. I have carried out the research in the archive and analysed the aerial images with support by Torbjörn Josefsson. I have written the paper together with Torbjörn Josefsson, with comments and support by Lars Östlund.

Abbreviations

cf	compare
FSC	Forest Stewardship Council
GIS	Geographic Information System
NGO	Non-Governmental Organisation
PEFC	Programme for the Endorsement of Forest Certification
pp.	pages
The State Forests	In Swedish: Domänverket, today called Sveaskog AB and the Property Board of Sweden

1 Introduction

The introduction of modern forestry practices and clear-cutting[1] represented a major shift in attitudes towards Europe's forests. However, many questions about this shift remain unanswered. Can we pinpoint the beginning of the history of modern forestry and clear-cutting in Europe? What was the background to this shift? Taking the transition from the late Middle Ages to Modern History as a point of departure, it is possible to identify some key moments in the history of European forestry. In the late 1500s, times of "plague and depression" ended, Europe's economic development began advancing rapidly, and the use of its forests began to change. Deforestation became a major problem in many parts of Europe during the Middle Ages, and large forested areas were cleared for agricultural purposes during the period between approximately 1500 and 1750 (Williams 2006). When industrialization[2] began in around 1750, the use and management of forests changed again (Erb et al. 2008; Williams 2006). The industrial revolution began in the United Kingdom (UK) but other countries including Holland, Belgium, parts of France, and parts of Germany were also involved. However, the UK became industrially dominant and the global economy thus developed around the country. Thanks partly to industrialization and partly to colonization, the UK occupied a position of substantial global influence and power for a long time (de Vries 1994; Mokyr 1985). In the 1800s, industrialization spread to other countries in Western Europe, North America, and Japan (Mokyr 1985). Europe's expanding industries required large amounts of wood, and Sweden, Russia, Norway, Finland and Austria had large forests, enabling them to meet this demand (Björklund 1984; Streyffert 1931). This led to more intensive use of the forests, necessitating the adoption of forest management practices that ensured regeneration and long-term sustainability.

1. Logging of all the trees in a given area at the same time.

2. The shift from a predominantly agriculturally dominated economy towards a more industrially dominated economy.

However, at that time forest management attracted little interest in Sweden and there was no indication that any such management practices were likely to be developed. Instead, the development of scientific forestry and the work that led to the concept of sustainable forest management began in Germany (Hölzl 2010).

It is thus possible to say at least something about when modern forestry and clear-cutting in Europe began. To obtain a better understanding of its development, we can analyse historical forest records, study the extent of previous forestry, or learn from the discussions about forestry that took place at the time. Ideally, these methods should be combined to obtain the most comprehensive picture possible.

1.1 Background

The fundamental principles of the sustainable forest management model applied in Sweden today have their origins in 18th century Germany and the core concept of this model is in many ways very similar to that proposed over 200 years ago. The forester Heinrich Cotta was one of the pioneers of sustainable forest management. The model that later became dominant in Sweden was based on clear-cutting, a system that Cotta advocated in Germany in the 1800s (Johann 2007; Cotta 1865). The main purposes of a clear-cutting system were to create order in the forest and ensure regrowth. Order was established by dividing the forest into several distinct areas each of roughly equal sizes by drawing straight lines on a map. One of these areas would be logged each year; after one rotation period, the whole forest would have been logged, by which time the area logged first would have regenerated and be ready to be logged once again. The clear-cut areas were regenerated by planting or sowing, allowing control over the distribution of tree species in the forest. This method also made it possible to start managing the forest immediately, for example by performing thinnings. All planning and management actions were carefully recorded in forest management plans and on forest maps (Morgenstern 2007; Cotta 1865). These ideas were brought to Sweden in the early 1800s by Danish and German foresters and by Swedish foresters who had visited other European countries where clear-cutting was practised. They subsequently became widely accepted and implemented in practical forest management in southern and central Sweden during the 1800s (Brynte 2002).

It is less clear when clear-cutting became an established forest management method in northern Sweden. An article published by the *Journal of the Forestry*

Association of northern Sweden[3] states that one large commercial forest company in northern Sweden had been using clear-cutting and prescribed burning on *"vast areas"*[4] since the early 1800s (Lundberg 1893). In 1918, the same journal published an article with the heading *"The breakthrough and implementation of the clear-cutting system"*[5] (Berg 1918). However, there is also evidence suggesting that clear-cutting only became widespread in northern Sweden in around 1950. For example, Ebeling (1959) wrote: *"Then came the 1950s and the time of the great clear-cuttings in the upper-north"*[6]. Ericsson et al. (2000) and Hörnfeldt (2014) have also identified the 1950s as the era in which clear-cutting became established. To fully understand how and why this inconsistency emerged one must understand how the various regions of Sweden differed in terms of logging, legislation, and forest ownership during the 1800s.

Historical forest management practices differed considerably between different parts of Sweden, and the history of forestry in southern Sweden is quite different to that in central and northern Sweden. The forests of southern Sweden consisted largely of deciduous trees, and the region's history of forestry is strongly connected to its distribution of forest ownership. Peasant-owned forests were relatively common in southern Sweden, and the proportion of state-owned forest land was relatively small, unlike in the northern region (Brunet et al. 2011; Juhlin Dannfelt 1959). The forests were seen only as complementary resources to agriculture and mining. However, organised forestry was introduced to southern Sweden in the early 1800s by Danish and German foresters working on large estates, some of which established Sweden's first forest management plans in the 1830s (Brunet et al. 2012; Brunet 2005). In central Sweden, heavy logging took place during the 1800s and there was extensive clear-cutting, especially in the vicinity of iron works. Concerns about the loss of forests and deforestation were raised, but there was never any actual threat of forest deficiency in this area (Östlund 1999). The supposedly imminent forest shortage during this time was probably due to the fact that only the largest Scots pine (*Pinus sylvestris* L.) trees were considered worth logging for commercial purposes. The adoption of more organized forest management systems based on clear-cutting became increasingly common after 1850, especially in the areas around iron works (Nordquist 1959). During the 1800s, the forests of northern Sweden were

3. Swedish: *Norrlands Skogsvårdsförbunds tidskrift*
4. Swedish: "*ofantliga arealer"*
5. Swedish: *Trakthuggningens genombrott och tillämpning*
6. Swedish:*"Så kom 1950-talet och därmed de stora trakthyggenas tid i övre Norrland."*

managed through high-grading[7], mostly of Scots pine (Östlund et al. 1997), and large areas of forest remained unexploited.

The first modern forest law in Sweden was introduced in 1903, although it had been preceded by a number of other policies and regulations relating to the use of forests. In the 1700s, the Swedish government imposed regulations on the forest management methods of private forest owners (Stjernquist 1973). However, for various reasons including the sparse population, poor communications, and poorly developed local administration capabilities, these regulations were rarely obeyed and were disapplied in the late 1700s (Stjernquist 1973). Consequently, private forests were managed with very little state intervention in the 1800s. However, there were special regulations on the use of private forests in some areas such as the counties of Norrbotten and Västerbotten in northern Sweden, which were intended to protect the young forests from logging (Anon. 1885). These regulations should have limited the misuse of the forests, among other things, but there was never any actual forest management in the way we understand it today (Holmgren 1959).

Two official policies[8] dictated that publicly owned forests in northern Sweden should be subjected to high-grading (Berg 1918). These policies heavily influenced timber extraction by private forest companies in the region because they sourced some of their timber from state-owned forests. Towards the end of the 1800s, foresters started to realize that the regrowth of the logged areas was insufficient to meet future demand because it was too slow and too small-scale. Another problem was that the stocking level in the forests were too low and that the land should have been able to produce more than it actually did. The introduction of forest legislation to solve these problems with regeneration was discussed by the *Forestry Association of northern Sweden*[9] (Anon. 1885; Anon. 1883). Although foresters felt that regrowth needed to be regulated and that forest legislation was needed, they also wanted forest owners to have full freedom of action with regard to logging (Berg 1918). Because a mutually acceptable compromise on this issue was not reached, no forest legislation was introduced in the 1800s.

This lack of modern forest legislation meant that there were no restrictions on the use of forestry methods. Choices of methods varied widely between different parts of Sweden. In central Sweden, the activities of the ironworks in the 1700s and 1800s had given rise to large clear-cut areas even though the clear-

7. Swedish: dimensionshuggning. A silvicultural practice that aims at removing only the largest and most valuable trees without any consideration for the future quality of the forest (Puettmann et al. 2009).

8. Swedish: *Cirkulär 1867* and *Cirkulär 1869*

9. *Norrlands skogsvårdsförbund*

cutting system had not yet been introduced (Östlund 1999). Because ironworks could use smaller trees as well as larger ones, the areas around ironworks came to resemble large clear-cuts. In the first decades of the 1800s, modern forestry and clear-cutting according to German principles were introduced in some areas of central Sweden. The situation in northern Sweden was different because the forests of this sparsely-populated region were difficult to access and had not been used to the same extent as in central Sweden. Here, the largest and best trees were still logged by high-grading. This approach remained dominant until the end of the 1800s when the demand for different types of wood products increased, leading to greater pressure on the remaining forests in northern Sweden. This in turn necessitated forest regeneration after logging, prompting the adoption of a different logging strategy.

Accordingly, the old extensive style of forest usage was replaced with an intensified strategy directed towards larger areas and trees of all dimensions, including smaller ones. This was made possible by technical developments and the establishment of several pulp mills in northern Sweden in the late 1800s. Although the clear-cutting system was introduced in northern Sweden in the late 1800s, it was not until the 1950s that it became widely accepted and subsequently became the region's dominant forest management method. The details of this transition is currently unclear, however, and we do not fully understand how the clear-cutting system developed during this period.

Clear-cutting has been the predominant forest management method in Sweden for about 70 years, but several questions about its benefits and long-term viability have been raised in the last two decades, and alternative forest management methods have been discussed, studied, and applied. When evaluating the clear-cutting system and timber production against other benefits of forests, such as biodiversity and its social value, it is important to understand the entire history of the clear-cutting system in order to properly analyse its impacts and implications.

1.2 Aim

The overall aim of my thesis is to present a historical analysis of the expansion and development of the clear-cutting system in Sweden. The main objectives are to:

- Examine and describe how and to what extent the clear-cutting system was introduced and practised in central and northern Sweden from the 1800s until the 1950s and the driving forces behind this development.
- Determine why the clear-cutting system became so strongly associated with the 1950s in northern Sweden.

- Compare different methods and sources that can be used in forest historical studies.
- Discuss the consequences of past forest management for today's forestry.

More broadly, I want to discuss clear-cutting in Sweden from a landowner perspective and also a wider international perspective.

2 Materials and methods

The results in this thesis are based on analyses of various historical records. Historical records are things that give us information about what happened in the past, and may be classified as either primary or secondary sources. Primary sources are physical objects that remain from a given event (such as forest accounting records, timber purchase documents, forest management plans, or forest maps) or eyewitnesses (Kjeldstadli 1998; Cipolla 1991). Secondary sources are sources that provide second-hand information about an event (Kjeldstadli 1998; Cipolla 1991), e.g. letters, journals, foresters' notes, or reports from forest excursions. In the late 1600s, scholars in Europe began to systematically distinguish between primary and secondary sources and to define rules that historians should observe when using different kinds of sources (Cipolla 1991). Ideally, historians want to work with primary sources, i.e. the sources that were closest in time and space to the event of interest, particularly eyewitness accounts (Kjeldstadli 1998). If primary sources are unavailable, secondary sources can be used provided that caution is taken with regard to their possible deficiencies (Cipolla 1991). It should be noted that a given source may be regarded as a primary source in one context but a secondary source in another (Cipolla 1991). For example, if a forester working for a specific commercial forest company wrote an article about forestry at that company, the article would be considered a primary source of information on that company's business, operations, and history. However, as a source on forestry-related issues in general, the article would be considered a secondary source.

In this thesis, the analysis in paper I is based on a source that I considered both a primary and a secondary source (a forestry journal), while papers II and III are based on primary sources (forest management plans, forest maps, and aerial images). I consider the source in paper I to be both a primary and a secondary source because while some parts are clearly secondary (e.g. texts discussing legislation, because they are texts about another text), others (such as excursion reports, which contain quotations from participants alongside the

writer's own interpretations and opinions on the excursion) are balanced on the border between primary and secondary sources.

A powerful approach when working with historical data is to combine different methods, for example by complementing analysis of historical records with experiments, field surveys, or simulations. This approach was exemplified by Čufar et al. (2014), who studied the history of construction and timber economy by analysing historical records (e.g. forest management plans), dendroprovenancing, and dendrochronological analysis of wood material. In this way, they were able to determine the history of the construction of a castle in Slovenia thought to have been built in the 12th/13th century. Dendrochronological analysis revealed the felling dates of the castle's timbers and thus its likely years of construction. Comparisons with historical records showed that the timber was probably taken from nearby forests, which was also confirmed by dendroprovenancing. This study showcased the benefits such wide-ranging analytical strategies in which results obtained by one method can be confirmed by findings obtained with complementary techniques.

However, many forest history studies have relied solely on historical records. Santana Cordero et al. (2016) studied the extinction of coastal dune systems by analysing historical records such as written documents, maps, aerial photographs and explorers' written accounts. Similarly, Machar et al. (2017) used historical documents and forest management plans and maps to design a management strategy for European beech-dominated forests in protected areas. Using only historical records has advantages and is sometimes even necessary. For example, using a single methodological approach generally means that your sources will have similar sources of error that can then be treated in the same way, enabling uniform analysis of historical records. Analysing historical records also makes it possible to find patterns in the past and demonstrate structural contexts (Kjeldstadli 1998).

The studies included in this thesis draw on different types of historical records and collectively provide a holistic perspective on early forestry in Sweden. The historical source for the first study (paper I) was the *Journal of the Forestry Association of northern Sweden*. This paper reveals the theories and ideas that motivated the introduction and initial implementation of clear-cutting in northern Sweden. The second study (paper II) shows how these ideas were put into practice by examining forest management plans and forest maps of a state-owned forest area in central Sweden. Finally, the third study (paper III), uses aerial images to analyse the extent of the implementation of clear-cutting in northern Sweden in the early1900s.

2.1 Definitions

To facilitate both the analysis and the reading of this thesis, I have compiled terms and definitions that are common in the studied sources along with my interpretations of their meanings based on information from the studied sources and other literature (Table 1).

Table 1. *Forestry terms (in English and Swedish) and their definitions. The table begins with more general terms and progresses towards more specialized ones*

English term	Swedish term	Description
Forestry	Skogsbruk	The art, science, and practice of studying and managing forests, plantations, and related natural forest resources (Puettmann et al. 2009).
Sustainability	Hållbarhet	The ability to maintain a process or state at a certain level indefinitely (Puettmann et al. 2009).
Sustainable yield	Hållbart uttag	The amount of a natural resource, such as wood, that can be extracted from a site without reducing the standing volume of wood or production potential (Puettmann et al. 2009).
Silviculture	Skogsskötsel	The art and science of producing and tending a forest to achieve management objectives (Puettmann et al. 2009).
Silvicultural system	Skogsskötselsystem/ Skogsbrukssätt	A defined and specific system including established ways of logging, regenerating, and manage growing forests (Puettmann et al. 2009).
Forest management	Skogsskötsel/Skogsförvaltning	The integration of silvicultural practices and business concepts (e.g. analysing economic alternatives) to achieve a landowner's objectives (Bettinger et al. 2017).

English term	Swedish term	Description
High-grading	Dimensionshuggning	A silvicultural practice that aims to remove only the most valuable trees without any consideration for the future quality of the forest (Puettmann et al. 2009).
Selective cutting	Blädning	A silvicultural system that removes only a small proportion of trees, usually the oldest or the largest, either single scattered trees or in small groups at relatively short intervals, commonly five to twenty years. Typically applied to uneven-aged forests (Puettmann et al. 2009).
Clear-cutting	Trakthuggning/Kalhuggning	A silvicultural system in which all trees in a given (usually named a forest stand) area cut for commercial reasons and removed (Puettmann et al. 2009).
Clear-cut	Kalhygge/Trakthygge	A cut forest stand either with no trees, with seed trees (trees of the same height evenly distributed), or with residual trees (residual trees/groups of trees of different height).
Continuous cover forestry	Kontinuitetsskogsbruk	A silvicultural system that provides continuous and uninterrupted maintenance of forest cover and avoids clear-cutting (Pommerening & Murphy 2004).

2.2 Historical source criticism vs source review

When working with historical records, it is essential to consider several factors including the publisher of the source, the target group of the source, and the time and social context in which the source material originated. Source criticism was described by Torstendahl (2005) as a set of methods to be applied in a certain way in certain situations, whereas Kjeldstadli (1998) described it as a set of rules. Both approaches provide guidance on how to treat sources to avoid distorting

the information they offer. Cipolla (1991) describes source criticism as a rigorous methodology that has justified history's current claims to scientific status and that basically involves four processes: (1) deciphering texts, (2) interpreting their substance or content, (3) confirming their authenticity, and (4) ascertaining their reliability.

According to Kjeldstadli (1998), source criticism could equally well be called source review because it is not really about criticising the source in general but reviewing it to see what information it holds. He supports this claim by stating that if the goal of historical research is to erect a building of explanations then we need a foundation of secure statements about who did what, where, and when. By answering the four key questions below, source review allow us to ensure that the four walls of this foundation are solid and strong.

