Forest Ecology and Management 304 (2013) 312–321

Contents lists available at SciVerse ScienceDirect

Forest Ecology and Management

journal homepage: www.elsevier.com/locate/foreco

Full length article

Retaining trees for conservation at clearcutting has increased structural diversity in young Swedish production forests ☆

Nic Kruys [a], Jonas Fridman [b], Frank Götmark [c], Per Simonsson [d], Lena Gustafsson [e,*]

[a] Enetjärn Natur AB, Uppsala Office, Dragarbrunnsgatan 65, SE-753 20 Uppsala, Sweden
[b] Swedish University of Agricultural Sciences, Department of Forest Resource Management, SE-901 83 Umeå, Sweden
[c] University of Gothenburg, Department of Biological and Environmental Sciences, Box 463, SE-405 30 Göteborg, Sweden
[d] SCA Skog, SE-851 88 Sundsvall, Sweden
[e] Swedish University of Agricultural Sciences, Department of Ecology, P.O. Box 7044, SE-750 07 Uppsala, Sweden

ARTICLE INFO

Article history:
Received 10 January 2013
Received in revised form 10 May 2013
Accepted 11 May 2013
Available online 6 June 2013

Keywords:
Biodiversity
Dead wood
Logging
Monitoring
National Forest Inventory
Variable retention

ABSTRACT

Retaining trees for conservation at final harvest is becoming increasingly common within forestry globally, especially connected to clearcutting. The main action is to leave single living and dead trees, tree patches and buffer strips, to benefit biodiversity and to enhance ecosystem functioning. We present the first national analysis of effects on structural components from applying the retention approach. In Sweden retention forestry has been practiced large-scale for about 25 years, prescribed by the law and a requirement in certification standards. By analyzing data from the Swedish National Forest Inventory we found that the volume of dead trees ($\geqslant$100 mm in diameter; single trees and trees in patches <0.02 ha; data for larger retention patches not available) in stands 0–10 years old increased about 70% during the period 1997–2007, with a current average level of 8 m^3 ha^{-1}, and with a larger increase rate in this age class than in other forest ages. Retained living trees ($\geqslant$150 mm in diameter; single trees and trees in patches <0.02 ha; data for larger retention patches not available) decreased in quantity from 1955 until the early 1980s, with lowest levels of about 5 ha^{-1} (excluding *Pinus sylvestris*, commonly used as a seed tree) and then increased, approximately reaching the 1950s level by 2007, with about 15 trees ha^{-1} on average. Large-scale application of the clearcutting practice is the probable cause of the decrease, whilst retention actions are the likely explanation for the increase during the last decades. Our study clearly shows that young forests have become structurally richer since the introduction of the retention approach in forestry. However, comparatively low amounts of dead wood in forests 0–10 years old compared to what is available in old forests imply loss at harvest and studies of possible mechanisms to explain this are needed. Our results can indicate possible changes in other parts of the world, where the retention approach has been introduced more recently.

1. Introduction

Clearcutting is a widespread forest harvesting method (Sands, 2005), and has been criticized for causing negative environmental effects (McDermott et al., 2010). As a response to this, a new approach has been introduced during the last 25 years in, e.g. NW USA (Aubry et al., 2004), Canada (Work et al., 2003), Finland, Sweden and Norway (Gustafsson et al., 2010), Estonia (Lõhmus and Lõhmus, 2010), Tasmania (Baker and Read, 2011) and Argentina (Martínez Pastur et al., 2009). It is based on the long-term retention of structures and organisms, such as live and dead trees, at the time of harvest to achieve a level of continuity in forest structure, composition and complexity that promotes biodiversity and sustains ecological functions (Gustafsson et al., 2012). The retention approach is based on the importance for production forestry to emulate patterns and processes from natural forest landscapes. One important function is to enrich structural diversity in the developing stand compared to conventional clearcutting, e.g. to increase the amount of old living trees and also dead wood (Franklin et al., 1997). Other specific aims include to "life-boat" species over the regeneration phase, to increase connectivity in the landscape, to promote species associated with dead and living trees in early successional stages, and to enhance ecosystem functions like herbivory, mycorrhizal processes and tree regeneration (Gustafsson et al., 2010).

Despite the wide application of the retention approach there is a lack of quantitative evaluations of its effects on structural qualities in forests. Sweden is an ideal case for such an analysis since the retention approach has been practiced in this country for more than two decades (Eckerberg, 1988; Götmark et al., 2009;

* Corresponding author. Tel.: +46 18 672747; fax: +46 18 672890.
E-mail address: lena.gustafsson@slu.se (L. Gustafsson).

0378-1127/$ - see front matter © 2013 The Authors. Published by Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.foreco.2013.05.018

Gustafsson and Perhans, 2010), and an extensive and high-quality National Forest Inventory data-base exists that can be used for detailed analysis.

Due to a long history of industrial forestry in North Europe, and especially in Sweden and Finland, production forests have become more even-aged and much less structurally diverse than intact forests. Amounts of dead wood, old trees and other properties of importance to biodiversity are much lower compared with natural forest landscapes (Fridman and Walheim, 2000; Peterken, 2001; Josefsson and Östlund, 2011). The importance of incorporating old-growth elements in managed forests is increasingly being recognized (e.g. Bauhus et al., 2009), and dead trees and old living trees are known to be of large importance to biodiversity, not the least to threatened species (e.g. Bernes, 2011).

A multiscale model for forest conservation is applied in Sweden, implying that conservation actions are taken at different scale-levels from individual trees to areas embracing hundreds or thousands of ha. The highest level, up to 1000 ha or more, includes formally protected areas such as national parks and nature reserves. At the next, intermediate level (ca. 1–50 ha) there are both formally protected and voluntary set-asides through certification, many of which are so called woodland key habitats (Timonen et al., 2010). Retention approaches represent the lowest scale level, implying that trees of importance to biodiversity and ecosystem function are left unlogged, mainly at final felling operations, but also during thinning. Single living trees are retained, and tree patches may be left as 'islands' in felled areas or adjacent to non-felled stands, often as buffer strips along lakes, rivers, wetlands and near settlements. Standing and lying dead trees are also retained, and according to instructions they should not be harmed during logging operations. Dead wood is created, in Sweden primarily through artificially creating snags by cutting trees at a height of 3–4 m, but also by retaining living trees of which some or many will eventually become windthrown. The state is responsible for establishing nature reserves, while both the state and the forest owners protect also smaller areas.

Retention requirements have been part of Swedish forest legislation since the 1970s, and were made well-known to landowners through the "Richer Forest" campaign by the Swedish Forest Agency in the beginning of the 1990s. They were further consolidated with the launch of a new forest policy in the mid 1990s in which environmental and production goals were assigned equal value (Bush, 2010). Certification processes within FSC (Forest Stewardship Council) and PEFC (Program for the Endorsement of Forest Certification) emphasize retention requirements in their standards, and have also been driving forces for implementation of this practice. About 70% of the Swedish productive forest land is certified according to either FSC or PEFC, or both systems. The average proportion retained area per clearcut is 3% (Swedish Forest Agency, 2012). In January 2005 a storm, "Gudrun", hit southern Sweden and 70 million m^3 trees fell, equivalent to twice the amount of the normal annual cut in the storm area (Swedish Forest Agency, 2006), and also strongly affecting retention amounts and patterns.

