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COMMENTARY

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Widespread Unquantified Conversion of Old Boreal Forests to Plantations

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Key Points:

- Old previously uncut boreal forests are cut at a fast rate
- The conversions of natural boreal forests to planted and seeded managed forests are not monitored
- The slow growth of boreal forests implies that the present natural to managed forest conversions may define the landscapes for centuries

Supporting Information:

Supporting Information may be found in the online version of this article.

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Abstract Across the boreal biome, clear-cutting of old, previously non clear-cut forests with high naturalness followed by tree planting or seeding is a major land use change. However, how much previously uncut forest has been converted to plantations remains unquantified. We combine Swedish national databases on clear-cuts and forest inventories to show that at least 19% of all clear-cuts since 2003 have occurred in old forests that were most likely not previously cut and planted or seeded. Old forests have been cut and lost at a steady rate of ~1.4% per year for the same period, and at this rate they will disappear by the 2070s. There is further evidence that this type of unreported forest conversion is occurring across much of the world's boreal forest.

Plain Language Summary Natural ecosystems that have seen limited direct human impact are threatened by land use change. Land use in boreal regions is dominated by forestry but the rate at which older boreal forests with high naturalness are converted to planted and seeded forest for wood harvesting remains unquantified. We used a set of uniquely detailed databases and maps to estimate the share of old and previously uncut forests in annual harvests and at which rate these forests are being lost in Sweden. The results indicate that about a fifth of cut forest area since 2003 was cuts of previously uncut old forest. If the present trajectory continues, the remaining unprotected old and previously uncut forests will be converted to planted and seeded managed forests within a couple of decades. Given the slow development and distinct structural and ecological characteristics of these old forests, this loss may define the landscape for centuries.

1. Introduction

Forests provide a range of critical ecosystem services to society (Gauthier et al., 2015; Millennium Ecosystem Assessment, 2005; Pan et al., 2011). Monitoring and managing forests to maintain these services, under increasing demand for wood products (European Commission, 2013) across a diversity of forest types and land uses, is challenging. One key prerequisite to meeting this challenge is distinguishing natural forests and forests established through planting or seeding following harvest, that often exhibit profound differences in ecological and biogeochemical functions (Savilaakso et al., 2021; Vilà et al., 2013). Older, uncut boreal forests store more carbon (Fredeen et al., 2005; Jonsson et al., 2020) and harbor larger numbers of species than planted forests do (Bradshaw et al., 2009; Jonsson et al., 2020; Patry et al., 2017; Savilaakso et al., 2021), in part linked to larger amounts of old and large dead trees (Fridman, 2000; Martin et al., 2021; Nordén et al., 2013; Santaniello et al., 2017). In an increasingly fragmented landscape, strict protection of these old forests may greatly increase habitat connectivity (Mikusiński et al., 2021), which is also culturally and economically important, for recreation and for reindeer herding because lichens found mainly in older forests are important winter food (Sandström et al., 2016).

Global assessments based on remotely sensed tree cover are often not able to distinguish between these two types of forest cover, despite their profound ecological differences (Hansen et al., 2013). These difficulties are amplified in boreal forests, where the diversity of trees is comparatively low, and where native species are often planted or seeded directly or using seeding trees. The relatively long rotation time (time between planting/seeding to clear-cut can be up to 100 years) also implies that historical conversions may predate both aerial and satellite records. This means that conversions from natural boreal forests to planted and seeded forests, with associated shifts in carbon storage, biodiversity and other forest values, are more difficult to detect than, for example, a conversion of

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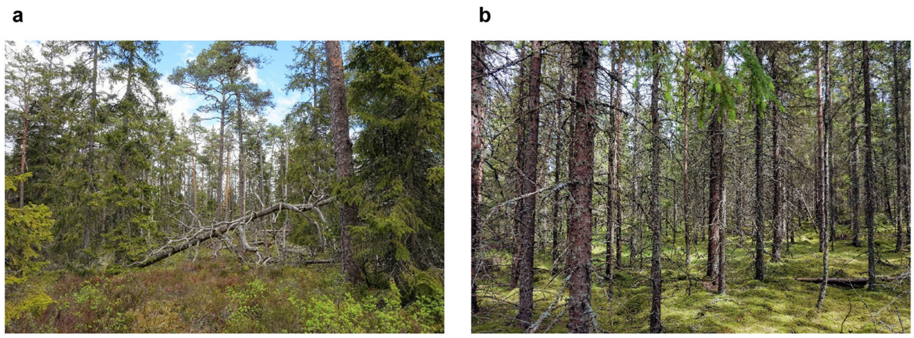

Figure 1. Example photographs of (a) an older uncut forest, and (b) an adjacent planted forest. The photos origin from southern Sweden.

tropical forests to oil palm plantation (Chong et al., 2017). Partly due to these difficulties, countries with boreal forest do not systematically map or track such conversions (Harris et al., 2019; Naturvårdsverket, 2020).

