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Effects of Forestry Intensification and Conservation on Green Infrastructures: A Spatio-Temporal Evaluation in Sweden

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Abstract: There is a rivalry between policies on intensification of forest management to meet the demands of a growing bioeconomy, and policies on green infrastructure functionality. Evaluation of the net effects of different policy instruments on real-world outcomes is crucial. First, we present data on final felling rates in wood production landscapes and stand age distribution dynamic in two case study regions, and changes in dead wood amounts in Sweden. Second, the growth of formally protected areas was compiled and changes in functional connectivity analysed in these regions, and the development of dead wood and green tree retention in Sweden was described. The case studies were the counties Dalarna and Jämtland (77,000 km^2) representing an expanding frontier of boreal forest transformation. In the wood production landscape, official final felling rates averaged 0.84%/year, extending the regional timber frontier. The amount of forest <60 years old increased from 27–34% in 1955 to 60–65% in 2017. The amounts of dead wood, a key forest naturalness indicator, declined from 1994 to 2016 in north Sweden, and increased in the south, albeit both at levels far below evidence-based biodiversity targets. Formal forest protection grew rapidly in the two counties from 1968 to 2020 but reached only 4% of productive forests. From 2000 to 2019, habitat network functionality for old Scots pine declined by 15–41%, and Norway spruce by 15–88%. There were mixed trends for dead wood and tree retention at the stand scale. The net result of the continued transformation of near-natural forest remnants and conservation efforts was negative at the regional and landscape levels, but partly positive at the stand scale. However, at all three scales, habitat amounts were far below critical thresholds for the maintenance of viable populations of species, let alone ecological integrity. Collaboration among stakeholder categories should reject opinionated narratives, and instead rely on evidence-based knowledge about green infrastructure pressures, responses, and states.

Keywords: biodiversity; bioeconomy; forest management; functional connectivity; policy implementation; spatial modelling; land sparing

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1. Introduction

Scenarios of climate change and forestry intensification have triggered the emergence of the three concepts circular economy, green economy, and bioeconomy. They are currently mainstreamed as key sustainability avenues with relevance for how forests ought to be managed [1]. D'Amato et al. [2] compared these concepts and concluded that green economy acts as an umbrella concept, which encompasses circular economy, and bioeconomy elements such as eco-efficiency and renewables, and nature-based solutions. However, the first two are more resource-focused, whereas green economy acknowledges ecological processes as a foundation. Regarding the social dimension, the green economy also includes eco-tourism and education, while the bioeconomy literature captures biosecurity and rural policies. Despite this, there seems to be little consensus about what bioeconomy actually implies. Bugge et al. [3] made a bibliometric analysis showing that bioeconomy research is distributed across many disciplines. Three visions of bioeconomy were identified, that is (1) bio-technological commercialisation, (2) a bio-resource vision focusing on establishing new value chains, and (3) a bio-ecology vision focusing on sustainability by optimising the use of energy and nutrients in ecosystems, promoting biodiversity, and avoiding monocultures. When considering weak vs. strong sustainability visions [4], all three visions identified by Bugge et al. [3] remain limited in questioning the current economic growth paradigm (e.g., [5–7]). Current debates about what sustainable forest management vs. bioeconomy is [3,8], and the trade-offs among different benefits of forest landscapes (e.g., [9,10]), calls for systems analyses defining both shallow and deep leverage points for the evolution of policy cultures, governance, and management [11].

As demonstrated by Fischer et al. [12] and Jakobsson et al. [13] contemporary conflicts concerning forest use in Sweden involve stakeholders with diverse portfolios of values, emotions, and opinions. However, empirical evidence-based knowledge about the states of forest landscapes is often not considered [14], and conflicts on forest issues are driven by opinions of strong stakeholder groups, such as the forest industry, some forest owner associations, and stakeholder groups focusing on single forest benefits. Coping with this wicked problem calls for effective documentation and communication of the net effects of pressures and responses on states (c.f., [15]) of representative habitat networks in forest landscapes (i.e., green infrastructures). This requires evidence-based estimates on the net effect of forestry intensification supporting a growing bioeconomy, and forest conservation instruments contributing to green infrastructure functionality. First, pressure including tree harvesting that changes stand age distributions in landscapes, deforestation through the establishment of wind energy facilities, mining, transport infrastructure, as well as changes in forest stand structure, may all affect green infrastructure functionality. Second, responses are measures taken to conserve biodiversity in the form of increased areas of formal and voluntary protection, new forest management systems, as well as habitat and landscape restoration. Third, estimates of the resulting states of representative green infrastructures for the conservation of biodiversity and provision of ecosystem services are needed.

Learning through evaluation [16] aims at assessing consequences of activities aimed at implementing policy about biodiversity conservation, i.e., species, their habitats, and the processes that maintain them (e.g., [17]). In Sweden, two key national-level guiding policies are the current forest policy [18], and the policy about biodiversity and ecosystem services [19]. The latter mirrors the Aichi targets [20], the EU strategy for biodiversity conservation by 2020 [21], and the European Commission's [22] document on green infrastructure. These Swedish policies prescribe "*conservation of naturally occurring species*", and "*by 2020 at least 20 percent of Sweden's land- and freshwater areas* … *should be protected or conserved*", which form " … *ecologically representative and well connected systems where reserves, other effective area-based protection actions or environmentally adapted use are parts. The systems shall be integrated in surrounding landscapes and be governed in an effective and inclusive manner.*" ([19] p. 91). Application of policy implementation tools including strategic, tactical, and operational planning, and subsequent management, is time-consuming. In addition, the net effects of contradictory policies and their consequences on the ground at different scales take time to develop. Societal processes also involve long time lags from policy via application to actual consequences on the ground. Matching the Swedish policy on biodiversity and ecosystem services, the EU strategy for biodiversity conservation by 2020, and the most recent forest policy revision in Sweden [23], focusing on analyses of representative habitat networks and landscape patterns during the past two decades (ca. 2000–2020) is therefore appropriate.

Local extinctions of species are generally caused by anthropogenic deterioration, loss, and fragmentation of habitats, which reduce functional connectivity, and thus, green infrastructure functionality [14]. This may also have significant genetic and evolutionary consequences for surviving isolated populations of focal species [24]. The importance of functional connectivity has been documented for a wide range of species linked to different forest land cover types and spatial scales. Wood-decaying fungal species are good indicators of the naturalness of forests in terms of the amounts of dead wood of different species, sizes, and decay stages. For example, Nordén et al. [25] showed that at the landscape scale, boreal old-forest connectivity was beneficial for indicator species, except in production landscapes where the amount of deadwood is limiting. Similarly, connectivity both within and among forest reserves has significant effects on wood-inhabiting fungal communities [26]. Habitat fragmentation also affects saproxylic insects at a local scale through the isolation of individual dead wood pieces [27]. Moreover, the connectivity of boreal streams after drought [28] and litter patches escaping fire [29] affect community structure and ecosystem functioning. Conservation actions should aim at securing functional connectivity among habitat patches and spatially distinct populations. Thus, an effective conservation strategy is to establish new conservation areas of near-natural areas in the vicinity of the high conservation value patches and increase the amount of large downed logs and other structures reflecting forest naturalness through restoration and biodiversity-oriented management [30].

The aim of this study involving both production landscapes and conservation areas, and the two dominating green infrastructures in boreal Sweden formed by older Scots pine (*Pinus sylvestris*) and Norway spruce (*Picea abies*) forests, is two-fold. First, we estimated pressure as final fellings of forests in production landscapes focusing on high sustained yield of wood, and effects on regional stand age distributions, and the amounts of dead wood. Second, we analysed the establishment of formally protected areas over time, changes in functional connectivity, and the development of green tree and dead wood retention. We also reviewed two attempts to cope with the conservation of green infrastructures in local landscapes. Finally, we discuss the results of our assessments; stress the need for comparing monitoring data with performance targets; scrutinise different data sources; and the challenges of engaging stakeholders in holistic analyses of net effects of pressures and responses on green infrastructures for biodiversity and human well-being.

2. Materials and Methods

2.1. Study Areas

2.1.1. Boreal Forest History Gradients

The biogeographic regional division of Sweden's forest ecosystems is based on three terrestrial biogeographical regions (alpine, boreal, and nemoral (or continental)). The boreal region is then further divided into three subregions: northern boreal, southern boreal, and boreo-nemoral (synonymous with hemiboreal) (see Figure 1). The border between the southern boreal and the hemiboreal regions is formed by a steep social-ecological transition zone called "Limes Norrlandicus" [31].

The transition from naturally dynamic forest landscapes to those designed with the focus to produce a high sustained yield of industrial raw material can be described as slowly regionally expanding frontiers of landscape transformation [32]. A first step was selective fellings of large trees in a naturally dynamic forest. In Sweden, this first frontier emerged in the SW corner of the Swedish boreal forest ecoregion during the 18th century [33]. An important prerequisite was that Swedish rivers run towards shipping ports and the customers, and not away from them, in contrast to other boreal forest regions in Canada and Russia [34]. The suite of river valleys north of the "Limes Norrlandicus" was thus an important precondition for the development of pulp and paper industries at the mouths of rivers entering the large Lake Vänern in SW Sweden, and the Baltic Sea in the east (Figure 1). This triggered a second frontier focusing on harvesting pulpwood in the entire boreal forest biome beginning >100 years ago, and the application of even-aged forest management [35]. However, the lower border of sub-alpine mountain forests (Figure 1) developed into a regulatory policy instrument that in practice succeeded to conserve the sub-alpine mountain forests in Sweden [23,36]. The current forest debate focuses on the few remaining near-natural forest fragments [37], some of which form intact forest landscapes [38].

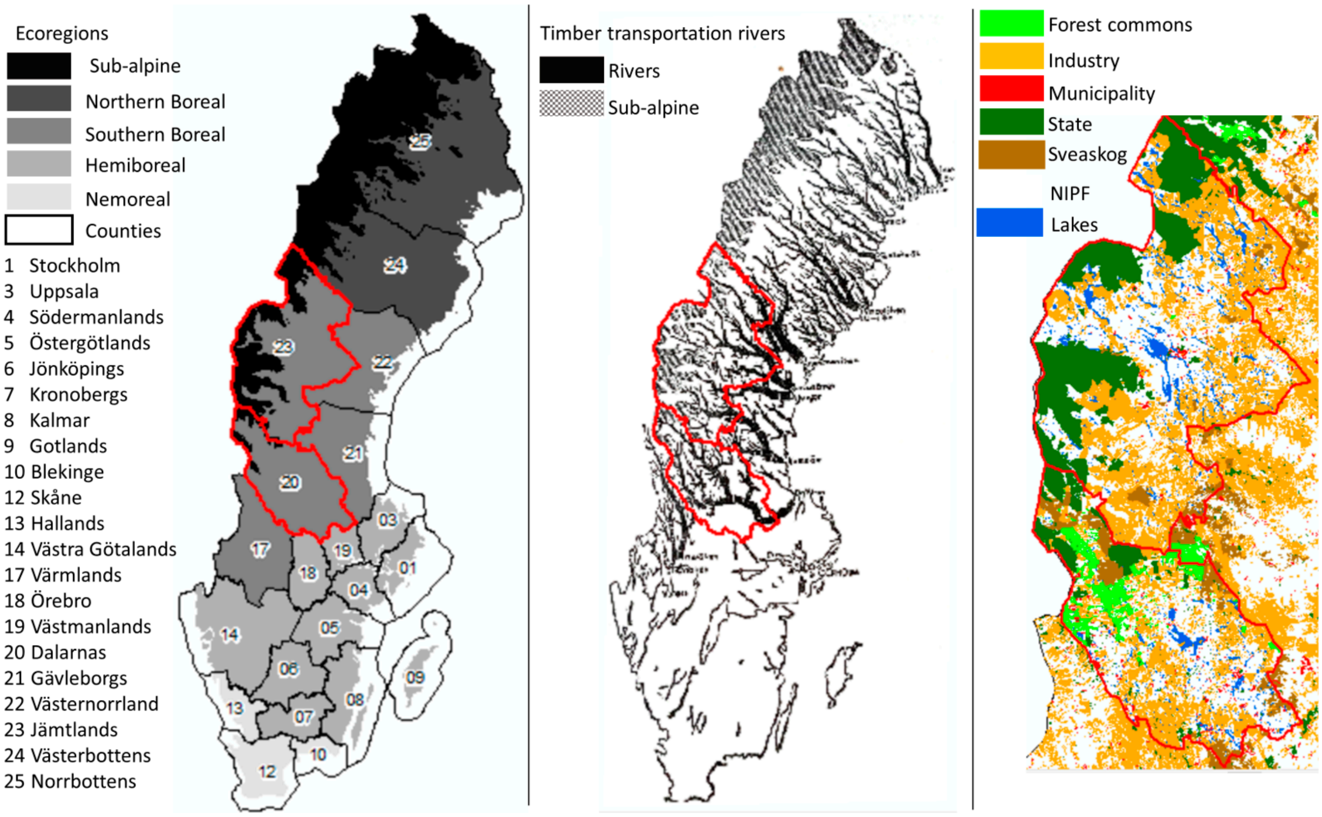

Figure 1. In Sweden, the boreal forest biome extends from the Limes Norrlandicus, the country's steepest socio-ecological transition zone [31], and to the Scandinavian mountain range in the northwest. Access to the boreal biome's wood resources was provided by a suite of rivers used for driving logs from upland areas to industries along the coast [39]. This study focuses on the counties marked 20 (Dalarna) and 26 (Jämtland), which are outlined in red.