1 *What* sources can we draw on to answer a question? It is important to obtain sources that are complete or at least representative.
2 What *are* these sources? What function did they have in the context and environment in which they were created? It is important to determine their origin and purpose (external source criticism).
3 What *is in* the sources? What meaning do they have? It is important to interpret them.
4 What can they be *used* for? It is important to determine the sources' relevance to the problem at hand. However, first and foremost we must ask how *credible* the information is (internal source criticism).

The implementation of source review will depend on whether you are working with at most a few documents or with a large body of material or series of sources. In the first case, each source should be thoroughly examined, while in the second case one should seek to assess the material as a whole, possibly via random sampling (Kjeldstadli 1998).

I have primarily used source review in my studies. This is because I think that the structure of this method is clear and makes it easy to describe the source and identify its strengths and weaknesses.

2.3 Written historical records

2.3.1 Journal of the Forestry Association of northern Sweden

The first study was based on a systematic analysis of all volumes of the *Journal of the Forestry Association of northern Sweden*, which was published between

1883 until 1960. In total, 1326 articles were screened, of which 198 were selected for further scrutiny. Source review was used to assess both the credibility of the journal itself and that of the specific articles selected for further analysis. I will now describe this source based on Kjeldstadlis (1998) foundation wall questions and my interpretation his method. The first question is (1) *What sources do we have to highlight a question?* The journal was chosen as the source for paper I because it was the most important journal discussing forestry in the region of interest, and it was typical of the period of investigation that most of the professional and scientific discussion about forestry were held in a single journal. I therefore considered it to be a complete and representative source. The next question is (2) *What are the sources that we are facing?* The journal was the leading forum in which foresters and forest scientists discussed forestry in northern Sweden and related topics. The third question is (3) *What is in the sources?* The journal's content was relatively broad; it published field excursion reports, meeting minutes, the results of field experiments, and lectures and essays written by authors including forest scientists and representatives of both public forest owners and private forest companies. Accordingly, its content provided information on the management of both state- and privately owned forests. The final question is (4) *What can they be used for?* Because the journal was the main forum for discussion of forestry in northern Sweden, it is a good source of information on the theories and ideas underpinning the introduction of modern forest management methods and clear-cutting in northern Sweden. It can be considered a credible source due to its publisher, diversity of authors, and the variety of texts.

Some of the questions that had to be considered when analysing this source are answered in the above descriptions, such as who wrote the texts, for whom, for what purpose, and in what context. Overall, I judged the texts to be objective, although of course different authors advocated for the use of different management methods and ideas. As a counterbalance to these texts, there were also near-neutral texts discussing excursions, meetings, laws, and so on.

Other studies on the history of forestry have drawn on and evaluated similar historical records. For example, Mårald et al. (2016) compared Swedish and American forestry journals during the 1900s and 2000s and tested two hypotheses: that foresters at the beginning of the twentieth century were more concerned with production and less concerned with ecology than foresters at the beginning of the twenty-first century, and that US foresters in the early twentieth century were less concerned with local site conditions than Swedish foresters. In their study, they found that early foresters in both countries had broader (and often more ecologically focused) concerns than expected, that the prominence of ecological concerns in the forestry literature has increased (in parallel with

concerns about production in the Nordic countries), and that timber management (in both Sweden and the United States) is closely connected to concerns about governance and state power. Simonsson et al. (2015) used a similar approach to analyse the debate about retention forestry in Sweden, the factors motivating its use, and its implementation. To this end, they systematically analysed articles published by one non-profit forest association and one environmental non-profit organization. They concluded that retention forestry in Sweden was driven by several interacting factors including widespread criticism from environmental NGOs and public, lists of threatened species, concern about potentially severe political restrictions, demands from foreign customers driven by environmental NGOs, the influence of *"New forestry"*[10], and forestry certification[11] requirements. The authors also argued that historical analysis of the forces driving changes in forest management is necessary to explain why changes occurred and to clarify changes in the perception and uses of forest ecosystems in modern society. The implementation of this study is in many ways similar to my own: the two journals it examined were the leading forums for discussions about forestry and environment during the studied period. Additionally, my selection of articles for further analysis was guided by a series of headings and questions; this approach was also adopted by Simonsson et al. (2015).

2.3.2 Forest management plans and forest maps

Ridö State forest, located on an island in Lake Mälaren in central Sweden, was the focus of paper II. The historical records for this area consisted of forest management plans and forest maps covering a period of roughly 180 years (1832-2014). Management plans with attached maps from 1832, 1869, 1896, 1915, 1929, 1947 and 1957 were analysed (Fig. 1). The historical forest management plans contain detailed information about variables such as tree species composition, stand age, standing volume, planned loggings and other types of management measures.

10. A concept linked to endangered species.
11. FSC and PEFC

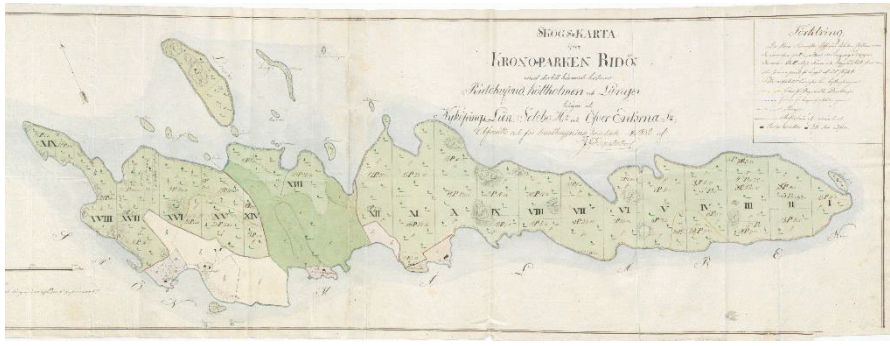

Figure 1. The forest map to the first forest management plan for Ridö State Forest, established in 1832. (Source: Regional State Archive [Landsarkivet], Härnösand, Sweden (paper II, table 1))

This source was evaluated using the previously mentioned foundation wall questions (Kjeldstadli 1998), of which the first is (1) *What sources do we have to highlight a question?* In this case, I wanted to study how clear-cutting had been applied over a long period, from its first implementation in Sweden to the present. Forest management plans and forest maps were considered suitable historical records for this purpose. A complete series of forest management plans with maps was available for the chosen studied area covering the period from the introduction of forest management and clear-cutting in 1832 to the present day. The extent to which the chosen area is representative of Sweden's forests could be debated because it is located on relatively small island. However, the uniqueness of access to a complete series of source material outweighs the disadvantages of a less representative study area. The second question is (2) *What are the sources we are facing?* The forest management plans and maps described the history of the forest, its current state, and planned logging activities and other forest management measures. The purpose of the foresters who made the plans and maps was to ensure a sustainable yield from the forest in the long run. The third foundation wall question is (3) *What is in the sources?* The historical forest management plans and maps were very detailed and contained information about most things worth knowing concerning the forest area in question, including things not directly related to forest management, such as grazing and fire history. In some cases, it was also possible to deduce the impacts of external factors such as the global economy. The final question is (4) *What can they be used for?* The plans and maps were very suitable sources for analysing practical forest management and determining which planned management actions were actually implemented by comparing plans from different time periods. The source can be considered credible because it consists of actual plans for a real state-owned forest area.

Various other studies have used old forest management plans as source records. For example, Boncina et al. (2003) used forest management plans from 1864 to 1988 to analyse long term changes in tree species composition in a mountainous forest area in Slovenia. These sources are quite similar to those used in paper II, and thus have similar advantages and problems. The authors concluded that forest monitoring can be an important part of ecosystem management and that data from old forest inventories and management plans are important for better understanding these ecosystems. However, they also identified some notable problems with these sources. In particular, they encountered many difficulties in assembling comparable data to analyse. For example, the methods used by foresters to conduct forest inventories changed over time; different minimum diameter thresholds were applied, and different size ranges for diameter classes were used. In addition, different measures of common stand parameters were used, along with different tariffs for determining growing stock. Sometimes only summarized data for coniferous and broadleaved trees were available, without data for individual tree species. I encountered some of these problems during my studies; for example, tree age ranges were divided differently in different forest management plans. I solved this by creating my own (wider) age classifications that could be applied to all the historical forest management plans. Another study that used similar historical records is that of Gimmi et al. (2009), who quantified disturbance effects on vegetation carbon pools in mountain forests in the Alptal region in Switzerland by analysing forest management plans from 1924 to 1987. These authors concluded that forest management plans have been and remain the main planning tools in Swiss forestry. Therefore, management plans are valuable sources for reconstructing forest changes in Switzerland. They noted that the management plans were irregularly distributed over time and therefore grouped them into three different time steps. This solution is similar to that I applied to certain parameters recorded in the Ridö State forest plans. The authors also encountered some problems with the historical records. For example, the management plans included annual time series for timber harvesting and unplanned fellings due to natural disturbances for each stand from 1906 to 2006. However, up until the 1950s most management plans only specified the total removal because the distinction between regular timber harvesting and unplanned felling was introduced in the 1950s. In addition, information on tree species was lacking in most cases (conversely, the Ridö State plans provided comprehensive information on tree species distributions). Overall, the information in the Swiss plans was very similar to that provided in the Ridö State plans; they provided information on natural disturbances and annual harvesting along with qualitative information on past forest use, the current forest state, and

guidelines for future forest use. These data provided valuable background information that facilitated interpretations.

2.4 Aerial images

The third study was based on aerial images and was conducted to learn more about the actual size and extent of the clear-cuts in northern Sweden in the early 1900s. The study area was located in the Västernorrland County in northern Sweden, where 18 landscapes[12] were chosen for aerial image interpretation. The first aerial images of Sweden were acquired in the 1930s by the *Mapping Agency*[13]. From the 1950s, the country was subjected to regular and comprehensive aerial photography. The aerial images in my study was taken in the 1940s. An archive of these aerial images is held at the *Swedish mapping, cadastral and land registration authority*[14] in Gävle in central Sweden. Track overviews of the aerial images allow you to see the flight paths and the individual images taken along each flight path.

Two criteria were applied when selecting images for paper III: that the images should be as old as possible and that there should be sufficient images of both state owned and privately owned forest areas. As before, source review was performed using the foundation wall approach of Kjeldstadli (1998). The first foundation wall question is (1) *What sources do we have to highlight a question?* The first aerial images in Sweden were taken in the 1930s, and these images were considered old enough for the purposes of the study. By measuring the size of the clear-cuts and even-aged young forest stands, it was possible to analyse the extent of these types of forests within a limited area in northern Sweden. The second foundation wall question is (2) *What are the sources that we are facing?* After the introduction of aerial photography in the 1930s, comprehensive aerial surveys of Sweden were performed regularly. The resulting images were used as background maps and as tools for community planning and map making. Therefore, the sources do not only provide information on forests. The third foundation wall question is (3) *What is in the sources?* These historical aerial images are black and white photos, each showing an area of land measuring approximately 6x6 km. The final question is (4) *What can the sources be used for?* Aerial images have many different applications, including mapping and landscape analysis. Analysing the extent of different forest types is closely related to both these uses. The images are primary sources and can be considered very reliable; they show snapshots of the forest, and there are guidelines on

12. Nine state-owned landscapes and nine privately owned landscapes.
13. Swedish: *Kartverket*
14. Swedish: *Lantmäteriet*

interpreting their contents. The fact that these images have been taken in the same way for a long time and an official body is responsible for taking them increases the source's reliability. The main difficulty of using this material relates to assessing what each image show. Image interpretation may be complicated by seasonal effects; images were usually taken in the summer, but some were taken during spring or fall. This can be important because during winter deciduous trees lack their leaves and the ground may be partly covered by snow or ice. Another potential complicating factor is the presence of non-productive land because clear-cuts can be confused with mires or rocky ground. Other important factors were topography, which can provide information about areas that might have been difficult to access for forestry, and poor image quality, which can make it difficult to see the tree tops when measuring tree heights in images.

A number of other studies have used aerial images as source records. Historical changes in forest cover and land ownership in a landscape in the Midwestern U.S. were described by Medley et al. (2003), who analysed aerial images from 1984 together with land ownership records from 1912 to 1983. In this study land-cover patches were digitized by visual interpretation (using clearly defined criteria), and GIS was used to determine total forest area, mean patch area, and patch shape. The same approach was used in my study, except clear-cuts were the main objective during registration rather than "patches". By analysing aerial image data, Stepper et al. (2015) concluded that canopy height models derived from repeat aerial image surveys can be useful tools for measuring canopy heights and assessing changes in forest height over time, including in highly structured mixed forests. They also refer to a forest mensuration textbook (van Laar and Akça 2007) that describes aerial stereo images as suitable for measurement of the top height of forest stands. I used tree heights and stand structure to estimate the ages of forest stands, but found that the heights of some stands were underestimated because of difficulties in distinguishing their tree tops. No such problems were mentioned by Stepper et al. (2015), probably because their aerial images (taken in 2009) were more recent than mine (taken in the 1940s). I believe that the lower image quality is why the tree tops "disappear" in some of the images studied here. However, I do not see this as a major limitation of my study because underestimation of tree heights would lead to underestimation of stand ages and thus underestimation of the ages of the corresponding clear-cuts.

3 Sustainable forestry

> "Looking at the historical origins of sustainability can deepen our understanding of an ecological discourse that has entered a global stage and is fraught with conflict as well as misunderstanding."
>
> - Hölzl 2010

To understand the introduction of clear-cutting and the rationale for its uptake in Sweden and around the world, it is necessary to broaden the scope and look at the ideas behind forestry, or more specifically "sustainable forestry". However, the meaning of the concept has changed over time. It initially referred only to removing damaged trees, regeneration after logging, and preventing deforestation (paper I). Its definition has since expanded to include efforts to maintain or even increase forest production as well as the standing stock of trees, and today encompasses both economic and ecological considerations.

3.1 Background/Development

The onset of the industrial revolution caused a pronounced increase in the demand for timber in Europe between the 1700s and 1800s, making deforestation into a significant problem. This made foresters aware that their forests were not regenerating or growing at the desired rate, indicating that they were not being used in a way that could be sustainable in the long run. It was clear that faster regeneration was needed to achieve sustainability, and that this would ideally be accompanied by increased wood production. This necessitated new ways of managing forests, prompting foresters in Germany to start experimenting by logging all trees in an area and then sowing or plant the cleared area. The introduction of this process of clear-cutting and artificial regeneration marked the beginning of a new forestry that could deliver large amounts of timber over time.

Over time, the focus of sustainable forestry in Germany shifted from regeneration to economic efficiency (Hölzl 2010). The development of sustainable forestry in Sweden was also initially motivated by fears of deforestation and a desire to improve forest regeneration, and subsequently evolved in the same manner as in Germany.

3.2 The forest must be regenerated

In northern Sweden, discussions about more sustainable forestry began in the late 1800s, when foresters realized that regrowth was not occurring at the rate needed to meet the industrial demand (paper I). There was also a fear of forest deficiency because Swedish foresters had heard that this had become a problem in other parts of Europe and in the US (Eliasson 2000; Wieslander 1936). What did the foresters think about sustainable forestry? My studies on articles and conversations between foresters in the *Journal of the Forestry Association of northern Sweden* indicated that they agreed on the need for regeneration, and that logging the best and largest trees while leaving the rest was not a satisfactory method for promoting regrowth (paper I). Accordingly, they also agreed that a forest management method involving active measures to improve regrowth was needed. They therefore turned their eyes to other countries and the methods applied there. Swedish foresters visited other European countries where they gathered new knowledge, and similar exchanges in the opposite direction occurred when Danish and German foresters came to visit and work in Swedish forests. The recognition of the need for sustainable forestry became a driving force in the development of clear-cutting in Sweden (paper I).

The central role of regeneration in the introduction of clear-cutting is demonstrated by the foundation of the *Association for Artificial Regeneration in northern Sweden*[15], which was established in 1882; regeneration was considered sufficiently important to both be the main purpose of the newly formed association and a key component of its name. Another example was the first (modern) Swedish Forestry Act of 1903, which became known as a regrowth law because its main purpose was to regulate forest growth. When the *Association for Artificial Regeneration in northern Sweden* started its activities in the late 1800s, promoting sustainable forestry was not yet one of the organization's stated goals. However, indirectly it was still some kind of goal because the association sought to increase forest regeneration in order to meet existing and future demand for timber (paper I). Towards the end of the 1800s,

15. Swedish: *Föreningen för skogskultur i Norrland* (the predecessor to the *Forestry Association of northern Sweden*, the source record for paper I)

the saw-mill driven exploitation of the forests in northern Sweden helped to spur interest in sustainable forestry.

Two important studies reported in the late 1800s and in the early 1900s that selective cutting was not a suitable forest management method in northern Sweden (Holmgren 1914; Örtenblad 1893). However, they drew this conclusion for different reasons. Örtenblad (1893) was the first to demonstrate poor regrowth after selective cutting in northern Sweden. According to him, this was primarily because the saplings did not receive enough light. Two decades later, Holmgren (1914) concluded that it was the condition of the forest land and its vegetation rather than light that primarily determined the rate of forest regeneration. According to him, clear-cuts should be so large that shade-tolerant mosses and berries would die, allowing grasses and herbs to take their place. Once this transition had occurred, the area could be regenerated. He recommended the use of self-seeding in areas with seed trees (Fig. 2), and planting or sowing elsewhere.