Based on data from the long-term Swedish National Forest Inventory (NFI), we here assess what can be achieved by the retention approach. The aim is to quantify the development over time of retained living trees (solitary and small tree groups) and dead trees after final harvest, with a focus on young forests (0–10 years old). We want to describe such changes in relation to regions, stand age classes, ownership categories, tree diameter, tree species (living trees), tree position (dead trees; standing or lying) and decay class (dead trees). Since Sweden was so early in application of the retention approach, results can demonstrate more general trends and help assess and predict development in countries and regions in which the retention approach has been introduced more recently.

2. Materials and methods

2.1. Swedish forests and forestry

Forests cover about 55% of Sweden's land area of 41 million ha (Swedish Forest Agency, 2012) and more than 90% of the productive forest land is managed more or less intensely with the clear-cutting method, introduced large-scale in the 1950s. Practices have since then been largely similar for small private forest owners, large forestry companies and other forest owners. After clear-cutting and soil preparation, regeneration is secured through planting (or sometimes with natural regeneration) of the conifers *Picea abies* (L.) Karst. and *Pinus sylvestris* L., later followed by pre-commercial thinning and thinning. Also birch, *Betula pendula* Roth., *Betula pubescens* Ehrh. is favoured to some extent. Rotation times vary between 60 and 100 years.

2.2. The Swedish National Forest Inventory (NFI)

NFI started 1923 and performs annual inventories of all land in Sweden, providing data at national and regional levels, with focus on forest and other wooded land. The present design was introduced in 1983 (Ranneby et al., 1987). Data on trees, forests and management history are recorded by field teams in a stratified random systematic cluster design with partial replacement, and in plots with radius of 7 m, 10 m or 20 m, depending on variable. Permanent plots are surveyed every 5–10 years, and at least 5 years of data are usually needed for reliable estimates (Axelsson et al., 2010).

The list of recorded variables in the NFI is extensive, covering both forestry and environmental aspects. Living and dead tree volumes and numbers can be compiled for regions, ownership categories and age classes. For variables relating to retention, the NFI measures the amount and qualitative aspects of trees without differentiating between reasons for retention (conservation, seed-tree or other). In addition, the plot-based NFI does not make extensive inventories of individual cut areas specifically looking for biodiversity values.

2.3. NFI data used

2.3.1. Geographic regions and forest land

Sweden was divided into four regions, corresponding to a division commonly used to represent NFI-data: N Norrland, S Norrland, Svealand, Götaland, which cover a north–south gradient in Sweden (Fig. 1). The southern parts of Svealand and Götaland represent a transition toward temperate forest in southernmost Sweden while more northern parts belong to the boreal forest zone (Nilsson, 1997).

The forest land area included in the analysis corresponds to what is defined as productive forest in Sweden, i.e. with an average potential yield capacity of at least 1 $m^3\ ha^{-1}\ yr^{-1}$ (standing volume, stem volume over bark). In addition, nature reserves, national parks or other types of formally protected areas (in 2009) were excluded from the data from all years. This was done to avoid any trends in the results due to managed forest land being transferred to a protected status. The analysed area comprises in total about 22.5 million ha.

2.3.2. Time periods

Time span for analyses of living trees covered 46 years and for dead trees 15 years (Table 1). Data were based on five-year running averages around a midpoint year which means that when a figure is mentioned, e.g. for 2007, the data used to calculate it are from 2005 to 2009. In the time trends of living trees an unexplained

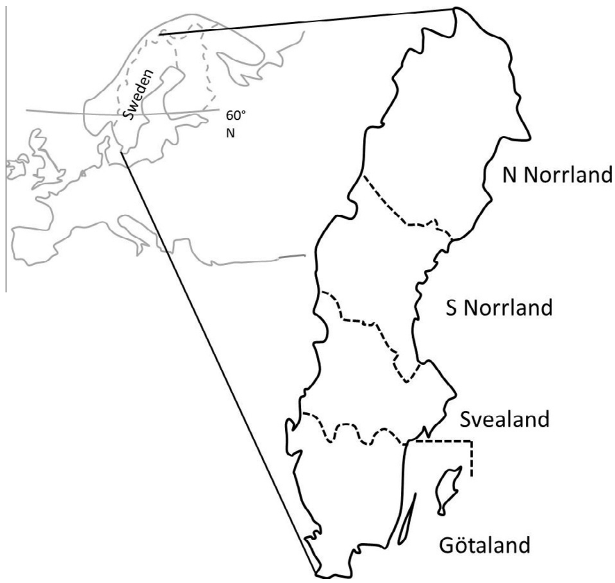

Fig. 1. Geographical regions used in the analysis.

"jump" occurs in the late 1970s to the beginning of the 1980s. The reason for this is yet unknown but we suspect that it can be due to either corrupt data or changes in methodology and design of the NFI. This problem does not affect our comparisons of 1955, 1989, and 2007, but should be kept in mind.

2.3.3. Age classes and forest ownership categories

Age classes were designed to cover different forest ages, with finer resolution for young forests than for older ones (Table 1). Three categories were chosen to describe forest owners: (1) "Forestry companies", which comprise the commercial forestry companies that own land in Sweden (23% of the productive forest land). (2) "Small private owners", which correspond to forests owned by individuals (cover 52%). (3) "Other owners", mostly comprised of publicly owned forests, diocese-owned forests or forests owned by publicly owned forestry companies, including the large state-owned forestry company Sveaskog (25%). Ownership data for the time series of living trees 1955–2007 are not presented since the definition of ownership categories has changed during this period.

2.3.4. Type of retention captured with the data

If an intact retention tree patch is sufficiently large ($\geqslant$0.02 ha) it will not be classified as the same age as the surrounding young forest but instead will be categorized as older forest. The same applies for retention trees left in a strip immediately adjacent to a surrounding forest, lake, wetland, road or near settlements. The results presented in this study are therefore confined to solitary retention trees and retention of trees in patches <0.02 ha.

2.3.5. Dead tree data

Dead trees in different stages of decay were not included in the Swedish NFI prior to 1994, which explains the relatively short time series. Dead trees with dbh (diameter at breast height, 1.3 m) $\geqslant$ 100 mm diameter and height/length > 1.3 m (for standing and lying dead wood, respectively) were included. Calculations of dead wood volumes were made by the National Forest Inventory according to common procedure, e.g. Fridman and Walheim (2000). Dead wood volume was subdivided into decay class, diameter class and position (Table 1). Decay classes were "hard" (decay classes 0 and 1 in the NFI measurement system which covers dead wood from the freshest windthrows to decay stages where $\geqslant$90% of the trunk consists of hard dead wood and there is very little effect of decomposer organisms on the wood), and "soft" (all inventoried dead wood of more advanced decay classes 2, 3 and 4 according to NFI standards; <90% of the trunk consists of hard dead wood and there are obvious effects of decomposer organisms on the wood).

2.3.6. Living tree data

Data were subdivided into tree species and only trees with dbh $\geqslant$ 150 mm were included (Table 1). *P. sylvestris* was included for reference purpose. It is one of the most common tree species in Sweden, but it is not possible to differentiate the reasons for leaving such trees after felling, i.e. seed trees vs. retained trees for nature consideration. Seed trees are usually harvested some years after the regeneration felling and do not qualify as retention trees. Exclusion of *P. sylvestris* from the study would underestimate the levels of nature consideration, especially in the region of N Norrland where it is the most common tree species. In contrast, inclusion of *P. sylvestris* provides an overestimate of retention amounts.

