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Forest management in Sweden

Current practice and historical background

SKOGSSTYRELSEN

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1 Preface

International exchanges of knowledge and experiences constitute a key component of every country's work for continuous improvement toward sustainable forest management. The success of international collaborative projects and other types of transnational activities is strongly contingent on effective communication, including exchange of information about the individual countries' forests and their management.

This publication has its origin in a bilateral collaboration project involving Sweden and Slovenia. In this project, the two countries sought opportunities for mutual learning in the field of forest management, particularly as regards continuous-cover forestry. As part of this work, it became obvious that collaborators from both countries needed a solid platform for reciprocal understanding, mainly as regards how forestry is being conducted in the two countries and why it has developed this way. Our hope is that this publication, which provides a summary of the current state and historical background of Swedish forest management, will contribute to a continued fruitful collaboration with Slovenia as well as to other future international collaborations in this field.

Most of the authors involved in the writing of this publication have together contributed in various ways and extents to the sections about abiotic and biotic conditions, the historical development of forest management and current forest management. The last section, which shortly addresses future outlooks for Swedish forest management, has been written by Prof. Erland Mårald (Umeå University). These outlooks were defined to capture different hypothetical futures for Swedish forests and forestry; they are not meant to represent the authors' standpoints about the desirability of different future developments.

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2 Introduction

Approximately two thirds of Sweden's land area are covered by forests. These forests are of high value for the provision of wood products and other ecosystem services, as well as for the conservation of biodiversity. Despite being a relatively small country, Sweden is an important actor in the international forestry arena in terms of timber harvesting levels, market shares, technological development, research and education. Various stakeholders in the Swedish forest arena are therefore involved in international collaborative projects or other types of transnational activities. To be truly effective, such cooperation necessitates good reciprocal knowledge of the countries' forests and forestry. Unfortunately, it is often challenging to obtain such knowledge in a condensed and easily accessible form. To obtain the full picture, it is usually necessary to consult a wide range of publications of different types, such as governmental, business and NGO reports, official statistics, scientific articles, corporate instructions and legal documents. Moreover, many of these publications are only available in Swedish language or require detailed prior knowledge of the specific conditions prevailing in Sweden, which limits their usefulness to an international readership.

The present report describes in a summarized form the historical development and current state of Swedish forest management, and also briefly discusses possible future developments. The principal aim is to make knowledge about Swedish forestry and its development widely available to a broad international (as well as domestic) readership. This report does not present comprehensive statistics about Swedish forestry, nor does it provide deep analyses of the forest sector or of differences with other countries. Rather, the aim is to provide a firm foundation for understanding the background to current forest management practices in Sweden, which will hopefully facilitate future international exchanges, collaborations and analyses in the area, as well as educational activities related to forestry. While the main focus is on forestry and its development, the report also briefly touches upon other aspects that have had or still have an impact on forestry.

Previous publications have addressed similar topics. The book *Forestry on society's terms*[1] by Karl-Göran Enander (Enander 2007) and publications by the Swedish Forest Agency (Ekelund & Hamilton 2001, Holmberg 2005) provide detailed Swedish-language accounts of the historical development of forest management, policy and management. The book *Agriculture and forestry in Sweden since 1900* edited by Antonsson *et al*. (2011) describes the footprints and impact of agriculture and forestry on the Swedish landscapes. The National Atlas of Sweden has published two volumes on forests, with numerous maps, figures and statistics about forests, forest management, the forest industry and their history (Nilsson 1990, Jansson *et al*. 2011). Moreover, the Royal Swedish Academy of Agriculture and Forestry has published brochures presenting brief introductions to Swedish forests and forestry in English (KSLA 2009, 2015). In addition, the Swedish forestry model has been analyzed and compared to other countries' governance models in recent scientific publications (see, for example,

[1] Original Swedish title: "*Skogsbruk på samhällets villkor*" (free translation by the authors of the present report).

Beland Lindahl *et al*. 2017, Sandström *et al.* 2017, Felton *et al*. 2019a). The present report draws upon these previous works as well as state-of-the-art expert knowledge about forest management practices to provide an English-language account of historical and contemporary forest use in Sweden. Building on past and current trends, the report also glimpses into possible futures for Swedish forestry.

3 Abiotic and biotic conditions

Sweden has an elongated shape in a north-south orientation, stretching from 55° to 69° N in latitude and from 11° to 24° E in longitude. Due to the northerly position of Sweden on the globe, its landscapes have been shaped by the Pleistocene glaciations. During the last ice age, almost all of Scandinavia was under a thick ice cover, except for western Jutland in Denmark and parts of northern Norway. The ice started to melt when the temperature began to increase about 12,000 years ago. The melting glaciers transformed the physical landscape, shaping the geomorphological formations and soils that would offer the foundation for the development of diverse ecosystems. From a geological time perspective, the plants, animals and fungi that today exist in Sweden colonized the area in relatively recent time, many of them in parallel with humans.

3.1 Abiotic conditions

Topography varies from south to north within Sweden. In the south, the terrain is relatively flat with low hills and several clay plains. The highest point south of the Mälaren Valley (i.e. latitude of Stockholm) is 377 meters above sea level. As one moves from Mälaren Valley northward, the terrain becomes more rugged, especially in the inland. The Scandinavian mountain range stretches in the western part of northern Sweden, along the Swedish-Norwegian border. The highest peak in Sweden, Mount Kebnekaise, is located in the northernmost county called Norrbotten (Fig. 1). It reaches 2097 meters above sea level. There are also some areas with flat terrain in northern Sweden, for example along the Baltic coast in the northeast, near the Finnish border, as well as in other areas dominated by plains or mire complexes. In the middle part of the Baltic coast of northern Sweden, there is a rugged coastal landscape called the High Coast. As a result of isostatic rebound following the retreat of the ice sheet, land is still gradually rising up along the Swedish coasts. The magnitude of the rebound is largest along the Gulf of Bothnia, where land rises approximately 9 mm per year (Wastenson & Fredén 2002). This process of gradual appearance of new land results in a typical forest vegetation succession gradient from the water edge inward.

The Swedish bedrock comprises three main components (Lundqvist 1994). The largest is the Baltic shield, a basement rock which is between 1 and 3 billion years old. The second component, called the Caledonian Mountains, is found in the Scandinavian mountains. This formation is shared with northwestern Ireland, the mountainous areas of northern Scotland, northeastern Greenland, Spitsbergen and the Appalachian Range in eastern North America. It was formed approximately 500 million years ago. The third component comprises the islands of Gotland and Öland, some parts of southernmost Sweden (Skåne county) and two areas in the north-central parts of the country (in the counties of Dalarna and Jämtland). These areas are dominated by sedimentary bedrock and very fertile soils. This bedrock was formed during the Cambrian to Tertiary period, from about 500 to 50 million years ago.

Most of the forest area in Sweden lies on the Baltic shield. Here, a range of processes during and following the latest ice age have created formations such as moraines and accumulations of sediment, for example along the larger rivers running from the Scandinavian mountains toward the southeast into the Gulf of Bothnia. Due to the relatively young nature of the soils, the availability of minerals is generally not a limiting factor for forest tree growth. Rather, growth is usually limited by the availability of nitrogen, especially in the northern parts of the country (Tamm 1991).

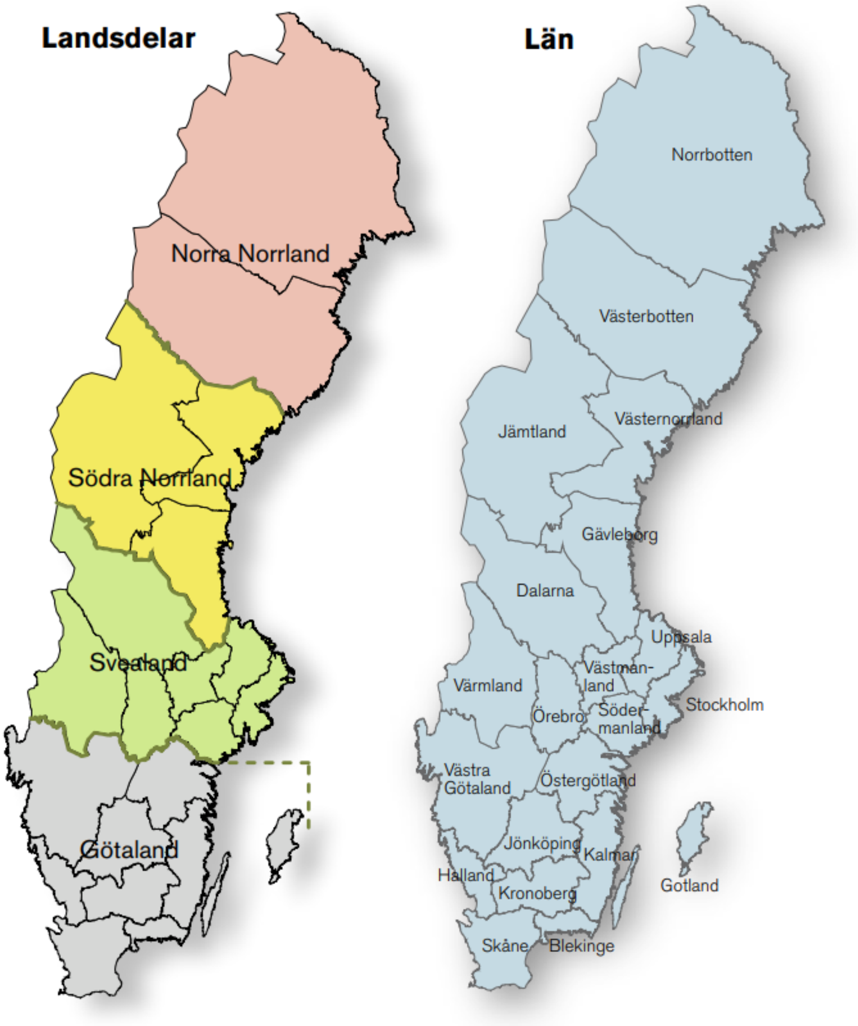

Fig. 1. *Left: The three "lands of Sweden" (*landsdelar*) used in some of the presentations of key figures about Swedish forests and forestry in the present report (Götaland, Svealand, Norrland), where Norrland is divided into a southern (Southern (*Södra*) Norrland) and a northern part (Northern (*Norra*) Norrland). Right: Sweden's administrative counties (län). Sources: Lantmäteriets GSD Vägkartan, © Lantmäteriet, published in SLU (2020).*

The main climatic gradient in Sweden stretches in a north-south direction and, in the northern part of the country, from the inland to the Baltic coast. The northernmost parts of the country and the Scandinavian Mountain range are characterized by a subarctic climate. North of the Arctic circle (which crosses Sweden approximately 300 km south of its northernmost point), the sun does not set at all during part of the summer, whereas there are only a few hours of light per day in December. However, due to the effects of the Gulf Stream, the climate across most of Sweden is relatively mild compared to other parts of the globe located at similar latitudes. In the northern half of the country there is normally a persistent snow cover during 4–6 months during the winter and the length of the vegetation period is 100−160 days (shorter in the inland and longer in the coastal areas). In south-central Sweden the period of snow cover is more limited and the vegetation period is 170−190 days. From Stockholm and southward, periods with snow cover are more ephemeral and irregular. The length of the vegetation period in southernmost Sweden is >200 days (SLU 2019a). The vegetation period has become longer throughout Sweden during the last 40 years. Future climate scenarios produced by the Swedish Meteorological and Hydrological Institute predict substantial further increases in the vegetation period's length in the coming decades (SMHI 2019).

There are a few large areas of agricultural land in southernmost Sweden and in other larger plains of the southern parts of the country. The highlands of southern Sweden (the part of Jönköping and Kronoberg counties called *Småländska höglandet*) are largely forested. Central and northern Sweden is mostly dominated by forest with various proportions of mires, waterbodies, rocky outcrops and farmland, except for the higher-altitude parts of the Scandinavian Mountains where alpine tundra dominates. The treeline occurs at about 1000 meters above sea level in the southern parts of the Scandinavian Mountain range and about 500 meters in the north. It is gradually rising in altitude as an effect of ongoing climate change (Kullman 2010).

The large-scale climatic gradients result in large differences in the productivity of the forest ecosystems. Forest productivity generally varies between 3 and 4 m^3 per hectare per year in the northern half of the country. At the latitude of Stockholm, it averages approximately 7 m^3 per hectare per year. In the country's southernmost county (Skåne), the average forest productivity is 11 m^3 per hectare per year (SLU 2018). On top of these large-scale climatic gradients, there is significant local-scale variation as a function of soil nutrient properties and water status.

Climatic gradients in Sweden do not only result in changes in tree volume growth; they also directly influence the probability of successful seed development, which may limit natural regeneration of some tree species, for example in the northwestern parts of the country.

3.2 Forest vegetation

Sweden comprises three broadly defined forest vegetation zones (Fig. 2). The largest is the boreal zone, which stretches from northernmost Sweden down to south-central Sweden. The southernmost parts of Sweden belong to the nemoral zone, dominated by southern broadleaved tree species[2]. The wide transition zone between the boreal zone and the nemoral zone is called the boreonemoral (or hemiboreal) zone.

[2] For simplicity, the term "broadleaved trees" is used throughout this report to depict non-coniferous deciduous tree species.

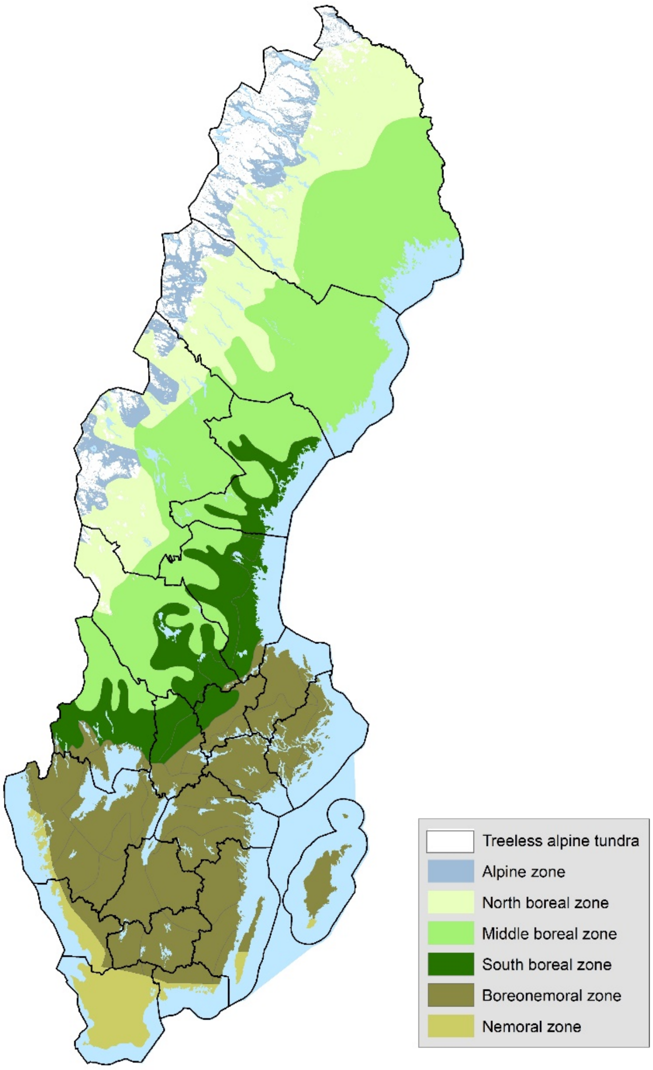

***Fig. 2**. Forest vegetation zones in Sweden according to the Classification of the Nordic Council of Minister (1984). Black lines depict county borders.*

Three subzones are usually distinguished within the boreal region: the north boreal zone found mostly at higher altitudes along the Scandinavian Mountain range (where a belt of mountain birch *Betula pubescens* ssp. *czerepanovii* of varying width separates the treeless alpine areas from the conifer-dominated forest), the middle boreal zone in the central inlands of northern Sweden and along the Bothnian Bay, and finally the south boreal zone stretching across south-central Sweden, along the Bothnian Sea coast and into the valleys of the major rivers of southern Norrland (Fig. 2).

The Swedish boreal forest is part of the taiga, the conifer-dominated forest belt that extends from the Norwegian coast to the eastern Russia, as well as from Alaska to eastern Canada. Although there is much variation in climate, soil conditions and topography, ecological patterns and processes are largely similar throughout the European taiga. As is the case for the taiga in general, Swedish boreal forests are dominated by conifers, with varying proportions of broadleaved trees. The latter are typically most abundant in early stages of succession after disturbance. The two canopy-forming conifers in natural Swedish boreal forests are Scots pine (*Pinus sylvestris*) and Norway spruce (*Picea abies*). The main broadleaved trees are silver birch (*Betula pendula*), downy birch (*Betula pubescens*), European aspen (*Populus tremula*), rowan (*Sorbus aucuparia*), grey alder (*Alnus incana*) and willows (*Salix* spp.). Depending on site properties and light conditions, the understory vegetation can be dominated by ericaceous shrubs or dwarf-shrubs, with varying proportions of herbs and small trees.

Life in the boreal forest is adapted to natural disturbances such as recurrent fires, windthrow, snow- and icebreak, flooding, outbreaks of cambium-feeding and defoliating insects, fungal diseases, browsing by ungulates such as moose (*Alces alces*) and the actions of beaver (*Castor fiber*) (Esseen *et al*. 1997). As a consequence, natural boreal forest landscapes are characterized by a complex mixture of even-aged forest dynamics following stand-replacing disturbances (e.g. intense fire or windthrow), cohort dynamics (mostly in pine-dominated forest subjected to low-intensity fires), gap dynamics (especially in wetter spruce-dominated forest) and patch dynamics driven by tree mortality at intermediate spatial scales (Kuuluvainen & Aakala 2011). Notably, many boreal forest species in Sweden are dependent on the environments created by forest fires.

Fig. 3. *Fire has had a major impact on the boreal forest landscape. Photo: Daniel Sjöholm.*

The southern edge of the boreal forest is called *Limes Norrlandicus*. This border separates the true boreal forest from the boreonemoral (or hemiboreal) forest. Stretching across large parts of southern Sweden (Fig. 2), the boreonemoral forest is a wide transition zone characterized by a mixture of boreal and nemoral elements. Here, southern (nemoral) broadleaved tree species such as pedunculate oak (*Quercus robur*) are found in various admixtures with boreal tree species such as Norway spruce.

The true nemoral zone covers a minor fraction of Sweden, being restricted to the southernmost parts of the country: it covers most of the county of Skåne, coastal areas of Halland, Västra Götaland and Blekinge, as well as parts of the islands of Öland and Gotland (Fig. 2). Its northern limit coincides with the southern edge of the natural distribution range of Norway spruce in Scandinavia (Gustafsson & Ahlén 1996). Note, however, that Norway spruce has been planted on a large scale throughout the nemoral zone of Sweden. The natural tree species composition in that zone includes southern broadleaved tree species such as European beech (*Fagus sylvatica*), pedunculate oak, elms (*Ulmus* spp.), European ash (*Fraxinus excelsior*), Norway maple (*Acer platanoides*), small-leaved lime (*Tilia cordata*), wild cherry (*Prunus avium*), and European hornbeam (*Carpinus betulus*). Scots pine also occurs naturally in parts of the nemoral zone. A relatively large proportion of the original forest area in that zone has been converted into agricultural land (Gustafsson & Ahlén 1996).

4 Historical development of forestry

4.1 The use of forests as a resource

Swedish forests have been used and influenced by humans through history in a variety of manners, with substantial variation among regions. There are great differences between the agricultural use of forests in southern Sweden, forest use around the mining areas and metal works of south-central Sweden, and the history of logging by sawmill companies in the river valleys of the northern parts of the country. Biophysical conditions as determined by climate and geology have been an important factor contributing to the variation in the historical use of forests over the country (Lindkvist *et al*. 2009).

This section summarizes the historical use of forests as a resource and some of the impacts of anthropogenic forest use on the landscape. This is done separately for the period before 1950 and that after 1950, to account for the important conceptual shift from selective cutting to mechanized clearcut forestry that took place in the mid-20th century.

