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HEADWATERS AND FORESTRY

Effect of riparian buffers on stream physiochemical properties

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Headwaters and forestry - Effect of riparian buffers on stream physiochemical properties
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Abstract

Forest management practices usually preserves riparian buffers along watercourses in order to protect stream water from physical, chemical and ecological changes caused by clear-cutting. The purpose of this thesis was to investigate whether there is a relationship between the size of the riparian buffer zone along small streams, i.e., headwaters, and a number of physical and chemical attributes of these streams. Twelve headwaters in the Västerbotten county and twelve in Jönköpings county were investigated. These headwaters had a range of buffer widths from “No buffer” (no trees left), Thin buffer” (< 5 m wide), to “Moderate buffer” (>5 m wide) and “Reference” (no harvest) streams were also included. Tested physical and chemical conditions were light in the riparian zone, air and water temperature, stream bed cover and water chemistry. Buffer width had a significant effect on reducing light levels and temperature in the riparian zone; a buffer width over 13 m on each side of the stream was needed to maintain light and air temperature as in reference conditions. Regarding water temperature, increasing sedimentation and water quality, no significant reducing effect of increasing riparian buffer width was found.

Key words: headwaters, forestry management, buffer zone, light, temperature, stream bed cover, water chemistry.

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1 Introduction

Freshwater is a scarce resource. Only 0.8% of all water on earth is in groundwater and surface water bodies (Shiklomanov 1993). Freshwaters, including lakes, watercourses and groundwater, provide humans with a vast number of ecosystem services. Among the most important is provision of clean, drinking water. Half of Sweden's reservoirs of drinking water comes directly from lakes and streams, without the need for extensive purification (Bernes 2011). Not only humans depend on freshwater resources. It is a keystone habitat and resource for number of organisms, both aquatic and terrestrial. In fact, the aquatic and terrestrial parts of the landscape are directly linked together, since the condition of the terrestrial parts of the catchments largely determine the properties of fluvial systems (Erdozain et.al. 2018; Nakano and Murakami 2001). Especially disturbances in the uplands are likely to be reflected in the adjacent watercourses (Ahtiainen and Huttunen 1999; Erdozain et.al. 2018).

The attributes of the riparian zone, i.e., the terrestrial area directly bordering streams, such as vegetation conditions are a regulating factor for the streams. Vegetation stabilizes the stream banks and prevents extensive sediment transport, provides allochthonous organic matter, and maintains shading which contributes to temperature regulation in the water (Lidman et. al. 2017; Kiffney, Richardson and Bull 2003, 2004; Krzeminska 2019; Wallace et.al. 2015). This is important because the streams' physical and chemical conditions in turn determine what kind of organisms and ecosystem processes can exist there. Land use, such as forestry, can change the physical and ecological conditions in the watercourses within the harvested catchments and further downstream (Erdozain et.al. 2018; Göthe, Lepori and Malmqvist 2009). Forestry operations alter hydrology of the entire catchment, typically increasing runoff (Buttle et. al. 2018). This can lead to increase load of fine organic matter, nutrients, sediment and dissolved minerals in to the streams (Ahtiainen and Huttunen 1999; Erdozain et.al. 2018; Schelker et. al. 2012;). If forest operations are conducted directly in the riparian zone, it can cause intensified disturbances in the streams, such as:

- Increasing levels of nutrients together with rising temperature and light due to removal of riparian vegetation. This may cause increased abundance of algae and shift of macroinvertebrate communities and consequently fish. (Ashton, Morgan and Stranko 2014; Nislow and Lowe 2006).
- Elevated stream bank erosion and sediment transport which can in turn also decrease the abundance of fish and invertebrate species which need clean riffle for spawning (Burdon, McIntosh and Harding 2013; Burkhead and Jelks 2001; Sutherland, Meyer and Gardiner 2002).
- Increased levels of dissolved organic carbon (DOC), which is an important part in both abiotic and biotic fluvial functions (Laudon et. al. 2009; Schelker et. al. 2012) For example, whole lake experiments have display shift in food web by increasing bacterial biomass and decrease autotrophic phytoplankton as a reaction to increasing DOC loading (Blomqvist et. al. 2001). High levels of DOC have also been demonstrated to have a negative effect on water pH (Laudon and Buffam 2008; Jonsson et. al. 2017). This may lead to declining species richness and diversity of macroinvertebrates (Baldigo et. al. 2009; Townsend, Hildrew and Francis 1983).

