Riparian forests

– a comparison of tree diversity, deadwood and canopy cover between primary and production riparian forests along headwaters

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Riparian forests – a comparison of tree diversity, deadwood and canopy cover between primary and production riparian forests along headwaters

Strandnära skogar – en jämförelse på trädfördelning, död ved och krontäckning mellan naturskogar och brukade skogar längs små vattendrag

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Abstract

Headwaters and their adjacent riparian forests (RF) have been recognized for years for their tight interlinkage and essential ecological and biogeochemical services. Notwithstanding, headwaters in Sweden have historically been overlooked in forest management, which has led to conifer-dominated RFs with simplified even-age structure. This simplified structure may not provide the same ecosystem functioning as a primary RF ecosystem, thus forest management that aims to mimic natural disturbances has been promoted as a more sustainable alternative. However, little is known about the stand characteristics of primary RFs and how they differ compared to mature production RFs along headwaters.

In this thesis, I investigated the stand characteristics (i.e. tree species, tree sizes, deadwood and stream canopy cover) in five primary RFs and five mature production RFs along headwaters in Västerbotten and Västernorrland county. Measurements were conducted in six 10x10 m plots along a 110 m stream transect. The primary RF had more tree species, higher tree density, lower mean DBH, more riparian deadwood and lower mean canopy cover compared to the production RF. The primary RF followed an inverse J-shape diameter distribution, while the production RF followed a uniform bell-shaped diameter distribution. Norway spruce was the dominant tree species in both RF types. No significant difference was found on in-stream deadwood between the primary and the production RF.

The presented results could aid to improve forest management to increase RFs functionality. However more research over climatic gradients and different forest types is needed before active and adaptive forest management can be applied.

Keywords: riparian forest, primary forest, production forest, tree diversity, deadwood, canopy cover

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Abbreviations

DBH	Diameter at breast height
GLMM	Generalized linear mixed-effects model
LMM	Linear mixed-effects model
MDC	Minimally disturbed condition
RF	Riparian forest

1. Introduction

1.1. Headwaters

Headwaters are small streams that has its beginning in the upmost part of a watershed. In Sweden, it has been estimated that over 90 % of the stream length has a watershed area $<15km^2$, meaning the majority of the total stream length constitutes of headwaters. Together, they form a large network of flowing water that cumulates to downstream water bodies (Bishop et al. 2008). Headwaters are recognized for serving important ecological and biogeochemical services (Creed et al. 2011; Wohl 2017; Richardson & Dudgeon 2020). They are the initial water source of the surficial water flow network and provide energy subsidies and nutrients to downstream water bodies (Wohl 2017). Headwaters are often distinguished from larger streams (besides their size) in the forested landscape by having high canopy closure, low fish abundance, periodic minimum flows and that they are dependent on allochthonous subsidies (leaf litter, invertebrates, e.g.) as energy source (Richardson & Danehy 2007). This creates a unique habitat for communities of organisms well adapted to this kind of environment. Furthermore, headwaters have a high surface to edge area and the hydrological connection between uplands and headwaters is facilitated through the vegetated area situated on the edge of streams, meaning they are tightly interlinked with surrounding terrestrial ecosystem, so called riparian forests (Richardson & Danehy 2007; Kuglerová et al. 2017).

1.2. Riparian Forests

Riparian forests (RF) are transition zones between aquatic and terrestrial ecosystems and serve many important ecological functions, as well as harbor a unique biodiversity and richness of associated species (Naiman & Décamps 1997; Sabo et al. 2005). Its unique environment provides suitable habitats for many forest dwelling species, as well as working as green corridors to increase connectivity in the landscape (De la Fuente et al. 2018). Furthermore, RFs potential for mitigating negative impacts on streams caused by upland disturbance, and provision of services to in-stream organisms have been recognized for a long time (Richardson et al. 2012). They are efficient filters that prevent leaching of nutrient, dissolved organic carbon and other biogeochemical substances to water bodies (Lowrance et al. 1984; Creed et al. 2008; Lidman et al. 2016). They stabilizes stream banks, which prevents erosion and sediment transport (Polvi et al. 2014), serve allochthonous food sources such as leaf litter, deadwood and invertebrates to in-stream organisms (Cummins et al. 1989; Baxter et al. 2004), provide shading and regulates light-input, which affects stream temperature and primary production (Dugdale et al. 2018), and create structures and form pools by supplying deadwood, which increases stream heterogeneity (Naiman et al. 2002).

However, the strong link between the aquatic and terrestrial ecosystems also makes both of the ecosystems more fragile. Habitat quality as well as biodiversity within both ecosystems can be severely altered by anthropogenic disturbances such as forestry and can cause change or complete loss of several important ecological and biogeochemical functions (Hjältén et al. 2016; Richardson 2019). Removal of trees within the riparian zone may increase light-input and elevate water temperature. This may alter the aquatic food web by promoting primary production and decrease subsidies provided from the terrestrial ecosystem (Dugdale et al. 2018). Intensive forest management may also lead to a decrease in deadwood, which may not only decrease stream heterogeneity but also the biodiversity in the riparian zone (since many species are dependent on deadwood substrate) (Jonsson et al. 2005). Furthermore, it has been showed that clear-cuts may increase nutrient leaching and sediment loads to nearby water bodies as well as cause higher peak flows due to surplus water, which would have otherwise been used for tree transpiration. (Ide et al. 2013; Palviainen et al. 2014). Considering that headwaters contribute to a majority of the stream length network and that substances are transported to downstream water bodies, these perturbations could lead to cumulative effects (Kuglerová et al. 2017). However, it has been shown that well-functioning RFs can mitigate those hydro-chemical impacts to a large degree (Kuglerová et al. 2014a).

Today, a common practice to mitigate the negative effects from forestry is to leave a buffer strip along the stream edge, usually with a fixed buffer width due to its convenience and fairly easy implementation (Richardson et al. 2012). However, this is not the case for all waterways. Small waterways, such as headwater streams, are and have historically been overlooked with minimal or no protection in forestry (Hasselquist et al. 2020; Kuglerová et al. 2020). This can partly be explained by lack of knowledge of their existence and thereby not being visible on existing maps (Bishop et al. 2008; Ågren & Lidberg 2019).

1.3. Forestry history in Sweden

Sweden has a long history of forestry which has changed the forested landscape dramatically. The exploitation started in the beginning of the 19^{th} century due to high demands on high quality timber in conjunction with the industrial revolution. It began with selective cuttings for large dimensions of trees in the south part of Sweden, henceforward expand towards the north, and finally the majority of the Swedish landscape (Östlund 1995). The timber was transported in waterways downstream to sawmills along the coastline. Rivers were cleaned and smaller streams where channelized and straightened to make the transportation more efficient (Törnlund & Östlund 2002). This resulted in a scanty forested landscape which was looked upon as a non-functional forest ecosystem and provoked a need for change in order to secure future production needs (Lisberg Jensen 2011). As a result, in 1903, the first Forestry Act was passed into law, which inter alia demanded forest regeneration after harvesting (Lundmark et al. 2013). In the beginning of the 20^{th} century, the pulp industry started to develop and expanded rapidly, inducing smaller tree dimensions to be harvested (Östlund et al. 1997). The increased demands for trees as natural resources brought new intensified forestry methods to life. During the 20^{th} century, ditching became a common practice in peatland and wetlands to increase tree growth, and many streams that were too small for timber floating where straightened to increase water flow and drainage. To simplify this process, many RFs were cut all the way down to the stream bank (Nilsson et al. 2005; Maher Hasselquist et al. 2021). Finally, a new rational forest management, which is still in use to this day, was introduced at a large scale in the middle of the 20^{th} century, known as the “rotation-forestry system”, with clearcutting, scarification, planting and thinning. This management approach favored two coniferous tree species, Norway spruce and Scots pine. (Kuuluvainen et al. 2012; Lundmark et al. 2013). Furthermore, up until 1990, dead trees and damaged trees were selectively cut and removed from the forested landscape as they were looked upon as a source for pathogens, fungi and damaging insects, which could potentially harm living trees (Linder & Östlund 1998). In addition, herbicides were introduced into forestry and were applied in a large scale in the 1960-1970s. The main reason for this was to reduce competition for wanted coniferous tree species (Norway spruce and Scots Pine) by removing unwanted deciduous tree species (Östlund et al. 2021).

