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How are riparian buffer zones around Swedish headwaters implemented?

- A case study


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Hur implementeras skyddszoner runt små vattendrag i Sverige?
- En fallstudie

Anna Jonsson

Keywords / *Nyckelord:*

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Abbreviations

RAS: Rapid Assessment Survey
SOSTPRO: Source Stream PROtection, collaboration project between Canada, Finland and Sweden.
WFD: Water framework directive
DEM: Digital elevation model
LMMs: Linear mixed effect models
GLMMs: General linear mixed effect models
PCA: Principal component analysis
I.I.: Impairment Index
END: Emulate Natural Disturbances

Abstract

Riparian zones are the transition zones between aquatic and terrestrial environments. They perform numerous important ecological functions. To protect these functions, keeping riparian buffer zones when performing forestry operations around streams is a commonly used practice. In this case study, I investigated how riparian buffer zones around 119 headwaters in northern and southern Sweden are implemented using Rapid Assessment Survey (RAS). I found that 11 % of streams had < 0.1 m wide buffer, 58 % had a buffer 0.1-5 m width, 26 % hade a buffer 5-15 m wide, and 5 % had a buffer wider than 15 m. Northern sites had significantly wider buffers than southern sites. Further, results indicated that neither size of the stream nor size of the clear-cut area influence which buffer width a stream would get. Tree type (coniferous/deciduous) composition of mature trees and saplings of retained buffers differed among buffer width categories and between southern and northern Sweden, and was to some degree a result of the forestry operations within buffers (selective logging). The results also supports that number of deadwood in the stream and shading of the stream are increasing, while the magnitude of impairments connected to forest operations are decreasing, with increasing buffer width. Knowledge of how Swedish headwaters are treated during forest operations, as demonstrated in this study, could help in assessing local effects on small streams due to forest operations as well as cumulative downstream effects on downstream reaches.

Sammanfattning

Den bäcknära zonen är övergångsområden mellan vatten- och landmiljö och den är värd för flera viktiga ekologiska funktioner. För att skydda dessa funktioner är det vanligt att lämna buffertzoner, remsor av träd vid vattendrag när skogsbruksåtgärder utförs. I denna fallstudie undersökte jag hur buffertzoner runt 119 små bäckar i norra och södra Sverige implementeras. Detta gjordes med hjälp av snabb utvärderings metod (RAS). Jag fann att, 11 % av bäckarna hade en buffertzon på <0.1 m, 58 % hade en buffertzon på 0.1-5 m, 26 % hade en buffertzon på 5-15 m och 5 % hade en buffertzon på >15 m. Studielokalerna i norra Sverige hade signifikant bredare buffertzoner än de i södra Sverige. Vidare indikerade resultatet på att varken storleken på bäcken eller storleken på kalhygget de flyter igenom verkar påverka vilken bredd buffertzonen ges. Trädtypssammansättning (barrträd/lövträd) av mogna träd och plantor skiljer sig mellan olika kategorier av buffertzons bredder. Resultaten visar också att mängden död ved i bäcken och skuggningen av bäcken ökar, medan mängden störningar direkt och indirekt kopplade till skogsbruk minskar med ökande bredd på buffertzonen. Kunskap om hur svenska små bäckar behandlas vid skogsbruksåtgärder, som i denna studie, kan bidra till att bedöma lokala effekter av skogsbruk på små bäckar samt kumulativa effekter på nedströms vattendrag.

Introduction

Background

Riparian zones are the transition zones between aquatic and terrestrial environments and are situated along the edges of all waterbodies. It has been well documented that these areas sustain important ecological functions (Naiman and Décamps 1997). For example, riparian zones along streams and rivers are important habitat for many species (Gundersen et al. 2010), they help avert excessive amounts of fine sediment and nutrients delivered from adjacent uplands with surface flow and groundwater (Hill 1996; Kreutzweiser and Capell, 2001), riparian trees and shrubs shade streams to prevent rising water temperatures (Gomi et al. 2006; Johnson and Almlöf 2016), their roots increase bank stability (Beeson and Doyle 1996) and they provide subsidies for aquatic organisms in form of leaf litter and other debris (Hoover et al. 2011).

Given that riparian forests have such high importance for the stream integrity, the complete removal of riparian trees through harvesting can cause large negative impacts (Sweeney and Newbold 2014) such as nutrient leakage (Löfgren et al. 2009), reduced amount of leaf litter to stream (Hoover et al. 2011), increased water temperatures (Gomi et al. 2006) and decreased biodiversity (Dupuis and Steventon 1999; Hylander and Gothner 2004). In addition to the negative effects related to removal of forest canopy, driving with heavy forest machines within riparian zones when performing different cutting operations can also result in negative consequences such as diverged flow paths (Ågren et al. 2015), bioaccumulation of methyl mercury (Garcia and Carignan 2015), nutrient leakage (Futter et al. 2010) and soil erosion causing sediment transport (Kreutzweiser and Capell 2001). Moreover, other forestry operations such as stump harvest and site preparation can increase total mercury and methylmercury levels in runoff (Eklöf et al. 2012). The magnitude of these impacts may differ depending on the environmental characteristics of the site and the execution of forestry operations.

This is why leaving strips of forests around streams when harvesting (from now on referred to as riparian buffer zones or simply buffers), is a commonly used management practice in today's forestry (Richardsson et al. 2012). To create functional riparian buffer zones that provides various desired functions, described above, has been a challenge for both researchers and practitioners. The width, structure and composition of the forest creating the buffers, together with site characteristics, such as topography and surface and subsurface water flowpaths affect the functionality of the buffers (Valett et al. 2002; Hoover et al. 2011; Sweeney and Newbold 2014; Bilby and Heffner 2016). These are important factors to consider when establishing riparian buffer designs (Kuglerová et al. 2014).

The general picture in many countries is that lakes and larger streams and rivers that are fish-bearing, receive most protection in form of a forested riparian buffer zones (Swanson and Franklin 1992). Small headwaters (1^{st}-2^{nd} order streams, *sensu* Strahler 1957) are often being compromised during buffer allocation and their buffers are either thin or completely missing (Kuglerová et al. 2017). Reasons for this are numerous, for example small streams are numerous across the forested landscapes and retaining riparian buffers along all of them would impose a large economic pressure for the forest owners. Further, small streams are difficult to visually locate during late-spring operations since they might be under snow cover, and they have been inadequately mapped in the past (Ågren et al. 2015). Finally, the importance of small streams on both local and downstream scales has been little appreciated by foresters in the past.

Regulations regarding riparian buffer zones

The EU water framework directive (WFD, 2000/60/EC), that was adopted in 2000, state that all waters within the European Union should achieve good ecological and chemical status by 2027 with no further degradation acceptable. Since forestry operations influence aquatic environments, regulating policies are of large importance in order to reach the goals set up by WFD. Different countries have different policy approaches and degree of prescriptiveness regarding delineation of riparian buffer zones and regulation of forestry operations within those zones. For example, in United States and Canada a summarizing study on jurisdictions regarding riparian management guidelines and regulations stated that the average requirement of buffer width around small streams was 19.9 m and 29.6 m, respectively (Lee et al. 2004). In contrast, Ring et al. (2017a) found that specified buffer width requirements varied between 1 m to 5 km, when exploring differences in national policies (both mandatory by laws and voluntary obligations, such as forest certification schemes) concerning riparian buffers around surface waters for the Nordic countries, Estonia and Latvia. Latvia and Norway had specified buffer width requirements starting from 10 m, while Sweden had no mandatory specified buffer width requirements but instead voluntary guidelines and recommendations.

The current recommended rules and guidelines regarding establishment of riparian buffers in Sweden are to be found in a number of documents published mostly by the Swedish forest agency (Skogsstyrelsen 2015; Anon 2014) and in the Swedish Forestry Act (Skogsstyrelsen 2017) but can also be found in various other documents published by different governmental and non-governmental organizations (e.g. in forestry portal www.skugskunskap.se; Henriksson 2007; Ring et al. 2008; Barklund 2009). Hereafter follows a summary (freely translated from Swedish) of those guidelines and regulations that applies for both perennial and temporary watercourses.

- Damages caused by forest management should be prevented or limited on land and water.
- Area with trees and shrubs that is needed to prevent or limit adverse effects on adjacent environments, must be left when managing forest to the extent necessary for consideration of species, water quality and landscape image.
- In forest management, harmful nutrient leaks and harmful mud transport to lakes and rivers must be prevented, and water quality maintained or improved.
- When performing forestry measures around streams and lakes, one should keep trees, shrubs and other vegetation to keep following functions:
- Provide stable shade of the stream over time.
- Contribute food to aquatic organisms through falling leaves and insects.

- Contribute deadwood to the water.
- Act as a filter for sediment transport from upland and stabilize shoreline to prevent erosion.
- Preserve important soil chemical processes such as, denitrification and nutrient uptake.
- Preserve biodiversity.

* When establishing riparian buffers a long-term goal is to create buffers that are multilayered and uneven-aged with a composition of species that are suitable for the site.
* Partial harvest within buffers is occasionally recommended if other functions such as sufficient shading of the stream can be still maintained. For example, partial harvest of coniferous trees that can promote recruitment of deciduous trees is recommended in some cases.
* All deciduous trees within 10 meters from streams should be left in stands dominated by coniferous.