4.1.1 Before 1950

4.1.1.1 Early forest use by the first humans colonizing the land after the glaciations

Early traces of people living in what is now the southernmost parts of Sweden are around 12,000 to 14,000 years old (Wygal & Heidenreich 2014). In Sweden's northernmost regions, the earliest human traces have been estimated to be 9,600 years old (Möller *et al*. 2012). Findings show that people lived close to the retreating ice sheet, living from hunting and fishing, sharing land with for example wild reindeer (*Rangifer tarandus*), wild horses (*Equus ferus*), moose, giant deer (*Megaloceros giganteus*) and mammoths (*Mammuthus primigenius*) (Wygal & Heidenreich 2014). From what we know, these activities had a relatively small impact on the forests (Hicks 2014).

Fig. 4*. People have lived at Nämforsen, northern Sweden, since the Neolithic age, ~6000 years ago. Rock carvings mainly of moose, salmonid fish (Salmo* sp.*), birds, people and boats. Nämforsen, Västernorrland. Photo: Erik Normark.*

4.1.1.2 Forest use in an agricultural context

In the southern parts of the country, agriculture was introduced around 4000 BC and seemingly became the dominant way of life in the period 1200−800 BC (Welinder 2011). This is when forests started to become transformed to a larger extent by humans. Parts of the formerly forested south Swedish landscapes were transformed into a largely deforested countryside with solitary groves as result of slash-and-burn clearance and grazing pressure from cattle, pigs, goats and sheep (Welinder 2011).

During the Iron Age (between 500 BC and AD 1000), agricultural expansion with deforestation, new settlements, fields, meadows and pastures altered with periods of recession, retreat and reforestation (Pedersen & Widgren 2011). Pollen diagrams from southern and central Scandinavia show that alders (*Alnus* spp.) decreased in abundance, while plants indicative of managed wetlands increased. Clearance-cairn fields from the first millennium BC still persist in present forests, especially in southern interior Sweden, giving witness of field systems that extended "well beyond what would later become infields and meadows" (Pedersen & Widgren 2011, p. 51).

In the first centuries AD, large areas were opened up for grazing, at the same time as grain cultivation increased in many regions. Stone walls from these ages, separating infields from outlying commons, are still found in modern pastures and woodlands on the islands of Gotland and Öland, as well as in the provinces of Östergötland and Uppland (Pedersen & Widgren 2011).

In southern Norrland, agriculture mainly occurred as single farms with small cultivated areas nearby. Hay was mainly collected from natural wetlands. Recent research suggests that pine forests in the northern parts of the country (sites along the Luleälven River) were regularly burnt to maintain grazing grounds. This practice started sometime between 200 and 800 AD and continued until the 18th century when society began to actively suppress forest fires (Hörnberg *et al.* 2018).

Before the 11th century, settlements in the southern and central parts of Sweden were concentrated to the plains in Skåne, central Östergötland, Västergötland (i.e. the eastern parts of what is today Västra Götaland county), and the areas around Lake Mälaren. In the northern parts of the country, there were settlements along the seacoast, along River Dalälven and by Lake Storsjön in Jämtland (Myrdal 2011). Sami livelihood largely dominated the boreal north (Norstedt 2018).

In the 11th century, a network of farms began to stretch out over the southern forests. In the 13th century, slavery was abolished in large parts of current Scandinavia and former slaves often settled in the forests to clear new land (Olsson 1999, Myrdal 2011). Settlers were also shipped north to clear land along the main rivers. With the 14th and 15th centuries came the great decline with plague, bad harvests and war. Small remote farms in the forest were generally the first to be abandoned. Recovery started in the late 15th century. Farms depended on livestock farming and thus on woodland pastures. Many villages were comparable to small islands isolated in "an ocean of trees" (Myrdal 2011). Forestland was subjected to slash-and-burn (i.e. cleared by burning) to provide the villages with grain and pasture. From the 16th century, Finns, who were specialized in slash-and-burn cultivation on forestland, were invited to colonize Swedish forests. The impact of that land use on the forest landscape is clearly discernable in the historical forest fire records for northern Sweden (Niklasson & Granström 2000). The use of slash-and-burn probably culminated in the 19th century (Bernes & Lundgren 2009).

Between year 1700 and 1879, the area under agricultural cultivation increased by 300 % in Sweden. This period is known as "the agrarian revolution". Increase of population and agriculture in southern Sweden resulted in additional deforestation. By the early 19th century, large areas in Skåne and in densely populated coastal areas were practically treeless (Bernes & Lundgren 2009).

Along the 19th century, forests were still mainly a resource subordinated to agriculture. The seasonal nature of agricultural work (due to the climate) made rural inhabitants dependent on other work besides agriculture, for example in the forest. Woodland farmers often produced and sold timber, handicrafts, tar and other forest products. A large share of the annual timber harvest was used as firewood, for fencing, construction of houses, furniture, barrels etc. The forests were also used as extensive grazing grounds for cattle and other domestic animals (Gadd 2011).

***Fig. 5**. Grazing livestock, which was conducted on a large scale in Swedish forests until the mid-20th century, has influenced the characteristics of the forest landscapes. Boda socken, Dalarna, 1930. Source: SLU Library.*

The expansion of arable land culminated in the 1930s. Since then, the area of agricultural land has slowly decreased due to abandonment and afforestation in combination with the expansion of urban areas and infrastructure (Bernes & Lundgren 2009). Forest grazing was largely discontinued in the 1940s (Lisberg Jensen 2011).

4.1.1.3 Sami use of forest resources

Sápmi is the area that encompasses the historical settlements of the Sami people, the indigenous people of Fennoscandia, since time immemorial. It stretches all over the Cap of the North and large parts of the Scandinavian and Kola peninsulas. The traditional lifestyle of the Sami people has historically revolved around fishing and hunting in combination with semi-nomadic reindeer husbandry (Norstedt 2018).

Fig. 6. *Sami people next to a goahti hut. Västerbotten, approx. 1935-1937. Photo: G. Haglund. Source: Västerbottens museum.*

The semi-nomadic Sami livelihood depended on the resources from forests, both for their own subsistence and for trade. Forests were used by the Sami for hunting and the collecting of berries and other wild foods, and as grazing grounds for the semi-domesticated reindeer, which feed on ground-living lichens and epiphytic lichens in the winter and grass and herbs in the summer. Trees were modified or felled for a range of different purposes: they were cut to provide reindeer with epiphytic lichens, stumps were used as storage facilities, bark was used for wrappings, and the inner-bark was collected as a source of nutrients. Tree parts were also used for building the traditional Sami goahti huts (*kåta* in Swedish) (Fig. 6). Around Sami settlements, forest vegetation was altered by harvest of wood for fuel and construction. Standing dead trees were usually the preferred source of firewood (Östlund *et al*. 2013). Due to the semi-nomadic lifestyle, the Sami impact on the landscape was however limited to intensively used hotspots surrounded by large areas of forests where the impact was low (Norstedt 2018). Many of the above-mentioned forest uses are still part of Sami culture today. Recent historical and archeological studies also show that the Sami practiced small-scale agriculture, which means that agriculture was introduced at approximately the same time in the norther parts of Sweden as in the southern landscapes (Bergman *et al.* 2013, Hörnberg *et al.* 2015, Bergman & Hörnberg 2015, Josefsson *et al.* 2017). The impacts of these practices are still visible in the landscape.

In the Sami districts (*lappmarkerna*), peasants were generally rare until the 1750s, but then colonization, led by the state (the Crown) and the church, expanded quickly (Norstedt 2018). Due to colonialization, the Sami and their rights to land was successively undermined. The first Reindeer Grazing Act was passed in 1886 and renewed in 1928. It transformed the land use rights in favor of the Swedish government and private land use. Moreover, it divided the Sami population into those with and without usufructuary rights to land (Lundmark 2008).

4.1.1.4 Tar and potash production

Tar from conifers has been produced since prehistoric times (Hjulström *et al.* 2006). In the 17th and 18th centuries, tar from Scots pine became an important export product for the expanding merchant fleets and navies in Europe, which used large amounts of that product as a water-repellent preservative for wood and rope. Tar was mainly produced and traded by farmers (Tirén 1937, Bernes & Lundgren 2009).

Potash (potassium carbonate, K_2CO_3) was another forest product of great importance prior to the 20th century. It was produced from wood-ash from broadleaved trees and used for the manufacturing of glass, soap and textile dyeing. The main centers of potash production were in the provinces of Skåne, Blekinge and Småland[3] and along the Baltic coast. Production culminated in the 1830s when Europe gained a financial boost after the Napoleonic wars (Tirén 1937, Bernes & Lundgren 2009, Kardell 2003).

Tar and potash production has had a clear influence on the characteristics of the forests. In some places, tar production activities led to shifts in the forest's tree species composition from Scots pine to Norway spruce, while the production of potash reduced the abundance of broadleaved trees such as beech in southwestern Sweden and birches in the north (Tirén 1937, Bernes 2011). However, the impact of these activities on the forest resources was not extensive from a national perspective. Tar and potash were to a large extent replaced by other products in the 1860s and 1870s (Bernes & Lundgren 2009). Other examples of forest products whose manufacturing historically required timber include lime, bricks, salt, alcohol and alum (Kardell 2003).

4.1.1.5 The mining industry

Bog ore was gathered and worked by farmers as far back as prehistoric times. This had an impact on the forest at a local scale, as firewood was used for mining,

[3] The historical province of Småland corresponds approximately to the three contemporary counties of Jönköping, Kronoberg and Kalmar (mainland only) shown in Fig. 1.

toasting and further processing the ore (Bernes & Lundgren 2009). Small-scale mining and processing of copper and iron has a long history in Sweden. The Falun copper mine (Dalarna), which developed into a very large industry in the 17th century, was established already sometime between year AD 850 and 1180.

Blast furnaces were introduced in the Nordic countries in the late 12th century. Iron manufacturing required charcoal, which burns more evenly and yields higher temperatures than wood. Larger-scale iron mining began in Bergslagen, the principal mining district of south-central Sweden, in the 13th century. The area was rich in iron ore and waterpower, as well as in timber which was converted into charcoal.

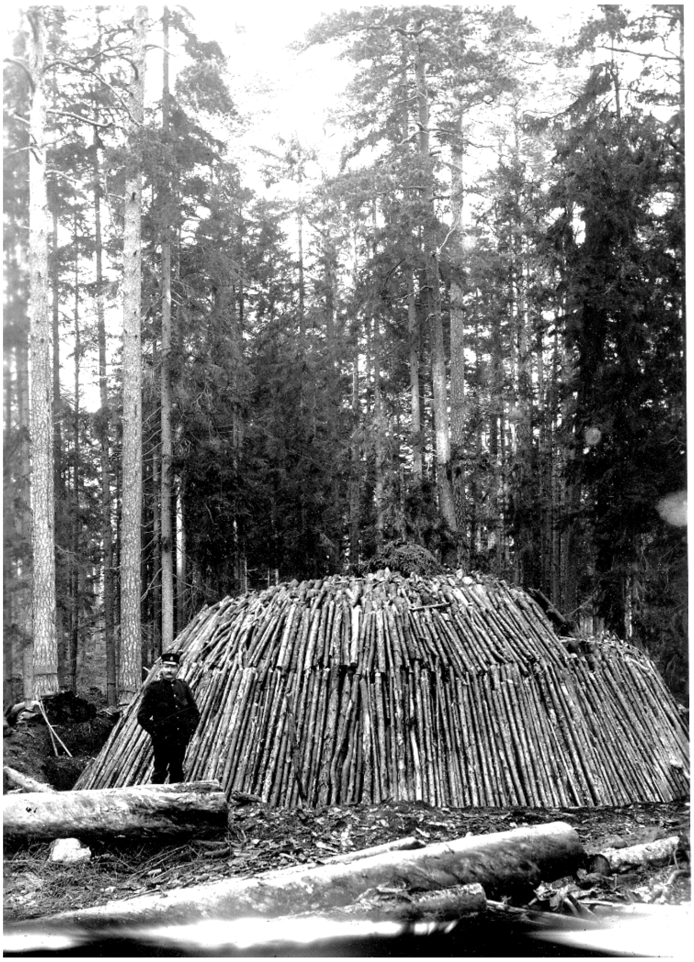

Fig. 7*. Charcoal pile. Södermanland, 1906. Source: SLU Library.*

To protect the ironworks' access to wood resources, the state gave them permission to harvest timber in nearby state-owned forests and in forests commons, either for free or for a fee. These forests were named *rekognitionsskogar* and were reserved for the metal works.

The mines and metal works expanded in the 17th and 18th century, which resulted in increased pressure on the forests and people surrounding them. It is estimated that in the 17th century, the Falun copper mine used around 700,000 m^3 of wood annually (Bernes & Lundgren 2009).

Producing one ton of wrought iron required at least six tons of charcoal. To produce six tons of charcoal required at least 100 m^3 of timber. Hence, the largest part of the workers involved in the production of iron did not work in the mines or the blast furnaces, but rather in the forest with the felling of trees and the production of charcoal (Bernes & Lundgren 2009). The owners of the ironworks often complained about a lack of charcoal, which was partly the result of locally overexploited forests, but also of peasants refusing to deliver charcoal to the iron works at very low prices.

In the 18th century, ironworks were established along the seacoast in northern Sweden. The iron ore was transported from Bergslagen to the north, where there still was an abundance of wood resource for charcoal production (Tirén 1937, Bernes & Lundgren 2009). By the mid-19th century, 230 blast furnaces and 450 trip hammers were still in use in the country (Nilsson 1990).

4.1.1.6 Selective cutting for sawmills and the pulp and paper industry

The use of charcoal for the mining industry in Sweden increased until 1885, when it got to large extent replaced by cheaper pit coal (Bernes & Lundgren 2009). By then, timber had become an important resource for the expanding sawmill industry. Regulations that protected the ironworks' access to forest resources were removed in 1863, which opened up for the establishment of new sawmills. Several old ironworks successively transformed into sawmill industries. Many of the present-day private forest companies have their historical roots in the ironworks (Kardell 2004).

This development was most significant in northern Sweden, where timber export increased strongly after the 1850s (Tirén 1937). The access to plentiful timber and to rivers for transportation, the demand from the British market, free trade, the introduction of stock companies in 1848 and of steam engines in 1849, have all been pointed out as important drivers behind the expansion of the forest industry in the mid-19th century. The extraction of saw-timber from the forests of Norrland increased 10-fold from the 1850s to the 1890s (Bernes 2011).

By then, production of pulp from wood fiber had also begun. The first pulp industry was established in Småland in 1872. The industry then expanded quickly mainly around the northern parts of Lake Vänern (Sweden's large lake) and by the river mouths along the Baltic coast. The Swedish pulp industry grew to become a dominating actor on the world market for several decades in the early 20th century.

Selective cutting was the dominating form of industrial forest management in Sweden during the 19th century and the 20th century until World War II. The focus was typically directed toward the trees to harvest, with little attention to what was left behind: easily reachable trees with high economic value were harvested, whereas less accessible trees and lower-quality trees were left standing. More accessible areas (e.g. coastal areas) were subjected to several waves of selective cuttings aiming for different timber assortments (with sequentially decreasing tree-size requirements), while landscapes in the northernmost and westernmost parts of Norrland were subjected to only one selective cutting or none due to their remoteness and limited accessibility.

This selective cutting system usually relied on natural regeneration in the created gaps, mostly through seeding from the remaining trees or the development of advanced growth (Näslund 1948, Tirén 1949). However, poor regrowth after felling was noted in several investigations and debates in the Swedish parliament (Enander 2007), leading to the realization that both conservation and reforestation were required if the country was to continue benefiting from the forest. This resulted in a Forestry Act in 1903 which, among other things, stipulated that an owner who felled forests would also have to provide for the regrowth of new forest (see Section 4.4 below). In 1923, the law was supplemented with the protection of young forest stands. Various forms of selective cutting continued on a large scale, in spite of some debate about the sustainability of this management method. The recession that the country suffered at the end of the 1920s led to repeated dimension cuttings which were profitable in the short term. In many areas, this resulted in poorly stocked residual forests with little economic value. The old traditional custom to let cows, horses, sheep and goats graze in the forest had a severe impact on the growth of tree seedlings over large areas (Kardell 2004).

4.1.1.7 Non-material use of forests

Forests have had a central role in tales, myths and folklore, which has been of great importance in peoples' daily life throughout history. The aesthetical and spiritual values of the forest have also inspired literature, art, music and architecture. This "non-material use of forests" has also resulted in monetary values besides a prospering culture and well-being (Lindkvist *et al*. 2009).

The forest has also been of importance for the construction of both individual and collective identities. Particularly in the époque of romanticism and later on in the national romantic era around the 1900s, the forests played a major role in the construction of a national identity. This cultural function of the forests still remains today (Lindkvist *et al*. 2009).

4.1.2 After 1950

This section summarizes the history of forest use after 1950, mainly from a timber resource perspective. Recent-time and contemporary forest uses linked to other ecosystem services are presented in Section 5.10 below.

4.1.2.1 Clearcut forestry before the large-scale implementation of environmental consideration

By the mid-20th century, criticisms against selective dimension cutting and forest grazing had been accumulating for a few decades. Emerging scientific knowledge about silviculture combined with the mechanization of forestry paved the road for a switch to a new management system. In 1950, the state-owned forestry organization Domänverket introduced clearcut forestry on a large scale, which marked the end of the selective cutting epoch. Even-aged management based on clearcutting has been the predominant method in Swedish forestry ever since (Andrén 1992, Hagner 2005, Lisberg Jensen 2011).

***Fig. 8**. After World War II, clearcut forestry was introduced. Implementation took place on a large scale, and single clearcuts could be very large. Most of the forest that subsequently regenerated in these areas has now reached middle age and is being thinned commercially. In many of these areas, there is a need to restore structures of importance to biodiversity. Source: SLU Library.*

Chainsaws and later harvesters replaced traditional saws and axes as the dominant tools for felling trees. Tractors and other motorized vehicles replaced the horse for timber carrying in the forest. An expanding network of forest roads allowed trucks to replace timber floating for transportation of the felled timber to the industry.

It was primarily in state and company owned large-scale forestry that the resource-demanding clearcut forestry could expand. At the time, clearcuts could be very large and they generally had straight edges. All trees including the undergrowth were typically removed. Soil scarification, regeneration through seeding or planting, fertilization and herbicide application were gradually incorporated into this silvicultural system (Ebeling 1957, Lindkvist *et al*. 2009, Lisberg Jensen 2011). The strive for industrial efficiency and rationalization often meant that the same general approach was applied on large areas, without considering natural variation in conditions for forest regeneration and growth (Ebeling 1957). Broadleaved trees were cleared mechanically (cutting) or chemically (spraying with herbicides) since there was no large-scale industrial demand for these tree species, which competed with the conifers. Poorly stocked residual forests were cleared and reforested with Norway spruce or Scots pine for improved production. Forest nurseries were established in many places (Kardell 2004). Forest research expanded and work with the genetic improvement of Norway spruce and Scots pine seedlings intensified.

This rationalization of forestry radically improved the state of the forests from a timber production perspective. Occupational safety issues also improved, at the same time as employment in forestry and forest industries decreased as an effect of increased mechanization and efficiency (Enander 2007). In 1979, it was declared in the Forestry Act that clearcut forestry was the only option in terms of harvesting method: final harvest had to be conducted as "…clear-felling with or without shelterwood or seed trees", and selective cutting could only be conducted in high-altitude areas along the Scandinavian mountain range or in especially sensitive areas (Anon. 1979a).

Forests originating from this era form the backbone of today's Swedish forest production. These forests are dominated by conifers with relatively high and sustained growth. However, the historical achievements in terms of productivity had an ecological and socio-cultural downside. Old-growth habitats were cleared out to give way for young coniferous production forests. Multi-aged stands were largely converted into even-aged stands (Axelsson & Östlund 2001). Key ecological structures, such as dead and dying trees, very old trees, older broadleaved trees, hollow trees and fire-scarred trees became increasingly rare in the forest landscapes (Esseen *et al.* 1997). Many of the species that later were to become red-listed as threatened or near-threatened in Sweden require these very structures as part of their habitats (Bernes 2011, Sandström *et al.* 2015). From a socio-cultural perspective, the conflicts between forestry and reindeer husbandry increased due to the loss of lichen-rich habitats but also due to the fragmentation of the forest landscape (Sandström 2015).