Figure 2. Clear-cut with seed trees of Scots pine in the county of Västerbotten in 1914. (Source: SLU, Forest Library)

A third contribution to the debate about regeneration in northern Sweden was "On the effect of our regeneration measures on the formation of saltpetre in the ground and its importance in the regeneration of conifereous forests"[16], published in 1917 by Henrik Hesselman. He conducted field trials to find out how best treat regeneration surfaces to promote the conversion of humus nitrogen into sodium nitrate, which favours the growth of conifers. Although subsequent work showed that Hesselman overestimated the significance of nitrate formation, these three studies (and particularly Hesselman's work) convincingly clarified the biological conditions required for efficient regeneration in northern Sweden (Carbonnier 1978).

One method that became important in preparing clear-cuts in northern Sweden for regeneration was Joel Wretlind's technique for controlled burning (Wretlind 1932). Wretlind was inspired by the forest stands that emerged after forest fires, and in the 1920s he began using controlled burnings to induce regeneration on forest land with a lot of raw humus. Many foresters initially objected to his prescribed burning approach, but his methods gained popularity when it became apparent that there was a dire need to restore Sweden's forests. As a result, they were eventually applied over large areas of northern Sweden. His methods and studies were recently analysed by Cogos et al. (2019), who suggested that in addition to being a forerunner of prescribed burning, he should also be regarded as an *"early proponent of eco-forestry"* because he opposed mechanical scarification and artificial regeneration, and claimed that *"nature's way"* was the best.

Clear-cutting played an important role in regeneration because it created good conditions for the establishment of new forest. However, other factors relevant to sustainable forestry were also recognized to be important, such as the choice of tree species (paper I). After clear-cutting, the foresters could freely choose what tree species to grow in the new forest, and there were several factors to base their choices on. Initially, these choices were primarily directed by demand, productivity, and perhaps even curiosity about new tree species (paper I; paper II). Subsequently, in the late 1800s and the early 1900s, more became known about site adaptation, leading to debate about which tree species were most suitable for the specific forest stands and conditions (paper I; paper II). Today, there are still more parameters to consider when selecting species for forest regeneration. According to Kimmins (1992), these choices are determined by one or more of the following factors; typically, a combination of factors is considered.

16. Swedish: *Om våra skogsföryngringsåtgärders inverkan på salpeterbildningen i marken och dess betydelse för barrskogens föryngring*.

- Match the ecology of the tree species with the ecology of the area in question.
- Prediction of the society's need for, as well as the potential economic value of, the fibre, timber or other components of the biomass in different tree species when they are ready to be logged.
- Consideration of other values such as biodiversity, insect or disease resistance, wind firmness, wildlife, stability on slopes and along waterways, or aesthetics.

3.3 Industry

Industrialization was clearly another major driving force behind the introduction of the clear-cutting system in northern Sweden, and had two major effects. First, the growing demand for timber from the already industrialized countries elsewhere in Europe created a *"timber frontier"* that gradually moved northwards and inland, where large areas of forest remained to be exploited. Second, whereas it was previously only large and old Scots pine trees that had appreciable economic value, the rapid expansion of industries in northern Sweden enabled the marketing of a wider range of tree dimensions and tree species (paper I). Conditions were similar in Finland (Michelsen 1999), but those in the other Nordic countries, Norway and Denmark, differed somewhat. Norway's circumstances were different because of the country's favourable position for transport; Norway's entire forest area had a network of rivers and lakes, with ready access to the sea for transport onwards. This favoured exploitation of the forest and the establishment of industries. Waterfalls played an especially important role in Norway's industrial development (Oxholm 1922). In Denmark, the introduction of sustainable forestry was not linked to industrialization in the same way as in northern Sweden; in the 1890s, the industrialization began to spread from the capital city Copenhagen to surrounding cities, and at the same time the German model was being phased out by the country's foresters (Serup 2004). Instead, the development of forestry mirrored that in Central Europe, where sustainable forestry had its roots.

Industrialization began in the 1700s in Europe and greatly increased demand for timber. As the forest resources of Central Europe were depleted, the pressure on Swedish forests increased. The pressure was particularly intense in the northern parts of the country because the forest land of southern and central Sweden was heavily deforested or dominated by young forest. A new way of using forests was required because the older methods of high-grading and selective cutting could not yield enough timber to meet the new demand. In addition, it was recognized that forest regeneration was needed to ensure the future supply of forest raw materials. These two factors motivated the adoption

of clear-cutting in northern Sweden. Industrialization thus created both a need for forest management methods supporting regeneration and the conditions that would enable the long-term application of such methods due to the establishment of new industries. Industrialization was thus a major driving force behind the introduction and first application of the clear-cutting system and sustainable forestry (paper I).

The sawmill industry became established in Sweden in the mid-1800s and played a major role in the country's industrialization (Björklund 1984). The sawmill and pulp industries of northern Sweden in particular expanded rapidly during the late 1800s and early 1900s, in parallel with the rapid shift away from high-grading to other forest management methods, namely clear-cutting and various forms of selective cutting (Fig. 3). This may have been partly because northern Sweden had several integrated industrial concerns. The development of the pulp industry in northern Sweden was unique in that pulp mills were often established in collaboration with ironworks and saw mills. As a result, integrated firms emerged in several places and achieved high profitability by being able to use a wide range of different tree species and timber dimensions. The situation in other European countries was quite different because the pulp industry was seen as a competitor of saw mills (Hamilton 1978).

Figure 3. A pulp mill (sulphite mill) in Svartvik, Västernorrland County, in 1910. (Source: SLU, Forest library)

3.3.1 Technology in forestry

The introduction of the clear-cutting system in northern Sweden has sometimes been linked to the mechanization of forest management in the mid-1900s (Lisberg Jensen 2011). It is easy to believe that mechanized forestry was required to cut large forest areas. However, since clear-cutting was first introduced in central Sweden in the early 1800s (paper II) and in northern Sweden in the late 1800s (paper I; paper III), it is obvious that clear-cutting was first applied at a time when the handsaw and axe were the most advanced tools for felling trees (Sundberg 1978). In the early 1900s, clear-cutting was already quite extensive in parts of northern Sweden (paper III). However, the mechanization of forestry clearly was important for the final breakthrough of the clear-cutting system in the 1950s in Sweden (Lisberg Jensen 2011), which coincided with the development of chainsaws light enough to be handled by a single operator (Sundberg 1978).

Technology (mechanization included) in forestry does not appear to have been a strongly debated topic before the 1960s. Between its first edition in 1883 and 1960, the *Journal of the Forestry Association of northern Sweden* published only three technologically oriented articles related to clear-cutting: one between 1921 and 1940, and two between 1941 and 1960 (paper I, table 1). Topics discussed in these articles included both regeneration and scarification. In the 1940s, it was argued that regrowth through natural regeneration should be promoted by finding suitable treatments for the cut forest areas. Large-scale scarification was considered essential for this purpose (Holmgren 1943). In the late 1950s, a joint committee involving various private forest companies and the State forest company was founded. A stated purpose of the committee was to further develop mechanical scarification methods (Fredén 1958).

Müller and Hanewinkel (2018) described how forest management in Germany went from manual tools to IT-based machinery in only a century, a development that can be divided into three different industrial revolutions. While the first "traditional" industrial revolution motivated a shift from exploitative to sustainable forestry, the second industrial revolution led to increased mechanization of the production process, mainly thanks to the advent of combustion engines, electrification, and mass production in the early 1900s (Bauernhansl et al. 2014). This included the introduction of one-man chainsaws and tractors in logging operations from the 1960s. Similar developments occurred in the US and in other European countries (Müller & Hanewinkel 2018). Forest management in Sweden has gone through a similar development and fully mechanized logging systems with harvesters have been used extensively since the 1970s (Ringdahl 2011).

3.3.2 Economy

One factor that has substantially affected the implementation of the clear-cutting system is the economic situation at the national, international, and corporate levels. This is because clear-cutting (unlike other methods, including selective cutting) was associated with regeneration costs, and because there was not always a market for all tree sizes (paper I). However, the reverse was clearly also true, i.e. forest management and timber production significantly impacted Sweden's economy at the time.

> "There can hardly be any doubt that timber usage was one of the strongest dynamic factors in Sweden's economic lift during the mid-1800s, when the foundations of our modern industrialized society were established."[17]
>
> - Söderlund 1951

The export of timber and wood products became highly important for the economic development of northern Sweden as it enabled the expansion of industries and logging in more remote areas (Björklund 1984; Söderlund 1951). In turn, this required more labour, which further benefited the region (Söderlund 1951).

During the first decades of the 1900s, Sweden's economy flourished (Hellström 1933). The expanding pulp industries and fuel poverty during World War I had a positive impact on the timber market and especially on demand for smaller trees, allowing logging to be intensified. As a result, clear-cutting was widely advocated and increasingly used in several parts of northern Sweden (paper I; Nordström 1959; Schard 1937). The 1920s resulted in both ups and downs in Sweden's economy and ended with a temporary boom (Schard 1937; Hellström 1933).

The biggest backlash against the clear-cutting system came during the economic crisis of the 1930s (paper I). On the 29th of October in 1929, the greatest stock market crash in the history of the United States occurred, triggering the beginning of the Great Depression in the US and Europe (Larsson 2014). The 1930s were characterized by this economic crisis, which greatly reduced the scope for sustainable forestry because it effectively eliminated demand for all forest products other than saw timber (Anon. 1944). In addition, clear-cutting necessitated costly regeneration, which was considered too expensive under the prevailing economic conditions (paper I). Consequently, selective cutting enjoyed a resurgence in popularity in northern Sweden between

17 Swedish: *"Det kan knappast råda någon tvekan om att trävaruhanteringen var en av de starkast verkande dynamiska faktorerna i Sveriges ekonomiska liv under de årtionden omkring 1800-talets mitt, då grunden lades till vårt moderna industrialiserade samhälle."*

1920 and 1940, which became known as the *"era of selective cutting"*[18] (Anon. 1974) (Fig. 4). However, the economy eventually recovered and so did the timber market. Shortly before the World War II, there was once again a market for all tree sizes and it became possible to apply clear-cutting again (Anon. 1944).

Figure 4. Selective cutting in a forest stand in Jämtland County in 1913. (Source: SLU, Forest library)

The development of forestry also changed the economic aspects of forest management. Before the 1940s, the goal of forestry in northern Sweden had been to use the volume-rich forests in the most economically profitable way (paper I). Afterwards, however, there was a transition from extensive and exploitative use of the forest to more intensive and reconstructive forest management strategies (Kempe 1954). With that said, even in the 1930s some foresters argued that it might sometimes be necessary to make economic sacrifices to enable sustainable forest management (Holmgren 1933). New forest management methods that should promote growth in young forests, such as thinning, emerged during the period from 1920 to 1940. During good times, it was rarely difficult to convince forest owners of the need for forest management actions like this. Unfortunately, it was harder to motivate them to take such actions during times of economic crisis when they offered no immediate profit (Schard 1937).

3.4 Knowledge formation/Field experiments

The clear-cutting system was a forest management method that was based on both new theories and previous practical experience when it was first applied in

18. Swedish: *blädningsepoken*

Germany in the 1700s (Hölzl 2010). Its adoption was heavily promoted by the foresters Georg Ludwig Hartig and Heinrich Cotta, who had both university educations and extensive practical forestry training (Mantel 1965).

The development of forestry in Germany occurred in several stages. They already used different ways of logging the forest when the first forest education started in 1763 (Hölzl 2010). After that, it took some time before the ideas of sustainable forestry and the clear-cutting system were articulated and implemented during the late 1700s (Hölzl 2010).

3.4.1 How the knowledge reached Sweden

The development of sustainable forestry and clear-cutting in Sweden differed substantially from that in Germany because forest education, sustainable forestry, and the clear-cutting system were introduced simultaneously during the early 1800s (Wahlgren 1928). The method spread widely and quickly, possibly because clear-cutting was already well-established elsewhere (so clear and straightforward guidelines were available), the idea was appealing because of its potential to create well-ordered forests, and because it could be implemented readily (paper I, II, III).

In 1828, the Swedish government decided that an institute of higher education in forestry – *the State Forest Institute*[19] – should be established in Sweden. The educational program offered at this institute was designed by Israel af Ström, a forest researcher who lived and worked in Djurgården[20] in central Sweden. He inherited his position from his father, who was a chief forest officer in Djurgården. In the early 1800s, Israel af Ström believed that the forest management practices at Djurgården needed to be reorganized, but recognized that he lacked the knowledge needed to implement such a reorganization (Wahlgren 1928). Thus, whereas sustainable forestry in Germany was introduced by foresters who had received higher education in forestry (Mantel 1965), Israel af Ström had studied the subject for only a short period (Wahlgren 1928). He therefore wanted to visit Germany to learn more about forest management, and sought founding for this purpose after consulting the district medical officer. However, it ended up being the latter who got the grant and went to Germany. As a result, af Ström had to finance his visit himself, and went to Denmark instead. At that time, Denmark was prominent in forestry and forest management (Wahlgren 1928). Sustainable forestry based on German ideas had been introduced in Denmark in the 1760s (Mather et al. 1998), and the country's foresters followed this model until the end of the 1800s (Serup 2004). Israel af

19. Swedish: *Skogsinstitutet*

20. A state owned forest area in Stockholm, central Sweden.

Ström established Sweden's first forest management plan in Djurgården in Stockholm in central Sweden (Wahlgren 1928). He is also mentioned in the first forest management plan for Ridö State forest; because of the latter site's proximity to Stockholm, it is likely that he was involved in the introduction of sustainable forestry there as well (paper II). The new institute facilitated the spread of the new ideas and forest management practices, and its students started implementing these ideas within a few years of starting their education. Each student was required to complete an internship during their education, which is demonstrated by (among other things) a forest management plan for Ridö State forest from 1869, which states that it was prepared by students from the school (paper II). Swedish foresters also gained knowledge about sustainable forestry and clear-cutting by visiting other European countries, especially Denmark and Germany.

The forest management plans of Sweden's landowners (both the state and private companies) were prepared in accordance with the German guidelines (paper II; Wahlgren 1928). These forest management plans were often very detailed and included descriptions of the forest's history, geology, topology, moisture content, tree species composition, and planned management actions. In Ridö State forest, clear-cutting based on German principles was first applied in 1832 (paper II). Unlike other areas of central Sweden, forestry in Ridö State forest was entirely idea-based rather than being connected to an ironworks or another industry. Aspects that the Swedish foresters took particular notice of included the division of forests and the forest management plans with their descriptions and maps, rotation periods, and regeneration. The rotation period for regrowth was set to 120 years because the forest included trees that would produce quality saw timber and construction timber in the future (paper II). The estimate of the rotation period was based on the few existing trees with saw timber qualities together with information on soil quality and location. The long-term plan from 1832 was followed up until 1869, when a new plan was set up by students from the Royal Forest Institute. This new plan differed from the previous one in terms of the choice of logging methods (selective cutting instead of clear-cutting) and featured a higher planned logging volume. In the next forest management plan, from 1896, the management method was changed back to clear-cutting because selective cutting was believed to increase the forest's vulnerability to storm damage. The next major change in the forest management at Ridö State forest occurred 1929. The plan from 1929 differs clearly from its predecessors in terms of how the forest is described and in terms of its maps. The first four forest maps (from 1832, 1869, 1896, and 1915) were drawn in accordance with the German guidelines, featuring linear divisions into annual logging areas (Fig. 1). Conversely, the forest maps from 1929 onwards feature

more irregularly shaped forest stands because by that point the foresters had started taking site characteristics into account, and recognised that it was not effective to apply the same forest management everywhere (Fig. 5).

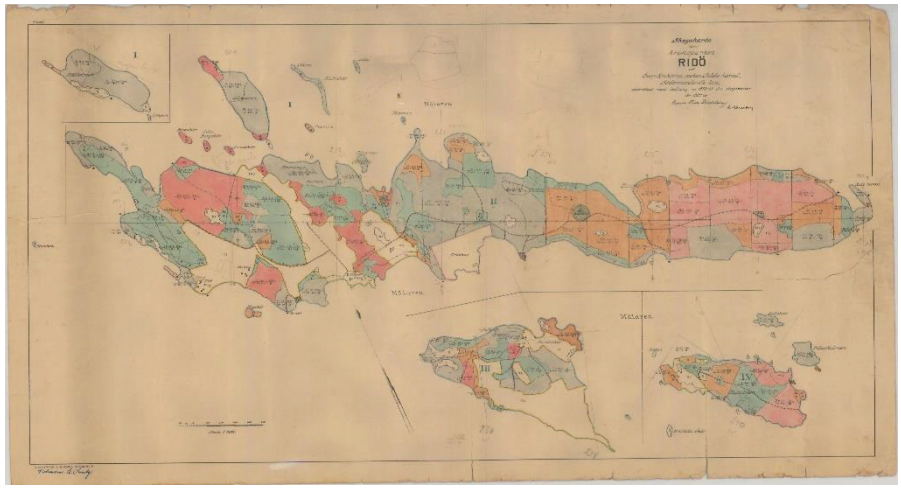

Figure 5. The Ridö State Forest map from 1929 feature more irregularly shaped forest stands than previous forest maps due to site-adapted forest management. (Source: Regional State Archive [Landsarkivet], Härnösand, Sweden (paper II, table 1))

The new knowledge about sustainable forestry laid the foundation for a new way of thinking about the forest. I think that there were two parts of the new theory that foresters had to come to grips with. The first was beginning to apply the ideas of sustainable forestry; foresters had not previously considered forest resources in this way. The second was the actual implementation of the clear-cutting system. The ideas and forest management methods were tested an evaluated, and the acquisition of new knowledge through local field trials thus became an important driving force behind the introduction of clear-cutting.