Further recommendations state that implementation of forestry operations around streams and lakes should be done according to following requirements:

- Serious driving damages, such as those that leads to export of sludge to lakes and streams, to changes in stretch flow paths or to damming of a watercourse, and to damages of peatlands adjacent to lakes and streams, should be prevented.
- No driving should be done in streams or discharge areas.
- No driving and ground damages that can lead to sludge transport into the water should be done within 10 m from streams
- If crossing of streams is necessary, use technical support such as permanent or temporary bridges. Entries and exits from the crossing should be protected, for example, by stock mats, excavator mats, pavement bridges or twigs.
- The bottom of the stream should not be damaged.

Policies are one important factor that determines how riparian buffers are being treated. However other factors, for example, forest ownership structure, forest stand structure (composition of commercial/non-commercial trees) and spatial-scale in management strategies, might also influence how buffers in practice are being designed. This is especially truth in countries where riparian buffers are allocated on voluntary basis. Finally, the consecutive decisions about buffers and other nature consideration measures can be made by practitioners at the time of the operations when they assessed the local conditions.

Over half of Sweden’s surface is covered by productive forest land (Anon. 2017) and forestry is an important industry for the national economy (FAO 2014). Modern forestry has been executed on most parts of the country over more than a century and substantially transformed the landscape (Östlund et al. 1997). The abundance of small streams is high in the forest landscape of Sweden (Esseen et al. 2004, Bishop et al. 2008) and thus, small watercourses in Sweden have been under a lot of pressure. Disregarding small headwaters when planning and implementing protective measures causes negative impacts locally but may also incur in possible damaging effects further downstream, leading to cumulative impairments (Kuglerová et al. 2017). To keep functional riparian buffers when performing different forestry operations around streams and wetlands is therefore part of a vision shared by Swedish forest stakeholders (Skogsstyrelsen 2016). If and how this vision is being fulfilled is, however, up for debate (Olsson 2009; Skogsstyrelsen 2011).

Aim

There are general guidelines and recommendations existing in Sweden about how riparian buffers should be designed. Although, there is a limited information is available on the actual practices of Swedish forestry around small watercourses across large scales. Lack of knowledge on how small headwaters are managed in reality during forestry operations make it difficult to quantify the local effect of forestry operations on small streams and consequently the cumulative impacts on downstream reaches. This also hinder us to further develop and adapt forestry plans (should we find that current protection plans are not efficient enough) and to sustain good ecological status of Swedish waters. Therefore, the aim of this study was to perform such in-field evaluation across large number of small streams in the Swedish forest landscape.

Research questions

This study aims to quantify and qualify how riparian buffers around small streams are designed. Following objectives are answered:

- Are riparian buffers kept around small streams in the landscape during current forestry operations? How wide are the riparian buffers around small streams? Is the size of the riparian buffers affected by their location in Sweden, the size of the adjacent streams or the size of the clear-cuts they are situated in?

-How does the tree type (coniferous/deciduous) composition of riparian buffers differ with different buffer width? How does the composition differ between partially logged and intact riparian buffers? Do the existing buffers provide the targeted functions (i.e., shading and dead wood provision)?

- Is the width of the riparian buffer zone linked to the magnitude of other impairments caused by forestry operations within the riparian buffers?

Material and Method

Study sites

This study is part of a project SOSTPRO (SOurce STream PROtection), initiated as a collaboration between University of British Columbia (Canada), University of Oulu (Finland) and Swedish University of Agricultural Sciences (Sweden), funded through the EU project Water JPI (http://www.waterjpi.eu). The SOSTPRO project aims at addressing the cumulative effects of forestry around small streams on downstream ecosystems thought monitoring, field studies, experiments and modelling approaches. As a first step of the SOSTPRO project a rapid assessment survey (RAS, Appendix 1) was performed on a vast number of streams in the three countries to assess the current practices of forestry. The Swedish data from Västerbotten County (northern Sweden) and Jönköping County (southern Sweden) (Fig. 1) are used in this thesis.

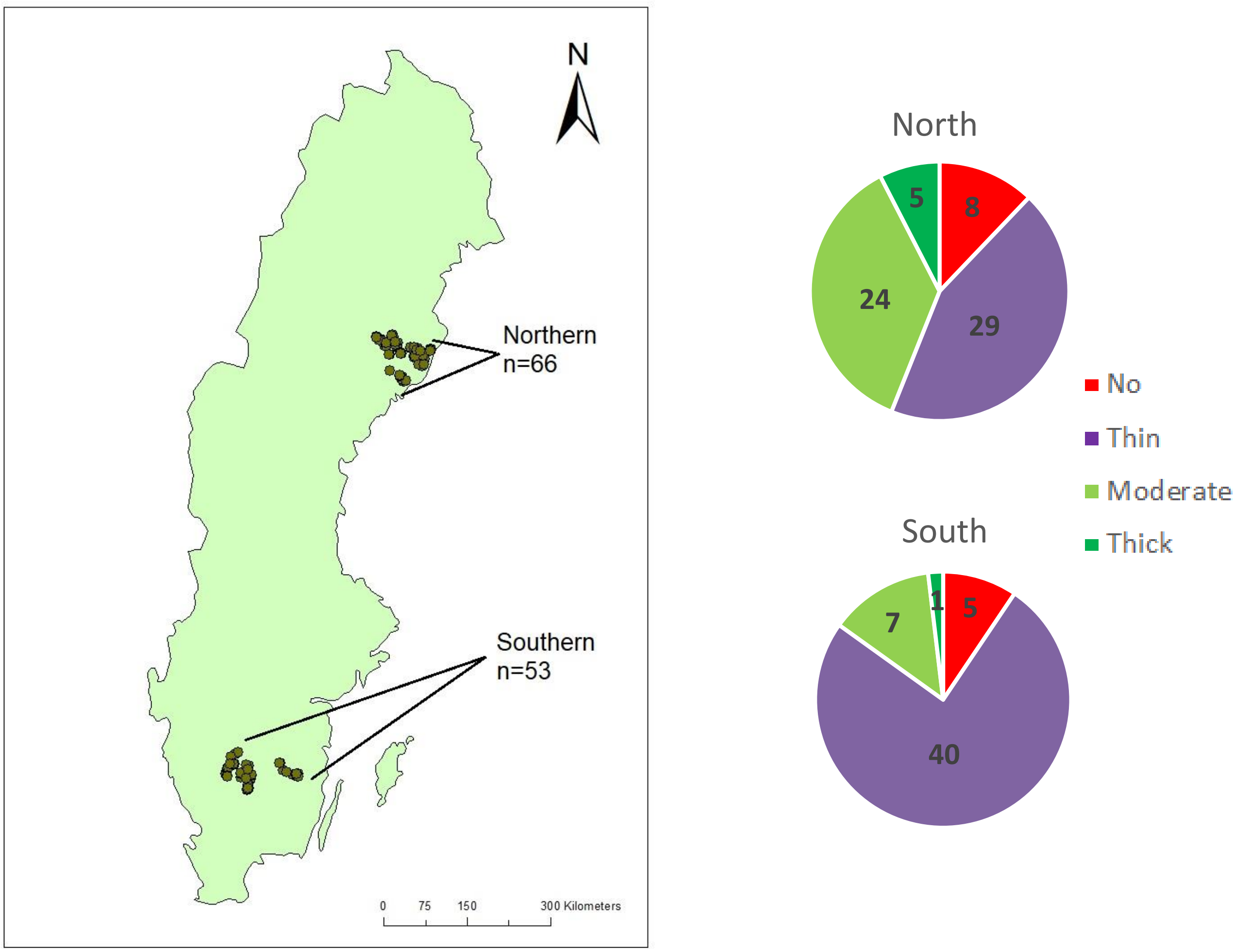


Fig 1. Map of Sweden showing the location of streams sampled, 66 sites in the north and 53 sites in the south. Pie charts represent the number of streams surveyed in each buffer width category (‘No’ buffer <0.1 m, ‘Thin’ buffer 0.1-5 m, ‘Moderate’ buffer 5-15 m and ‘Thick’ buffer >15 m), based on random site selection (see methods).

To locate the study sites, spatial data on clear-cut blocks were received from three Swedish forestry companies in the north and one in the south Sweden. Clear-cut polygons were intersected with stream layer to locate stream segments flowing through recent clear-cuts in both regions. W. Lidberg at the Swedish University of Agricultural Sciences provided the stream layer. Size, i.e. catchment area, of streams included was set to 0.1 km^2 – 15 km^2 and clear-cuts made between 2010 and 2016 was included in the study. To make fieldwork more effective, stream segments situated more than 200 meters from a road were excluded. During field visits sites which were evaluated by the field personnel as a ditch, too disturbed to measure (i.e., stream channel was missing due to extensive driving) or were completely missing were excluded. The rest of the streams that was examined were randomly selected from all the potential candidates created by intersecting small streams with recent harvest polygons and 200 m roads buffer (this yielded about 300 and 500 candidate stream segments in the south, north respectively). In total 119 streams, 66 in the north and 53 in the south of Sweden were examined (Fig. 1). All spatial analyses for site selection were done in RStudio (R Core Team 2017) by the PIs of the project.