These measures resulted in a landscape transformation, from structural complexity in terms of old-growth uneven-aged stands, abundance of deadwood and mixed tree species into a monoculture of even-aged conifer stands (Linder & Östlund 1998). Natural disturbances such as wildfires and insect outbreaks were suppressed and replaced with anthropogenic disturbances. This transformation has led to scarcity of old-growth forests within the Swedish forest landscape and the ones that are left are highly fragmented. (Östlund et al. 1997; Linder & Östlund 1998; Axelsson & Östlund 2001). Simultaneously, many forest dwelling species depending on old-growth forest structures for their survival have also decreased in numbers (Johansson et al. 2013). The loss of biodiversity can have severe consequences on ecosystem functioning among reducing essential ecosystem services, such as plant productivity and decomposition rates (Hooper et al. 2012; Kardol et al. 2018). According to a recent study by Hasselquist et al. (2021) mature Norway spruce is now the dominant tree species in RFs (especially along headwaters) as a consequence of past forest management. Therefore, RFs that are affected by the past management practices are likely not functioning as well as they would in its natural state before the exploitation took place. If RFs have simplified structure and diversity, it is unlikely that they will protect streams from the negative effects of forestry once they become riparian buffers. Thus, forest management mimicking natural forest dynamics and disturbance regimes has been promoted as a more sustainable alternative (Kreutzweiser et al. 2012; Kuglerová et al. 2017; Kuuluvainen et al. 2021). However, in order to implement this in practice, more knowledge about the structural and ecological attributes of natural RF (i.e. unimpacted by commercial forestry) ecosystems along headwaters are needed, yet research within this area is limited.

1.4. The use of riparian primary forests as reference for future forest management

An old-growth forest can be described as a level of naturalness for a specific forest that environ late successional stand dynamics. They are usually characterized by the presence of large old trees, great heterogeneity in tree sizes and spacing, several canopy levels and accumulation of deadwood in different sizes and decay stages (Buchwald 2005). A primary forest on the other hand, is a term used for describing a forest area, which encompasses several levels of forest types describing their degree of naturalness, assembling to what can be referred to as an “intact” forest ecosystem. Besides including old-growth forests, primary forests also include primeval, virgin, frontier, near-virgin and long untouched forests. (Buchwald 2005; Sabatini et al. 2021).

It has been pointed out that primary forest ecosystems provide higher ecosystem functioning, more ecological values and are more heterogenous (which is essential for a resilient and healthy ecosystem) than forest ecosystems that has been altered by human activities (Watson et al. 2018). Knowing this, primary RFs could be useful as references of natural forest ecosystems for scientific research when comparing with production RFs, as well as for management purposes that aims to mimic natural conditions. However, the scarcity of primary RFs and the lack of knowledge about their location (especially around headwaters) have complicated their utilization as management goals for improving future forest management. This has changed thanks to a recent study by Sabatini et al. (2021), which have compiled an extensive database of the last remaining primary forests in Europe, thus enabling research within the area.

1.5. Aim and hypothesis

The purpose of this study is to increase knowledge about the stand characteristics of primary RFs and identify differences between primary RFs and mature production RFs along headwaters in northern Sweden. More specifically, I focus on differences in forest structure, including tree species composition, tree sizes and diameter distribution of living trees, quantity of deadwood and headwater canopy cover. This may not only provide valuable information about what mature production RFs are lacking in terms of tree diversity, deadwood and canopy cover, but also give reference values on what to strive for in future forest management in RFs along headwater streams that aims to mimic natural conditions.

This will be answered through these three questions:

1. How does the diameter distribution (i.e. tree size) differ between the primary RF and the production RF?

I hypothesized that the diameter distribution will look different between the two types of RF. The primary RF will be more heterogenous in its tree sizes compared to the production RF, which will have a more uniform tree size distribution.

2. How does quantity of deadwood in the riparian zone and quantity of in-stream deadwood differ between the primary RF and the production RF?

I hypothesized that more deadwood objects would be found both in the riparian zone and in-stream zone in the primary RF compared to the production RF.

3. How does headwater canopy cover differ between the primary RF and production RF?

I hypothesized that the canopy cover will be higher in the production RF compared to the primary RF.

2. Material and methods

2.1. Criteria for primary and production forests

Unified terminology for “naturalness” of forests is lacking or is defined differently, both within nations but also internationally. This could lead to misunderstandings or confusion between parties in decision-making processes as well as in science (Buchwald 2005). In this study, the same definition as FAO has been used when it comes to primary forests. According to FAO (2020), a primary forest is defined as:

> “Naturally regenerated forest of native tree species, where there are no clearly visible indications of human activities and the ecological processes are not significantly disturbed.”

This does not however, exclude the possibility that the forest has been used by humans in the past. The definition includes forests that has been used and managed historically by indigenous people such as the Sámi people or settlers, as well as forest management, but to an extent that the forest has maintained or re-established natural ecological processes and stand dynamics.

Production forests used in this study is defined as forests that has been subjected to commercial logging and exposed to clearcutting, and consequent planting and thinning activities all the way to the stream bank. It also had to be a mature forest which had fulfilled the criterium of minimum required age for harvest according to The Swedish Forestry Act 10§ (SFS 1979:429).

2.2. Study sites

Data was collected in field between September 13 and September 17 together with my supervisor and a field assistant. Ten RFs along headwaters were visited within Västerbotten and Västernorrland county (Fig. 1). Five of the streams are located within a primary forest (Sites 1-5) and five are located within a production forest (Sites 6-10) affected by commercial forestry all the way down to the stream bank. Sites that were included within the primary RF were carefully selected from the EPFD v2.0 (European primary forest database v2.0) (Sabatini et al. 2021) to make sure they fulfilled similar criteria as FAO in regards to their definition of primary forests (FAO 2020). The coordinates of the potential sites were analyzed in available topographic maps to locate headwaters, of which data collection could take place. Stream width varied between 0.3 and 6.7 meters with an average width of 1.5 meters. The reason for the big span was due to some streams were very incised while others braided. Nevertheless, all streams were classified as small streams according to Kuglerová et al. (2020) and majority of them had no permanent tributaries visible on the topographic maps, which qualified them for being headwaters. Two of the primary RF sites were located within Gammtrattens nature reserve (Sites 2 and 3) and two were located within Kålhuvudets nature reserve (Sites 4 and 5). The last site was located within Vändåtbergets nature reserve (Site 1). Våndåtberget was not included in the EPFD v2.0 but fulfilled same criteria as the rest of the sites based on a report from Länsstyrelsen Västernorrland in 1981 (Eckerberg 1981) and was therefore used due to its vicinity to nearby road and other primary RF sites. The production RF sites were selected from previous or ongoing research of the supervisor in mature production stands.