3.4.2 Field surveys

The *State Forest Research Institute*[21] was established in 1902 with the aim of helping to answer basic questions about the biological and forest management aspects of sustainable forestry through surveys and comparative experimentation (Wahlgren 1928). It should be noted that forestry experiments had been conducted prior to its establishment and the forest field surveys were probably conducted in several different forms. For example, it is possible that the management activities undertaken at the Ridö State Forest were (to at least some

21. *Statens skogsforskningsinstitut*

extent) done as a part of a forest experiment. I suggest this because of Israel af Ström's involvement in the activities on the island, the area's proximity to Stockholm where the head office of the State forestry department was located at the time, the fact that students from the State Forest Institute made the forest management plan for 1869, and because clear-cutting was chosen as the first management method applied when introducing forestry into the area (paper II).

Some private forest owners also conducted field trials to broaden their knowledge of clear-cutting and how it worked under Swedish conditions. In northern Sweden, the private forest company Mo och Domsjö AB conducted its own field surveys focusing on regeneration and ditching; the company's managing director, Frans Kempe, saw clear-cutting and the subsequent sowing or planting as solutions to the problems of regeneration and sustainability (Andrén 1992; Carlgren 1917). The initiation of experiments directly linked to clear-cutting in northern Sweden acted as a driving force for the establishment of this forest management method in this region (paper I) (Fig. 6).

Figure 6. Foresters from the forest company Mo och Domsjö AB visits an experimental area with plants established by self-seeding in Västernorrland County in 1924. (Source: Forest library, Umeå).

The first State forestry research park (Siljansfors in the county of Dalarna) was established in 1921, and was soon followed by others including Kulbäcksliden and Svartberget research parks in the county of Västerbotten in 1922, Tönnersjöheden in the county of Halland in 1923, and Bogesund research park

in the county of Stockholm in 1950 (Allard 1978). Important topics studied in these parks included waterlogged forests, provenance, insect life, soil fauna, and scarification (Enander 2007). However, clear-cutting was not mentioned as a specific area of research, perhaps because it was an established method at that time.

Lars Tirén was the scientific director of the Kulbäcksliden research park from 1927 to 1958 and several of the approaches used in his research to analyse human impacts on the forest were new at the time but remain relevant today (Östlund and Roturier 2011). Tirén used both historical and ecological methods, and concluded that (among other things) there was a need for improved regeneration methods and thinning was important for tree growth (Tirén 1937). He established several regeneration experiments, some of which remain in progress today, and his work continues to influence forestry research (Östlund and Roturier 2011). He emphasized that the forests had been subjected to considerable impact even long before forest management began in the real sense and that it was important to examine these early "experiments". This resulted in his work *"Forestry historical studies in the Degerfors district of the Province of Västerbotten"*[22], where he thoroughly described the history of Kulbäcksliden, including a detailed analysis its fire history (Tirén 1937). Östlund and Roturier (2011) have analysed his research and concluded that it has many merits but that it can also be criticized for a lack of objective sampling methods; the selection of stands and trees was judged to be excessively subjective.

3.5 Sustainability from a more recent perspective

There is no doubt that sustainable forestry is an important issue today: it will be central in the transition to a bio-based economy[23] (D'Amato et al. 2020; Bennich et al. 2018), was identified as a key factor in mitigating climate change (Johansson 2018; Popovic & Mijajlovic 2013), and is considered essential for protecting biodiversity (Holm 2015; Spiecker 2003). However, Kunnas and Myllyntaus (2020) discuss the interesting aspects of bioeconomy and whether it is a new concept of old methods, or if it is actually something new. They suggest that bioeconomy does not seem to make any major difference to the forest use. The change lies within trying to reconcile all conflicting goals simultaneously.

For commercial forest companies and forest owners' associations, sustainable forestry is often synonymous with certification by the FSC (Forest Stewardship Council) or PEFC (Programme for the Endorsement of Forest

22. Swedish: *Skogshistoriska studier i trakten av Degerfors i Västerbotten*

23. The replacement of fossil fuels with renewable raw materials from the forest, land, and sea to reduce climate impact.

Certification Schemes). FSC present themselves as "the world's most trusted sustainable forest management solution". Their stated mission is to *"promote environmentally appropriate, socially beneficial, and economically viable management of the world's forests"*; an FSC forest management certification confirms that the forest is being managed in a way that preserves biological diversity and benefits the lives of local people and workers while ensuring sustained economic viability (Anon. 2020a). The Swedish PEFC certification system for sustainable forestry is based on the definition of sustainable forestry adopted in Forest Europe in 1993 (Anon. 2015a; Anon. 1993b) and later also by the Food and Agriculture Organization (FAO) of the United Nations (2020b):

> "Sustainable forestry means the management and utilization of forest and forest land in such a way, and at such a rate that biodiversity, productivity, regeneration capacity, vitality and ability to, both now and in the future, fulfil important ecological, economic and social functions at local, national and global levels are preserved without damaging other ecosystems."

The Swedish Society for Nature Conservation[24] is a non-profit environmental organization that evaluates sustainable forestry in terms of three dimensions (economic, socio-cultural and environmental) that are considered to constitute an indivisible whole (Anon. 2020c):

> "Of course, all three dimensions include preserving all forest ecosystem services for generations to come. The raw material is only one of these services. The description of sustainable forestry must be based on established knowledge of ecosystem services and land use must be within the framework set by nature."

The principle of sustainable development was first outlined by the American environmental scientist and author Lester R. Brown in 1981 (Brown 1982). It received international recognition in 1987 when the UN World Commission on Environment and Development, also called the Brundtland Commission, used the term in the report *"Our common future"*. This report described the principle of sustainable development as *"development that meets the needs of the present without compromising the ability of future generations to meet their own needs"* (Anon. 1987). It formed the basis for the decisions taken in 1992 at the UN Conference on Environment and Development UNCED in Rio de Janeiro, Brazil, which recognized the principle that all development must be sustainable (Hopkins et al. 1996). Since the Rio conference, much work has been done internationally to define what sustainable forestry means in practice. Different criteria and indicators are used to assess the sustainability of forestry in the tropics and in countries with boreal and temperate forests outside Europe

24. Swedish: *Naturskyddsföreningen*

(Larrubia et al. 2017). Criteria for and indicators of sustainable forestry for Europe have been developed within the forest policy cooperation Forest Europe (Anon. 2016).

However, the connection between the concept of *"sustainability"* and forestry is not new, although its meaning has changed somewhat over time. The term *"sustained use"*[25] was used in reference to the conservation and cultivation of forests by the German Hans Carl von Carlowitz in the early 1700s, in response to concerns that a shortage of wood and timber could damage the national economic welfare (Hölzl 2010). Since then, the meaning of sustainable forestry has changed in line with changes in forest science. It is easy to think that movement towards innovative thinking about forest management and sustainable forestry would have been natural and easy as the demand for diverse wood products increased. However, the introduction of sustainable forestry in Germany was anything but simple and became very contentious; efforts to control the forest resources through accounting, planning of management, and policing sparked protests. This was mainly due to a perceived focus on timber production, financial revenues for state treasuries, the mandatory reorganization of forest structure, and restricted access to forests for users other than scientifically trained personnel (Hölzl 2010). I have not found any indications that the introduction of forest management and the movements towards a sustainable forestry was as controversial in Sweden as it was in Germany. There was a strong desire to retain old methods such as various forms of selective cutting in some parts of Sweden, but this was mainly because the foresters wanted to hold on to old habits rather than because they considered sustainable forestry controversial (paper I). However, clear-cutting was strongly criticised in Sweden during the 1960s when groups outside commercial forestry began to question its use as well as its aesthetic and environmental effects (Simonsson et al. 2015).

Today, there are clearly differences in the interpretation of sustainable forestry. Clear-cutting was introduced in response to the regeneration issue but stands for something completely different today. In the early 1900s, clear-cutting was synonymous with sustainable forestry (or vice versa) (paper I), but today it is not. The concepts of sustainable forestry and clear-cutting have thus not developed in a synchronized way from the early 1900s to the present. I think that there are lessons to be learned from this. An important factor in this case is that these issues have significantly more stakeholders today than they did previously, including forest companies, forest owners associations, environmental associations, international certification authorities, recreational interest groups, hunters, reindeer husbandry practitioners, and so on. This complicates the issue

25. German: *nachhaltigkeit*

because several of these groups have different aims, which has caused conflict between some of them (Sjölander-Lindqvist & Sandström 2019; Simonsson et al. 2015; Horstkotte et al. 2014). When discussing clear-cutting and sustainable forestry, it might be good to bear their original meanings in mind, and the way in which they were originally linked. For the future, it may be beneficial to take into account the historical meanings of different concepts and methods to help stakeholders better understand one-another and to get along more smoothly as new concepts and methods are discussed and developed.

4 An idea-based forestry

The development of forestry and the introduction of clear-cutting in Sweden in the 1800s required several different kinds of change. Foresters had to slightly change their mindset and start looking at the forest as a system that could be managed in a way that was sustainable in the long run. They also needed to apply new methods, including clear-cutting and regeneration strategies (paper I). While there had been many previous attempts to introduce or test alternative management strategies, the concept of sustainability had not really permeated the forestry profession. The introduction of clear-cutting changed the perception of the forest; whereas foresters had previously feared that the forest resources might be finite, they came to believe that it could be made into a continually growing resource through better forestry (paper I). Thus, rather than simply being logged and left, forests would now be actively managed. However, such management required planning, which in turn required answers to many questions. When and how should logging be done? Is scarification needed? Which is better – natural regeneration, sowing or planting? Which tree species should be cultivated? Over what time horizon should plans be made? (paper II). All of the decisions made also had to be thoroughly documented in a forest management plan with an accompanying map to enable controlled long-term management of the forest (Hölzl 2010). This more structured way of working was new to the foresters. The clear-cutting system was introduced alongside this modern approach to sustainable forestry. This forest management method had some fundamental novel parts. As described in the preceding chapters, this method entailed dividing the forest land into sub-areas, one of which would be logged each year and then regenerated. In addition, all management operations had to be carefully planned and described in a forest management plan. Foresters played the leading roles in the practical implementation of this new approach to forestry. In this chapter, I analyse the discussions that took place within the forest sector during the introduction of sustainable forestry in Sweden, Germany, and some of the other European countries. These countries initially followed similar

trajectories to Sweden, but in some cases subsequently took completely different directions.

4.1 The foresters

In many European countries, the introduction of sustainable forestry was driven by a few key individual foresters who saw the future more clearly than their contemporaries (Hölzl 2010). The concept of forest sustainability was first formulated by the German mining administrator Hans Carl von Carlowitz (1645-1714) in 1713 (Hölzl 2010). He in turn inspired his compatriots Heinrich Cotta (1763-1844) and Georg Ludwig Hartig (1764-1837), who elaborated upon his ideas by developing the clear-cutting system (Warde 2018). Heinrich Cotta was arguably the person who had the greatest individual impact on German and European forest science (Seegers et al. 2011). He founded a private forest school in the 1790s (which later became a State forest academy) and served as its director. Students from other countries in Europe, including Scandinavia, attended this school, so he had a profound influence on the development of European forestry (Ciancio & Nocentini 2000; Warde 2018). The work of building up Germany's forest sector was led by Cotta, whose contributions were described as epoch-making due to his combination of practical experiences and scientific thinking (Seegers et al. 2011). The forest management method Cotta advocated was an early form of clear-cutting based on the forest area[26]: the forest was divided into a set of equally sized sub-areas that were then logged in a specific order based on instructions specified in a forest management plan (Hölzl 2010). Georg Ludwig Hartig also conducted extensive early work towards sustainable forestry. Hartig ran a forestry school and subsequently organized and led the management of Germany's state-owned forests (Warde 2018). He was the first to use a forest management planning method that was based on timber volume[27], and tried to use this method to sustain or gradually increase timber yields over mulitple logging periods (von Gadow 2005). It was this method that Heinrich Cotta subsequently modified when proposing planning based on area instead of timber volume (Warde 2018). Eventually, a method based on both timber volume and forest area[28] was developed; this method later formed the basis for the Swedish forest management (von Gadow 2005).

Because of their work on forest-related issues in Germany in the early 1800s, Cotta and Hartig were labelled "forest science pioneers"[29] (Hess 1873). Friedrich

26. German: *das Flächenfackwerk*
27. German: *das Massenfachwerk*
28. German: *das kombinierte Fachwerk*
29. German: *Koryphäen der Forstwissenschaft*

Wilhelm Pfeil (1783-1859) is another member of this group of prominent early German foresters. Pfeil was a professor of forest science at the University of Berlin and developed both site and soil science. He emphasized the importance of studying local conditions before establishing forest management principles and was the first forester to assert the connections between the forest and the national economy. Pfeil also emphasized the beauty of the forest (Schwenk et al. 1971). Other prominent German foresters were Johann Christian Hundeshagen (1783-1834), Carl Justus Heyer (1797-1856) and Gottlob König (1776-1849) (Hasel 1985).

Foresters in other European countries also distinguished themselves in various ways. In the early 1900s in Norway, the forester Agnar Johannes Barth (1871-1948) argued that high-grading was causing the destruction of the forests (Barth 1916) and sought to counteract this by improving artificial forest regeneration (Barth 1913) (Fig. 7). In Finland, Claës Wilhelm Gyldén (1802-1872) became director of the National Board of Survey and Forests from 1854, and as such played a key role in the planning and implementing state forestry in Finland (Michelsen 1995). Aimo Kaarlo Cajander (1879-1943) was a Finnish botanist and politician who also became a forestry professor and was mainly known for developing the theory of forest types (Nyyssönen 1997). In Switzerland, Albert Engler (1869-1923) was a prominent forester who was primarily known for his work on seed provenance (Fischer 1960).

Figure 7. Professor Agnar Barth, Norway, to the left and professor Gunnar Schotte, Sweden, to the right in and experimental area in Sweden in 1913. (Source: SLU, Forest library)

The first foresters in each country to address the issue of sustainable forestry were also the ones who in various ways came to characterize the first phase with new forest management methods (Hölzl 2010; Carbonnier 1978). Many of these foresters subsequently established institutions of higher education in forestry in their countries. Because of this, they are likely to have strongly influenced the

education of the foresters who studied at those institutions, and thus the knowledge that those foresters possessed upon graduating (Hölzl 2010; Brynte 2002; Hasel 1985; Wahlgren 1928). It also seems to have been relatively common for these foresters to follow their own paths in forest management during their working lives even if that sometimes entailed acting against recommended policies. For example, in Sweden some state foresters implemented clear-cutting in contradiction to the preferred policies of the time because they believed in the method (paper I, II, III). Similarly, some foresters at private companies initiated experiments to determine how clear-cutting worked in the conditions in northern Sweden (paper I). Actions and foresters such as these are likely to have strongly influenced the field's development.

The following list of individuals, which is in no way exhaustive, includes some of the most prominent Swedish foresters of the 1800s and early 1900s and states how they have affected the development of forestry. The first person on the list, **Israel af Ström** (1778-1856), is generally considered the father of modern forestry in Sweden (Björkman 1877) because he was one of the country's first "real" foresters and played a major role in the introduction and development of forestry in Sweden. He was educated at Uppsala University and then became the head forester at the Kungliga Djurgården. His main achievement was establishing the State Forest Institute in 1828. His inspiration as a forester came mainly from Germany, and he made study trips abroad to learn new things. He also laid out the founding principles of modern forest management, including regrowth, management, and final cutting. **Carl Ludvig Obbarius** (1780-1860) was a German forester who came to work and live in Sweden and was contemporary of af Ström. He worked primarily in the mining regions of central Sweden, and was appointed director of the Westsura private forest institute in Västmanland County in 1843. He was an enthusiastic advocate of Hartig's and Cotta's clear-cutting system. Like af Ström, Obbarius played a major role in introducing clear-cutting and modern forestry into central Sweden. However, whereas af Ström worked for the state, Obbarius worked in the private forest sector. Another important forester at the time was **Gustaf Eriksson Segerdahl** (1803-1891), a chief forest officer and teacher of forest management who eventually became head of the State Forest Institute and wrote books about forest management (Segerdahl 1861). **Axel Cnattingius** (1839-1897) was a trained forester who became head of the forest school in Hunneberga, Västra Götaland County. He published a Swedish forest dictionary and several forest science works. Another forester who published many works and textbooks was **Gottfrid Holmerz** (1839-1907), who had an education in forestry and worked as a director of the State Forest Institute. **Veit Thorsten Örtenblad** (1855-1917) was a botanist educated in forestry who became divisional chief of the forest

department at the *National Board of Crown Forests and Lands*[30]. He conducted growth surveys in the forests of Dalarna County and northern Sweden, and worked to adapt forest management to suit the varying natural conditions in different parts of Sweden. **Frans Kempe** (1847-1924) was an industrialist with a bachelor's degree in medicine who became managing director at Mo och Domsjö AB and initiated forest experiments in regeneration and ditching on the company's land. As such, he played an important role in the development and implementation of clear-cutting in northern Sweden. **Karl Fredenberg** (1857-1936) was educated in forestry and served as director of the State Forest Institute before becoming director general and chief of the National Board of Crown Forests and Lands. He made study trips to Germany, Austria and France. **Uno Wallmo** (1860-1946) was educated at the State Forest Institute and then worked as chief forest officer at the National Board of Crown Forests and Lands in central Sweden. Upon leaving this position, he worked in forest management at private mills. In 1897, his book *"Rational logging"*[31] was published and attracted considerable attention among foresters. He is regarded as the man who introduced selective cutting into Sweden and was a prolific writer. **Anders Wahlgren** (1861-1928) was a scientific forest researcher focused on forest history and forest management for regeneration. He worked as a director at the State Forest Institute and as a head of the *Royal College of Forestry*[32]. In addition, he served as a professor of forest management and contributed to forestry textbooks and posters. **Anders Holmgren** (1874-1968) (Fig. 8) and **Joel Wretlind** (1888-1965) (Fig. 9) are the individuals who arguably contributed the most to the introduction and development of clear-cutting in northern Sweden.