Field - data collection

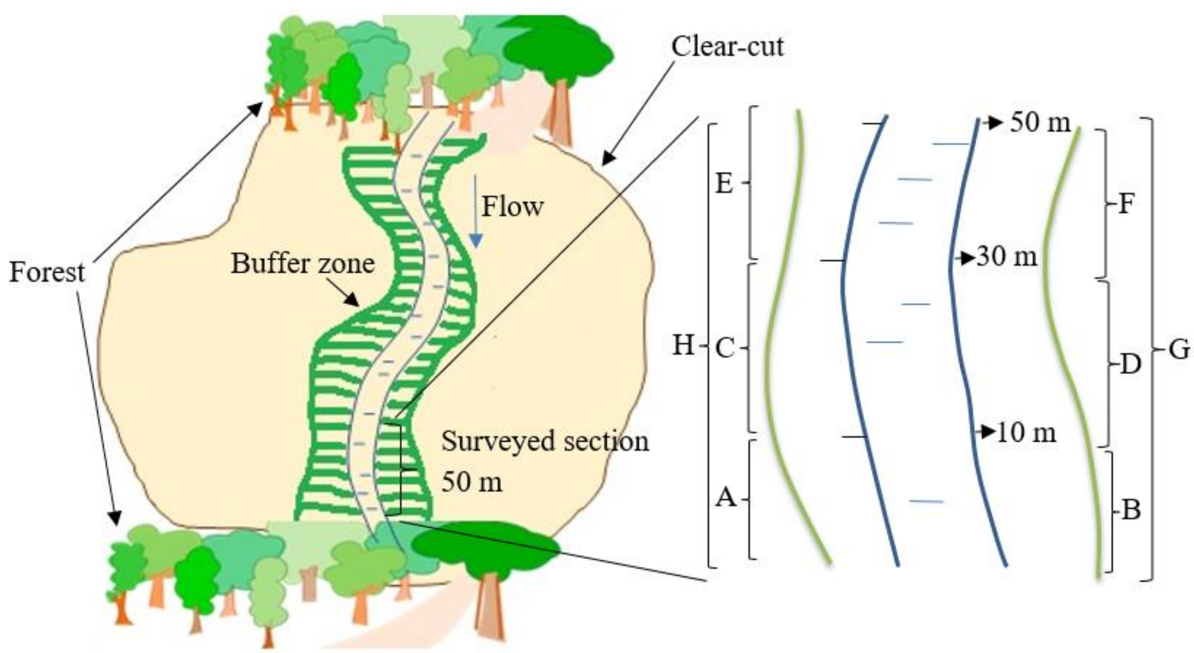
Field data were collected between June and August 2017 by two different field technicians in the south and north, all northern sites and 12 of the southern sites were examined by me. On each site a RAS protocol (Appendix 1) was performed which included data on riparian buffer configuration (buffer width and tree type [coniferous/deciduous] composition of mature trees and saplings), structural components of stream (shading and deadwood), and major impairments within the riparian buffer that were clearly linked to harvest operations (machine tracks, blow down trees, stream crossings, erosion, algae blooms and siltation, see Table 1). A number of other parameters was also sampled according to RAS (Appendix 1), but not used in this study.

Table 1. Variables from the RAS protocol used in this study, how they were used in statistical modeling (response or explanatory variable), how they were acquired or measured, and classification of each variable. RAS protocol was performed along a 50 m long reach at each site, which was further divided for some measurements.

Variable	**Type of variable in statistical analyses**	**Measurement location**	**Classification**
Buffer width	Response and explanatory	Visual estimation at three marks (10, 30, 50 m), left and right side of the stream separately.	Width of buffer (m)
Mature tree type composition within buffer (coniferous/deciduous)	Response	Visual estimation within 3 buffer sections (divided by the marks at 10, 30, and 50 m), left and right side of the stream separately.	Percent mature trees (%)
Saplings type (coniferous/deciduous) composition within buffer	Response	Visual estimation within 3 buffer sections (divided by the marks at 10, 30, and 50 m), left and right side of the stream separately.	Percent saplings, defined as saplings < 2 meter (%)
Stream size	Explanatory	Extracted with software Whitebox through flow accumulation values for each site sampled.	Catchment area (km^2)
Clear-cut size	Explanatory	Obtained from cutblock polygons in software ArcGIS.	Size of cut block, defined as adjacent polygons, harvested the same year and owned by the same company (km^2)
Shading of stream	Response	Visual estimation within 3 stream sections (divided by the marks at 10, 30, and 50 m)	Percent of the stream shaded (%)
Deadwood in stream	Response	Counted within 3 stream sections (divided by the marks at 10, 30, and 50 m)	Number of pieces, defined as >1 meter long and >10 cm diameter in the stream (#)
Machine tracks	Response	Visual estimation on the entire 50 meter section, within 30 m lateral distance on both sides of the stream.	No marks (0), Low - one or two shallow tracks (1), Medium - a few tracks, not too deep (2), Serious - numerous tracks within 30m from the stream or a few very deep tracks (3)
Blown down trees	Response	Visual estimation on the entire 50 meter section within 30 m lateral distance on both sides of the stream	No marks (0), Low – 1 or 2 trees blown down (1), Medium - a few trees blown down (2), Serious - many trees blown down (3)
Stream crossings	Response	Visual estimation on the entire 50 meter stream section	No marks (0), Low - stream crossings with permanent bridge or culvert (1), Medium - stream crossing with temporal bridge (2), Serious - stream crossing present without a bridge (3)
Erosion	Response	Visual estimation on the entire 50 meter stream section	No marks (0), Low - <20 % of section length (1), Medium - 20-50 % of section length (2), Serious - > 50% of section length (3) had erosion marks.
Algae blooms	Response	Visual estimation on the entire 50 meter stream section	No marks (0), Low - <20 % of section length (1), Medium - 20-50 % of section length (2), Serious - > 50% of section length (3) had algae blooms.
Siltation	Response	Visual estimation on the entire 50 meter stream section	No marks (0), Low - <20 % of section length (1), Medium - 20-50 % of section length (2), Serious - > 50% of section length (3) had sediment deposition.

Sampling was performed on a 50 m long stream stretch along the most downstream part of each stream situated within each clear-cut. This part of the stream was chosen to capture the total effects (e.g., sedimentation, algae bloom due to warming of water) on the stream made by the clear-cut (Fig. 2). At three marks, that is 10, 30 and 50 meters upstream from the forest edge (0 mark), buffer width, tree type composition of mature trees and saplings was visually estimated as an average of each buffer section (section A-F, Fig. 2, Table 2). Number of dead wood pieces in the stream was counted and percent shading of the stream was estimated at three marks as an average of each stream section (section 0-10, 10-30, 30-50 m, Fig. 2, Table 1). Magnitude of impairments within the buffer was estimated as an average of both sides of the stream on the entire 50 meter stretch and 30 m lateral distance from the stream, irrespective of buffer width (G, H, Fig. 2), by scoring from no marks to serious (see Table 1). To separate sites that had a buffer which were partially harvested from the sites that had intact buffers, we noted marks of partial harvest (i.e., stumps) within buffers in the protocol.

Fig 2. Schematic picture of sample design. Different letter marks sections along the stream where different variables were sampled.



Stream mapping

Although a stream layer was initially used to localize the study sites, newer version of digital elevation model (DEM) and thus flow accumulation maps were available after the completion of the field surveys. Therefore I performed additional spatial analyses for each sampled stream. To acquire size of streams i.e. catchment area and to map the stream networks I used the size of the catchment area draining into a sampling site, both derived from a preprocessed DEM (2x2 resolution). To determine flow direction and flow accumulation values of each pixel a D_8

algorithm (O'Callaghan & Mark 1984) was applied on the pre-processed DEM. The flow accumulation raster with a flow initiation threshold value of 10 ha was used to generate a new vector layer of stream network on most of the area. However, some of the surveyed streams were not generated with this threshold. Flow initiation threshold value for those streams was then lowered so they could be mapped. The lowest threshold value used was 2 ha. The flow initiation threshold value 10 ha was originally used because 10 ha is considered to be threshold for streams flowing all year round in Swedish landscape (Ågren et al. 2014). The size of each stream (catchment area, km^2) was calculated by extracting the flow accumulation value at each site where sampling was performed. A few manual corrections of the stream networks were made considering the field notes. All network analyses were performed in software Whitebox GAT (Lindsay 2016).

Size of clear-cuts was acquired using desktop ArcGIS (Esri Inc. 2016) by extracting size of each harvest polygon. A clear-cut was defined as all adjacent polygons, harvested the same year and owned by the same company.

Statistical analysis

In statistical analysis, buffer width was a continuous variable when it was used as a response variable (Table 1). When I used buffer width as an explanatory factor both continuous and a categorical scales were used. To categorize buffer width I converted the continuous widths into 4 categories (similar to Ring et al. 2017); that is 'no' buffer (0-0.1 meter), 'thin' buffer (0.1-5 meter), 'moderate' buffer (5-15 meter), and 'thick' buffer (>15 meter). When used as a continuous variable, average of the six measurements (section A-F, Fig. 2, Table 1) at each site was used.

