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Riparian buffer management through time in the Krycklan catchment

– has the composition in riparian zones been affected by previous management since 1963?

Kantzonsskötsel sett över tid i Krycklans avrinningsområde
- har sammansättningen i kantzoner påverkats av tidigare skogsskötsel sedan 1963?

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ABSTRACT

Ecosystem services and many conflicting interests make management of small streams in the forest an important topic. Streams need to be protected in a way that maintains water quality, quantity and riparian characteristics. In 2013 the Swedish Forest Agency presented new Strategic Management Objectives (SMOs or "målbilder"), that included directives for protecting streams in the forest by better management of riparian zones and creation of buffers. The aim of this study was to determine how past forest management has affected riparian zones. The data was collected within the Krycklan Catchment Study area in Vindeln, Västerbotten County, Sweden in autumn of 2019. Characteristics of the riparian zones, such as species richness of woody plants and the presence of stumps, were inventoried and have been analysed both over time and at different distances from the stream. Additionally, a subjective visual analysis of aerial photos (from 1963 to 2013) and a measure of the buffer width left after a harvest were made. The results showed a connection between both species richness of all woody plants and deciduous species related to distance from stream and age class. Presence of stumps for deciduous trees decreased over time. There were also differences in riparian buffer width over time. It was difficult to see a correlation between past forest management and the components inventoried in riparian zones. The changes in the Forestry Act in 1993 could have had some effect on the protection of streams. The SMOs from 2013 have not yet had an effect on riparian zones.

Keywords: Riparian zone, riparian buffer, forest management, silviculture, water protection, stream protection, aquatic ecosystEMS

SAMMANFATTNING

Ekosystemtjänster och många intressenter gör skydd av små vattendrag i skogen till en viktig fråga. Vattendragen måste skyddas och skötas så kvaliteten och kvantiteten inte sjunker. Politik och lagar har reglerat hur skogsbruk ska bedrivas och 2013 kom nya målbilder vilket kunde utveckla skydd för vattendrag ytterligare. Målet med detta kandidatarbete var att se hur den historiska skogsskötseln har påverkat och utvecklat kantzoner över tid. Denna infallsvinkel är intressant för framtida skötsel och skydd av dels vattendrag men också av skogens- och vattnets ekosystem. Datat som är använt kommer från Krycklans avrinningsområde, Vindeln, Västerbottens län, Sverige och är insamlat hösten 2019. Olika komponenter i kantzonen som till exempel artrikedom och förekomst av stubbar har inventerats och analyserats. För att komplettera analysen har subjektiva analyser gjorts av flygfoton (från 1963 till 2013) och bredden på lämnade kantzoner efter avverkning har mätts. Resultatet visade att det fanns ett samband mellan de olika inventerade komponenterna och åldersklass respektive avstånd från vattendraget. Det syntes skillnad i bredd på kantzoner som var lämnade innan och efter 1993. Det var svårt att se en korrelation mellan tidigare skogsskötsel och de inventerade komponenterna i kantzoner. Ändringarna i Skogsvårdslagen 1993 kan ha haft en effekt på kantzoner och det önskade skyddet av vattendrag. Målbilderna från 2013 har inte påverkat zonerna i denna studie.

Nyckelord: Kantzoner, skogsbruk, skogsskötsel, skydd av vattendrag, vattenekosystem

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Abbreviations

Words that will be used in this study and the explanations of them:

GIS	Geographic Information System
Ha	Hectare
Riparian buffer	A strip of forest left unharvested next to streams created to protect riparian zones and buffer the effects of forestry on streams
Riparian zone	The temporarily flooded areas adjacent to streams that makes the boundary between aquatic and terrestrial ecosystems, that help regulate the ecological functions of both systems
SMO	Strategic Management Objectives or “Målbilder”

1. INTRODUCTION

The forest ecosystem in Sweden contains many components, where trees, water and soil are the main ones. All of these components gives Sweden both a strong economic welfare as well as many ecosystem services (Skogsstyrelsen 2018). The ecosystem services that can be connected to the forests are many, for example, products such as timber and pulpwood, air purification, clean water, climate regulation and cultural services such as recreational activities (Felton *et al.* 2016; Martínez Pastur *et al.* 2018; Skogsstyrelsen 2018; Kritzberg *et al.* 2020). The diversity of ecosystem services makes the forest essential for the wellbeing of the society (Felton *et al.* 2016; Martínez Pastur *et al.* 2018). Forests needs to be managed with consideration to the ecosystem services but also with consideration to decision makers' interests. Many people have an interest in the forest, for example hunters, reindeer herders, forest owners and people who values recreation and social values in the forest. All these different interests creates conflicts about how the forest should be managed and used. Policies that steer how the forest should be managed are important tools to change forest management (Hasselquist *et al.* 2019). This means that forest policies both on national and international levels can be used to achieve new goals for future forest management.

1.1. Swedish Forestry Act

The first Forestry Act in Sweden was enacted in 1903 to secure regeneration after harvest. Since then many changes and additional regulations have extended the Forestry Act. The extension of the Forestry Act in 1979 aimed to *"include requirements for environmental protection"* (Hasselquist *et al.* 2019), and is important for this study. The Forestry Act was updated in 1993 to include the regulation where economic and environmental values should be equally valued in the forestry sector (Regeringen 2014; Hasselquist *et al.* 2019). The Forestry Act before 1993 valued economic values and timber production over ecological values (Regeringen 1979). In 2013, the Swedish Forestry Act was again amended to highlight and extend the environmental goal to consider forest water protection. The Swedish Forest Agency presented in 2013 new Strategic Management Objectives (SMOs) called "målbilder" (Hasselquist *et al.* 2019). In these SMOs, there are objectives for environmental, social and cultural protections. One important objective refers to protection of lakes and streams (Andersson *et al.* 2013). Lakes and streams today, should be bordered by a strip of forest after a harvest. The strip of forest is called a riparian buffer or a forest buffer (*see Abbreviations*) and occurs when trees are left along the water in the forest for protection of the water resource (Ring *et al.* 2018). According to the SMOs for protection of streams and riparian zones, there are six functions of the riparian zones that must be maintained. These six functions are: preserve important soil chemical processes, act as a filter for sediment transport and prevent erosion by stabilizing the shoreline, contribute food to aquatic organisms, shading of the stream, contribute dead wood to the water and preserve biodiversity (Skogsstyrelsen 2014). Buffers are important for maintaining water quality, quantity and biodiversity (Kreutzweiser & Capell 2001; McDonnell 2003; Sabo *et al.* 2005) but the guidelines for shaping riparian buffers need to be further investigated (Laudon *et al.* 2016).

1.2. Protection of streams

The management of the landscape in Sweden has affected the connection between the forest and the streams. Forestry is one example of a human activity which has affected the water resource (Hjältén *et al.* 2016). Currently, to protect the streams and other freshwater ecosystems, a riparian buffer is created in connection with harvest of a forested site (Castelle *et al.* 1994; Richardson *et al.* 2012). Forestry must consider protection of streams due to the high number and diversity of values and services provided by aquatic ecosystems (Gundersen *et al.* 2010; Kuglerová *et al.* 2014). Riparian buffers protect streams from, for example, pollution by filtering nutrients and pesticides (Naiman & Décamps 1997) and increased exposure to sunlight by reduced canopy cover (Richardson *et al.* 2012). Riparian buffers also protect groundwater discharge areas from being exposed and disturbed (Kuglerová *et al.* 2014). Streams need to be protected from forestry to maintain fish populations and their habitats, to keep a stable temperature in the water and to continue to put in organic matter to the stream, such as food for organisms (Richardson *et al.* 2012). A riparian zone with deciduous species increases the species richness in the stream (Skogsstyrelsen 2014). If the stream has no buffer or an insufficient buffer it would likely result in reduced water quality (Laudon *et al.* 2016), stream bank erosion (Richardson *et al.* 2012) and higher risk of changes in the stream ecosystem (Kuglerová *et al.* 2014).

The riparian buffers are not only useful for protecting aquatic ecosystems but are also useful for protecting terrestrial ecosystems (Kuglerová *et al.* 2014). Riparian zones in boreal forest are important for plant biodiversity and are the most species rich part of the landscape (Hylander *et al.* 2002; Dynesius *et al.* 2009; Kuglerová *et al.* 2014, 2016). Riparian zones are important habitats for birds, small mammals and herbivores (Naiman & Décamps 1997). The riparian zone is important for the dispersal of wildlife species, working as dispersal corridors as an example (Spackman & Hughes 1995; Mosley *et al.* 2011; Richardson *et al.* 2012).

1.2.1. Management of riparian buffers

To maintain healthy freshwater ecosystems, the riparian buffers need to be managed well. Today, streams are typically protected with fixed width riparian buffers of one tree length made up of native vegetation (Richardson *et al.* 2012; Skogsstyrelsen 2014). Recent research shows, in contrast, that approximately 69% of small streams lack buffer protection or have a small buffer (<5 meters) in Sweden (Jonsson 2018; Hasselquist *et al.* 2019). For some buffers, selective harvesting or thinning can increase the effectiveness of the protection (Kreutzweiser *et al.* 2012; Sibley *et al.* 2012). Selective harvesting or thinning creates disturbance and variation in the riparian buffer which some species require, in addition to a possible higher timber extraction and an increased growth rate of the remaining trees (Richardson *et al.* 2012). Selective harvest and thinning in riparian buffers would result in remaining stumps of different tree species, which is great for biodiversity of bryophytes (Hylander *et al.* 2005). Currently the Swedish Forest Agency suggests to not harvest deciduous tree species in an area of 10 meters from the stream to increase the species richness (Skogsstyrelsen 2014). This can be compared with before 2013, when there were no restrictions in selective harvest of riparian zones, or even further back in the history, when the forest was harvested all the way to the stream (Hasselquist *et al.* 2019). The plant species composition in the riparian buffer should be varied with, for example, late successional vegetation, large wood and riparian specific species (Richardson *et al.* 2012).