2.1.2. Dalarna and Jämtland Counties

Extending from latitude 60 to 65 N and ranging from altitudes of 55 to 1796 m a.s.l., these two counties include the gradient from the northernmost hemiboreal to boreal and sub-alpine mountain forests in Sweden (Figure 1). The tree line ranges from ca. 800 m a.s.l. in the south to ca. 600 m a.s.l. in the north. While in Dalarna, Scots pine dominates over Norway spruce, in Jämtland their proportions are similar (Table 1). Stands dominated (>70%) by Scots pine or Norway spruce make up 76% and 68%, respectively.

These regions are drained by five major river systems, which were used extensively for long-distance transportation of wood for a century, ceasing around 1970, after which road and rail transport of timber and pulpwood took over.

When it comes to land ownership, (Figure 1, see [14] for entire Sweden), forests in Dalarna and Jämtland are mostly owned by non-industrial private forest owners (43%), private forest industry (41%), with the remainder (16%) distributed between the National Property Board, the state forest company Sveaskog Co., public bodies such as municipalities, the church, and forest commons [40]. For our analyses, we used the most recent compilation of forest land ownership polygons [41].

Table 1. Characteristics of Dalarna and Jämtland Counties [40]. Note that the estimates of productive forest based on the National Forest Inventory are lower than according to land cover data (*).

	Forest and Land Cover Type	**Dalarna**	**Jämtland**
Proportion of productive forest area (%)	Scots pine	58.7	33.3
	Norway spruce	17.3	34.8
	Exotics	1	7.7
	Mixed coniferous mix	12.6	11
	Conifer/broadleaf mix	3.6	7.6
	Deciduous	3.9	3.8
	Bare	2.9	2.8
Total area productive forest area (1000 ha)	Total	1873 (1978 *)	2549 (2689 *)
Proportion of traditional land use classes (2015–2019)	Productive forest land *	70.2	54.8
	Pasture land	0.3	0.2
	Arable land	2.7	0.8
	Mire	16.1	16.6
	Rock surface	0.6	1
	Subalpine woodland	3.2	7.3
	Alpine area	2.8	17
	Urban land	2.3	0.7
	Other land	1.9	1.5
Total land area (1000 ha)		2819	4905

2.1.3. Previous Assessments of Habitat Networks in Dalarna and Jämtland Counties

For Dalarna County, as a basis for planning for the establishment of formally protected forest areas as contributions to green infrastructures, three studies were carried out during the past two decades: (1) spatial modelling of forest stands that meet the requirements of specialized forest focal species (the "wRESEx" project [42]), (2) an analysis of where endangered and specialized species are found in Dalarna, and (3) an inventory of high conservation value forests. The spatial modelling of forest stands was based on stand data in forest management plans and satellite images from 2002. To assess temporal changes from 2002 to 2012 in green infrastructure functionality, Angelstam and Andersson [43] replicated this spatial modelling study by updating the amount of old forest using the Swedish Forest Agency's inventory of final fellings up to and including 2011. The replicated habitat modelling focused on old Scots pine forest with capercaillie (*Tetrao urogallus*) [44] and the pine wood living beetle *Tragosoma depsarium* as focal species [45], and old Norway spruce forest with the guild of resident passerine birds (*Certhia familiaris*, *Paridae* spp.) [46] and three-toed woodpecker (*Picoides tridactylus*) [47] as focal species. The results were presented for Dalarna County, for different natural geographical regions, and four different forest owner categories.

In Jämtland, work on the Swedish Environmental Objective "Living Forests" is a priority, and its regional environmental goal programs are stated as a challenge to "create a development towards green infrastructure to reduce the fragmentation of populations and habitats on the land environment". In 2015, Lindgren and Olsson [48] analysed the changes that have taken place in the Scots pine and Norway spruce green infrastructures in Jämtland County for the period 2004–2013. This work was an introduction to the county administrative board's work to produce a regional action plan for green infrastructure. The aim was to support conservation initiatives at the landscape level, in collaboration with various forestry actors in the county. The report also provided a common knowledge base about forests in Jämtland County as a habitat for various forest-dwelling species, where final felling rates and degree of fragmentation are key factors for green infrastructure functionality. The results were specified for the same forest types as in Dalarna County, for different geographical areas in the county, and different types of landowners. The Lindgren and Olsson [48] report was designed so that the analysis should be comparable with the analysis previously made for the neighbouring Dalarna County [42,43].

2.2. Overview of Methods to Assess Policy Implementation Outcomes

Evaluation of policy implementation is about what develops between the establishment of an agreed policy and the ultimate impact of subsequent actions in the real world [49]. Rauschmayer et al. [50] focused on three steps for evaluation, being (1) the policy process, (2) outputs (e.g., policy instruments, strategic assessments, planning processes), and (3) the consequences in terms of outcomes on the ground (e.g., the functionality of green infrastructures in terms of functional habitat networks for biodiversity conservation). This study focuses on the outcomes (Figure 2) and their consequences (Figure 3).

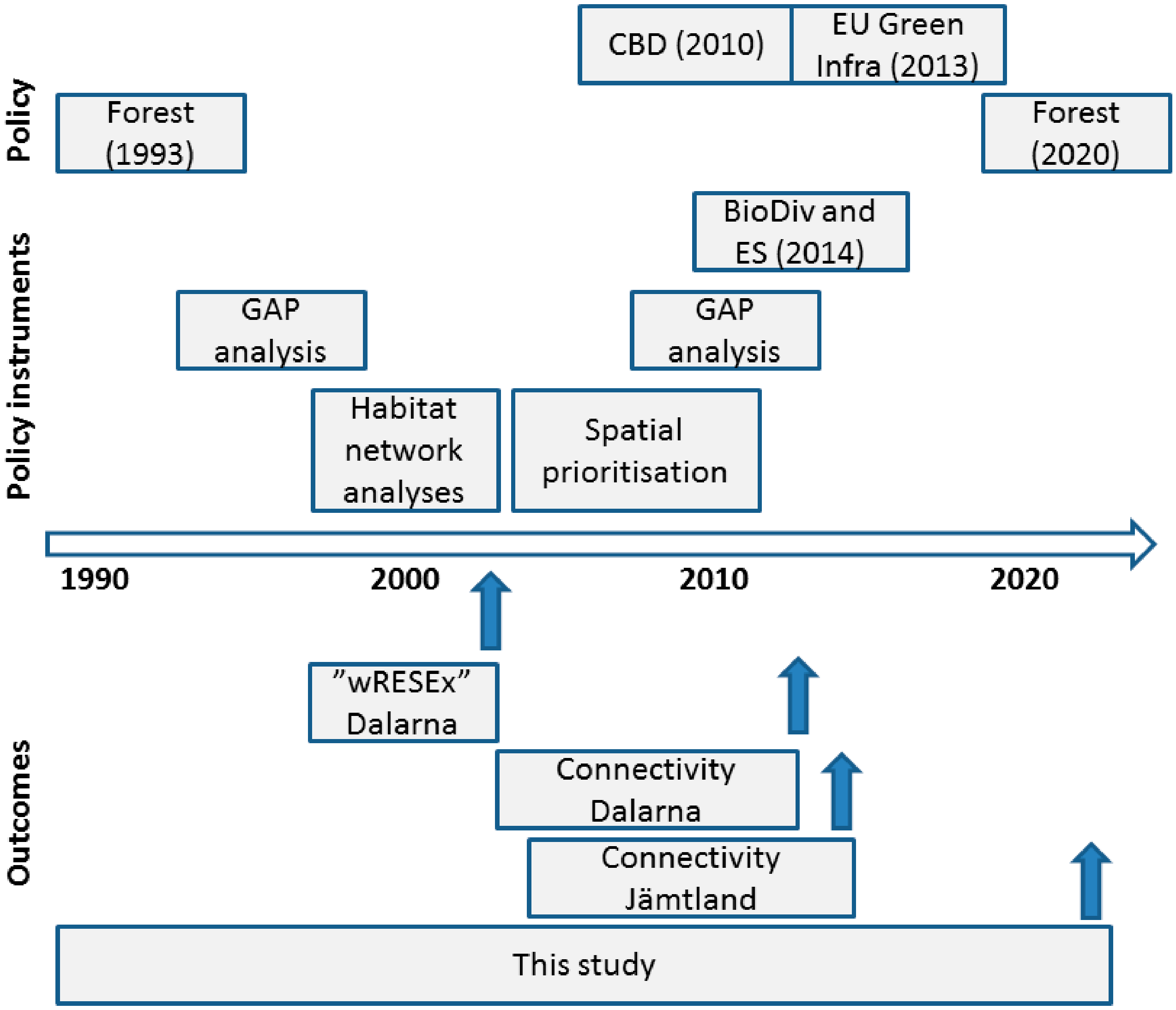

Figure 2. Overview of policies and policy instruments in Sweden 1990–2020, and previous assessments of outcomes regarding the development of forest habitat networks. See text for details.

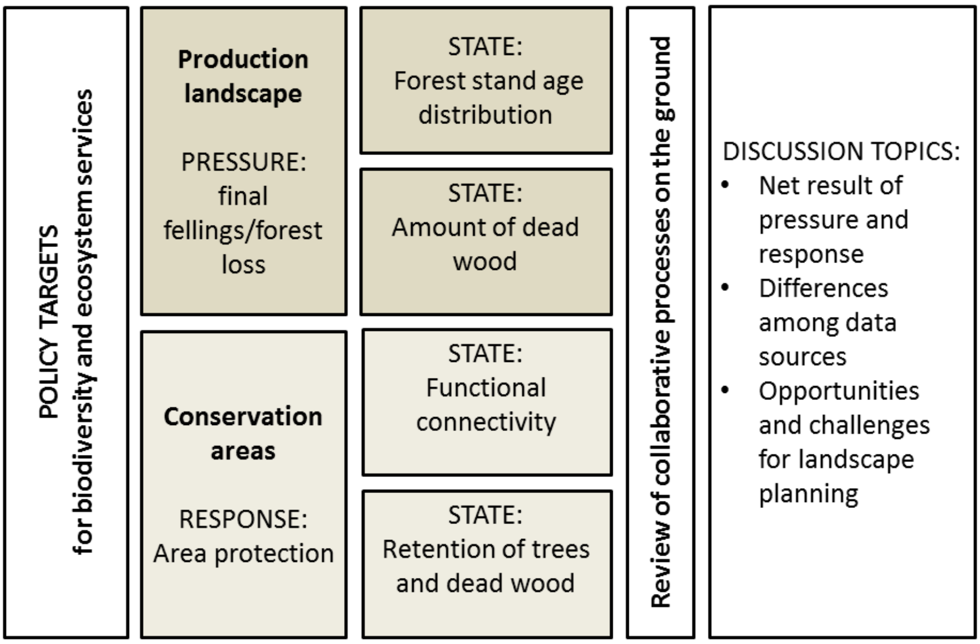

Figure 3. Overview of the approach to assess the net effects of pressures and responses on the states of green infrastructures for forest biodiversity conservation at stand, landscape, and regional scales.

