WHAT DOES
SCIENCE
TELL US?

Forestry makes the soil grow

Our hidden carbon capture and storage

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Storing carbon in forest soils is an important contribution to mitigating global climate change. The report provides an overview of Swedish forest soils, including impacts of active forest management. It is based on leading forest soil science, official national statistics and national reports to the UN Framework Convention on Climate Change (UNFCCC).

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Summary

1

Responsible and active forest management, as practiced in Sweden, leads to major removals of atmospheric carbon, of which a significant proportion is safely stored in forest soils.

2

At the landscape scale, there is a persistent increase of carbon storage in forests, both in living biomass and in forest soils.

3

At the local, individual stand level, wood harvesting through clear-cutting and preparing forest sites for planting does not cause additional leakage of carbon. Instead, lower tree growth during the regeneration phase explains temporary net carbon losses in young stands.

4

Long-term forest management in Sweden builds soil carbon storage, mainly through increased forest growth and fire suppression.

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Active forest management is part of the climate solution

Forests are crucial for every dimension of sustainable development as articulated in the UN Strategic Plan for Forests.[1] Around the world different types of forests contribute to a diversity of social, economic and environmental aspirations. Well-managed forests enhance both human well-being and nature conservation – now and for future generations. This includes important opportunities for balancing our impact on the global climate.

Climate change negotiations have generally not focused on actively managed forests. Public sector investments have instead been channeled towards reducing deforestation as conversion of forests to other land uses cause large climate emissions.[2] Forests are also used in political "net-zero" targets, such as the EU Green Deal[3] aiming to park more carbon in forests so as to offset fossil emissions in other sectors. By contrast, benefits from active management of forests, including production of renewable wood-based products, have received less political attention.[4] Therefore, significant opportunities for climate solutions from forests may be unaccounted for.

Recent reports have highlighted how the forest-based sector contributes to climate goals.[5] As a co-benefit of financial returns, the circular forest-based bioeconomy (Figure 1) leads to both increased storage of carbon in the forest and displacement of fossil emissions by wood-based products.

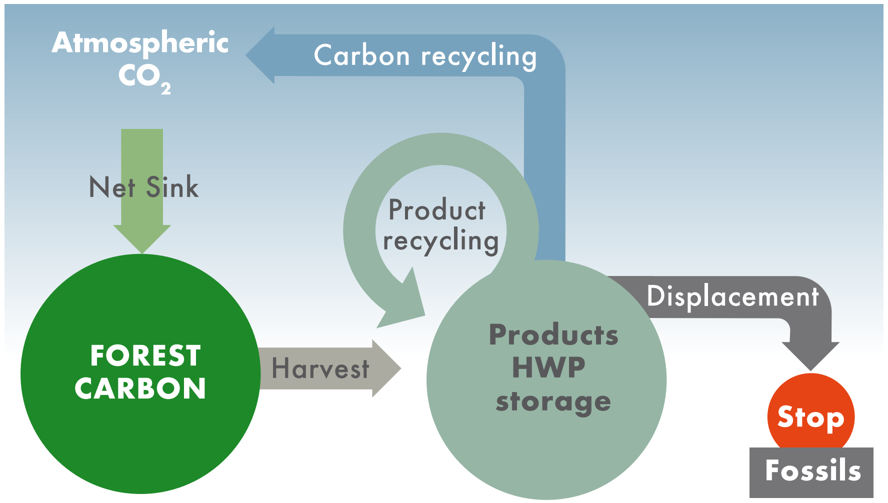


FIGURE 1. Illustration of carbon flows in the circular forest bioeconomy, including reduced fossil emissions through displacement. Forest carbon includes carbon in the soil.

1. United Nations, 2017
2. UNFCCC, 2015
3. European Commission, 2021
4. Holmgren, 2021; Kauppi et al., 2020
5. e.g., Jonsson et al., 2021; JRC, 2021; Swedish Forest Industries, 2021

The Swedish forest soil inventory

Since 1983, forest soils are monitored at 23,500 fixed sample plots distributed systematically across Sweden and revisited over a ten-year cycle. Soils are sampled and evaluated as to physical, chemical, organic, morphological and biological properties (Figure 2).

The inventory is funded by the Swedish Environmental Protection Agency and implemented by the Swedish University of Agricultural Sciences.[6] It is integrated with the National Forest Inventory, which means that soil data can be directly linked to tree and vegetation developments on each plot. The large and representative sample over almost 40 years constitutes a solid foundation for many scientific studies, assessment of national environmental indicators and for reporting to the UNFCCC.