4.1.2.2 Retention forestry

During the 1970s and the 1980s, consideration of environmental values became increasingly relevant for forestry as a response to the criticisms from the public (see Section 4.3). Ecological research about forest species, soils and water developed (Hägglund & Lundmark 1977). Knowledge about red-listed species grew in importance, and many foresters returned to the school bench to learn about forest ecology and biodiversity. The concept of site adapted forestry was launched as a means to better adapt forestry measures to local ecological conditions (Lundmark 1986). One of the most important developments is that the clearcuts became less "clear". Environmental consideration through tree retention in harvested stands was implemented on a large scale in the 1990s. Goat willows, aspens, oaks, very old trees and dead trees are examples of trees that became increasingly preserved during harvesting so that they would persist in the next forest generations (Simonsson *et al.* 2015). High stumps were created to increase the amounts of substrate for dead-tree dependent species in the forest. Buffer zones became increasingly retained along watercourses and water bodies, and valuable habitats were left as retention patches. This approach is today known as "retention forestry" (Gustafsson *et al.* 2012, Simonsson *et al.* 2015).

***Fig. 9**. High stumps can be grouped and created close to retention trees or rocky areas. Länna, Uppsala county. Photo: Erik Normark.*

The forest policy of the early 1990s (see section 4.4) was intended to result in a greater variety of management practices, for example by opening up the possibility to use of alternative silvicultural methods consistent with continuous cover forestry (Gov. Bill 1992/1993:226 1992). Since the 2000s, society has exerted increasing pressure on forestry to use such selective harvest methods, particularly in parts of northwestern Sweden's forest landscapes that have never been clearcut, as well as in forests where recreational and other social values are of special importance. In 2015, part of the Forestry Act was changed in a way that more clearly allowed the use of selective cutting as an alternative to clearcut forestry. Selective harvest systems have, however, only been implemented to a very small extent in recent decades (Sténs *et al.* 2019).

4.2 Forestland ownership through history

Contrary to the situation in many other European countries, forest ownership in Sweden has not been influenced by any radical changes after World War II. Today's proportions of the forest area owned by non-industrial private forest owners, the state and forestry companies (see Fig. 18) are very similar to those found in 1945 (Lindkvist *et al*. 2009, SFA 2014). Still, Sweden had important land ownership reforms before that; these were implemented mostly from the 18th century.

A liberal-capitalist concept of property rights was introduced in the 18th century. The absolutist and centralist government by the state, i.e. the Swedish King, which had dominated since the 16th century and declared overall ownership to all national assets, was successively abandoned. It was however not until after the coup d'état against the Swedish King in 1809 that forest and land became more of a commodity that could be disposed and traded by individual owners (Jörnmark 2004, Lundmark 2008).

Before the 19th century, forest was regarded as common land. In more densely populated areas (Götaland and Svealand), access to resources from this common land was mainly restricted to the local peasant-farmers. In northern Dalarna and Norrland, however, the common land, including the vast forestland, was regarded as crown land, which in practice was used as open-access common land (Myrdal & Morell 2011). With reforms beginning in the 18th century, farmers and companies who had disposed state owned forests could more freely purchase the land from the state. In 1750s, a series of land reform laws passed ("*storskifte*") with the aim to redistribute and consolidate arable land in villages to make agriculture more effective. More far-reaching land reforms were carried out in the 19th century with the introduction of the "*enskifte*" and "*laga skifte*". Through the *laga skifte*, the common land, including forest, was parceled out to individual farmers. For rural tenants, landless people and the Sami, it became harder to access resources in the forests (Eliasson 2002, Lundmark 2008). The Swedish population almost doubled between 1750 and 1850 and the number of landless people increased by 127 % during the period 1750–1800 and by 86% during 1800–1850. Between 1840 and 1920, almost 1 million Swedes emigrated, mainly to North America, to find settlements and work.

Another land reform, the delineation ("*avvittringen*"), including delimitation of land between the crown and other owners, began in 1683 and continued in different forms until the 1920s. The process led to severe conflicts in the northern parts of the country, and some of these conflicts still linger on among owners and users of forests today. In the province of Jämtland, large areas were transferred from the state to private farmers. Further north, the state kept larger proportions of the forestland.

Non-peasant Sami were not granted ownership to the lands they had used or to their traditional settlement sites. However, the first reindeer grazing act of 1886 gave pasture rights to reindeer-herding Sami, including rights to hunt and fish, but under close control by the Swedish state (Norstedt 2018). The rights of the Sami to herd reindeer on forestland became increasingly controversial as new property right regimes and industries developed and expanded in northern Sweden.

The delineation and other land reforms meant that individual farmers became owners of forests which were previously regarded as commons or, in the northern parts of Sweden, as lands belonging to the Sami. Now, both forest properties and their resources could be traded on a market. Forest companies began to purchase timber, harvest rights and whole properties from individual owners. Farmers started to lose control over their forest properties. This was not appreciated by the state, which saw these developments as a threat to the wealth of the farmers and the country. The parliament tried to hinder the process by introducing new legislation. In 1906 a law was passed that prohibited companies from purchasing forestland, first in the north, then in the whole country. This legislation is essentially still in force today, although some degree of deregulation occurred in the 1990s (Lindkvist *et al*. 2009).

4.3 Environmental issues and biodiversity conservation

Environmental consideration includes, in a broad sense, the protection of natural values, cultural heritage, as well as esthetical and recreational values. Although the most far-reaching advances in environmental consideration took place after the 1990s, there is a long history of environmental work linked to forests in Sweden.

In pace with the development of general societal trends, different environmental issues and consideration tools have dominated through time. From the early 1900s to the 1960s, the focus was mainly on the establishment of protected areas and the preservation of natural monuments (Simonsson 2016). Sweden was the first country in Europe to establish national parks in 1909 (SEPA 2019a). The conservation philosophy at that time was largely based on the desire to preserve a limited number of "pristine" land areas, often spectacular landscapes. The preservation of these areas was motivated by science, as the areas would serve as natural references, but also by their symbolic value as national treasures and by their importance for tourism and recreation (Niklasson & Nilsson 2005, Bernes & Lundgren 2009). Many of the early national parks comprised mainly alpine ecosystems, which at the time were considered as economic wastelands, but some of the parks also contained substantial areas of forest. The number of national parks increased gradually during the past century, reaching a current total of 30 national parks, many of which are forested (SEPA 2019a). The national parks have played an important role for the conservation of natural and recreational values, and often also cultural heritage.

***Fig. 10**. Sweden's largest forested national park, Muddus National Park, was founded in 1942. Located in Lapland close to the Scandinavian mountain range, it covers nearly 50,000 hectares. Photo: Jan Schützer /N.*

In the early 20th century, there was strong interest in protecting outstanding natural elements such as giant trees (Niklasson & Nilsson 2005). The conservation legislation from 1909 also allowed the designation of such natural monuments. Hundreds of natural monuments were formally protected in Sweden. These were mostly large or peculiar individual trees (mainly oaks, pines, beech and ash), groups of trees or geological formations (SEPA 2019b). These monuments were considered valuable not only for nature conservation, but also as cultural heritage, for example in the case of giant oaks in the cultural landscapes.

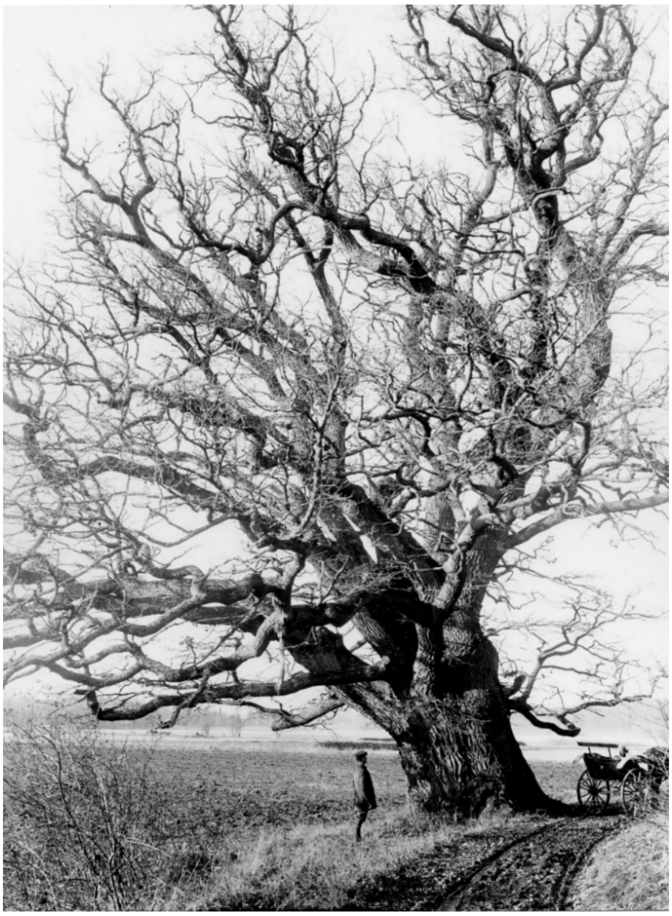

***Fig. 11**. Most of the natural monuments that gained protection during the early 20th century were outstanding trees such as this giant oak. Photo from 1923, Ekeby hov, Stockholm. Source: SLU Library.*

During the first half of the 20th century, the state forest owner Domänverket designated a few hundred state forest reserves (called "*domänreservat"*), mostly to protect areas of old-growth coniferous forest. A few reserves were also established by large forestry companies as reference areas, but these early types of voluntary set-asides did not cover any significant areas on a national scale (Simonsson 2016). In 1964, a new environmental legislation introduced an additional formal conservation tool which was to become the principal tool for area-based forest conservation in the country: nature reserves (Anon. 1964). The designation of nature reserves by the county administration boards allowed the conservation of biologically valuable forested areas that were not necessarily large or spectacular enough to qualify as national parks. The several thousand nature reserves that became formally established (on public or private land) account for the largest proportion of today's formally protected forest area in Sweden.

Notwithstanding the area protection initiatives described above, consideration of environmental and social issues took very little place in Swedish forestry until the 1960s. Economy and rationalization were the watchwords in the forest sector during the 1950s and most of the 1960s. However, the emergence of the environmental movement in the 1960s and early 1970s − spurred mainly by increased awareness about the negative effects of air and water pollution − resulted in a new situation with an increasingly strong public opinion about forestry. In the 1960s, the main issues were the establishment of spruce plantations on former agricultural land (which was perceived as a threat to the old cultural landscape) and the logging of beech forests in southern Sweden (Lindkvist *et al*. 2011; Simonsson 2016). The debate increased in intensity during the early 1970s, mostly triggered by concerns about the use of chemical biocides (herbicides and insecticides) and fertilizers (Lindkvist *et al*. 2011). Spraying of herbicides eventually became forbidden in the 1980s.

The debate in the early 1970s rapidly broadened in scope to also include a questioning of the appropriateness of clearcutting as a harvesting method, and particularly the size of the clearcuts (Enander 2007, Simonsson *et al*. 2015). The total clearcut area had more than doubled during the period 1957−1972, and mechanization of forestry operations had allowed the creation of large clearcuts, some reaching several hundred hectares in the northern parts of the country (Enander 2007, Simonsson 2016). The concerns dealt mostly with esthetical issues linked to the sizes of the clearcuts. In addition, some stakeholders (e.g. workers' unions) also worried that forests were being overexploited, thereby risking future employment in forestry (Enander 2007). Concern over the integrity of the forest ecosystem was also raised, mainly by ecologists and the environmental movement (Lindkvist *et al*. 2011, Sténs *et al*. 2019).

Public pressure led the government to establish a working group to investigate the extent and environmental effects of clearcutting. The working group's report (Anon. 1974) reiterated the official position that clearcutting was the most appropriate harvesting method, but also recommended that forest owners be obliged to report planned clearcutting activities to governmental authorities. This requirement became included in the legislation in 1974 and is still in force today (Simonsson 2016). The working group also discussed the use of shelterwood as a means to improve the esthetical value of the forest and recommended that clearcut ploughing be restricted to areas where no alternatives were available (Enander 2007).

Another effect of the working group's investigation was the introduction of general requirements for nature consideration in the Swedish Forestry Act in 1974. Provisions pertaining to nature consideration in forestry operations were expanded in the Forestry Act of 1979. These required that a few types of biologically valuable trees (e.g. berry-producing trees and trees with larger bird nests) and some smaller biotopes of importance to the fauna and flora be protected upon harvesting. They also included requirements pertaining to the conservation of recreational values and cultural heritage. In addition, the Forestry Act of 1979 introduced the possibility to apply sanctions in case of violation of the environmental conservation provisions (Ekelund & Hamilton 2001, Enander 2007). In spite of these changes to the legislation, on-the-ground implementation of environmental consideration measures remained very limited in Swedish forests during the 1970s and 1980s.

***Fig. 12**. Clearcut from the 1970s.* Trågaliden, Västerbotten, 1978. *Photo: Sune Jonsson. Source: Västerbottens museum.*

Increased awareness about nature conservation issues led to the initiation of systematic work aiming to compile and disseminate information about threats to species. This resulted in the publication, in 1975, of the first national red list of threatened species for Sweden, which was restricted to vertebrate animals (Ahlén 1975). In the following years, the National Board of Forestry[4] published several books addressing the conservation of fauna and flora in forestry (Ahlén *et al*. 1979, Ingelög 1981). It became generally recognized that forestry had negative effects on large numbers of specialized species, and concrete conservation measures were proposed.

In the late 1970s and early 1980s, an intensive debate grew about the need to protect additional areas of old-growth forests. Environmental NGOs were very active in requesting major increases in the area of protected forest (Simonsson 2016). During 1978–1982, governmental agencies performed a national survey of old-growth forests as a basis for the planning of additional forest protection. This was followed by significant increases in public funding for the establishment of protected areas in the mid-1980s, resulting in substantial expansion of the protected area network through the establishment of new nature reserves and state

[4] The National Board of Forestry was the central governmental agency responsible for forests and forestry, a role which is today assumed by the Swedish Forest Agency.

forest reserves. In parallel, during the later parts of the 1980s, forestry companies gradually introduced instructions for improved environmental consideration during forestry operations.

Environmental issues were not restricted to the boreal zone; they were also present in the southernmost parts of the country. Here, one of the main concerns was the conversion of nemoral broadleaved forests into spruce plantations. In 1974, a new law was introduced to ensure that beech forest was to be replaced by new beech forest after harvest. A decade later, in 1984, another law was introduced to regulate the management of all nemoral broadleaved forests, with the aim to ensure that their areal extent would not decrease. This law introduced a requirement to obtain permit from the Swedish Forest Agency for clearcutting nemoral broadleaved forest and an interdiction to convert such forest into stands of non-nemoral tree species.

During the period stretching from the early 1970s to the early 1980s, the rate of felling in high-altitude forests along the Scandinavian mountain range more than doubled (Claesson 2018). This triggered a debate about forestry in high-altitude forests. Environmental NGOs conducted a large-scale campaign targeting politicians, arguing that clearcutting should be prohibited in high-altitude forests. The main arguments pertained to forest regeneration, reindeer husbandry, recreational values and wildlife conservation. Gradually, the focus shifted toward emphasizing the value of high-altitude forests as a unique and large-scale continuous stretch of unmanaged forest (Simonsson 2016). As an example of response to the pressure, the state forest owner Domänverket established a group of montane forest reserves covering approximately 200,000 hectares along the Scandinavian mountain range in 1987 (Ekelund & Hamilton 2001). In 1990, modifications were made to the Forestry Act specifying that forestry in high-altitude should not be conducted in ways that would be incompatible with significant interests pertaining to nature conservation, natural heritage or reindeer husbandry (Anon. 1990).

After more than two decades of intensive debate about conservation issues in Swedish forests, the most significant breakthroughs for biodiversity conservation occurred in the early 1990s. The Rio Summit of 1992 had put biodiversity on the international agenda. A key question in Sweden was the choice of a strategy for the fulfillment of the new national environmental goals pertaining to biodiversity conservation. A working group analyzed two main alternatives: (1) purely production-oriented management on the majority of the forestland, combined with a relatively large proportion of protected forests (~15 % of the forest area below the altitudinal limit for forest production); (2) environmental consideration on all land used for forest production, combined with a lesser area of protected forests (Liljelund *et al.* 1992). The working group proposed alternative #2, which was adopted by the parliament. This forest policy decision meant that nature consideration as well as consideration of cultural heritage, esthetical values and social values should be implemented on all land used for forestry. In line with this policy, a new Forestry Act was adopted in 1993. Responsibility for reaching the environmental goal was to be shared by the government and the forest owners. This Forestry Act, which is the one in force today, includes a large section (30th paragraph) describing what is expected from the forest owners in terms of consideration of natural and cultural values in the forest (SFA 2019c).

Up until the early 1990s, much of the conservation focus had been placed on the preservation of old-growth forests, with limited attention to actual or potential occurrences of red-listed species. In 1990, the concept of “woodland key habitat” was coined (Nitare & Norén 1992). Woodland key habitats were defined as forest areas hosting red-listed species or areas where one can expect to find such species. In 1993, a first national woodland key habitat inventory was launched by the National Board of Forestry. The large forestry companies performed own inventories under the control of the National Board of Forestry. The forest’s structure, its history, the physical environment and the presence of indicator species were used as a basis for the identification of the key habitats. The aim was to provide necessary knowledge for the government’s and forest owners’ work with conservation and management

***Fig. 13**. Woodland key habitats have been identified and registered since the early 1990s in Sweden as part of systematic surveys and other activities. The presence of indicator species – for example lichens and mosses growing on tree trunks – is one of the criteria used for the identification of the key habitats. Photo: Yaman Albolbol.*

In 1994, a new formal protection form called “biotope protection areas” was introduced in the Swedish legislation, as a means to allow the protection of relatively small areas of high conservation value such as woodland key habitats. The National Board of Forestry was given responsibility for biotope protection areas in forest. In parallel, “conservation agreements” were introduced as an additional formal protection form whereby forest owners sign an agreement with the government to protect a forest area for up to 50 years.

The 1990s also witnessed the development of forest certification in Sweden. In 1996, a broad working group was established for the development of a first national Forest Stewardship Council (FSC) standard. This group included representatives from a range of stakeholders in forest, including forest owner associations, the forest industry, environmental NGOs, workers' unions and the Sami people. Shortly after, the forest owner's association withdrew from the group and developed a parallel forest certification standard within the Pan European Forest Certification (PEFC) system, this time without the participation of the environmental NGOs (Simonsson *et al*. 2015). These certification standards acted as a complement to the Forestry Act by setting requirements for consideration of environmental, social and economic values in forest management planning and operations. In terms of nature consideration, the Swedish certification standards included detailed quantitative requirements for e.g. the retention of green trees and dead trees at harvesting. The FSC standard – to which all large Swedish forestry companies (including the state-owned forestry company Sveaskog) adhere – required, among other things, that at least 10 green trees per hectare should be preserved at harvest (Simonsson *et al*. 2015). It also introduced a requirement for forest owners to dedicate at least 5% of their productive forest area to conservation in the form of voluntary set-asides. The forest owners' voluntary set-asides soon became recognized as a major national tool for forest protection in addition to the formally protected areas designated by the government.

Sweden became a member state of the European Union (EU) in 1995. The establishment of the Swedish part of Natura 2000 – the EU-wide network of protected areas – began in the mid-1990s and the network is still in development today. The Natura 2000 site selection process has largely built upon the network of previously existing areas that were formally protected through national legislation (e.g. nature reserves, national parks, biotope protection areas). In 2007, the requirements set by the EU Habitats Directive and the EU Birds Directive became implemented in the national legislation. Implementation of this legislation by the Swedish Forest Agency requires assessing the effects of forestry operations on the conservation status of listed species, which in some cases has resulted in interdictions to clearcut specific forest stands.

Information about present-day environmental consideration in Swedish forestry (including statistics about formally and voluntary protected forests) is presented in Section 5.9 below.

4.4 The development of forest policies over time

The historical accounts of the development of forestry presented above touch upon several key policies influencing forests and their use. Drawing on these historical accounts, this section presents an analysis and synthesis of the development of the forest policy landscape in Sweden with reference to the multiplicity of goals and functions associated with forests.

Society's interest in the forest resource has varied greatly over the years and has, among other things, been dependent on the value of the forest. Regulations have been around for a long time. Already in the 15th century there were provisions on how oak and beech may be felled. The delineation process, as well as the various land reforms from the 18th century onwards (see Section 4.2), made the ownership of the forest more clearly regulated and was, to some extent, devoted to strengthening ownership. Mining influenced the availability of forest raw materials, which gave birth to the first thoughts about a more comprehensive regulation for forest management.