2.3.7. Measures of variation and statistical analysis

For each tree quantity X (m^3 ha^{-1} for dead wood and number of trees ha^{-1} for living trees) the standard error (SE) was calculated

Table 1
Criteria for living and dead trees included in the study, and type of data from NFI used.

	Living trees	Dead trees
Dimensions	dbh $\geqslant$ 150 mm (dbh, diameter at breast height, 1.3 m)	dbh $\geqslant$ 100 mm, divided into diameter classes 100–199 mm, 200–299 mm, 300–399 mm, $\geqslant$400 mm
Qualities	*Picea abies*, *Betula* spp. (*Betula pubescens* Ehrh., *Betula pendula* Roth), *Quercus* spp. (*Quercus robur* L. and *Quercus petraea* (Matt.) Liebl.)), *Fagus sylvatica* L. and "other deciduous species" (mainly alder *Alnus* spp. and aspen *Populus tremula* L). *Pinus sylvestris* was included for reference purpose (often used a seed tree)	Decay classes (see text for description)
Positions	–	Standing or fallen
Measurement	Numbers	m^3
Time period	1953–2009	1994–2009
Period length for averages	Five-year running averages	
Age classes	0–10 years, 11–20 years, 21–60 years, 61–100 years,>100 years	
Forest owners	Forestry companies, small private owners, others (for definition, see text)	
Number of NFI-plots analysed	Living trees: between 6000 and 18,000 depending on year. Dead wood: ca. 6000 per year	

(see e.g. Fridman and Walheim, 2000). 95% confidence intervals were then calculated as X ± 1.96 × SE; with non-overlapping intervals indicating significant differences. Variation measures are not given for *P. sylvestris* since this tree species was included for reference only.

3. Results

3.1. Dead wood volume

Trends in dead wood volume (dbh ⩾ 100 mm) in young forests (0–10 years old) using five-year averages show that the volume ha^{-1} had increased significantly by about 70% in Sweden during the period 1997–2007 (Table 2). The most pronounced increase pattern (>250%) was observed for Götaland, and was especially evident during the period 2003–2007 (the storm Gudrun was in 2005). There was a large increase over time also in Svealand (>80%). Northern Sweden showed more moderate changes, with an about 50% increase in S Norrland and only about 10% increase in N Norrland. All changes in the regions were significant except for N Norrland. For the whole country, and for regions N Norrland and S Norrland amounts had stabilized between 2005 and 2007, while a similar flattening out was seen for Götaland only between 2006 and 2007.

Forests aged 11–20 years and 21–60 years had consistently lower dead wood amounts than forests 0–10 years during the period between 1997 and 2007, while older forests (61–100 years and >100 years) had the highest dead wood amounts. Dead wood volumes of both oldest age-classes increased over time, but slightly less than in the youngest age class. The increase between 1997 and 2007 was significant for forests 0–10 years, for forests >60 years old, and for all forest ages taken together (Table 3).

The hard dead wood, i.e. recently killed trees, increased significantly from 2.0 m^3 ha^{-1} to about 5 m^3ha^{-1} from 1997 to 2007 for the whole country. Thus this decay class contributed largely to the observed total increase, since soft dead wood volumes ha^{-1} had a much smaller and non-significant increase (Fig. 2a). Dead tree volume in the largest class (dbh ⩾ 400 mm) as well as finer diameter dead trees (dbh ⩾100 mm and ⩽400 mm) both increased significantly in forests 0–10 years old during 1997–2007 (Fig. 2b).

Forestry companies was the owner category that left the most dead wood per hectare in young forest (0–10 years old) calculated for the whole country, and with a significant increase from about 6 m^3 ha^{-1} in 1997 to almost 10 m^3 ha^{-1} in 2007. The increase from 1997 to 2007 was significant also for small private owners, from about 3.5 m^3 ha^{-1} to about 7 m^3 ha^1. The average volumes for other forest owners were about 5 m^3 ha^{-1} in 1997 and about 7 m^3 ha^{-1} in 2007 but this increase was not significant (Fig. 2c).

In 2007, dead wood levels in young forests (0–10 years old) constituted the third most dead wood dense age class in all regions (about 8 m^3 ha^{-1}), following the two oldest age classes 61–100 years (about 10 m^3 ha^{-1}) and >100 years (about 15 m^3 ha^{-1}). Forests 11–20 years old had significantly lower volumes than the youngest forests, for both 1997 and 2007 (Fig. 3). The dead wood volume in the young forest (0–10 years old) varied between 9 m^3 ha^{-1} and 6 m^3 ha^{-1} depending on region, with highest levels in S Norrland, and lowest in N Norrland.

3.2. Number of living trees

When young forests (0–10 years old) in 1955, 1989 and 2007 are compared, the number of living trees ha^{-1} (dbh > 150 mm) has varied between 10 and 35 trees ha^{-1} (5 and 15 trees ha^{-1} without *P. sylvestris*) (Fig. 4). The lowest numbers were found in the middle of the period. Forests aged 11–20 years had a similar decrease in the middle of the time period (1989). For older forests (>20 years old) there had been an increase over the time period (Fig. 4).

The decline in the middle of the period 1955–2007 for forests aged 0–10 years could be seen for all four regions both including *P. sylvestris* (Table 4), and excluding this tree species (Table 5). Excluding *P. sylvestris*, no significant difference in the number of living trees between 1955 and 2007 could be seen for any region, except for S Norrland which had a significant decrease (Table 5). For all regions except Götaland, without *P. sylvestris*, there was a tendency for flattening out in the tree number ha^{-1} from the late 1990s and onwards. Including *P. sylvestris* there were even signs of a decrease from 2005 to 2007 (Table 4).

Trees of "other deciduous trees species", and *Fagus sylvatica* and *Quercus* spp. had increased significantly in forests 0–10 years old between 1955 and 2007 (Fig. 5). Trees of *Betula* spp. and *P. abies* declined from 1955 to 1989 and then increased again. Nevertheless, for *P. abies* there was a significant decline between 1955 and 2007 while *Betula* spp. had in 2007 returned to the level of 1955 (Fig. 5).

In 2007, the average number of living trees ha^{-1} in young forests (0–10 years old), excluding *P. sylvestris*, was about 14 ha^{-1}, with large variations between regions with Götaland having most, about 25 ha^{-1}, and S Norrland, N Norrland having least, both about 9 ha^{-1} (Table 5). Including *P. sylvestris* the number was about 25 ha^{-1} for the whole country, most for Götaland with about 34 ha^{-1}, and least for S Norrland with about 18 ha^{-1} (Table 4). *P. sylvestris* was the most common tree species in young forests (0–10 years old) for the whole of Sweden with an average total of about 11 trees ha^{-1}, and was especially common in N Norrland (about 15 ha^{-1}) (Fig. 6). Excluding this tree species, the most common tree taxa in young forests was *Betula* spp. (about 6 trees ha^{-1}), followed by *P. abies* (about 4 trees ha^{-1}), and "other deciduous tree species" (about 3 trees ha^{-1}). *Betula* spp., *P. abies*, and "other deciduous tree species" were especially common in Götaland (Fig. 6).