To prevent these negative impacts of forest harvest, management recommendations and practice often retain unharvested strips of forests, i.e., riparian buffers, along watercourses. However, small streams (i.e., headwaters) are often neglected during buffer allocation (Kuglerová et.al. 2017; Ring et. al. 2017; SKSFS 2013:2). This is despite that studies have recognized the importance of healthy headwaters for downstream water quality (Alexander et. al. 2007, Dodds and Oakes 2007). This is because streams form dendritic networks (Grant et al. 2007) and downstream areas are directly dependent on the substances delivered from upstream. Further, it has been estimated that headwater streams form 50-75 % of the total stream network lengths in the world (Downing et al. 2012; Leopold, Wolman and Miller 1964) and about 80 % in Sweden (Bishop et al. 2008), therefore their cumulative impairments could be detrimental to ecosystems services in larger rivers. If we do not protect the source streams the impact on the whole catchment can be devastating.

Recommendations have been made to include headwaters while allocating riparian buffers, but this is still not a common practice in Sweden (Kuglerová et.al. 2017; Ring et. al. 2018). One potential reason why headwaters is typically compromised during buffer allocation is that there is still a debate on how effective buffer zones in protecting the headwaters are and how wide they should be along the small streams (Richardson and Béraud 2014). The assumption is that organisms and processes react predictively to changes in abiotic conditions (Erdozain et.al. 2018; Nakano and Murakami 2001). Therefore, it is important to understand the protective effect of buffers on physical and chemical conditions in headwater streams.

1.1 Purpose

The aim of this thesis is to investigate whether there is a relationship between the width of the buffer zone along headwater streams and the physiochemical conditions in the streams. The conditions that will be tested are light at the water surface, water and air temperature, stream bed cover and water chemistry.

These conditions strongly relate to fundamental functions in the stream ecosystem, such as primary production, organic matter decomposition and algae growth which supply the communities of aquatic insects and consequently fish.

2 Method

The data used for this thesis is based on measurements performed during summer and autumn of 2018 in Sweden within the SOSTPRO project. The data is provided by Lenka Kuglerová, leader for the Swedish part of the project. SOSTPRO "Source Stream (headwater) Protection from forest practices" is a collaboration between University of British Columbia in Canada, University of Oulu in Finland and Swedish Agricultural University, Umeå in Sweden. The SOSTPRO project aims to investigate how different forestry practices around headwaters affect the ecosystem integrity and the ecosystem services both locally and downstream. The project has performed measurements both of the physical and the biological condition in stream with different buffer width (Richardson n.d.) Data used in this thesis is a part of all data within the SOSTPRO project and was selected to fit the purpose of this thesis. Biological data were not available at the time of this thesis.

2.1 Study sites

To assess the effects of different buffer width on conditions in headwater streams, four categories of sites was determined: 1) no buffer (0 – 1 m wide), 2) thin buffer (1 – 5 m wide), 3) moderate buffer (> 5 m wide) and 4) reference with no logging activity nearby the site. Data was collected from two areas in Sweden one in the county of Västerbotten in the northern part of Sweden and one in the county of Jönköping in the southern part of Sweden. Twelve different headwaters, three in each buffer category, within a radius of 100 km^2 where selected in each county. Headwater categories 1-3 were all located in areas where clear-cutting was performed between 2010 and 2016. The selected headwaters had a catchment area of 0.5 – 2.7 km^2 which corresponds to 1-3 m wide channels. The study sites were all designed as a 50 m reach positioned as far downstream as possible within the particular clear-cut. The selected sites were otherwise similar in slope and elevation.

2.2 Data collection

In-situ measurements used for this thesis were:

- Buffer width was measured perpendicular to the stream in four places 10 m apart on both sides.

- Standing tree species in the riparian buffers and their status were counted within four 10x10 m plots, two at each side of the stream. Statuses registered were standing alive and standing dead. Tree species were simplified to tree types in the analysis as coniferous standing alive and standing dead, and deciduous standing alive and standing dead.