During the growth of the forest industry in the later parts of the 19^{th} century, it became clearer that Sweden needed to regulate forest utilization in order to ensure a continued contribution of the forest resource to the country's welfare in the future. In 1903, a Forestry Act was established with the explicit aim of ensuring continuous regeneration of the raw material base in privately owned forests. Hence, the Forestry Act of 1903 signified a reinforcement of top-down legal governance. The most important regulation was a requirement for forest regeneration after felling (Fig. 14; Stjernquist 1973). Moreover, governmental agencies of a new kind – the "county forestry boards" – were established to promote forest regeneration by disseminating information, distributing financial aid, and providing seeds and seedlings to forest owners.

Overall, an underlying societal agreement between the state, individual forest owners and the forest industry can be discerned. The main challenges were framed in such a way as to support industrialization while securing the financial viability of farmers as small-scale forest owners and long-term sustainable supplies of forest resources, which represented a major share of the country's exports. Under the agreement, farmers collectively owned the largest share of forest, and the forest industry had to accept this. However, the forest owners had to accept that government-appointed professionals supervised and controlled forest management, to increase production and meet requirements of the forest industry. Hence, forest companies could continue to expand without obtaining more forestland, being supplied with material from all forest owners nationally. The state increased its power and influence over private forests but wielded power mainly via "soft law", through collaboration, economic incentives, advice, education and persuasion (Applestrand 2007). Due to these changes, forests and forestry were transformed from a largely locally regulated "appendage" of agriculture and proto-industry into a national industrial endeavor with all stakeholders sharing the economic risks and benefits (Donner-Amnell 2004, Lehtinen *et al*. 2004).

The post-World War II era brought economic growth, urbanization, modernization, and the expansion of welfare institutions. In Scandinavia, this expansion included the development of the "Nordic welfare model", based on the idea that the state should redistribute wealth, guide the building of a modern society and spread prosperity to every citizen in the nation (Hilson 2008, Árnason & Wittrock 2012). Efficient use of natural resources was an essential part of this modernization project. An important issue in this respect was that forestry practices were considered poorly developed, and undertaken by actors who were still only partially integrated in the market economy and still relied on unadvanced technology. Moreover, industries offering better salaries and working conditions absorbed workers, making it increasingly difficult to maintain the forestry workforce. The low productivity in forestry threatened to reduce the forest industry's international competitiveness, thereby endangering the whole welfare project.

The Forestry Act was gradually reinforced, and by 1948 it included strong regulations promoting afforestation and even-aged forest stand management for sustained and even yield, as a means to maintain supplies for the industry. These regulations were extended to apply to all forests, regardless of ownership, in 1979 (Jansson *et al*. 2011). Intensive forestry was legitimized by the perceived possibility it offered to expand welfare to everyone. Involved stakeholders were the state, the forest industry, forest owners, trade unions and (according to the rhetoric) ultimately all citizens of the welfare state. Consequently, the forest owners lost more of their independence regarding management goals and approaches. Their duty was to manage their forest to produce timber for the expanding state owned and private owned forest industry. In compensation, individual forest owners and lumberjacks acquired access to welfare services, and to state-subsidized forest assessment to increase production. Power was mainly exercised collaboratively between the dominant actors, but also through "hard law" to ensure that every forest owner applied appropriate management practices. Hence, this contract had a strong emphasis on collective action: everyone should manage their forests in the same way to meet the same common goal.

During the 1970s and 1980s, new detailed political decisions largely governed what a forest owner had the opportunity to do with their forest. These included, for example, thinning duties and demands for clearcutting of old forest. This entailed a detailed regulation of forestry. Society's goals during this period were mainly to secure future wood supply, although in the end of the 1970s nature conservation interests led to some focus change (see Section 4.3). However, the main focus was still on securing long-term production of forest raw materials.

Year	*1903*	*1918*	*1923*	*1948*	*1974*	*1979*	*1983*	*1993*	*2008*
Mandatory regeneration									
Protection of young to middle-aged forests									
Requirements for sustainable forestry				*Prod*				*Env*	
Requirements for nature conservation and the environment									
Notification of clear-felling to government obligatory									
Pre-commercial thinning obligatory									
Establishment of new forest obligatory if poor production status									
Thinning of young forest obligatory									
Cutting of a certain proportion of older forest obligatory									
Forest management plan obligatory									

Fig. 14*. Developments of the Swedish Forestry Act since 1903 which have influenced opportunities for landowners to formulate their own goals for their forest and forest management. Green boxes indicate periods during which the requirements figured in the Forestry Act. "Prod": production objective; "Env": environmental objective. Source: Adapted from Antonson & Jansson (2011).*

In the 1990s, the Swedish forest arena sharply shifted due to globalization, changes in political pressures regarding forest production and environmental interests, and new approaches to governance. This new societal agreement is usually described as “the Swedish Forestry Model” (Sandström & Sténs 2015, Beland Lindahl *et al*. 2017), or “the Nordic Forestry Model”, as it was also adopted in Finland (Donner Amnell 2004, Lehtinien 2008, Beland Lindahl *et al*. 2015). In general terms, this model is associated with a combination of competitive, high productivity forestry and maintenance of biodiversity in forest production landscapes through joint efforts by the state and forest owners. It, in the way it has been named, also alludes to the Nordic welfare model, with a long tradition of seeking consensus and balancing multiple interests for the common good.

Retention forestry (Gustafsson *et al*. 2012, Lindenmayer *et al*. 2012; see Section 4.1.2.2) became the most important tool for the implementation of the Nordic Forestry Model combining timber production and biodiversity conservation goals in the same landscapes. Some influences on the currently prevailing forest management approach came from abroad, notably from the modified forms of forest management developed in North America in response to the strong environmental criticism against clearcut forestry around 1990. One was the “new forestry” system (and its later refinement “ecosystem management”) introduced by the United States Forest Service to meet environmental criticism (Freeman 2002). New forestry focused on maintaining biological legacies and increasing spatial complexity in the forest landscape. In the 1990s, representatives from the Swedish Forest Agency visited north-western USA to see how the management system worked. These experiences had a clear influence on Swedish policy-making (Simonsson *et al*. 2015).

The altered balance between production and environmental goals was manifested in the Forestry Act of 1993, the first paragraph of which states: “The forest is a national resource. It shall be managed in such a way as to provide a valuable yield and at the same time preserve biodiversity” (SFA 2019c). While these two objectives are treated as “equal”, the Act also states that social, cultural and aesthetic values, and Sami reindeer herding, should be cared for. In addition, the 16 national environmental quality objectives, established in 1999 and 2005 (SEPA 2018), also contributed to shifting priorities from sustainable timber production to handling multiple goals. For example, the environmental objective *Sustainable forests* has influenced Swedish forest management through the adoption of sub-targets pertaining to the amounts of dead trees, older forest, protected areas, etc.

The governance of forest also changed radically. Liberalization and deregulation of the forest sector followed a general international neoliberal turn in the 1980s and 1990s. In the environmental arena, this is often described as an “eco-modern” way to respond to environmental challenges (Hajer 1995). That is, a view that environmental goals and economic growth do not conflict – instead they go hand-in-hand, supporting each other. Via eco-innovations, eco-entrepreneurship, environmental labelling of commercial products, the monetarization of environmental values and costs, establishment of markets and market solutions, and increasing consumers’ awareness, the assumption was that it should be possible to create sustainable win-win situations that both benefit the environment and promote economic growth. This trend also strongly influenced international forest policy from the early 1990s onwards. Leading principles and ways to implement forest policy became: marketization, enhancement of the private sector's role, deregulation and voluntarism (Humphreys 2009, 2014). The state's role became more a steering function through the release of market forces and activation of incentives for competition and development (Appelstrand 2012).

In this context, "freedom with responsibility" became the main Swedish principle underlying the relationship between the state and private forest owners. Thus, Swedish forest policy (which only slightly more than a decade earlier had introduced "hard law") radically shifted back to "soft law" whereby forest legislation only imposed minimal requirements (Applestrand 2012). As long as the forest owners stayed within the general limits of the law, they could decide how to achieve (and trade-off) the multiple production and environmental objectives. The forest owner became the main decision-maker. There was an explicit desire that the greater freedom would lead to a greater variation in the selection of forest management approaches. The focus of national and regional forestry boards shifted from law enforcement to knowledge dissemination and advising, monitoring and evaluation. To meet environmental targets in this deregulated environment, voluntary measures going beyond legal minimum levels were required. Consequently, a large proportion of Swedish forestland became registered in the voluntary, market-based FSC and PEFC certification schemes (Johansson 2013, Johansson & Keskitalo 2014; see Section 4.3 above).

During the period from 1993 to today, almost all policy changes concern environmental considerations. Most of these changes are due to the Swedish accession to the European Union and to the associated implementation of EU directives, such as the EU Birds Directive, the EU Habitats Directives and the EU Water Directive, but also the Council Regulation (EC No 338/97) on the protection of species of wild fauna and flora by regulating trade therein.

As an illustrative example of policy change, the 1989 Handbook to the Forestry Act[5] consisted of 111 pages of text including appendices. In 1994, the same publication had been reduced to 66 pages, of which 12 pages specifically addressed nature conservation, cultural environment conservation and reindeer husbandry. In 2019, the handbook had grown to 91 pages, of which 22 pages concerned nature conservation, cultural environment conservation and reindeer husbandry.

[5] A publication containing the official law text of the Forestry Act and the Swedish Forest Agency's recommendations regarding its implementation (SFA 2019c; available online on the Agency's website).

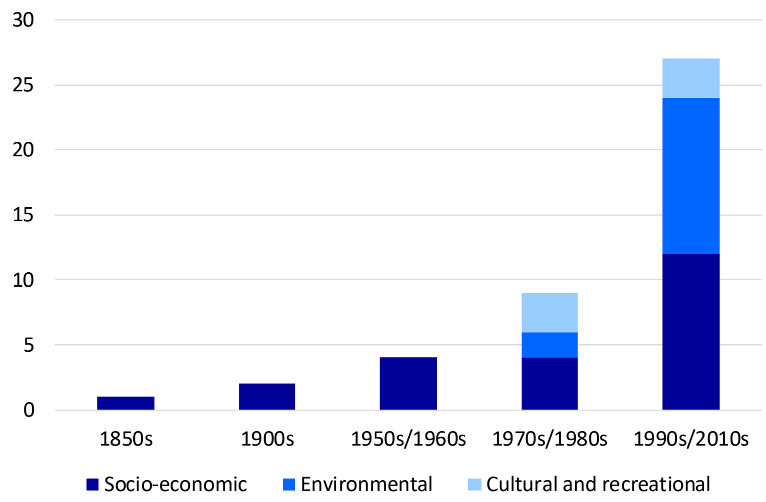

Fig. 15*. Number of explicitly mentioned societal goals or main orientations for the forest in Swedish forest legislation from 1850 to 2015. Adapted from Mårald et al. (2017) and Beland Lindahl et al. (2017).*

To summarize, society has had increasing influence on forest policy through history and the range of goals included in forest has widened accordingly (Fig. 15). The 1960s and early 1970s were characterized by vivid discussions about environmental impacts of forestry, which led to some changes in forest policy. At the end of the 1970s, there was great concern for timber shortages in the industry (Virkesförsörjningsutredningen 1981). Production issues were in focus and forestry became regulated in detail. In the beginning of the 1990s, environmental issues were given a major place on the agenda. This, together with a recoil in the field of detail control, led to major transformations in forest policy and a switch to freedom under responsibility. During the whole period, the state, the forest owners and the forest industry have been key actors, jointly defining the desired objective: a form of forestry that provides sustainable yields, efficiency and profitability (Siiskonen 2013). During the last decades, other actors with other perspectives, most importantly environmental perspectives, have entered the forest arena. Moreover, some general shifts in forest governance can be discerned. Until the late 1980s Old Public Administration – top-down, state-led "rowing" towards a few politically defined objectives – dominated. The shift to the neoliberal Swedish Forestry Model entailed adoption of New Public Management, with policy-makers acting by "steering" the market and fostering entrepreneurialism (Appelstrand 2012).

5 Current forest management and use

5.1 Conditions forming present forest management

In Sweden, property rights are strong from an international perspective (Levy-Carciente *et al*. 2016), and the individual forest owners are key actors in the forest arena (Stjernquist 1973). Nevertheless, most of the Swedish forests provide multiple benefits and are open to everyone, due to the Swedish tradition of right of common access to private land (*allemansrätten*; Bengtsson 2004) and other regulated usufructuary rights (Sténs & Sandström 2013). Hence, forests and forestry are of national importance to everyone, rather than merely those who have property rights or are directly dependent on forest resources.

The forest social arena is not constant, but dynamic; it has undergone several transformations in the past, and it will continue to change in the future. About one hundred years ago, during the 1920s and 1930s, as much as 50 % of the country's export revenues came from forest products (Siiskonen 2013). In addition, 150 years ago, 90 % of the Swedish population lived close to forests in the countryside, while nowadays 85 % live in urban areas.

Today, the forest industry accounts for 9–12 % of the employment, exports, turnover and added value in the Swedish industry (SFA 2014). The forest industry is strongly export-oriented: more than 80 % of the forest-based products are exported, placing Sweden among the world's largest exporters of these products. Thus, forestry clearly plays a substantial role in Sweden's economy, at the same time as it provides large volumes of renewable raw materials for a growing bioeconomy.

The essence of the current social contract for Swedish forest governance is the effort to balance real-time claims on the forests regarding production, environmental conservation and other interests. Important stakeholders are the forest industry, the government, the environmental movement, other non-governmental organizations (NGOs) and market actors. The forest owners have been granted the right to manage the forest in accordance with their own goals, but with duties (mandatory and voluntary) to balance production and environmental demands in practice. The current societal contract builds upon the assumption that rational and well-informed individual actions by forest owners, consumers and market actors will result in collective action in desirable directions.

5.2 Forest area, standing volumes and annual harvest

Forests cover 28 million hectares in Sweden, including 23.6 million hectares of productive forestland (SLU 2020), where 'productive forestland' is defined as forest producing at least 1 m^3 of wood per hectare per year. The unproductive forests that do not reach that minimum threshold (often referred to as "forest impediments") are mostly found as open forests on peatlands, on rocky outcrops and at high altitudes. The area of productive forestland outside formally protected areas was 22.3 million hectares as of 2018.

According to the Swedish National Forest Inventory (NFI), the total standing volume on all forestland was 3.55 billion m^3 (stem and bark) in 2015–2019. Outside formally protected areas where forestry activities are not allowed, the total standing volume was 3.12 billion m^3. This corresponds to an average standing volume of 139 m^3 per hectare.

The standing volume in Sweden has almost doubled since the beginning of the NFI in the 1920s (Fig. 16). This increase is largely explained by enhanced growth through effective forest management (e.g. silvicultural treatments and associated changes in forest age-class distribution and tree species composition, use of genetically improved regeneration material), in combination with other factors such as afforestation of former agricultural land, the fertilizing effects of nitrogen deposition and climate change.

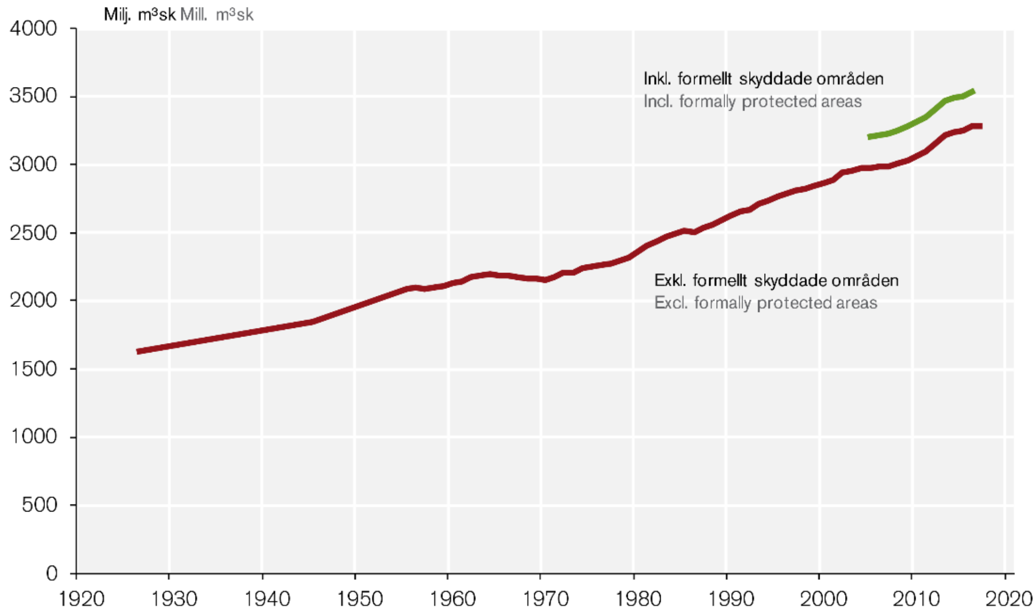

***Fig. 16**. Total standing volume in Sweden 1926–2017. Includes all land use classes except high mountains and urban land. Outside (red) and including (green) formally protected areas as of 2018. Mean values for the two first inventories 1923–1929 and 1938–1952 followed by moving five-year averages (m^3, stem and bark). Source: SLU (2020).*

Norway spruce and Scots pine together comprise 80 % of the standing timber volume in Swedish forests, with roughly equal shares (Table 1). Birch comes in the third place with 12 % of the standing volume, followed by 14 tree species with less than 2 % each (Table 1).

On the national scale, introduced tree species comprise a relatively small share of the forest area in Sweden compared to many other European countries (Forest Europe 2015). The current Forestry Act states that introduced tree species can only be used in exceptional cases (SFA 2019c). Lodgepole pine (*Pinus contorta*), an introduced conifer originating from North America, is the most common nonnative tree species in Sweden. It occurs mostly in the northern parts of the country. This species nowadays stands for 1.4 % of the timber volume in Sweden as a whole and 2.3 % of the forest area (SLU 2018). Note, however, that lodgepole pine may be relatively abundant at the local scale in parts of north-central Sweden (SLU 2010).

Table 1. Volume share of different tree species (percent of standing volume) for four Swedish regions with similar forest areas, ordered from north to south (Northern Norrland, Southern Norrland, Svealand and Götaland; see Fig. 1). Source: SLU (2020)

	Northern Norrland	Southern Norrland	Svealand	Götaland	Total
Norway spruce (*Picea abies*)	49.8	42.5	40.1	45.9	**40.3**
Scots pine (*Pinus sylvestris*)	31.6	37.5	41.1	29.5	**39.3**
Birch (*Betula pendula, B. pubescens*)	15.5	13.3	10.7	10.8	**12.4**
Alder (*Alnus glutinosa, A. incana*)	0.2	1.4	2.1	2.8	**1.7**
Aspen (*Populus tremula*)	0.7	0.9	2.7	2.3	**1.7**
Lodgepole pine (*Pinus contorta*)	1.6	3.4	0.5	0	**1.3**
Oak (*Quercus robur*, *Q. petraea*)	0	0	0.7	4.1	**1.3**
Beech (*Fagus sylvatica*)	0	0	0	2.2	**0.6**
Goat willow (*Salix caprea*)	0.5	0.7	0.4	0.5	**0.5**
Other nemoral broadleaved trees	0	0	0.3	1.0	**0.3**
Rowan (*Sorbus aucuparia*)	0.1	0.2	0.2	0.3	**0.2**
Larch (*Larix* spp.)	0	0	0.1	0.2	**0.1**
Other non-nemoral broadleaved trees	0	0.1	0.1	0.3	**0.1**

The average annual harvest in Sweden was about 84 million m^3 (stem and bark) during the period 2015/16–2018/19 (Table 2). This corresponds to 72 million m^3 solid wood per year (assuming a conversion factor of 0.82). The total harvest corresponds to an average of 3.8 m^3 (stem and bark) per hectare of productive forestland per year (excluding nature reserves and other areas where forestry is not allowed).

In forest statistics, Sweden is often divided into four regions with similar forest areas: Northern Norrland, Southern Norrland, Svealand and Götaland (from north to south; Fig. 1). The harvested volume is largest in Götaland and smallest in Northern Norrland (Table 2), in accordance with the general south-north gradient of decreasing forest productivity.