Every year, all EU countries report their climate impact to the UNFCCC in so-called National Inventory Reports.[7] These reports include a section on Land Use, Land Use Change and Forestry (LULUCF) where changes in biomass and soil carbon pools are provided. For changes in forest soil carbon, many EU countries state "not occurring", "not applicable" or "not estimated", alternatively report modeled estimates, mainly because systematic soil monitoring systems are not in place. One exception is Germany where the national forest soil inventory reports increasing soil carbon in managed forests.[9] Nine EU countries report on changes in forest mineral soils (EEA, 2021, p.695). Sweden stands out with its ambitious and systematic national forest soil inventory, providing accurate information based on measurements – of forest soil carbon developments over time.

6. SLU, 2021
7. EEA, 2021
8. Grüneberg et al., 2019
9. EEA, 2021, p.695

Photo: Johan Stendahl, SLU

FIGURE 2. The Swedish Forest Soil Inventory monitors soil developments at 23,500 plots systematically distributed across Sweden.

Forest soils in Sweden

Forest soils have an important role in the climate change equation. In Sweden, as elsewhere in temperate and boreal forest, soils store more carbon than living trees (Figure 3). Processes and changes in the forest soil are, however, much slower than in the living tree biomass. Nevertheless, also slow changes in such a major carbon pool, 5.8 gigatons of carbon dioxide equivalents (Gt CO_2e) can significantly influence the atmosphere. Without knowledge on forest soil dynamics and how we impact them, an analysis of the circular forest bioeconomy will not be complete.

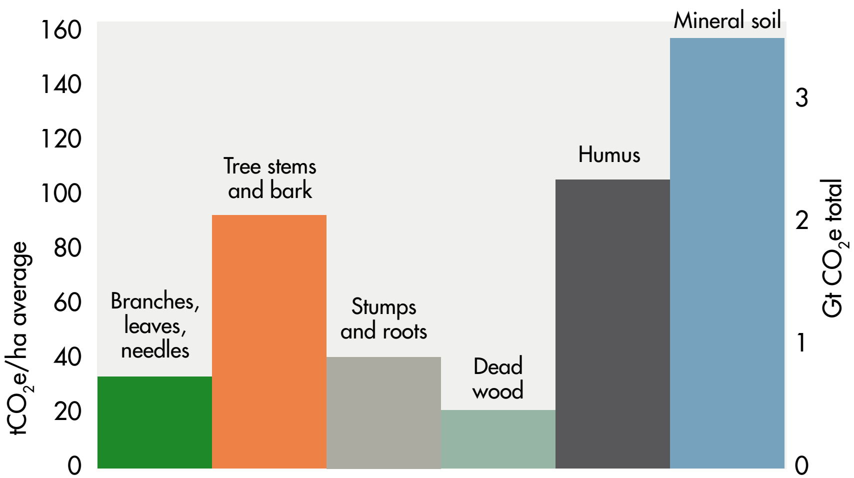


FIGURE 3. Carbon storage in Swedish forests by major carbon pools. Humus and mineral soil contain 260 t CO_2e/ha or totally 5.8 Gt CO_2e. This corresponds to 59% of the forest carbon storage. *Data from the Swedish Forest Soil Inventory and National Forest Inventory (SLU, 2017).*

Forest soils are complex and also display a high degree of variation. While trees and tree growth are relatively straightforward to measure and model, soil properties develop slowly and are highly variable – physically, chemically and biologically – also in the local scale. This makes them notoriously difficult to sample, measure and monitor with acceptable statistical accuracy. On a continental scale, such as Europe, it is impossible to generalize across a multitude of soil types that have been exposed to quite different climatic, geographic and historic conditions.

In Sweden most forest soils have been shaped after the latest glacial period, meaning that most forest soils are young (<10 000 years). Another feature is that due to a cold and humid climate, decomposition of biomass is slower than the input (provided mainly as litter from trees) which leads to an accumulation of forest soil carbon over time. Besides the biomass input, most Swedish forest soils have historically been influenced by wildfires that were frequent on most land until forests gradually came under active management. Over the past 150 years, wildfires have been suppressed, allowing soil carbon to steadily increase on practically all land.