Before statistical analyses, I assessed whether the data fulfill the assumptions necessary for statistical tests. Data on buffer widths, catchment areas, clear cut size, tree type (coniferous/deciduous) composition of mature trees and saplings were not normally distributed (Shapiro-Wilk test: $p < 0.05$), however any transformation (logarithmic, square-root, arcsine square-root) did not help the distribution. All other variables were normally distributed. All statistical analyses were made in RStudio (Rstudio team 2016), and packages *lme4* (Bates et al. 2015), *lmerTest* (Kuznetsova et al. 2017) and *lsmeans* (Lenth 2016) were chosen to overcome the problem of non-normal data and spatial grouping of sites (see below).

Riparian buffer widths and factors affecting it

First, Wilcoxon rank sum test was used to test whether there were general differences in buffer width between north and south. Further, because of the spatial non-independence of sites situated in the north and south, I chose to use linear mixed effect models (LMMs, Baayen et al. 2008) for testing whether size of the clear cut, and size of the stream affected the buffer width. In these models, buffer width was set as response variable, stream size and clear-cut size was set as a fixed factor, respectively. Location (south vs. north) was kept as a random factor.

Tree type composition of canopy and sub-canopy

When testing for potential differences in tree type composition for both mature trees and saplings within different buffer classes, separate models were constructed for northern and southern Sweden because of the observed difference in tree composition and buffer widths between the two locations during the field surveys.

To test for potential differences in composition of type (coniferous/deciduous) of mature trees in different buffer classes, LMMs were used. In these models, percent of mature trees of each type was set as a response variable and interaction between buffer class and type of tree (coniferous vs. deciduous) was set as a fixed factor. Site (because multiple counts were performed within each site in different sections, see Table 2) was kept as random factor. Buffer class 'No' was excluded from this analysis because no mature trees were present in 0-0.1 meter wide buffers.

To understand how the composition of tree types (coniferous/deciduous) changed between intact and partially harvested buffers, and to assess which type of trees that was harvested from the buffers (if partially harvested), I tested for differences in tree type (coniferous/deciduous) composition of mature trees in different buffer classes in respect to whether buffer was intact buffer zones or partially harvested (LMMs). Percent of mature trees was set as response variable while buffer class interacting with type of tree were kept as fixed explanatory variables. This analyses assumed that the composition of the buffers before harvesting was similar along all investigated streams (separately for north and south) which is a reasonable assumption given the large scale forestry practices (Ring et al. 2017b) and the size of the streams being small thus not having differently developed floodplains. Site was set as random factor and modelling was done separately for north/south and intact/partially harvested sites (Table 2).

I analyzed differences in composition (coniferous/deciduous) of saplings in the same way as mature trees except that buffer class 'No' was included because 0-0.1 m wide buffers still contained saplings. Further, I did not separate between partially harvested and intact buffers for the analyses of saplings.

Other structural components

When testing for relationship between buffer width and shading of stream, LMMs were used. In this model, shading (average of the three segments measured at each site, Table 1) was set as a response variable and buffer zone width (continuous) as a fixed factor. Location (south/north) was set as a random factor. Moreover, linkages between number of deadwood and buffer width was tested with general mixed effect models (GLMMs) with Poisson error distribution (because dead wood data were counts). For each site, I added the number of deadwoods of all three stream segments measured (Fig. 2, Table 1). The shading and deadwood analyses were made for all sites combined, with location within Sweden being a random factor, not fixed one. This is because I did not expect that how are trees shading and providing dead wood is dependent on the location within Sweden, rather being a function of the buffer width.

Table 2. Number of observations (n) of each variable divided by north/south and buffer class, if applicable. In total 66 streams in the north and 53 streams in the south was surveyed. In statistical modelling of the differences in tree type (coniferous/deciduous) composition of mature trees/saplings in different buffers classes, every site had six observations (n), one for each of the sections along the stream (Fig. 2). Given the differing number of streams within each buffer class (see Fig. 1) the number of observations for each variable tested in the statistical model also differ.

Variable	**Buffer class**	**North (*n*)**	**South (*n*)**
Clear-cut size	-	66	52
Catchment area	-	66	53
Mature trees	'Thin' 'Moderate' 'Thick'	133 100 45	131 39 7
Intact buffer	'Thin' 'Moderate' 'Thick'	31 56 24	25 11 3
Partially harvested buffer	'Thin' 'Moderate' 'Thick'	102 44 21	106 28 4
Saplings	'No' 'Thin' 'Moderate' 'Thick'	84 154 100 45	110 152 38 7
Shading	-	66	53
Deadwood	-	66	53
Impairment index	-	66	51
PCA	'No' 'Thin' 'Moderate' 'Thick'	8 29 24 5	5 38 7 1

Impairments

When investigating relationship between different impairments (machine tracks, blow down trees, stream crossings, erosion, algae blooms and siltation) and buffer width, scores (from 'no' marks [0] to 'serious' marks [3], see Table 1) for all the six impairments were summed together, creating an impairment index value (I.I.) for each site. To understand if impairments are more likely to occur when the buffer width decreases, I created a linear regression model between the I.I. and buffer width. Additionally, I also wanted to know if different impairments had a dependent relationship to each other (irrespective of buffer width), that is if they were more likely to occur together at individual sites. To address this, I chose to perform a principal component analysis (PCA) with the scores of all six impairments. PCA is an ordination type analysis that project surveyed sites into an ordination space and place sites that have similar conditions spatially closer in the ordination space. To visualize the relation between impairments and how they correlate with the ordination axis, vectors for individual impairments were plotted onto the ordination space.

Results

Riparian buffer widths and factors affecting it

Mean buffer width around all streams sampled (n = 119) was 4.09 meter. 13 streams (11 % of the observations) had 'no' buffer zone (0-0.1 meter), 69 streams (58% of the observations) had a 'thin' buffer zone (0.1-5 meter), 31 streams (26 % of the observations) had a 'moderate' buffer zone (5-15 meter) and 6 streams (5 % of the observations) had a 'thick' buffer zone (>15 meter) (Fig. 1 & 3). Mean buffer width in the north was 5.46 meters, and in the south 2.39 meters and this difference was statistically significant ($p < 0.001$, Fig. 4A).

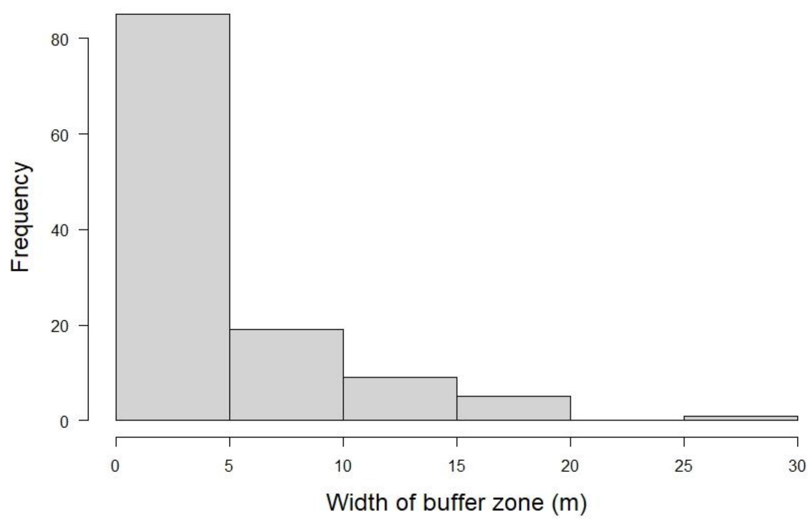


Fig 3. Histogram showing frequency of riparian buffer widths retained around small streams on clear-cuts in Sweden (north and south of Sweden combined).

Investigated streams had catchment areas ranging between 0.004 km^2 and 12 km^2, mean catchment area was 1.04 km^2. The size of clear-cuts with sampled streams flowing through it ranged between 0.0077 km^2 and 1.13 km^2. Mean area of clear-cut in the north was 0.222 km^2, and in the south 0.087 km^2 and this difference was statistically significant ($p < 0.001$, Fig. 4B).

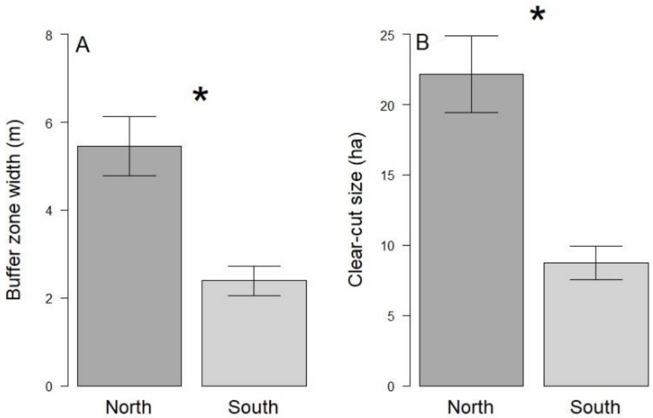


Fig 4. A) Mean (± 1 SE) width of riparian buffer zone around small streams flowing through clear-cuts. B) Mean (± 1 SE) size of clear-cut with sampled small streams flowing through them. Results showed separately for northern (dark grey) and southern (light grey) Sweden. The differences between south and north were statistically significant (indicated by the asterix above the bars).

There was no trend visible in the data regarding the relationship between width of the buffer zone and stream size measured by the catchment area (p=0.24, Fig. 5, left panel). Similarly, no significant relationship between width of riparian buffer zones and size of clear-cuts could be detected (p=0.20), although, a slight increasing trend could be seen for southern sites (Fig. 5, right panel).