An effective buffer should cover the three basic principles that define a riparian zone as proposed by Nilsson and Svedmark (2002). They are:

> "(1) The flow regime determines the successional evolution of riparian plant communities and ecological processes. (2) The riparian corridor serves as a pathway for redistribution of organic and inorganic material that influences plant communities along rivers. (3) The riparian system is a transition zone between land and water ecosystems and is disproportionately plant species-rich when compared to surrounding ecosystems" (Nilsson & Svedmark 2002).

There is no exact description of how a buffer should be managed from the Swedish Forest Agency (Skogsstyrelsen 2014) but researchers are developing methods to manage riparian buffers in a desired way (Kuglerová *et al.* 2014, 2017). One example is the site-specific riparian buffer, which optimizes the buffer based on ground water discharge areas. Forest management needs to increase the sustainability in the silviculture of the forests and the site-specific riparian buffer is a step in right direction (Kuglerová *et al.* 2014).

1.3. Effects of past forest management

Throughout history, many changes in forest management and protection of streams have been developed through political decisions (Hasselquist *et al.* 2019). Forests today, goes through one or more cleaning and thinning, where competing and undesired trees are removed (Pettersson *et al.* 2012; Agestam 2015). In the past, these trees were often deciduous and, for example, herbicides were used to remove deciduous species (Östlund *et al.* 1997). Forest policy changes and its effect on stream protection is an area that has had little attention in Swedish research, but have recently been studied by Ring et. al. (2018) and Hasselquist et. al. (2019). The articles consider characteristics of riparian buffers in managed forests in Sweden and analyse how forest policy and practice have developed in Sweden over 50 years, focusing on riparian buffers. Two master's theses have also recently touched on this problem (Jonsson 2018; Åström 2020). This present study is a follow-up to the master's thesis by Åström (2020). This thesis analysed if riparian buffer management needed to be changed to a more active management for deciduous trees to achieve the SMOs (Åström 2020).

One question which need more research is how management interventions in the past have affected riparian zones today, specifically species diversity of riparian trees in riparian zones. Little is known about how the riparian zones of today will influence streams and other aquatic resources over long term (Ring *et al.* 2018). There is also a lack of research of riparian buffers under 5- and 10 meters wide which this study will focus on (Hickey & Doran 2004). Small streams (<3 meters width) are prioritized in this study. To be able to provide more information about these problems and reduce knowledge gaps, it is necessary to look back in history to see if and how previous management has shaped the protection of small streams.

1.4. Aim of the study and Hypotheses

The aim of this study is to see how the protection of small streams (<3 meters width) has developed from not being protected at all in the past, to the riparian buffers that protect streams today. The purpose of this study is to determine how the forest management has been conducted within riparian zones in the past, to get insight into the possibilities for improving management of current and future riparian buffers. Have changed management policies affected the riparian zones and their species composition (for example, species richness and proportion of deciduous species)? This question led to the question in this thesis: Is the change in deciduous species and species richness in riparian zones due to past management? Accordingly, has past management led to different species richness in riparian zones depending on the width of the buffers and when the buffers were made?

The goal with this study is to analyse previously collected field inventory data (Åström 2020) on species richness of coniferous and deciduous shrubs and trees in riparian zones of different ages, as well as stumps of conifers and deciduous trees. This data provided the possibility to use quantitative methods and statistical analyses in this study. To complement the data-analysis, historical aerial photos taken every decade between 1963 and 2013 are visually analysed and quantified in a GIS-software to assess management operations in the riparian zones. The goal is to relate changes in species richness and proportion of deciduous species to past management interventions within the riparian zones.

The hypotheses:

- The species richness and proportion of deciduous species in the riparian zone will be lower in the age classes <1975 (1963-1975) and <1993 (1975-1993), increase for <2013 (1993-2013) and be highest in <2019 (2013-2019). Species richness and proportion of deciduous species will be highest closest to the stream compared to far away from the stream.
- The number and proportion of deciduous stumps will decrease over time. The change in which tree species that are targeted for thinning will be most obvious after 2013 due to the implementation of the SMOs. Further, the number and proportion of deciduous stumps will increase with the distance from stream.
- The width of the riparian buffer will increase over the studied time period, and before 2013, the buffers will be small or not existing.
- The changes seen in species richness, proportion of deciduous species and presence of stumps in the riparian zones of different ages are due to changes in past forest management.

2. MATERIALS AND METHODS

2.1. Materials

The data in this study were collected in a field inventory by Åström (2020) in or adjacent to the Krycklan Catchment Study area close to Vindeln, Västerbotten County, Sweden. This studied catchment area is *"typical of catchments dominated by Swedish forests…"* and contains 87% production forest of Norway spruce (*Picea abies (L.) H. Karst*) and Scots pine (*Pinus Sylvestris (L.)*), 10% of water bodies and streams and 3% of farms and arable land. The forests were managed by both non-industrial private forest owners and by forest companies (Laudon *et al.* 2013).

Inventoried data were collected in autumn 2019 (late September/early October). All measures were carried out adjacent to streams with a width less than 3 meters. Trees, shrubs (<1.3 meters), stumps and stream width were inventoried. A total of 16 sites were inventoried and the sites were placed in forests divided into four different age classes. Four sites in each age class were selected by Åström (2020). These age classes were separated based on important changes in forest management or important changes in forest policy during the last 50 years (Hasselquist *et al.* 2019). The age classes were <1975, <1993, <2013 and <2019. Age class <1975 represented harvests before 1975 which correspond to the forestry before the Forestry Act in 1979 (Åström 2020). The Forestry Act in 1979 aimed to "include requirements for environmental protection" in forest management (Hasselquist *et al.* 2019). Age class <1993 represented harvests between 1985 and 1993 which was after the Forestry Act which came 1979. Age class <2013 represented harvests between 1993 and 2013 which were after the change of the Forestry Act 1993 which equated environmental goals and production goals Age class <2019 represented harvests after 2013 when the SMOs were created and implemented (Andersson *et al.* 2013; Åström 2020).

The 16 sites from the field inventory contained 4 transects each. The transects followed edge to edge on altering sides of the stream. The starting side for the first transect was randomly chosen by tossing a coin. Each transect was divided into 3 different distances from the stream (0-5 meters, 5-10 meters and 10-15 meters) (*Figure 1*). The total number of different inventoried distances from stream was 192 (i.e., 16 streams/sites x 4 transects x 3 distances from the stream). A GPS coordinate was registered at the first transect on each site (Åström 2020).

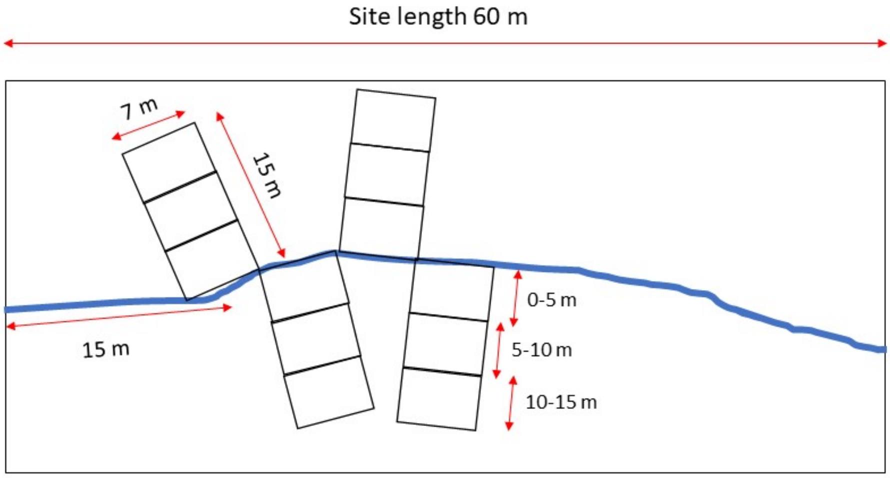

Figure 1. Sampling design. The site length was 60 meters. Transects were 15 meters x 7 meters. The first transect started 15 meters from the edge of the site. Each area of different distance from the stream was 7 meters x 5 meters and was located 0-5 meters, 5-10 meters and 10-15 meters from the stream.

In this study data for number of different species (both shrubs and trees combined), number of stumps, divided into conifers deciduous and total, and the average width of the streams were used.

In addition to the inventoried data, aerial photos of the Krycklan Catchment Study area were used. Aerial photos from 1963, 1975, 1985, 1993, 2004, 2009 and 2013 were interpreted and cover a time span of 50 years. The aerial photos derived from an earlier work by Hasselquist et al (2019) covering how the policies have changed management for riparian zones over the last 50 years. In addition to the aerial photos, coordinates for inventoried sites and a shapefile of streams in the Krycklan Catchment Study area were used.

2.2. Methods

2.2.1. Species richness

The data of inventoried shrubs and trees (combined) divided into different species were processed. In MS Excel (only Excel further on), the number of different species (both shrubs and trees combined) were counted (using the function “COUNT”). The count was made for all different distances from the stream, in each transect, in each site and in each age class. An extra check was made that the result only counted each species one time, even if the inventoried data included both shrub and tree of the same species. This extra check was made because the data were originally calculated with the assumption that *“shrub and small tree species would also be occurring in the > 1.3 m trees”* (Åström 2020). Therefore, species richness includes tree species that do not necessarily occur in the > 1.3 meters size.

The species richness was analysed with MiniTab (version 18.1) in a “nested Two-Way ANOVA” where the mean and standard error of the species richness were compared over the different age classes and over the different distances from the stream. The species richness was a numeric response or dependent variable and the age class and distance from stream were two categorical predictors or independent variables. In addition to age class and distance from stream, the variables site number and transect were used. The transect was nested in site number plus age class and the site number was nested in age class. All predictors/factors were fixed when using the “nested Two-Way ANOVA. The predictors made the “nested Two-Way ANOVA” a preferable statistical test used in this study (Samuels *et al.* 2016). In the study normal distribution was tested for all response variables. If the response variable was not normally distributed, it was transformed by taking, for example the logarithm, to pass normality. The significance level of 5% was used throughout the whole study.