The Swedish Forest Soil Inventory provides a wide range of representative and statistically verified information about forest soils. Figure 4 shows the large-scale spatial variation with highest soil carbon contents in the south-west where forest growth is relatively high. Figure 5 is important for this report as it shows the soil carbon content across age classes in the forest. It confirms that forest carbon content does not vary significantly with stand age, which suggests that there is little impact during the phase of clearcutting and regeneration.

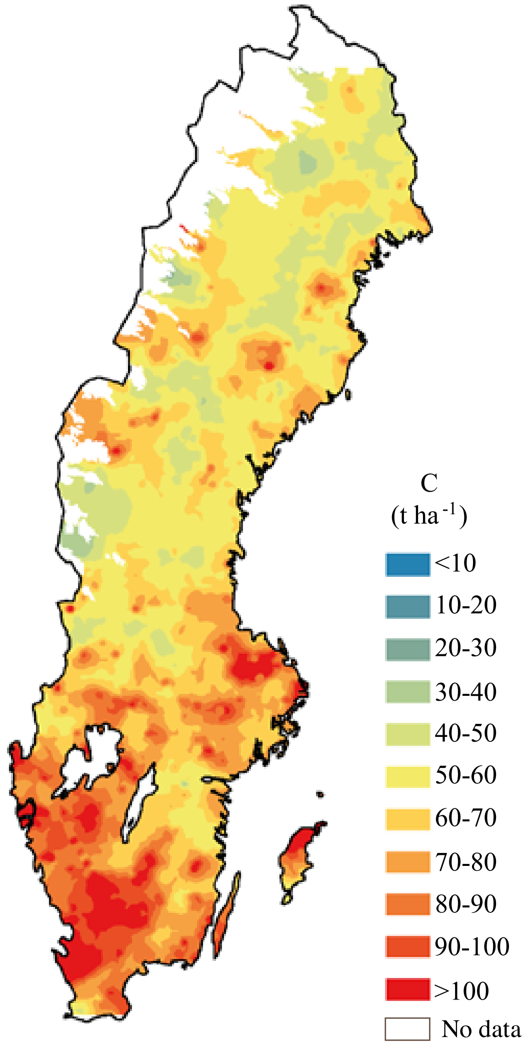


FIGURE 4. Variation of forest soil carbon across Sweden on productive forest land (about 2/3 of the overall land area). Soil carbon content is highest in the South-west where forest productivity is also highest *(SLU, 2017).*

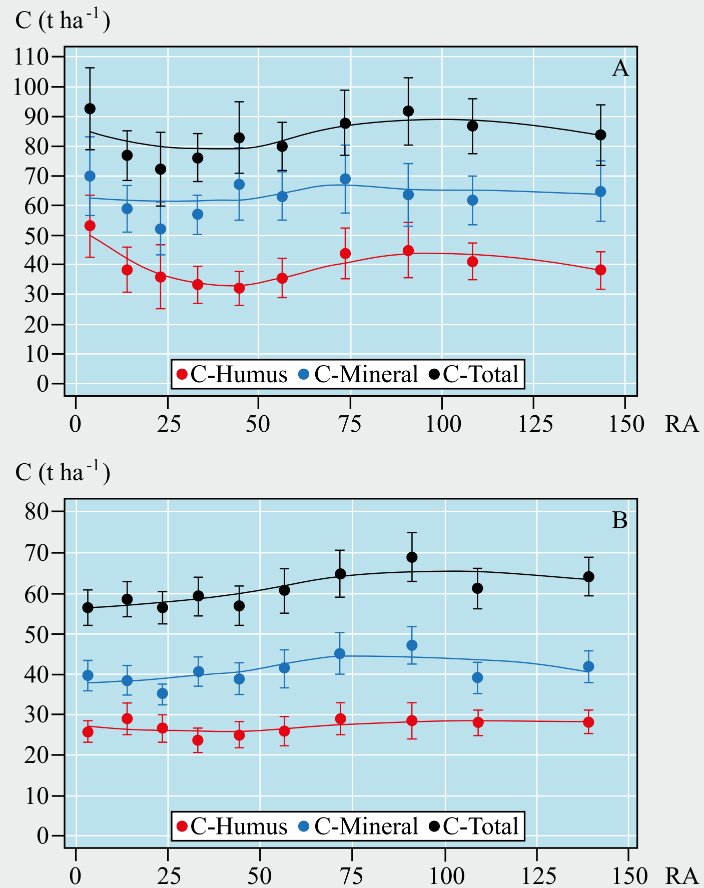


FIGURE 5. Variation of forest soil carbon across stand age for actively managed forests in southern region Götaland (at the top, representing 5 million ha) and northern regions Svealand and Norrland (at the bottom, representing 18 million ha). Small fluctuations across stand ages suggests that the clear-cutting and regeneration phase does not significantly impact the soil carbon development (Stand ages on the x-axis have been normalised to Relative Age (RA), expressing the stand age in percentage of the normal stand rotation time for the site in question). *(SLU, 2017)*