Awareness about the importance of sufficient amounts of different representative habitats, and to secure functional connectivity, was brought to attention at the national level through a regional gap analysis about the need for formal area protection in Sweden [51], and by individual regional county administrations, among which Dalarna County was a pioneer [42]. In the project "Frequency Analysis of Areas with High Nature Conservation Value", the Swedish Environmental Protection Agency published a working model for spatial analysis to define concentrations of high nature value forest core sites, named core regions, which would be applied uniformly over the entire country [52]. This approach formed the base for a national strategy for formal forest protection [53], which was confirmed in 2017 [54] and was also integrated with the regional action plans for green infrastructure (see [19]). While Dalarna finished this work in 2018, Jämtland was the only county in Sweden that did not, due to resistance from forestry stakeholders. The process of applying the policy outputs for formal protection has so far been sustained for ca. 15 years (Figure 2), and final felling and intermediate forest thinning aimed at production of raw material for the forest industry have continued, and forms a spatially expanding frontier.

Forest biodiversity conservation in Sweden, and the other Baltic Sea region countries, focuses on multi-scaled set-asides [55]. To evaluate the net effects of forest harvesting in production landscapes forming the matrix around conservation areas, and establishment of conservation areas at different scales, we performed a suite of analyses (Figure 3, Table 2). Since "no park is an island", processes and patterns at different spatial scales in the production landscape must be analysed. First, the expanding frontier of transformation of near-natural forest landscapes needs to be addressed. Second, patches of high conservation value forests are set aside to design functionally connected and ecologically representative habitat networks, i.e., different kinds of green infrastructures [19,22]. Third, retention trees and tree groups that are left during final felling in the context of even-aged forestry (e.g., [56,57]). This corresponds to three spatial scales: stand, landscape and region.

Table 2. List of indicators, verifier variables describing forest landscapes' managed matrix and conservation areas, and data sources used for analyses of green infrastructure functionality in the counties Dalarna and Jämtland.

	Indicator	Verifier Variable	Sources
The production landscape matrix managed for high sustained yield of industrial raw material	Pressure through loss of older forest	Yearly data and maps for four 5-year periods for two data sets	Hansen et al. "forest loss" data (2001–2019) Forest Agency borders of fellings 1998–2019
	Effect on the stand age distribution	Changes in the two counties	NFI 1955–2017
	Effect of dead wood in the entire forest landscape	Changes in the amount of dead wood in Sweden	Jonsson et al. (2016), 1994–2012) and updated with one more NFI survey period (2012–2016)
Conservation areas	Response through the creation of different categories of protected areas	Changes over time in the two counties	Swedish Environmental Protection Agency
	Effect on High Conservation Value Forests forming green infrastructures	Changes in functional connectivity 2002–2012, for the 2000–2019 period, and divided into spruce and pine	Angelstam and Andersson (2013), Lindgren and Olofsson (2019) (kNN for 2000 minus clearcuts 2000–2019),
	Effect on retention of trees and dead wood on harvested areas	Changes in the amounts of live trees and standing and lying dead wood	Swedish Forest Agency Statistics from 1994/95 to 2010/11

2.3. Production Landscapes as Matrix

2.3.1. Forest Canopy Loss

The term forest has multiple meanings. Given that policy objectives in Sweden focus on forests producing >1 m^3 ha^{-1} we concentrated on indicators that reflect this stratum of forest landscapes. This excludes unproductive forests, as well as natural and cultural woodlands. We used two independent open-access spatial datasets and selected the period 2001–2019. First, we analysed spatial data collected by the Swedish Forest Agency to control forest owners' notifications about planned final fellings of productive forest stands, and to provide official forest statistics for national reporting. This data included both a forest mask for productive forest areas and polygons for all final fellings of productive forest stands. Forest in this database is defined according to FAO forest definitions "*Land spanning more than 0.5 hectares with trees higher than 5 m and a canopy cover of more than 10 percent*" (http://www.fao.org/3/am665e/am665e.pdf, accessed on 5 March 2021).

Second, we analysed spatial data collected using the Hansen et al. [58] approach to map forest loss, a data set that also includes the forest canopy cover for the year 2000. Here, forest loss is defined as "*a stand replacement disturbance, or a change from a forest to non-forest state*". Forest cover is defined as canopy closure for all vegetation taller than 5 m in height and presented as a percentage per output grid cell, in the range 0–100. Thus, forest areas that have been subject to final felling having a tree height of <5 m were excluded. It should be noted that this spatial dataset contains all areas with tree canopy loss in 30 × 30 m pixels (900 m^2), i.e., both final fellings and an unknown proportion of thinning. In contrast, the Swedish Forest Agency monitoring is focused on notified final fellings on productive forest sites only, and the forest mask includes all forest land.

We created a 25 km^2 (5 × 5 km) fishnet across the two counties and populated each cell with the area proportions of forest cover and the yearly (2001–2019) clear-cut areas, and forest loss tree canopy loss, respectively. A 100-year forest rotation equates to a 1% harvesting threshold per year. In addition, to visualize spatial patterns of forest management intensity, we analysed both spatial datasets during four time periods; 2001–2005, 2006–2010, 2011–2015, 2016–2019. This was created by applying the mean values for each of the 25 km^2 fishnet cells over the given periods.

2.3.2. Age Distributions

Data about the forest stand age distribution for each of the two counties, both below and within the sub-alpine mountain forest region, was received as 63 running 5-year means from the National Forest Inventory 1955–2017 (Per Nilsson, National Forest Inventory, SLU, Umeå, Sweden, pers. comm.).

2.3.3. Dead Wood

The amount of dead wood of different decay stages and diameters is a key biodiversity indicator of both naturally dynamic forest ecosystems and ancient woodlands (e.g., [59]). However, the amounts of dead wood vary greatly among landscapes with different histories of forest use (e.g., [60]), and thus the opportunity for biodiversity conservation differs. Data from the National Forest Inventory [40] was used for the years 1994–1998, 2003–2007, 2003–2012, and 2012–2016, thus adding one additional period to those three reported in detail by Jonsson et al. [61]. Data for the current period 2017–2021 remains to be completed.

Evaluation of the extent to which a habitat and resource, such as dead wood for species are sufficiently abundant, means that long-term monitoring of an indicator needs to be compared to evidence-based performance targets. For example, Lonsdale et al. [62] reported an average of 94 m^3 ha^{-1} dead wood in N America in N Europe. Reviews [63,64], confirm this order of magnitude. However, the sufficient amount of dead wood is considerably lower. For example, Nordén et al. [25] identified a threshold value of 29 m^3 ha^{-1} for the necessary amount of Norway spruce logs for the presence of indicator species. Peak threshold values for multiple studies representing boreal coniferous forests are 20–30 m^3 ha^{-1} [63]. To describe the relationship between the indicator values derived from the National Forest Inventory data and the threshold values, the graphs in the results all range up to 10 m^3 ha^{-1}.

2.4. Conservation Areas

2.4.1. Protected Areas

Data about the accumulated amount of formally protected areas were derived from the official register of protected areas (S. Wennberg, Swedish Environmental Protection Agency, Stockholm, Sweden, pers. comm.).

2.4.2. Habitat Modelling to Assess Functional Connectivity

Habitat modelling of focal species [65–67] and virtual species [68] is a useful tool that can be used in regional forest biodiversity planning to help understand the net effects of pressures and responses on green infrastructure functionality of land cover change. Habitat modelling was made in (1) each region for 10 years in Dalarna County (2002–2012), and 13 years in Jämtland County (2001–2014), and (2) for the period 2001–2019. The studies in Dalarna and Jämtland were made in the same way [69], but with different land cover data. In the first step, pixels were selected with the land cover themes that correspond to the habitat requirements of the selected focal species (Table 3) [69,70]. Since different forest habitat types provide different resources for species, they were given a weighting based on their importance as a habitat for particular species [42]. To connect forest patches very close to each other, a buffer of 25 m (one pixel) or 100 m (4 pixels) depending on the species was made. In the second step, the buffered areas that are large enough to ensure a territory or home area for the species were selected. In the third step, the functional connectivity was identified as areas where habitat patches are of sufficient size and located in the same neighbourhood based on the species' home range size. In the fourth step, the original pixels within areas that ought to be protected are selected. To create single green infrastructure themes, we overlaid the two modelling approaches and presented their union for Scots pine and Norway spruce, respectively.

Table 3. Variables and parameter values used for spatial analyses of habitat network functionality of two forest types in the two case study counties. For a discussion on the focal species concept and individual species see References [14,69].

Forest Type	Focal Species	Patch Requirements	Buffer	Home Range (km^2)	Threshold (Required Habitat)
Old spruce > 70	*Picoides tridactylus*	10 ha	25 m	4	25%
	Resident passerine birds	20 ha	25 m	1	60%
Old pine > 70	*Tragosoma depsarium*	10 ha (<400 m a.s.l. *)	0 m	25	25%
	Tetrao urogallus	200 ha	100 m	16	25%

* otherwise too cold climate for this species.

2.4.3. Retention of Trees and Dead Wood

Data were acquired from National Forest Inventory follow-up (Neil Cory, Swedish Forest Agency, Jönköping, Sweden, pers. comm.). The monitoring of retention trees is made with a time lag of 7 years. The reported period is from the forest harvest seasons 1994/95 to 2010/11.

2.5. Narratives of What Happens on the Ground

The green infrastructure core regions [52], or hotspot tracts, identified through habitat modelling, can be viewed as individual social-ecological systems. For each of the two county case study regions, we identified a characteristic local core region. In Dalarna, the county administrative board identified 44 core regions [71–73]. As this county is dominated by Scots pine forests, we chose the core region of Gåsberget [71,74], also named Ore Skogsrike in a citizen science project [71,74], which is located in the northernmost part of Rättvik municipality. In Jämtland County, with large areas of Norway spruce forests, the Björkvattnet area was chosen. It is a part of the large intact forest landscape [37] with high conservation values and is located in Strömsund municipality. Analyses of documents, focus groups, participatory observations, and expert interviews were used to describe the opportunities and threats to maintaining functional green infrastructures in these two core regions as green infrastructure hotspots.

3. Results

3.1. The Production Landscape as the Matrix

3.1.1. Tree Canopy Loss and Final Fellings

The two data sets selected to mirror pressure on forests in the production forests forming the matrix around conservation areas yielded different results regarding the mean tree canopy loss (Figure 4). While the Hansen et al. [58] data for the 19 years, 2001–2019, indicated a mean annual loss of 2.1 ± 0.14 SE % for Dalarna and of 2.0 ± 0.14 SE % for Jämtland, the Swedish Forest Agency data indicated a mean annual proportion of final fellings of 0.84 ± 0.05 SE % and 0.85 ± 0.08 SE %, respectively. During the 10-year period, 2001–2019, on average 26,500 ha and 32,500 ha were harvested annually through final fellings in Dalarna and Jämtland, respectively. In total, this corresponds to average annual values of 0.84% (Figure 4). Neither the Hansen data nor the Swedish Forest Agency's annual monitoring of the fate of stands notified by forest owners to be harvested showed any clear trend over time.

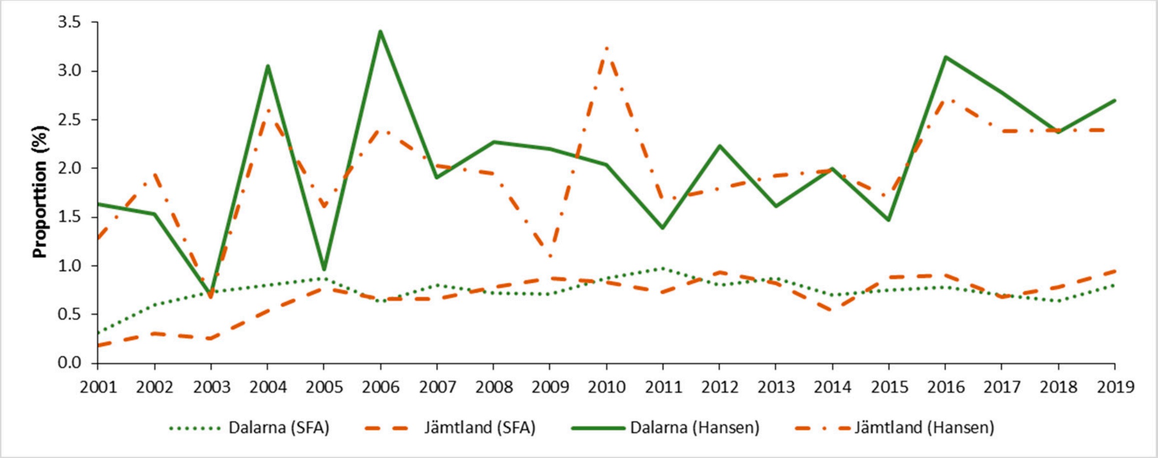

Figure 4. Graph showing the annual proportion of tree cover loss in the Dalarna and Jämtland counties for the period 2001–2019. (SFA) represents the Swedish Forest Agency data on forest clear-cuts, and (Hansen) represents the forest canopy loss data created by Hansen et al. [58].