2.2.2. Proportion of deciduous species

The number of deciduous species for each age class and each distance from the stream was calculated in Excel. For that, a count (using the function “COUNT”) of number of deciduous species (both shrubs and trees combined) was made. The count of deciduous species was divided with the count of total number of all species (the species richness). This calculation was made to get the proportion of deciduous species in relation to all species present in the inventoried area. The proportion of deciduous species was analysed statistically with a “nested Two-Way ANOVA”. The proportion of deciduous species was the response variable and analysed in the same way as described for the analysis of the species richness.

2.2.3. Stumps

The number of stumps/ha and the proportion (number stumps/ha divided with total number of stumps/ha) of deciduous versus conifer stumps were analysed; data was also received for unknown stumps but not analysed (average unknown stumps per site was 13%). A "nested Two-Way ANOVA" was used to analyse the number of conifer stumps, number of deciduous stumps as well as the proportion of deciduous and conifer stumps with regard to age class and distance from stream in same way as mentioned in 2.2.1. For some of the inventoried sites there were no stumps recorded. No stumps resulted in a division with zero when the proportion was calculated. Data with no stumps were deleted and omitted in the analysis of the proportion of stumps. For the data where stumps were present, but there were, for example, zero deciduous stumps, the result was a true zero and was counted in the result when the data for proportion of stumps were analysed. For the number of stumps/ha all data including zero stumps/ha was included in the analyses.

2.2.4. Aerial photos

The aerial photos were visually analysed in ArcGIS software (ArcMap version 10.7.1.11595). Only photos showing one specific year were used. In the analysis, aerial photos, coordinates of inventoried sites, and streams over the area were used. A first visual analysis was made by comparing aerial photos between the different years. Changes in forest cover were noted for all years and for all sites. If a harvest was noticed, a measure of the width of the riparian buffer was made. For some sites, the aerial photos were insufficient, and instead Google maps (Google 2020) and Eniro (Eniro 2020) were used to measure the buffer widths for the missing years.

To analyse and measure the buffer width in detail for each site, areas of 15 meters x approximately 60 meters were created along each side of the stream corresponding to the site set-up (*Figure 2*). The buffer started at the coordinate point for the site and went from closest road. No roads crossed the buffers. The area was made with the ArcMap tool "Buffer" with the settings of 15 meters width of the area and with flat endings. To see the forest under the area layer, the transparency, under the menu properties, of the layer was set to 60%.

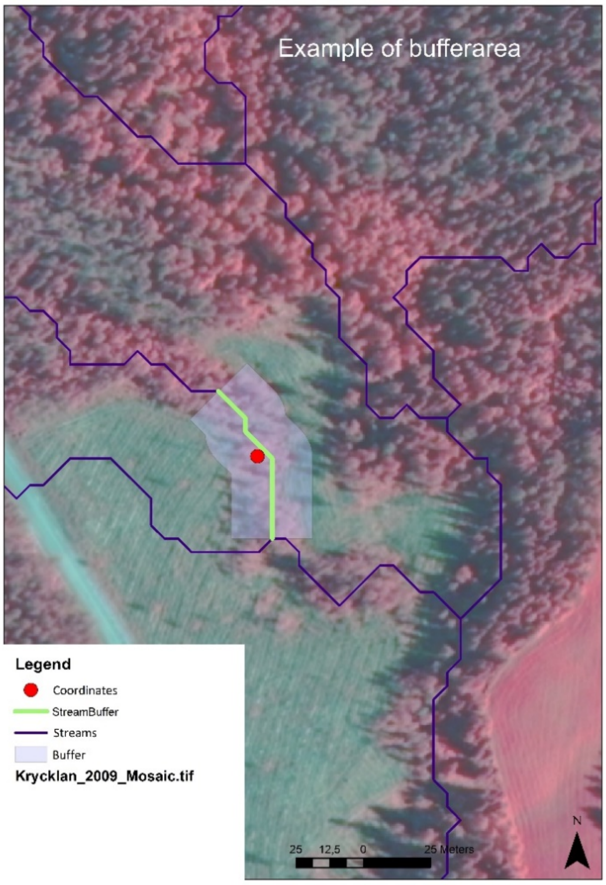

Figure 2. Example of how a buffer area can look. In that area the forest cover and width of riparian buffer were measured. The 'Buffer' is the area around the stream with the length of approximately 60 meters and width of 15 meters on each side of the stream. 'Coordinates' is the point where the first transect was made in the inventory. 'Streams' show the layer of water courses in the area from a property map. 'Krycklan_2009_Mosaic.tif' is the aerial photo which was taken in 2009. 'StreamBuffer' is the segment of the stream inventoried, approximately 60 meters long.

Depending on how the forest looked at each site for each year, it was allocated to one of 5 different categories (which were subjectively evaluated). The categories were: H = Harvest, Y = Seedlings/young forest, MF O = Mature forest, canopy not totally enclosed, MF C = Mature forest, closed canopy and N = No picture available. When a harvest was detected, the possible riparian buffer width was measured at six points. A mean of the width of the riparian buffer was calculated. A harvested site with no riparian buffer led to a mean of zero. To compare how the width of the riparian buffers and how the forest management have changed over time an "One-Way ANOVA", with normal distribution tested, was made in MiniTab. A regression of the average buffer width and year of buffer creation together with a regression of the average buffer width compared to average stream width was done (both with normal distribution tested). The last regression with average buffer width compared to average stream width was only analysed for sites with buffer width >0 meter.

3. RESULTS

3.1. Species richness

Age class was a statistically significant predictor to species richness for riparian shrubs and trees combined (*P-value=<0.001*). Species richness compared over age classes showed a higher species richness in age classes <1993 and <2013 and lower species richness in age classes <1975 and <2019 (*Figure 3*). The lowest species richness was in age class <1975 with a species richness of approximately 3.3 species. The highest species richness was in age class <2013 with a species richness of approximately 4.5 species.

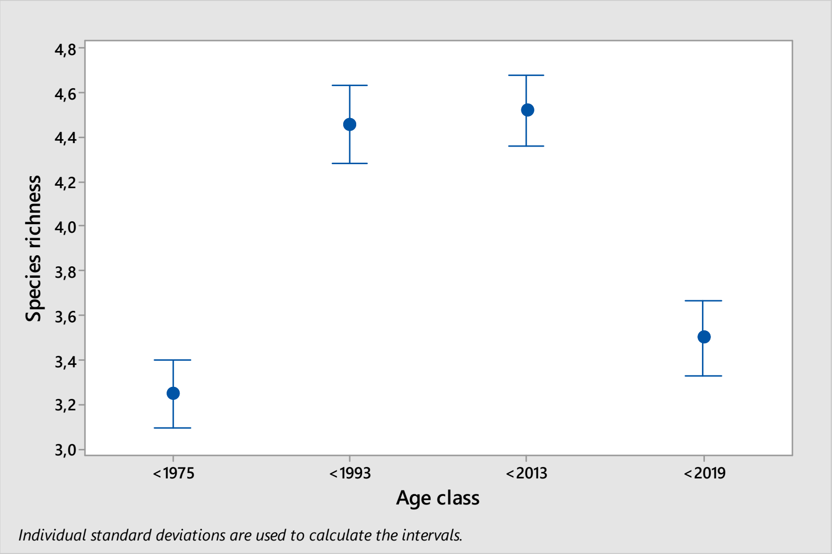

Figure 3. Average species richness (number of species in each inventoried plot) in different age classes. Bars are one standard error of the mean.

Distance from the stream was a statistically significant predictor (*P-value=0.019*) for species richness of riparian shrubs and trees combined. Species richness was highest in the area closest to the water (0-5 meters) with approximately 4.3 species per inventoried site closest to stream and then decreased with the distance from the stream to approximately 3.7 and 3.8 species per inventoried site at the distances 5-10 and 10-15 meters, respectively (*Figure 4*).

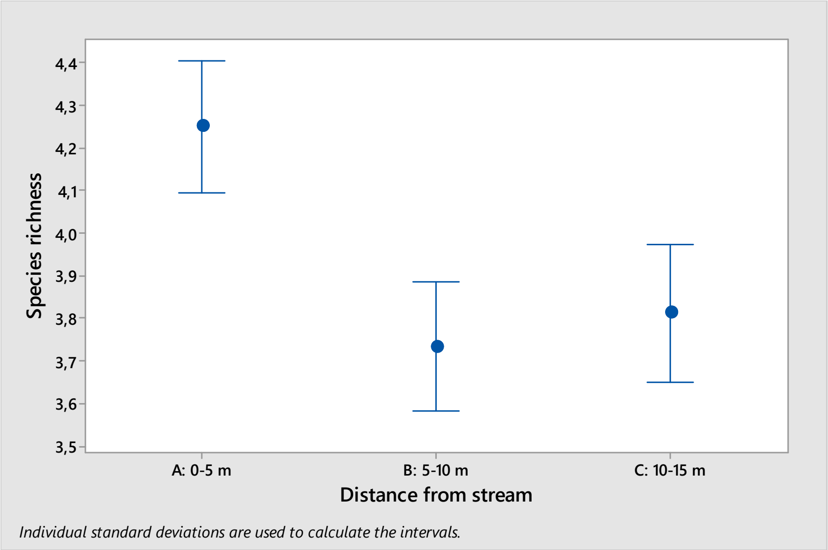

Figure 4. Average species richness (number of species in each inventoried plot) at different distances from the stream. Bars are one standard error of the mean.

3.2. Proportion of deciduous species

The proportion of deciduous species was compared over age classes, which was a significant predictor (*P-value=0.008*). The trend showed a decrease in the proportion of deciduous species over time (*Figure 5 and Appendix 1*). The proportion of deciduous species was highest in the oldest age class (approximately 0.65 in <1975) and lowest in the youngest age class (approximately 0.54 in <2019) (*Figure 5*).