4. Discussion

4.1. Changes in the structural diversity of young forests

Our study is the first national analysis on effects over time of retention measures on the structures of dead wood and living trees in production forests. It clearly shows that tree retention for conservation at clearcutting has increased the amounts of dead and living trees in young forests (0–10 years old). For dead trees this

Table 2
Dead wood volume (m^3 ha^{-1}; dbh ⩾ 100 mm and height/length ⩾ 1.3 m) in young forests (0–10 years) during 1997–2007 using five-year averages, by region. 95% confidence intervals are given for 1997 and 2007, respectively.

	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Götaland	2.56 + 0.41	3.00	3.29	3.70	3.83	4.11	6.19	7.35	8.14	9.00	9.02 + 0.57
Svealand	3.56 + 0.46	4.34	4.81	5.08	5.64	5.98	5.58	6.02	6.31	6.32	6.59 + 1.49
Southern Norrland	6.20 + 0.59	6.30	6.90	7.15	7.74	8.36	8.86	8.95	9.44	9.48	9.39 + 0.87
Northern Norrland	5.21 + 0.80	4.79	5.34	4.93	5.62	5.38	5.69	5.44	5.94	5.74	5.60 + 1.16
Sweden total	4.56 + 0.92	4.76	5.24	5.35	5.84	6.09	6.67	6.98	7.49	7.64	7.66 + 0.84

Table 3
Dead wood volume ($m^3\ ha^{-1}$; dbh $\geqslant$ 100 mm and height/length $\geqslant$ 1.3 m) during 1997–2007 using five-year averages, by forest age classes, for the whole of Sweden. 95% confidence intervals are given for 1997 and 2007, respectively.

	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
0–10 years	4.56 + 0.41	4.76	5.24	5.35	5.84	6.09	6.67	6.98	7.49	7.64	7.66 + 0.57
11–20 years	3.24 + 0.34	3.07	2.99	3.03	3.11	3.22	3.28	3.33	3.47	3.78	3.75 + 0.43
21–60 years	3.93 + 0.28	3.83	3.87	3.69	3.74	3.62	3.70	3.62	3.70	3.71	3.76 + 0.24
61–100 years	7.51 + 0.46	7.75	7.64	7.54	8.11	8.12	8.70	9.07	9.62	9.81	10.18 + 0.72
100 + years	12.21 + 0.79	12.17	11.96	12.26	12.87	12.95	13.36	13.79	13.98	14.39	14.65 + 0.86
All ages	6.41 + 0.26	6.44	6.41	6.43	6.76	6.75	7.02	7.21	7.44	7.59	7.71 + 0.32

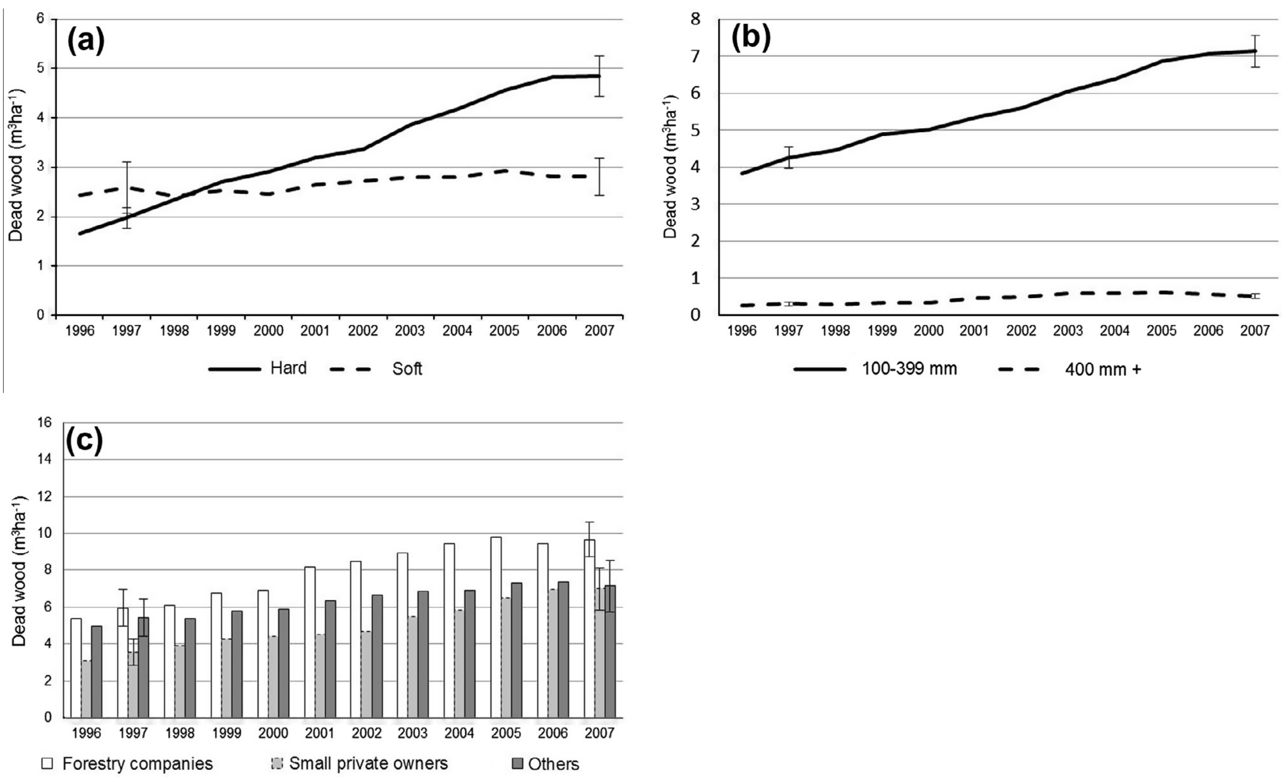

Fig. 2. Dead wood volume (dbh $\geqslant$ 100 mm diameter and height/length $\geqslant$ 1.3 m) in 0–10 year old forests for the whole of Sweden during 1996–2007. (a) By decay classes, (b) by dbh and (c) by forest owner categories. Five-year averages with error bars for 1997 and 2007 showing 95% confidence intervals.

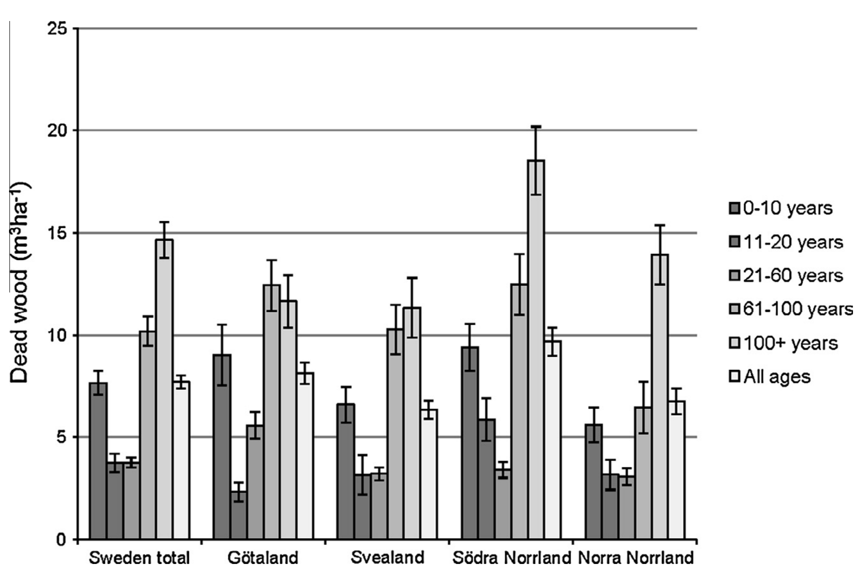

Fig. 3. Dead wood volume (dbh $\geqslant$ 100 mm and height/length $\geqslant$ 1.3 m) by forest age and region during 2007. Five-year averages (2005–2009) with error bars showing 95% confidence intervals.