Reflecting the forest ownership distribution, in both counties, clear-fellings made during the period 2001–2019 were dominated by the industrial forest owners and non-industrial private forest (NIPF) owners. A comparison of the distribution of harvested and owned areas, respectively, shows that the ratio was highest for industrial owners (1.14), followed by NIPF owners (0.93), and the rest (0.81) (Figure 5). Note that these ratios are based on total counts and are therefore not statistical samples requiring statistical testing.

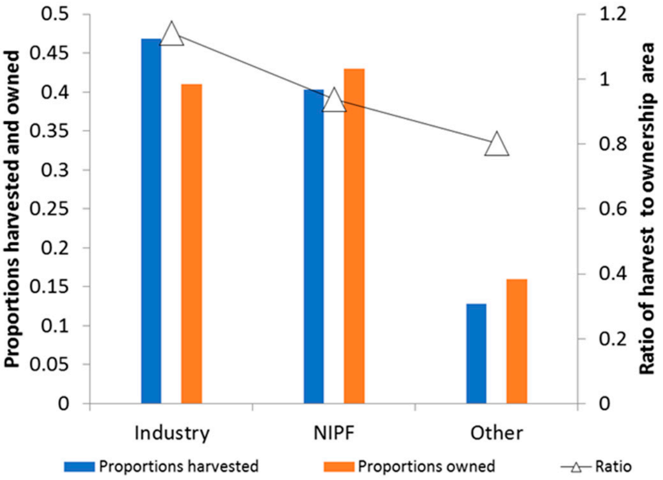

Figure 5. Proportions of productive forests harvested through final fellings during the period 2001–2019, and the proportions of the forest land owned, by three categories of forest owners (Figure 1) in Dalarna and Jämtland Counties.

The spatial distribution of forest cover exhibited an increase from >80% in the lowland areas in the east to 20–40% in the sub-alpine mountain areas close to the Scandinavian Mountain range along with the western parts of the counties Dalarna and Jämtland, both bordering Norway (Figure 6). Within each of the four periods analysed, there was considerable spatial variation in the annual proportion of final fellings at the scale of 5 × 5 raster cells, ranging from <0.5% to >2%. Comparing the four periods in Figure 6 indicates a westward movement of harvested proportions.

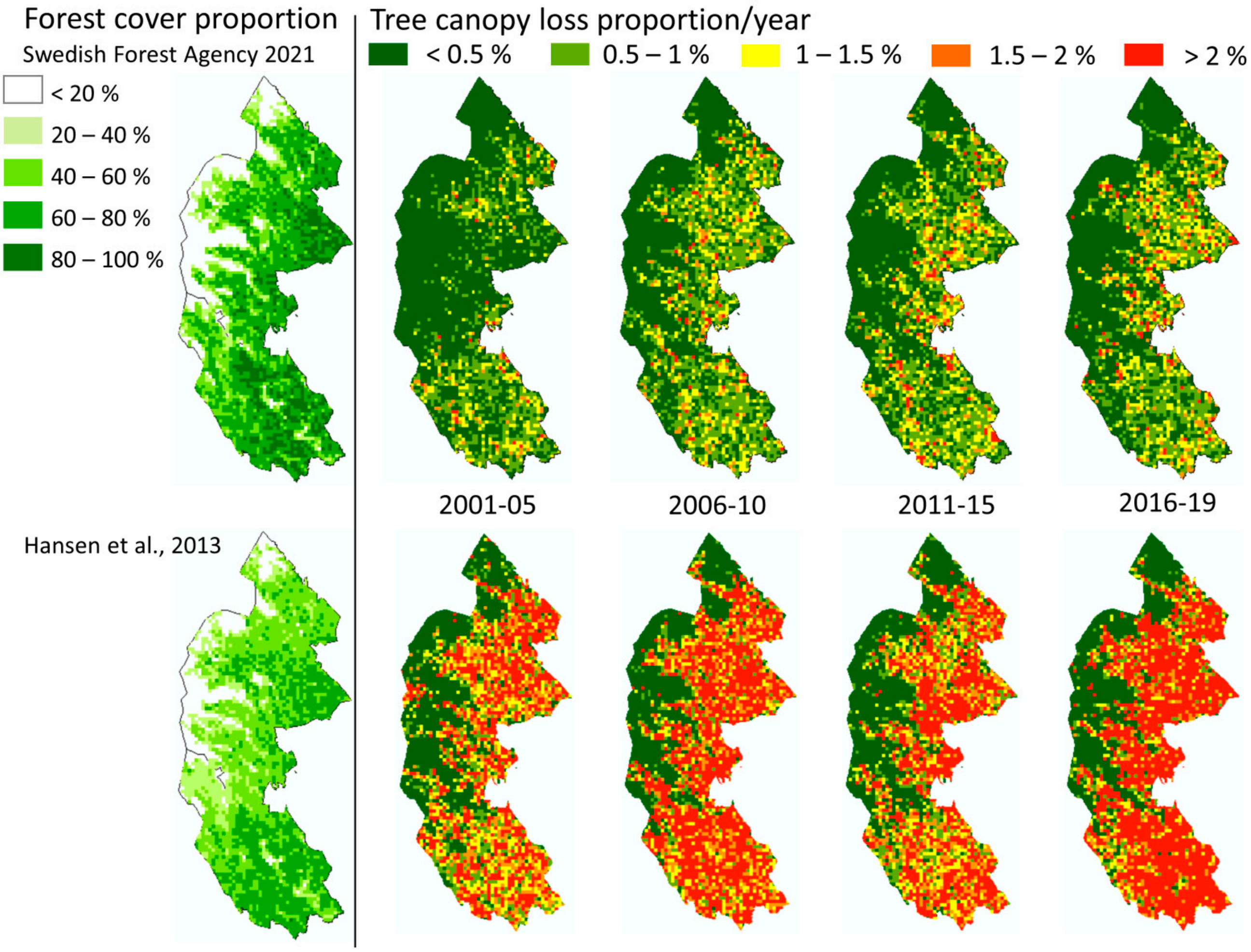

Figure 6. Maps showing the mean annual forest canopy loss in Dalarna and Jämtland counties of Sweden in 5 × 5 km raster cells for four time periods using two individual forest change databases, viz. following Hansen et al., [58] (**bottom**), and the Swedish Forest Agency (**top**).

3.1.2. Landscape Scale—Forest Stand Age Distributions

Regarding forests below the sub-alpine mountain forest border, in both Dalarna and Jämtland counties, there was a gradual increase from the 1960s to 2017 in the mean amount of forest aged 0–60 years, and a simultaneous decline in the age class 61–120 years (Figure 7). Located further south, and thus, reached by logging frontiers earlier, the amount of forest 121–160 years and >160 years is lower in Dalarna compared to Jämtland (3% vs. 4%, and 12% vs. 16%, respectively). Regarding forests above the mountain forest border, first, they make up 26,700 of 1,869,800 ha (i.e., 1.4%) in Dalarna, but 218,000 of 2,387,100 ha (i.e., 9.1%) in Jämtland. This explains the difference in variability of 5-year running mean values (Figure 7, right). Nevertheless, the amounts of forests of 121–160 years and >160 years are much higher above the mountain forest border (29% vs. 36%, and 11% vs. 13%, respectively) than below. Above the mountain forest border the trends for the entire period 1955–2017 were positive for both 121–160 and >160 years old stands in both counties ($r > 0.248$, $p < 0.05$). Below the mountain forest border, in both counties, 121–160 years old areas developed positively, but for >160 years old stands there was no trend. However, compared to evidence-based benchmarks [75], the amount of older forests is very low below the mountain forest border.

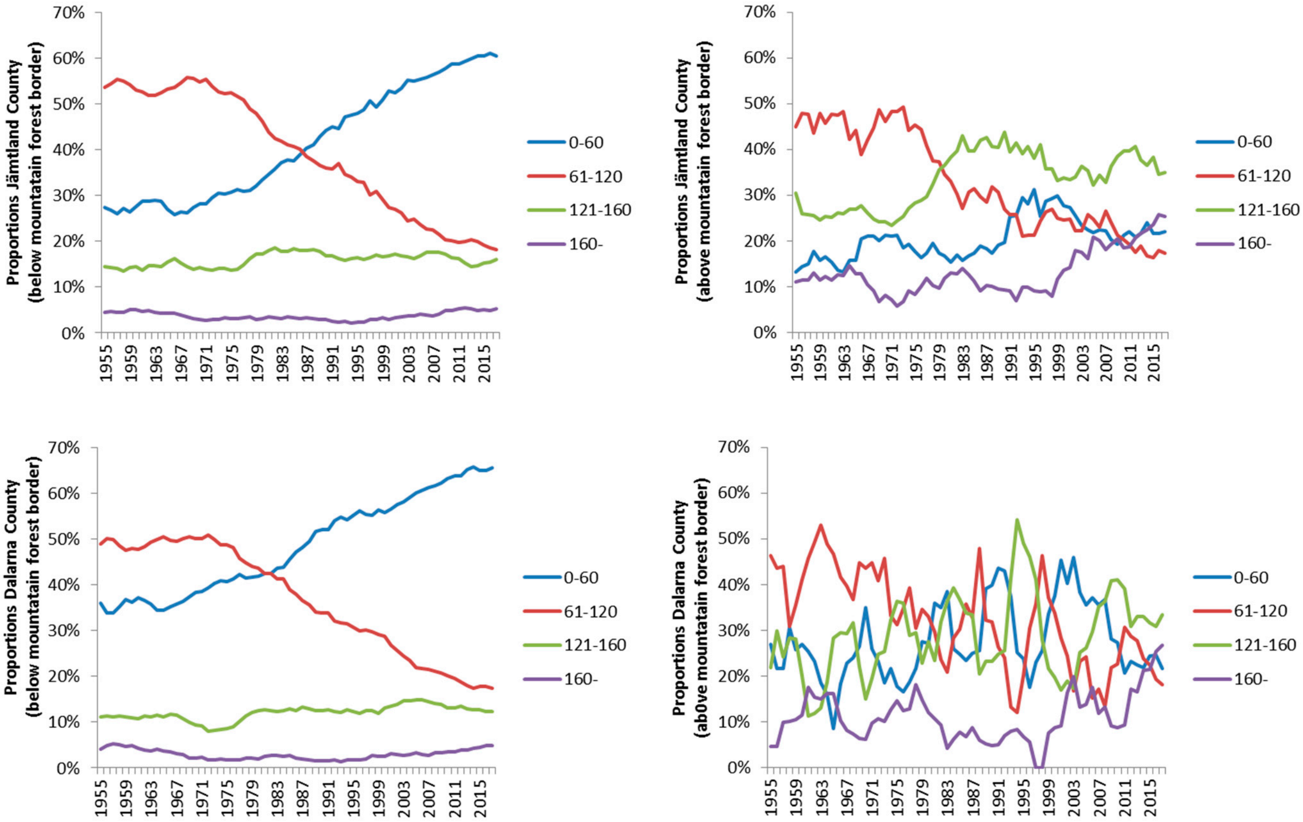

Figure 7. Stand age distribution below and above the mountain forest border in Dalarna and Dalarna Counties 1955–2017 (5-year running means). Note that mountain forests make up only 1.4% in Dalarna County, but 9.1% in Jämtland County. This explains the latter 5-year mean graph's erratic performance.