Figure 8. The forester Anders Holmgren, who was of significant importance for the introduction and development of the clear-cutting system in northern Sweden. (Source: SLU, Forest library)

30. Swedish: *Kungl. Domänstyrelsen*
31. Swedish: *Rationell skogsafverkning*
32. Swedish: *Skoghögskolan*

Holmgren was educated at the State Forest Institute and then worked as a principal at a forest school in Bispgården, Jämtland County. He eventually became a chief forest officer at the National Board of Crown Forest and Lands in northern Sweden and was often hired as an expert on investigating conditions in northern forests. Holmgren developed the strip-cutting method[33], under which the forest is logged in rectangular corridor-like clear-cuts that should be narrow enough to enable self-seeding from surrounding forest while minimizing the risk of storm damage. Wretlind worked as district forest officer in the Forest Service[34], and conducted experiments showing that forests can be regenerated by clear-cutting and prescribed burning.

Figure 9. The forester Joel Wretlind, who advocated clear-cutting and prescribed burning. (Source: Forest library)

Gunnar Schotte (1874-1925) was director and head of the State Forest Research Institute and occasionally worked together with Anders Wahlgren. He established experimental areas and wrote many essays on forestry topics. **Erik W. Höjer** (1898-1979) was director general and the chief of the Forest Service who was in charge of implementing the well-known State forest policy 1/50[35] of 1950, which prohibited selective-cutting and recommended the use of clear-cutting as an alternative. **Fredrik Ebeling** (1909-1982) was director general and chief of the the *National Board of Forestry*[36], and used his ecological knowledge to promote sustainable forest use in northern Sweden. **Henning Hamilton** (1929-) was forestry chief at Graningeverken[37], chief forester at Södra Skogsägarna[38], managing director of the Swedish Forestry

33. Swedish: *kulisshuggning*

34. Swedish: *Domänverket*

35. Swedish: *Cirkulär 1/50*

36. Swedish: *Skogsstyrelsen*

37. A company that included sawmill, wood grinding, hydroelectric power station, and nail mill and was a major forest owner.

38. A forest owners' association in southern Sweden.

Association,[39] and head of the information department at Södra skogsägarna. He published several books, essays and papers on forest issues.

The Swedish foresters thus had diverse backgrounds, although most of them had some form of forestry education. In this way, they resemble the previously mentioned German foresters, most of whom had a higher education in forestry (Hasel 1985). However, Israel af Ström played a major role in the development of Swedish forestry despite having no formal forest education; instead, he inherited his position as head forester from his father (Wahlgren 1928; Björkman 1877). Af Ström established Sweden's first school of higher forest education in forestry (Wahlgren 1928), where most of the foresters included in the earlier list were educated. He was a typical forerunner, with many characteristics in common with other previously discussed pioneers of modern forestry such as von Carlowitz in Germany, Barth in Norway, and Cajander in Finland. These individuals had no formal forestry education but were dedicated to developing forestry, and established institutes of higher education in forestry in their countries.

The annual excursions organized by the *Forestry Association of northern Sweden* were important forums for Swedish foresters (paper I) (Fig. 10).

Figure 10. A group picture of foresters participating in a field excursion in the county of Norrbotten, arranged by the Forestry Association of northern Sweden in 1916. Henrik Hesselman, Anders Wahlgren, and Gunnar Schotte, among others, participated. (Source: SLU, Forest library)

39. Swedish: *Sveriges Skogsvårdsförbund*

Foresters from other countries such as Denmark, Norway, Finland, and Germany, sometimes joined these excursions, which probably facilitated the spread and sharing of knowledge (paper I). These excursions visited various kinds of forests in northern Sweden with different land ownership structures (paper I, fig. 1), and often had between 100 and 200 participants (paper I, table 3). These participants often included at least some of the foresters mentioned in the preceding list, along with larger forest owners and forestry professionals. The discussions during these excursions sometimes resulted in articles written by excursion participants that were subsequently published in the *Journal of the Forestry Association in northern Sweden*. Occasionally, another forester responded to the views expressed in the article by publishing an article of their own or a short note in the journal. The discussions from the excursions thus continued and were elaborated upon, and were made accessible to the wider forestry community. Uno Wallmo and Anders Holmgren in particular debated extensively during the first decades of the 1900s, both in writing and during field excursions, often arguing the relative merits of selective cutting and clear-cutting.

The above discussion shows that although we today have shorter information paths as well as more and faster channels for discussing and disseminating information, the opportunity to express opinions and debate also existed in the late 1800s and early 1900s. Foresters were thus quite well informed about current issues and what was happening in forestry in different parts of Sweden and Europe.

4.2 What the foresters discussed

Developments in several European countries were similar in that the transition towards sustainable forestry[40] was motivated by losses of forest resources due the increased demand for wood created by industrialization. This led to questions about how forest regeneration could be achieved, which in turn created interest in the principles of German forestry. The early development of sustainable forestry in these countries was thus similar.

It is interesting to analyse how different countries chose to relate to the German ideas after introducing sustainable forestry, and to see whether each country adhered to the original ideas or attempted to adapt them to local conditions. Serup (2004) analysed the development of the forestry discourse in Denmark. Until 1870, German foresters and German forestry strongly

40. Defined as the ability to take logs from the forest without harming the wood supply available to future generations.

influenced the Danish discourse. Subsequently, initiatives were taken to change forest education and forest management to better suit Danish conditions. The establishment of forest associations in the late 1800s and early 1900s played a central role in establishing a Danish discourse because they gave foresters opportunities to debate issues and exchange experiences (Serup 2004). The Danish debate also occurred in forestry journals (Serup 2004). The same was true in Sweden, where journals were the leading forums for forestry discussion. Accordingly, paper I focuses on the material published and discussed in the country's leading forestry journal.

I suggest that these old forestry journals are excellent sources for following the development of the forestry sector at the time and the related discussions. The major forest journals in the various countries of Europe were all established during the same period: The Journal of the Forestry Association of northern Sweden [Swedish: *Norrlands skogsvårdsförbunds tidskrift*] in 1883 and the Journal of the Swedish Forestry Association [Swedish: *Svenska skogsvårdsförningens tidsskrift*] in 1903 in Sweden; the Journal of Forestry [Danish: *Tidsskrift for Skovbrug*] in 1876 and the Journal of the Forest Service [Danish: *Tidsskrift for Skovvæsen*] in 1888 in Denmark; the Yearbook of the Norwegian Forest Association [Norwegian: *Den norske Forstforenings Aarbog*] (1881-1892), the Journal of Forestry [Norwegian: *Tidsskrift for Skogbruk*] (1893-1984), and the Forest Journal [Norwegian: *Forstligt Tidskrift*] (1902-1905) in Norway; the Journal of Forest and Hunting [German: *der Allgemeine Forst und Jagdzeitung*] (1832-) in Germany; the Swiss Journal of Forestry [German: *die Schweizerische Zeitschrift für Forstwesen*] in 1850 and Forest and Wood [German: *Wald und Holz*] in 1919 in Switzerland; and the Central Journal for all Forestry [German: *Centralblatt für das gesamte Forstwesen*] in 1875 and the Forest Journal [German; *Forstzeitung*] in 1893 in Austria. One reason why many European forestry journals were established around the same time (late 1800s and early 1900s), despite the differing timelines of forestry development in different countries may be that the rapid establishment of pulp mills and paper mills created a marked for such journals (Esterhammer 2020). Many of the topics discussed in this chapter were debated in these journals.

Many of Europe's foresters feared deforestation during the late 1800s, so regeneration (or the lack thereof) quickly became a matter of fundamental concern (paper I; Kaplan et al. 2009; Ericsson et al. 2000; Barth 1916). Another approach to deal with the regeneration issue was the residual forests that was left after high-grading. In the Nordic countries, unproductive forest stands formed by many years of high-grading and selective cutting were cleared and replaced with new forest that was more productive and fast growing (cf Lie et al. 2012;

Ebeling 1959). These unproductive stands, so-called *"green lies"*[41] were invoked by foresters as a reason to start using clear-cutting and artificial regeneration, especially in northern Sweden (paper I; Lie et al. 2012; Lisberg Jensen 2011). Clear-cutting also offered a way to remove damaged trees and "over-aged" trees from forest (Linder and Östlund 1998). Another angle of the regeneration issue is that clear-cutting required regeneration activities, which in many cases meant planting or sowing. In turn, this required access to regeneration material. The transfer of forest regeneration material between the Nordic countries in the 1800s and 1900s was analysed by Myking et al. (2016), who showed that these transfers have affected the native gene pools in each country.

There were also notable differences between countries in terms of the debates about what aspects of forest management that were important and how forestry should be advanced. Some of these differences were related to the climatic differences between the countries. For example, the introduction of various exotic tree species was discussed from an early stage in Denmark (Ball 2008), but was not as important in Sweden, Norway and Finland. Although exotic tree species were also tested in these countries, the challenges for these were mainly to obtain sufficient regeneration material (plants and seeds) for Scots pine and Norway spruce (*Picea abies* (L.) Karst.) of suitable provenance (Myking et al. 2016). The regeneration issue was however clearly prominent in Sweden during the late 1800s. Information campaigns were conducted to raise public awareness of the need to secure future forest resources by planting or sowing, and to encourage school children to learn about and engage in these activities (Örtenblad 1900; Anon. 1883).

Although Swedish foresters largely agreed on the necessary direction of travel to create forestry that would be sustainable in the long run, some conflicts arose. One was between Israel af Ström and Carl Ludwig Obbarius. Af Ström wanted to create forests in which the number of even-aged stands was equal to the number of years in the fixed rotation period, whereas Obbarius favoured a more flexible approach to forest management both in terms of logged timber volume and applied forest management method (Brynte 2002). Subsequently, during the early 1900s, Anders Holmgren's strip cutting method (Holmgren 1914) was set against Uno Wallmo, who opposed all forms of clear-cutting and instead advocated his own version of selective cutting[42] (Wallmo 1897) .

Something that I find characteristic of the early implementation of clear-cutting in several countries is the remarkable faith that foresters placed in the new forest management and their conviction that it would give them absolute

41. Swedish: *gröna lögner*
42. Swedish: *rationell blädning*

control over the forest (paper II). This is demonstrated by the long timeframes of the forest management plans created in Sweden (paper II) and Denmark (Serup 2005), which incorporated logging plans covering periods of over 100 years. As such, its use demonstrates the forester's strong confidence in the new sustainable forestry methods. The foresters believed that replacing the existing forest with new forest and applying an appropriate management plan to the resulting young forest would allow them to better control the forest's development and achieve better long-term growth (paper II). This is consistent with the analysis of Lisberg Jensen (2011), who states that everything that was "old", including traces of former cuttings and forest utilization, should be removed in favour of a modern forestry and forest management. However, in Ridö State Forest the situation was different: there, clear-cutting was applied in mature and dense stands that lacked damaged or unproductive parts (paper II).

When analysing the *Journal of the Forestry Association of northern Sweden* (paper I), the scrutinized articles were divided into different categories (paper 1, table 1), making it possible to see how foresters' interest in different topics changed over time. From 1901 to 1940, the number of articles dealing with logging methods and forest biology increased slightly. However, the number of articles dealing with forest management increased significantly between 1921 and 1946: 20 articles on this topic were published during this period, compared to eight between 1901 and 1920. It should be noted however that this analysis does not account for changes in the total number of articles published in each issue of the journal over time. To some extent, the increase during this period can be related to the economic crisis that prevailed in Sweden and the rest of the world during the 1930s; this may have highlighted the need for more economically sustainable forestry practices, provoking greater discussion and analysis by foresters.

It should be noted that clear-cutting and its effects were being compared to those of selective cutting, which was regarded as the main alternative practical forest management strategy until the 1950s.

4.3 The advantages and disadvantages of clear-cutting

4.3.1 The advantages

The introduction of the new forestry was first and foremost a way of making forestry sustainable over time by ensuring that the forest was regenerated after logging. It was also expected to create more orderly forests by having logging done on an annual basis (paper I; Hölzl 2010). The clear-cutting system also

allowed foresters to make choices supporting high sustained production. Specifically, it allowed them to choose a suitable tree species to plant or sow after logging, and to choose management methods (e.g. thinning or ditching) suited to their goals (Wahlgren 1914).

Today, the main advantage of clear-cutting is held to be the prospect of greater financial returns than other management strategies (Andreassen & Øyen 2002). The clear-cut phase is also said to benefit species that depend on disturbances (Paillet et al. 2009). Additionally, some studies have suggested that clear-cutting may be beneficial in terms of the climate, although other studies have yielded opposing conclusions (Vestin et al. 2020; Popovic & Mijajlovic 2013).

4.3.2 The disadvantages

Opponents of clear-cutting argued that it jeopardized regeneration (paper I), and that it was more costly than alternative methods. The latter became especially important during the economic crisis of the 1930s, leading to an increase in selective cutting. Clear-cutting was costly because of the need for regeneration, which is avoided when using selective cutting had (paper I). The opponents also argued that clear-cutting was risky because it was based on rotation periods, and that the length of these periods was difficult to determine (Wallmo 1897).

An important drawback of the modern clear-cutting system used in Sweden is the negative effects on biodiversity: many common forest species are adversely affected during the clear-cut phase (Eggers et al 2020; Perhans et al. 2009). Furthermore, clear-cutting is considered aesthetically displeasing by many (Simonsson et al. 2015; Wiström et al. 2015), and it is generally not regarded as a suitable management method for forests that are also used as venues for outdoor activities or urban forests (Rydberg & Falck 2000; Eggers et al. 2019). Since clear-cutting is often followed by some form of scarification, it can also damage cultural heritage (Anon. 2019a) and degrade the conditions for ground lichens, which in turn has negative effects on reindeer husbandry (Horstkotte & Moen 2019; Berg et al. 2008;). An increased risk of soil damage and nutrient leakage is also sometimes highlighted as a negative effect of clear-cutting, but there is no conclusive evidence as to the magnitude of this effect (Johansson et al. 2013). Such damage probably depends heavily on ground conditions and how and where the forest machines are used.

4.4 The myth of clear-cutting

The introduction of clear-cutting in northern Sweden is usually described in terms of an abrupt shift away from the various forms of selective cutting in use previously (paper I; Hörnfelt 2014; Ericsson et al. 2000; Arpi 1959). Similar histories are claimed for Sweden's neighbouring countries, Norway and Finland (Kuuluvainen et al. 2012; Aasetre & Bele 2009; Storaunet et al. 2005).

However, my analysis of the *Journal of the Forestry Association of northern Sweden* suggests that this dramatic shift did not actually occur (paper I). Instead, there appears to have been a rather complex transformation process during which forestry based on clear-cutting was developed and refined, while other cutting methods were slowly abandoned (paper I). The analysis of the *Journal of the Forestry Association of northern Sweden* clearly showed that clear-cutting was well established in northern Sweden by around 1900 (paper I). For example, in one article, a large private forest company (*Graningeverken*) was said to have been using clear-cutting and prescribed burning over *"vast areas"*[43] since the early 1800s (Lundberg 1893). Another example is the publication of an article with the heading *"The breakthrough and implementation of the clear-cutting system"*[44] in 1918 (Berg 1918). The widespread early use of clear-cutting was also apparent in the aerial images: around 10% of the forest area in northern Sweden had been clear-cut in the early 1900s, and almost 40% of the forest area had been clear-cut by the end of the 1940s (paper III). The aerial images also clearly showed that clear-cutting was performed systematically over large contiguous areas because stands of every age category could be seen within individual areas (paper III, fig. 2). It was also found that clear-cutting was applied to a similar extent on both private and state land. In Västernorrland County, most forests are privately owned, compared to the rest of northern Sweden where forests are mostly state-owned. This suggests that the findings of the analysis are generally applicable across northern Sweden (paper III).

These results indicate that the widely accepted claim that clear-cutting was introduced in the 1950s is actually a myth. Nevertheless, this claim has somehow propagated and has continued to be taken as true in modern articles (Hörnfelt 2014; Ericsson et al. 2000) and textbooks (Arpi 1959). What was the purpose of creating and maintaining this myth?