Table 2. Annual harvested volume and mean harvested volume per hectare at final felling, for Sweden and four parts of the country (m^3 solid wood on bark) (SLU 2020). Average for the period 2015/16–2018/19.

	Million m^3/yr	m^3/ha at final felling
Northern Norrland	10,9	172
Southern Norrland	17,1	238
Svealand	25,4	280
Götaland	30,5	378
Total / average	**84,0**	**269**

Approximately 60 % of the harvested timber volume originates from final felling, 30 % from thinning and 10 % from the felling of shelter trees and other kinds of harvest (Table 3). About 60 % of the total harvest comes from private forest (non-industrial private forest owners) land and 40% from company-owned forests and state-owned forests.

Table 3. Annual harvested volume in Sweden divided into final felling, thinning, pre-commercial thinning and other kinds of cuttings, and into ownership categories (million cubic meters solid wood on bark, average for the period 2015/16–2018/19). Source: SLU (2020).

	Final felling	Thinning	Pre-commercial thinning	Other harvesting	Total
Companies	13,9	3,7	0,2	0,5	18,3
Other private owners	31,7	15,3	1,1	5,7	53,4
Public bodies	7,5	3,9	0,3	1,0	12,3
Total	53,0	23,8	1,6	7,1	84,0

The annual harvest has been lower than the total annual growth nearly every year since the mid-20th century. However, if considering only forestland available to forestry (i.e. excluding protected or set-aside areas), the gap between harvest and growth has decreased in recent years (Fig. 17).

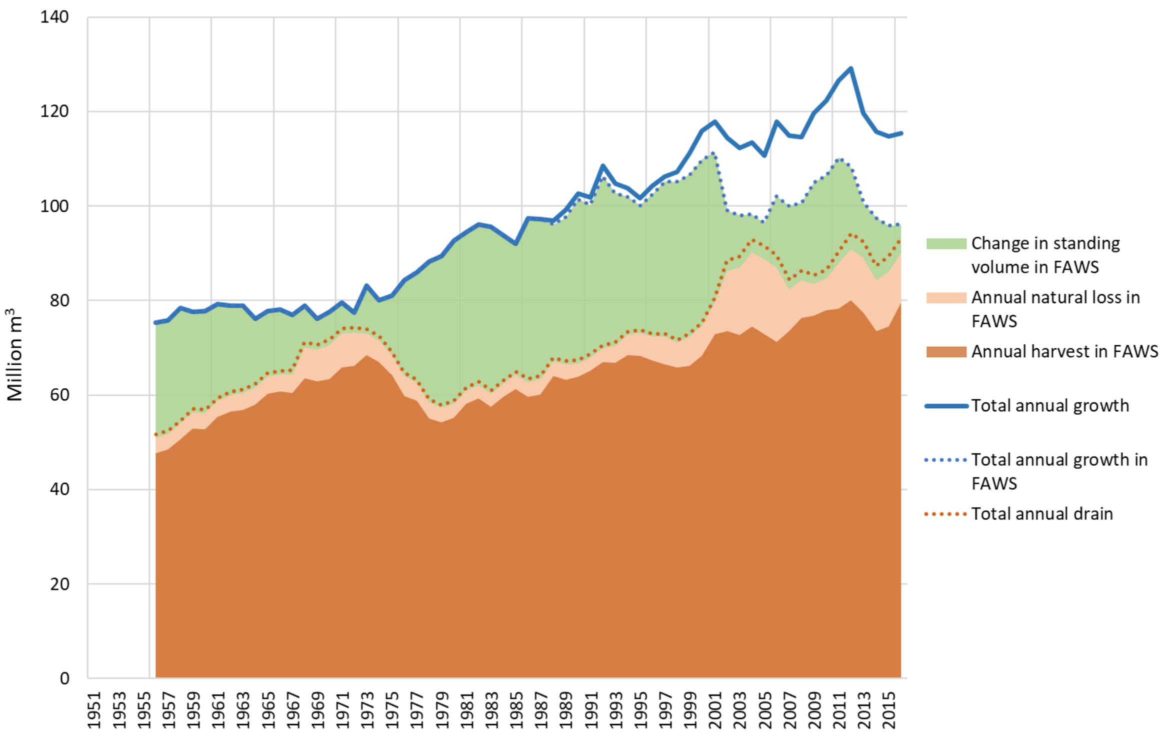

***Fig. 17**. Historical development of growth and drain in all productive forest and in forest available for wood supply (FAWS) 1956–2016 (five-year gliding average). FAWS depicts productive forest outside formally protected areas, voluntary set-asides and retention patches. Data from the National Forest Inventory, the Swedish Environmental Protection Agency and the Swedish Forest Agency in combination with assumptions about how the area of FAWS has developed over time before 2003. Source: SLU (2020).*

In 2017, the Swedish forest industry used 90 million m^3 of wood, of which approximately 10 % was imported. Half of the raw material was used as saw timber, the other half went to the pulp and paper mills. The sawmills deliver woodchips and sawdust mainly to the pulp and paper industry, but also to the plywood industry and the energy sector. Swedish forestry also supplies energy in the form of forest fuel. In 2017, primary forest fuel (branches and tops from felled trees, and trees too small to be used in the pulp and paper industry) contributed with 52 TWh to the energy sector, representing 14 % of Sweden's total energy use (SEA 2019). In addition, black liquor (a waste product from the paper industry) is used for energy, both in mills and as biodiesel mixed with fossil diesel.

5.3 Main actors involved in forest management

5.3.1 Current ownership structure

Approximately 330,000 non-industrial private forest owners (hereafter "individual forest owners"), representing 3 % of the Swedish population, together hold about half of the forestland. Approximately one-fourth (25 %) of the forestland is owned by forestry companies, 19 % by the state (the state-owned forestry company Sveaskog and the National Property Board *Fastighetsverket*) and other public owners, and 6 % by other private owners such as the Swedish Church, foundations and associations (SFA 2014). The share of forest area belonging to individual forest owners is highest in southern Sweden (approximately 80 %), while company and state-owned forests dominate in the northern parts of the country.

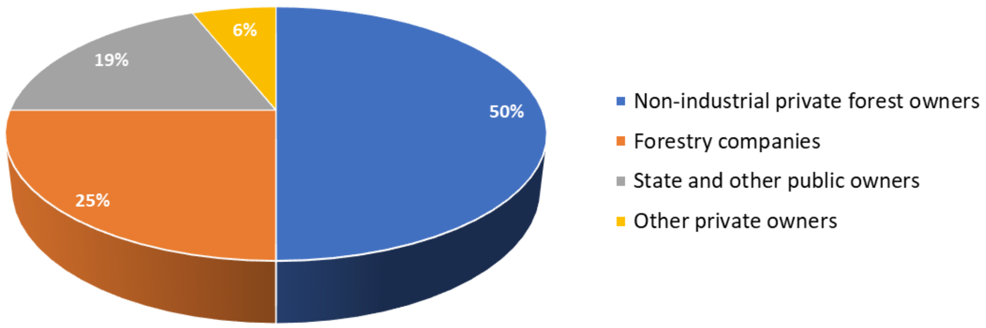

***Fig. 18**. Ownership of forest in Sweden by percent of area. Source: SFA (2014).*

5.3.2 The Swedish Forest Agency

The Swedish Forest Agency (*Skogsstyrelsen*) is the national authority in charge of forest related issues in Sweden. It is placed under the Ministry of Enterprise and Innovation (*Näringsdepartementet*). The forest agency has local offices in approximately 80 locations (22 districts) over the country, with the head office in Jönköping (southern Sweden). The total number of employees is about 900.

The Agency's main function is to promote a management of Sweden's forests that enables the objectives of forest policy to be attained. The most important activities of the Swedish Forest Agency are:

- Supervision of compliance with the Forestry Act
- Advice, extension and information, including the production and dissemination of spatial forest data
- Inventories, surveys and production of official statistics about forests and forestry
- Management of governmental subsidies
- Designation and management of protected areas in forest

- Work with enquiries and governmental commissions as well as forest policy development
- Contractual services

5.3.3 Forestry advice and decisions

An importance principle in Swedish forestry is that it is up to the owner of the forest to decide which forestry measures should be carried out and how they should be implemented, within the limits set by the law. Examples of legal obligations that are particularly important for forest owners are requirements to establish new forest after final harvest, to take sufficient environmental considerations at all forestry operations and to prevent insect damage to standing forest. The forest owner decides upon the timing of pre-commercial thinning, commercial thinnings, and final felling (as long as the stand exceeds the minimum harvesting age stated in the Forestry Act).

Advisors to individual forest owners include the Swedish Forest Agency, forest owners' associations, and other advisors such as staff at the forest companies. Up until the 1990s, the Swedish Forest Agency's advice mainly had a production focus: How to regenerate the forest after final felling? When and how should thinning be performed? When is the right time for final felling? Following the upgrading of the environmental goal in the Forestry Act of 1993, nature consideration during forestry operations became the main advice area. In recent years, however, interest and advice pertaining to timber production has increased to some extent.

Advising from the Swedish Forest Agency has also changed in its nature. In the past, the forest owner and the advisor most often met in the forest to discuss appropriate management on site. Today, advice is largely given online. The Swedish Forest Agency offers a service with web-based information about the owners' forest properties. The forest owner and the advisor can, in conference meetings, see the same maps and figures on their respective computer screens and discuss different management options.

One form of advice is given as forest management plans that describe an owner's forest and proposed silvicultural measures for different stands (see Section 5.4). Forestry plans are produced by several forestry actors, such as the Swedish Forest Agency, the forest owner associations and forest companies.

5.3.4 Actors involved in forestry operations on the ground

Most of the practical forest management is carried out by companies that specialize in some types of forestry operations. The more important tasks are scarification, planting and pre-commercial thinning, thinning, final felling, and slash harvest (including transportation of the timber and slash to forest road). Transport companies carry the timber to sawmills and to pulp or energy plants.

Companies specialized in planting and pre-commercial thinning carry out work throughout the year in southern Sweden, while in central and northern Sweden they can only work for 6-8 months due to snow cover. A large proportion of that work is done by foreign labor, mainly from Poland, the Baltic States and Romania (Lefévre & Persson 2009).

Almost all thinning and final felling is done mechanically with harvesters and forwarders. More than 90 % of the harvesting in Swedish forestry is carried out by contractors. A typical harvesting enterprise comprises one harvester and two forwarders. The owner of the enterprise employs the number of operators needed to ensure a high degree of utilization of the machines. The harvester and forwarders often run in two shifts and only stand still for a few hours during the night. There are also larger forest machine companies with several harvesters and forwarders.

In private forests, some of the forestry work is done by the owners themselves. This applies primarily to planting and pre-commercial thinning. Today about 30% of the planting, 60% of the pre-commercial thinning and 15% of the commercial thinning is done by forest owners themselves (SLU 2018).

5.3.5 Timber measurement

In Sweden, legislation for timber measurement has been in place for a very long time. It aims to give sellers and buyers of timber, pulpwood and forest fuel objective knowledge as a basis for trade. The legislation contributes to an uncorrupt and credible timber market, which is an important prerequisite for a long-term economically sound forestry industry. The law on timber measurement (Regeringskansliet 2014) states how timber measurement should be carried out and with what accuracy. It also requires that the result of the measurement be communicated to sellers and buyers.

Wood is measured at pulp mills and sawmills. Pulp wood is measured on the truck. For saw timber, each log is measured and quality classified individually. Forest fuel is assessed based on energy content. Those performing timber measurement must have documented control routines ensuring that measurements comply with laws and regulations.

Until 2018, wood measurement was handled by three timber measuring associations. Data was delivered to the Forestry Data Center, which sent measurement results to timber sellers and buyers. In January 2019, the three associations and the Forestry Data Center merged and formed Biometria, which is an economic association owned by buyers (forest industries and heating plants) and sellers (forest owner associations, the state-owned company Sveaskog and other sellers) in the wood market. Almost all timber in Sweden is measured by Biometria, in which sellers and buyers of timber cooperate for impartial measurement. The persons doing the timber measurement are employed by the association and are independent in relation to sellers and buyers.

5.3.6 Forest industry

In Sweden, forestry and the forest industry are intimately integrated into each other. To supply their industry, forest companies harvest on their own forestland, but also buy timber from individual forest owners (in most cases approximately as much as what they harvest on their own land).

There are four large forest owners' associations in Sweden, all of which have large sawmills that are supplied with timber sold by members of the associations, but also by forest owners who are not members. The largest association also operates three pulp mills, which together produce almost 2 million tons of pulp per year (Södra 2019).

Sweden's pulp and paper mills are mainly located along the seacoast and along the northern shores of Lake Vänern. A large pulp mill typically produces 0.5 million tons of pulp per year (although there are also larger ones). This requires about 1.2 million cubic meters of solid wood.

The sawmills are also mostly concentrated on the coast, but to a lesser extent than the pulp and paper mills. There are many large sawmills also in the interior of the country, except for northern Sweden's inland where several sawmills have been closed in the past decades. Instead, the timber is transported by truck to larger units by the coast. This has resulted in a reduced number of jobs in a region where the labor market and the tax force are weak and continuously decreasing. As of 2017, there were between 15 and 20 sawmills having a production capacity of more than 300,000 m^3 of sawn wood in Sweden.

5.3.7 Other actors

In addition to the state authorities, forest management organizations, timber traders and the industry, several other organizations also engage in the forest arena. These include: non-governmental organizations; national trade and employers' organizations linked to the pulp, paper and wood-processing industries; regional cooperative associations of individual forest owners; associations of forestry contractors; trade unions; forest research institutes; forest education institutions; and professional associations.

In particular, the environmental and nature protection movement has spawned an important group of organizations that participate in interactions in the arena, seeking to address concerns about nature conservation and broader environmental issues. Several other sectors and groups (including energy, recreation, tourism, hunting, agriculture and the Sami reindeer herding communities) are represented by influential organizations in the arena. These organizations also have global connections and are associated with (or members of) international organizations and corporations (Dargavel 2010).

5.4 Planning

Planning routines are used for developing forest holdings according to set goals and for timing of silvicultural and logging activities. Planning is dependent on the availability of high quality digital maps and good stand descriptions. The planning tools used in Swedish forestry differ between individual forest owners and the large forestry companies. Forest management plans for small-scale individual forest owners, with land holdings from about 10 to a few hundred hectares, normally cover a ten-year period. In these plans the forest is divided into compartments varying from approximately 0.5 to 10 hectares, were each compartment is described and operations in the coming 10 years are suggested. Most of these forest management plans are so called "green plans", which is a requirement by the two main forest certification schemes. The green plans include information about voluntary set-asides for nature conservation and environmental considerations in logging operations. Note, however, that most but not all individual forest owners have management plans for their properties.

***Fig. 19**. Even though remote-sensing and computer-supported planning systems are increasingly used, field planning is a necessity for deciding proper measures on the site. Data are collected in the field also in long-term planning. Björna, Västernorrland. Photo: Erik Normark.*

For larger forest holdings, the planning approach usually stretches over longer time horizons, but the digital maps and stand registers are similar as for smaller holdings, although the average compartment size is on average lager. The data in the plan is updated continuously. For strategic level planning, the harvest levels for the coming 5-10 years are estimated using a 100-year planning horizon. The objective is normally a sustained-yield forestry, optimizing the net present value of the entire holding given restrictions pertaining to set-asides and environmental consideration, as well as evenness in the timber flow to the industry. In addition to the long-term strategic plans, the larger landowners also develop landscape-scale multiple-use plans. These plans map existing conservation values in a landscape, including an assessment of which elements are partially or totally absent from the current forest landscape. Aquatic environments are part of these multiple-use plans. Information about cultural landmarks and important sites for reindeer husbandry and are also documented.

The estimates of logging levels are taken further through the tactical planning, which paves the way for minimizing the cost and environmental impact of transporting timber from a large number of logging sites in order to supply several different industries with varying quality demands. Prioritization tools help determine where investments in roads and maintenance should be made for maximum benefit.

The last planning level is that of operational planning of silvicultural and logging operations. Operational areas are split into sites to adapt silviculture to local conditions. Detailed environmental consideration plans are designed to provide maximum environmental benefit to the lowest possible cost. The borders of the area and the sites within it are established, as well as the location of watercourse crossings, logging trails and landings.

5.5 Even-aged forest management based on clearcutting

Even-aged management with tree retention is the dominating management system in Swedish forests today (Felton *et al*. 2019a). This system is characterized by the maintenance of a more or less even age structure of trees within individual forest stands, with one single tree cohort (not considering the trees retained for environmental conservation purposes) generally established through regeneration after clearcutting. It involves a sequence of silvicultural treatments that are implemented during the rotation. After clearcutting, the site is regenerated. Some years later, the stand is pre-commercially thinned once or more. This is normally followed by one to three commercial thinnings before the stand is finally felled through clearcutting. Environmental consideration measures (pertaining to natural, cultural, esthetical and recreational values) have to be implemented in connection with every silvicultural treatment during the rotation.

The rotation length, defined as the number of years between two final fellings (i.e. two clearcutting events), typically varies as a function of site properties, but may also be influenced by a range of additional socio-ecological factors (Roberge *et al*. 2018). The Forestry Act imposes minimum forest ages for clearcutting based on tree species, site productivity and geographical location. For Scots pine and Norway spruce stands, these minimum ages vary from 45 years in the most productive spruce forests of southern Sweden to 100 years in less productive forests of the northern parts of the country (SFA 2019c). In practice, however, rotations are often longer than the minimums prescribed by law (Fries *et al.* 2015).

All components of the clearcut forestry system have gradually been made more efficient since its introduction on a large scale in the middle of the 20th century. This has, for example, resulted in an increase in the timber volume produced per workday in Swedish forestry from about 3 m^3 in 1950 to about 25 m^3 today (Skogforsk 2019). A currently ongoing project run by the Swedish Forest Agency aims to further increase future timber volume growth and at the same time restore the forest landscape matrix via enhanced retention forestry (Normark & Fries 2019).

5.5.1 Regeneration

Work with forest regeneration begins as soon as possible after a stand has been harvested. Local site conditions determine the choice of tree species and regeneration method. Successful regeneration results in a high seedling survival rate, dense stands with a high growth, as well as low costs and high timber values over the rotation (Broman *et al*. 2018).

The most common regeneration method in Sweden is planting of seedlings. Today (average for years 2016–2019) planting is used on 84 % of the regeneration area, to compare with 64 % at the turn of the millennium (SFA 2019a). Direct seeding and natural regeneration under seed trees or shelter trees are used on 10 % and 4 % of the regeneration area, respectively. Field inventories show that on about 2 % of the regeneration area, no regeneration measures have been taken although it would have been necessary (SFA 2019a). Surveys by the Swedish Forest Agency show that the overall regeneration results 5–7 years after clear-felling have improved since the turn of the millennium. At that time, 73 % of the regenerated area met the requirements of the Forestry Act, to compare with 91 % today (average for 2016–2019).

Some proportion of the planted or sown trees usually die; these are generally replaced by naturally regenerated trees originating from seeds from neighboring stands or retention trees. As a result, even artificially regenerated young stands are almost always a combination of planted or sown seedlings originating from nurseries and naturally established seedlings. Due to the occurrence of natural seedling establishment from various tree species, regenerated forests are rarely pure monocultures.

5.5.1.1 Scarification

Scarification is a measure whereby the soil is mechanically prepared to offer a more suitable bed for forest regeneration. It is usually adapted to the regeneration method chosen. Scarification is a standard procedure before planting in Swedish forestry. When using seed trees, shelterwood and in the case of direct seeding, shallower scarification is usually applied. Scarification is usually not applied when using shelterwood on moist or peaty soils, or after severe ground burning.

If executed properly, scarification results in a high rate of tree survival and growth (Lundmark 1988). Scarification raises the soil temperature and decreases the risk of frost damage. It also helps improve the balance of water and oxygen in the soil. If well executed, scarification also releases nutrients and disturbs capillary water movements in the soil, reducing the risk of frost heaving. Scarification reduces competition from grass, herbaceous plants and shrubs. At the same time, it enhances seedling vitality and stress tolerance. It further reduces the risk of damage to the seedlings by the pine weevil (*Hylobius abietis*) (Petersson 2011). Stones, rocks, stumps, roots and forest residues all limit the success of scarification. During scarification, special attention is paid to avoid damage to trees (living and dead) left for conservation purposes, as well as to cultural heritage remnants.