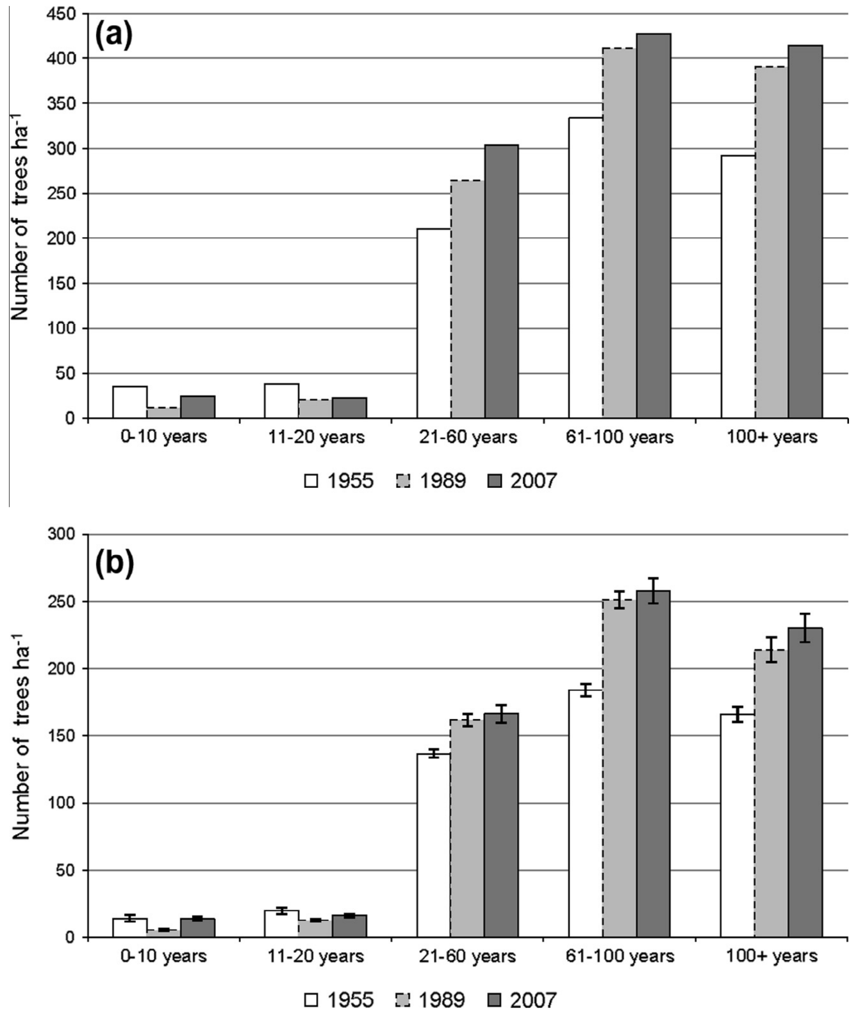

Fig. 4. Number of living trees ha^{-1} (dbh ⩾ 150 mm) in different forest ages in 1955, 1989 and 2007 for the whole of Sweden. (a) With *P. sylvestris* and (b) without *P. sylvestris*. Error bars for *P. sylvestris* were not possible to construct and thus lack in (a). In (b) error bars show 95% confidence intervals.

Table 4
Number of all living trees ha^{-1} (dbh ⩾ 150 mm) for forests aged 0–10 years for the whole of Sweden and for different regions during 1955–2007, including *Pinus sylvestris*. Confidence intervals for this tree species were not available, and thus could not be constructed. For regions, see Fig. 1.

	Year											
	1955	1960	1965	1970	1975	1980	1985	1989	1995	2000	2005	2007
Sweden total	35.36	31.77	24.19	20.17	16.45	18.73	11.99	11.84	19.78	24.92	25.94	24.87
Götaland	40.70	34.30	27.06	20.30	14.16	21.08	15.09	17.22	27.18	31.67	33.72	33.82
Svealand	43.40	36.16	27.55	19.81	14.92	15.15	12.37	12.42	21.43	26.46	27.77	25.67
Southern Norrland	37.43	34.12	24.42	21.29	13.24	16.17	8.09	8.56	15.30	22.25	20.75	17.91
Northern Norrland	26.66	25.70	19.57	19.53	22.45	22.58	13.19	11.14	17.44	20.67	22.73	22.39

Table 5
Number of all living trees ha^{-1} (dbh ⩾ 150 mm) for forests aged 0–10 years for the whole of Sweden and for different regions during 1955–2007, excluding *Pinus sylvestris*. 95% confidence intervals are given for 1955, 1989 and 2007, respectively. For regions, see Fig. 1.

	Year											
	1955	1960	1965	1970	1975	1980	1985	1989	1995	2000	2005	2007
Sweden total	14.18 ± 0.97	13.39	9.62	8.19	9.11	8.51	5.16	5.58 ± 0.71	8.15	11.94	12.70	13.77 ± 1.43
Götaland	22.00 ± 1.77	18.69	16.42	13.06	10.41	14.28	9.51	10.34 ± 1.80	13.80	19.21	22.40	24.65 ± 3.96
Svealand	12.03 ± 1.27	11.39	8.03	6.29	9.23	5.32	4.35	4.94 ± 1.14	7.54	11.41	12.90	12.86 ± 2.22
Southern Norrland	16.06 ± 2.42	14.82	8.74	9.24	8.25	8.07	3.57	4.39 ± 1.44	6.86	10.27	8.38	9.05 ± 2.13
Northern Norrland	10.57 ± 1.18	11.28	7.22	5.75	8.88	7.88	4.62	4.33 ± 1.32	5.81	7.95	8.33	8.80 ± 2.57