- Light in the riparian zone was measured in two ways; 1) with the HOBO Pendant® Temperature/Light 64K Data Logger. There was one logger per site placed ca 1 m above the water surface and the logger was set to record light intensity (lux) and temperature (°C) once every hour during the month July to October; and 2) with a densiometer, a hand-held devise reflecting the degree of canopy openness. Densiometer readings were performed right above the water surface at 19 locations, every 2.5 m along the reach. Daily average, minimum and maximum values from the HOBO logger was calculated and used for statistical analysis.

- Air temperature above the channel and water temperature were also measured with the HOBO loggers. The loggers were set to record temperature once every hour during the month July to October. Daily average, minimum and maximum temperature were calculated from the data set and used for statistical analysis. Because of severe drought during summer 2018 (SMHI 2019), water temperature data were used only from September-October, to avoid temperature record during the drought.

- Stream bed cover was visually estimated as proportions in 10 small quadrates (50 x 50 cm) placed on the stream bottom. In this thesis I used simplified particle size scale, including fine organic material, fine sediment (sum of silt and sand) and coarse sediment (sum of gravel, pebbles and rocks). Woody debris (> 1 m length and > 10 cm DBH) was counted in the entire 50 m stream reach.

- Water chemistry measurements included, DOC (dissolved organic carbon), N-tot (total nitrogen), P-PO4 (phosphorus and phosphate) and pH. Grab samples were collected once a month in June, July, September and October. Samples were filtered in the field (500 µm filter) and store in fridge until analyses (typically within a week of collection). Lab instrument used to analyze the water samples were a Titrator for pH, total organic carbon analyzer (TOC-V CPH) for the DOC and N-tot and an Auto Analyzer (AA3) for the phosphorus and phosphate. Because of the drought during the summer only data from September and October was used. This includes two sampling occasions.

2.3 Statistical analysis

To assess the effect of buffer width on the different physiochemical variables the dataset was analyzed with the Excel Analysis ToolPak. All measurements were checked for normal distribution. Data from the northern and southern sites were analysed separately because preliminary data screening showed large differences between the two regions. Due to the low number of replicates (12 in each region) linear regression was chosen to analyse the relationships between buffer width and the physiochemical conditions in the streams. Buffer width is thereby defined as the explanatory variable of the physiochemical responses. Both the independent and dependent variables are on a continuous scale thus regression analysis is suitable. Reference sites were visualized in the figures but not included in the analysis, because reference sites had infinite buffer width. In addition, a correlation analysis was used to compare the data from the two different way of measuring light in the channel, densiometer and HOBO light logger. Finally, the distribution of standing tree types was visually analysed in relation to the shade given by the canopy in the buffer zone.

3 Result

Both northern and southern sites were dominated by *Picea abies* and *Betula pendula / pubescens*. There was also a few *Pinus sylvestris* and in the southern sites a few *Alnus incana*. Lying dead trees was also dominated by *Picea abies* and *Betula pendula / pubescence,* with a higher proportion of *Picea abies,* in both north and south. In the north, the average bankfull width was 0.9 m ranging between 0.5-1.3 m, average bankfull depth was 0.3 m with a range between 0.2-0.5 m. In the south average bankfull width was 1.3 m ranging between 0.6-3.2 m, average bankfull depth was 0.4 m with a range between 0.3-0.6 m.

3.1 Riparian buffers

The average buffer width among all sites was 11.50 m and the range were 1.14-34.40 m. The narrowest buffer in the north was 3.89 m and the widest was 13.05 m while in the south the narrowest buffer was 1.14 m and the widest was 35.4 m (Table 1). When the average buffer width was calculated from the site measurements it was discovered that one site in the south and one site in the north had been incorrectly categorized (table 1). This was because the buffer width was visually estimated in the field and there were differences in the buffer width on the right and left sides of the stream. Since regression was chosen as analysis method this was not a problem in the analysis.

Table 1 Average buffer width at each site.