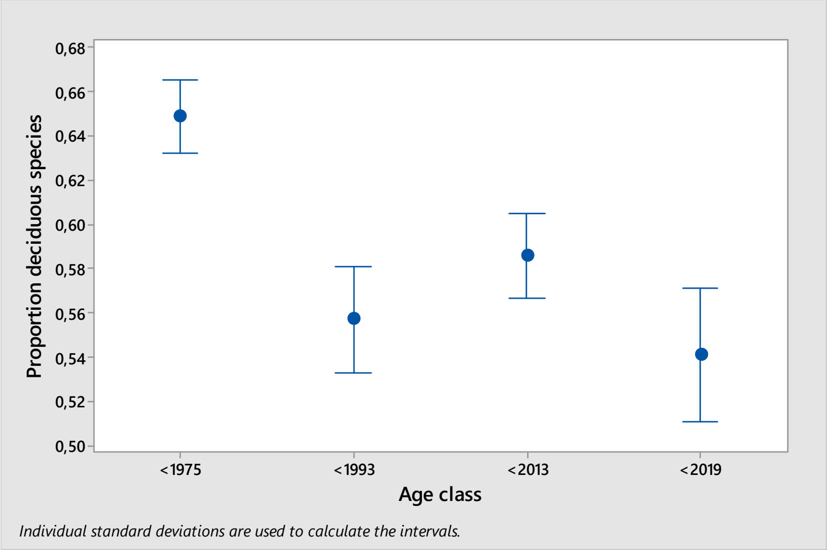

Figure 5. Average proportion of species that are deciduous over the different age classes. Bars are one standard error of the mean. The figure is showing the proportion of the total number species (both shrubs and trees combined) in the riparian zone that were deciduous.

Distance from stream was also a statistically significant predictor for proportion of deciduous species (*P-value=0.024*). With the comparison of proportion of deciduous species with distance from stream, the result showed the highest proportion of deciduous species closest to the stream (*Figure 6 and Appendix 1*). Proportion of deciduous species decreased from approximately 0.62 (0-5 meters from the stream) to approximately 0.56 (10-15 meters from stream).

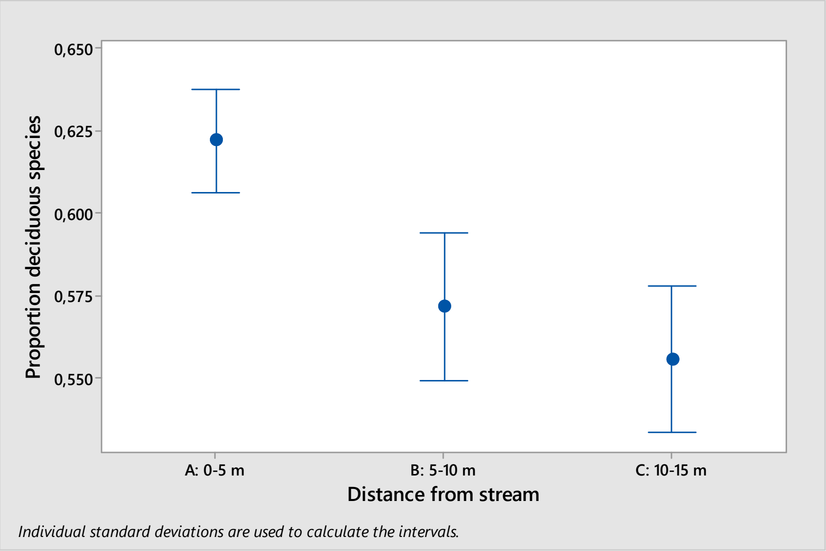

Figure 6. Average proportion of species that are deciduous over the different distances from the stream. Bars are one standard error of the mean. The figure is showing the proportion of the total number species (both shrubs and trees combined) in the riparian zone that were deciduous.

3.3. Stumps

The analyses covered both the number of stumps/ha and proportion of stumps. The results for analysing conifer stumps (number of conifer stumps/ha and proportion of conifer stumps) were more significant compared to deciduous stumps (*Appendix 1*). The results for deciduous stumps were inverse to the conifer stumps, especially the proportion of stumps, and are reported in Appendix 1.

Age class was a statistically significant predictor to number of conifer stumps/ha (*P-value=<0.001*). The result for number of conifer stumps/ha compared among different age classes showed that for age classes <2013 and <2019 there were more conifer stumps/ha remaining compared to <1975 and <1993 *(Figure 7*). In age class <1993 the number of conifer stumps/ha was lowest (approximately 200 stumps/ha). After 1993 the number increased with approximately 300 stumps/ha until age class <2019, which had approximately 500 stumps/ha. The number of deciduous stumps/ha compared to age class was not possible to statistically analyse because it was not normally distributed (*Appendix 1*). For each age class the number of deciduous stumps/ha was lower than the number of conifer stumps/ha (*Figure 7*). The number of deciduous stumps/ha varied between approximately 155 stumps/ha in age class <1975 to approximately 30 stumps/ha in age class <2013. From age class <2013 to age class <2019 there was an increase of deciduous stumps/ha of approximately 35 stumps/ha to a total of 65 deciduous stumps/ha (*Figure 7*).

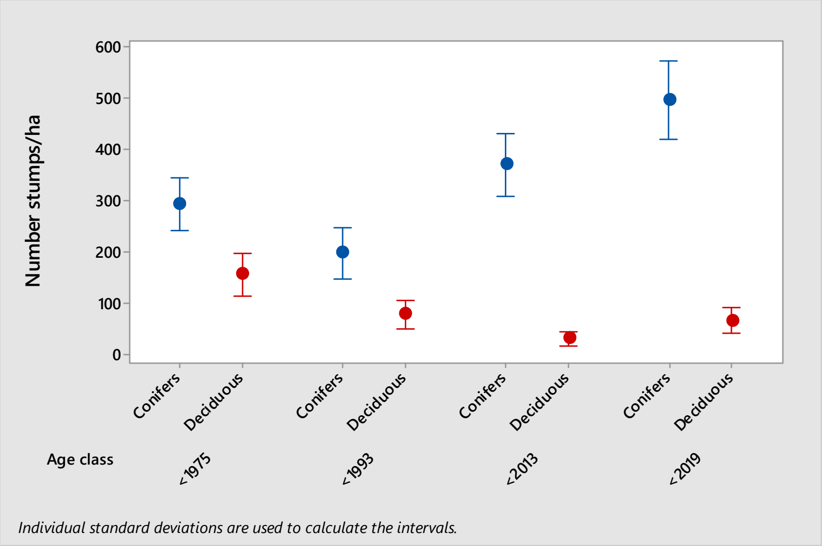

Figure 7. Average number conifer respectively deciduous stumps/ha over the different age classes. Bars are one standard error of the mean.

Distance from stream was a statistically significant predictor to number of conifer stumps/ha (*P-value=<0.001*). The number of conifer stumps/ha was highest 5-10 meters away from the stream, with approximately 430 stumps/ha *(Figure 8)*. In 0-5 meters from the stream the number of conifer stumps/ha was lowest (approximately 190 stumps/ha) and in 10-15 meters from the stream the number of conifer stumps/ha was approximately 390 stumps/ha. The number of deciduous stumps/ha compared to different distances from the stream was not possible to statistically analyse because it was not normally distributed (*Appendix 1*). For each different distance from the stream the number of deciduous stumps/ha was lower than the number of conifer stumps/ha (*Figure 8*). The number of deciduous stumps/ha varied between approximately 90 stumps/ha 0-5 meters from the stream, approximately 70 stumps/ha 5-10 meters from the stream and approximately 80 stumps/ha 10-15 meters from the stream (*Figure 8*).

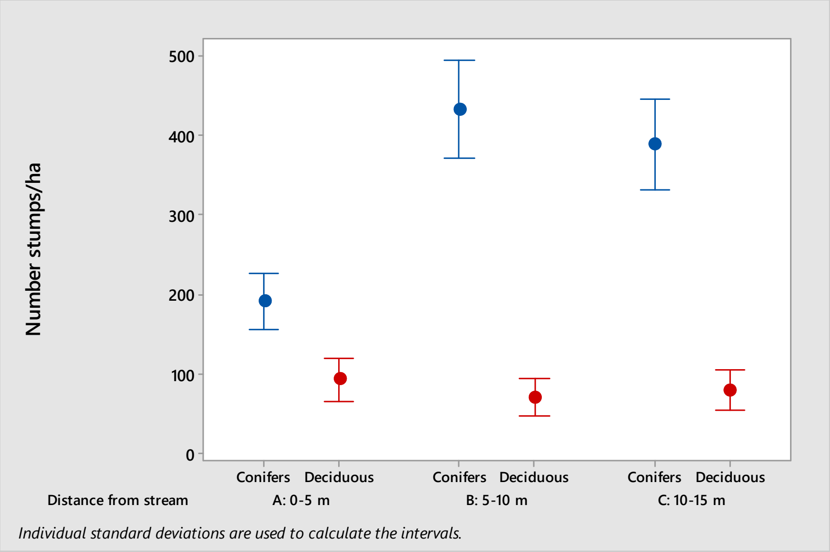

Figure 8. Average number conifer respectively deciduous stumps/ha over the different distances from the stream. Bars are one standard error of the mean.

Age class was a statistically significant predictor to proportion of conifer stumps (*P-value=<0.001*). The proportion of conifer stumps showed that for age classes <2013 and <2019 there were more conifer stumps (approximately 0.83 and 0.87) compared to <1975 and <1993 (approximately 0.62 and 0.48) *(Figure 9*).

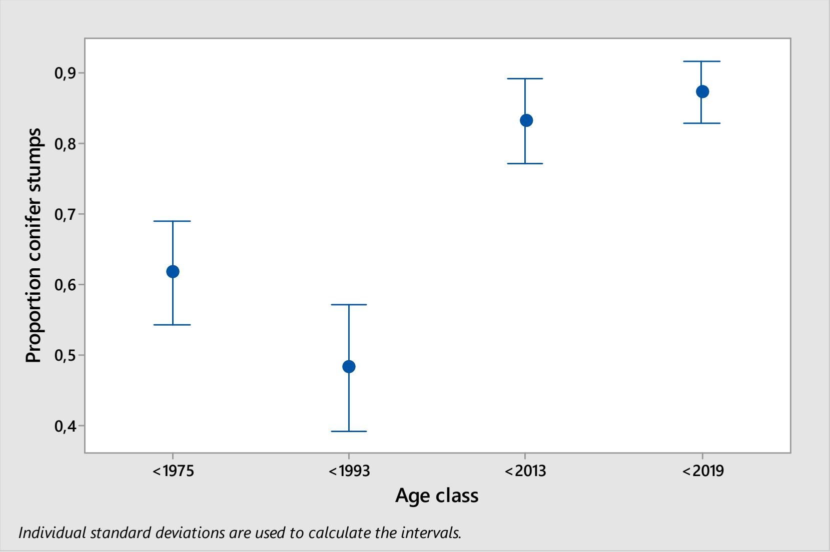

Figure 9. Average proportion of conifer stumps over the different age classes. Bars are one standard error of the mean.