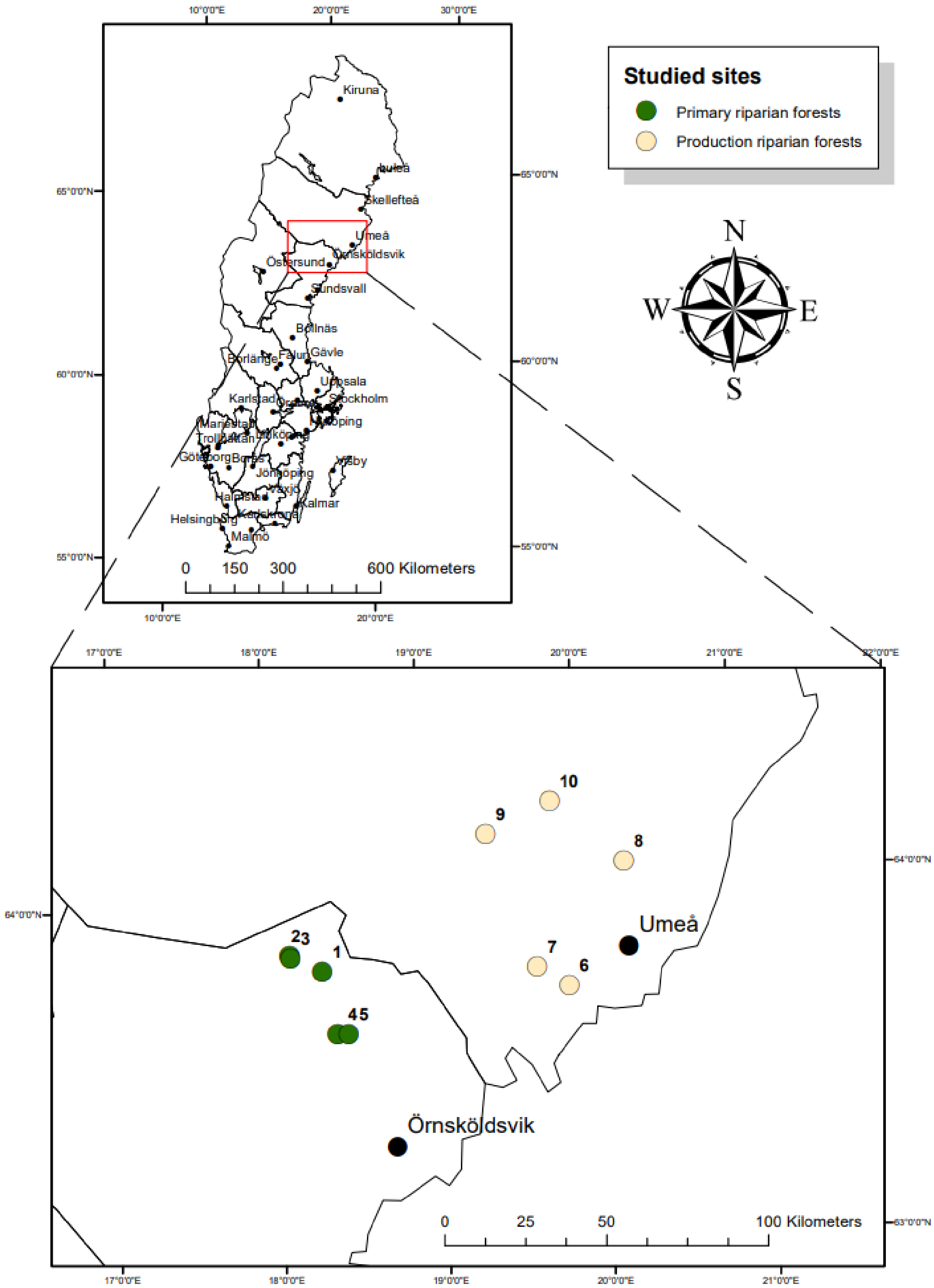

Figure 1. Map of visited sites in Västerbotten and Västernorrland county. The green dots represent primary RFs (1-5), the beige dots represent production RFs (6-10), and the black dots represent cities.

2.3. Study design

At each site, six plots (10x10 m) were established within a 110 m long transect and with a distance of 10 m apart from each other along a headwater stream section. Three plots were placed on the right bank and three plots on the left bank, creating a zig-zag pattern (Fig. 2). In one case (Site 3, Plot 2), one plot happened to be located within an area defined as a wetland, therefore we moved the plot on the opposite side of the stream, resulting in four plots at one bank and two at the other. In another case (Site 1, Plot 5), the last plot was moved 30 m upstream due to a presence of a wetland. The stream edge was used as border line of the 10x10 m plots, meaning that the stream itself was not included in the plot (Fig. 2). Within each plot, measurements of tree diversity, deadwood and canopy cover took place.

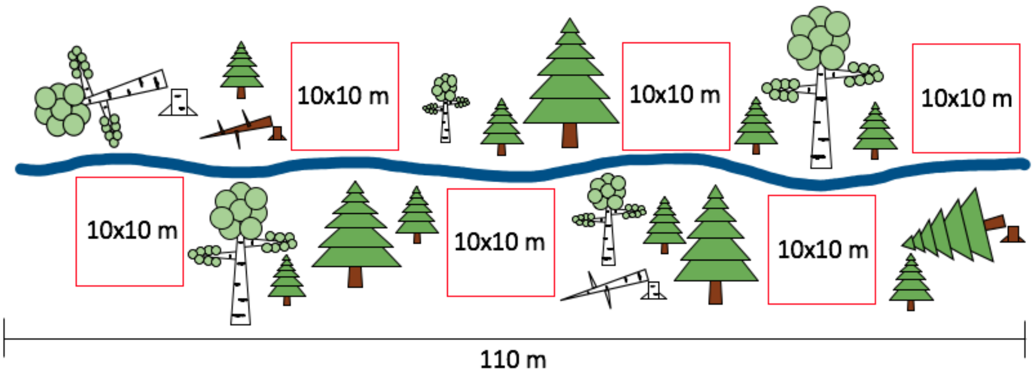

Figure 2. Illustration showing locations of the six 10x10 m plots within 110 m transect along the headwater stream.

For tree diversity, all standing living trees bigger than 5 cm in stem diameter 1.3 m above ground (also known as diameter in breast height or in short DBH) that were located inside the plot was measured with a caliper. In addition, tree species were also noted. For deadwood in the riparian zone, a caliper was used to measure DBH and measuring tape was used for length. Only trees rooted within the plot were measured. In cases where the root part had gone missing, DBH was measured from the end of the thickest part of the stem. In the riparian zone, only trees bigger than 5 cm in DBH was included. In addition, if the stem was a snag (standing deadwood) or log (lying deadwood) was also noted. For bridges (suspended logs above stream) and in-channel (logs in the stream) deadwood, everything longer than 1 m or/and bigger than 5 cm on the middle part of the stem was included. Canopy cover (%) above the stream was measured by taking hemispherical photographs of the canopy in three places (at 0, 5 and 10 m mark of the plot) standing in the stream. The software GLAMA (Gap Light Analysis Mobile Application), along with an external fish eye lens, was used for calculating canopy cover. GLAMA is a free to use android application which has been designed for similar fieldwork (Tichý 2016).

2.4. Calculations

For calculating in-stream (bridge and in-channel) volume of deadwood I assumed that each stem had more or less a cylindric shape since the middle part of the stem was used as diameter and therefore the following equation was used to calculate the volume:

$$V = r^2 \pi l$$

in which V = volume (m^3), r = radius of the stem and l = length of the stem.

The basal area was calculated for each individual tree by using the following function:

$$BA = 2\pi r$$

in which BA = basal area (m^2) and r = radius of the stem.

Count of individual objects was used for most riparian measurements (both standing living trees and deadwood). This was because tree height measurements were not recorded in the field due to time constraints and because DBH was intended to be used when analyzing tree-size distributions. Furthermore, the count data of individual objects (i.e. standing living trees and deadwood) and the basal area in the riparian zone was recalculated to their mean value per hectare. The count data of in-stream deadwood (i.e. bridge and in-channel) was recalculated to their mean per 100 m stream length.

2.5. Data analysis

A template was created in excel and printed on rain proof paper sheets for in field measurements and notes (Appendix 1.). Collected data was then compiled and logged in Microsoft Excel to facilitate further analysis. The stand characteristics for each RF type was compiled onto a table with descriptive means, standard deviation (SD) and minimum and maximum (range) values (Table 1). All statistical analyses were however made on the raw data set. The statistical software R-studio (version 4.1.2) was used for all analyzes (R Core Team 2021) with the extension packages *fitdistrplus* (Delignette-Muller & Dutang 2015), *lme4* (Bates et al. 2015), *lmerTest* (Kuznetsova et al. 2017) and *ggplot2* (Wickham 2016). The significant level was set to $\alpha = 0.05$.

Table 1. Comparison of stand characteristics between primary and production RF with mean, standard deviation (SD) and minimum and maximum (range) for recorded values.

Characteristics	Primary riparian forest Mean ± SD (range)	Production riparian forest Mean ± SD (range)
Standing trees alive		
Density (no/ha)	1130 ± 670 (500 – 3200)	617 ± 242 (200 – 1400)
Diameter (cm)	16.9 ± 10.5 (5.0 – 51.3)	25.3 ± 9.9 (5.0 – 54.7)
Basal area (m^2/ha)	35.3 ± 15.4 (8.3 – 82.3)	35.7 ± 12.3 (16.9 – 70.0)
Riparian deadwood		
Density (no/ha)	480 ± 304 (0 – 1400)	197 ± 173 (0 – 600)
- Log	223 ± 227 (0 – 900)	117 ± 139 (0 – 500)
- Snag	257 ± 174 (0 – 600)	80 ± 92 (0 – 300)
Diameter (cm)	10.2 ± 4.8 (5 – 22.2)	10.9 ± 5.7 (5 – 24.9)
In-stream deadwood		
Frequency (no/100 m)	31.0 ± 31.7 (0 – 140)	38.3 ± 44.3 (0 – 190)
- Bridge	7.3 ± 8.3 (0 – 30)	8.3 ± 11.8 (0 – 40)
- In-channel	23.7 ± 27.5 (0 – 120)	30.0 ± 37.0 (0 – 160)
Diameter (cm)	9.8 ± 6.3 (2.5 – 26-5)	9.3 ± 6.0 (1.9 – 30.5)
Length (m)	1.3 ± 1.2 (0.2 – 7.6)	1.6 ± 1.3 (0.4 – 6.9)
Volume (m^3)	0.018 ± 0.040 (0.0003 – 0.310)	0.021 ± 0.051 (0.0002 – 0.389)
Canopy cover		
Canopy cover (%)	57.6 ± 11.5 (16 – 78)	68.2 ± 7.2 (51 – 84)

2.5.1. Diameter distribution

For the first question, two different tests were used. First, a Kolmogorov-Smirnoff test (K-S test) was used to check whether the DBH (cm) distribution between the two types of RF (i.e., primary. vs. production) were significantly different from each other (Table 2). Second, a linear mixed-effects model (LMM) was used to test if the DBH was significantly different between the two types of RF. However, after analyzing the residuals, they did not follow a normal distribution, which is required when using LMM (Zuur et al. 2009b). The skewness of the residuals was then analyzed in a Cullen and Frey graph, which shows a skewness-kurtosis plot that helps choosing a candidate that best describes the distribution of the data (Delignette-Muller & Dutang 2015). In this case it was the Gamma distribution (inverse). Therefore, LMM was rejected and a generalized linear mixed-effects model (GLMM) with a Gamma (inverse) distribution fit by maximum likelihood (ML) was used instead to test if the DBH was significantly different between the two types of RF. (Table 2). Furthermore, Satterthwaite method was used to calculate the p-value.