The firm establishment of the myth that the clear-cutting system was introduced in northern Sweden in the 1950s suggests that there were compelling reasons for its creation and maintenance. The main motive I have been able to find is a desire to maintain a positive historical narrative among Swedish

43. Swedish: *ofantliga arealer*
44. Swedish: *Trakthuggningens genombrott och tillämpning*

foresters (paper I). There was a perceived need to make a distinct break from old traditions and to remove the old, extensive and irrational methods that were based on tradition and practical experience in order to replace them with new, intensive, and rational methods grounded in modern and theoretical knowledge (paper I). Perhaps, as suggested in a Danish study, it was also felt that "*that jolts may be required to achieve the passage from unsustainability to sustainability of forest management"* (Mather et al. 1998). Two additional and closely related motives are production and economy. Clear-cutting was obviously better than other forest management methods in terms of production. Its economic benefits were noticed quickly, and were confirmed by subsequent scientific studies. The cutting costs for different forms of selective cutting exceed those for clear-cutting, continuous cover forests are assumed to have a lower volume production than those subjected to clear-cutting (Andreassen & Øyen 2002), and forests managed with various forms of selective cutting have a lower present value than those managed by clear-cutting (Wikström 2008). This made it important to establish clear-cutting as the only conceivable method, and is also probably why clear-cutting remains the dominant forest management method in Sweden.

It was probably no coincidence that the 1950s were chosen as the "start" of this mythologized new era. The state forest policy articulated in "Circular 1/50", which prohibited selective cutting, was introduced in 1950 (Nordström 1959). At about the same time, the mechanization of forest management began. These two factors facilitated clear-cutting and also created conditions consisted with a (simulated) breakpoint separating the supposed past of forestry from its future based on clear-cutting. In this way, a policy decision and technical advancement supported the creation of a myth: it was easy for people to believe that clear-cutting only began to be applied on a large scale when the use of selective cutting was prohibited, and that its uptake was furthered by the introduction of mechanized forestry, which facilitated the management of the large forest areas of northern Sweden.

However, the reality is that clear-cutting was applied long before 1950, even though it was nominally prohibited by state policies before then, and that clear-cutting could be performed successfully with axes and saws before the advent of mechanization. The State forest policy 1/50 is mentioned as a *"distinct turning point"* by Lundqvist et al. (2009), but according to a forester working at the State forestry at that time, the policy had few significant practical consequences[45].

It is difficult to determine when this myth became established, and I suspect it may not be possible to specify an exact time with confidence. However, it is clear that nothing special happened around 1950: neither that year nor any year

45. Personal comm. André, P. Retired forester, National Forest Service in Skellefteå, Interview October 3 2012.

shortly thereafter was discussed as being in any way remarkable in the contemporary literature (paper I). However, the myth must have taken root shortly after 1950. For example, the government report *"Clear-cuts"*[46] from 1974 stated that clear-cutting was practiced in a few cases in the early 1900s but did not become established before the 1930s, when the era of selective cutting started (Anon. 1974). It went on to describe the introduction of the clear-cutting system in northern Sweden in around 1950. Similarly, in 1959, Ebeling wrote: *"Then came the 1950s and the time of the large clear-cuttings in the upper-north"*. This quote appeared in a publication called "Sweden's forests during 100 years"[47], which was published in two parts by the National Board of Crown Forests and Lands, and may be as close we can get to the source of the myth concerning the establishment clear-cutting in northern Sweden.

46. Swedish: *Kalhyggen*
47. Swedish: *Sveriges skogar under 100 år*

5 Clear-cutting in practice

Some of the reasons why clear-cutting quickly became popular in Germany were that it was a method that was easy to understand and perform. It offered simple guidelines for classifying and assessing forest stands, along with general rules for management and logging (Noble and Dirzo 1997; Knuchel 1953). In general, clear-cutting in Sweden was applied in accordance with the principles developed in Germany. Swedish foresters took particular notice of some aspects, including the division of the forests, the design of the forest management plans and maps, logging methods, and rotation periods (paper I; paper II). These principles were applied in Ridö State Forest: the forest was divided in sub-units using parallel lines oriented in the north-south direction (paper II, fig. 2a), the management plan was divided into 24 consecutive 5 year periods that began in 1832 and ended in 1952 (paper II, table 3), the preferred logging method was clear-cutting, and the rotation period was based on the ages of trees suitable for saw timber production (paper II). However, foresters quickly realized that forest management plans with time horizons of a century or more were not reasonable, and the new forest management plans with more realistic time horizons of 20-40 years were soon created (paper II).

5.1 The role of the foresters

It is evident that the foresters played a significant role in the development and practical application of sustainable forestry and clear-cutting. One thing that may have favoured the introduction of clear-cutting in Sweden, and especially in northern Sweden, is that the foresters did not always adhere to policies on the use of forest management methods, and instead adopted management methods based on their own beliefs (paper I). In many cases, this meant performing clear-cutting even though regulations called for selective cutting (Holmgren and Törngren 1932). However, the following quotes indicate that foresters

recognized the importance of firmly establishing the new forest management ideas.

> ”That many and large, difficult questions still have to be solved through the collaboration of ideas and practice, before the proper timber marketing methods have forged its way, is certain. Even when this has happened, in the individual cases, when the axe will swing, it will depend on whether the one holding the shaft is penetrated by the will not only to harvest but also to create values.”[48]
>
> - Beronius 1917

The foresters responded quickly to the effects of their management actions on the forest and adapted their methods in response; in some cases, they changed their forest management methods completely. In Ridö State Forest, the foresters applied clear-cutting from the moment they introduced forest management. According to the forest management plans, selective cutting was also applied during a period that began in 1869. After applying selective cutting for some years, they returned to clear-cutting because they felt that selective cutting made the forest more susceptible to storm damage (paper II). This stands in contrast to the prevailing modern opinion that clear-cutting increases susceptibility to storm damage when compared to continuous cover forestry (Heinrichs and Schmidt 2009). When considering the impact of storm damage, it should be noted that the forest in in question is located on a small (approximately 400 ha) elongated island, which may have influenced the risk of storm damage. Alternatively, selective cutting may have been used during a period when there were more storms than usual, or there may have been a combination of factors that caused selective cutting to fail in this area (paper II). However, the clear-cutting system was also promoted elsewhere as a method that created storm-resistant forests, whereas selective cutting was considered to increase the risk of storm damage (paper I).

It is possible that selective cutting would also have worked well in Ridö State Forest if the foresters had given it more time, but they acted quickly in response to the apparent effects of their chosen forest management method and then re-adjusted their management practices (paper II). While it is possible that they acted too hastily, they at least tried to account for and respond to the effects of different management actions. In Finland, shifts between different uses also occurred. Kunnas and Myllyntaus (2020) describe that these shifts were also often rapid compared to the length of the rotation period. This can be compared

48. Swedish: *”Att många och stora, svåra frågor ännu återstå att lösa genom samverkan av teori och praktik, innan de riktiga stämplingsmetoderna hunnit arbeta sig fram, är visst. Även när så en gång skett, kommer det i de enskilda fallen, när yxan går, ändock bero på, om den, som håller i skaftet, är genomträngd av viljan att icke blott skörda utan även skapa värden.”*

to the current situation, in which clear-cutting has been used for about 70 years without appreciable interruption, even though various studies have found that it can adversely affect biodiversity and other desirable forest qualities (Jonsson and Siitonen 2012). It is difficult to say why the situation in the 1800s was different, but I suggest that one contributing factor may have been that few forestry experiments had been conducted at that time (paper I). Consequently, foresters may have used their management capabilities to conduct impromptu forestry experiments of sorts, at least in Ridö State Forest (paper II). The foresters had a vision that they would create forests for sustainable timber production, a vision that they also managed to achieve (paper II).

5.2 The clear-cuts

In the early 1800s, the forest management plans for Ridö State Forest were static and based on a specific division. The idea was that each area of the forest would have a fixed rotation period and the same management actions could be applied everywhere (paper II). From the 1930s, the forest management plans gradually became more site-adapted: boundaries of individual forest stands were redrawn according to the conditions in the area (soil, topography, and so on), and logging, regeneration, tree species selection, and management actions were also adapted to local conditions (paper I, II). The foresters had realized that certain tree species grew better at certain sites, meaning that the choice of logging methods had to be adjusted based on site characteristics and tree species (paper II). Another change that occurred over time was that the area of the forest stands became smaller as the divisions of the forest became more specialized (paper II, fig. 2a-h). A similar trend was seen in other parts of Sweden and in Norway as well (cf Lie et al. 2011; Axelsson and Östlund 2001). Whereas the first management plans for Ridö State Forest were long and comprehensive, those produced from 1929 onwards were shorter and more concise (paper II). My interpretation of this is that the foresters had begun to find their feet and were becoming familiar with clear-cutting.

5.2.1 Appearance

The aerial images clearly show how forestry and clear-cutting have progressed over the landscape because stands with straight borders and even-aged young forest, completely clear-cut areas, stands with residual forest, stands with seed trees, and old and uneven-aged forest can all be seen in single areas (paper III, fig. 3). This shows that the clear-cutting system in northern Sweden in the early 1900s was not an experimental method applied only in a few places; rather, it

was used frequently and areas were logged systematically and sequentially. It is thus clear that by the early 1900s, both state forest organisations and private forest companies were regularly conducting clear-cutting (Fig.11). In both cases, there was a clear connection to the original German idea that forest areas should be subdivided into plots that are logged sequentially, one per year, over a rotation period (Hölzl 2010).

Figure 11. A forest stand in Anundsjö, Västernorrland County, that was clear-cut in 1914. (Source: SLU, Forest library)

When analysing the aerial images, clear-cuts with seed trees was the land category with the largest mean compartment size in both state-owned and private company-owned forest (paper III, fig. 4). This is consistent with the fact that when the earliest images were taken, the main goal of foresters was to promote natural regeneration (paper I). At the 60th anniversary of the *Forestry Association of northern Sweden* in 1943, the regeneration issue was still being highlighted as the most important question for the future (Holmgren 1943).

5.2.2 State and private implementations of clear-cutting

It is interesting to compare state-owned forests to those held by private companies, partly to see if the adoption of sustainable forestry and clear-cutting differed between the different owner types and partly because they have not always been subject to the same regulations and policies.

The analysis of aerial images of Västernorrland County clarified how clear-cutting was applied in northern Sweden during the first decades of the 1900s (paper III). The implementation of clear-cutting in state-owned and privately owned forests was compared, revealing that the land use patterns in both cases were similar, although the private areas had a slightly higher proportion of older clear-cuts (paper III, fig. 3) and somewhat larger clear-cut areas as well (paper III, fig. 4, table 3). While these differences were not significant, they are consistent with other sources: the available records indicate that both private forest companies active nearby, namely Graningeverken (active within the study area) and Mo och Domsjö AB (active in Västernorrland County but not within the atudy area) were performing clear-cutting at that time (Andrén 1992; Lundberg 1893). Mo och Domsjö AB both advocated and applied clear-cutting, and even conducted its own field trials and research on clear-cutting (Andrén 1992; Carlgren 1917). Another factor that may have caused the proportions of clear-cuts in state forests to be lower than in privately owned forests was that selective cutting was the management method recommended for state forests at the time (paper III).

The practical forest management measures implemented in both Sweden and other Nordic countries clearly show that the choice of tree species for regeneration was widely considered important for sustainable forestry (paper II; Serup 2005; Braathe 1980). Foresters supportive of clear-cutting highlighted the opportunity to control the tree species composition of the regenerated forest as a key advantage of the method (paper I). It is possible that the low proportion of clear-cuts with seed trees in northern Sweden in the early 1900s (paper III) reflects the extent to which foresters exploited this opportunity. Clear-cuts with seed trees were only observed in 50% of the studied landscapes, and the proportion of clear-cuts containing seed trees was low in both state-owned forest and in forests owned by private companies. In the state-owned forest landscapes this proportion ranged from 0 to 6% with a mean of 1,1%, while in the privately owned forests it was between 0 and 7% with a mean of 2,1% (paper III). Since almost 40% of the study area had been clear-cut before the 1940s, there is reason to believe that planting and sowing were common. However, I had expected a larger proportion of clear-cuts with seed trees. It may be that more seed trees were once present but that some of those trees have since been logged.

The amount of space allocated to data on different tree species in the forest management plans shows that this issue was considered important and also provides insight into the foresters' thoughts and ideas about the subject (paper II). In Ridö State Forest, considerable emphasis was placed on regeneration because the forest management plan called for the entirety of the island's forest to be logged area-wise over a period of 120 years. This would give the forest and

the foresters a fresh start, enabling the foresters to control the tree species distribution by planting or sowing and then perform the most appropriate management actions to maximize production. Some stands were planted or sowed with grey alder (*Alnus incana* (L.) Moench), silver fir (*Abies alba* Mill.), and pedunculate oak (*Quercus robus* L.), but Scots pine and Norway spruce were predominant tree species.

In general, since the introduction of the concepts of sustainable forestry and clear-cutting, multi-aged and multi-storied stands have been replaced with homogenous even-aged stands, and the proportion of deciduous-rich forests in central and northern Sweden has decreased (Axelsson et al. 2002; Östlund et al. 1997). The developments in Ridö State Forest reflects these trends to some degree, but not perfectly: the initially multi-aged mixed coniferous forests were largely replaced with even-aged coniferous forests with a high proportion of deciduous trees (paper II, fig. 3a, b). The deciduous component actually increased between late 1800s and the present day (paper II, fig. 3a) despite browsing and pre-commercial thinning. This was due to forest management actions because birch (*Betula* sp.) regenerated on clear-cuts and thinning operations led to the removal of conifers. Clear-cutting often increases the abundance of pioneer trees such as birch and aspen (*Populus tremula*) (Zmihorski et al. 2010).

5.3 The development of clear-cutting after 1950

Today, clear-cutting has been the dominant forest management method for about 70 years. It is believed to reduce biodiversity (Jonasson and Siitonen 2012) and increase the risk of storm damage (Heinrichs and Schmidt 2009), but although these problems have been recognized for a long time, clear-cutting has continued to be the main applied method.

Clear-cutting is often said to mimic nature's own way of regenerating forests through fire and natural regeneration, which produces even-aged stands and cohort stands (Mielikäinen & Hynynen 2003). However, several scholars have shown that logging adversely affects biodiversity, whereas fire is often positive for biodiversity. For example, Heikkala et al. (2016) studied the effects of retention forestry, prescribed burning, and clear-cutting on saproxylic beetle assemblages and concluded that clear-cutting does not mimic the dynamics of fire. Jonsson & Siitonen (2012) also found that clear-cutting adversely affected saproxylic species because it causes resource competition between species that depend on dead wood. Bergeron et al. (2002) identifies another problem: although the argument above assumes that fires produce even-aged stands, this is not necessarily the case. Conversely, other studies have concluded that boreal

forests that have been subjected to logging typically are similar (in terms of composition, species diversity, and productivity) to stands that grew after fires (Reich et al. 2001). However, Reich et al. (2001) also note that they do not consider logging and fire to have identical effects, nor do they argue that logging can replace fire and thus eliminate threats to biodiversity and productivity.

6 International perspective on clear-cutting

6.1 Germany – Where it all began

Germany has a long history of forestry, but also of deforestation and forest restoration. The country's forest coverage in the early medieval period (the 7th century) was around 90%, but by the late 13th century it was only around 20 % (Bork & Lang 2003). This was due to population growth, which prompted logging to support settlements and agricultural activities (Grober 2012; Williams 2006). The forest resource continued to decline due to intensive use as a source for livestock fodder and energy (Grober 2012). However, the population declined during the 14th century because of starvation, epidemic plagues, and floods, allowing the forests to slowly recover; by 1450, the forest coverage was above 40 %. Subsequently, anthropogenic activity and demand for wood caused forest cover to fall around 30% by the beginning of the Thirty Years War in 1618. The forest cover level has since remained relatively steady (Reinhardt-Imjela 2018; Williams 2006; Bork & Lang 2003).

The decrease in forest coverage had consequences for several activities in the country. In the 1700s, the mining industry was threatened not by a lack of ore but because mining had consumed so much forest. Forests in the vicinity of mines had almost completely disappeared due to heavy logging over several decades without regard for forest regeneration (Grober 2012; Hölzl 2010). The mining administrator Hans Carl von Carlowitz addressed this problem and was the first to discuss the concept of sustainability in the context of forestry (Hölzl 2010). In 1713, he published the thesis *"Sylvicultura Oeconomica, or a guide to the cultivation of native trees"*[49], in which he compiled the existing knowledge about forest management at the time (von Carlowitz 1713). He described useful

49. German: *Sylvicultura Oeconomica, oder Haußwirtliche Nachricht und Naturmäßige Anweisung zur Wilden Baum-zucht*

tree species and offered suggestions for solving the timber shortage in a way that would be sustainable in the long term. He also noted that timber should be used with caution to achieve a balance between planting, growing, and logging of trees, so that their benefits could be enjoyed "continuously and forever". Areas where the forest had been completely logged should thus be replaced with new forest (von Carlowitz 1713).

Morgenstern (2007) described the late 1700s as a period characterized by the rapid development of science, including botany and forestry. The establishment of forest schools in several regions of Germany signalled the beginning of a creative period during which many scientific books were published on subjects including tree species, soil science, and climate. In Württemberg, the chief forester Johann Georg von Seutter reformed the forest service by replacing numerous individuals with trained foresters. Foresters who had a higher education could draw on the emerging new research results and discuss them with similarly trained intellectuals. Two of these foresters were Heinrich Cotta and Georg Ludwig Hartig, both of whom had ideas about how to achieve sustainable forestry (Morgenstern 2007).

The economic, social and environmental demands placed on the forest and forestry gave rise to the concept of "close-to-nature" forest management in the early 1800s (Grober 2012), or an "increasing tendency to consider forests as a part of a 'household of nature'" as Hölzl (2010) put it. Long before similar conclusions were drawn using modern science methods, some foresters came to believe that it was possible to create both ecologically and economically valuable forests by using natural processes and avoiding clear-cutting. These early practical experiences strongly influenced the development of German forestry, emphasizing the value of structurally diverse mixed stands, long regeneration periods, and natural regeneration methods. Many of today's most valuable old forests (in terms of both timber and biodiversity) originate from these early initiatives. Selective cutting or group selection cutting allows for natural regeneration and facilitates regeneration using material that is already present (Anon. 2020g; Hölzl 2010).