Distance from stream was a statistically significant predictor to proportion of conifer stumps (*P-value=<0.015*). Proportion of conifer stumps increased from approximately 0.55 (0-5 meters from the stream) to approximately 0.8 (10-15 meters from the stream) *(Figure 10*).

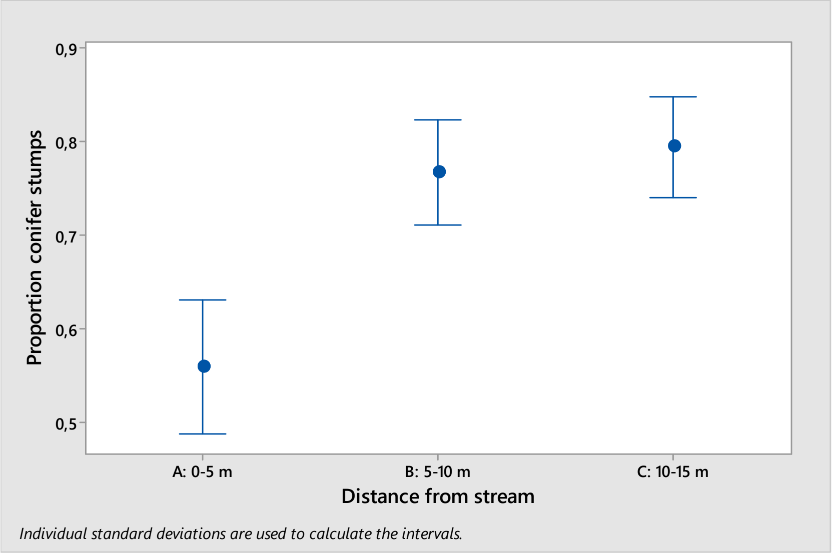

Figure 10. Average proportion of conifer stumps over the different distances from the stream. Bars are one standard error of the mean.

3.4. Aerial photos

The visual analyse of the aerial photos contains two parts, first the estimation of how the forest looked and second the measurements of the buffer width *(Appendix 2)*.

The visual assessment that was made for every inventoried coordinate and every different year of the aerial photos resulted in a table *(Appendix 2)*. In summary, the result showed 14 harvests over approximately 50 years (*Table 1*). Two more sites were part of the age class <1975 but no aerial photo showed those harvest (*Appendix 2*). The differences between forested land, riparian buffer and no riparian buffer can be seen in figures 11-14. One example shows when the harvest machine operator has not left a buffer (*Figures 11-12*) and one example shows when the harvest machine operator has left a buffer (*Figures 13-14*). The categories for every figure are presented in the captions below and the definitions can be seen in the Material and Methods section or in Appendix 2.

Table 1. Number of detected harvests for the different aerial photos analysed.

Year	1963	1975	1985	1993	2004	2009	2013	2019
Number of harvests	1	1	2	2	0	2	1	5

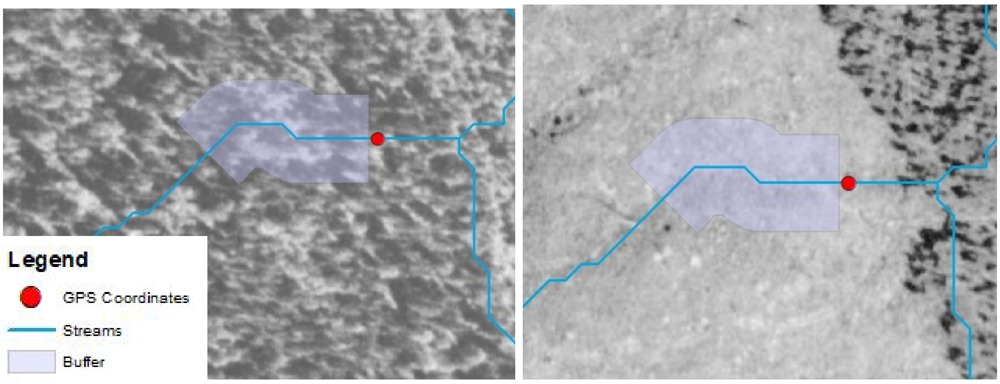

Figure 11. Figure to the left: 1985site2, aerial photo from year 1975. Mature forest canopy open (MF O). Figure to the right: 1985site2, aerial photo from year 1985, a harvest has been made and no buffer have been made. Harvest (H).

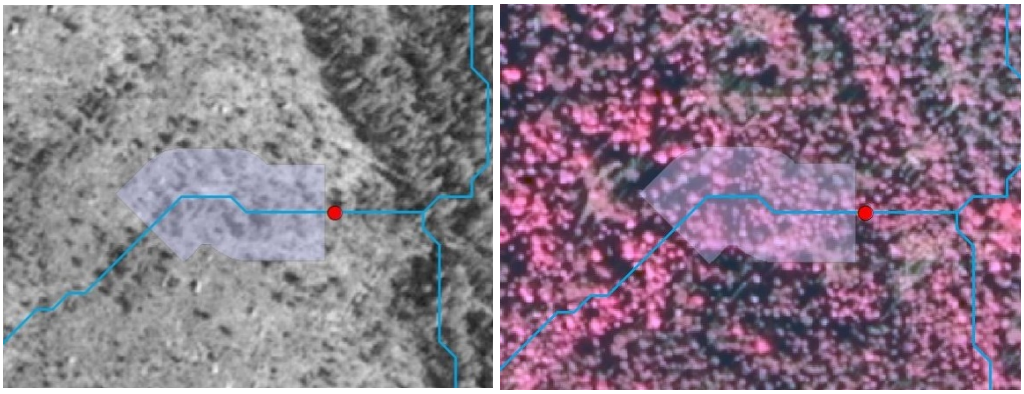

Figure 12. Figure to the left: 1985site2, aerial photo from year 1993. Seedlings start to come. Seedlings/Young forest (Y). Figure to the right: 1985site2, aerial photo from year 2013. Mature forest canopy open (MF O).

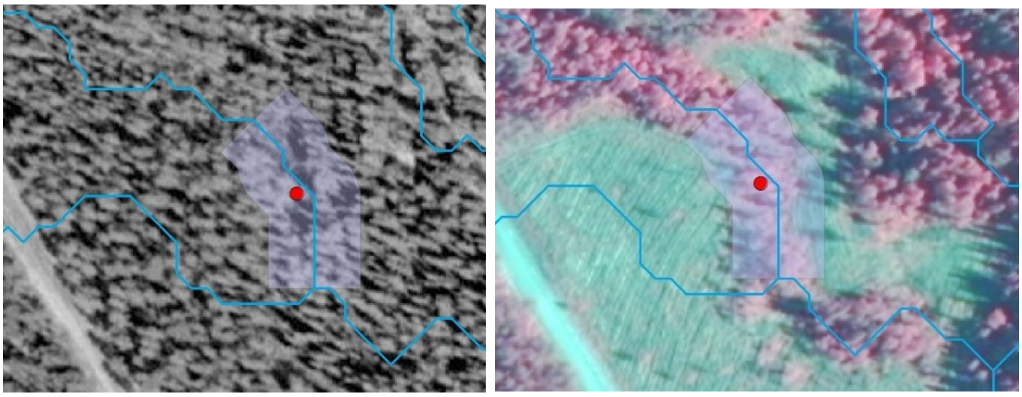

Figure 13. Figure to the left: 2004site4, aerial photo from year 1993. Mature forest canopy closed (MF C). Figure to the right: 2004site4, aerial photo from year 2009. A harvest has been made and the machine has left a buffer. Harvest (H).

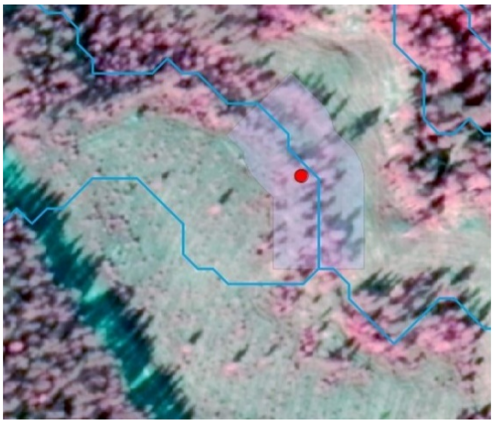

Figure 14. 2004site4, aerial photo from year 2013. Seedlings starts to come. Seedlings/Young forest (Y).

The average buffer width was significantly different based on the age classes (*P-value=0.014*). Before 1993, there were few sites which had buffers adjacent to the streams. If a site had a buffer it was quite small (1.33-6 meters wide on each side of the stream). After 1993, harvested sites always had a riparian buffer, although the width varied among sites. The average width of riparian buffers after 1993 varied between 3.67 and 19.83 meters on each side of the stream. In age class <1975, buffers had similar width as in the age class <2019 but only two out of four sites were possible to measure in age class <1975 (*Figure 15*).