2.5.2. Deadwood

Riparian deadwood

For the second question, GLMM with a Poisson (log) distribution fit by ML was used to test whether the number of recorded deadwood objects in the riparian zone between the two types of RF were significantly different from each other. In addition, number of recorded deadwood objects was split into two groups (logs and snags) (Table 2). The Poisson (log) distribution is commonly used for count data (Zuur et al. 2009a) and was therefore used in this model. Furthermore, Satterthwaite method was used to calculate p-values and Bonferroni-correction was used to counteract the p-values for multiple testing.

In-stream deadwood

For the second part of the second question, GLMM with a Poisson (log) distribution fit by ML was used to test whether the number of recorded in-stream deadwood objects between the two types of RF were significantly different from each other. In addition, number of recorded deadwood objects was split into to two groups (bridges and in-channel). The Poisson (log) distribution is commonly used for count data (Zuur et al. 2009a) and was therefore used in this model. Furthermore, Satterthwaite method was used to calculate p-values and Bonferroni-correction was used to counteract the p-values for multiple testing.

2.5.3. Canopy cover

For the third question, LMM with a normal distribution fit by ML was used to test whether the headwater canopy cover (%) differed between the two types of RF (Table 2). After analyzing the residuals, I concluded that the data still followed a normal distribution and LMM was therefore used in the model. Furthermore, Satterthwaite method was used to calculate the p-value.

Table 2. Table showing the distribution of the data set along with response and explanatory variables, fixed and random effects and statistical test used for the models

Model	Data distribution	Response variable	Explanatory variable	Fixed effect	Random effect	Statistical test
1.	Gamma (inverse)	Standing alive trees DBH (cm)	Type of RF			K-S
2.	Gamma (inverse)	Standing alive trees DBH (cm)	Type of RF	Type of RF	Site/Plot	GLMM
3.1.	Poisson (log)	Riparian deadwood (no)	Type of RF	Type of RF	Site	GLMM
3.2.	Poisson (log)	- Log			Site	GLMM
3.3.	Poisson (log)	- Snag			Site	GLMM
4.1.	Poisson (log)	In-stream deadwood (no/10 m)	Type of RF	Type of RF	Site	GLMM
4.2.	Poisson (log)	- Bridge			Site	GLMM
4.3.	Poisson (log)	- Channel			Site	GLMM
5.	Normal	Canopy cover (%)	Type of RF	Type of RF	Site/Plot	LMM

2.5.4. Mixed-effects models

LMM (for normally distributed data) and GLMM (for non-normally distributed data) was used based on the hierarchal study design with multiple plots (six plots) within each site (five sites per type of RF) with the assumption that plots within sites are more likely to be similar (and dependent) to each other than plots among sites (Fig. 3). For example, the tree species composition is more likely to be similar in plots within site number one in comparison to the plots in site number two and so forth, even though both sites may represent the same type of RF. Thus, there is a random effect (Table 2) which determines how data are related, in this case the site and the plot. This randomness is taken into account by LMM and GLMM which includes both fixed and random effects and therefore makes it a powerful statistical tool for clustered or nested data sets (Zuur et al. 2009b).

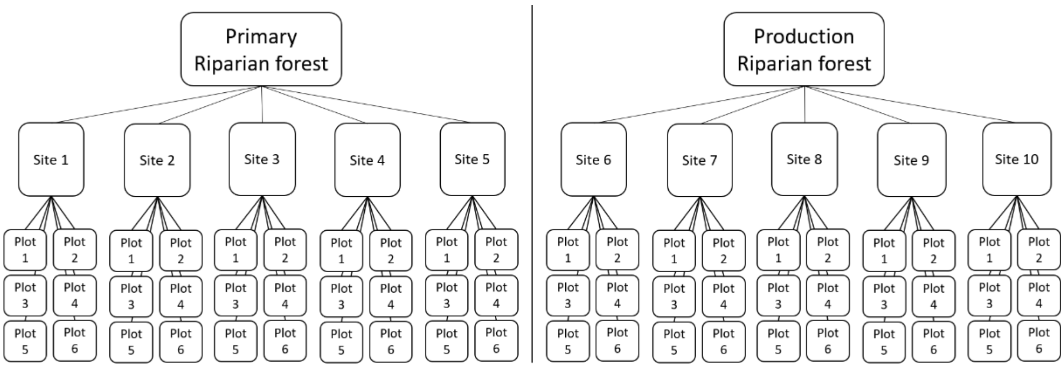

Figure 3. Scheme illustrating the hierarchical structure of the study design. Sites represent the five forest stands for each type of RF visited in field and the six plots within each site are the 10x10 m quadrants where measurements took place.

3. Results

3.1. Stand characteristics

3.1.1. Standing alive trees

In total, 524 objects of standing alive trees were inventoried in a total area of 6000 m^2. Almost twice as many (339 objects) were recorded in primary compared to production RF (185 objects), which corresponds to an average of 1130 and 617 stems/ha, respectively. The average basal area was 35 m^2/ha for primary and 36 m^2/ha for production RF (Table 2.).

Seven different tree species were found in primary RF; grey alder (*Alnus incana*), aspen (*Populus tremula*), birch (*Betula pubescens*), Scots pine (*Pinus sylvestris*), rowan (*Sorbus aucuparia*), Norway spruce (*Picea abies*) and willow (*Salix sp.*). In production RF, five different tree species were observed; grey alder, aspen, birch, Scots pine and Norway spruce. Norway spruce was the dominant tree species at both RF types, corresponded to 79 % (267 objects or 890 stems/ha) of recorded standing alive trees in primary and 78 % (145 objects or 483 stems/ha) in production RF. Birch was the second dominant tree species at both types of RF, corresponded to 15 % (51 objects or 170 stems/ha) in primary and 15 % (27 objects or 90 stems/ha) in production RF, followed by pine which corresponded to 3 % (11 objects or 37 stems/ha) and 4 % (9 objects or 30 stems/ha) in primary and production RF, respectively. Grey alder, aspen, rowan and willow corresponded to less than 3 % altogether for each forest type (Fig. 4A and 4B).

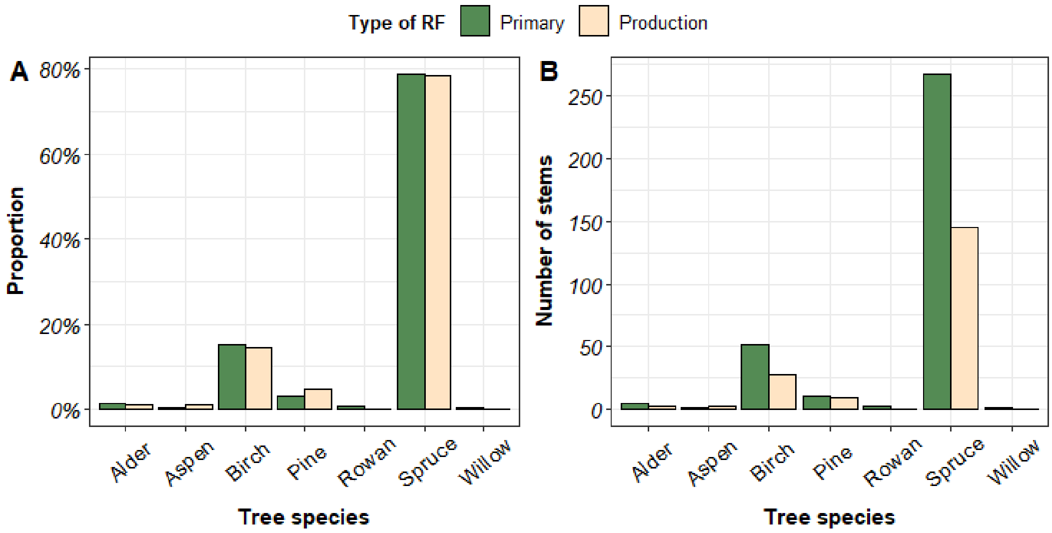

Figure 4. Bar plots showing the proportion (A) and number of stems (B) on the y-axis and tree species on the x-axis that was recorded in each RF type. The green bar represents primary RF and the beige bar represents production RF.

3.1.2. Diameter distribution

Diameter distribution of trees recorded in primary and production RF was significantly different (K-S test: $D = 0.41$; $p < 0.001$) from each other. For primary RF most trees were observed in the smallest diameter class 5-10 cm (113 objects or 377 stems/ha) and followed a near inverse J-shape distribution. For production RF, most trees were observed in the diameter class 25-30 cm (44 objects or 93 stems/ha) and followed a near normal distribution (Fig. 5).