Fig. 20*. Scarification of a clearcut. Gideå, Västernorrland. Photo: Erik Normark.*

5.5.1.2 Choice of tree species

The trees planted in Swedish forests are mainly conifers. This is mainly because of their wood properties, which are demanded by the industry, and also because of their relatively low management costs. Despite this, the Swedish forests consists of 18 % broadleaved trees (proportion of standing volume; SLU 2018), mainly as a result of natural seeding and sprouting from stumps. Scots pine is usually more suitable on low-fertility and coarse-texture sites, while Norway spruce is planted on richer sites with fine-texture soil. The North American lodgepole pine is also used to some extent in the northern parts of the country (approx. 3200 hectares were regenerated annually with lodgepole pine in 2017; SFA 2019a). In southern Sweden, ungulate browsing damage to young production forests has led to a development whereby sites traditionally regenerated with Scots pine and sites that could be regenerated with broadleaved trees are instead regenerated with Norway spruce. This large-scale shift in tree species is expected to have negative consequences for biodiversity and a range of ecosystem services (Felton *et al.* 2019b).

5.5.1.3 Seed and seedling production

The great majority of seedlings planted in Sweden originate from seeds produced in seed orchards. In the seed orchard, selected trees are grafted and managed to produce seed crops for the forest nurseries. The grafts are pruned regularly to enable manual cone harvest from a mobile elevating work platform.

The trees in the orchards originate from the Swedish tree breeding programs. These programs are long-term undertakings that started with the selection of so called “plus trees” in the forest during the 1950s-1980s. Through a recurrent selection system, based on field progeny tests, the breeding populations are gradually improved regarding traits such as survival, growth rate, quality and climate adaptation potential. The first-generation seed orchards, which were established during the 1960s-1980s, have proved to produce seeds with an 8 % increased growth potential compared to unimproved origins from the same region. Today the first third-generation seed orchards are giving their first seed crops, with an estimated increased growth potential of 20-25 % (Rosvall & Wennström 2008). The breeding programs for Norway spruce, Scots pine, lodgepole pine, silver birch and a few other broadleaves are designed to maintain long-term genetic diversity by using a large numbers of founder trees and ensuring that they all are represented in coming generations

In Sweden, between 350 and 400 million forest tree seedlings are planted each year. They are grown in highly mechanized nurseries where the production capacity is usually between 10 and 100 million seedlings per year. There are also a number of smaller nurseries with a production of less than 1 million seedlings per year. Hence, the seedling production is largely industrial and the cultivation is monitored, controlled and regulated continuously so that seedlings of the right quality can be delivered at the right time at a competitive price. The seedlings are most commonly raised in container systems, produced in different sizes from 30 to 120 cm^3 peat volume. After germination and initial growth in greenhouses, seedlings are moved into the open for further cultivation over one or two seasons, depending on the seedling batch and seedling size.

To reduce the risk of frost damage and to increase growth, it is common practice to use genetic material from other geographical locations for artificial regeneration. Today, Norway spruce seedlings planted in southern Sweden are mostly obtained from genetic material originating from Belarus and the Baltic States, whereas spruce seedlings used in northern Sweden mostly originate from more southerly Swedish areas. For Scots pine, local breeding material is usually used in southern Sweden whereas in northern Sweden it is common to use material with a more northerly origin than the plantation site. All geographic transfer of genetic material is guided by extensive series of long-term field provenance and progeny trials. As a result of this moving of genetic material over large geographic areas (and of subsequent spreading of genes through wind-dispersed pollen), the genetic composition of Swedish forests is gradually changing (Westin 2016). The effects of these changes on the genetic composition and diversity of trees across the whole forest landscape, as well as possible ecological impacts, are poorly known.

Fig. 21*. After germination and initial growth in greenhouses, the seedlings are moved into the open for additional tended growth and hardening. Watering of seedlings. Gideå nursery, Västernorrland. Photo: Erik Normark.*

5.5.1.4 Planting

Planting is the main method for forest regeneration in Sweden, as it is considered a robust artificial regeneration method that suits nearly all types of sites. Scarification and planting take place as soon as possible after harvesting to minimize the length of the regeneration period. Planting is normally done manually, mainly during spring and early summer but also sometimes in the autumn. No trees should be planted on cultural heritage remnants or in their immediate vicinity.

The choice of seedling size is based on the risk of frost heaving, summer frost, competing vegetation and pine weevil damage. Larger seedlings generally survive better than smaller ones (Johansson *et al*. 2014). Large pine seedlings also grow faster than smaller ones. Planting under shelterwood can be a good method in areas exposed to early-summer frost. In southern Sweden, planting spruce under a thin pine shelterwood is often a good option that provides extra seeds, reduced competition from field- and shrub-layer vegetation, less pine weevil damage and the chance for establishment of mixed coniferous forest.

Fig. 22. *Artificial regeneration through planting. Ängebo, Hälsingland. Photo: Erik Normark.*

5.5.1.5 Direct seeding and natural regeneration

For some pine sites, direct seeding may be a suitable artificial regeneration method. When well executed, direct seeding can result in dense stands with trees having well-developed root systems. Direct seeding is cheaper than planting, but seedlings get established somewhat later, which may prolong the the rotation. Moreover, availability of large enough quantities of high-quality seeds can sometimes be an issue.

Given suitable pine sites with a favorable climate (temperature) and a good number of ‘storm-proof’ trees, natural regeneration under seed trees can be used. The method is less predictable than artificial regeneration and it is sensitive to storm damage. It requires a good scarification, but when used on the right sites with the right methods, it can result in high-density pine regeneration.

Fig. 23. *Seed trees in pine forest. Bjurholm, Västerbotten. Photo: Erik Normark.*

Spruce forests on moist and peaty sites in a favorable climate can be regenerated using shelterwood. Establishing shelterwood with 250 trees per hectare reduces common problems with regeneration such as water stress, frost heaving and competition from other vegetation. Shelterwood is prone to storm damage and requires high skills to select sites with proper conditions (Normark 2015).

5.5.2 Pre-commercial thinning

Pre-commercial thinning, or spacing, is a physically demanding motor-manual measure. It involves transforming thickets into a young forest of selected trees occurring at a suitable spacing, often 2000-2500 stems per hectare. Pre-commercial thinning affects the character and vitality of the stand by regulating the number of trees, the mix of tree species and the variation in height. It provides the retained trees with improved growth opportunities by giving them better access to light, water and nutrients. During pre-commercial thinning, attention is paid to allow the growth of tree species of special importance for the conservation of biodiversity, for example rowan, sallow, aspen and birch.

Most young stands are pre-commercially thinned 5 to 10 years after establishment, when the main stems have reached 2 to 3 meters in height and regeneration has thereby been secured. When correctly conducted, pre-commercial thinning reduces the costs of future thinnings.

***Fig. 24**. Young forest stand recently subjected to pre-commercial thinning. Grytsjö, Västernorrland. Photo: Erik Normark.*

If executed too late, pre-commercial thinning costs increase and work becomes more cumbersome, while the risk of snow damage increases (Pettersson *et al*. 2012). In sites where growth is slow or sites that have been replanted, the broadleaved trees can quickly overtake the conifers in terms of growth. This is particularly a problem for the growth of Scots pine, which is a light-demanding species. In these cases, pre-commercial thinning should be performed early and it will often involve several thinning rounds.

Although pre-commercial thinning is generally considered an economically profitable silvicultural measure, large areas are not treated or are treated too late from a stand development perspective (Bergquist *et al*. 2016). Some forest owners delay deliberately pre-commercial thinning in pine stands because of the risk for browsing damage by moose (spruce is rarely browsed). Most stands which have not been pre-commercially thinned will eventually be treated by difficult thinning operations. These are expensive and typically result in relatively small quantities of commercial timber because of small tree diameters.

5.5.3 Thinning

Commercial thinning (hereafter ‘thinning’) involves reducing the number of stems in the forest so that the remaining trees can reach proper dimensions. Thinning increases the future value of the timber by promoting growth among the trees having highest quality. At the same time, it usually provides revenues from the harvested timber. By opening up the forest, thinning also changes the way it is experienced by visitors.

Thinning is usually fully mechanized: it is performed with single-grip harvesters and forwarders. The main method is thinning from below, with a focus on timber quality. This means that a relatively high number of slender stems and a few larger trees of low quality are removed, while the best stems are retained and allowed to grow. The first thinning is recommended when the trees reach heights of 12-14 m. If the forest is suitable, a second thinning can take place when the trees are around 18 m height (Broman *et al*. 2018).

Historically, very limited nature consideration has been taken at thinning compared to final felling. However, there is increasing awareness about the importance of the large areas of today’s thinning-stage forest for the future of forest biodiversity, as these will form the bulk of mature forests in tomorrow’s landscapes. In many cases, existing natural values are reinforced during thinning, for example by retaining large pines or broadleaved trees, and creating high stumps. Today’s thinning is often conducted in relatively homogeneous middle-aged stands that lack older trees. The Swedish Forest Agency and other stakeholders have recently started advocating the active creation of natural values in such stands, for example through veteranization and killing of trees (Normark & Fries 2019). Concentrating conservation efforts in space during thinning facilitates conservation work during subsequent harvesting, which increases opportunities for maintaining conservation values in the future.

Fig. 25*. Thinning increases the future value of the timber by promoting the growth of the highest quality trees. Strömbacka, Hälsingland. Photo: Erik Normark.*

5.5.4 Harvesting

As in the case of thinning, harvesting (so-called “final felling”) is usually fully mechanized and involves the use of single-grip harvesters. Each harvested tree is usually debranched and cut to length directly at the cutting site by the harvester. The logs are then hauled to the roadside landing by a forwarder.

Harvesting of a mature forest has a major impact on local ecosystems and their biodiversity. To mitigate these impacts as well as impacts on cultural and social values, a range of environmental conservation measures are implemented. These include, for example, the retention of patches of forest with high conservation values within the cutblocks (e.g. older swamp forest, forest on steep slopes or next to cliffs, forest around springs or in ravines, patches of old forest with high abundance of epiphytic lichens), the retention of buffer strips along watercourses and wetlands, the retention of living trees with particular natural, cultural, or social values, the retention of standing and lying dead trees, the creation of high stumps, and the protection of cultural remnants, trails and other recreational areas. In situations where there are few trees with special conservation value, some more “ecologically trivial” trees are usually left on site to develop into future conservation trees.

The risk for erosion can locally be an issue when harvesting takes place on finer soils (including moraines with larger proportions of fine fractions) or sandy soils. To mitigate erosion risk, the driving of the machines is carefully planned. On sensitive soils, harvesting is often done on frozen ground. The soil can also be protected by driving on harvesting residues (branches and tops). The crossing of streams and other watercourses also requires careful planning and execution.

Today, harvesting takes place all year round, even in northern Sweden. However, there are sometimes shorter periods when the forest machines cannot operate due to too deep snow. In the southern part of the country, much of the precipitation even during winter comes as rain and the ground is almost never frozen, which may limit accessibility by the machines. With climate change, these difficulties affecting harvesting operations are expected to increase.

Fig. 26*. The high stumps and the tree newly placed on the ground help the scarifier avoid damaging the old log under the moss. Bergvallen, Jämtland county. Photo: Erik Normark.*

Tree tops and branches are often harvested after logging, then chipped and transported to diverse facilities for use as bioenergy. However, tops and branches are not harvested everywhere; this practice is less common in remote areas where the local demand for bioenergy is lower and costs for transportation are relatively high. Where tops and branches are harvested, some proportion is usually left on-site for environmental reasons. Under some conditions, the harvest of tops and branches is followed by the spreading of ash on the clearcut to mitigate nutrient loss and prevent acidification (Drott *et al*. 2019).

5.6 Forest management in southern Sweden's nemoral forest

In the nemoral zone of southernmost Sweden, clearcut management based on the use of coniferous trees (mainly planted Norway spruce) dominates strongly, but a wider variety of silvicultural methods are being used in broadleaved forests. Beech is often regenerated under a shelterwood which is gradually made sparser through thinnings. Oak is normally planted or regenerated by sowing acorns and managed in even-aged stands with frequent thinnings, both pre-commercial thinnings and commercial thinnings yielding pulpwood and timber (Löf *et al.* 2015). A typical goal is to obtain oak stands with less than one hundred large diameter trees per hectare harvested at an age of 120 to 180 years. Other southern broadleaved tree species (ash, lime, elms, maple, hornbeam) are grown and managed on a very small scale.

5.7 Management to increase variation in the forests

Swedish forestry has since the mid-20th century been dominated by the clearcut system focusing on high and even yield of spruce and pine timber in even-aged stands. Even-aged clearcut management is an effective way to obtain high growth as well as a predictable and sustainable long-term flow of raw wood material to the industry. It is easy to plan and perform over large areas with a limited workforce. In recent decades, however, there has been growing concern that a too rigid and uniform implementation of this silvicultural system may present some drawbacks in relation to the multiplicity of goals associated with forests.

One of the aims of the current Forestry Act from 1993 is to increase the variation in silvicultural systems and methods, by giving the forest owners a large freedom in their choice of management methods. The intended variation is expected to deliver a wider range of ecosystem services from the forest, and to lead to improved environmental values. Increasing variation also has the potential to reduce risks, increase resilience and improve the possibilities to meet changing management goals in the future.

An increased variation in the forests can be obtained in various ways at the scales of stands, holdings or landscapes. Within even-aged management, it can be achieved for example by increasing the use of tree species that are uncommon in today's managed forest landscapes (Felton *et al*. 2019b), promoting the development of mixed-species stands (Felton *et al*. 2016), and prolonging rotations (Roberge *et al*. 2016). Increased variation can also be achieved by increasing the use of silvicultural methods that retain a continuous forest cover through time (Sténs *et al*. 2019).

Continuous cover forestry is a term that covers several silvicultural methods and systems. The Swedish government has set a goal for the Forest Agency to promote an increased use of these systems. A common denominator in all continuous cover forestry systems is that they never result in larger tree-less areas. The term includes single-tree selection, group selection and regular and irregular shelterwood systems. Motivations for adopting continuous cover management may vary. For Swedish conditions, three objectives are often mentioned: 1) to create or maintain habitat for species requiring tree cover continuity, e.g. some mycorrhizal fungi and epiphytic lichens; 2) to promote recreational values in urban and peri-urban areas; 3) to promote stand and vegetation structures which are favorable to reindeer grazing and herding (Sonesson *et al*. 2016). Moreover, in some wet and frost-prone sites, continuous cover forestry systems may offer the easiest solution for successful regeneration.

Stands managed with − or suitable for – single-tree selection are rare in Sweden because of the long history of even-aged management. A prerequisite is that there is a natural layering of the tree vegetation that can be developed into a full-layered stand suitable for single-tree selection management. The only native tree species that is suitable for single-tree selection is Norway spruce, maybe in southernmost Sweden admixed with beech (Lundqvist *et al*. 2014). Results from research plots in Sweden and Finland indicate a reduced growth of approximately 20% compared to even-aged forestry (Hannerz *et al*. 2017, Lundqvist 2017, Hynynen *et al*. 2019). The difference in long-term growth can increase in the future, since systems relying on natural regeneration cannot benefit from the improved growth obtained through the tree breeding programs.

Irregular shelterwood systems can vary a lot with respect to gap size, shelter tree density and tree species favored. In larger gaps and low density shelterwoods, light demanding tree species such as pine and birch can be regenerated. Continuous cover forestry is used in a limited extent in Sweden today and we know little about the extent to which the different methods are used.

5.8 Infrastructure

Infrastructure for forestry in Sweden can be divided into four main components:

- Forest data
- Information flows
- Harvesting and terrain transport
- Roads and vehicles for transport to industry

All these parts are important, and much research and development work has been performed to streamline the various components to increase timber production, reduce costs and increase revenues. This infrastructure has contributed to high competitiveness of the Swedish forest industry despite relatively low forest ecosystem productivity from a global perspective. The infrastructure also contributes to the access to various forest ecosystem services (see Section 5.10) in addition to the provision of wood products.

5.8.1 Forest data

Detailed forest geodata are generally used for long-term planning and for operational planning of specific forestry measures. Traditionally, aerial photographs and satellite images have been used as the main geodata sources. During the past decade, country-wide geodata originating from airborne laser scanning has also been widely used. There are now publicly available online basic forest data on for example wood volumes, tree heights and topography with a resolution of less than 10 m × 10 m. In addition, laser data has been used to produce soil moisture maps for assessment of the bearing capacity for harvesters and forwarders.

All private forest owners have access to digital information about their forest property through the Swedish Forest Agency's website, map programs with basic forest data, planning tools and a complete guide for creating and sending notification of clear-felling to the Agency.

This type of basic forest data is typically supplemented by forest maps where compartments with associated stock data are delimited. High quality forest data is a prerequisite for efficient forest management where the right measure is implemented at the right time. For example, they allow thinning a specific stand in the right year and with a suitable harvest level to optimize yield and economy. Note, however, that planning almost always involves some work on the ground to ensure that the coming felling is properly delimited and that proper environmental considerations is taken.

5.8.2 Information flows

Since forestry measures such as final felling and regeneration are carried out by several different persons or contractors, it is important that information about what is done and planned to be done is transferred to those who are responsible for the next steps. For example, a plan for how a final felling should be conducted (including details about environmental measures) must be effectively transferred to the contractor. For this to work, information is normally handled digitally to ensure easy and quick access by everyone who needs. Digital information management also allows stand registers to be continuously updated with all implemented forestry measures and current stand data. Effective digital data transfer is dependent on the presence of good internet connection in the areas where forest operations are being conducted. This is still lacking for about 10–20 % of the managed forest area in Sweden.

5.8.3 Harvesting and terrain transport

More than 90 % of all logging in Swedish forestry is mechanized. Single-grip harvesters are used for felling the tree, debranching it and cutting the stem into lengths. To optimize wood revenues, the harvesters are equipped with high-tech solutions for felling, processing and measuring both length and diameter. In an ideal situation, the selection of timber to be harvested and the harvester's cutting of the stems into lengths is done in accordance with a customer's specific demands. To achieve this, the industry, usually a sawmill, specifies what range of qualities they need for the coming period. The harvester receives an order and reports, digitally, to the industry that the delivery is available at a certain position.

The felled timber is transported from the harvesting site to the forest road by forwarders. Approximately 70 % of the Swedish forestland is located within 500 m of a road and half within 300 m (Skogskunskap 2019). The average terrain transport distance in Swedish forestry is just under 500 m.

Fig. 27*. The forwarder brings timber to the forest road. The timber is loaded onto a truck which takes it to the industry. Kamsjö, Västerbotten. Photo: Erik Normark.*

5.8.4 Roads and vehicles for transport to industry

When the timber has reached the forest road, it is loaded onto timber trucks and transported to the industry, typically a sawmill or a pulp or paper plant. In Sweden, there is a vast network of roads specifically built for forestry. The roads have been constructed and are maintained by the forest owners that they serve. The total length of forest roads is approximately 210,000 km, which is about one third of the total road length in the country (Axelsson *et al*. 2018).

In 2017, the Swedish forest industry transported timber and pulp about 6 billion tkm (SFIF 2019a). Two-thirds of the forest industry's domestic transport work is done by truck and one-third by rail. Wood chips and sawn products are mostly transported by truck, while pulp and paper are mostly transported by rail. The average transport distance by truck is about 100 km and by rail about 320 km. Swedish timber trucks have a maximum length of 24 m and a gross weight of 64 tons. Tests are ongoing with larger trucks that can be loaded with 74 tons. About 2 million turns of timber trucks are needed for transportation of all timber harvested during one year in Swedish forestry. Export of wood products to other countries is mostly done by ship.

5.9 Present-day environmental consideration in Swedish forests

Today's environmental consideration in Swedish forests is based on a combination of environmental consideration in the managed forest matrix and area protection. The main current environmental conservation measures implemented in connection with different silvicultural treatments in production forests are described in in Section 5.5 above, while the historical development of the principal forms of protected areas is summarized in Section 4.3.

Environmental consideration in managed forest involves the retention, protection, promotion and creation of natural, cultural, esthetic and recreational values during silvicultural treatments in the forest stands. In 2011, the Swedish Forest Agency launched a large collaborative project involving a wide range of stakeholders in Swedish forests to develop targets for environmental considerations on the ground (SFA 2013). As part of that project, targets have been commonly developed for the consideration of care-demanding habitats, trees and shrubs with special conservation value, dead wood, watercourse, waterbodies and wetlands, outdoor life and recreation, and cultural heritage sites. Targets have also been developed for machine driving in forest, crossing of streams during forestry operations, as well as ditch maintenance and protective ditching. The various stakeholders in Swedish forestry are currently implementing these targets in their operations.