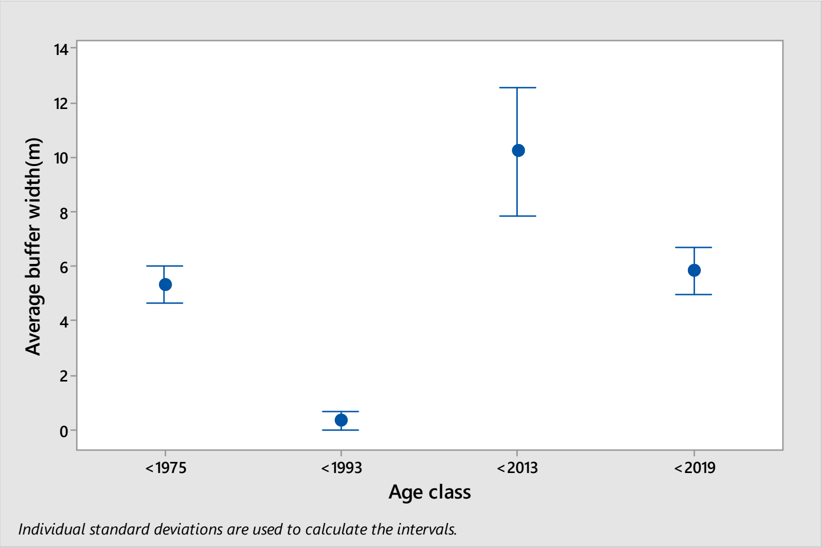

Figure 15. Average buffer width on each side of the stream (in meter) over the different age classes. Bars are one standard error of the mean. Age class <1975 incudes only two measurements because no aerial photo showed the other two harvests that was a part of age class <1975.

When the buffer width was regressed with the year of buffer, there was a statistically significant trend (*P-value=0.047; Figure 16*). There was no statistically significant relationship between average buffer width and stream width (*P-value=0.323; Figure 17*) but an increasing trend, i.e., wider streams tended to have wider buffers, was noticed.

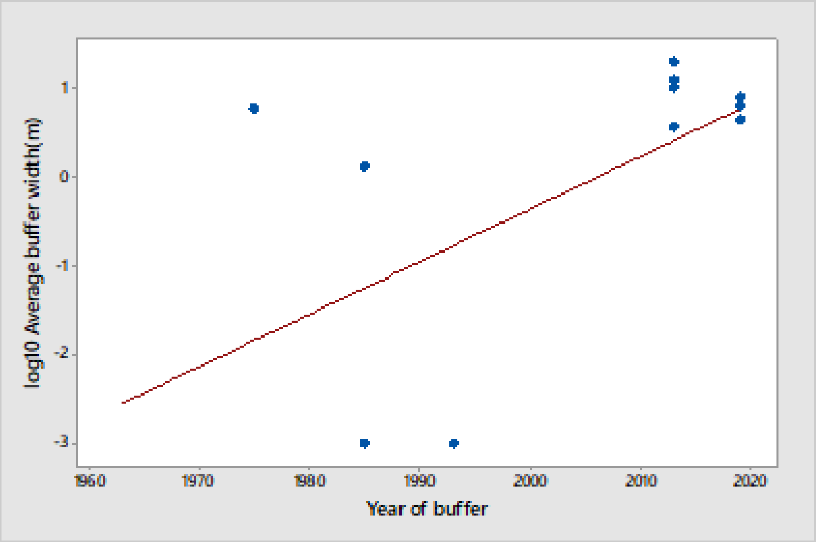

Figure 16. Average buffer width in meters over the year the buffers were made. Log10 values for the average buffer width to make it normal distributed. Blue dots in the graph are sites where a buffer was measured (width ≥0 meter).

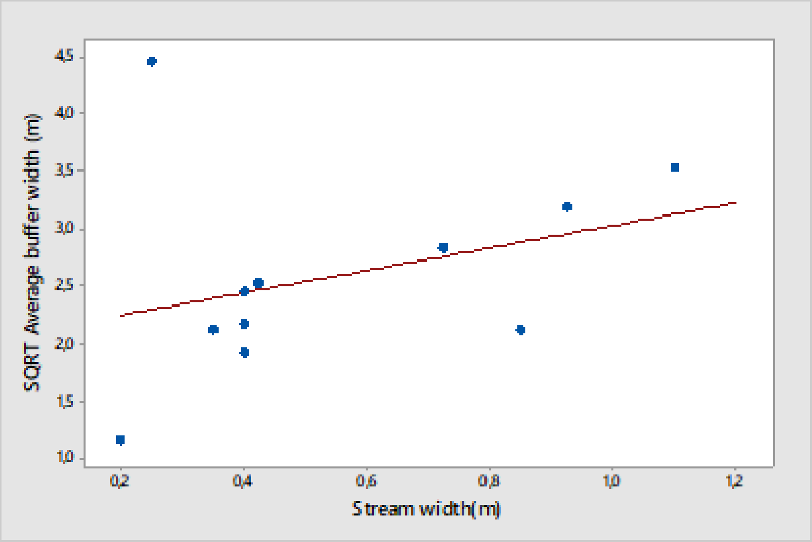

Figure 17. Average buffer width over stream width in meters. Square rooted (SQRT) values for the average buffer width to make it normal distributed. Blue dots in the graph are sites where a buffer was measured (width >0 meter).

A summary of the results of all statistical analyses and graphs not shown in the Results section can be seen in Appendix 1. The results of the visual analysis of riparian zones and the measured buffer width in the aerial photos can be seen in Appendix 2.

4. DISCUSSION

4.1. Discussion of results

4.1.1. Species richness and Proportion of deciduous species

The hypotheses for species richness and proportion of deciduous species in the riparian zone was that the results would be lowest in age classes <1975 and <1993, increase for <2013, and be highest in <2019. This hypothesis was rejected. Species richness was highest in the two middle age classes, <1993 and <2013, and lowest in the oldest and youngest age classes <1975 and <2019 (*Figure 3*). This result of species richness goes in line with the result of Åström´s thesis (Åström 2020), even if Åström only used shrubs instead of both shrubs and trees combined. The proportion of species that were deciduous decreased over time, with the highest proportion of deciduous species in the <1975 age class, then decreasing to <1993, then slightly increased between <1993 and <2013 and was lowest in <2019 (*Figure 5*). The result of proportion of deciduous species, compared to Åström´s result (Åström 2020), showed a different trend with the lowest proportion of "deciduous trees" in age class <1975. A reason for that was that this study used both deciduous shrubs and trees combined compared to Åström which only used deciduous trees (>1.3 meters). This means that the species which were found in the shrub layer does not necessarily reached the tree layer (>1.3 meters), probably due to cleaning, thinning and natural succession (Widenfalk & Weslien 2009; Pettersson *et al.* 2012).

A higher species richness of riparian woody plants in the middle age classes compared to the oldest and youngest age classes could be explained by age class <1975 having older forests and recently harvested forests in age class <2019 being more similar to them. Mature managed forest is typically more homogenous and the riparian buffers in the harvests from <2019 likely contains similarly managed forests as the <1975 age class. In mature managed forest the possibility for new species to establish is small because of the managed forests to monocultures (Felton *et al.* 2016). For the buffers in age class <2019, the new species have not yet had time to establish. The vegetation needs time to establish after dispersal and germination and therefore a time lag occurs (Karlsson 2001; Åström 2020). The result could also be connected to the intermediate disturbance hypothesis (Connell 1978). In the age classes <1993 and <2013 it has likely been enough time since the disturbance of humans, like final felling, cleaning and thinning which disturbs the canopy cover. These management actions could result in an increase of plant species richness (Widenfalk & Weslien 2009). As the intermediate disturbance hypothesis says, it is intermediate disturbances which leads to highest biodiversity in the nature (Connell 1978).

The result of the proportion of deciduous species over different age classes (*Figure 5*) could depend on how the forest was managed before it was harvested. Cleaning and thinning have likely affected the forest stands (Widenfalk & Weslien 2009) and could be one factor that led to a decrease in the proportion of deciduous species between <1975 and <1993 and between <2013 and <2019. The reason for the low proportion of deciduous species in the <2019 sites could also be due to the slow regeneration of broadleaf trees in Sweden. Broadleaf trees are almost always naturally regenerated in Sweden (Hallsby 2013). Naturally regeneration of deciduous trees takes between 3-5 years before the seedlings have established (Karlsson 2001). The forest remaining in the buffers made in age class <2019 had probably similar structure as the forest that was harvested before 1975 (Åström 2020).

For distance from stream, the hypothesis was that the species richness and proportion of deciduous species would be highest closest to the stream compared to far away from the stream. This hypothesis was mostly supported. The species richness was highest closest to the stream but the difference between 5-10 meters and 10-15 meters from the stream was small (*Figure 4*). For the proportion of deciduous species versus distance from stream, the highest proportion of deciduous species was closest to the stream (0-5 meters) (*Figure 6).*

The higher species richness closest to the stream could be explained by the closeness to the water. This could be due to management strategies where it was suggested to leave, for example, deciduous species closest to the water in most management action (Skogsstyrelsen 2014; Ring *et al.* 2018). A higher species richness closer to the stream has been shown in other studies from northern Scandinavia. This result of species richness goes in line with the result of Åström´s thesis (Åström 2020), even if Åström only used shrubs instead of both shrubs and trees combined. In the boreal region riparian zones compared to upland forest had a higher number of vascular plant species (Nilsson *et al.* 2013; Kuglerová *et al.* 2014). A recently written article by Ring et al. (2018) showed that the closest area to the stream (0-5 meter) had a higher stem volume and a higher share of *Alnus spp*, compared to longer distances from the stream. This could be due to the intermediate disturbance hypothesis since land closest to the stream gets flooded which can represent disturbance of intermediate magnitude (Connell 1978). Additionally, the growing conditions, in particular, the soil moisture, could be different closest to the stream (Ring *et al.* 2018).

4.1.2. Stumps

The hypothesis for the number of deciduous stumps compared to age class was that it would decrease over time. The hypothesis about the number of deciduous stumps across age classes was mainly supported (*Figure 7*). The result of the number deciduous and conifer stumps/ha showed that there were more conifer stumps/ha in all age classes (*Figure 7*). Probably, the forest in this study had less deciduous trees available and when the forest was harvested the number of deciduous stumps/ha would be less, compared to conifers. This cannot be said with certainty because of no information about the number of standing trees before the stumps were created. The decrease over time for number deciduous stumps/ha and the lower number of deciduous stumps/ha compared to conifer stumps/ha (*Figure 7*) could go in line with the goal of the Swedish Forest Agency which want to maintain deciduous trees close to the streams (Skogsstyrelsen 2014). The result does not necessarily mean that it is more deciduous trees left standing close to the streams in the forest due to less deciduous stumps.