3.1.3. Stand Scale—Dead Wood

The amount of dead wood in the entire productive forest landscape across all five Swedish forest ecoregions was 7.3 (range 6.3–8.8) m^3 ha^{-1} (Figure 8). In a detailed analysis of the first three periods reported in Figure 8, Jonsson et al. [61] showed that dead wood (mainly Norway spruce) had increased in the southern part of the country, but remained stable or decreased in the north. Heterogeneity of dead wood types was low in terms of tree species, diameter, and decay classes. Overall, most of the increase can be attributed to south Swedish storm events ("Gudrun" in 2005 and "Per" in 2007) creating a pulse of hard dead wood, and not to effects of the current forest certification requirements and forest policy aiming at voluntary set-asides and tree retention.

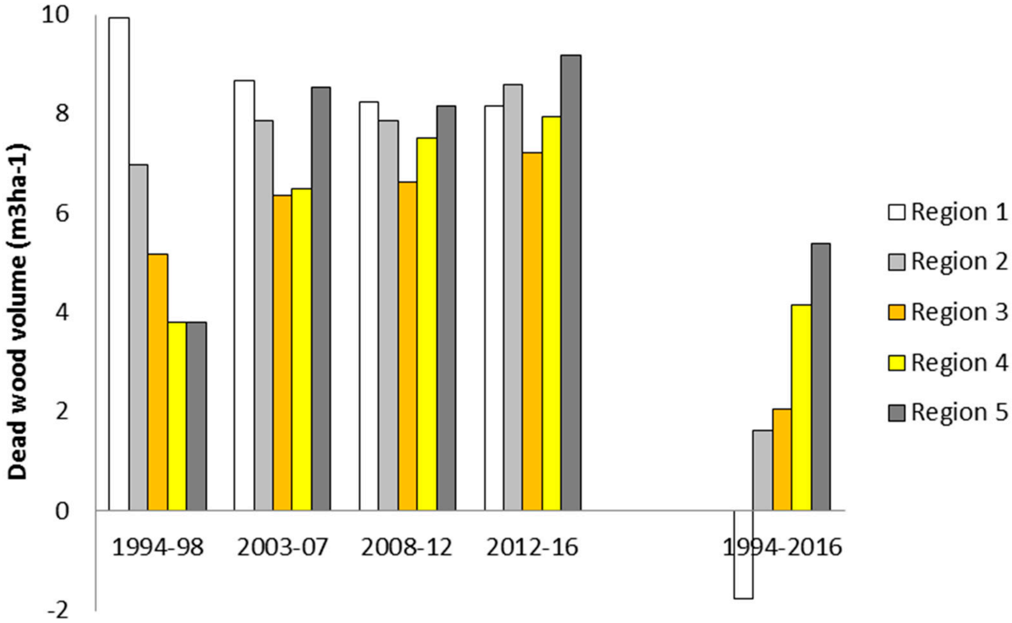

Figure 8. Trends in dead wood among five Swedish forest regions (see Figure 1). Dalarna County is located in region 3 and Jämtland in region 4. The highest value on the y-axis is half of the lowest threshold value for sufficient amounts of dead wood [63].

3.2. Conservation Areas

3.2.1. Establishment of Formally Protected Areas

Increased political interest in biodiversity conservation from the 1970s, subsequent inventories to locate near-natural forest remnants in the late 1980s, and funding available to compensate landowners, led to rapid increases in formal forest protection from around 1990 (Figure 9). In 2020, the proportion of formal protection was 4.1% in Dalarna and 4.3% in Jämtland Counties. However, their regional distribution was very uneven. In 2018, the proportion below the sub-alpine mountain forest border was only 2.5%, whereas the proportion within the sub-alpine mountain forests was 52.5%.

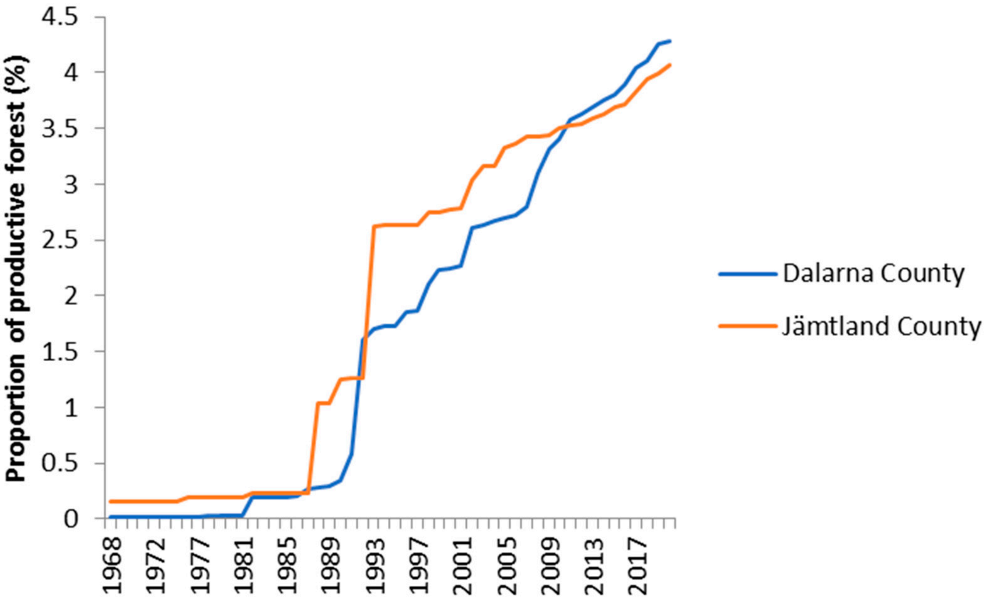

Figure 9. Proportions of formally protected productive forest totally, both above and below the sub-alpine mountain forest border, in Dalarna and Jämtland Counties.

3.2.2. Green Infrastructure Connectivity in Dalarna (2002–2012) and Jämtland (2000–2013)

Scots pine and Norway spruce are the two dominating forest types in Dalarna and Jämtland counties. Using the same methodology, both Angelstam and Andersson [43] and Lindgren and Olsson [48] showed the habitat network functionality declined during the studied decade periods (2002–2012 (i.e., 10 years) and 2000–2013 (i.e., 13 years), respectively) (Figure 10). The average annual habitat network loss was 2.7% for Scots pine and 2.8% for Norway spruce, and 3.8% vs. 1.7% for the two counties Dalarna and Jämtland, respectively. Note that while in Dalarna only 1.4% of forests are located in the subalpine mountain forest border, but in Jämtland 9.1%.

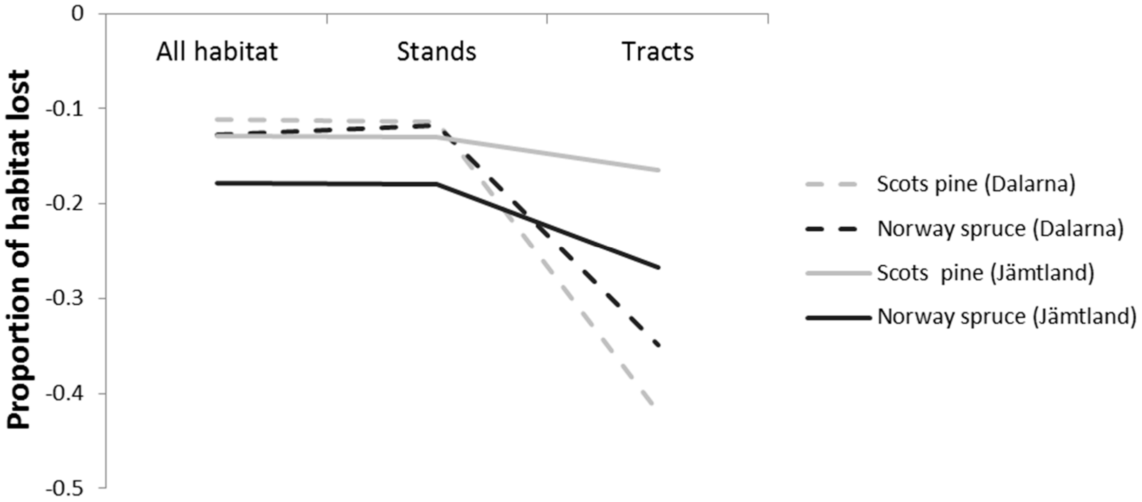

Figure 10. Assessment of the development of green infrastructure functionality in two Swedish regions Dalarna County (Angelstam and Andersson 2013 [43]) and Jämtland (Lindgren and Olssson 2019 [48]) (see map in Figure 1).

3.2.3. Connectivity of Green Infrastructures in Dalarna and Jämtland (2001–2019)

For all four suites of focal species with their respective parameter values, replication of the two previous studies [43,48] show that old Scots pine and old Norway spruce forests are severely fragmented (Table 4). On average the current proportion of remaining old forest that the habitat models suggest form functional forest habitat networks were 13% for *Tetrao urogallus*, 1% for *Tragosoma depsarium*, 16% for *Picoides tridactylus*, and 3% for the guild of resident passerine birds in the two counties analysed.

Table 4. Habitat network functionality through the lenses of two focal species for Scots pine and Norway spruce, respectively. The total area of both tree species is 208,906 ha in Dalarna, and 755,578 ha in Jämtland.

	Scots Pine				**Norway Spruce**			
	Tetrao urogallus		***Tragosoma depsarium***		***Picoides tridactylus***		**Resident Passerine Birds**	
	Dalarna	**Jämtland**	**Dalarna**	**Jämtland**	**Dalarna**	**Jämtland**	**Dalarna**	**Jämtland**
All forest >70 years	271,356	243,958	168,540	135,667	93,483	355,921	93,483	355,921
Stands	264,061	225,146	61,586	46,941	55,374	292,313	41,870	260,077
Tracts	42,282	25,661	2744	1506	7451	86,084	907	14,673

The net results of pressures in terms of final felling of older forest and forest protection have resulted in a reduction of habitat network functionality negatively. From 2000 to 2019 habitat network functionality for old Scots pine declined by 15–41%, and Norway spruce by 15–88% (Figure 11). The habitat maps for Dalarna County clearly illustrate that the Scots pine and Norway spruce forests form different large non-overlapping green infrastructures (Figure 12).

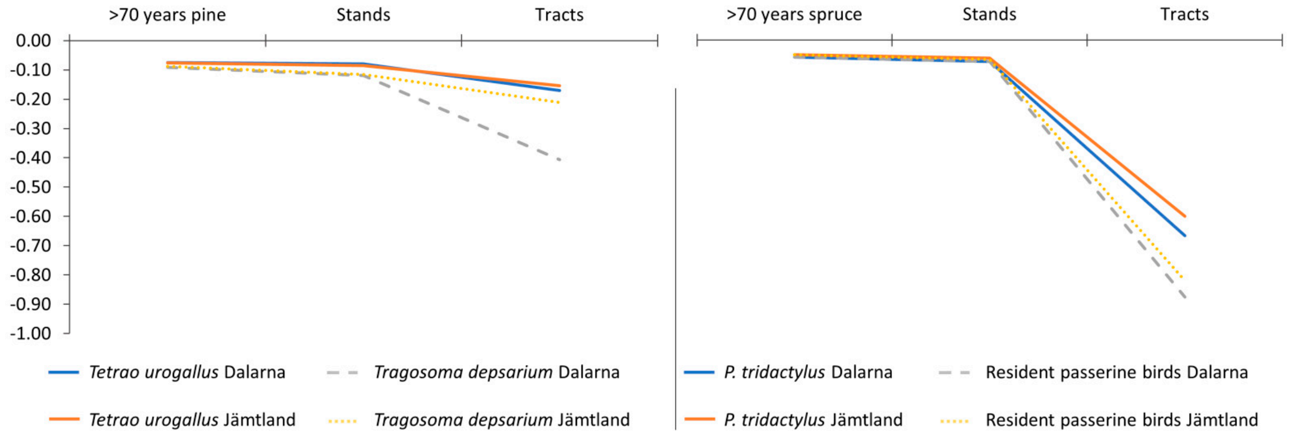

Figure 11. Loss of habitat functionality for four specialised Scots pine (**left**) and Norway spruce (**right**) forest species 2000–2019.