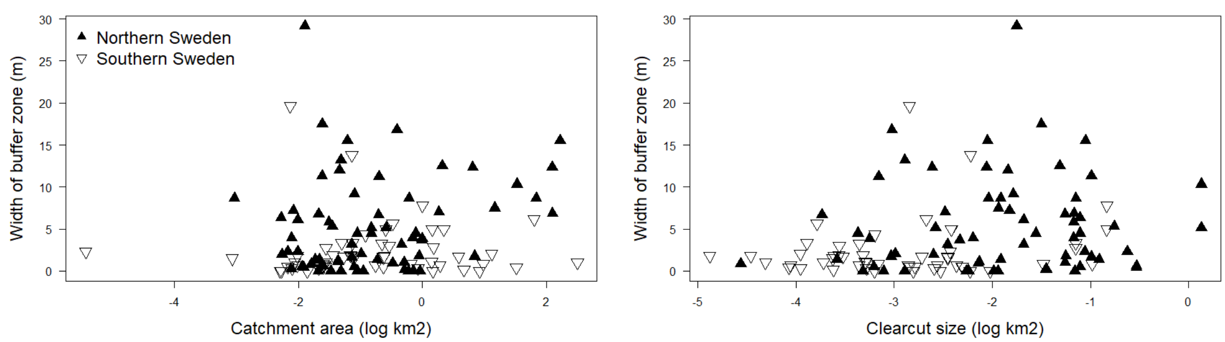


Fig 5. Scatterplot showing relationship between width of riparian buffer zone around small streams and catchment area of stream (i.e., stream size, left panel) and clear cut size (right panel), respectively. Explanatory variables are log transformed for better visibility. Data points are showed separately for northern (black) and southern (white) sites.

Tree type composition of canopy and sub-canopy

Composition of canopy

In northern sites, 'moderate' buffers and 'thick' buffers showed a significantly higher proportion of coniferous than deciduous trees ('moderate': estimate= 28.41, p<0.001, 'thick': estimate=36.72, p<0.001). In 'thin' buffers no statistically significant difference between the proportion of mature coniferous and deciduous trees could be detected (Fig. 6, left panel). No significant differences in proportion of coniferous or deciduous mature trees could be detected with an increase of buffer width, although a slight increasing trend can be seen in the proportion of coniferous trees. In contrast, the proportion of deciduous trees had a tendency, albeit not significant, to be lower with increasing buffer width (Fig 6, left panel).

In southern sites the patterns observed were somewhat different compared to the northern sites. In 'thick' buffers there was a significantly higher proportion of deciduous than coniferous trees (estimate=55.29, p=0.04), however it has to be remembered that I only recorded 1 stream with 'thick' buffer in the south. No significant difference could be seen between coniferous and deciduous trees in 'thin' and 'moderate' buffers. Further, no statistically significant changes in the proportion of mature coniferous and deciduous trees were detected with increasing buffer width (Fig. 6, right panel).

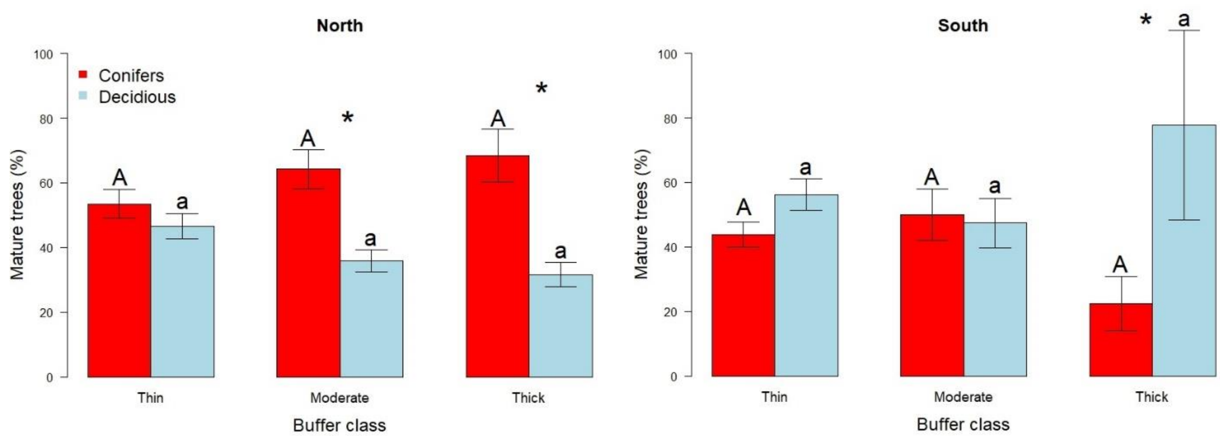


Fig 6. Mean (± 1 SE) percentage of mature trees per tree type (coniferous vs. deciduous) and buffer class, and shown separately for the sites in northern and southern Sweden. Differences (contrasts) were tested among buffer classes for the two types of trees separately (indicated but the different letters) but not among buffer classes for different type of trees (i.e., *A* and *a* do not indicate statistical significance). The statistical differences within each buffer class between the types of trees are indicated by the asterix.

Composition of canopy in intact and partially harvested buffers

When I split the data set into buffers that had been partially logged and buffers that had not, to assess how the canopy composition is affected by partial harvest, the results changed. Within intact buffers in northern sites, I found significantly higher proportion of coniferous trees in the 'thick' buffers compared to 'thin' (estimate= 25.10, p=0.002) and 'moderate' (estimate=18.28, p=0.024) buffers, while 'moderate' and 'thin' buffers didn't differ in respect to proportion of coniferous trees (Fig. 7B). Correspondingly the proportion of deciduous trees was significantly lower in 'thick' buffers compared to 'thin' (estimate=25.10, p=0.002) and 'moderate' (estimate=18.28, p=0.024) ones. Further, in northern intact buffers the proportion of coniferous trees was significantly higher than the proportion of deciduous trees in all buffer classes (Fig. 7A). In partially harvested buffers no such trend was detected either for coniferous or for deciduous trees nor between the two types of trees within buffer classes.

In southern sites, neither in intact nor partially harvested buffers any significant differences in coniferous or deciduous trees among the three buffer classes were detected. As opposed to partially harvested buffers, where no differences in the proportion of coniferous vs. deciduous trees within the individual buffer classes was detected (Fig. 7D), intact buffers had a significantly higher proportion of deciduous trees than coniferous trees in all three buffer classes (Fig. 7C).

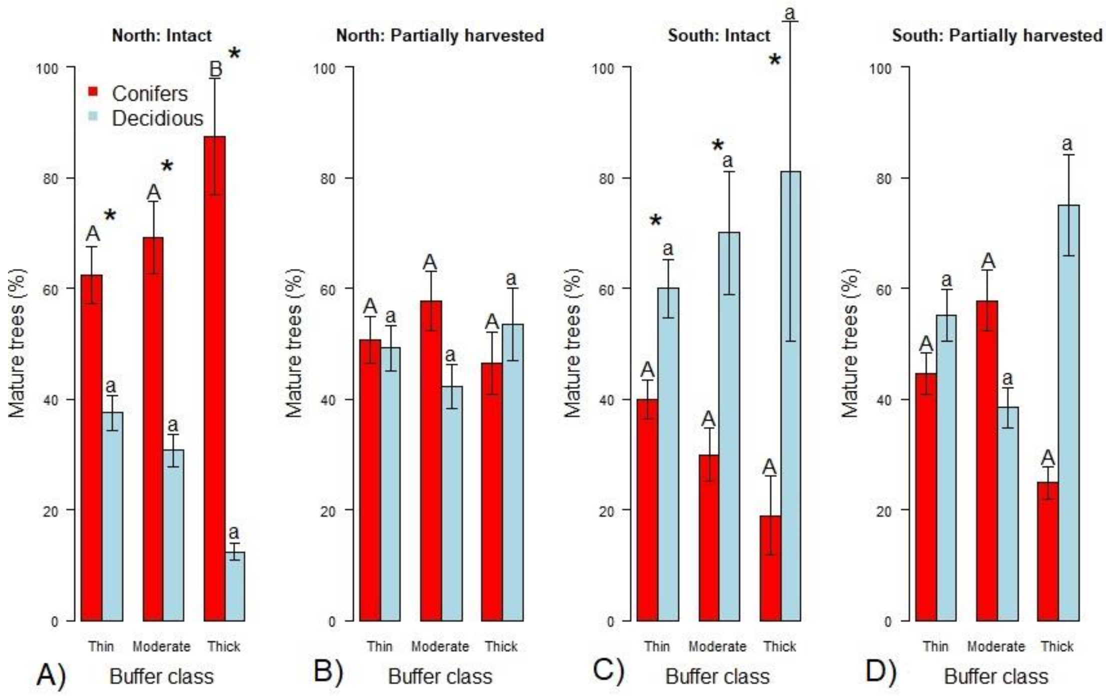


Fig 7. Mean (± 1 SE) percentage of mature trees in intact and partially harvested buffers. Percentages of trees are presented per type (coniferous and deciduous) for each buffer class and shown separately for northern and southern Sweden. Differences were tested among buffer classes for the two types of trees separately (indicated but the different letters) but not among buffer classes for different type of trees (i.e., *A* and *a* do not indicate statistical significance). The statistical differences within each buffer class between the types of trees are indicated by the asterix.