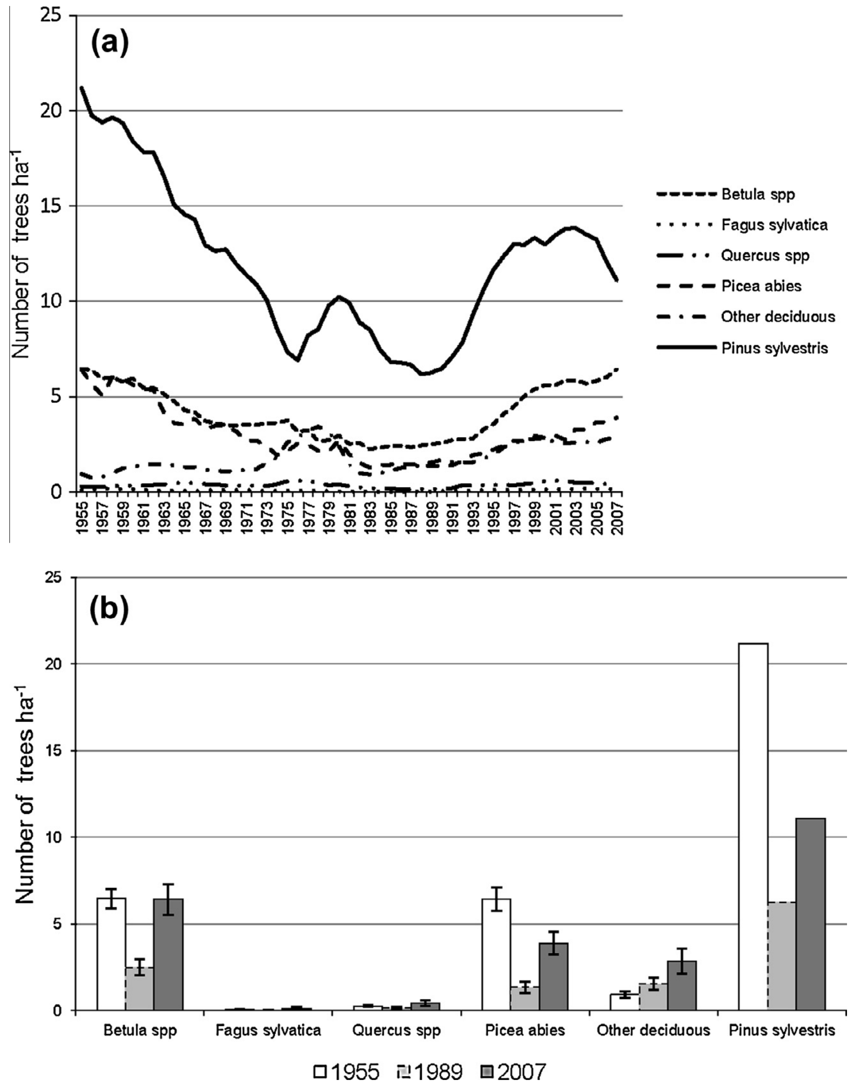

Fig. 5. Number of living trees ha^{-1} (dbh $\geqslant$ 150 mm) in forests 0–10 years for the whole of Sweden by tree species. (a) 1955–2007 and (b) 1955, 1989 and 2007, with 95% confidence intervals. Error bars for *P. sylvestris* were not possible to construct and are thus lacking.

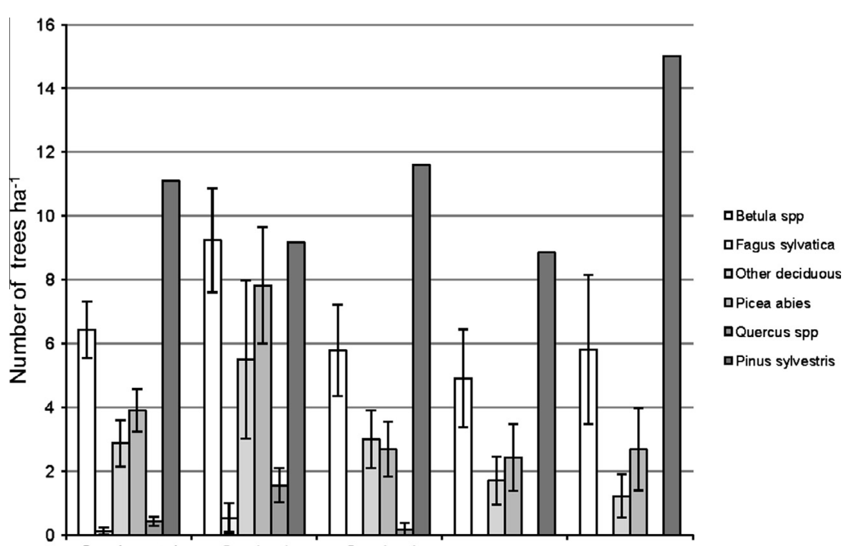

Fig. 6. Number of living trees (dbh $\geqslant$ 150 mm) ha^{-1} in young forests (0–10 years) in 2007 by tree species and region. Five-year averages (2005–2009) with error bars showing 95% confidence intervals. Error bars for *P. sylvestris* were not possible to construct and are thus lacking.

increase means that the volume in the youngest forest age-class has increased with 70% during the period 1997–2007. For living trees a decline in numbers from the 1950s until the 1980s was followed by an increase, and the number of living trees ha^{-1} is now close to the 1950s levels. Our results are not surprising considering that the period of large-scale retention practice spans more than 20 years. The focus on the approach in Sweden increased in the new forest policy of 1993, including wider and more specific recommendations in the Forestry Act. Further, Sweden was the first country to produce a national FSC-certification standard, in 1998, with retention actions as important components.

4.2. The NFI-data used and comparisons with other studies

Fundamental in the interpretation of data from this study is that the NFI-inventory only captures a subset of all retained trees. Retention patches or edge zones $\geqslant$0.02 ha are not included. For a complete picture of all retention components, all trees and forest patches excluded from logging for conservation reasons have to be identified. Still, the existing NFI-data offer excellent information on long-term development of dead trees and a subset of living trees, and also enable comparisons of forest age classes.

The only available international comparison on retention amounts indicates that countries in north Europe generally have lower levels than many other countries and regions; for instance the average retained area is less than 5% for Sweden while it is 5–20% for British Columbia, Canada and Washington and Oregon, USA (Gustafsson et al., 2012). We cannot make comparisons with these data since our levels were expressed as volumes (dead wood) and number (living trees). Still, number of living trees would have been considerably larger, should we have been able to include larger patches than 0.02 ha. Also dead wood volumes most probably would have been higher since it is likely that there are more dead trees within than outside retention patches.

Since 1999 the Swedish Forest Agency runs a nation-wide monitoring of regeneration and environmental considerations taken at final harvest of stands. In this "Polytax" inventory an annual random sample of >1000 clearcuts is surveyed (Statistical Yearbook of Forestry 2012). As the inventory concentrates on the regeneration period, there is no possibility to extract data on the whole range of forest age classes, like within the NFI. Concerning volumes of dead trees the Polytax reports an average of 12 m^3 ha^{-1} in forests 5–7 years old (Swedish Forest Agency, 2012), as compared to the NFI-data presented here of 8 m^3 in forests 0–10 years old. In the Polytax inventory large patches and edge zones are included, contrary to the NFI data, and this is a likely explanation for the difference. For living trees Polytax only reports trees with "special conservation value", including *P. sylvestris*, which precludes comparisons. Götmark et al. (2009) analysed NFI-data to compare the periods 1983–87 and 1998–2002 regarding quantities of broadleaved conservation trees in Götaland and large parts of Svealand, and found similar levels as in our study. They also found that the density of retention trees increased with the productivity of the forest land (analysed by site index).