It is possible that selective harvesting has occurred in the inventoried sites because even in sites which had retained riparian buffers, stumps were observed. This means that some trees were harvested within the buffers. Selective harvesting could be good because the riparian buffer can still provide protection to the stream meanwhile disturbance and variation within the buffer are created. In addition to this, timber extraction and profit from the buffer can be achieved with selective harvesting (Richardson *et al.* 2012). There were no or a thin buffer in age class <1975 and <1993 (*Figure 15*), which could have led to a high number of both conifer and deciduous stumps in that age classes. This pattern was not observed probably due to the sampling error that old stumps have decomposed and was hard to see.

For the distance from stream, the hypothesis was that the number of deciduous stumps would increase with increased distance from stream. For the number of deciduous stumps compared to distance from stream, the hypothesis was rejected because of a not statistically significant result (*Appendix 1*). The result of the number deciduous and conifer stumps/ha showed that there were more conifer stumps/ha in all different distances from the stream. The result could go in line with the SMOs stated by the Swedish Forest Agency, which want to maintain deciduous trees close to streams for preserving the species richness (Skogsstyrelsen 2014).

The trend of number deciduous stumps/ha showed no distinct difference between the different distances from the stream. Approximately the same number of deciduous trees have been harvested in every distance from the stream (0-5, 5-10 and 10-15 meters) (*Figure 8*). According to the SMOs the number of deciduous stumps/ha could have been higher 10-15 meters from the stream in order to leave deciduous trees up to 10 meters from the stream (Skogsstyrelsen 2014). This has not been showed in the results of this study and one explanation of this could be that in every distance from the stream all different age classes are included.

The higher number of conifer stumps/ha could be a sign of the naturally occurring species in the area. A lower proportion of deciduous species with increasing distance from the stream did most likely affect the number of deciduous and conifer stumps/ha inventoried in every site (*Figure 6 and Figure 8*). A high proportion of conifer species could have led to a higher number of conifer trees harvested.

The hypothesis for the proportion of deciduous stumps compared to age class was that it would decrease over time. The hypothesis about the proportion of deciduous stumps across age classes was mainly supported (*Appendix 1*). The proportion of deciduous stumps has decreased over time which should correspond to an increase in the proportion of deciduous species remaining in the riparian zone, but it did not (*Figure 5 and Appendix 1)*. The reason for this result is probably an effect of different management actions to different stands over the rotation period. If more deciduous trees were left standing in the riparian zone, compared to conifer trees, it is better for protection of the stream, than if there was no buffer or a buffer with just conifers (Skogsstyrelsen 2014). To achieve a high species richness and a high biodiversity, a mix of conifers- and deciduous species in the riparian buffer are required (Nilsson & Svedmark 2002). The conclusion from this is that there is naturally very few deciduous species in the inventoried sites, which could be a result of past management (Widenfalk & Weslien 2009).

The hypothesis also included that a higher proportion of conifer stumps versus the proportion of deciduous stumps would be present after <2013. Between <2013 and <2019 the increase in proportion of deciduous stumps was negligible. The proportion of conifer stumps was higher than the proportion of deciduous stumps in <2019, supporting the hypothesis (*Figure 9 and Appendix 1).* The proportion of deciduous stumps should have decreased over time due to the Swedish Forest Agency´s SMOs, from 2013, including not harvesting deciduous trees in the riparian buffer (Skogsstyrelsen 2014). The result from this study (higher proportion of conifer stumps compared to proportion of deciduous stumps in age class <2019) showed that the forestry could be working towards the objectives (*Figure 9 and Appendix 1*). On the other hand, the higher proportion of conifer stumps could be a result of the naturally occurring species in the area. A low number of deciduous species possible to harvest would give a high proportion of conifer stumps.

For the distance from stream, the hypothesis was that the proportion of deciduous stumps would increase with increased distance from stream. For the proportion of deciduous stumps compared to distance from stream, the hypothesis was rejected because of a not statistically significant result (*Appendix 1*). The result of analysing the proportion of both conifer and deciduous stumps showed that the proportion of conifer stumps increased with distance from stream (*Figure 10*). The proportion of deciduous stumps decreased with distance from the stream (*Appendix 1*). The decrease in the proportion of deciduous stumps with distance from stream could be due to the low number of deciduous species as mentioned earlier. This could also reflect the species composition in different areas of the riparian zone. The species composition in riparian zones could be due to different management actions and growing conditions, for example the soil moisture, which benefits deciduous species in wet areas (Ring *et al.* 2018). The relationship between the proportion of conifer and deciduous stumps over time does not reflect the change in forest policy. The new SMOs stated that deciduous species should be left in 10 meters width from the stream (Skogsstyrelsen 2014), which has not been achieved.

4.1.3. Aerial photos

The hypothesis for the width of the riparian buffers was that buffers would become wider over the studied time horizon and before <2013 the buffer width would be small or not existing. The age class <1975 had a small and approximately similar buffer width to age class <2019, age class <1993 did not have a buffer or a small buffer and for the remaining age class, <2013, there was a buffer left at every site but with a wide range in widths (*Figure 15 and Appendix 2*). Thus, the hypothesis was partially supported (*Appendix 1*).

Another particular detail to mention was that only two out of four sites in age class <1975 was possible to measure (*Appendix 2*). Those two sites had buffer widths of almost the same size as the sites in age class <2019. The objective with the riparian buffer seen in age class <1975 were unknown and with few sampling sites it was difficult to make a conclusion about why the width of riparian buffers were similar in age class <2019 as in age class <1975. One reason for the remaining buffer in age class <1975 could be the ability for the machines to drive on wetter areas. With more modern machines with a lower pressure on the ground, the machines gives the ability to drive on wetter areas. Another reason for the riparian buffer to exist, but be small, in <1975 and be lower in <1993 could be due to that the age class <1975 was a time when rests from selective logging could still remain.

The <1993 sites (final felling year of 1985-1993) had a small or not even existing riparian buffer probably because those sites were established in the monocultural even-aged forestry (Ring *et al.* 2018). The increase in the buffer width, between age class <1993 and age class <2013, indicates that the change in the Forestry Act from 1993 had some effect on the protection of streams and on the management of riparian buffers. The addition to the Forestry Act in 2013 has not increased the buffer width. The small buffer width in <2019 could depend on a time lag after introducing the SMOs in 2013 (Hasselquist *et al.* 2019; Åström 2020). Another explanation for the small buffer width in age class <2019, compared to age class <2013, could also depend on narrower streams in the <2019 sites compared to the <2013 sites.

In this study, the average buffer width was 5.8 meters in <2019 (*Figure 15*). Such width is too small to reach the SMOs from 2013, which has stated one tree length as an acceptable buffer width and that all deciduous trees should be left within 10 meters from the stream (Skogsstyrelsen 2014). The results from both this study and from Åström(2020)´s and Jonsson(2018)´s theses are a sign that the policies had some effect after 1993, compared to after the SMOs in 2013, and the forestry sector left a buffer after that year. The result showed only a small part of the stream network and the streams included in this study are small. Small streams have historically been ignored by foresters (Kuglerová *et al.* 2017), and although not significant, there was a trend in the buffer width compared to stream width which confirms that larger streams are more likely to have a larger buffer (*Figure 17*).

The hypothesis for the changes in species richness, proportion of deciduous species and presence of stumps was that it would be due to past forest management. The past management seen in aerial photos was difficult to connect to the results from analysing species richness, proportion of deciduous species and stumps, which reject the hypothesis due to lack of data. More research and stronger correlations between buffer width and the management and characteristics in the riparian zones needs to done. The possibility of having all 7 aerial photos (1963, 1975, 1985, 1993, 2004, 2009 and 2013), of one site, and the ability to see the site in Eniro or Google maps for a newer picture (approximately 2019) gave 8 different pictures in total. The progress of the forest succession could be partly followed in time series of approximately 56 years. The different canopy covers made in the subjective analysis of the aerial photos showed, for example, that the forest went from open to closed, from closed to harvested and the possible left buffer was measured and after that new seedlings came up (*Appendix 2*). Now the cycle starts again and, in the future, a mature forest open and closed and a harvest can be seen. Unfortunately, it was not possible to connect changes of past forest management to changes in species richness, proportion of deciduous species and presence of stumps in riparian zones of different ages. One reason for this, was that cleaning or thinning activities was not possible to see in the aerial photographs. Therefore, past management that has been done before the harvest is unknown. Other reasons that affect the conclusions will be discussed in the strengths and weaknesses part of this section.

Although this study did not explicitly ask for what a good or bad buffer is, couple of things could be concluded from the results. The requirements for buffers on small streams (<3 meters width) are not clear. From the result of this study it was not possible to make any conclusions about the past managements effects on the species composition in the riparian zones, but it was possible to see that policies have had the intention to change the management of the riparian zones. Enormous development both within science and technology has given the forestry sector good tools to manage the forest and riparian zones in a better way for the ecological values compared to the 1970s. Therefore, it is difficult to compare the different years in how the consideration to streams and riparian zones were applied without thinking about the huge improvement in the forestry sector. The latest changes in the protection of the water resource is hard to measure today, probably due to a time lag in implementation (Hasselquist *et al.* 2019; Åström 2020). Recent research has investigated the possibility to use a more flexible buffer width (Kuglerová *et al.* 2014) compared to the fixed width buffer which is common today (Richardson *et al.* 2012).

The possibility to do selective thinning (Richardson *et al.* 2012) could also be an alternative if the objectives for the riparian zone and the streams quality and quantity are promoted. Forestry goals, for example increased biomass harvest, need to be reached in the same time as reduced effect on ecosystem services, for example water quality, are accomplished (Laudon *et al.* 2011). A trade-off is needed when leaving a riparian buffer, mainly weighing the impacts of harvest as an economical benefit to the ecological functions of the riparian buffer. The ecological functions could be for example *"receive water and nutrients from the upslope areas"* and *"habitats for biodiversity"* (Gundersen *et al.* 2010). The forestry management plans could be one example of how the forestry sector could develop to reach the goals of both production and environment (Laudon *et al.* 2011). The future of the stream protection is difficult to predict but the most important objective to reach is that the ecosystem services from the forest and the streams are maintained.