While clear-cutting was still in its early stages in Sweden, experiments with other forest management methods had begun in Germany. Why then was Sweden so heavily inspired by Germany use of clear-cutting but not by the concept of close-to-nature? One reason may be that Germany's forest resources had declined in a way that Sweden's had not, which may have contributed to a desire to preserve forest lands with continuous tree cover, leading to a preference for methods that avoid clear-cutting. Additionally, German forests suffer from soil erosion on slopes and require flood risk management strategies (Reinhardt-

Imjela et al. 2018), both of which have encouraged foresters to adopt close-to-nature strategies.

6.2 Other European countries soon followed

Forestry practices in some European countries developed along very similar lines to those in Germany, with an initial focus on clear-cutting followed by a transition to some kind of close-to-nature forestry. Notably, this occurred in Austria (Härtl et al. 2015), Slovenia (Pirnat & Hladnik 2018), Switzerland (Schüts 1999), and Denmark (Larsen 2012). Conversely, Finnish forestry developed in a manner more like that in Sweden, with a continuing tradition of clear-cutting (Kuuluvainen et al. 2012; Löfman & Kouki 2001).

6.2.1 Denmark

Alongside German foresters, Danish forestry contributed significantly to the adoption of sustainable forestry and clear-cutting in Sweden (paper I, II). Danish foresters came to Sweden to work (Brunet 2005), and Swedish foresters went on study trips to Denmark (Brynte 2002; Wahlgren 1928), allowing ideas relating to sustainable forestry to spread from Denmark to Sweden. The development of sustainable forestry in Denmark proceeded similarly to that in Germany and was thus ahead more rapid than in Sweden. Whereas Denmark's forest coverage was almost complete in the Middle Ages, it fell to about 20-25% in the 1600s and then to 4% in the early 1800s because of extensive deforestation resulting from human activities (Mather et al. 1998). Today, forest coverage is about 14 % (Anon. 2020d). In the 1700s, problems due to deforestation became increasingly prominent. Construction timber could be obtained from Norway[50], but the lack of firewood became problematic (Mather et al. 1998). In response to this, sustainable forestry based on German ideas was introduced in state forests in the 1760s by the German forester Johann Georg van Langen (Serup 2005).

In 1784, formal forest education was incorporated into the programmes of the royal military academies in Kiel and Elsinore (Fritzbøger 2018). This represents a clear point of difference between Sweden and Denmark: in Denmark forestry education institutes were established after the German concept of sustainable forestry had been widely adopted, whereas in Sweden the introduction of sustainable forestry in the early 1800s was accompanied by the founding of the State forest institute (paper II). Serup (2004) states that until the end of the 1800s, forest management in Denmark was *"based on an*

50. Norway was under Danish control until 1814.

unsystematic accumulation of experience from practical forestry". However, the founding of the Danish Experimental Forestry Service[51], as an independent research institution in 1901 made forest research a priority. In Sweden, the corresponding institution was founded in 1902 (Wahlgren 1928). Given that modern forestry methods were introduced in Sweden much later than in Germany, this shows that the development of forestry in Sweden progressed substantially more quickly than it did in Denmark. Before 1870, the Danish forestry discourse was heavily influenced by German foresters and German forestry. Subsequently, measures were taken to change forest education and forest management to better suit Danish conditions (Serup 2004). Since 2002, Denmark's National Forest Programme has required Danish public forests to be managed in accordance close-to-nature principles by creating optimal conditions for natural regeneration, avoiding clear-cutting, creating uneven aged mixed forest stands of site-adapted tree species and promoting biodiversity (Larsen 2012).

6.2.2 Finland

About 75 % of Finland's area is covered by forests (Anon. 2020d). Because Finland's territorial borders changed during the studied period, it is difficult to specify how the proportion of forest cover has varied over time (Myllyntaus & Mattila 2002). Nevertheless, like in many other European countries, Finland's forest cover has been affected by human activities. For example, Edmund von Berg described the devastating effects of slash-and-burn cultivation and tar production on forests (von Berg 1859). The period of slash-and-burn cultivation lasted from the 1700s until the late 1800s in Finland (Michelsen 1995), but modern researchers do not agree on whether or not it caused sustained damage to the forests (Myllyntaus & Mattila 2002). Löfman and Kouki (2001) argued that until the early 1900s, the forests of Fennoscandia were not used intensively, resulting in only in minor changes structural changes. However, new ways to manage the forests were needed, and Finnish foresters therefore drew knowledge from Germany, but also from Sweden. Finland's independence in 1917 became of significant importance to forestry, as the revenues increased because of, among other things, increased logging and improved forest management (Kunnas & Myllyntaus 2020). The situation in Finland is in many ways similar to that in Sweden. For example there was also a policy that would act against selective cutting[52] from 1948, similar to the Swedish State forest policy 1/50. The foundation of the Finnish policy was laid during a week-long excursion in

51. Danish: *Statens Forstlige Forsøgsvæsen*
52. Swedish: *Appell mot blädningsartad behandling av skogen*

southern Finland where nine prominent Swedish foresters gave their views on Finnish forest management (Appelroth 1988). It appears like Finland have a similar history to Sweden with the 1950s as "the era of clear-cutting" (Kuuluvainen et al. 2012).

In a forest management manual for Finnish forests from 1853, the forester Gyldén describes that the first step towards sustainable forestry is to "clean" the forest, which in practice meant removing and using standing dead trees and windfalls (Gyldén 1853). Although forest "cleaning" is also involved in the German approach to sustainable forestry, regeneration was seen as the main priority and the first step towards sustainable forestry both in Germany (Hölzl 2010) and in Sweden (paper I). The deviation from this view in Finland may indicate that there actually was a need to clean the forests to enable subsequent management actions. Alternatively, Finnish foresters may have simply wanted to go their own way. Although the development of forestry Finland resembled that in Sweden in many ways, it is clear that there were different views on some issues. For example, Finnish foresters considered it important to adapt forest management practices to the conditions within the country rather than adopting ideas and methods developed based on the situation in another country (paper II; von Berg 1859).

A state forestry institution was founded in Finland in 1859, followed shortly by a research institute where the country's first forest officers were educated according to the German model. Before that, Finland's foresters had been educated in Germany, Sweden, or Russia (Michelsen 1999). It is thus clear that there was a constant exchange of experiences between European countries during this period (paper I, II).

Although the development of forestry in Sweden and Finland was clearly similar in many ways, their approaches to forestry now differ somewhat because according to Finnish forest legislation, other forest management methods than clear-cutting became allowed in 2014 (Rämö & Tahvonen 2014).

6.2.3 Switzerland

About 30 % of Switzerland is covered by forest (Anon. 2020f). Sustainable forestry was introduced in Switzerland around 1800, after which artificial regeneration became increasingly common. During the 1830s, the number of set plants increased sharply (Bürgi & Schuler 2003). However, the development of forestry in Germany and Switzerland was very different. Karl Gayer was a German forestry professor, who warned about the risks of conifer monocultures in the 1800s (Lowood 1990) and received greater support for his opinions in Switzerland than in his home country (Fischer 1960). Swiss foresters were also

reluctant to pursue clear-cutting and artificial regeneration. Despite this reluctance, clear-cutting and artificial regeneration were eventually widely performed because the principles of the new sustainable forestry were most easily implemented by clear-cutting (Lowood 1990). The prospect of greater control over the forests, higher potential yield, and additional income contributed to the success of the new methods (Bürgi & Schuler 2003). However, in practice these benefits were not realised. Fischer (1960) suggested four reasons why this seemingly economical and logical management method worked poorly in practice. First, the large conifer monocultures were highly susceptible to insect pests and diseases. Second, poor results were obtained due to the use of regeneration material of foreign provenance. Third, ploughing destroyed the natural soil structure preventing the conifers from growing well. Fourth, there was no knowledge of management methods such as thinning, which meant that stand density was too high so the trees developed poorly.

In the early 1900s, close-to-nature silviculture became increasingly important. Clear-cutting was banned in protected forests in 1902 and required a state permission in other forests. Therefore, there has been a transition from scientifically constructed forestry to a more nature-oriented forestry (Bürgi & Schuler 2003).

7 Today and future forestry

7.1 Forestry today

Swedish forestry today is governed by the Forestry Act of 1993 (Anon 2019b). The forest policy that was introduced by the Swedish Parliament in 1993 (1993a) is characterized by two equally important goals – an environmental goal and a production goal. The initial paragraph of the Forestry Act of 1993 (Anon. 2019b) describes these two goals:

The environmental goal

> "The natural production capacity of the forest land must be preserved. A biological diversity and genetic variation in the forest must be ensured. The forest should be used so that plant and animal species that naturally belong in the forest are given the conditions to survive under natural conditions and in viable populations. Endangered species and habitats must be protected. The forest's cultural environment values as well as its aesthetic and social values must be protected."[53]

The production goal

> "The forest and the forest land should be utilized efficiently and responsibly so that it provides a sustainable rate of return. The focus of the forest production should give freedom of action regarding the use of what the forest produces."[54]

53. "Skogsmarkens naturgivna produktionsförmåga ska bevaras. En biologisk mångfald och genetisk variation i skogen ska säkras. Skogen ska brukas så att växt- och djurarter som naturligt hör hemma i skogen ges förutsättningar att fortleva under naturliga betingelser och i livskraftiga bestånd. Hotade arter och naturtyper ska skyddas. Skogens kulturmiljövärden samt dess estetiska och sociala värden ska värnas."

54. "Skogen och skogsmarken ska utnyttjas effektivt och ansvarsfullt så att den ger en uthålligt god avkastning. Skogsproduktionens inriktning ska ge handlingsfrihet i fråga om användningen av vad skogen producerar."

These goals should be achieved through both efforts of the forest owner and cooperation between different forest policy authorities. The forestry legislation sets out the framework and the basic requirements for conducting forestry.

Clear-cutting has dominated the Swedish forestry since the 1950s, and until recently the Forestry Act mandated its use. However, over the past ten years the *National Board of Forestry*[55] has worked to increase the proportion of continuous cover forestry. As a result, it became permissible to apply continuous cover forestry in some forested areas as a complement to clear-cutting (Bengtsson & Rosell 2010). The National Board of Forestry suggests that the use of continuous cover forestry should be increased wherever it is justified for environmental, cultural environment, or management reasons, or to support recreational values and reindeer husbandry. Under the definition of the National Forestry Board, the term continuous cover forestry encompasses all forest management methods that leave the land with continuous tree cover (Bengtsson & Rosell 2010). Such methods include selective cutting (which creates full-layered forests) as well as group selection cutting and shelterwood left standing, both of which allow the "forest feeling" to be retained. The expectations of and demands for forest ecosystem services are both increasing, and the increasing importance of qualities whose value is not readily expressed in economic (e.g. biodiversity, social worth, and health benefits) require a new approach to the forestry. There is thus a need to learn how to implement a more varied style of forestry than was used previously. The National Forestry Board states that based on current knowledge, the benefits of clear-cutting are high production and good economic performance. However, the board also notes that additional comparative studies are needed to clarify the differences between forest management methods.

7.2 Lessons from the past and guidance for the future

Learning from forest history is nothing new. Even in the early 1800s, some prominent German foresters, including Heinrich Cotta, Georg Ludwig Hartig, and Friedrich Wilhelm Pfeil emphasized the importance of basing forest science on forest historical knowledge (Brandl 1999). Accordingly, the header of the website of Forestry in Germany[56] says *"Forestry in Germany – looking ahead but based on tradition"*[57], indicating recognition of the need to take history in account in today's and future forestry (Anon. 2020g). Knowledge of forest

55. Swedish: *Skogsstyrelsen*
56. German: *Forstwirtschaft in Deutschland*
57. German: *Forstwirtschaft in Deutschland – Vorausschauend aus Tradition*

history can provide perspective on the present and be a useful comparative reference in the future. Although the forestry in many European countries have similar origins (Williams 2006), appreciable differences exists today. Knowledge of past forest management and differences in implementation between countries can help explain why these differences emerged despite the similar histories of forestry across Europe.

My studies show how important it is to find and use historical records. The journal analysed in paper I was the most important forum for forestry discussion in the late 1800s and early 1900s. By analysing its content over a long period, I was able to follow the development of the ideas, research results, and discussions that form the basis of today's forestry. To analyse how these ideas and discussions were translated into practice, paper II examined a complementary set of historical forest management plans and forest maps. This allowed me to follow the planning and implementation of clear-cutting, regeneration and other management activities at the stand level over almost 200 years. Finally, the analysis of early aerial images presented in in paper III provided new knowledge on the appearance of the forest landscape in Västernorrland County and the likely appearance of forests elsewhere in northern Sweden. By inspecting the images, I was able to determine how much of the landscape had been clear-cut and thereby estimate the frequency of clear-cutting in the early 1900s.

Forest history studies such as those presented in papers I-III allow the history of forests to be understood and can clarify the relationships between phenomena and process of interest such as nature conservation and the history of forest management. Szabó (2010) stresses that history is important in ecology and presents three broad arguments justifying this claim, namely that history matters in ecology because (1) it aids understanding of current patterns and processes in nature, (2) it fosters better-informed management and policy decisions, and (3) it places ecology and conservation in a wider interdisciplinary context. Bürgi and Gimmi (2007) present three similar reasons for studying historical ecology: (a) preserving cultural heritage in ecosystems and landscapes, (b) understanding historical trajectories of patterns and processes in ecosystems and landscapes, and (c) informing ecosystem and landscape management. These arguments are relevant to my studies because they illustrate the need to understand the history of forestry and forest ecology, especially at a time when the urban population is growing and view of the forest is changing.

My interpretation of paper I, II and III is that organized forestry has been going on for longer time than most of today's researchers and foresters believe. As a result, some forest stands may have been clear-cut or radically harvested twice since the introduction of modern forestry, as in Ridö State Forest (paper II). A major part of the island Ridön is scheduled to become a nature reserve in

the near future (paper II; Anon. 2015b). The County Administrative Board's[58] purpose in protecting the island in this way is to preserve its broad-leaved deciduous forests, to take advantage of the value of other forest environments, for example through prescribed burning, and to maximize the area's recreational value (Anon. 2015b). These goals are socially valuable but also ecologically important because they support the restoration of forest types that were previously common but are now increasingly rare such as deciduous forests and uneven-aged mixed forests (Brunet et al. 2012; Axelsson et al. 2002). However, it is also important not to base future management plans only on a forest's history or "original" state (Swetnam et al. 1999). It should be noted that the island is located in a relatively densely populated part of Sweden, where it can be difficult to find suitable areas for nature conservation and prescribed burning (Anon. 2015b). The fact that it is an island also facilitates demarcation for both purposes. It is also interesting to see how the County Administrative Board manage and assess forest areas like this. The fact that the forest has potential for becoming a nature reserve is interesting considering that the area has been managed by clear-cutting for almost 200 years (Fig. 12). However, the history often adds values rather than "destroys", and in this context, I think it is important to be able to discuss the potential value of set asides, preservation, and restoration. Ridön was by no means free from human impact before the introduction of forestry and clear-cutting: it has a long history, the Ridö tavern was an important "resting place" along the waterways. In the 1600s and 1700s it was mainly used by fishermen and farmers, who certainly also used its forests to varying degrees (paper II; Anon. 2011). Ridön was probably one of the first areas in Sweden where forestry based on German ideas was introduced, and is likely to have been a site of experimental forestry research. The island is thus an unusual case in that clear-cutting appears to have been the first management method applied on the island, and was not preceded by any kind of selective cutting. In addition, there is an almost complete series of forest management plans and forest management maps for the island covering the period from the introduction of forestry in 1832 to the present (paper II), which is almost unique. When preserving forests with cultural values those in charge must choose which historical environments they want to re-create and to be able to preserve these environments it is necessary to repeat certain human measures (Myllyntaus 2010). Considering these aspects, I think that establishing deciduous forests and prescribed burning on the island may not be ideal; instead, it is arguably its history of forestry that should be preserved.

58. Swedish: Länsstyrelsen

Figure 12. Photos from Ridön, taken in 2013, showing two different forest stands in the eastern part of the island (Photo: The County administrative board [Länsstyrelsen], Stockholm, 2013-05-22).

Biodiversity and protection of key species are major concerns in forest conservation. Levels needed to support viable populations, natural habitats and dispersal pathways are all important factors in this context. However, the way in which we think about these factors may need to be adjusted if forests have a longer history of forestry and clear-cutting than previously thought. With the 200 year clear-cutting history in Ridö State Forest in mind, I think that another interesting aspect is for how long a forest must develop after clear-cutting and subsequent regeneration to develop nature conservation values and habitats for conservation of species. An interesting thing connected to species and Ridön is that the forest management plans and forest maps from 1947 and 1957 indicates places for bird nests of osprey (*Pandion haliaetus*) on the eastern part of the island. In the County Administrative Board's description for a future nature reserve on Ridön, there is a recent photo showing a nest of osprey in the same part of the island as 70 years ago (Fig. 13).