Key concerns on forestry and soils
Clear-cutting and site preparation

Concerns have been raised that common forest management practices in Sweden have a negative impact on forest soil carbon. Specifically clear-cutting and site preparation for new stands have been targeted. Some senior scientists have stated that "clear-cut sites release a lot of carbon dioxide for a long period of time". [10] Similar claims have been used to influence policy in opinion pieces[11] as well as national public service news[12] and international press.[13] Also the recent EU Forest Strategy alludes to soil carbon losses after clear-cutting.[14] But is this true?

Views that clear-cutting and site preparation are negative for the global climate seem to be based on a too narrow perspective – both in time and space. For a complete and correct picture, it is necessary to consider

(a) the overall carbon flows over time for a single forest stand and

(b) how developments in a single stand fits into the wider managed forest landscape.

Clear-cutting is part of the rotational forest management system generally applied in Sweden and many other forestry regions. Following the harvesting of trees, the stand is regenerated – usually through site preparation and planting. Additional natural regeneration leads to a mix of planted and naturally regenerated tress in the new stands.15 The stand is tended and thinned until the new stand is between 60 and 100 years old – depending on the location within Sweden – at which time harvesting commences again. Management includes nature conservation measures, which have been implemented incrementally under the current forest law of 1994.16 It is also important to consider that the managed forest landscape contains a mosaic of stands in different ages as well as set-aside conservation areas.

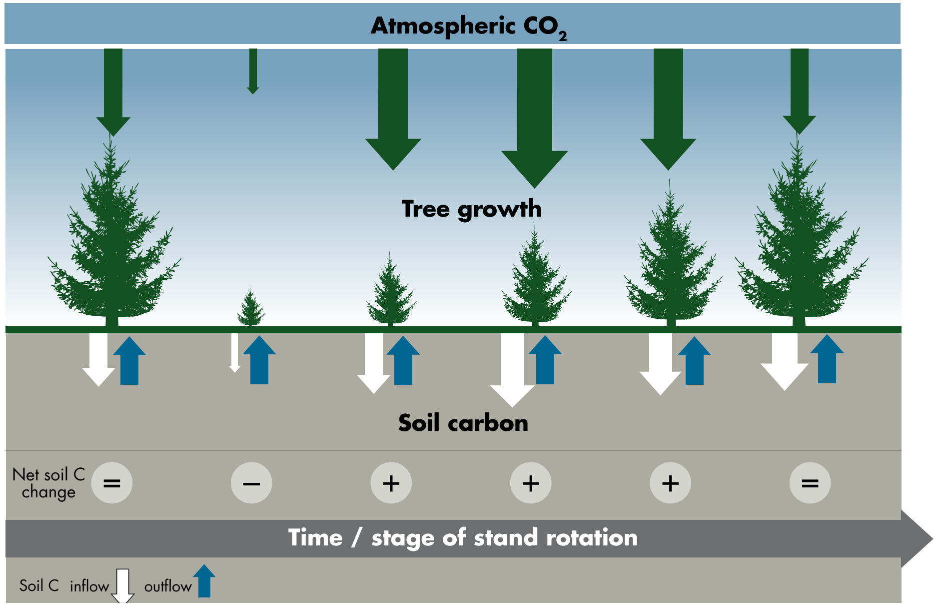


FIGURE 6. Indicative illustration of main carbon flows over a stand rotation. Fluctuation in the inflow of organic matter is the main determinant for net changes of soil carbon. *Based on Naturvårdsverket (2020) and SLU (2017)*

10. Protect The Forest Sweden and Greenpeace Nordic, 2021
11. Svenska Dagbladet, 2017
12. Sveriges Television, 2021
13. de Volkskrant, 2021
14. European Commission, 2021
15. SLU, 2019
16. Swedish Forest Industries, 2021

Rotational forest management has evolved based on centuries of forestry experience and science. For most Swedish conditions it is considered a superior method for ensuring a high and valuable wood production over the long-term, which is why alternative continuous-cover approaches are seldom applied anymore. Selective felling practices were widely applied before 1960. Subsequent transition to rotational forestry has led to large increases in forest growth, higher average stocks and consequently greater wood harvests.