Northern sites	Buffer width (m)	Southern sites	Buffer width (m)
No buffer 1N	0.00	No buffer 1S	0.15
No buffer 2N	0.30	No buffer 2S	0.00
No buffer 3N	0.00	No buffer 3S	0.13
Thin buffer 1N	3.89	Thin buffer 1S	18.90
Thin buffer 2N	1.25	Thin buffer 2S	1.14
Thin buffer 3N	3.38	Thin buffer 3S	3.20
Moderate buffer 1N	5.95	Moderate buffer 1S	20.95
Moderate buffer 2N	4.21	Moderate buffer 2S	26.70
Moderate buffer 3N	13.05	Moderate buffer 3S	35.40

3.2 Light in the riparian zone

I found a significantly decreasing light intensity with increasing buffer width in both northern ($R^2 = 0.61$, $p = 0.02$) and southern ($R^2 = 0.59$, $p = 0.02$) Sweden (figure 1).

The two methods, which were used for measuring light in the riparian zone i.e., densiometer (measuring openness) and the logger (measuring light intensity) were highly significantly correlated in both regions (north: $r = 0.84$, $p = 0.008$; south: $r = 0.86$, $p = 0.003$).

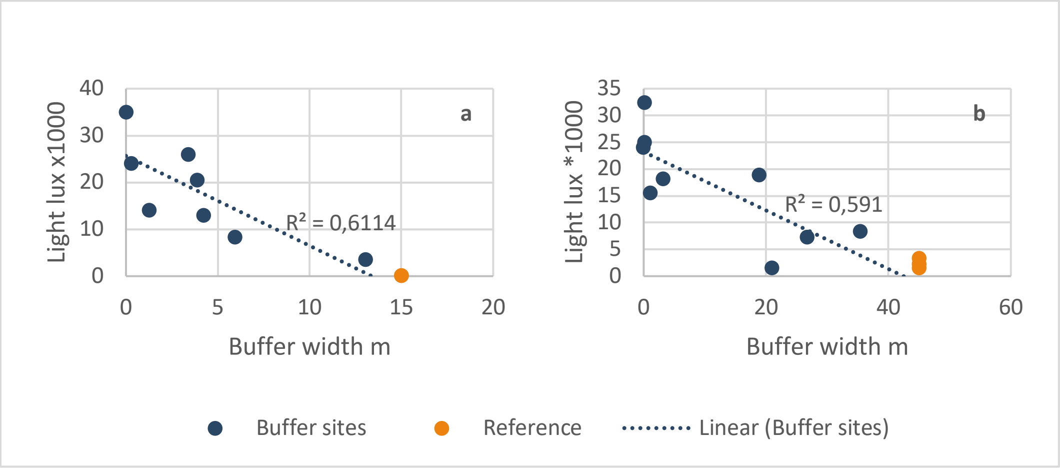

Figure 1 Light in the riparian zone (lux) (regression analysis) as a response to increasing buffer width (meter). Reference sites as visual comparison not included in regression. Northern sites (a) and southern sites (b) are separated.

The riparian buffers were dominated by coniferous trees both in the north and the south, although in the south higher abundance of deciduous trees was observed compared to the north (figure 2). In addition, alive trees were dominating in both regions. Shading was consequently mostly provided by coniferous trees, however in the southern sites, deciduous trees were providing enough shade, especially in the thin buffer category (figure 2).