4.3. Dead wood

The information on dead wood amounts from the NFI-data raises questions about the turnover between age classes. The amount in the oldest age classes >100 years and >60–100 years, i.e., those that are mature for final felling, is much higher than that of the youngest forests. If all dead wood from the old forest would be retained at harvest, the amounts should be fairly equal in the youngest and oldest forests. That this is not the case has earlier been shown by Fridman and Walheim (2000), and is also clear in our data. The disappearance of dead wood could be due to damage from heavy machinery (harvesters, forwarders, tractors) during logging and soil scarification (Hautala et al., 2004), natural decomposition of soft wood (e.g. of birch) after harvest, and possibly by harvest of wind-thrown retention trees by forest owners, as indicated by some studies (e.g. Liungman, 2000). The increasing extraction of tops and branches for bioenergy use (Swedish Forest Agency, 2012) may also reduce the dead wood resource (Rudolphi and Gustafsson, 2005). Another explanation may be that old forests with low amounts of dead wood are more frequently harvested than old forests with high amounts of dead wood. This may be due to differences in forest owner behavior with some small, private forest owners harvesting at a lower rate (e.g. through longer rotation periods), which could lead to accumulation of dead wood. Deeper analyses are needed to reveal if such a mechanism is likely. Overall, there seems to be a large potential for maintaining higher dead wood levels from the harvested forests.

Low levels of dead wood in the northernmost region N Norrland are difficult to explain. Forests > 100 years old held the highest volumes of dead wood indicating that there is a potential for retaining dead trees in young forests after felling. A possible explanation that cannot be resolved in this study is that forest-owner behavior may differ between regions. If forest owners in N Norrland are more likely to retain dead wood in retention zones and patches, this would affect the present results. Also, at least to some extent, it could also indicate that fallen trees are extracted as firewood for local use to a larger extent than in other regions.

Each region shows a similar pattern with the highest amounts of dead wood in the oldest forest age classes and the lowest amounts in intermediate age classes (21–60 years). A large part of the intermediate age classes were clearcut at a time before retention actions became common practice, and have not produced any considerable amounts of dead wood since then. According to retention recommendations, retention should be practiced at all logging operations, i.e. also at thinnings. The low amounts in intermediate age classes may indicate that retention at thinning operations is slow to develop. About twice as high deadwood amounts occurred in the age class 0–10 years compared to the age class 11–20 years, in 2007. This indicates that the increase in dead wood has been much higher during the last 10-year period than during the preceding 10-year period. To some extent, decomposition of dead trees such as birches might have occurred 11–20 years after harvest. Deeper analysis of dead wood development before 1997 is not possible though, since such complete dead-wood data are only available from after 1994.

4.4. Living trees

The number of living trees in forests 0–10 years old was in 2007 roughly at the same level as in 1955 (excluding the commonly used seed tree *P. sylvestris*), after a substantial decrease during the 1970s and 1980s. The high levels about 50 years ago were most likely due to a larger use of Norway spruce as a seed tree, more restricted harvest of deciduous trees, and that small, crooked and damaged trees were left at site. The restoration during the last two decades is without doubt due to the retention practice. The decrease of Norway spruce and Scots pine in the middle of the period reflects mechanization and the expansion of clearcutting around 1950 (National Atlas of Sweden, 2011). For birch the use of herbicides during the 1970s and 1980s was an additional cause. Interestingly, the collective group "other deciduous trees" increased considerably during the study period. These are mainly trees with a predominantly northern distribution in Sweden (*Alnus* spp., *Populus tremula*, *Salix caprea*, *Sorbus aucuparia*). Their increase might reflect instructions to forestry staff to give priority to such tree species, since they are known to be of high importance to biodiversity (e.g. Kouki et al., 2004, and references therein).

The flattening out of number of living trees during the last 10 years (excluding *P. sylvestris*) for all regions except Götaland, needs further investigation. It may be due to retention trees being increasingly concentrated into large patches, not detected in the NFI-statistics. It could also imply that there has been a real decrease in retention quantities. In a recent analysis of data from Polytax, decreasing retention amounts were found for the ownership category small private owners during the last 10-year period (Swedish Forest Agency and Swedish Environmental Protection Agency, 2011).

P. sylvestris is the most common tree species in the youngest forests. However, in the NFI-data that we used, there is no possibility to differentiate between *Pinus* trees retained for conservation and *Pinus* trees retained as seed trees. Since *Pinus* trees make up 45% of all living trees in the youngest forests, possibilities for interpretation of retention amounts are hereby restricted. It is common practice to remove the seed trees 10–20 years after logging. Saving some seed trees offer a great opportunity for restoration of old individuals of this tree species, which in Sweden can reach an age of more than 700 years (Andersson and Niklasson, 2004). Birches, *Betula pubescens* and *B. pendula*, are popular in public opinion and are also commonly retained tree species. *P. abies* is the most common tree species in Swedish forests and plantations (Swedish Forest Agency, 2012) but it is comparatively less retained, which might be surprising. An explanation is forest owner behavior; *Picea* trees are known to be sensitive to windthrow (e.g. Esseen, 1994), and are thus mostly retained within patches, potentially excluding them from the retention trees included in this study.

4.5. Impact of the storm Gudrun

The large increase in dead wood from 2003 to 2007 in the southernmost region Götaland is explained by the severe storm Gudrun in 2005. Since quantities are running five-year averages, such an event is reflected two years before as well as two years afterwards. The number of living Norway spruce trees in forests aged 0–10 years increased also from 4 ha^{-1} to 8 ha^{-1} between 2003 and 2007 (data not shown). Many forests in Götaland are spruce-dominated, and the statistics 2003–2007 reveal that NFI-plots located in forests struck by the storms often were classified as forests aged 0–10 years. This temporary addition of spruce trees evidently exceeded the number of wind-thrown retention trees; about 1/4 of retention trees are estimated to have fallen in the Gudrun storm (Swedish Forest Agency, 2006).

4.6. Transferability to other regions

Considering that retention approaches are becoming increasingly common in boreal and temperate regions (Gustafsson et al., 2012) the development of structural components over time in Sweden can indicate possible developments in other parts of the world where clearcutting with retention is practiced. In regions where forests have been used for industrial extraction of timber during several decades, like in parts of North Europe, structures of importance to biodiversity have become heavily depleted. If retention approaches are applied in such areas, a trend similar to Sweden with increasing amounts of dead and living trees in young forests can be expected. On the other hand, the situation will be opposite in regions where forestry is expanding into intact forests which have never been industrially logged, like in parts of Russia, South America, Canada and Australia. Compared to such forests, conventional logging, even if combined with 5–10% retention levels, will lead to changed forests with lower structural diversity (e.g. Peterken, 2001; Kuuluvainen, 2009). Thus, in such regions retention is not a restoration action but instead a way to keep as much as possible of forests in natural conditions. When harvest is considered for such forests, forms of conservation-oriented partial cutting offer alternatives for a sustainable forestry (e.g. Götmark et al., 2005; Bauhus et al., 2009).

4.7. Conclusions and future research

Our study shows that data from national forest inventories, designed in a similar way as the Swedish one, can reveal changes over time in the structural diversity of young forests created by retention actions, even at low retention levels. Interesting future analyses include to project development for long time periods, to understand temporal fluctuations but also spatial patterns of retained trees. To model amounts of living and dead trees over time, better knowledge is needed on the mortality rate of different tree species, and also on the decay rate of dead wood. Assuming that retention will become a permanent practice, in 100 years time when all forests have been harvested at least once in Sweden, 3% of the total area of production forest would be expected to be set aside as retention (Swedish Forest Agency, 2012). In total, this amounts to almost 700,000 ha of forest land, and would complement nature reserves and other larger areas formally protected by the state.

Acknowledgements

The study was supported by a grant to Lena Gustafsson from the Swedish Research Council Formas (215-2009-569), and conducted within the research program Smart Tree Retention.