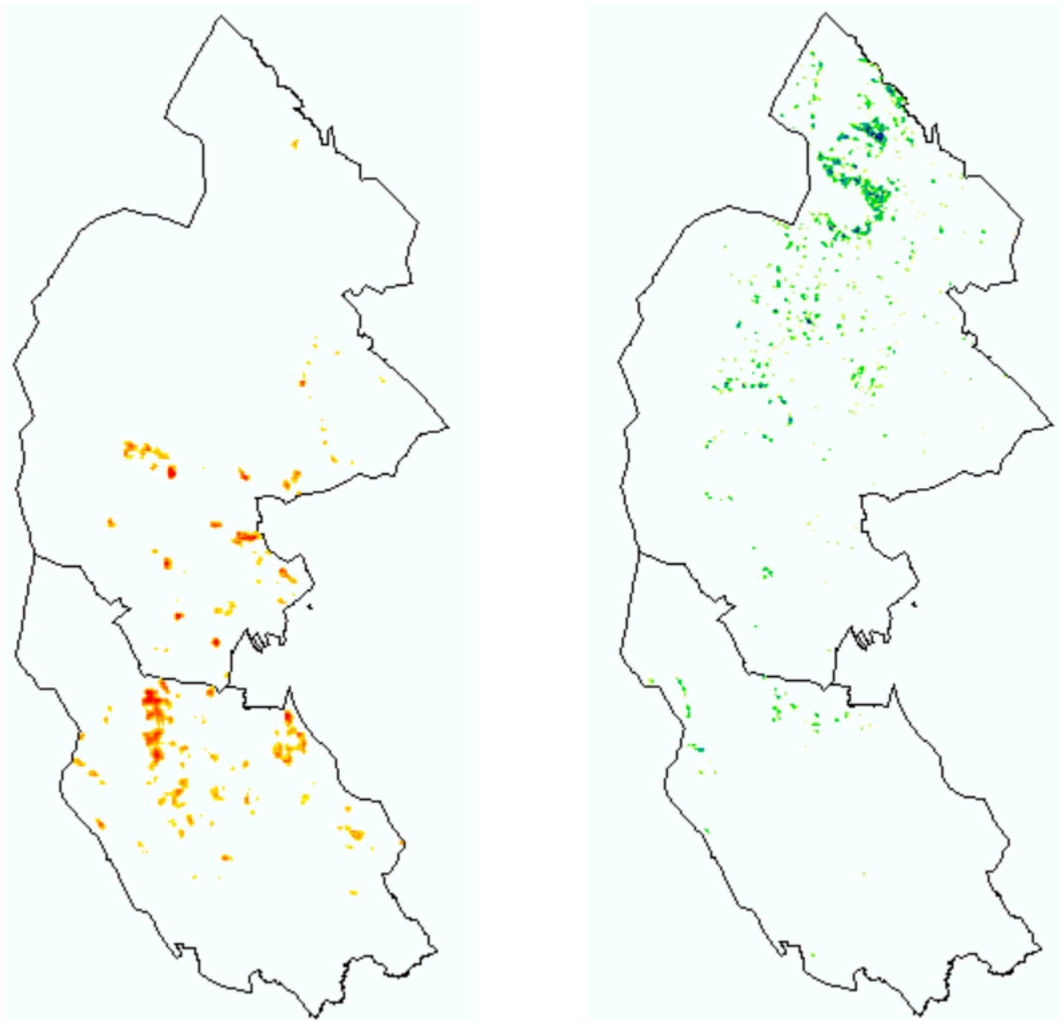

Figure 12. Spatial distribution of functional habitat networks in 2019 with patches of sufficient quality and size which satisfy the requirements of the Scots pine focal species bird *Tetrao urogallus* and the beetle *Tragosoma depsarium* (**left**), and Norway spruce focal species like a complete guild of resident passerine birds and the woodpecker *Picoides tridactylus* (**right**).

3.2.4. Stand Scale Retention of Dead Wood in Different Stages of Decay, and Trees

Annual monitoring of the volume of dead wood left on clear-cuts in Sweden (Figure 13) showed significant increases for the dead wood decay stages hard (r = 0.92), soft (r = 0.87), and decayed (r = 0.67), but a significant decrease for the stage very decayed (r = −0.62). However, all the absolute values were very low compared to evidence-based threshold values of 20–30 m^3 ha^{-1}. Figure 14 illustrates the significant increases over time of lying dead wood (r = 0.97) and created high stumps (r = 0.88), and significant decreases of living trees (r = −0.81). For snags and natural high stumps, there was no significant trend.

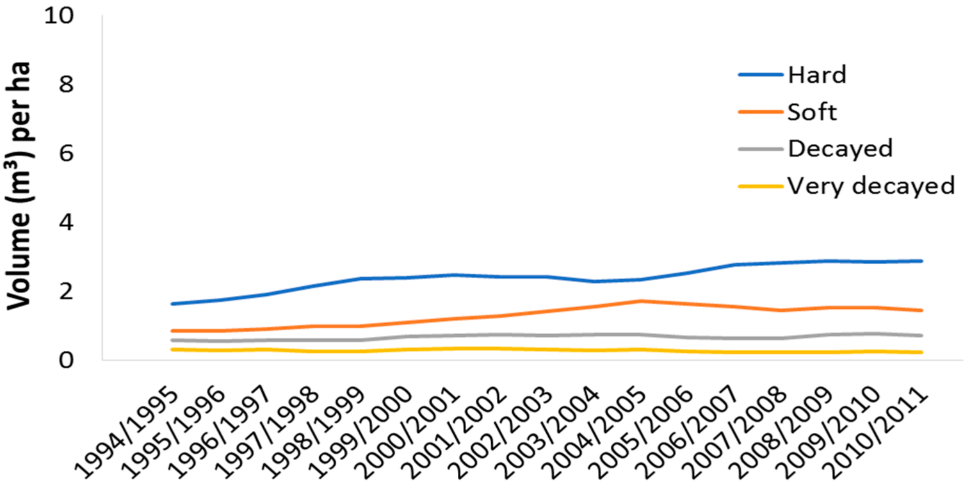

Figure 13. Development over time in the amount of dead wood of different decay stages on areas subject to final fellings that remains after 5 years in southern Sweden and 7 years in northern Sweden. Ten m^3 ha^{-1} is half of the lowest evidence-based threshold value for the conservation of species dependent on dead wood; see also Figure 18 and the associated text.

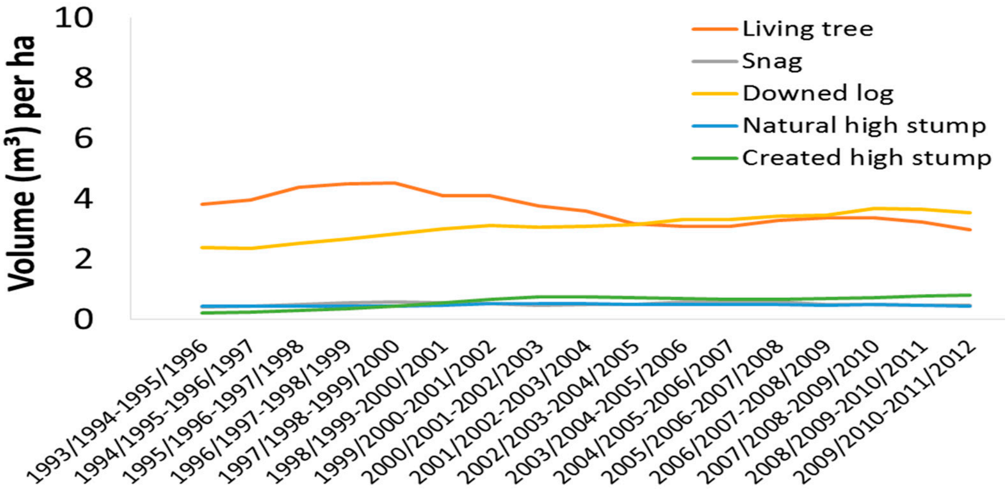

Figure 14. Trends for the amounts of four types of retention structures left in forest stands subject to final felling in Sweden. Ten m^3 ha^{-1} is half of the lowest evidence-based threshold value for the conservation of species dependent on dead wood; see also Figure 18 and the associated text.

3.3. Narratives

3.3.1. Core Region of Gåsberget

One of the hotspots for Scots pine habitat networks was identified in the NE part of Dalarna County (Figure 12), located in the upland area where the three Counties Dalarna, Jämtland, and Gävleborg meet (Figure 15, Table 5). Public sector authorities, landowners, and civil society groups have since the 1980s identified this northernmost tip of Rättvik municipality as a key remnant of near-natural Scots pine forests, and late seral stages of the deciduous forest after the stand-replacing fire in 1888. Repeated surveys confirm this [73,74].

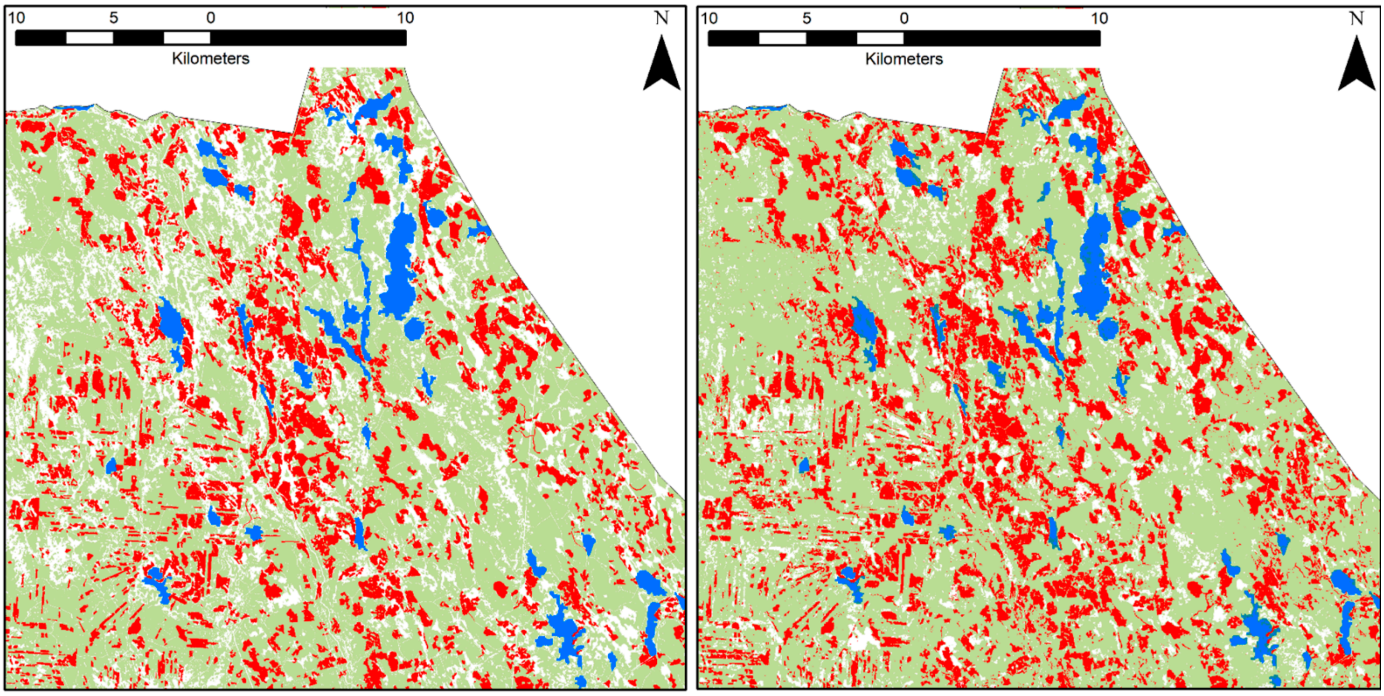

Figure 15. Maps of the core region of Gåsberget/Ore Skogsrike area (latitude 61.5 N and longitude 15.2E), located in the northernmost part of Rättvik municipality in Dalarna County, showing final fellings 2000–2020 according to the Swedish Forest Agency with the forest mask of the national land cover data (**left**), and the accumulated forest canopy loss 2000–2020 [58] with the corresponding forest mask (**right**).