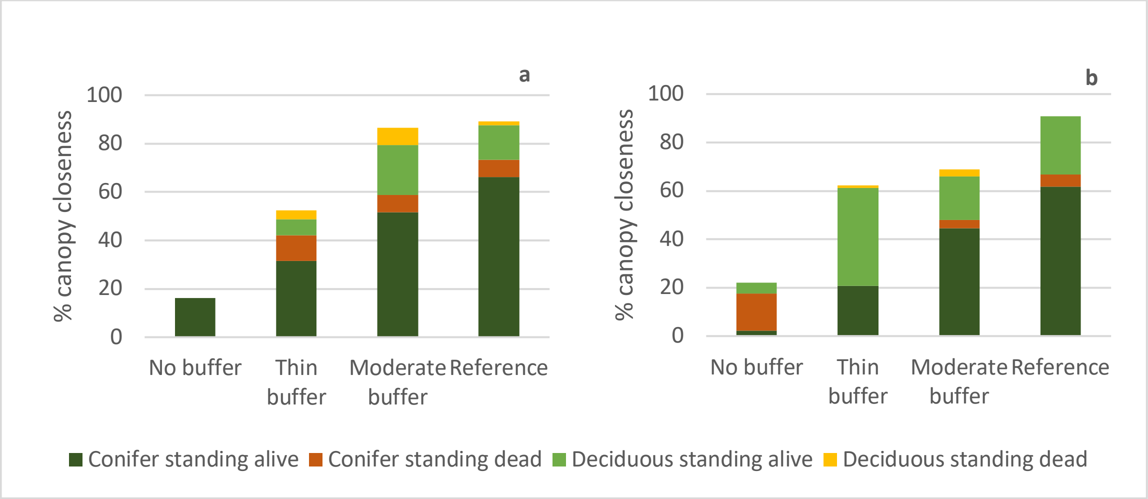

Figure 2 Average percent canopy closeness (measured by densiometer) per buffer width category. The bars are split by its proportion of tree types per buffer width category. Northern sites (a) and southern sites (b) are separated.

3.3 Air temperature

I found a significantly decreasing daily average air temperature during June-October with increasing buffer width in both northern ($R^2 = 0.77$, $p = 0.004$) and southern ($R^2 = 0.77$, $p = 0.002$) Sweden (table2, figure 3). Maximum air temperature was significantly decreasing with increasing buffer width in both north ($R^2 = 0.88$, $p = <0.001$) and south ($R^2 = 0.73$, $p = 0.003$) (table2, figure 3). Minimum air temperature was significantly increasing with increasing buffer width in both north ($R^2 = 0.61$, $p = 0.02$) and south ($R^2 = 0.46$, $p = 0.04$) (table2, figure 3).

Table 2 Air temperature average, minimum and maximum temperature (regression analysis) as a response to increasing buffer width.
Mean (μ), standard error (SE), coefficient of determination (R^2) and *p*-value.
Northern and southern sites are separated

		Average	Min	Max
North df = 6	μ	18.63°	8.77°	29.58°
	SE	0.58	0.75	1.10
	R^2	0.77	0.61	0.88
	p	0.004	0.02	0.001
South df = 7	μ	18.57	9.31	30.30
	SE	1.14	1.11	3.52
	R^2	0.77	0.46	0.73
	p	0.002	0.04	0.003

Further, the range between maximum and minimum temperature declines with increasing buffer width (figure 3).

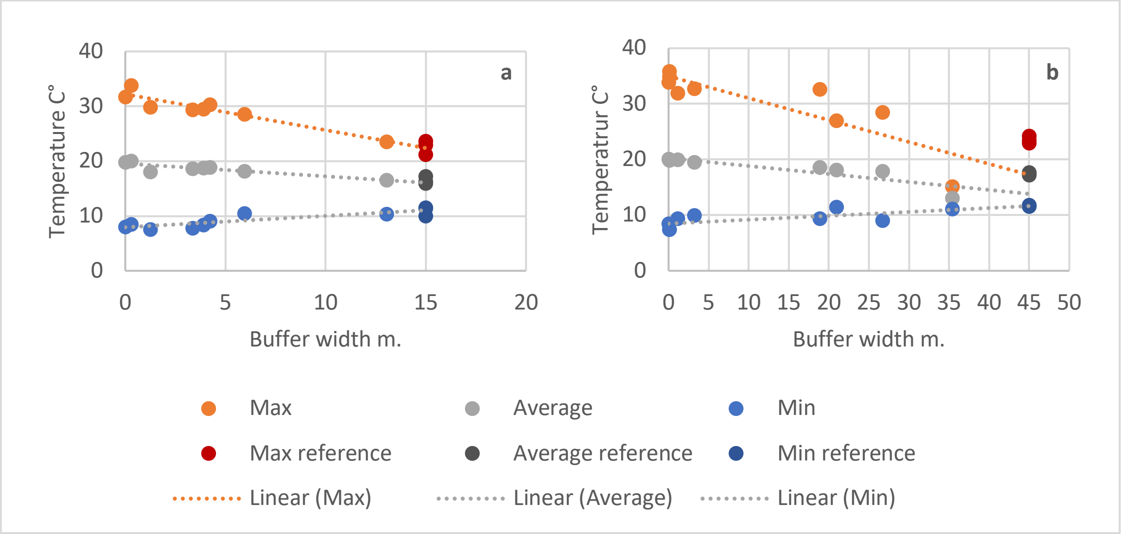

Figure 3 Air temperature, average, minimum and maximum (regression analysis) as a response to increasing buffer width. Reference sites as visual comparison not included in the regression. Northern sites (a) and southern sites (b) are separated.