As a first insight into the potential extent, rate and spatial pattern of conversion from older uncut forest to planted and seeded forest in the boreal zone we use a uniquely detailed set of databases on forest structure and clear-cutting available in one major boreal forest nation: Sweden. Sweden has the largest forest cover in Europe (excluding Russian Federation) and is a major exporter of sawnwood and paper (8% of world exports in 2019) (FAO, 2021). Forestry in Sweden is currently almost exclusively rotation-forestry, where large areas of forests are clear-cut, planted, thinned and then cut again over a time scale of 50–100 years. This management follows government regulations designed to promote wood production, and lately, to limit negative impacts on biodiversity (Lindahl et al., 2017). Examples of an uncut forest and a planted forest are shown in Figure 1.

2. Methods

We cross-referenced the stand ages of a large database of forest inventory plots ($n = 74{,}288$) surveyed from 1996 to 2019 with a national clear-cut database to determine the rate and pattern of clear-cutting in differently aged productive forests. The clear-cut database comprises spatially explicit geographical polygons delineating close to a million compulsory reported individual cuts from 2003 until 2019, verified by the Swedish forest agency (Skogstyrelsen, 2021a). The inventory plots were established by the Swedish forest inventory on five regional grids spanning the whole country, designed to provide an unbiased sample of unprotected productive forest land nationally (Fridman et al., 2014). A basal area weighted stand age is calculated in each inventory plot, based on age determination of tree cores from a subset of cored trees (3–5 trees). In plots with uneven tree age, this implies that the oldest tree in the plots will be older than the stand age.

To produce estimates of forests and clear-cuts for all of Sweden from the NFI plot level data we averaged regional estimates using the productive forest area as weights and estimated confidence bands using bootstrapping. Further details on the methods with associated figures and an uncertainty assessment are available in Supporting Information S1.

2.1. Using Stand Age to Infer Naturalness

The only available map of potentially uncut forest does not include southern Sweden and is based on aerial photography and satellite images where the earliest photos were taken 1955 to 1970, depending on location (Ahlkrona et al., 2017), implying that it is unlikely that this map will capture early clear-cuts.

Since there is no national map indicating whether a forest has been clear-cut and planted or seeded we relied on historical records to relate plot-level stand age with the likelihood of past clear-cutting and planting or seeding. Analysis of the discussion and articles in the Journal of the Forest Association of northern Sweden between 1883 and 1960 (Lundmark et al., 2013) and a regional study using aerial photography from the 1940s indicates that the widespread adoption of rotation-forestry in Sweden occurred between 1900 and 1950, with ~10% of the forest area being clear-cut by the early 1900s (Lundmark et al., 2021). Forests with a current mean plot-level

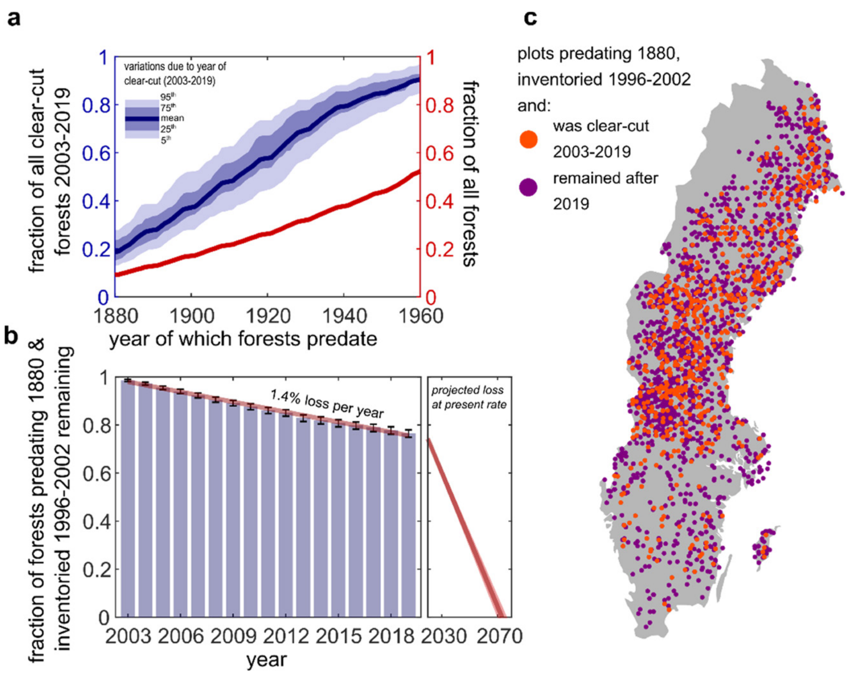

Figure 2. Clear-cutting and losses of old and potentially uncut forest. (a) Fraction of clear-cuts during 2003–2019 by which year the forests predate. The shaded blue area indicates the variability between years 2003–2019, and their mean. The red curve indicates the fraction of all inventoried forests 2003–2019 that predates a given year. (b) Fraction of plots with stand age predating 1880 and inventoried 1996–2002 and remaining in 2003–2019. The fraction not remaining has been clear-cut. The red curve indicates a regression curve of losses of plots with stand age predating 1880 ($R^2 > 0.99$). The right-hand panel show a projection based on the regression curve from the end of the analysis period (2020 and forward). Light red shading indicates 95% confidence intervals. (c) Map of the plots traced in panel (b) indicating where plots with stand age predating 1880 have been clear-cut between 2003 and 2019 and where they remained after year 2019.