Composition of sub-canopy

In northern sites, ‘no’ buffer had significantly lower proportion of coniferous saplings than ‘thin’ buffers (estimate=12.16, p=0.048) and ‘thick’ buffers (estimate=22.37, p<0.001), whilst no significant difference in coniferous saplings could be detected between buffer classes ‘no’ and ‘moderate’. Correspondingly, the proportion of deciduous saplings significantly increased from ‘no’ buffers to ‘thick’ buffers (estimate =17.07, p =0.016) while no significant difference in proportion of deciduous saplings could be detected between the other classes (Fig. 8, left panel). All buffer classes, except ‘thick’, had significantly higher proportion of deciduous than coniferous saplings.

In southern sites, there was no detectable statistical difference in the proportions of coniferous or deciduous saplings across the buffer classes. All buffer classes had, however significantly higher proportion of deciduous than coniferous saplings, which was same result as for northern Sweden (Fig. 8, right panel).

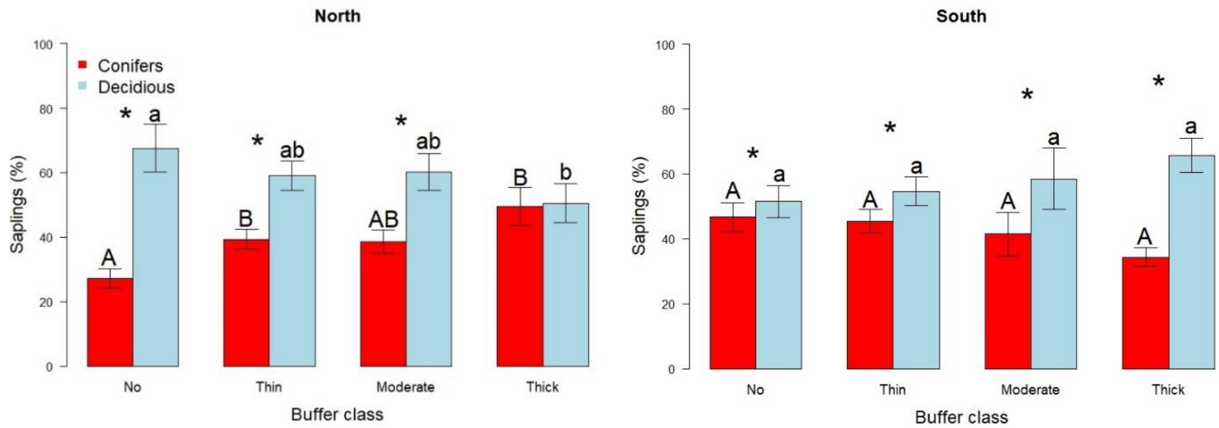


Fig 8. Mean (± 1 SE) percentage of saplings divided per type (coniferous vs. deciduous) and each buffer class and shown separately for northern and southern Sweden. Differences were tested among buffer classes for the two types of saplings separately (indicated but the different letters) but not among buffer classes for different type of saplings (i.e., *A* and *a* do not indicate statistical significance). The statistical differences within each buffer class between the types of saplings (coniferous vs. deciduous) are indicated by the asterix.

Other structural components

A significant positive relationship between buffer zone width and shading of stream was found (estimate=11.38, p=< 0.001, Fig. 11 left panel). Similarly, I found a significant positive relationship between buffer zone width and number of deadwood in the stream (estimate=0.15, P< 0.001, Fig. 11 right panel) although this trend was weaker than the one for shading (lower r^2).

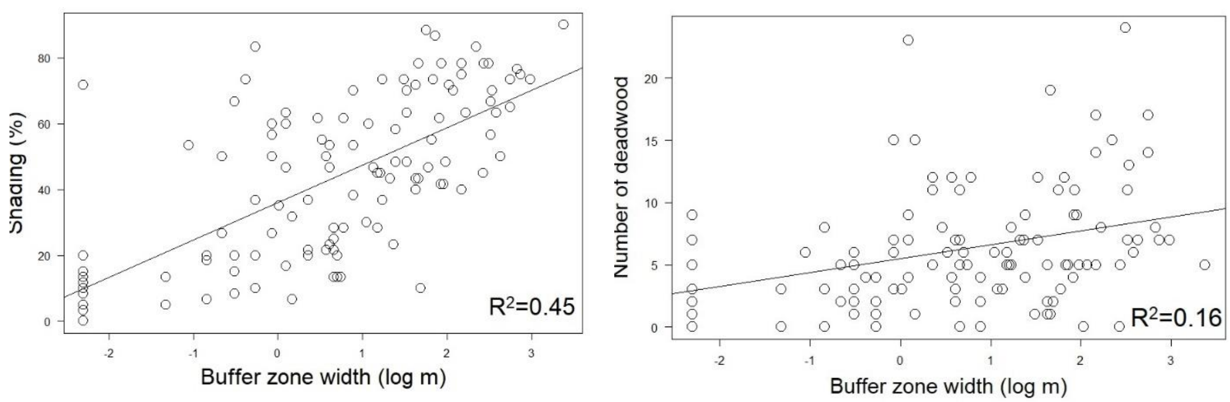


Fig 11. Scatterplots showing relationship between widths of buffer zone and shading of stream (left panel), and number of deadwood in stream (right panel). Buffer width is log transformed on the x axes for better visibility.

Impairments

The Impairment Index (I.I.) was created by summing up the scores for the six individual impairments measured at each site (machine tracks, blown down trees, stream crossings, erosion, algae, and siltation). With increasing buffer width, a statistically significant decrease of I.I. was detected (estimate = -0.08, $p < 0.01$), although, the fit of the model was poor (Fig. 12). This was mostly because of the numerous zero scores for three of the variables included in the I.I. (algae bloom, siltation and erosion).

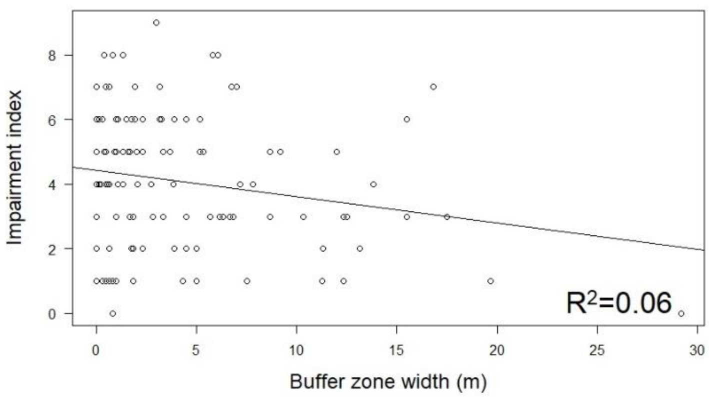


Fig 12. Scatterplot showing relationship between impairment index (combined scores for machine tracks, blow down trees, stream crossings, erosion, algae blooms and siltation) and buffer width. Sites with higher impairment index has a higher amount of impairments.

In the PCA of the six impairment categories, the first two components explained 79 %. First axis explained about 53 % of the total variance and was strongly positively correlated with stream crossings (r= 0.96) and positively correlated (r= 0.23) with machine tracks (Fig. 13). The second axis, explained 26 % of the total variance and was strongly positively correlated (r = 0.97) with blow down trees and positively correlated (r =0.2) with machine tracks (Fig. 13). Algae bloom, siltation and erosion had low correlations (r <0.15) with both axis one and two, likely due to the large number of zeros in the data. The PCA ordination plots shows that the sites which were imparied by stream crossings and machine tracks were not likely the same ones which were impaired by blown down trees (Fig. 13).

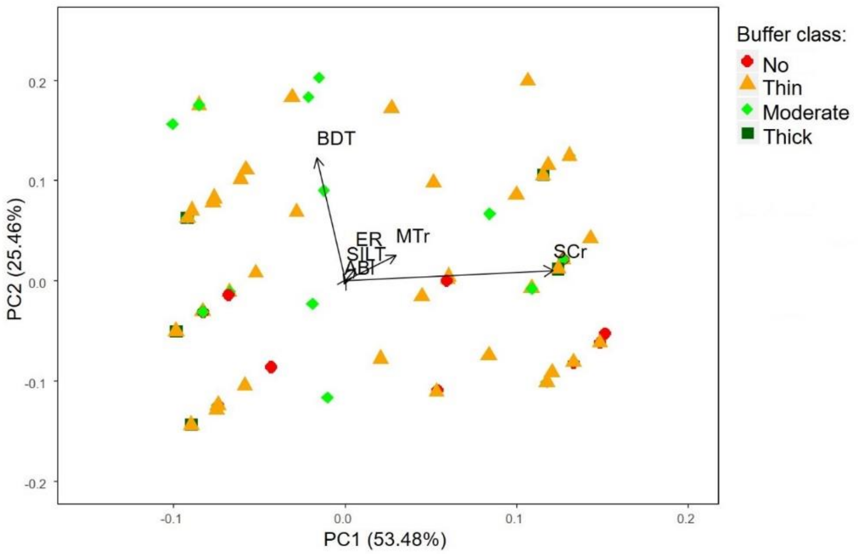


Fig 13. Results of PCA-analysis for the six impairments within riparian buffer zones. Diagram displays vectors for the individual impairments (BDT=Blow down trees, Mtr=Machine tracks, SCr=Stream crossings, ER=Erosion, SILT=Siltation, ABl=Algae blooms) and how they scale with the PC axis. For better visualization I color coded sites based on their buffer width classification.