References

Andersson, M., Niklasson, M., 2004. Rekordgammal tall på Hornslandet i Hälsingland. Sven. Bot. Tidskr. 98, 333–338 (In Swedish with English abstract).
Aubry, K.B., Halpern, C.B., Maguire, D.A., 2004. Ecological effects of variable-retention harvests in the northwestern United States: the DEMO study. For. Snow Landsc. Res. 78, 119–137.
Axelsson, A.-L., Ståhl, G., Söderberg, U., Peterson, H., Fridman, J., Lundström, A., 2010. National forest inventories reports: Sweden. In: Tomppo, E., Gschwantner, T., Lawrence, M., McRoberts, R.E. (Eds.), National Forest Inventories – Pathways for Common Reporting. Springer, Heidelberg, Dordrecht, London, New York, pp. 541–553.
Baker, S.C., Read, S., 2011. Variable retention silviculture in Tasmania's wet forests – background and ecological evaluation. Aust. For. 74, 218–232.
Bauhus, J., Puettmann, K., Messier, C., 2009. Silviculture for old-growth attributes. For. Ecol. Manage. 258, 525–537.
Bernes, C., 2011. Biodiversity in Sweden Monitor 22. Swedish Environmental Protection Agency, Stockholm.
Bush, T., 2010. Biodiversity and sectoral responsibility in the development of Swedish forestry policy, 1988–1993. Scand. J. Hist. 35, 471–498.
Eckerberg, K., 1988. Clear felling and environmental protection – results from an investigation in Swedish forests. J. Environ. Manage. 27, 237–256.
Esseen, P.A., 1994. Tree mortality patterns after experimental fragmentation of an old-growth conifer forest. Biol. Conserv. 68, 19–28.
Franklin, J.F., Berg, D.R., Thornburgh, D.A., Tappeiner, J.C., 1997. Alternative silvicultural approaches to timber harvesting: variable retention systems. In: Kohm, K.A., Franklin, J.F. (Eds.), Creating a Forestry for the 21st century. The Science of Forest Management. Island Press, Washington, USA, pp. 111–139.
Fridman, J., Walheim, M., 2000. Amount, structure and dynamics of dead wood on managed forestland in Sweden. For. Ecol. Manage. 131, 23–36.
Götmark, F., Paltto, H., Nordén, B., Götmark, E., 2005. Evaluating partial cutting in broadleaved temperate forest under strong experimental control: short-term effects on herbaceous plants. For. Ecol. Manage. 214, 124–141.
Götmark, F., Fridman, J., Kempe, G., 2009. Education and advice contribute to increased density of broadleaved conservation trees, but not saplings, in young forest in Sweden. J. Environ. Manage. 90, 1081–1088.
Gustafsson, L., Perhans, K., 2010. Biodiversity conservation in Swedish forests: ways forward for a 30-year-old multi-scaled approach. AMBIO 39, 546–554.
Gustafsson, L., Kouki, J., Sverdrup-Thygeson, A., 2010. Tree retention as a conservation measure in clear-cut forests of northern Europe: a review of ecological consequences. Scand. J. For. Res. 25, 295–308.
Gustafsson, L., Baker, S.C., Bauhus, J., Beese, W.J., Brodie, A., Kouki, J., Lindenmayer, D.B., Lõhmus, A., Martínez Pastur, G., Messier, C., Neyland, M., Palik, B., Sverdrup-Thygeson, A., Volney, J.A., Wayne, A., Franklin, J.F., 2012. Retention forestry to maintain multifunctional forests: a world perspective. BioScience 62, 633–645.

Hautala, H., Jalonen, J., Laaka-Lindberg, S., Vanha-Majamaa, I., 2004. Impacts of retention felling on coarse woody debris (CWD) in mature boreal spruce forests in Finland. Biodivers. Conserv. 13, 1541–1554.

Josefsson, T., Östlund, L., 2011. Increased production and depletion: the impact of forestry on northern Sweden's forest landscape. In: Antonsson, H., Jansson, U. (Eds.), Agriculture and Forestry in Sweden since 1900 – Geographical and Historical Studies. Skogs-och lantbrukshistoriska Meddelanden, The Royal Academy of Agriculture and Forestry, Stockholm, pp. 338–353.

Kouki, J., Arnold, K., Martikainen, P., 2004. Long-term persistence of aspen – a key host for many threatened species - is endangered in old-growth conservation areas in Finland. J. Nat. Conserv. 12, 41–52.

Kuuluvainen, T., 2009. Forest management and biodiversity conservation based on natural ecosystem dynamics in northern Europe: the complexity challenge. AMBIO 38, 309–315.

Liungman, M., 2000. Monitoring Retention of Trees and CWD on Clearcuts in South-Western Sweden. Honour's thesis. Department of Zoology, University of Gothenburg.

Lõhmus, A., Lõhmus, P., 2010. Epiphyte communities on the trunks of retention trees stabilize in 5 years after timber harvesting, but remain threatened due to tree loss. Biol. Conserv. 143, 891–898.

Martínez Pastur, G., Lencinas, M.V., Cellini, J.M., Peri, P.L., Esteban, R.S., 2009. Timber management with variable retention in *Nothofagus pumilio* forests of Southern Patagonia. For. Ecol. Manage. 258, 436–443.

McDermott, C.L., Cashore, B., Kanowski, P.J., 2010. Global Environmental Policies. An International Comparison. Earthscan, London, Washington DC.

National Atlas of Sweden, 2011. Agriculture and Forestry. Jansson, U., (Ed.). The Royal Academy of Agriculture and Forestry. SNA Publisher, Stockholm.

Nilsson, S.G., 1997. Forests in the temperate-boreal transition: natural and man-made features. Ecol. Bull. 46, 61–71.

Peterken, G.F., 2001. Natural Woodland: Ecology and Conservation in northern Temperate Regions. The Press Syndicate of the University of Cambridge, UK.

Ranneby, B., Cruse, T., Hägglund, B., Jonasson, H., Swärd, J., 1987. Designing a new National Forest survey for Sweden. Stud. For. Suec. 177, 1–29.

Rudolphi, J., Gustafsson, L., 2005. Effects of forest fuel harvest on the amount of deadwood on clearcuts. Scand. J. For. Res. 20, 235–242.

Sands, R., 2005. Forestry in a Global Context. CABI International, Wallingford, UK.

Swedish Forest Agency, 2006. Stormen 2005 – en skoglig analys. Meddelande 1-2006. Skogsstyrelsen, Jönköping (in Swedish).

Swedish Forest Agency, Swedish Enivonmental Protection Agency, 2011. Skogs-och miljöpolitiska mål – brister, orsaker och förslag på åtgärder. Meddelande 2-2011. Skogsstyrelsen, Jönköping (in Swedish).

Swedish Forest Agency, 2012. Statistical Yearbook of Forestry 2012. Official Statistics of Sweden, Jönköping (in Swedish and English).

Timonen, J., Siitonen, J., Gustafsson, L., Kotiaho, J.S., Stokland, J.N., Sverdrup-Thygeson, A., Mönkkönen, M., 2010. Woodland key habitats in northern Europe: concepts, inventory and protection. Scand. J. For. Res. 25, 309–324.

Work, T.T., Spence, J.R., Volney, W.J.A., Morgantini, L.E., Innes, J.L., 2003. Integrating biodiversity and forestry practices in western Canada. For. Chron. 79, 906–916.