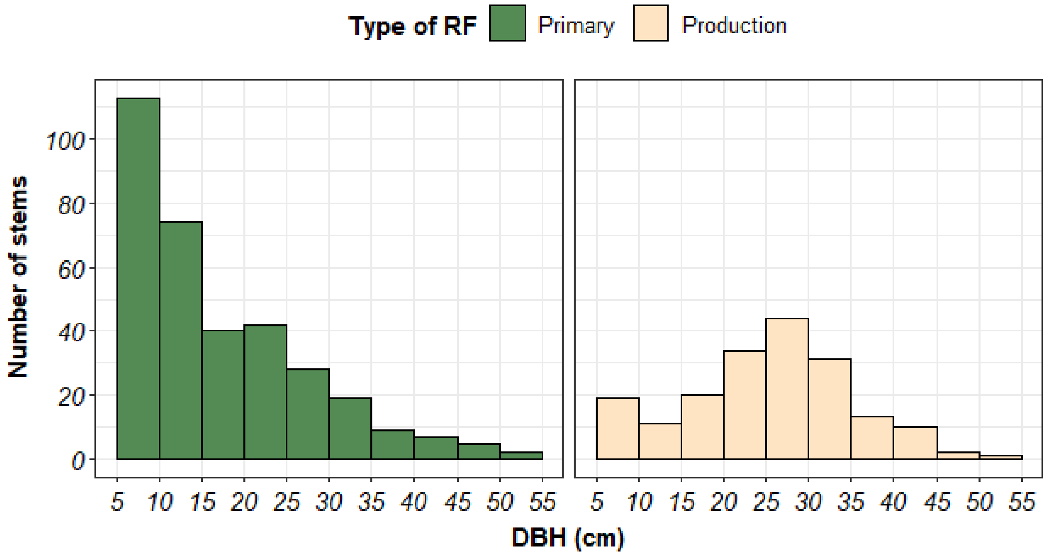

Figure 5. Histogram showing the diameter distribution between the two types of RF with number of trees recorded on the y-axis and DBH (cm) on the x-axis. The value on the far left in each bar are included within the count of that bar, while the value on the far right in each bar is excluded. For example: 5-9.99 cm is included in the first bar, 10-14.99 is included in the second bar etc.

Diameter recorded for primary and production RF were significantly different (GLMM: $\beta = -0.02$; $t = -2.69$; $p = 0.007$) from each other. Higher average DBH was found in production RF, which had a mean DBH of 25.3 cm (SD ±9.9) and a median DBH of 26.0 cm. Primary RF had a mean DBH of 16.9 cm (SD ±10.5) and a median DBH of 13.9 cm (Fig. 6).

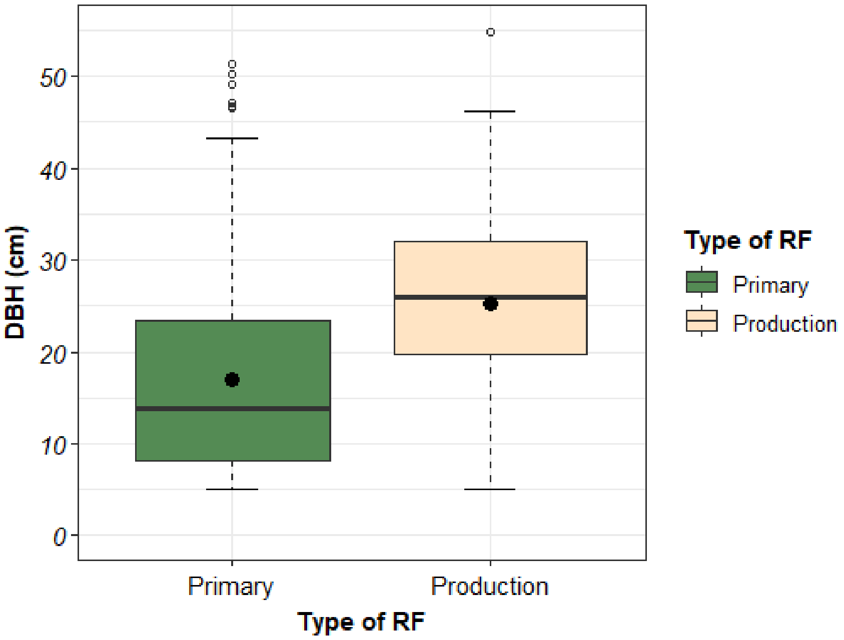

Figure 6. Box plot showing the DBH in cm of the recorded standing alive trees on the y-axis and type of RF on x-axis. The green box to the left represents primary RF and the beige box to the right represents production RF. The black circle represents the mean value, the black horizontal line represents the median value and the box covers 50 % of the sample.

3.2. Deadwood

3.2.1. Riparian deadwood

Number of deadwood objects in the riparian zone recorded in primary and production RF were significantly different (GLMM: $\beta = -1.05$; $z = -2.53$; $p = 0.012$) from each other. More deadwood objects were recorded in primary RF (144 objects) compared to production RF (59 objects). This corresponded to the mean of 480 objects/ha (SD ±304) for primary RF and 197 objects/ha (SD ±173) for production RF. The median was 500 objects/ha and 200 objects/ha, respectively (Fig. 7A).

Similar trend was seen after dividing deadwood objects into logs (i.e., lying deadwood) and snags (i.e., standing deadwood). Primary RF had more logs (67 objects) and snags (77 objects) compared to production RF (35 logs and 24 snags). The difference was significant for snags (GLMM: $\beta = -1.17$; $z = -4.01$; $p < 0.001$) but not for logs (GLMM: $\beta = -0.91$; $z = -1.69$; $p = 0.091$) between the type of RF. When recalculated per hectare, the mean for number of logs was 223 objects/ha (SD ±227) for primary RF and 117 objects/ha (SD ±139) for production RF. The median was 200 objects/ha and 100 objects/ha, respectively. The mean for number of snags was 257 objects/ha (SD ±174) for primary RF and 80 objects/ha (SD ±92) for production RF. The median was 250 objects/ha and 100 objects/ha, respectively (Fig. 7B).

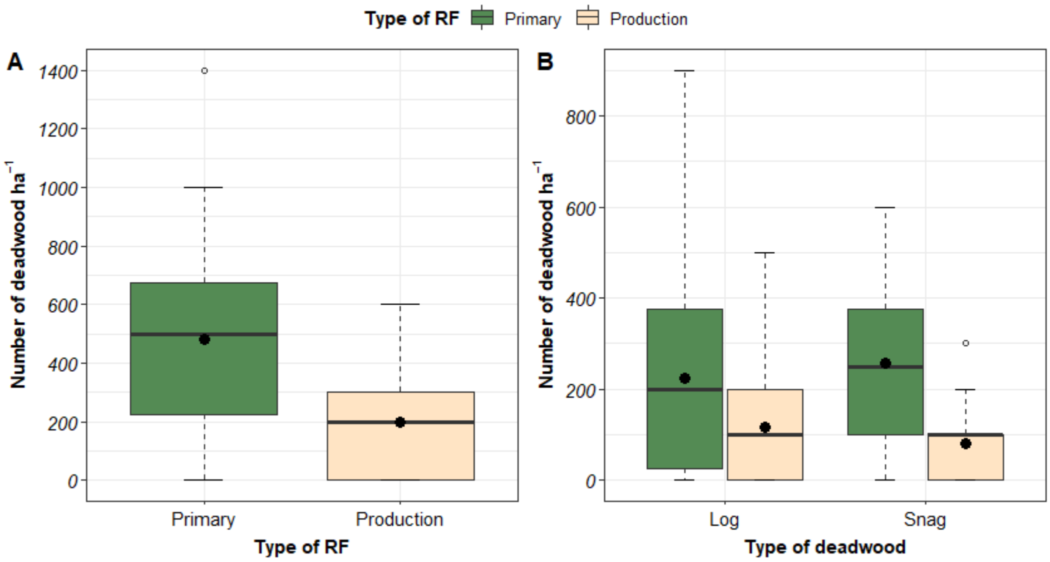

Figure 7. Box plots showing number of deadwood/ha on the y-axis and type of RF (A) and type of deadwood (B) on the x-axis. The box plot to the left shows all deadwood types (including snags and logs) and the left boxplot shows deadwood in snags and logs between the RF types. The green boxes represent primary RF and the beige boxes represent production RF. The black circle represents the mean value, the black horizontal line represents the median value and the box covers 50 % of the sample.

3.2.2. In-stream deadwood

Number of in-stream deadwood objects recorded in primary and production RF showed no significant difference (GLMM: $\beta = 0.083$; $z = 0.167$; $p = 0.867$) from each other. More deadwood objects were recorded in production RF (115 objects) compared to primary RF (93 objects). This corresponded to the mean of 31 objects/100 m stream (SD ±32) for primary RF and 38 objects/100 m stream (SD ±44) for production RF. The median was 20 objects/100 m stream and 30 objects/100 m stream, respectively (Fig. 8A).