Discussion

To keep buffer zones around streams is one of the most effective way of protecting stream integrity and mitigating negative effects on water quality done by forestry operations (Lee et al. 2004; Gundersen et al. 2010; Richardsson et al. 2012). Today, recommendations and guidelines from the Swedish forestry agency are rigorous and provide a large amount of general as well as very specific information on how buffers should be designed to be functional (Skogsstyrelsen 2015; Anon, 2014). In this case study, I intended to assess what is the reality of buffer implementation along small headwater stream in contemporary forestry. I used a specifically designed Rapid Assessment Protocol (RAS) to achieve such evaluation.

Riparian buffer widths and factors affecting it

Regardless of recommended guidelines (Anon 2014; Skogsstyrelsen 2015; Skogsstyrelsen 2017) 11 % of streams surveyed had no mature trees left as buffer and most buffers (58%) were < 5 meter wide. On the other hand, I also found buffers of about 30 meters width, which was far above the mean buffer width of 4.09 meters and generally above the recommended standards for small streams (e.g., Kuglerová at al. 2017; Ring et al. 2017a). According to the recommendation from the Swedish forestry agency, buffer zones "…are expected to provide stable shade over time, contribute with food and deadwood to water and act as a filter for sediment transport". Several previous studies suggest that buffer zones <5 m wide are not sufficient in obtaining all functions required (Castelle et al. 1994; Hickey and Doran 2004; Sweeney and Newbold 2004) On the other hand, latest research from Canada suggests that buffers could be thin or completely missing if the management goal is to emulate natural disturbances (END), such as fire or wind throw (Kreutzweisser et al. 2012; Musetta-Lambert et al. 2017). Similarly, some researchers are suggesting that variable buffer widths, based on hydrological conditions of riparian soils, can create thin buffers at some locations while keeping thick buffers on others (Kuglerová et al. 2014; Laudon et al. 2016; Kuglerová et al. 2017; Laudon and Sponseller 2017). These locally adapted buffers that consider soil characteristics in respect to hydrology has proven to be a more cost-effective alternative compared to fixed-width buffers (Tiwari et al. 2016). More research is however needed to understand how such novel buffers achieve the goals of protecting stream integrity and water quality on local as well as integrated catchment scale. The project SOSTPRO, which this thesis is part of, aims to fill exactly these knowledge gaps.

Size of the riparian buffers was significantly larger in the northern sites which indicates that location could be one factor deciding how riparian buffers are being established (Ring et al. 2017b). In the south, all clear-cuts surveyed was owned by the same forest company while northern sites was owned by three different forest companies, and this might have influenced the south and north differences. The differences in population densities and proportion of forest land between southern and northern Sweden, where southern Sweden has considerably higher population density and lower proportion of forest land than northern Sweden (Statistiska centralbyrån 2014) together with differences in land-use history (Östlund et al. 1997) can be part of the explanation why southern buffers are significantly thinner than northern buffers. Further, streams surveyed in southern Sweden were situated on significantly smaller clear-cuts than in northern Sweden. Management scale, i.e. size of forest compartments, used for planning forestry operations might also have influenced the difference in buffer widths between south and north (Pohjanmies et al. 2017). I saw, at least for southern Swedish sites, that buffer width had a tendency to increase in larger clear-cuts (albeit not significant). On the other hand, size of clear-cuts did not have any significant influence on buffer width in the spatial content of this study. This result suggests that size of the clear-cut is not a factor that plays a part when deciding on buffer design. Which factors, environmental but also social and economic, that are actually driving how forest management is carried out around streams are not well documented here or in other publications (but see González et al. 2017; or Lovell and Sullivan 2006 for agricultural buffers). Further investigation regarding this could be helpful on the way to improve forest management procedures. Finally, a possible source of error in the south-north analysis is that two different field technicians performed the inventories in southern and northern parts of Sweden which could create a subjective bias. Many of the relationships which are behind the observed differences between south and north are not uncovered in this thesis and will require further investigation.

The general picture today is that larger streams and rivers receive most protection in the form of forested buffer zones while small streams are being neglected (Kuglerová et al. 2017). Suggested reasons for this is that larger streams yield fish (Swanson and Franklin 1992), they are visible on maps used in forest management practices (Bishop et al. 2008), are easier to spot in the landscape when performing forestry operations, and they are fewer in numbers (Downing et al. 2012). Considering this, it is surprising that in this study I did not find support that size of the stream would matter when deciding the width of the buffer zone. My results show that stream size had no effect on buffer width. However, all streams included in this study are considered small and most of them could be lacking from standard resolution topographic maps (Ågren et al. 2015). The results might have been different if larger streams, with catchments areas up to 20 km^2, were included.

Tree type composition of canopy and sub-canopy

Composition of canopy

Canopy composition and structure of created riparian buffer zones has proven to be of importance for their functionality (Bilby and Heffner, 2016; Dewalle, 2010; Hoover et al., 2011). Swedish guidelines suggest that when creating buffers, one aim is to produce un-even aged and multilayered buffers that has a species composition that is suitable for the site. At the same time, it is suggested that both deciduous and coniferous species should be left standing (Anon. 2014). To explore how this goal is followed, information on what composition of trees that was there pre-harvest has to be accounted for. In this study, no such data were available. Instead, I accounted for study by Ring et al. (2017b) that investigated the composition of intact riparian forests around small streams as an example on what are riparian forests in Sweden composed of. The results of this present study indicate that in the northern sites, there is a higher proportion of mature conifers and a lower proportion of deciduous mature trees with increasing buffer width. This is a similar pattern in canopy composition to what Ring et al. (2017b) found in Sweden and were also found in other regions (Pabst and Spies 1999; Harper and Macdonald 2001). Ring et al. (2017b) found that with increasing distance from streams a higher proportion of conifers and a lower proportion of deciduous trees was found. This suggest that the canopy composition of the northern sites buffers is similar to the composition of pre-harvest operations. Thus, it seems that the buffers which are left on the site are not being particularly designed according the goal of creating 'multilayered and un-even aged forests'. Instead, they are delineated only considering its width. In southern sites no change in proportion between mature conifers and mature deciduous trees between 'thin' buffers and 'moderate' buffers although 'thick' buffers had a significantly higher proportion of deciduous trees than conifers. This is in contrast to what was found in Ring et al. (2017b). They documented that riparian forests consisted of a higher proportion of conifer than deciduous trees also in southern Sweden, similar to northern Sweden. Our results combined with these of Ring et al. (2017b) implies that deciduous trees are being favored to be left when designing buffers in the south of Sweden. This in turn indicated that forestry practitioners favor logging of coniferous species, clearly due to the value of their timber (Anon. 2016). One thing which have to be kept in mind is that we had only limited number of observations in the 'thick' buffer category in the south of Sweden (n= 7).

Composition of canopy in intact and partially harvested buffers

I tried to answer the question about what type of trees are preferred when harvesting within riparian buffers by assessing the differences between partially harvested and intact (no harvest) buffers. I found that in northern sites, intact buffers had an increase in proportion of conifers between 'moderate' and 'thick' buffers, while the proportion of deciduous trees decreased. This is a similar trend in canopy composition to what Ring et al. (2017b) found in unharvested riparian forests along a lateral gradient from streams. I found that partially harvested buffer zones had no such change in canopy composition with increasing buffer width. This result indicates that when partial harvest within buffers are performed in northern Sweden, deciduous trees are being left to a higher extent then conifers. This is in line with recommendations set by the Swedish forest agency which state that all deciduous trees within 10 meter from streams should be left in stands dominated by conifers and that partial harvest is an allowed strategy. A trend observed in the results (although not statistically tested for), indicated a somewhat higher proportion of deciduous trees in the partially harvested than intact buffers. This is interesting and could be an indication that buffers consisting of more deciduous trees pre-harvest, for example wetter areas that host more deciduous trees and in general consist of less commercial valuable trees, are more likely to be partially harvested than buffers with more coniferous trees.

In southern sites, intact buffers had a higher proportion of deciduous trees than conifers in all buffer classes whilst partially harvested buffers had no detectable difference between conifers and deciduous trees in any of the buffer classes. Therefore it seems that when partial harvest is being performed within buffers in south of Sweden conifers are being left to a higher extent then deciduous trees. Yet again, the low number of observations in buffer category ‘thick’ (intact: n=3, partially harvested: n=4) and ‘moderate’ (intact: n=11, partially harvested: n=28) in both intact and partially harvested buffers makes the result less general.