Clear-cutting and site preparation leads to two possible impacts on soil carbon dynamics[17]:

1. The inflow of organic material is reduced as tree growth is temporarily lower in the regenerated stand, which leads to lower production of litter. This is an obvious and uncontroversial effect that can also be accurately quantified through tree measurements and tree growth modeling taking into account also growth by non-tree vegetation. One also need to consider the pulse of organic material inflow at the harvesting event – leaves, branches, roots and stumps that are left in the forest – as this to some extent compensates for a lower production of litter in years to come (Figures 6 and 7);
2. The rate of carbon outflow may change due to the removal of trees and changes in the microclimate after harvesting. This can affect respiration by soil organisms during decomposition of organic matter, temporarily leading to either increased or decreased emission of carbon dioxide. Here, neither the magnitude or the direction of change is obvious, and it is difficult to draw general conclusions. The literature is, however, clear in that the magnitude of change is much smaller than changes in organic material input.[18] (Figure 6 and 7).

17. Mayer et al., 2020
18. Johnson, 1992; Mjöfors, 2015; Mjöfors et al., 2017

Conclusively, at the stand level soil carbon fluxes will be determined mainly by tree growth. Further, it is not accurate to characterize the changes in soil carbon after clear-cutting as "increased losses". Rather, it is the dynamic and normal effect of tree growth in rotational stand management that causes a temporary reduction of organic inflow, and thereby a temporary net loss of forest carbon. This is further corroborated by results from the Swedish Forest Soil Inventory as discussed above (Figure 5)

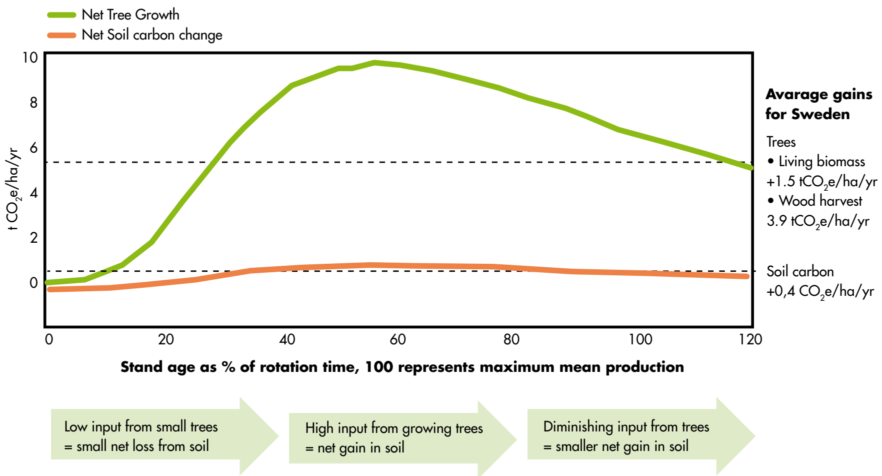


FIGURE 7. Schematic illustration of carbon dynamics in a forest stand as a function of stand age. Tree uptake of carbon varies considerably more than soil carbon change. Young stands have a net loss of soil carbon, due to lower production of biomass. In total both living biomass and soil carbon increase in Swedish forests. *Based on Naturvårdsverket (2021), SLU (2021b, 2017)*

Long-term impact of active forest management

For a complete picture, we need to take single-stand developments to the landscape level where we will find stands across all ages. For a typical Swedish forest landscape we know that there is a steady increase of standing tree volume as harvesting is lower than the growth.[19] Every year the carbon storage in Swedish living trees increase by about 35 million tons of carbon dioxide equivalents (CO_2e). In addition, forest soils show a steady carbon storage increase at about 5 million tons per year. Taken together, the net sink in the forest counteracts about 80% of Swedish territorial emissions of greenhouse gases[20]. Over the past 30 years, Swedish forests have drawn down and kept away 1.16 gigaton carbon dioxide (Gt CO_2) from the atmosphere (Figure 8).