Similar trend was seen after dividing deadwood objects into bridges and in-channel. Production RF had more bridges (25 objects) and in-channel deadwood (90 objects) compared to primary RF (22 bridges and 71 in-channel objects). However, no significant difference was found for either bridges (GLMM: $\beta = 0.10$; $t = 0.25$; $p = 0.806$) nor in-channel deadwood (GLMM: $\beta = 0.13$; $z = 0.23$; $p = 0.815$) between the type of RF. When recalculated per hectare, the mean for number of bridges was 7 objects/100 m stream (SD ±8) for primary RF and 8 objects/100 m stream (SD ±12) for production RF. The median was 10 objects/100 m stream and 0 objects/100 m stream, respectively. The mean for number of in-channel deadwood was 24 objects/100 m stream (SD ±27) for primary RF and 30 objects/100 m stream (SD

±37) for production RF. The median was 15 objects/100 m stream and 20 objects/100 m stream, respectively (Fig. 8B).

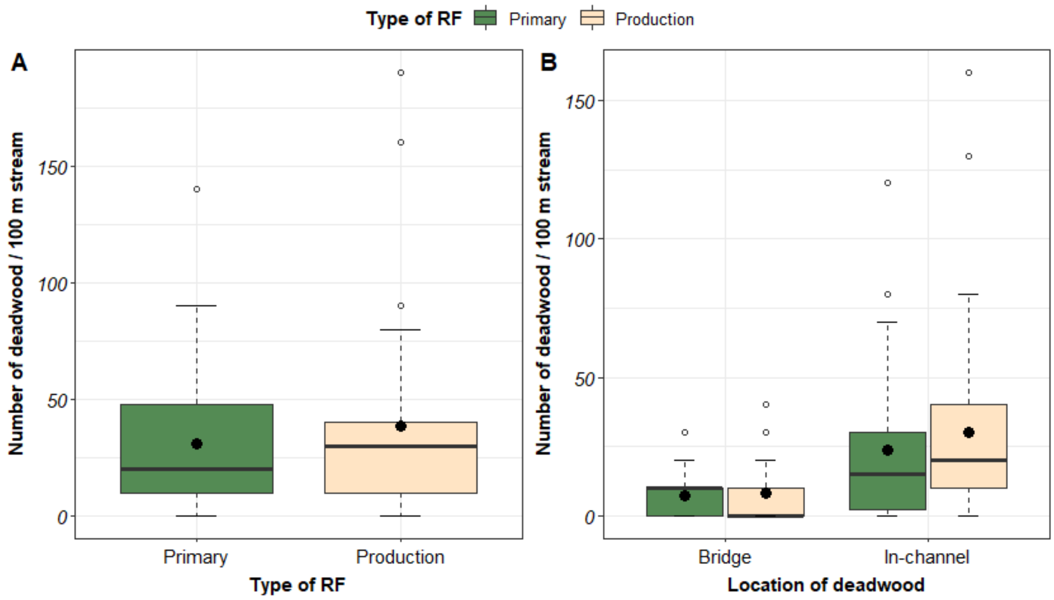

Figure 8. Box plots showing number of deadwood/ 100 m stream on the y-axis and type of RF (A) and location of deadwood (B) on the x-axis. The box plot to the left shows all in-stream deadwood objects (bridge and in-channel) and the left boxplot shows deadwood in bridges and in-channel between the RF types. The green boxes represent primary RF and the beige boxes represent production RF. The black circle represents the mean value, the black horizontal line represents the median value and the box covers 50 % of the sample.

3.3. Canopy cover

The canopy cover (%) recorded for primary RF and production RF was significantly different ($\beta = 10.66$; $t = 2.49$; $p = 0.032$) from each other. Higher canopy cover was found in production RF, which had a mean of 68.2 % (SD ±7.2) and a median of 67.5 %. Primary RF had a mean of 57.6 % (SD ±11.5) and a median of 60.5 % (Fig. 9).

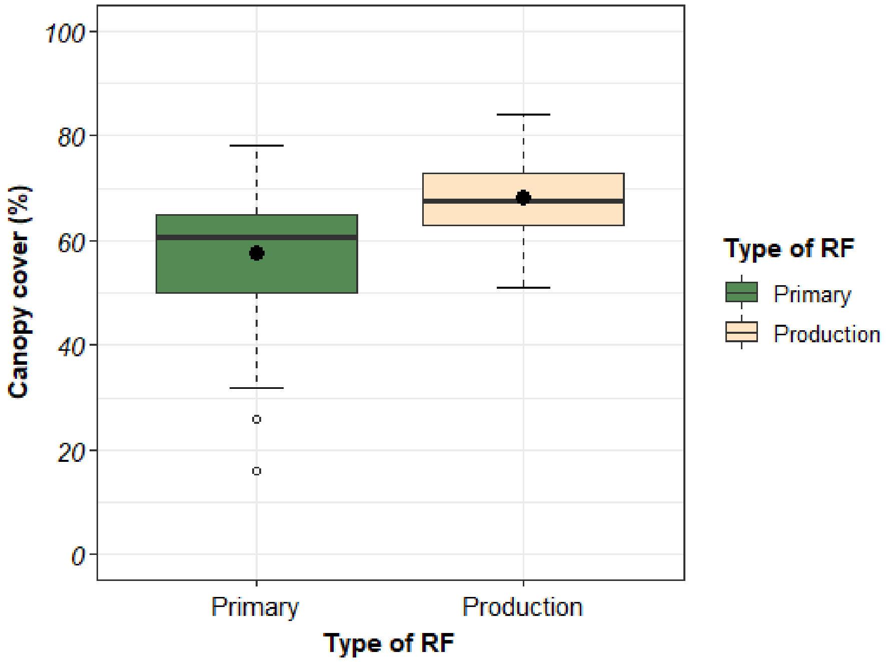

Figure 9. Box plot showing stream canopy cover (%) on the y axis and type of RF on the x-axis. The green box to the left represents primary RF and the beige box to the right represents production RF. The black circle represents the mean value, the black middle line represents the median value and the box covers 50 % of the sample.

4. Discussion

The purpose of this study was to broaden the knowledge about primary RFs along headwaters in the boreal forest in Sweden and how they differ in their stand characteristics compared to RFs situated in production stands. Before I start to discuss the result, I believe that it is important to once again mention that a primary forest do not mean that the forest is untouched. Considering how intensively managed the Swedish forest has been over the last century (Lundmark et al. 2013), it is very unlikely that the primary RF sites used in this study has not been affected by humans at all. If we also take long-distance travelling air pollutants into account as a disturbance agent (Grennfelt et al. 2020), the chances are likely close to zero that the sites are unaffected by humans. Furthermore, since RFs work as a filter of biogeochemical substances (Lidman et al. 2016) and are the last terrestrial point before groundwater discharges into streams (Kuglerová et al. 2014b), it is fair to assume that these ecosystems are affected by anthropogenic perturbations in one way or another. The question is to what extent and how do we describe their state of naturalness?

Stoddard et al. (2006) uses a definition of describing the biological state of streams integrity as minimally disturbed condition (MDC), which refers to a state of naturalness that best explains an intact ecosystem without any significant signs of human disturbances (including air pollution). This definition can be put into relation to the term used in this study, primary forest, which describes several forest types based on their levels of naturalness, whereas old-growth forests and long-untouched forests (unmodified for the last 60-80 years) being the forest types with the lowest naturalness level in the group (Buchwald 2005). As for that, I would describe the primary RF sites in this study as combination of MDC and old-growth/long-untouched forest types. Nevertheless, no matter what we choose to call the primary RF sites, these are some of the rarest minimally disturbed forests that could be found in Sweden, and are probably the best source of inspiration for forest management that aims to mimic natural conditions.

4.1. Diameter distribution and tree species composition

The results from this study showed that the diameter distribution of standing alive trees between the primary RF and production RF were significantly different, which confirms my hypothesis. The reason behind this hypothesis was based on previous studies where they found that forests that has been developed under natural succession over a long period of time tend to strive towards an inverse J-shaped DBH distribution (Linder et al. 1997; Linder 1998), while production forest stands develop a unimodal distribution with a slight skewness (Burkhart & Tomé 2012a).

Almost twice as many trees were recorded in the primary RF (1130 stems/ha) compared to the production RF (617 stems/ha). The tree density showed similar results as a previous studies in old-growth forests in northern Sweden (Nilsson et al. 2003; Dahlström & Nilsson 2006). However, Dahlström & Nilsson (2006) found almost more than triple as many stems (1765 stems/ha) in the mature production RF compared to this study, which is kind of surprising. One explanation for this difference could be dissimilarities in how the forest has been managed. The lower tree density recorded in the production RF in this study was most likely due to more intensive thinning operations to enhance tree growth for high quality timber (Lundmark et al. 2013).