Composition of sub-canopy

In northern Sweden, sites in category ‘no’ buffer had significantly lower proportion of conifer saplings and higher proportion of deciduous saplings than ‘thick’ buffers. One reason for this could be the difference in light conditions and level of disturbance between sites with ‘no’ buffers and sites with ’thick’ buffers. Increased solar input and disturbance (e.g. no buffers) are promoting regeneration of early successional and shade-intolerant species such as deciduous trees while less solar input and disturbance (e.g. thick buffers) are endorsing regeneration of shade-tolerant species for example conifers (Palik et al. 2012; Mallik et al. 2014). In southern sites, all buffer classes had a significantly higher proportion of deciduous saplings than coniferous. No difference in composition of saplings could be detected between different buffer classes. Due to the low number of observations in the ‘thick’ buffer category (n=7), results regarding these are less reliable. It is likely that with increased number of sites sampled with ‘thick’ buffers similar pattern to northern Sweden might have been detectable. Regardless, the composition of sub-canopy in southern Sweden corresponded well with the composition of canopy in intact buffers and is probably a result of seed source.

Since the majority of Sweden’s forests have been exposed to forestry operations it is clear that humans play a crucial role in determining the composition of future riparian forests (Östlund et al. 1997). Several studies have concluded that the complexity in structure and composition of riparian forest follows a spatial lateral gradient from the stream edge into the uplands (Pabst and Spies 1999; Harper and Macdonald 2001; Ring et al. 2017b). When designing and delineating the zone appropriate for protection to achieve desired functions, it is clear that this gradient and characteristics of the natural riparian forests need to be considered in all forest operations carried out around streams.

Other structural components

This study shows a significant positive relationship between buffer zone width and shading of stream. To provide stable shade of the stream over time is one of the functions that should be achieved according to the recommendations of the Swedish forest agency (Anon 2014). Shading is an important aspect of riparian canopies because it prevents increased light levels as well as warming up the stream water. Headwater streams are especially sensitive to these changes because their canopies are usually fully closed, due to their small widths (Richardson and Danehy 2007). Several streams surveyed in this study had no trees left as buffer or buffers < 5m wide. According to several previous studies this is not enough shading to ensure stream temperature not to rise (Gomi et al. 2006; Wilkerson et al. 2006; Sweeney and Newbold, 2014).

When stream temperature rises and more light is available, this can be detrimental for some cold-water and shade adapted species (Warren et al. 2016). At the same time, I found that riparian forests along small streams in boreal Sweden had higher proportion of commercial coniferous tree species (spruce and pine), at least in the north. These types of trees have a large shading potential and provide low-quality resource subsidy for stream organisms. Opening of canopy can promote regeneration of deciduous trees, as I showed with the sapling data. The deciduous tree species generally provide subsidies of higher quality for aquatic consumers (Lidman et al. 2017). Further, some increment of light penetration through the closed canopy above small streams can support organisms with higher light level demand yet will not eliminate shade-adapted species either (Mallik et al. 2013). Thus, the riparian forests can benefit from some level of intervention and locally 5 m width may be sufficient. However, assessment of how much of the total stream length can be exposed to increased solar input has to be done to prevent the risk of increased water temperatures.

Further, recommendations also state that riparian buffers should be designed to contribute with deadwood to stream (Anon. 2014). In this study a significant positive relationship was found between the amount of deadwood in streams and buffer width. In contrast to leaves that can blow over distances and get trapped in streams, deadwood which falls directly into the streams is delivered primarily by the closest trees (Harper and Macdonald 2001; Bilby and Heffner 2016). Deadwood is important due to its role in contributing with dissolved organic carbon to streams and thereby play a vital role in support of stream food webs (Richardson and Danehy 2007), affecting width of the channel and creating dams and pools which provide habitat for fish and other aquatic organisms (Bilby and Bisson 2001). To leave mature trees directly adjacent to streams is therefore important to ensure deadwood contribution and clearly this function is provided more when buffers are wider.

Impairments

Results of this study showed a negative relationship between magnitude of combined impairments and width of riparian buffers. This relationship was not very strong (r^2=0.06) due to the nature of the data (i.e., scores) yet it did indicate that creating a wider buffer zone can reduce the amount of direct (machine tracks, stream crossing) and indirect (blow down trees, algae growth, sedimentation and erosion) impairments caused by cutting operations. One reason why linkage between magnitude of impairments and buffer width is weak might be that width of the buffer is not the only factor determining how effective buffers turns out to be in minimizing negative forestry effects. Recent studies have shown that to prevent impairments caused by forestry, especially the ones related to soil damages, factors such as soil wetness, topography and surface and subsurface water flow paths also has to be considered when planning and executing operations (Kuglerová et al. 2014; Ågren et al. 2014; Laudon et al. 2016). One interesting finding in this thesis is that the PCA-analysis showed that sites which were impaired by stream crossings and machine tracks (i.e., driving damages) are less likely to have many blow down trees. A possible explanation for this could be that for a site to have blown down trees it is required that trees were left as a buffer to start with, and this might in turn have made these sites less likely to have damages made by driving in originally left buffers. No conclusion regarding dependence between sites which were impaired by erosion, siltation or algae blooms can be done in this thesis since I had very low scores for these measurements. Nevertheless these effects are usually connected to forest harvest (Castelle et al. 1994; Sweeney and Newbold 2014) and will be addressed in the SOSTPRO project further.

Conclusion

This work has shown that there is an inconsistency on how riparian buffer zones are implemented around headwaters in Sweden today. The majority (69 %) of all streams surveyed had a buffer width < 5 m, which is argued by many to be insufficient to achieve all desired functions presented by the Swedish forestry agency. However, it is not only the width of the buffer that explains how functional it is. Up-to-date research implies that several other factors such as ground water flow paths and characteristics of natural disturbances should be taken into consideration when planning and performing forestry operations around streams. Including these aspects into planning and execution of all forestry operations around streams can help to mitigate other forestry effects, such as soil damages caused by rutting and stream crossings. I also found that the composition of riparian buffers is affected by partial harvesting and differs between different widths of created buffers. Knowledge on what trees are being left to form the riparian buffer zones is important to evaluate if desired functions of buffer zones are fulfilled and therefor one of the emphases of the present study. To be able to fully assess the local effects of forestry on small streams and the cumulative impacts on downstream reaches more field-based research on treatment effects needs to be performed and evaluated. Only after that the research can provide the best decision support system tools which the forest practitioners can utilize during planning and forestry operations.

Acknowledgements

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Litterature

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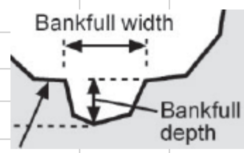
Appendix 1. Rapid Assessment Survey protocol

PROTOCOL				
Site name or code:				notes
Date				
Name of surveyor				
Catchment area				estimated from map later
Length (m) of the stream within harvest				estimated from map later
Coordinates lower				
Picture numbers (at least 5 pohotgraphs				
	Yes	No (why not?)		
Surveys performed on 50 m stream length				

STREAM SURVEY

Channel description	YES	NO		
Stream straight (% of reach)				
Stream meandering (% of reach)				
Stream breided				
Lake outlet				
Mire outlet				
	10 m mark	30m mark	50 m mark	
Stream bankful width in meters (estimated at three marks)				
Stream bankful depth (measured at three marks				
Type of flow (as % of the section up to the mark)				
Riffle				
Rapid flow				
Slow flow				
No flow				stadning water
No water				
Bottom quality (as % of the section up to the mark)				
Fine sediment (including organic)				
Sand				
Gravel + pebbles				
Rocks + boulders				
Dead wood (# of pieces estimated in each sections)				1 piece > 1 m and 10 cm diameter
Macrophytes abundayce (% of the reach - bryophytes and plants)				



RIPARIAN SURVEY	10 m mark		30m mark		50 m mark	
give separate descrition for left and right bansk (looking upstream) if applicable	Left bank	Right bank	Left bank	Right bank	Left bank	Right bank
Buffer width in m (estimated as average within each section)						
Shading (estimated as % of the steam shaded in each section)						
Mature trees species composition (# estimated in each 10 m section)						
Coniferous						
Decidious						
Dominant species (name if you can)						
Saplings species composition (# estimated in each 10 m section)						
Coniferous						
Decidious						
Dominant species (name if you can)						
Understory composition (presence estimated in each section) YES x NO						
Bryophytes						
Grasses and sedges						
Hebs						
	YES (how many)		NO			
Discharge areas or seeps within 30 m from the stream				discharge areas characterized by observed standing or running water in the riparian zone or as a small wetland		

IMPAIRMENTS	YES	NO		
Discharge areas or seeps harvested ?				
Discharge areas or seeps driven trhough?				
Forest drain ditches entering the streams?				
Soil preparation (scarrification or trenching) within 30 m from stream?				
Partial harvest within riparian buffers?				
Impairments estimated in the entire 50 m section	Serious	Medium	Low	No marks
Machine tracks (serious - numerous tracks within 30 m from the stream or a few tracks very deep; medium - a few tracks, not too deep; low - one or two shallow tracks)				
Increased siltation (serious - sediment deposition observed on > 50% of the sestion length, medium 20-50 % of the section legth, low < 20 % length)				
Stream crossing (serious - stream crossing present withough a bridge, medium - stream crossing with temporal bridge, low - stream crossing with permanent bridge or culvert)				
Blown down trees (serious - many, medium - a few, low - 1-2 trees blown down)				
Increased errosion(serious - errosion marks observed on > 50% of the sestion length, medium 20-50 % of the section legth, low < 20 % length)				
Alga blooms (serious - blooms observed on > 50% of the sestion length, medium 20-50 % of the section legth, low < 20 % length				

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