The average forest soil in Sweden contains ca 70 tons of carbon per hectare, which means that the average post-glacial accumulation over the past 10 000 years has been 0.007 ton carbon per hectare and year (tC/ha/yr) (or 7 kgC/ha/yr). However, current accumulation in forests with mineral soil is much higher at about 0.1 tC/ha/yr. Finland reports a similar rate for their mineral soils[21], whereas other boreal regions where forest management is less intensive have significantly lower rates of soil carbon accumulation.

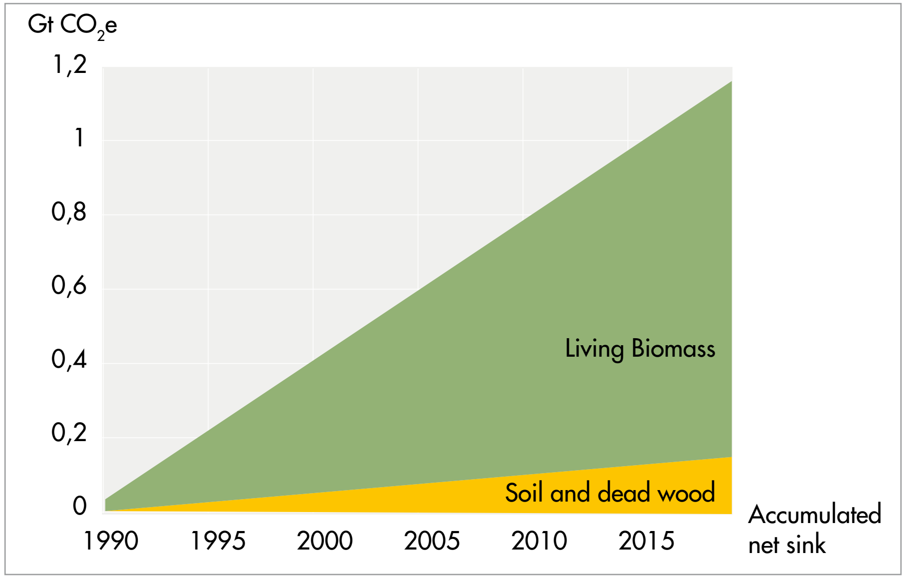
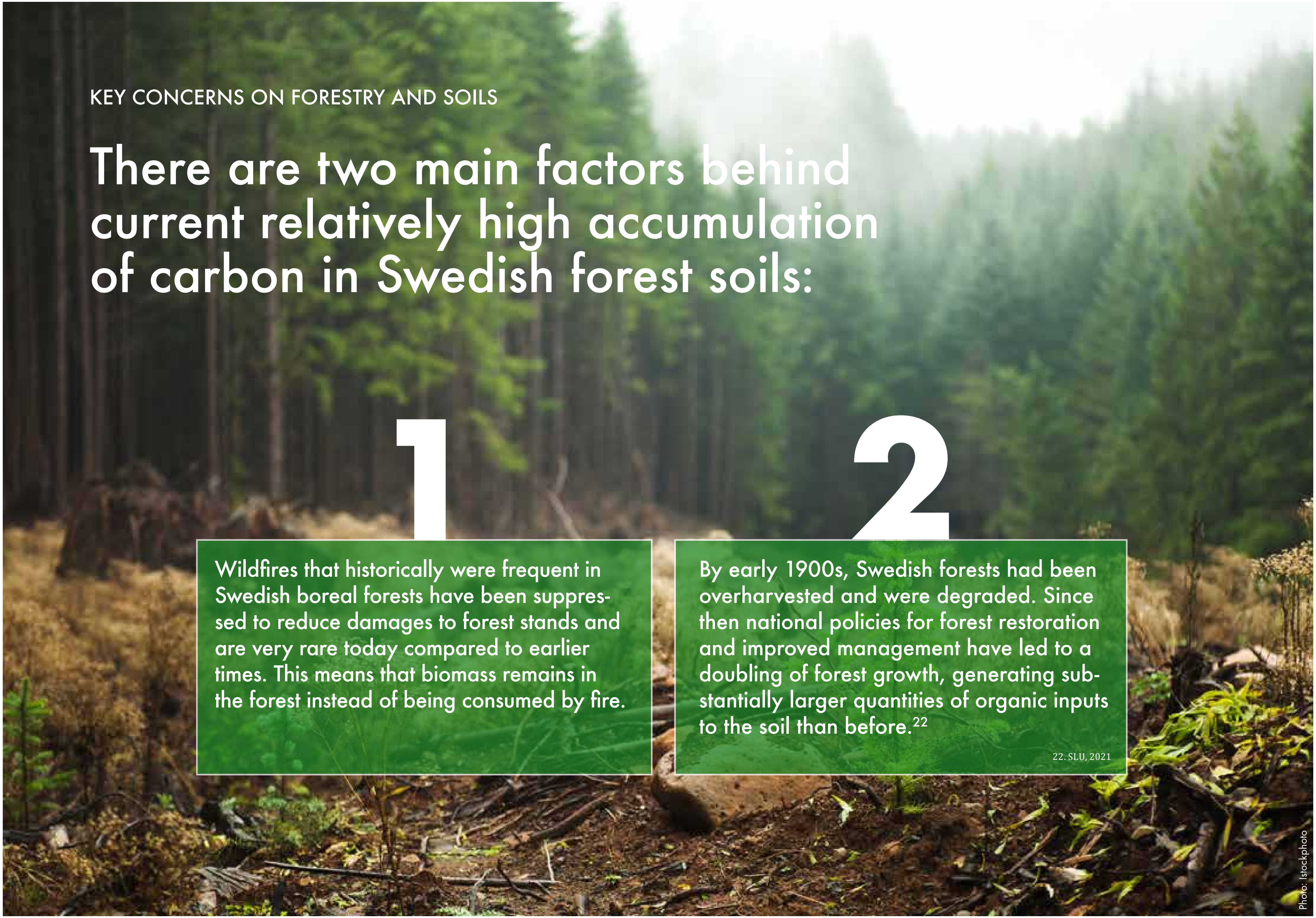