Linder (1998) also showed that the proportion of shade-tolerant tree species (i.e. Norway spruce) would increase over time and outcompete non-shade-tolerant tree species such as Scots pine, birch etc., if perturbations were missing. Especially on mesic-moist soils, with low fire frequency and sites with stand conditions that favorizes ingrowth of Norway spruce (Esseen et al. 1997; Linder 1998). These stand conditions may be similar to those that could be found in the RFs examined in this study. In addition, since most of the studied sites were small headwaters with incised channels, flooding events in the riparian area are less likely to occur (Kuglerová et al. 2015), which may also favor Norway spruce over time. This could explain the findings in this study of Norway spruce being the dominant tree species in the primary RF (79%). Norway spruce was also the dominant tree species (78%) in the production RF. However, that is more likely explained by forest management that has been promoting even-aged forest stands and using Norway spruce as a fast-growing tree species for wood-based products (Lundmark et al. 2013; Maher Hasselquist et al. 2021).

The findings on proportion of tree species presented in this study resemble results of a study by Dahlström & Nilsson (2006), where they also showed that Norway spruce was clearly the dominant tree species in both the old-growth RF and the mature production forest, followed by Scots pine and birch. However, even though the proportion in tree species composition was similar between both types of RFs in this study, the total number of trees recorded was higher in the primary RF for all species (except aspen). This is important to point out, especially for deciduous tree species with low recorded numbers. In contrast to coniferous tree species, deciduous tree species have shown to improve ecosystem functioning in the riparian area and in-stream condition by providing higher litter quality (Lidman et al. 2017), which promotes microbial processes (i.e. immobilization, denitrification) and prevents leaching of nutrients and dissolved organic carbon (Camino-Serrano et al. 2014; Duan et al. 2014). Deciduous tree species are also important for the biodiversity of both the aquatic and terrestrial ecosystem as they provide habitats and substrate for threatened species, such as the umbrella species white-backed woodpecker (Bell et al. 2015) and macroinvertebrates (Jonsson et al. 2017). Both rowan and willow were present in low numbers in the primary RF, but absent in the production RF, and almost twice as many birch trees were recorded in the primary RF compared to the production RF. This means that the primary RF has a higher biodiversity and potentially higher resilience compared to the production RF. Furthermore, the primary RF had more tree species, meaning, more trees can work as replacement if some were to be lost during forest development. However, the results also showed almost twice as many Norway spruces in the primary RF. This could lead less deciduous tree species as they become outcompeted by Norway spruce over time (Linder 1998). Linder (1998) suggested that the reason why Norway spruce is increasing in primary forests is because of the exclusion of natural forest fires, and that fire suppression may have resulted in an unnatural vegetation that do not resemble a natural forest. Fire has been considered as one of the most important disturbance agent in the boreal forest and is essential for resembling natural stand dynamics (Zackrisson 1977). Zackrisson (1977) estimated the average fire interval on wetter sites to 160 years, which suggests that prescribed burning should be conducted in RFs every 160 years in order to mimic natural disturbance regimes.

Furthermore, the results showed that the production RF had a significantly higher mean DBH (25.3 cm) compared to the primary RF (16.9 cm). This was expected considering that the primary RF with inverse J-shape distribution will have more trees in the lowest diameter class (5-10 cm) and the decrease in number when DBH increases (Burkhart & Tomé 2012a), while the production RF with a normal distribution will have more trees in the middle diameter class (25-30 cm) (Burkhart & Tomé 2012b). In the production RF, small trees are usually removed in pre-commercial thinning and thinning operations, and that is most likely why there were less smaller trees (Lundmark et al. 2013). Another important aspect, which should characterize old-growth forests, is the presence of large trees. It has been estimated that at least 20 stems/ha (>40 cm DBH) were common in natural forests in Sweden pre-industrial time (Nilsson et al. 2003). The results in this study showed that the primary RF had 47 stems/ha (> 40 cm DBH), which is twice as many as the estimated value. On the other hand, the production RF had also high number of large trees (43 stems/ha). The reason for the high number of large trees present in both the production and primary RF is likely because RFs have a higher plant productivity in comparison to upland forests (Naiman et al. 1998) and should thus result in larger trees. Nilsson et al. (2003) estimates were based on upland forests, causing the large difference between their study and the results presented here. Nevertheless, very large trees (> 55 cm DBH) were absent in both types of RF. This could be a result from historical forest management when trees of large dimensions were selectively cut (Östlund 1995). In a report by Eckerberg (1981), selective cuttings was performed within Vändåtbergets nature reserve (Site 1) in the early 1900's, which makes it fair to assume that most of the visited primary RF sites have experienced similar events in the past. In addition, cuttings for firewood and potash may also have suppressed the development of large trees to a certain extent (Östlund et al. 1998).

4.2. Deadwood

Deadwood is an important feature for many vital ecosystem functions (Esseen et al. 1997). When trees die, they start to decompose and enter several different stages of decay. Throughout this process they provide energy, nutrients and habitats for many organisms as well as act as seedbeds for regeneration of plants. Snags and logs are both important deadwood features and provide unique, but dissimilar, environments for associated species (Esseen et al. 1997). Many wood-living species prefer large deadwood objects. However, that does not neglect the importance of small deadwood objects as they host different species communities, which are of equal importance for a functional and healthy ecosystem (Jonsson et al. 2005).

4.2.1. Riparian deadwood

Large amounts of deadwood are a common feature in old-growth forests, but are often lacking in production forests (Esseen et al. 1997). The results from this study was not an exception. The number of deadwood objects recorded in the primary RF (480 objects/ha) where about 2.5 times higher compared to the production RF (197 objects/ha), which confirms my hypothesis of finding more deadwood objects in the primary RF. This theory assumed that the primary RF, which has been unaffected by commercial forestry, have a higher mortality rate through natural causes such as self-thinning, age and natural disturbance regimes (Esseen et al. 1997). The deadwood would also be left on site, causing an accumulation of deadwood over time. Meanwhile, in production RFs with rotation-forestry, trees are instead harvested and removed from the forest (Roberge et al. 2020), resulting in less potential sources for deadwood to be developed. The results also showed that the greatest different between the two types of RF was in number of snags, which suggest that trees dieback are more likely to occur in the primary RF as a consequence of higher tree density and competition between individual trees (Linder 1998). This natural dynamic is suppressed in production stands by active management throughout the rotation period (Roberge et al. 2020).

Most of the previous studies on RFs have reported volumes of deadwood instead for number of objects, which makes comparisons difficult. A finish study conducted in mature production and old-growth forests in the southwest part of Finland, showed similar values (slightly lower) compared to the ones presented in this study. They also included all deadwood objects (> 5 cm DBH) and found 110 stems/ha in mature production forests and 353 stems/ha in old-growth forests (Siitonen et al. 2000). Dahlström & Nilsson (2006) found similar results in RFs along headwaters in Sweden when comparing volumes of deadwood in old-growth and production forests. Furthermore, Siitonen (2001) concluded that volumes of deadwood in production forests are usually less than 30 % of the volume found in old-growth forests. Since volumes are highly dependent on tree sizes, high quantitative values (i.e. number of deadwood objects) do not necessarily mean high volumes, which makes comparisons with the estimated value from Siitonen (2001) difficult. Nevertheless, results from previous studies are consistent with the results in this study of finding more deadwood in old-growth forests compared to mature production forests. Furthermore, considering the ecological value of small deadwood objects (Jonsson et al. 2005), more research should be conducted on number of deadwood objects in the RF and its effects on ecosystem functions and processes.

4.2.2. In-stream deadwood

The number of in-stream deadwood objects per 100 m stream length recorded in the primary RF (31 objects) showed no significant difference compared to the production RF (38 objects), which contradicted my hypothesis of finding more in-stream deadwood objects in the primary RF. This theory was based on the same assumption as riparian deadwood related to forest management. There was neither any significant difference between number of bridges and in-channel deadwood objects between the two types of RF.

These results were unexpected, considering that there was a significant difference in number of deadwood objects found in the riparian area between the two types of RF, and that previous studies have found a correlation between the proportions of deadwood recorded in the riparian area and the in-stream area (Dahlström & Nilsson 2004, 2006). Dahlström & Nilsson (2004) found significantly more deadwood objects per 100 m stream length in old-growth forests (66 objects) compared to production forests (36 objects) along headwater streams in north-central part of Sweden. The dissimilarities in comparison to this study could partly be explained by two log jams recorded in one of the sites located within the production RF (Site 6), resulting in a similar value as the primary RF. Another possible explanations could be increased input of logging residues from pre-commercial thinning and thinning operations, that fall into the streams in the production RF (Dahlström et al. 2005). Furthermore, considering the fact that in-stream deadwood can be transported downstream (Braudrick & Grant 2000) and that only a small proportion of the total stream length was investigated in this study (600 m) compared to Dahlström & Nilsson (2004) (1716 m), it is likely that the results from this study have a lower accuracy of representing the true value. Therefore, longer total stream length should be considered in future studies when estimating the quantity of in-stream deadwood.