The project Ore Skogsrike mapped high conservation value forests in the 2010s, and the project "Green infrastructure in Gåsberget conservation value tract" began in 2018 as collaboration with Dalarna County, Swedish Forest Agency, Sveaskog, Stora Enso, and the Swedish University of Agricultural Sciences. Bergstedt [71] provides an overview of the project's aims and methodology, data about the Gåsberget area, and describes the underlying objectives of the ongoing work for the period 2018–2020. The aim was to develop approaches for how the public sector and private industry could collaborate in a landscape regarding green infrastructure concerning (1) methods for determining how areas are best managed with considerate use or different types of protection in a landscape perspective, (2) forestry measures for prudent use, and (3) methods for how authorities and companies can collaborate in the planning, and practical execution, of nature conservation initiatives for effective nature conservation.

With small proportions of protected, set-aside, and other conservation areas amounting to ca. 20–25% in the core region of Gåsberget, the focus was on analysing the preconditions for improving the number of structures like large-diameter downed logs in production forests. A final report is expected during autumn 2021. This core area with Ejheden Ekopark is located near other core areas such as the 2018 fires in Olingdal and Kårböle, and old forest remnants in, Orsa Finnmark with Hamra National Park. It is a candidate area for landscape restoration. A notable gap in the social system was the insufficient level of broad stakeholder engagement.

Table 5. Characteristics of core regions as hotspot tracts for green infrastructure in Dalarna and Jämtland Counties.

	Dalarna County **Gåsberget * ("Ore Skogsrike")**	**Jämtland County** **Björkvattnet**
Area (ha)	Ca. 40,000	Ca. 70,000
Forest proportion (%)	82	41
pCF forest(%)	36	32
Core area (%)	27	30
Forest types	Forest fire in 1888 created a rare example of multi-cohort Scots pine and late deciduous forest succession	Old-growth spruce, border mountain birch
Formal protection (%)	5	0
Voluntary set-asides (%)	16	NA
Other and uncertain (%)	7	NA
Forest ownership	NIPF (17%), industry (83%)	NIPF (58%), industry (42%)
Final felling rate (%/year)	1.1 (0.4–1.8)	a passing frontier

* from green infrastructure action plan for Dalarna.

3.3.2. Core Region of Björkvattnet

Strömsund municipality in northern Jämtland County hosts one of Sweden's 13 large (>50,000 ha) intact forest landscapes [76], defined through the methodology of Yaroshenko et al. [77]. Mapping of potential continuous cover forests, and their persistence in terms of the absence of forest harvesting, show that this intact forest landscape (the northernmost Norway spruce cluster in Figure 12) has shrunk at Björkvattnet (Figure 16). This is due to past clear-felling along the shores of all large lakes in the westernmost corner of Strömsund municipality.

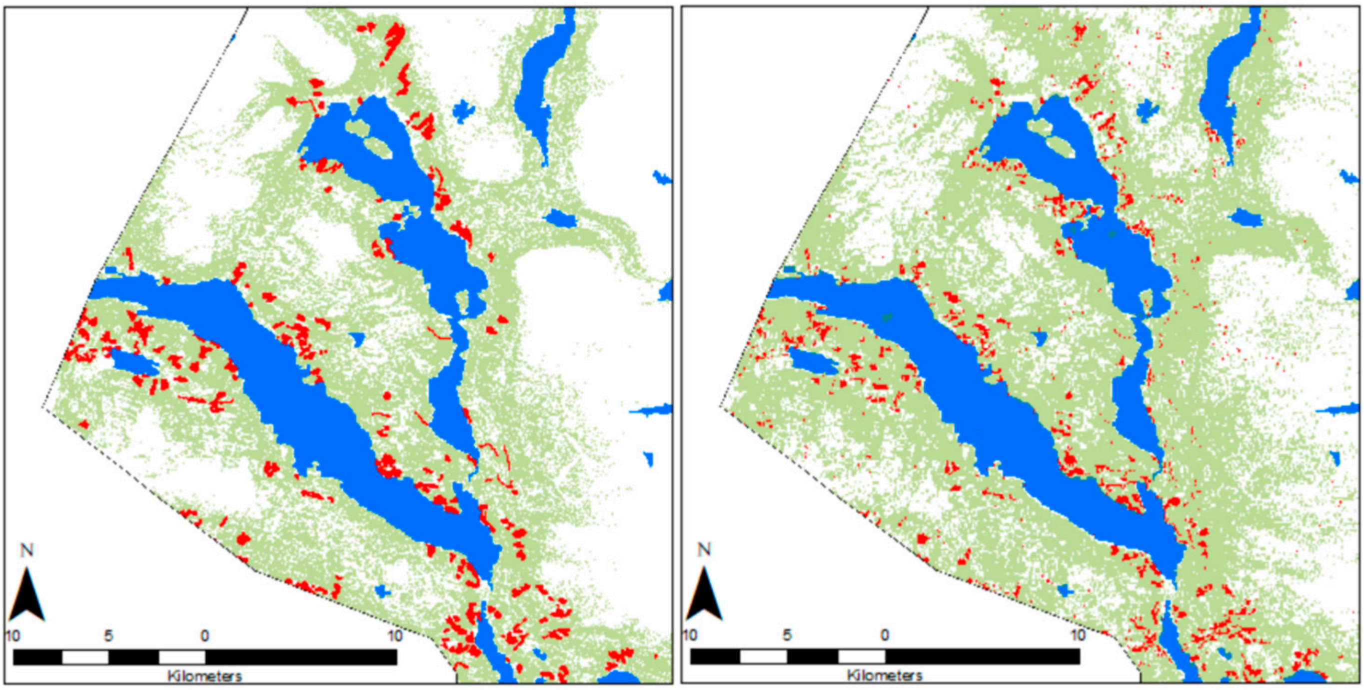

Figure 16. Maps of Björkvattnet (the small lake in the southwest) area (latitude 64.6 N and longitude 13.58 E), which is located in the westernmost part of Strömsund municipality in Jämtland County, along the border to Norway, showing final fellings 2000–2020 according to the Swedish Forest Agency with the forest mask of the national land cover data (**left**), and the accumulated forest canopy loss 2000–2020 [58] with the corresponding forest mask (**right**).

In 2017, the forest company Holmen Skog Co. decided to sell about 7000 ha of forest around Björkvattnet (Figure 16, Table 5). The argument was that these forests were too far away from the company's industries. The regional forest owner Persson Invest Skog bought these forests, and the voluntary provisions by Holmen were re-opened. Half of the forests at Björkvattnet have been bought by another company, but Persson Invest Skog will manage the forests. In a newspaper interview the owner " ... *wants to harvest as much as he can* ... " and intends to sue the state if final fellings are denied at Björkvattnet. This can be viewed as a means to understanding if more can be harvested than what Holmen Skog Co. had imagined when they made their voluntary conservation allocations in the framework of FSC certification. An interviewed ENGO representative stated that this is an example of how "*a certified forest company that cannot harvest key biotopes gets rid of the forest by selling to a less careful landowner, who feels no responsibility and intends to harvest old forest that we cannot get back for the foreseeable future*". Using a citizen science approach established in 1991, in 2018 a biodiversity assessment of Björkvattnet's high conservation value forests was arranged [78]. The findings of high biodiversity values during the assessment resulted in a request being submitted to the Jämtland County Administration to create a nature reserve. Civil servants from Jämtland County have expressed appreciation of the citizen science approach applied. However, instead of undertaking action to conserve remnant fragments of Europe's last intact forest landscapes [37] having documented high conservation values [78], the forest industry and its stakeholders want to harvest these forests based on the argument that green transition requires final felling of forest stands and subsequent production of long-lived wood products [79]. Thus, as the timber frontier expands the future of remnant high conservation value forests as components of intact forest landscapes such as Björkvattnet remain uncertain.

4. Discussion

4.1. The Net Result of Pressure and Response

Learning towards ecologically sustainable forest management requires continuous evaluation of the net effect of both pressures and responses on biodiversity states. The functionality of green infrastructures is affected not only by the number of suitable habitat patches according to habitat modelling, but also by what the surrounding production landscape looks like. The extents of formal and voluntary nature conservation considerations and different types of forest management, as well as how these are distributed in the landscape, are also important factors to consider. Evaluating the implementation of policies about sustainable development as a social process, and sustainability as consequences requires an integrative approach. The scene can be described as "*nested sets of coevolving social and natural subsystems connected through feedbacks, time lags, and cross-scale interactions*" [80].

This case study shows that after ca. 150 years of expansion of the frontier transforming near-natural forest landscapes to industrial production landscapes, only very small amounts of functional habitat networks remain. Moreover, as exemplified by old Scots pine and Norway spruce forests, the amounts of functional habitat networks continue to shrink. The transitions of age-class distributions have increased the contrast between the production forestry matrix and conservation areas. This is despite the increasing amount of formally protected areas, an increase of voluntary set-asides, which however are small and sometimes not long-lived, and tree retention forestry [14].

Data about the net effects of pressures and responses affecting changes in the amount of dead wood were presented in the most recent report from the National Forest Inventory [40]. This forms an illustrative example of the need for a holistic perspective. First, natural tree mortality and voluntary tree retention are two factors supplying dead wood, and second, harvested and removed wood, and decayed wood volumes, are two loss factors (Figure 17). The net effect of those four processes was an annual increase of 0.3×10^6 m^3, i.e., corresponding to 0.015 m^3 ha^{-1} on the available 20.0×10^6 ha used for wood production [40]. Thus, even if positive trends for some of the variables capturing the level of naturalness of forest stands were observed, the absolute levels and amount of positive change are far below evidence-based knowledge. This applies to the stand scale (e.g., different dead wood assortments), the landscape scale (e.g., old forest stands), and the regional scale (e.g., loss of the EU's last intact forest landscapes) [37].

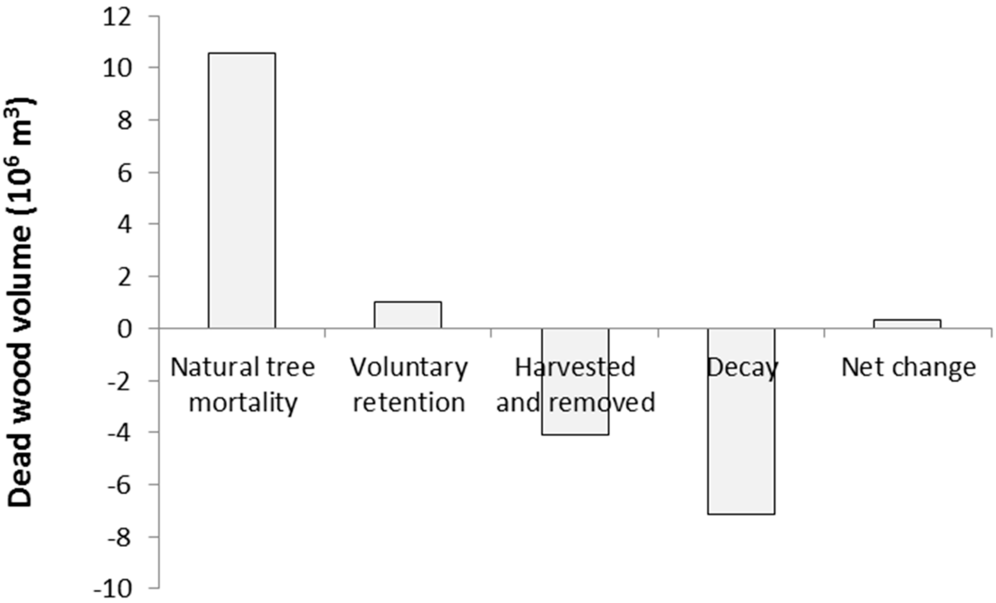

Figure 17. Annual gains and losses of dead wood (>10 cm dbh) on productive forest land in Sweden. Data from NFI 2012–2017, covering the period 2011–2016 [40].