The level of implementation of the targets on the ground is being monitored by the forest companies and the Swedish Forest Agency. Recent official statistics show that the mean proportion of the forest area left as retention patches for environmental consideration on clearcuts is approx. 11 % on a national scale (SFA 2019b). The amount of hard dead wood in production forest has increased since the 1990s, which may be an effect of the improved environmental consideration in forestry operations. However, monitoring results by the Swedish Forest Agency also show that improvements are needed in some areas. For example, during 1999–2015 approximately 9–20% of care-demanding habitats and 7–12% of riparian buffer zones in harvested stands have been strongly negatively affected during felling operations (Andersson *et al*. 2019).

Protected areas include larger areas that are formally protected by the state (mainly nature reserves, national parks, biotope protection areas, conservation agreements) and areas that are voluntarily set aside by the landowners. Protected areas currently cover 11 % of the productive forest area in Sweden: 6% as formally protected areas and 5 % as voluntary set-asides (SFA 2019b; Table 4). If considering all forestland − including unproductive forest with a growth below 1 m^3 per hectare per year − a total of 13 % of the forestland area is protected through formal protection (9 %) or as voluntary set-asides (4%) (SFA 2019b). In addition, there are large areas of unproductive forests outside formally and voluntarily protected areas which are in practice protected from forest management by the Forestry Act (12 % of the country's forestland area; SFA 2019b). These also contribute with large additional areas of unmanaged forest providing habitat for many threatened species. The proportions of formally protected areas, voluntarily set aside areas and unproductive forest in different regions of Sweden are presented in Fig. 28.

Table 4. Formally protected forest, voluntary set-asides and unproductive forest as of 2018. Areas are rounded to the nearest 100 hectares. Overlap between categories is excluded according to a predefined hierarchy (see SFA 2019b).

	Area of productive forest (ha)	Total forest area (ha)	Proportion of productive forest	Proportion of all forest
Formally protected forest	1 381 800	2 335 400	6%	9%
Voluntary set-asides	1 210 100	1 210 100	5%	4%
Unproductive forest[a]	--	3 239 500	--	12%

[a] Outside formally protected or voluntary set aside forest. Forest management is forbidden on all unproductive forests with an area >0.1 ha (no matter protection status) according to the Swedish Forestry Act

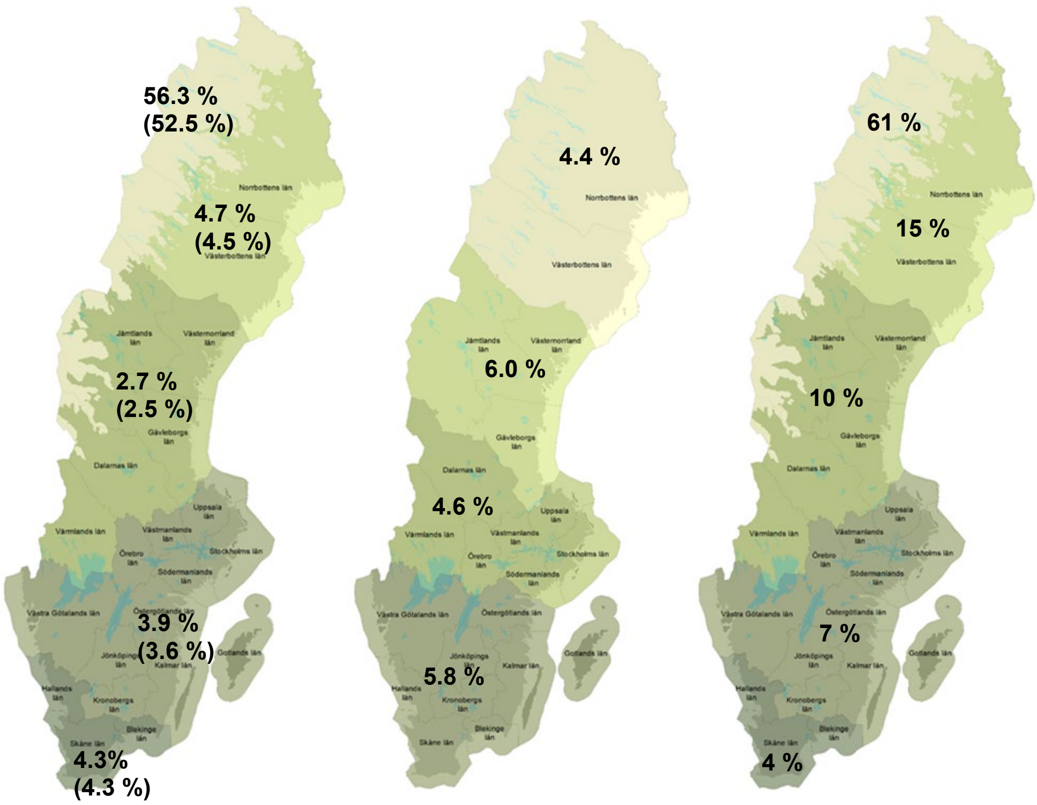

Fig. 28. Proportions of (A) formally protected forest relative to the total forest area (equivalent figures for productive forest area in parenthesis), (B) voluntary set-asides relative to productive forest area and (C) unproductive forest relative to the total forest area, for different regions of Sweden depicted by different shades of green. Source: SFA (2019b).

A recent development in conservation work in Swedish forests is the increasing use of active management measures conducted specifically for conservation purposes (hereafter ʻnature conservation management') (e.g. Grönlund *et al*. 2019). The aim of nature conservation management is to restore or maintain key ecosystem properties linked to disturbance regimes to which species are evolutionarily adapted (e.g. fire, cattle grazing). Nature conservation management measures have been implemented increasingly in recent years, mainly in formally protected areas and in voluntary set-asides. The most commonly used nature conservation management measures in Sweden are prescribed burning (to mitigate the lack of natural forest fires, which are largely suppressed), removal of spruce undergrowth, clearing around large trees or groups of trees of high conservation value (e.g. large aspens or oaks), mechanical damaging or killing of trees to provide substrates for saproxylic species, opening-up of the canopy (e.g. gap cutting), restoration of hydrological regimes and cattle grazing (Nitare 2014). The Swedish Forest Agency and other parts of the forest sector have recently started advocating the large-scale use of some conservation management measures also in managed production forest stands in connection with silvicultural treatments (Normark & Fries 2019).

Fig. 29*. Active forest management for biodiversity conservation purposes in a north-Swedish nature reserve. Spruces around an old aspen were felled to favor the growth and survival of the aspen and of the epiphytic species using it as a substrate. The dead spruces were left on-site to provide substrates for dead wood dependent species. Photo: J.-M. Roberge.*

5.10 Forest ecosystem services

Ecosystem services are benefits that humans gain from the natural environment and from properly functioning ecosystems. Forest ecosystem services are of great importance for human well-being and constitute a major contribution to the Swedish economy. The right of public access to almost all forestland is an key factor favoring the delivery of ecosystem services in Sweden.

This section presents a short overview of the ecosystem services provided by forest ecosystems in Sweden. Two ecosystem services are described in more detail: (1) wood products and bioenergy, due to their dominating position in shaping contemporary Swedish forestry and because of their importance to the economy, and (2) reindeer husbandry, a natural-resource based industry protected by the Swedish constitution which takes place on a very large proportion of the total Swedish forestland area. Other ecosystem services are summarized based on a recent account by the Swedish Forest Agency (SFA 2017).

5.10.1 Wood products and bioenergy

In Sweden, most of the timber suitable for sawing is used for the production of sawn timber, whereas the rest is used for other wood products such as pulp and paper, as well as for bioenergy. Sweden was the world’s second largest exporter of pulp, paper and sawn timber after Canada in 2017 (SFIF 2019b). The total export value in 2018 was SEK 145 billion (EUR 13.5 billion according to exchange rate in June 2019). These exports amount to 4 million tons of pulp, 9 million tons of paper (mainly graphic paper and packaging materials) and 13 million m^3 of sawn timber. The Swedish sawmill industry is the world’s third largest exporter of coniferous sawn wood products and the sixth largest producer (SFIF 2019b).

The Swedish forest industry consumes an average of 21 TWh of electricity per year (SFIF 2019c). It is just over 15 % of Sweden’s total electricity use. At the same time, the companies produce 40 % of the electricity they need themselves in the form of back pressure, water and wind power. The forest industry is 95 % fossil-free in its processes, thanks to the use of the bioenergy produced in-house. The surplus of bioenergy is delivered to the rest of society. In many places in Sweden, excess heat from the mills is used in the municipal district heating networks. In addition, large amounts of bark, woodchips, sawdust and pellets are supplied from sawmills and pulp mills to municipalities and households for heating. Woodchips originating the harvest of tops and branches after logging are also used as a source of bioenergy. As mentioned above, half of the forest raw material in Sweden is used to produce energy. By developing new materials and products from a part of what is now used for energy, the value added of the forest industry can increase. Such a development is perceived as beneficial to the transition to a sustainable, fossil-free society, since many of the products that can be produced from petroleum can also be made from wood raw material. Swedish research and development is ongoing in the field of industrial production of wooden buildings, as well as regarding the development of textiles, smart packaging, biofuels, lightweight materials, energy storage materials, medical applications and bioplastic from forest raw materials.

5.10.2 Reindeer husbandry

The indigenous people in Sweden, the Sami, have the exclusive right (usufructuary rights) to herd reindeer on approximately 50 % of the Swedish land area (located in the northern part of the country) in order to produce meat, hides and crafting material. A large proportion of the land used for reindeer husbandry is also productive forestland currently owned privately or by the state. Hence, the forest industry and Sami reindeer herders use the same land, but for different purposes, and this multiple-use situation is a source of conflict (Sandström & Widmark 2007). To manage conflicts between the two sectors, consultation procedures were introduced by the Swedish parliament in 1979 and about 20 years later they were extended to cover a larger geographical area through the FSC certification system (Anon. 1971; Anon. 1979b). However, several studies and assessments by for example the Council of Europe, the UN special rapporteur on indigenous affairs, and the OECD conclude that the current legislation and the FSC standards regulating the relationships between forestry and reindeer husbandry do not give sufficient protection to the natural grazing areas needed for reindeer husbandry (Widmark and Sandström 2011, UN 2011; Sandström 2015, Council of Europe 2017, Brännström 2017, OECD 2019). Ongoing research primarily focuses on how the two sectors can adjust to each other on a management level, while the more politically sensitive issues on property rights are rarely discussed.

5.10.3 Other ecosystem services

Ecosystem services can be grouped into four broad categories: provisioning services (delivery of tangible products), regulating services (such as prevention of damage from natural hazards), cultural services (e.g. contribution to physical and mental wellbeing) and supporting services (which are necessary for the production of all other services) (SFA 2017).

In 2017, the Swedish Forest Agency assessed the status of forest ecosystem services. A summary of this assessment is presented in Table 5. The status varies from “good” (10 of 30 assessed services) to “moderate” (13 services) and “inadequate” (7 services). More details about the specific types of ecosystem services and assessments of their statuses are presented in the report “Forest ecosystem services – status and pressures” (SFA 2017).

Table 5. Status of forest ecosystem services in Sweden (SFA 2017).

	Ecosystem service	Status
Provisioning	Sawn timber and pulpwood	Good
	Biomass-based energy sources (mostly rest products from harvesting, forest industry, transformation industry and society)	Good
	Game (mainly moose, red deer *Cervus elaphus*, roe deer *Capreolus capreolus*, fallow deer *Dama dama*, hares *Lepus* spp., wild boar *Sus scrofa*, tetraonid grouse, red fox *Vulpes vulpes*, beaver, brown bear *Ursus arctos*)	Good
	Reared animals (reindeer husbandry, also forest grazing by cattle, goats, sheep and horses)	Moderate
	Forest berries (mainly bilberry *Vaccinium myrtillus* and lingonberry *Vaccinium vitis-idaea*)	Good
	Mushrooms	Moderate
	Drinking water	Moderate
	Freshwater fish	Inadequate
	Genetic resources	Moderate
	Other provisioning services (e.g. chemicals)	Good
Regulating	Climate regulation	Good
	Prevention of storm damage and other weather-related damages	Inadequate
	Prevention of erosion and landslides	Inadequate
	Water flow regulation	Moderate
	Natural control of pests and disease	Inadequate
	Ensuring the quality and quantity of ground and surface water	Moderate
	Air purification	Good
Supporting	Biogeochemical cycling	Inadequate
	Soil fertility	Good
	Pollination	Good
	Photosynthesis	Good
	Habitats and natural environments	Inadequate
	Biological diversity	Inadequate
	Stability and resilience	Moderate
	Seed dispersal	Moderate
Cultural	Everyday recreational activities and exercise	Moderate
	Forest and nature for tourism	Moderate
	Mental and physical well-being	Moderate
	Environment and esthetics	Moderate
	Knowledge and information	Moderate

5.11 Damage to forests and the influence of climate change

Several biotic and abiotic damaging agents impact the Swedish forests. Some of these agents are, to some extent, part of the natural disturbance regimes of the forest ecosystems. Still, abiotic and biotic damaging agents may have clear negative impact on production forestry (through effects on e.g. regeneration, tree growth and timber quality) and on the provision of many other ecosystem services from the forest, and they may sometimes even compromise human safety. It is difficult to rank the different damaging agents according to their relative importance, because they affect the forest in different ways, at different developmental stages and with varying intensities and frequencies. Some of the damaging agents having the greatest economic significance for Swedish forestry and forest ecosystem services are: browsing by ungulates, bark beetle outbreaks, storm felling, pine weevil damage, root rot and forest fires. This section presents basic information about the impacts of these damaging agents in Swedish forests.

5.11.1 Browsing by ungulates

Ungulates such as moose and other deer (red deer, roe deer and fallow deer) occur at high population densities in large parts of Sweden and cause substantial damage to forests, especially younger pine forest and broadleaved forest. Ungulate browsing is today considered the most serious damage agent in young Scots pine forests that are 0.5−4 meters in height (Kårén 2018) (Fig. 30). Browsing damage has a great impact on tree growth and timber quality. A recent analysis shows that browsing damage decreases the annual forest growth by approx. 6.4 million m^3 on a national scale (about 5 % of the annual increment) and incurs costs of SEK 7.2 billion per year to forestry and the forest industry (Bergquist *et al*. 2019). Many broadleaved tree species such as aspen, rowan, willows and oaks are particularly heavily browsed by moose and deer. As a result, these trees often have difficulties to grow and get recruited into the main canopy layer, which has negative effects on the biodiversity dependent on the presence of larger individuals of these tree species (Angelstam *et al*. 2000).

To meet the risk for moose damage in young pine stands, forest owners relatively often plant Norway spruce on sites that would be more suitable for Scots pine. This leads to lower growth and increased risk for drought stress followed by bark beetle infestation. Another measure sometimes used to adapt to the risk of browsing damage is to delay pre-commercial thinning in pine stands until they have grown higher. This usually results in stands that are denser than what is economically optimal.

***Fig. 30**. A young pine stand severely damaged by moose browsing during the winter 2017/2018. Styrnäs, Ångermanland. Photo: Clas Fries.*

5.11.2 Bark beetle outbreaks

Spruce bark beetles (*Ips typographus*) mainly colonize storm-felled or otherwise weakened Norway spruces. In case of mass occurrence, however, the beetles may also attack relatively vital spruces. Bark beetle outbreaks following storms during 1970–2015 are estimated to have killed spruces corresponding to a total timber volume of about 10 million m^3 (Lindelöw 2017). In south-eastern Sweden, spruce has suffered substantial bark beetle damage due to longer drought periods. It is estimated that 2.5 million m^3 were damaged in Götaland as a result of the extremely dry and hot summer of 2018 (SFA 2019d). In 2019 the damage was estimated to 5 million m^3 in Götaland and 2.5 million m^3 in Svealand (SFA 2020a, SFA 2020b). A climate with predicted increased frequency of dry and warm events during summers (SMHI 2019) is likely to pose significant problems in southern Sweden, as it would make the spruces more stressed and hence vulnerable to bark beetles, and allow for more generations of bark beetles to be produced every year (Eriksson *et al*. 2016).

5.11.3 Storm felling

Large-scale storm felling has occurred on several occasions since the turn of the millennium in Sweden. The most damaging storm-felling event was, by far, the cyclone named Gudrun, which felled 75 million m^3 in southern Sweden in January 2005. In recent years, storms damaging significant timber volumes (more than 1 million m^3) have occurred about every other year on average. Spruce forests in southern Sweden are most prone to storm felling. Storm felling is often followed by bark beetle infestations. To reduce the magnitude of such carry-on impacts, the Forestry Act sets limits to the amounts of recently dead coniferous trees that may be left in the forest (SFA 2019c). Climate change may increase future storm felling damage in Sweden, mainly due to decreased occurrence of ground frost and increased rainfall during the storm season, which make the trees less resistant to windthrow (Mason & Valinger 2014, Eriksson *et al*. 2016).

5.11.4 Pine weevil damage

The pine weevil (*Hylobius abietis*) causes severe damage to planted pine and spruce seedlings in Swedish forests, especially in the south (SLU 2019b). To prevent seedling death, seedlings were earlier treated with insecticides. These insecticides are now largely banned, although exemptions from the general interdiction can be given for one year at a time. Instead, the most common seedling protection methods today are based on devices that preclude the beetle from accessing the seedling or provide an unattractive surface on the seedling's stem, in combination with scarification.

5.11.5 Root rot

Root rot is a collective name for damage to tree roots and stems caused by several wood decomposing fungi. The most important damaging fungus for Swedish forestry is *Heterobasidion annosum* (Berglund & Rönnberg 2017). Root rot is estimated to cost Swedish forestry SEK 0.5–1 billion per year in timber losses and other costs. The most noticeable losses are observed in spruce, but pine and several deciduous trees are also affected. When thinning spruce in southern Sweden at temperatures above 5° C, the stumps' surface is normally treated with the fungus *Phlebiopsis gigantea* to prevent root rot from spreading through the stumps and root systems. This kind of stump treatment is also sometimes conducted at final felling. A warmer future climate is expected to lead to increased incidence of root rot (Eriksson *et al*. 2016).

5.11.6 Forest fires

Forest fires have damaged relatively large areas of Swedish forest in recent years. In 2014, about 14,000 hectares of forest burned in one continuous area about 150 km west of Stockholm. This was the largest forest fire since at least the mid-20th century in Sweden. During the dry summer of 2018, a total of about 25,000 hectares burned in various locations, mainly in southern Norrland.

When larger quantities of timber are damaged by fire, some portion of the usable timber is harvested and sawn in sawmills or used for energy production in heating plants. After finishing the sawing, the sawmills must be completely cleaned from soot. Fire damaged wood cannot be used in the pulp and paper industry. Some burnt forest is usually left standing for the conservation of the many red-listed species that are dependent on burnt substrates.

The present Swedish strategy to reduce the damage caused by forest fires is to strengthen the firefighting organization, rather than adapt forest management to reduce the forest's vulnerability to fire. It is expected that climate change, which probably will lead to longer dry periods in Scandinavia, will increase the risk of forest fires in the future (Eriksson *et al.* 2016).

At the same time as wildfires are being fought, prescribed burning is being used in conservation management (see Section 5.9) in protected and set-aside areas, as well as on some clearcuts (both for conservation and regeneration purposes). The use of prescribed burning in conservation is motivated by the fact that the forest area annually subjected to wildfire in Sweden is only a minor fraction of the historical levels to which many boreal species are evolutionarily adapted. Hence, fire has two partly conflicting roles in Swedish forests, being seen as a damaging agent in production forests and at the same time as an important prerequisite for the conservation of biodiversity.

5.11.7 Other damaging agents

Other damaging agents affecting Swedish forests include, among others, drought, freezing damage, snowbreak, damage by defoliating insects and various types of fungal diseases. As examples of the latter, ash and elms are severely threatened by diseases caused by non-native fungal pathogens: ash dieback (caused by *Hymenoscyphus fraxineus*) and the Dutch elm disease (caused by *Ophiostoma novo-ulmi*, *O. ulmi*). As a consequence, ash is now red-listed nationally as an endangered species, while the three Swedish elm species (*Ulmus glabra*, *U. minor*, *U. laevis*) are listed as critically endangered (Eide 2020).