4.3. Canopy cover

The canopy cover was significantly different between the primary (57 %) and the production (68 %) RF, which confirms my hypothesis of finding higher canopy cover in the production RF. The theory behind this hypothesis assumed that the production RF would have a denser top canopy layer, which would block more incoming light compared to the primary RF with a multi-layered canopy. The primary forest would also be encountered more frequently by cohort and gap disturbances, resulting in a greater variation in canopy cover and a lower average value. Old-growth forests are generally more structurally complex than mature production RFs, including large gaps between trees in the top canopy layer, which allows a more heterogenous light input to the stream channel (Keeton et al. 2007).

The results from this study were consistent with previous studies in the field of finding a lower mean and greater variation in canopy cover along headwater streams adjacent to old-growth RFs compared to mature production RFs (Stovall et al. 2009; Warren et al. 2013; Kaylor et al. 2017). Forested headwaters have been recognized of having high canopy closure (i.e. high shading) and strong interaction with surrounding terrestrial ecosystem, which assumes that forested headwaters are mainly driven by heterotrophic food webs (Richardson & Danehy 2007). However, the results from this study suggests that headwaters in primary forests might be more complex than that. This can be supported by McNeely et al. (2007) who recorded a high proportion of aquatic invertebrates in forested headwater streams that are highly dependent on primary producers (i.e. algae) as a carbon source. This insight highlights the complexity of light input to forested headwaters and how it may affect the aquatic food web (Stovall et al. 2009; Kaylor et al. 2017). Patches receiving more incoming light (sunflecks) might result in an increased primary production, while shaded patches are unaffected, creating a uniqueness and more diverse environment for various aquatic organisms along the stream length (Keeton et al. 2007; Warren et al. 2013). Sunflecks are important for growth of many understory plants in the terrestrial ecosystem, which increases habitat diversity (Pelt & Franklin 2000). This signifies that heterogenous light input to forested headwaters might be as important for stream biodiversity. However, our understanding on how sunflecks impact overall stream biodiversity (Warren et al. 2013) and how aquatic species communities interact with each other in headwaters (McNeely et al. 2007) is limited, and more research is needed.

4.4. Forest management implications and concluding remarks

In Sweden, headwaters and their adjacent RFs have received little to no attention when it comes to protection against forestry operations (Kuglerová et al. 2020). As mentioned, this can partly be explained by not being visible on available property maps (Bishop et al. 2008), but also by insufficient and vague legal policies on how they should be protected in order to preserve ecological functionality and stream integrity (Lindahl et al. 2017; Kuglerová et al. 2020). Fixed-width riparian buffers are fairly easy to implement, but may result in homogenous even-aged conifer stands with low functionality if not any active changes are made. Thus, forest management mimicking natural disturbance regimes have been suggested as an strategy to increase the ecological functionality of the RF (Kreutzweiser et al. 2012). This method can be significantly improved and potentially implemented once we increase our understanding of RFs in their natural range of variation.

Many previous studies have focus on differences in stand characteristics between old-growth forests and mature production forests in upland forest landscapes. However, studies on stand characteristics in RFs (especially primary forests) along headwaters are still rare. That is why the primarily aim of this study was to increase our understanding about primary RFs along headwaters in northern Sweden and identify differences compared to mature production RF. The results showed that the primary RF were more heterogenous in tree species, had a higher stem density and a lower average DBH compared to the mature production RF. More deadwood objects in the riparian area were recorded in the primary RF, but no significant difference could be found between the primary RF and the mature production RF in number of in-stream deadwood objects. Furthermore, the primary RF had a lower average canopy cover and a greater variation in canopy cover along the headwater stream length compared to the mature production RF.

Based on our current knowledge and the results presented in this study, if the goal is to mimic natural forest dynamics and disturbance regimes in RFs along headwaters in northern Sweden, forest owners should aim towards increasing the spatial heterogeneity in tree sizes, the number of deadwood objects (especially in the riparian area) and increase variation in canopy cover. This could be achieved by several different silvicultural methods, which may differ depending on the current stage of the RF (see Maher Hasselquist et al. 2021). Selective cuttings could mimic natural cohort and gap dynamics and would allow establishment and regeneration of new trees, and a greater variation of light-input to streams. Larger disturbances, such as canopy removal all the way to the stream edge, could also be promoted in dryer areas (and in small patches) to mimic natural forest fires and promote ingrowth of early-successional tree species (i.e. deciduous tree species) (Maher Hasselquist et al. 2021).

The results from this study could aid to improve forest management and increase RFs functionality. However, more research needs to be conducted in Sweden to fully understand the forest dynamics across climatic gradients, RFs types and how silvicultural methods mimicking natural disturbance regimes may affect aquatic and terrestrial ecosystems. Only after knowing that, we can start with active and adaptive RF management, which is best fitted to a particular location.

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Appendix 1

Appendix 1. Template for taking field notes

Observer	

Site Name	
Coordiantes	

Plot nr.	

Distance from begining	

Standing trees (> 5 cm dbh or > 2 m tall):					*Tree status: SD=Standing dead, SA= Standing alive*				
	Sp	DBH (cm)	hight (m)	Status		Sp	DBH (cm)	hight (m)	Status
Tree 1					Tree 11				
Tree 2					Tree 12				
Tree 3					Tree 13				
Tree 4					Tree 14				
Tree 5					Tree 15				
Tree 6					Tree 16				
Tree 7					Tree 17				
Tree 8					Tree 18				
Tree 9					Tree 19				
Tree 10					Tree 20				

Bushes and shrubs (1-2 m tall of < 5 cm dbh)		**Bushes and shrubs (< 1 m tall)**	
decid count		decid count	
conif count		conif count	

Stump count	

Deadwood (> 5 cm dbh or > 1 m long):						*Dedwood status: 1-5 decomp. Class, 6 for snags* *Deadwood location: riparian, in-channel, bridge*					
	Sp	DBH (cm)	length (m)	Status	location		Sp	DBH	hight (m)	Status	location
Wood 1						Wood 11					
Wood 2						Wood 12					
Wood 3						Wood 13					
Wood 4						Wood 14					
Wood 5						Wood 15					
Wood 6						Wood 16					
Wood 7						Wood 17					
Wood 8						Wood 18					
Wood 9						Wood 19					
Wood 10						Wood 20					

Canopy shade	
	%
0 m	
5 m	
10 m	

Stream width		
	m	**channel form** *(braided, single channel, incised, open)*
0 m		
5 m		
10 m		

SENASTE UTGIVNA NUMMER

2021:07	Författare: David Falk Drivers of topsoil saturated hydraulic conductivity in three contrasting landscapes in Kenya - Restoring soil hydraulic conductivity in degraded tropical landscapes
2021:08	Författare: Jon Nordström En märr som hette Mor – De sista härjedalska hästkörarnas berättelser från tiden innan skogsbrukets mekanisering.
2021:09	Författare: Roberto Stelstra Implementation of native tree species in Rwandan forest plantations – Recommendations for a sustainable sector
2021:10	Författare: Kazi Samiul Islam Effects of warming on leaf – root carbon and nitrogen exchange of an ericaceous dwarf shrub.
2021:11	Författare: Ellika Hermansson Ett riktigt hästarbete –skogsarbete med häst i sydvästra Sverige, förr, nu och i framtiden
2021:12	Författare: Fabian Balele Wildfire dynamics, local people's fire use and underlying factors for wildfires at Liwale
2021:13	Författare: Martina Lundkvist Samband mellan ståndortsfaktorer, genetik och historiska skördedata från tall- och granfröplantager – krävs ökad precision vid val av lokaler för nyafröplantager?
2021:14	Författare: Maria Grånemo "I stand here. I will not move" – Women in forestry in northern Sweden during the 20th century
2021:15	Författare: Tim Schacherl Evaluating Drought Impacts on Ecosystem Water Use Efficiency of Three Different Boreal Forest Sites
2022:01	Författare: Alice Cosatti The end of the timber frontier in northern Sweden – Early logging, natural forests and the frontier concept
2022:02	Författare: Pontus Nyqvist Utvärdering av metod för att morfologiskt särskilja björkarterna Betula pendula och Betula pubescens
2022:03	Författare: Julia Nygårdh Mosippans (Pulsatilla vernalis L.) reaktion på brandstörning – En populationsstudie på en av Sveriges rikaste mosippslokaler
2022:04	Författare: Oskar Karlsson Effects on natural seed regenerated Silver birch (Betula pendula Roth) and Downey birch (Betula pubescens Ehrh) by mechanical soil scarification and environmental factors
2022:05	Författare: Eric Lundqvist Riparian forests – a comparison of tree diversity, deadwood and canopy cover between primary and production riparian forests along headwaters