FIGURE 8. Accumulated net carbon sink in Swedish forests since 1990 as reported by Sweden to UNFCCC *(Naturvårdsverket, 2021)*. The net sink in soils include gains in mineral soils (>90% of the land area) and losses in organic soils (<10% of the land area).

19. SLU, 2021
20. Naturvårdsverket, 2021
21. Statistics Finland, 2021



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There are two main factors behind current relatively high accumulation of carbon in Swedish forest soils:

1

Wildfires that historically were frequent in Swedish boreal forests have been suppressed to reduce damages to forest stands and are very rare today compared to earlier times. This means that biomass remains in the forest instead of being consumed by fire.

2

By early 1900s, Swedish forests had been overharvested and were degraded. Since then national policies for forest restoration and improved management have led to a doubling of forest growth, generating substantially larger quantities of organic inputs to the soil than before.[22]

22. SLU, 2021

Other considerations

- Organic soils represent less than 10% of productive forest land in Sweden[23] but require attention as the balance between uptake and losses is more delicate. In addition to carbon dioxide other GHG gases (NH_4 and N_2O) may be released if the water table comes close to the surface. Temporary drainage is sometimes applied during forest regeneration as the ground water table rises after harvesting. This aims to maintain the water table below the surface, thereby facilitating plant growth.

- As opposed to mineral soils, organic soils are often a source of carbon, often due to historical drainage of the land. Losses from organic forest soils are reported at about 5 million tons of CO_2e per year[24] and are included (Figure 8). This estimate includes the emissions of methane and nitrous oxide converted into CO_2-equivalents.

- During forest logging operations, heavy machinery may impact soil processes, e.g. through compaction. However, there is no available evidence whether this leads to changes in soil carbon storage.

- Climate change affects Swedish forests. Some scenarios point to a higher growth due to warmer conditions. Others to higher risks and constraints due to droughts or other weather extremes.[25] Impacts from these changes on forest soil processes are not yet well understood.

23 Nilsson et al., 2015
24 Naturvårdsverket, 2021
25 IPCC, 2021

Conclusion

Active forestry leads to increasing carbon storage in forest soils throughout Sweden. The reasons are that long-term and stable demand for wood (a) stimulates forest growth through silviculture measures and (b) motivates the suppression of fires.

Clearcutting and soil preparations do not cause additional carbon leakage in managed forests under rotational management.
Soil carbon fluxes are mainly determined by tree growth in the stand, which is temporarily lower during the regeneration phase.

Sweden has a world-class national inventory of forests and forest soils. As a result we have long-term time series of measurements that provide verified knowledge of real-world developments. At the same time, investments must continue towards improved data, innovative research and enhanced official statistics.

Photo: Istockphoto

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