In some situations, several of the agents mentioned above may affect the same forest stand simultaneously, which can result in particularly severe damage. For example, increasing areas of young forest in northern Sweden have been affected by a combination of ungulate browsing and a range of fungal pathogens in recent years ("multi-damaged" young forest; Normark 2019).

5.11.8 Adaptation to climate change

Climate change is expected to increase tree volume growth thanks to a longer vegetation period (Bergh *et al*. 2003) but – as illustrated above – it is also expected to entail an increased risk of various types of damage to forests. In addition to the examples above, another expected effect of climate change is that damage to the ground when driving with harvesters and forwarders is likely to increase due to shorter periods with ground frost in the winter.

Some forest owners have started adapting forest management to reduce the risk of damage linked to climate change (Eriksson *et al*. 2015). One possible means of adjustment is to perform pre-commercial and commercial thinning relatively early and to leave a relatively low number of stems per hectare, thus making trees and stands more resistant to storms, droughts and pests. The use of a wider range of tree species, either in mixed or single-species stands, is also seen as one possible way to reduce the forest's vulnerability to damaging agents (Mason & Valinger 2014, Eriksson *et al.* 2016). Other recommendations pertaining to climate change adaptation in Swedish forestry include shortening rotations in Norway spruce stands to decrease storm-felling risk, as well as using machines and methods that enable harvesting under soil conditions worsened by climate change (Keskitalo *et al*. 2016).

5.12 Swedish forest management from a global perspective

Sweden is one of the European Union's member states having the largest forest resources: the country accounts for nearly one-sixth of the total standing timber volume within the Union (Bernes 2011). If the Nordic countries' exports of forest products (pulp, paper and sawn wood) are added together, they amount to a total of 39 million tons, which is larger than Canada's export (33 million tons) (SFIF 2019d). One reason for the relatively large export volumes from the Sweden, Finland and Norway in relation to their land area is that in these countries, almost all productive forestland that is not explicitly allocated to conservation or other purposes is actively used for forestry. Another reason is that since World War II, there have been strong societal incentives in the Nordic countries to consistently work for increasing efficiency in forestry. A strong driving force has been the great importance of the forest industry for the countries' economies and employment. An additional driving force for increasing efficiency is the fact that Nordic forestry must handle trees that are relatively small compared to the situation in many countries located at more southerly latitudes. Indeed, at the first commercial thinning the volume of the harvested trees is usually between 0.05 and 0.10 m^3, while at final felling tree volumes normally vary between 0.5 and 1 m^3 (although spruces sometimes exceed 1 m^3 at final felling on fertile sites in southern Sweden). Large resources have been allocated to research and development within silviculture and forest operations, and in the last years also in various forms of digital technology.

5.13 Research and development

There is a long tradition of collaboration in research and development between the government and the forestry sector in Sweden. Forest-related research (addressing e.g. forest management, forest biology, wood-based materials, forest policy and economics) is being conducted in some form at most Swedish universities. Many of them also offer courses related to forests or forestry. Two of these universities offer complete education programs in forestry: the Swedish University of Agricultural Sciences (SLU; with several campuses spread across the country) and Linnaeus University (located in Växjö and Kalmar).

SLU has been assigned by the government the twin tasks of providing suitably qualified professionals to the forestry sector and pursuing innovative forestry research. The academic staff at SLU in subjects related to forests and forestry includes about 65 professors and over 160 PhD students, with an annual output of about 30 PhD degrees. Available research infrastructure includes several laboratories and a wide range of experimental sites all over Sweden. SLU’s unit for field-based research administers nine experimental forests and more than 1600 active long-term forest field experiments (www.silvaboreal.com). Collaboration with the forestry sector has a strong tradition at SLU and is regarded as a cornerstone for both research and education. SLU acts as a national data host for many environmental monitoring and assessment programs, such as the National Forest Inventory (NFI) and the Forest Soil Inventory. The NFI is based on more than 30,000 permanent sample plots combined with temporary sample plots. Environmental monitoring contributes to the official Swedish statistics about changes in the environment and is the basis for evaluating progress towards national environmental quality objectives.

Another key actor in applied forestry research is the Forestry Research Institute of Sweden (*Skogforsk*). This institute is financed jointly by the government and the forest industry. The demand-driven applied research includes a wide variety of fields, such as forest technology, raw-material utilization, environmental impact and conservation, forest tree breeding, logistics, forest bioenergy and silviculture. Of the Institute’s staff of about 120, some 80 are researchers. Skogforsk has also been responsible for tree breeding activities in Sweden since the 1930s.

An important arena in research and development is the Royal Swedish Academy of Agriculture and Forestry (KSLA). It is an active forum for sharing science and practical experience involving researchers, forestry and agricultural professionals and organizations, as well as government agencies. The Academy runs projects and manages stipends and grants for forestry research.

In addition to the institutions mentioned above, many companies contribute to research and development in the Swedish forestry sector, for example in the development of innovative products from forest raw materials.

6 Future outlooks for Swedish forest management

In Sweden, forestry was an important part of the industrialization processes in the 19th century, essential for establishment of the welfare state in the mid-20th century, and a vital resource for multinational companies and other players in the global arena during the last half century (Mårald *et al*. 2017). Although international demand for forest products was the driving force for this development, until the second half of the 20th century the political regulation of forestland was mainly a domestic matter, under the aegis of the national government. Forest interests were able to establish a domestic forest regime – "the forest sector" – consisting of several hundred thousand small-scale private forest owners, large forest companies and the state, with distinct legislations, authorities, professionals and non-governmental organizations.

From the 1960s onwards, the emergence of environmentalism challenged the production-oriented forest sector (see Sections 4.3 and 4.4). The "Swedish forestry model" established in the early 1990s seeks to balance production and biodiversity through entrepreneurialism, voluntarism, education and ambitious goal setting. Furthermore, during the last 25 years forest politics and governance have become much more globalized, being influenced by transnational organizations, debates and international politics. Today, national forest politics are dictated and restricted by international law, including several conventions that are not primarily intended to regulate forests or forestry.

Hence, the development of the Swedish forest sector can be described as a balancing act between, on the one hand, national and international interests, and, on the other hand, industrial production and environmental considerations. When turning the focus towards the future, it is likely that the balance between these dimensions will continue to be crucial for Swedish forest governance and management. Based on this assumption, four ideal-typical (hypothetical) future outlooks can be extrapolated (Fig. 31). "The new forest sector" may evolve if the national control over forest governance continues and so does the production-oriented focus. "The resource supplier" is likewise production-oriented but increasingly determined by international demands and intentions. "National natural forests" illustrates a possible development with a stronger environmental guidance within a national realm. Finally, "European wilderness" exemplifies a change towards a stronger international influence to enhance environmental protection of Swedish forests.

	Industrial production	**Environmental care**
National governance	The new forest sector	National natural forests
International governance	The resource supplier	European wilderness

Fig. 31. *Four ideal-typical future outlooks for the Swedish forest sector.*

In the following section the four possible futures are elaborated, including two different versions of each outlook.[6] It is unlikely that any of these outlooks will be realized in a pure form; in practice many different combinations are possible. Unforeseeable circumstances, for instance impacts of global climate change, may alter the foundations of the Swedish forest arena, making all these outlooks obsolete.

6.1 Four hypothetical future outlooks

6.1.1 The new forest sector

In this hypothetical outlook, the traditionally strong Swedish forest industrial production interests continue to dominate within a nationally framed forest sector with prioritized economic objectives. In practice, this entails optimization of forest management to achieve high levels of production. This is a continuation of the rationalization efforts that started in the 1950s, but now with an increased focus on improved (and perhaps even genetically modified) tree material, digitalization, automatized harvesting and transportation, and a shift towards new forms of wood-based products (i.e. bioplastics, fuels, textiles, sanitary ware). It includes an eco-modernistic way of handling environmental and climate challenges by developing technological solutions and further improving efficiency. In this outlook, forest production is intensive and achieved through even-aged management with clearcutting under short rotations, maybe in part concentrated to plantations with high input of fertilizers and biocides. This is a capital-intensive production with few employees, which suits large-scale forest owners and forest companies. The position of small-scale forest owners which do not have resources to invest and compete becomes weaker in that outlook.

"The new forest sector" could, however, take another form due to national political ambitions. Small-scale forest owners and forest owners' organizations have traditionally had a strong influence on national politics in Sweden. Thus, political interests may instead promote the development of rural areas and small-scale entrepreneurial forestry. This entails a production-oriented forestry but with affordable and adjusted technological solutions, including governmental subsidies and support. This is a more labor-intensive forestry that covers most parts of the country, probably still with clearcutting as the main method. However, this outlook could also involve some use of continuous cover forestry, for example to produce certain timber qualities or even as a means to extract timber from high-natural value forests.

In both forms of "the new forest sector", a few main actors (i.e. forest owners, forest companies and the state) would continue to dominate Swedish forestry.

6.1.2 The resource supplier

In this hypothetical outlook, the national sovereignty over the domestic forest resources is weakened and instead international economic interests become stronger. This would not be the first time such a shift occurs in Sweden. In the second half of the 19th century, forest companies (supported by international

[6] These outlooks represent different hypothetical futures for Swedish forests and forestry; they are not meant to represent the authors' or the Swedish Forest Agency's standpoints about desirable futures.

capital) bought huge areas of forestland in northern Sweden. After an intensive political debate, the parliament in 1906 passed an act that forbid companies to buy more land. In the 1990s, the right to own and purchase forestland was partly deregulated. A continuation along the deregulation path would open up Swedish forests to international investments and possible takeover. This may direct forest production towards international market demands with minor local social considerations, for instance to supply raw material to a growing international bioenergy industry or use Swedish forests for climate compensation for international carbon-intensive industries. In this outlook, forest management can both become more high-technological and automatized and/or more labor intensive with a growing international migrant seasonal workforce.

A shift towards a stronger international influence may also take a more incremental path. It is argued that there is an ongoing change in the international forest industry, whereby the power moves from multinational forestry companies to global wood retailers (Dauvergne & Lister 2011). “Big box-companies” may become the dominant actors in the forest product market. These companies are closely connected to the costumers and thus sensitive to customers’ attitudes and changing values in society. For example, some of these companies demand that all wood-based products they use must come from certificated forest production. If such global companies become stronger and if they increase their business governance over forest production, this development may drastically reduce the space for maneuvering for the Swedish government as well as for forest owners and the forest industry.

6.1.3 National natural forests

In this hypothetical outlook, environmental considerations become stronger than production interests, and forest use is still mainly regulated within a national dominion. In Sweden, the forests have always been regarded as a common good, thereby promoting regulations and restrictions of private property rights. The “common good” has so far mainly been seen as an economic resource that provides important benefits to citizens, companies and public welfare. During the last half-century, the environment, the climate and ecosystem services have instead increasingly been defined as the common good. If this value shift from economic to environmental concerns continues, priorities in national politics will change. This outlook could entail, for instance, that all state-owned land (currently owned by Sveaskog and the National Property Board of Sweden) becomes nature reserves and that the state purchases more private forestland to further increase the formally protected area. Moreover, the ambition and scope of “retention forestry” and continuous cover forestry on privately owned land may be enhanced to ensure the provision of more ecosystem services.

This shift might also develop in a more bottom-up fashion, with small-scale forest owners as prime movers. Already today about 25 % of all Swedish forest owners no longer live near their forest property (SFA 2014), and this share is expected to grow. Research shows that among these forest owners, an economic and industrial-oriented forestry is not always prioritized (Nordlund & Westin 2011, Andersson & Keskitalo 2019). There are instead other purposes to own and manage forests, such as hunting, promoting biodiversity, mitigating climate change, shaping beautiful landscapes or preserving cultural heritage. There is likewise an openness to try other forms of forest management such as continuous cover forestry systems, mixed tree species production and the use of alternative tree species, close-to-nature-forestry, voluntary set-asides and active conservation management. Through established usufructuary rights – the Swedish right of public access as well as indigenous and hunting rights – other domestic actors and the public often also have a desire that management should create more natural-looking forests. Hence, a new form of forest owners in cooperation with other benefiters of the forests might together change the direction of forest management and use away from a forest industrial logic.

6.1.4 European wilderness

In this hypothetical outlook, Swedish forest policy becomes increasingly regulated by environmental edicts from the United Nations and the European Union. Already today, United Nations' policies such as the Convention on Biological Diversity, the Aarhus Convention, the Paris Agreement and the Sustainable Development Goals have a considerable influence. Likewise, the European Union's directives regarding species conservation, water and landscapes as well as Agenda 2030 are implemented in the Swedish forest context. In the European Union administrative system, forests and forestry are not a separate policy dominion. Instead these questions are placed under policy areas concerning industry, energy, agriculture or the environment, and it could well be that forest issues increasingly become a matter of environmental regulation. Such change may be reinforced by pressure from global environmental non-governmental organizations. Already in the early 1990s, after a heated forest debate and threats about international boycott of the forest industry, many European countries (and state-owned forests in the United States) turned to a "post-industrial forestry" with focus on ecosystem management to improve biodiversity and multifunctional uses (Mather 2001). In Sweden, this shift resulted in the "Swedish forestry model", where forest production interest still was the strongest part. However, as a small country in the fringes of Europe it may be hard to continue following a forest production-oriented route next time the international public opinion pushes towards a stronger environmental focus in forest politics.

The evolution of this outlook may also occur due to a market-based shift from resource extraction to global tourism. The forest industry is still a very important contributor to Sweden's national economy, but due to rationalization the work force has shrunk considerably. Especially in rural areas, a rationalized forestry no longer fully supports local employment and society, and with digitalization and automatization forestry may soon have a negligible influence on local economy. In this context, global tourism is often described as a savior that can create place-bound employment and local development, and ecotourism is an expanding business area. The Scandinavian mountain range in northern Sweden has for a long time been marketed as "the last European wilderness", and many visiting tourists probably would prefer not to see any traces of industrial forestry in this area. This understanding may expand to other forest areas around Sweden. Already today, there is in Europe a strong interest in "rewilding", i.e. restoring and protecting natural landscapes and ecological processes over large scales (Jepson 2016). Hence, to attract global tourism, rewilding management may become an economically viable option for private forest owners and local societies. An increased use of continuous cover forestry measures could also become a key tool for accommodating global nature-based tourism in managed forests as part of this hypothetical outlook.

6.2 Concluding remarks

The ideal-typical outlooks, including the two versions in each of them, are summarized in Table 6 regarding their orientation, main actors, mode of management and incentives.

Table 6. Summary of four hypothetical future outlooks for Swedish forest management.

	Orientation	Main actors	Mode of management	Incentives
The new forest sector	Production/ National	1. The forest industry	Rationalization and intensive forestry	Business development
		2. Small-scale forest owners	Adjusted management and technology	Rural development
The resource supplier	Production/ International	1. Global capital	Rationalization and/or migrant workforce	Raw material demand/ forestland takeover
		2. Global retailers	Increased demands on certification	Profit/ customer attitudes
National natural forests	Environmental/ National	1. The state/ domestic opinion	Nature reserves , enhanced retention forestry, continuous cover forestry	Environmental common good
		2. New forest owners	Alternative and varied	Individual motivations
European wilderness	Environmental/ International	1. UN/EU and global ENGOs	Ecosystem management	International politics and goals
		2. Global tourism/local societies	Rewilding, continuous cover forestry	Attract tourism/place-bound development

Traditionally, Swedish forest governance and management have strived for uniformity. However, the goal of the current forest policy is to achieve more “variation” in forestry (Miljödepartementet 2014; see Section 5.7). Some have also suggested that forestland could be more clearly differentiated regarding the main purposes of land use, such as in “triad” forest management (Klingström 2011). With these prospects in mind, the four hypothetical outlooks, including their variants, may be realized in different combinations, locations and scales. For instance, a more concentrated intensive and high-technological forestry may be combined with protected state-owned forests or rewilded private forestland to attract tourism and create rural development. Enhanced demands on certification from global retailers may similarly go hand-in-hand with adjusted management in small-scale private-owned forestry.

All the outlooks are extrapolations of trends that can be observed in the present, and hence presuppose that future developments are continuations of already existing paths. There might however occur radical events or regime shifts that could change this basis. Seen from our present situation, global climate change is a likely candidate in this respect. The expected effect on Swedish forests varies from optimistic scenarios that a warmer climate will create better conditions for forest growth (Lundmark *et al*. 2014) to pessimistic predictions about frequent fires, droughts, insect outbreaks and changing seasons, or even an ecological regime shift (Hanewinkel *et al*. 2003). Likewise, expected societal consequences vary from optimistic assumptions that climate change can be mitigated and handled by politics, the market and innovations to pessimistic predictions of unprecedented challenges for the democratic institutions, infrastructure, local society and international relations (Oreskes *et al*. 2014).

Since 1948, Swedish forest governance and policy have been relatively stable. In spite of a stronger environmental critique, a production-oriented forestry based on even-aged management (with some variations) has dominated during the whole period. Seen from a historical, ecological and climatic perspective, this is a short period of time, corresponding to one tree generation or less (depending on location), a few human generations, and a mere blink in climate system processes. Irrespective of what will influence the conditions for Swedish forest governance and management, unfolding courses of events might force society to rethink the very foundations of how forests should be understood, used and managed.

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2012:5 Skogsbrukets frivilliga avsättningar
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2016:13 Målanpassad ungskogsskötsel
2016:14 Översyn av Skogsstyrelsens beräkningsmodell för bruttoavverkning

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2018:14 Tillvarata jobbpotentialen i de gröna näringarna – Naturnära jobb – Delredovisning av regeringsuppdrag
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2019:24 Skogsskötsel med nya möjligheter – Rapport från Samverkansprocess skogsproduktion
2019:25 Mera Tall 2016-2019 – Redovisning/utvärdering (av annat projekt än regeringsuppdrag)

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2020:2 Registrering av nyckelbiotoper i samband med avverkningsanmälningar och tillståndsansökningar
Syntes och rekommendationer
2020:3 The second report on
The state of the world´s forest genetic resources
2020:4 Forest management in Sweden
Current practice and historical background

AV SKOGSSTYRELSEN PUBLICERADE MEDDELANDEN

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2012:1 Förslag på regelförenklingar i skogsvårdslagstiftningen
2012:2 Uppdrag om nationella bestämmelser som kompletterar EU:s timmerförordning
2012:3 Beredskap vid skador på skog
2013:1 Dialog och samverkan mellan skogsbruk och rennäring
2013:2 Uppdrag om förslag till ny lagstiftning om virkesmätning
2013:3 Adaptiv skogsskötsel
2013:4 Ask och askskottsjukan i Sverige
2013:5 Förstudie om ett nationellt skogsprogram för Sverige – Förslag och ställningstaganden
2013:6 Förstudie om ett nationellt skogsprogram för Sverige – omvärldsanalys
2013:7 Ökad jämställdhet bland skogsägare
2013:8 Naturvårdsavtal för områden med sociala värden
2013:9 Skogens sociala värden – en kunskapssammanställning
2014:1 Översyn av föreskrifter och allmänna råd till 30 § SvL – Del 2
2014:2 Skogslandskapets vatten – en lägesbeskrivning av arbetet med styrmedel och åtgärder
2015:1 Förenkling i skogsvårdslagstiftningen – Redovisning av regeringsuppdrag
2015:2 Redovisning av arbete med skogens sociala värde
2015:3 Rundvirkes- och skogsbränslebalanser för år 2013 – SKA 15
2015:4 Renskogsavtal och lägesbeskrivning i frågor om skogsbruk – rennäring
2015:6 Utvärdering av ekonomiska stöd
2016:1 Kunskapsplattform för skogsproduktion – Tillståndet i skogen, problem och tänkbara insatser och åtgärder
2016:2 Analys av hur Skogsstyrelsen verkar för att miljömålen ska nås
2016:3 Delrapport – Främja anställning av nyanlända i de gröna näringarna och naturvården
2016:4 Skogliga skattningar från laserdata
2016:5 Kulturarv i skogen
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2016:8 Agenda 2030 – underlag för genomförande – Ett regeringsuppdrag
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2017:3 Regeringsuppdrag om jämställdhet i skogsbruket
2017:4 Avrapportering av regeringsuppdrag om frivilliga avsättningar

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This report describes in a summarized form the historical development and current state of Swedish forest management. Additionally, it provides a few glimpses into possible futures. It is the fruit of a collaboration among experts in the fields of forest management, biodiversity conservation, history and political science.

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