Without putting results from monitoring in relation to the evidence-based threshold and benchmark intervals (Figure 18), the risks for misunderstandings and opposing interpretations among stakeholder groups are immense. For example, during the 16 years for monitoring of dead wood on harvested forest stands, the amount increased from 3.4 to 5.3 m^3 ha^{-1} (Figure 13), i.e., by 56%. For some stakeholders, this could be interpreted as that the state of a key biodiversity habitat is good. However, focusing only on the increase does not acknowledge the context, namely that absolute values need to be compared with a norm, such based on reviews of evidence-based knowledge, which for dead wood is about volumes [63], qualities such as the development stages of dead wood from hard to decayed (e.g., [61]), and connectivity. For the two types of decayed dead wood, the change reported in Figure 13 was from 0.6 to 0.7 m^3 ha^{-1} and 0.3 to 0.2 m^3 ha^{-1}, respectively. Examples for stand age distributions demonstrate the same pattern (e.g., [75]).

Finally, different species have different requirements regarding habitat type and quality, patch size, and functional connectivity, all of which affect the results of spatial analyses. We encourage research designed to quantify how much of different habitats species with different life-history traits require to be present versus having viable populations, and also what is required to secure ecological integrity and resilience.

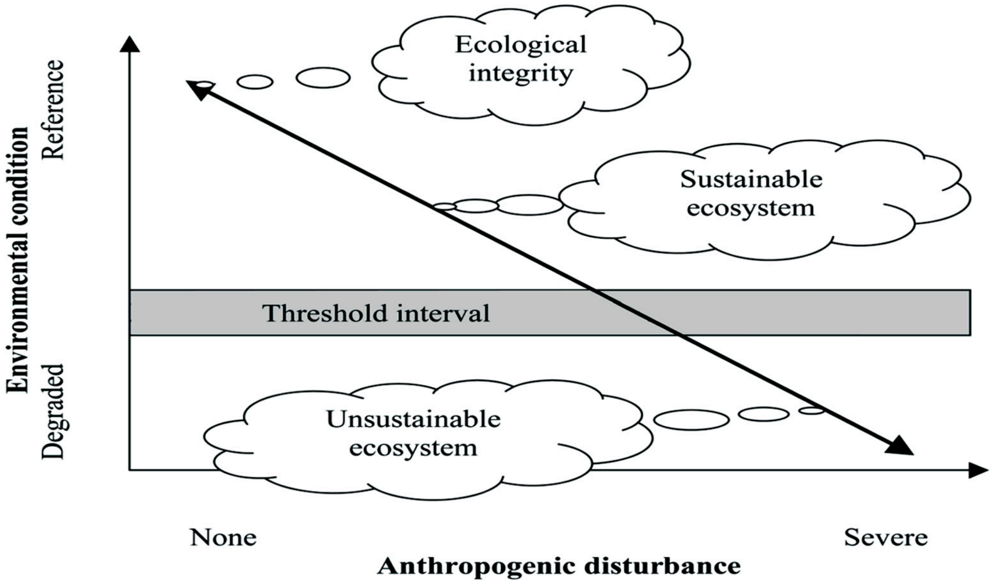

Figure 18. Environmental conditions can range from degraded to benchmark reference conditions, and anthropogenic disturbances or transformations can range from none to severe [15]. Monitoring of any indicator needs to be compared with a threshold interval, analogous to tipping points and planetary boundaries, to determine its status, e.g., being unsustainable, sustainable in the short term, or even with long-term ecological integrity [81].

4.2. Data Sources to Be Used with Care

Sustained yield forestry developed as an agricultural cropping system [82], focusing on wood and successional rotations. Today, however, forest landscapes are expected to provide multiple ecosystem services and are increasingly subject to uncertainties in the biosphere, society, and economy. This paradigm shift has broadened the focal spatial extent of planning and management from stands to landscapes, forced considerations to cascading and non-linear effects, and requires interactions among actors with different stakes [83]. This calls for monitoring of all types of fellings affecting forest patterns and processes at all spatial scales.

The two datasets used to estimate pressure on green infrastructure functionality yielded different estimates. The reason is that they measure different aspects of anthropogenic and natural forest disturbances [84], mirror different ranges of patch sizes, and use different definitions of forest masks (e.g., Figures 15 and 16). While the Swedish Forest Agency's data aims at monitoring final harvesting notification by landowners, the global forest loss data measures tree canopy loss of any kind for each pixel. We argue that the latter [58] data better represents the range of effects different kinds of forest harvesting and other disturbances can have on forest biodiversity and the portfolios of ecosystem services [85]. For instance, we observed that areas reported as having tree canopy loss were not always clear-felled but had been subject to commercial thinning. This involves the harvest of ca. 30% of stems, and the establishment of a dense network of trails for harvesting and terrain transport of the harvested wood. An increased incidence and intensity of thinning would reinforce this pattern. Although not clear-felled, thinned areas have negative impacts on wildlife species through simplification of forest structure by reducing vertical layering, removal of damaged trees and damage to the soil, field layer and secondary layers, as well as release of stored carbon [86]. In Sweden, annually, just below 200,000 ha is subject to final clear felling, and just above 300,000 ha is commercially thinned for pulpwood harvests [40]. Focusing on final fellings only, such as made by the Swedish Forest Agency, does not show the complete picture of forest change. Thinning should thus also be monitored and reported transparently. Another source of ambiguity is what spatial and thematic definition of forest is used, e.g., productive forest, unproductive and woodland, and if harvested areas count as part of the forest fund or not. This is important when calculating, comparing, and presenting proportions for different purposes.

Altogether, this can explain why tree canopy loss figures with finer grain resolution are higher than the results from the monitoring of clear-felled areas. This discrepancy has resulted in rebuttals (e.g., [87–90]) to a European-wide analysis of tree canopy loss [91]. As it turned out, seemingly abrupt increases in tree canopy loss could be attributed to a transition to more sensitive sensors used for remote sensing [87,89]. We, therefore, argue for in-depth studies to address what different spatial data can tell regarding both spatial and temporal comparisons of both anthropogenic and natural disturbances that take place at different spatial scales [84]. For example, how estimates of tree canopy loss vary among forest site types with different contrast with the canopy would be valuable to know. Analyses of satellite remote sensing data can be compared with orthophotos to evaluate the intensity of thinning for estimates of tree canopy loss. To conclude, we support employing a diversity of spatial data, thereby improving monitoring of the effect of forest harvesting on the diversity of benefits forest landscapes provide in time and space.

4.3. Landscape Planning Based on Informed Dialogue, or Truth Decay

The bio-economy narrative implies increasing biomass harvest levels to the economically sustainable maximum. However, this harms habitat suitability for focal species, deadwood diversity, carbon storage, and yields of wild berries (e.g., [92]). Realising current policies about biodiversity and ecosystem services calls for protecting the few remaining remnants of high conservation value forests [93], coping with reduced functionality connectivity [94], and engaging in habitat and landscape restoration in production landscapes. This is reinforced by the 2030 EU Biodiversity Target [1].

Combining different forest management regimes, such as continuous cover, retention forestry, and based on natural disturbances [95], can alleviate the negative effects of increasing harvest levels to biodiversity and non-wood ecosystem services. It is also crucial to evaluate initiatives proposed and applied with arguments that support green infrastructure functionality, such as the extent to which forest certification standards sufficiently reflect evidence-based knowledge [96].

The location of final fellings can affect whether or not remaining forests contribute to habitat network functionality. For example, if remnant patches of high conservation value forest are left exposed as isolated islands without connectivity to neighbouring forest patches of sufficient quality and size, all these stands may disappear as functional components of the habitat network [97]. Thus, landscape-level spatial forest planning is crucial to minimize the ecological costs of increasing harvest levels [14].

To counteract the ongoing fragmentation of functioning habitat networks for older Scots pine forests and Norway spruce forests in Dalarna and Jämtland Counties, spatial planning is required throughout the landscape. This implies a great need for collaboration among actors representing different sectors, and among levels of decision-making. Since different landowner categories' land holdings form a complex mosaic, there is a need to develop meeting places so that different actors can share information on formal forest protection, voluntary allocations, nature conservation considerations in production forestry, forest management methods, and nature conservation. This is called a landscape approach [98–100]. Borrini-Feyerabend et al. [101] and Barbour et al. [102] suggested four steps.

1. Form networks of actors and stakeholders. Initially, self-organization of fora for conservation and use, gradually based on mapping of stakeholders and actor analysis in the focal area, is needed. There are several selection principles. In addition to the area principle for stakeholder analysis, since perceived problems often cover a limited area, the principle of interest should be considered. Green infrastructure policy aims at both biodiversity conservation, and also support human well-being and welfare. Increased urbanisation, public concerns about human footprints caused by excessive flying to a remote tourism destination, and recently the increased use

of protected areas and green spaces increases the number and diversity of green infrastructure beneficiaries. For example, in the US, people increased the use of green infrastructure to cope with the stress of the COVID-19 pandemic and to perform outdoor activities with social distancing [103]. The same pattern is observed in Sweden. It is difficult to run processes that do not consist of committed people with financial resources. The principles of relevance and representation are used to ensure that the composition of the groups does not become unequally distributed. The narratives about green infrastructure core regions/areas in the counties Dalarna and Jämtland County indicate that some stakeholders perceived that the process has so far not been inclusive.

2. Produce knowledge about both ecological and social systems. Working with a learning organization with people who have relevant competence, awareness of what the organization works towards, and the ability to create teams. Provide support to local actors and work continuously with a broad perspective for analyses that thus become interesting for many actors and stakeholders. Prepare for the first meeting with the actors and stakeholders identified.
3. Collaborate through dialogue and shared learning. Here, a process leader and tools for constructive dialogue, joint learning, negotiation, and agreements are needed. Collaboration is not about being completely in agreement, but about taking advantage of the differences that exist and learning from them, regardless of who carries the insight.
4. Creating solutions and implementation. Implement agreements, organise management and care before a model for landscape planning through collaboration. Work continuously with planning, actions, and evaluation. Ongoing meetings are held for continuous learning by evaluating results and adapting future planning depending on the results achieved.

However, such an ideal model faces many real-world wicked problems. A key challenge is to handle the decay of truth, i.e., the diminishing role of facts, data, and analysis in political and civic discourses, which has been fuelled by new and rapidly evolving digital arenas [104]. There are competing interests and narratives [105]. A balance between interests cannot, however, be achieved if one part lies and the other is telling the truth. The Norway spruce landscape case study Björkvattnet illustrates this through associated forest industry opinions that wood products are long-lived, and thus better at storing carbon than old-growth forest ecosystems [79]. This statement is refuted by empirical research [106]. Forests that store much carbon have more intact biodiversity [107,108]. Despite this, the number of notifications to make final fellings in mountain forests has increased four-fold during the past year. The future of the EU's last large intact forest landscapes in Sweden, which if harvested will release carbon, is thus uncertain. Hence, the 2020 forest policy inquiry [23] proposed state investments to protect the entire subalpine regions remaining old forests. Therefore, the pressure is high on the north Swedish old forests located at the current timber frontier in terms of first exposure to massive clear felling. An explanation can be sought in the Swedish National Forest Inventory, where the most recent estimate is that ca. 96% of the wood produced on land that is not formally or voluntarily protected is felled annually [40]. This makes it difficult to consider multiple benefits of forest landscapes, especially given the current lack of coordination and integration at landscape, national, and EU levels [109].

5. Conclusions

While policies and practices are aimed at improving the amount and quality of representative green infrastructures for biodiversity conservation, our attempt to evaluate policy implementation processes during two decades shows that both wood production landscapes, and high conservation values in terms of dead wood, old forests, and intact forest landscapes, have actually deteriorated over time. This illustrates that there is rivalry and trade-offs between wood production, biodiversity conservation, and other forest landscape benefits. This stresses the need for widespread application of assessments of the net effects of pressures on ecosystems, and responses that aim of coping with pressures. In addition, other components of multi-scale efforts towards biodiversity, and long-term effects, need to be evaluated to understand if current green infrastructure fragments are lifeboats or sinking ships. This requires systems analyses that include species, habitats, and processes that maintain them in both entire landscapes and regions. Focusing on wood production landscapes, portfolios of natural-disturbance-based forest management methods are needed, which can support climate adaptation and mitigation efforts that include full cradle-to-grave carbon accounting. A key task for research is to define safe borders for operations, such as evidence-based knowledge of how much habitat at different scales is needed for different species, and how habitat quality and amount can be protected, managed, and restored. With the carrot-stick-sermon analogy [110] for policy implementation this means that while sermon is too weak, land owners could get paid for biodiversity conservation and carbon storage, which go hand in hand; or through regulation by the market, the Swedish government, or the EU.

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