Figure 13. (A) On the map from 1957, of the easternmost part of the Ridön island, a bird nest of osprey (Swedish: fiskgjusbo) is marked with a X. (B) In a recent taken photo of the easternmost part of Ridön a bird nest of osprey can be seen in the top of the spruce in the back. (Source A: The Regional State Archive [Landsarkivet], Härnösand, Sweden (paper II; table 1); B: The Administrative Board [Länsstyrelsen], Stockholm, 2013-05-22)

Historical knowledge can fundamentally change our understanding of ecosystems dynamics in terms of the physical structure of ecosystems, ecosystem functions, species interactions, and phase shifts, all of which must be taken into account when setting restoration and conservation goals (McClenachan et al. 2015). In most forests, tree continuity is emphasized to

support species conservation and biodiversity (Sténs et al. 2019). However, there is also evidence that some species may thrive in managed forest environments. For example, Jonason et al. (2014), showed that clear-cuts areas that had previously been grasslands exhibited greater floral species diversity than clear-cuts with longer forest continuity. Similarly, species diversity and abundance of butterflies were higher in clear-cuts that were previously meadows than those with longer forest continuity (Blixt et al. 2015). Accordingly, Jonason et al. (2016) subsequently argued that focusing on mimicking the dynamics of old-growth forests may be a less effective than mimicking the historical land use patterns at the site if one's claim is to increase biodiversity.

The history of forestry during periods of ongoing debate about the benefits of different logging methods is particularly interesting because a wide range of methods were tested during those periods. Different variants of these methods were implemented and discussed at length. This was reflected in the articles, reports, excursion summaries, and discussions published in the *Journal of the Forestry Association of northern Sweden* (paper I), and in practical forestry: foresters readily switched between different forest management methods, tree species, and other management measures (paper II). If the situation called for a change of forest management method, such as the switch from clear-cutting to selective cutting during the economic crisis of the 1930s, then that change was made (paper I).

By studying forest areas using archive sources extending far back in time, it is possible to analyse in detail how forest management has affected the forest structure in the short and long-term. Although the use of archival sources has a long tradition in historical ecology (Szabó 2015), such sources have been considered non-traditional and have therefore been subjected to criticism, especially in cases where they have contradicted prevailing beliefs (McClenachan et al. 2015). Analysis of historical records can yield surprising results, giving rise to new hypotheses that can be tested using additional data, as well as new understanding of ecological dynamics that can be immediately applied (McClenachan et al. 2015).

8 Concluding remarks

8.1 Clear-cutting was introduced in the 1800s

The clear-cutting system was introduced in the early 1800s in central Sweden and was based on German ideas about sustainable forestry. At that time, sustainability meant ensuring regeneration after logging. In central Sweden, clear-cutting was primarily regarded as a forest management method that enabled restoration of logged forests in which regeneration had previously been too sparse. During the late 1800s, the method spread to northern Sweden, where it enabled the exploitation of more remote forests. The clear-cutting system was constantly developed and refined during the period from its introduction until its large-scale breakthrough in around 1950. However, its popularity declined temporarily during the selective cutting era between the 1930s and 1950.

The introduction of clear-cutting in central Sweden was motivated by the fear of deforestation; clear-cutting was seen as a method that would restore previously logged forests and create new forests with good regeneration, growth and volume. The situation in northern Sweden was somewhat more complex; the driving forces behind the introduction and development of the clear-cutting system in in northern Sweden were:

- Industrialization, which was important in several ways. First, the increasing need for timber and wood products in the industrialized countries of Europe pushed the timber frontier further north and further inland, and necessitated the use of clear-cutting to obtain sufficient volumes of timber. Second, the rapid expansion of new industries, mainly sawmills and pulp mills, in northern Sweden, enabled clear-cutting by creating a market for smaller trees that had not reached saw-timber size. Third, several industries in northern Sweden were built up or expanded as integrated industries, which favoured the clear-cutting system.

- The need for sustainable forestry to counteract poor regrowth and deforestation. In the mid-1800s, large parts of Sweden experienced deforestation due to logging for the mining industry and ironworks. It seems that foresters believed there was a high risk of further deforestation unless steps were taken to prevent it. Together with the growing demand for timber, this facilitated acceptance of new forest management methods such as clear-cutting.
- Inspiration from Germany. The foundations of sustainable forestry had already been laid in Germany during the 1700s, and clear-cutting was central to them. Germany was thus a source of ideas that supported the establishment and further development of Swedish forest management.
- New forestry research in northern Sweden. Initially, the only available forestry research results originated from experiments conducted in southern Sweden or other countries. The onset of field surveys in the forests in northern Sweden therefore spurred the development and implementation of the clear-cutting in this region.
- Economic booms, particularly during the first two decades of the 1900s made the regeneration costs associated with clear-cutting easier for firms to bear.

8.2 Clear-cutting was widespread in the early 1900s

Excursion protocols, essays, reports, and aerial images from the early 1900s all shows that clear-cutting was widely used in parts of northern Sweden during this period. The merits of the clear-cutting system were frequently debated in the early 1900s, but the intensity of the debate declined in the late 1920s; my interpretation of this is that clear-cutting had become widely accepted by that time. Around 1950, it was hardly discussed at all. In addition, the analysis of aerial images revealed that 10% of the study area in Västernorrland County had been clear-cut in the early 1900s, and by the end of the 1940s the proportion of clear-cut land had increased to almost 40%. I hypothesize that the clear-cutting system have developed and expanded similarly in other parts of northern Sweden, especially in those where saw mills and pulp mills had been established in the early 1900s. In my regional study, it appeared that clear-cutting was implemented to a similar degree by state foresters and private companies. It is possible that the same was also true in other parts of northern Sweden. However, there is also some evidence that private companies played the leading role in the adoption of clear-cutting. Nevertheless, it is clear that in at least some cases the

state acted against its own regulations by implementing clear-cutting instead of selective cutting before the State forest policy 1/50 came into force in 1950.

8.3 A myth of clear-cutting was created to indicate the start of a new era in forestry

For a long time, the general opinion was that clear-cutting was introduced in northern Sweden around 1950. However, the analysis presented here shows that it was actually introduced in the late 1800s but coexisted with other logging methods until around 1950. There are several plausible reasons for the emergence and promotion of the myth that clear-cutting only became widespread after 1950. First, there was a need among foresters for a positive historical narrative and to make a definitive break with the various forms of selective cutting that were still in use and to encourage the exclusive use of the clear-cutting system and rational forestry with well-defined rotation periods involving clear-cutting followed by regeneration through planting or sowing. Two other important motives were production and economy: clear-cutting was more profitable than other methods. The introduction of the State forest policy 1/50 and the mechanization of forestry that began in the 1950s helped to consolidate this myth. References to the early 1950s as the "era of clear-cutting" first appeared in the literature during the late 1950s, so it is likely that the myth originated around that time.

8.4 Aerial images provide a very detailed picture of past forest management

The old aerial images examined in this work are important sources of information that would be very difficult to obtain in any other way. Uniquely, they make it possible to determine what the forest landscape looked like in the early 1900s, and to quantify the extent of early clear-cutting in a part of Västernorrland County. It would be interesting to study other areas in northern Sweden in the same way, and to use aerial images to study other aspects of historical forest management such as the structure of high-graded forests, high altitude clear-cuts, and the distribution of clear-cuts in relation to transportation routes and industries. Another interesting approach would be to combine the oldest aerial images with contemporaneous forest management plans and forest maps to identify patterns and connections that could be used to infer the history of areas for which old aerial images are not available.

8.5 Revealing the history of forest management is best done by using different methods and sources

Combined analysis of different forest historical methods, records and approaches can provide a deeper understanding of forest history than would otherwise be obtained. The studies presented here draw on three different and complementary types of historical records that collectively provide a comprehensive overview of early forest management in Sweden. The journal analysed in paper I provided vital insights into the theoretical discussion and ideas surrounding the introduction and initial implementation of the clear-cutting system. In paper II, I showed how these ideas were put into practice by analysing forest management plans and forest maps, while the aerial images in paper III revealed the extent to which clear-cutting had been implemented in the early 1900s.

8.6 Clear-cutting history in relation to today's forestry

My results demonstrate the importance of analysing historical records from both contemporaneous and modern perspectives. Paper I analysed the discussions, reports, essays and protocols published in a major forestry journal over an extended period, providing important insights into the debates, theories, and ideas that shaped modern forestry. In paper II, I was able to find and analyse a long time series of forest management plans and forest maps that provided a unique opportunity to follow the planning and implementation of stand-level forest management at over time. Finally, in paper III I examined aerial images from the 1940s, which revealed the extent to which clear-cutting had been used during the early 1900s; if I had analysed only more recent aerial images, the widespread early use of clear-cutting would not have been apparent. My analysis of early aerial images thus greatly improved the understanding of the landscape in Västernorrland County (and possibly other parts of northern Sweden) as well as the spread of clear-cutting in the early 20th century. Without such knowledge, one may be led to incorrect conclusions about how and why today's forests look the way they do.

This thesis presents evidence that clear-cutting has been conducted for a longer time than is generally believed, which has implications for our understanding of the processes that shaped modern forests and the services they provide. We need to take this into account when creating nature reserves or engaging in other types of nature conservation: today's forests were not shaped solely by natural processes, and some of the present non-financial value of forests may be at least partly due to anthropogenic influence. A longer time of

systematic forest management may also have affected the forests' economic value in both positive and negative direction.

We can also learn from the differences in forest management practices adopted in different countries. Forestry in Sweden and many other European countries draws heavily on German ideas and the clear-cutting system. Today, clear-cutting is the dominant method in some countries, while in others it is barely applied at all. Knowledge of historical forest management can explain why this divergence occurred despite the similar origins of forestry practices in many European countries.

Information on forestry practices during times of open debate about the merits of different logging methods is particularly interesting because the participants in these debates also often implemented and tested the methods they were discussing. Foresters thus switched between different forest management methods, choices of tree species, and management actions. This is exemplified by the early decades of the 1900s, when both clear-cutting and selective cutting were regarded as reasonable forest management methods and were thus both used and further developed. Conversely, from the 1950s, opinion in forestry became more homogenous and clear-cutting was practiced almost uniformly. I therefore think that it is important to create an environment that supports open discussion and the application of different forest management methods in order to promote the development of innovative ideas in forestry.

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Popular science summary

Sweden's forests have been used as a source of timber and wood products for a long time and in different ways during different periods. For a long time, high-grading was the country's dominant logging method. This meant that only the largest and best trees were logged and especially Scots pine trees. However, the removal of all large trees created "residual forests" containing only small trees of low quality that grew poorly. Indeed, some areas of central Sweden became completely clear of forest because new trees failed to grow after logging. This created a fear of widespread forest loss in the 1800s. Swedish foresters therefore turned their eyes to Germany and German ideas about sustainable forestry. The German approach relied on clear-cutting, whereby the forest was divided into areas of equal size. Each year, one such area would be clear-cut and then planted or sown to promote regeneration, resulting in the establishment of a new forest. This method was considered to enable logging in a manner that could be continued indefinitely.

While the clear-cutting system was introduced in central Sweden in the early 1800s, it did not reach northern Sweden until the end of the 1800s, when industrialization and the associated demand for timber necessitated an increase in forest production. In the early 1900s, many industries were quickly established in northern Sweden. In particular, many pulp mills were set up and helped to spur the adoption of clear-cutting by creating demand for smaller trees unsuitable for the production of saw timber. However, other logging methods were also used, notably various forms of selective cutting, which involves logging only trees of (for example) a certain diameter or quality. The period from the early 1900s to the 1950s is interesting in that several logging methods were developed and applied to varying degrees, depending on factors such as the national and international economic conditions. Selective cutting eventually was phased out in around 1950, and clear-cutting became essentially the only used system in northern Sweden.

Despite the history discussed above, it is widely believed that clear-cutting was only introduced in northern Sweden in the 1950s. My studies provide several lines of evidence showing that clear-cutting was common in this part of the country even in the early 1900s. For example, articles in forest journals and forest excursion protocols from that time describe the clear-cutting system as being common, and old aerial images clearly show that large forest areas had been systematically clear-cut. By the end of the 1940s, two-fifths of the study area in Västernorrland County had been clear-cut. It is thus strange that clear-cutting in northern Sweden has become associated with the 1950s. I suggest that this is because there was a need to separate old traditions reliant on methods considered non-rational from the new forestry, which was based on research and science. Therefore, this "myth" was created, probably in the late 1950s, to encourage foresters to abandon the old ways. The fact that mechanization and the introduction of chainsaws and other machines coincided with this probably helped reinforce this myth.

The clear-cutting system was introduced in central Sweden in the early 1800s and in northern Sweden in the late 1800s, and has been the country's dominant logging method since the 1950s. However, little is known about how this method developed in the 1800s and early 1900s. Today, the use of clear-cutting is increasingly being questioned, so understanding its historical use and development can provide insights into today's forestry and the ongoing discussions about forest management today. My studies also illustrates the advantages of combining different historical records and methods to obtain a comprehensive picture of forest historical events.

Populärvetenskaplig sammanfattning

Sveriges skogar har under lång tid nyttjats för virkesbehov och träprodukter på olika sätt under olika perioder. Länge var dimensionshuggning den dominerande avverkningsmetoden i landet och då avverkades bara de största och bästa träden av framför allt tall. Men detta orsakade uppkomsten av ”restskogar”, där alla stora träd var avverkade och de träd som fanns kvar var huvudsakligen klena, av dålig kvalitet samt växte dåligt. En del områden i mellersta Sverige blev helt tomma på skog eftersom det inte kom några nya plantor efter avverkningen. Detta skapade en rädsla för skogsbrist under 1800-talet. De svenska skogsmännen vände blicken mot Tyskland och de idéer som fanns där om ett hållbart skogsbruk. Den tyska skogsskötseln baserades på kalhyggesbruket, som innebar att skogen delades in i mindre områden av samma storlek och där sedan ett område per år kalavverkades och därefter planterades eller såddes. På så vis etablerades ny skog och metoden ansågs som ett långsiktigt hållbart alternativ.

Efter att kalhyggesbruket introducerats i mellersta Sverige i början av 1800-talet dröjde det till slutet av samma århundrade innan metoden nådde norra Sverige. Det var det ökade virkesbehovet till följd av industrialiseringen som drev på denna utveckling och krävde en ökning av skogsproduktionen. I början av 1900-talet etablerades på kort tid en mängd industrier i Norrland, där framför allt massaindustrierna möjliggjorde för användandet av kalhuggning eftersom även klenare träd som inte lämpade sig som sågtimmer kunde tas tillvara. Men även andra avverkningsmetoder användes och då främst olika varianter av blädning, vilket innebär att skogen avverkades utifrån träd av till exempel en viss diameter eller kvalitet. Tiden från början av 1900-talet fram till 1950-talet är intressant på så vis att ett flertal avverkningsmetoder utvecklades och användes i olika omfattning beroende på faktorer såsom till exempel det ekonomiska läget i Sverige och världen. Men så småningom fasades blädning ut och kring 1950 fick kalhyggesbruket sitt definitiva genombrott i Norrland.

Trots denna historik har det funnits en vedertagen sanning att kalhyggesbruket introducerades i Norrland först på 1950-talet. Mina studier

visar på flera olika sätt att kalhyggesbruket var vanligt i norra Sverige redan i början av 1900-talet. I tidskrifter och exkursionsprotokoll från den tiden beskrivs kalhyggesbruket vara vanligt förekommande och gamla flygbilder visar tydligt hur stora skogsområden systematiskt avverkades genom kalhuggning. I slutet av 1940-talet hade två femtedelar av studieområdet i Västernorrland kalhuggits. Därför kan det upplevas som märkligt att kalhyggesbruket i Norrland blivit så starkt förknippat med 1950-talet. Jag tror att detta beror på att det behövdes en gränsdragning mellan de gamla traditionerna med metoder som inte ansågs vara rationella, och det nya skogsbruket, med metoder som var baserade på forskning och vetenskap. Därför skapades denna ”myt”, sannolikt någon gång i slutet av 1950-talet, för att få skogsmännen att överge de gamla sätten. Att mekaniseringen av skogsbruket, med introduktionen av motorsågar och andra maskiner, också inträffade vid den här tiden har sannolikt bidragit till att förstärka myten.

Kalhyggesbruket introducerades i mellersta Sverige i början av 1800-talet, i norra Sverige i slutet av 1800-talet och har alltsedan 1950-talet varit den dominerande avverkningsmetoden i landet. Men kunskapen om hur metoden utvecklades under 1800-talet och början av 1900-talet har varit begränsad. Idag, när kalhyggesbruket blir alltmer ifrågasatt, kan en ökad förståelse för hur metoden har använts förr och hur den har utvecklats bidra med insikter om varför dagens skogar ser ut som de gör och till den pågående diskussionen om dagens skogsskötsel. Mina studier ger också exempel på fördelarna med att kombinera olika typer av historiskt material och olika metoder för att på så vis kunna få en helhetsbild av skogshistoriska händelser.

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This thesis focuses on the introduction, development and implementation of clear-cutting in central and northern Sweden during the 1800s and early 1900s. A combination of different historical records, methods, and approaches revealed that clear-cutting has been used for a longer time than previously believed, which may be of importance for forestry and nature conservation today. Analysis of forest historical records from both contemporaneous and present perspectives may provide a deeper understanding of forest and forestry history than would otherwise be obtained.

Hanna Lundmark received her graduate education at the Department of Forest Ecology and Management, SLU, Umeå. She has a Degree of Master of Science in Forestry with a major in Biology from SLU, Umeå.

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