stand age substantially predating this transitional period (predating 1880 for the purpose of our analysis) have therefore likely never been clear-cut. We analyzed forest plots based on the year their stand age predated instead of an approach based solely on stand age which changes over time and where the loss of old uncut forests can be compensated by an increasing share of planted and seeded forests when they age (Skogstyrelsen, 2021b).

3. Results

Forests predating 1880 (>140 years old in 2020) accounted for 18.7% (95% CI: [17.6, 19.8]) of clear-cuts between 2003 and 2019 (Figure 2a). Since these forests predate the onset of widespread clear-cutting by some margin, this suggests that a considerable portion of recent harvests have relied on the conversion of old uncut forest to clear-cut and planted and seeded forests.

Because also young forests may not have experienced clear-cutting but regenerated following natural disturbances or more intensive selective logging, an unknown fraction of younger forests not predating 1880 may also be previously non clear-cut forests. For all age classes of potentially uncut forests, their share of clear-cuts is ~2 times higher than their relative abundance across the country, implying that old uncut forests are being inadvertently or otherwise targeted (Figure 2a).

By tracing the fate of all unprotected forest plots with stand age predating 1880 and inventoried between 1996 and 2002, we find that forest land predating 1880 have been cut at a remarkably stable rate of 1.40% (95% CI: [1.33, 1.46]) per year since 2003 (Figure 2b). The clear-cutting of these older forests occurs across the country but is more common in the north, in large part because many of the older forests in southern Sweden were already clear-cut by 1996 (Figure 2c). At this rate, all unprotected older forests in Sweden will be converted to planted or seeded forest within decades (year ~2073, 95% CI: [2070, 2076]). Only 19.1% (95% CI: [17.8, 20.4]) of forests predating 1880 and inventoried between 2003 and 2019 are protected under some kind of regulatory framework, and 0.95% (95% CI: [0.59, 1.50]) are strictly protected in national parks (overlay with maps on protection from Naturvårdsverket (2021)). The unprotected, old and non clear-cut forests may provide a richer set of ecosystem values than similar forests in currently protected areas because the unprotected forests are generally found in warmer, more productive regions.

4. Discussion and Conclusion

The conversion of old natural forest to planted and seeded forests has potentially important implications for ecosystem functions and local communities but remains poorly understood in part because the pattern and rate of the forest conversion has not been systematically monitored. The extent to which clear-cut and planted and seeded forests achieve the same ecosystem functions and values as uncut, natural and freely developing forests, and over what time scale, remains poorly known. Given this lack of knowledge and the rate at which the old forests are cut, further work addressing these knowledge gaps is an urgent priority.

Beyond Sweden, large scale analysis and modeling of high-resolution satellite remote sensing data suggests that forestry is the major driver of widespread harvest (around 10% gross tree cover loss between 2001 and 2021 in Canada and the Russian federation (World Resource Institute, 2014)) of more southern and more productive forests throughout the boreal biome (Curtis et al., 2018). A regional study from eastern Canada suggests that the majority of this harvest is associated with clear-cuts of the most productive old boreal forest stands (Martin et al., 2020). These regional and remote sensing-based assessments echo our results for Sweden, which together with other supporting scientific literature (Bradshaw et al., 2009; Cyr et al., 2009; Potapov et al., 2012) and some anecdotal evidence from media and NGO reports (Eremenko, 2014; Lindwall, 2019; Vinyard & Skene, 2020) strongly suggest that this process is not limited to Sweden but widespread across the boreal forest zone.

We argue that it is crucial that these land conversions are mapped and monitored across the boreal zone in a coordinated and systematic way, and that targeted studies investigate the implications of the conversions for carbon storage, biodiversity, recreational and cultural values. Given the widespread disapproval about similar conversions in tropical countries we call upon northern governments to urgently investigate these ongoing large-scale conversions in their own territories, to map their scope, analyze their implications and, where feasible, to protect the forests that have not yet been clear-cut.

Data Availability Statement

The clear-cutting database is publicly available at http://geodpags.skogsstyrelsen.se/geodataport/feeds/UtfordAvverk.xml. The forest plot data is available from the following open access database: https://zenodo.org/record/7244666 (https://doi.org/10.5281/zenodo.7244666).

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