4.2. Strengths and Weaknesses

A reason that made our general hypothesis not possible to support was for example that not all collected data was able to be used. In the dataset received in the beginning of the work with this study, one variable was "unknown stumps". The analyses in this study did not use the stumps that Åström (2020) was not able to assign either conifer- or deciduous stumps. The percentage of unknown stumps was on average 13%. The use of only deciduous- and conifer-classed stumps makes the study's result uncertain and would have been better if it was possible to identify all stumps to species level. Probably, in the older age classes the stumps are more decomposed and covered by mosses (or other vegetation) which made older stumps harder to recognise and classify.

This study had a relatively small geographic area from where the relatively small amount of data was collected. The data from Åström (2020) was from 16 sites within Krycklan Catchment Study area, Vindeln, Västerbotten, Sweden, which made the result applicable on similar sites in at least Västerbotten County but also in northern Sweden. A more general result could have been achieved if the dataset had been collected from more locations from different parts of Sweden.

Due to different resolution of the aerial photographs, only a subjective visual estimation of the amount of forest cover in every riparian zone was made. This led to a result that was based on only visual estimates of the area around the streams. The most difficult thing with analysing the forest in aerial photos was to decide if the mature forest had an open or closed canopy, due to shadows in the aerial photos (*Appendix 2*). As mention in 4.1.3 it was hard to recognise cleanings and thinnings from the aerial photos, which made the analyse of past management insufficient. On the other hand, the buffers were easy to see in contrast to the bare ground after the harvest and those aerial photos are therefore a good tool for estimating buffer width from the past.

Improvement for the aerial photograph evaluation would be if time of the year for each photo was known. If one photo was taken when the leaves had fallen, and other when they were still on the trees the canopy cover could be evaluated differently A good alternative would have been if the aerial photos were taken every year from the same month.

4.3. Conclusion

The results from this study have focused on how past management actions have affected the species richness in riparian zones today. The species richness was lower in the age class <2019 than in <2013 and <1993. The proportion of deciduous species was lowest in <2019. The number and proportion of conifer stumps increased from age class <1993 to age class <2019 and the number and proportion of deciduous stumps had the reverse pattern. Before the change of the Forestry Act in 1993 the riparian buffers were small or absent. After 1993 the riparian buffers were present in varying width. The start of using riparian buffers for protection of streams could be due to the change in the Forestry Act in 1993 when economy and ecology was valued equally. In contrast, the change in how the protection of streams was carried out, in the SMOs from 2013, has not shown any strong effect on the buffer width and tree species composition of the riparian zones today. The answer on this study's question was therefore that it was difficult to see any effects of past management on species richness, proportion of deciduous species and presence of stumps. The significant results for this study could be related to past management, for example cleaning and thinning, but also to succession in the riparian zones and insufficient data makes the answer unsure.

For future research, there should be a focus on how the riparian zones will be or not be a part of the forest management in Sweden. If and how the riparian zones should be managed, with selective harvests or thinnings, is a question for the future. Riparian zones of small streams should be continued to be prioritized in future research because of the importance of the aquatic ecosystems.

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Appendix 1

Results of nested Two-Way-, One-Way ANOVA and regression tests:

*Table S2. Result of the ANOVA tests made in MiniTab (version 18.1). The P-values with statistical significance are shown in bold. *The data for number of deciduous stumps/ha was not normal distributed and it was not possible to transform the data to meet the assumptions of normality. **The test of Average buffer width was done with a One-way ANOVA.*

Response variable	**Predictor**	**P-value**	**F-value**	**DF (Degrees of freedom)**
Species richness	Age class	**<0.001**	19.99	3
Species richness	Distance from stream	**0.019**	4.06	2
Proportion of deciduous species	Age class	**0.008**	4.13	3
Proportion of deciduous species	Distance from stream	**0.024**	3.84	2
Number of conifer stumps/ha	Age class	**<0.001**	6.53	3
Number of conifer stumps/ha	Distance from stream	**<0.001**	8.18	2
Number of deciduous stumps/ha*	Age class	0.059	2.54	3
Number of deciduous stumps/ha*	Distance from stream	0.790	0.24	2
Proportion of conifer stumps	Age class	**<0.001**	7.78	3
Proportion of conifer stumps	Distance from stream	**0.015**	4.45	2
Proportion of deciduous stumps	Age class	**0.019**	3.5	3
Proportion of deciduous stumps	Distance from stream	0.232	1.49	2
Average buffer width**	Age class	**0.014**	5.82	3

Table S3. Result of regression of average buffer width compared to year of creating buffer and stream width. The P-value with statistical significance are shown in bold.

Response variable	Predictor	P-value	F-value	DF (Degrees of freedom)
Log10 Average buffer width	Year of buffer	**0.047**	5.01	1
SQRT Average buffer width	Stream width (m)	0.323	1.09	1

Interval plots and fitted line plots that were not shown in the report:

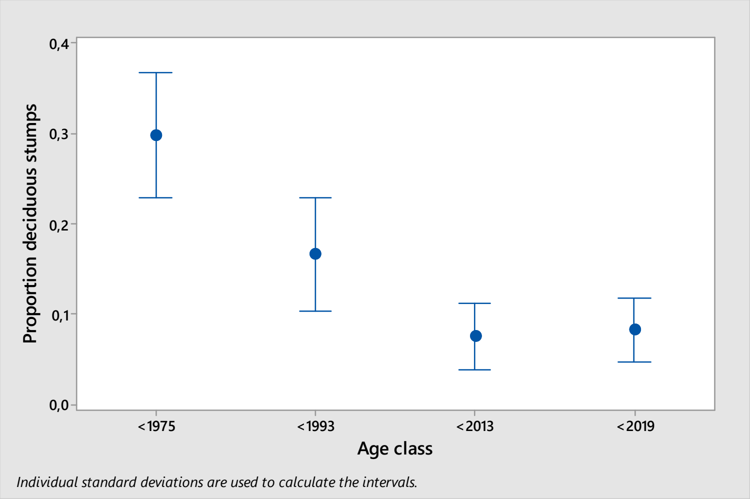

Figure S18. Proportion of deciduous stumps over the different age classes. Bars are one standard error of the mean.

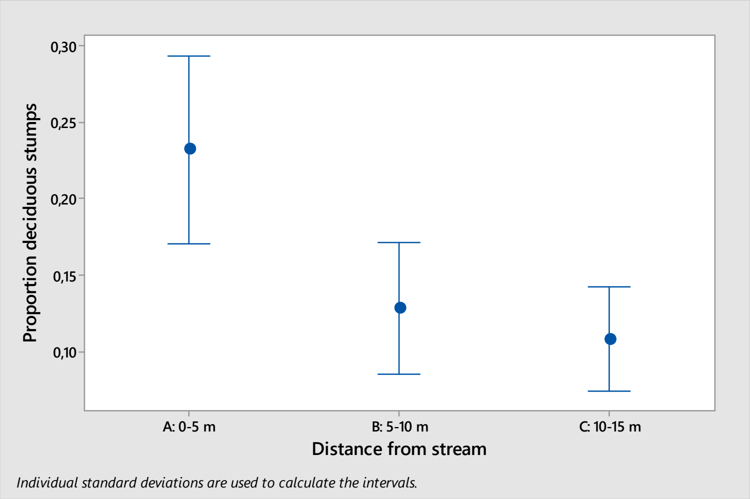

Figure S19. Proportion of deciduous stumps over the different distances of the stream. Bars are one standard error of the mean.

Appendix 2

Result of the subjective visual analysis of inventoried riparian zones on aerial photos showed in table S4. The different classifications presented with a short description below.

H=Harvest
N=No picture available
Y=Seedlings/Young forest
MF_C=Mature forest canopy Closed
MF_O=Mature forest canopy Open
- =No picture on harvest seen, no measure was made

Table S4. Result of the visual analyse of the aerial photos for every site. For the sites where a harvest, H, was detected the buffer width was measured. Year of buffer was when the harvest was located in the aerial photos and the buffer width was measured. Buffer width is the average buffer width on each side of the stream (for 6 different measures, 3 on each side).

OBJECT ID	Age class	Year of buffer	1963	1975	1985	1993	2004	2009	2013	2019	Buffer width (m)
1963site1	<1975	1963	H	Y	Y	MF_O	MF_O	MF_O	MF_C	MF_C	4.67
1963site3	<1975	-	N	MF_O	N	MF_C	N	N	N	MF_C	-
1963site4	<1975	-	N	MF_O	N	MF_C	N	N	N	MF_C	-
1975site1	<1975	1975	MF_C	H	MF_O	MF_O	MF_O	MF_C	MF_C	MF_C	6
1985site1	<1993	1985	MF_O	MF_C	H	Y	Y	MF_O	MF_C	MF_C	1.33
1985site2	<1993	1985	MF_O	MF_O	H	Y	Y	MF_O	MF_O	MF_O	0
1993site1	<1993	1993	MF_O	MF_C	MF_C	H	Y	MF_O	MF_O	MF_C	0
1993site2	<1993	1993	MF_O	MF_O	MF_C	H	Y	Y	MF_O	MF_O	0
2004site1	<2013	2009	MF_O	MF_O	MF_O	MF_C	MF_C	H	Y	Y	19.83
2004site2	<2013	2013	MF O	MF O	MF O	MF_C	MF_C	MF_C	H	Y	3.67
2013site1	<2013	2019	N	MF_O	N	MF_C	N	N	N	H	12.5
2004site4	<2013	2009	MF_O	MF_O	MF_O	MF_C	MF_C	H	Y	Y	10.17
2019site1	<2019	2019	MF_O	MF_O	MF_O	MF_C	MF_C	MF_C	MF_C	H	4.5
2019site2	<2019	2019	MF_O	MF_O	N	MF_C	N	N	MF_C	H	4.5
2019site3	<2019	2019	MF_O	MF_O	MF_C	MF_C	MF_C	MF_C	MF_C	H	6.33
2019site4	<2019	2019	MF_O	MF_O	MF_O	MF_C	MF_C	MF_C	MF_C	H	8