3.4 Water temperature

Daily average, minimum or maximum water temperatures during September-October did not show any significant response to increasing buffer width, neither in the north nor the south. Average water temperature in the north was 7.03° and the temperature ranged between 1.20-14.77°. In the south the average water temperature was 10.44° and ranged between 4.25-16.55° (table 3, figure 4).

Table 3 Water temperature average, minimum and maximum temperature (regression analysis) as a response to increasing buffer width.
Mean (μ), standard error (SE), coefficient of determination (R^2) and *p*-value.
Northern and southern sites are separated

		Average	Min	Max
North df = 6	μ	7.03°	1.20°	14.77°
	SE	0.32	0.84	3.42
	R^2	0.06	0.30	0.21
	p	0.57	0.16	0.26
South df = 7	μ	10.44	4.25	16.55
	SE	0.50	0.79	1.89
	R^2	0.14	0.13	0.41
	p	0.33	0.34	0.07

A non-significant negative trend in maximum water temperature as a response to an increasing buffer width can be seen in figure 4. Further, the range between maximum and minimum temperature declines with increasing buffer width.

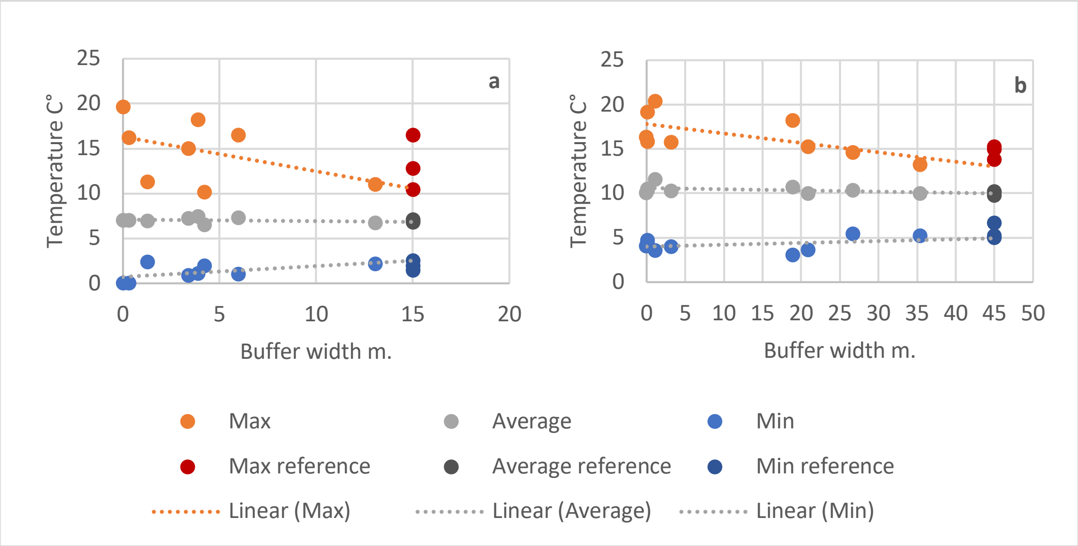

Figure 4 Water temperature, average, minimum and maximum (regression analysis) as a response to increasing buffer width. Reference sites as visual comparison not included in the regression. Northern sites (a) and southern sites (b) are separated.

3.5 Stream bed cover

The regression analysis result of stream bed cover is displayed in table 3, there was no significant response of any of the stream bed cover categories to increasing buffer width. Average stream bed cover among all sites was dominated by fine organic substrate and coarse substrate in both the northern (40% fine organic, 37% coarse, 17% fine inorganic) and southern (33% fine organic, 40% coarse, 21% fine inorganic) sites. Average number of woody debris in the north was 5.67 ranged between 1-12, in the north average number was 7 ranged between 3 and 17 (table 3).

Table 4 Stream bed cover (regression analysis) as a response to increasing buffer width. Mean (µ), min, max, standard error (SE), coefficient of determination (R^2) and *p*-values are presented. Note: fine organic-, fine inorganic- and coarse cover are measured in percent, woody debris in counts. Northern and southern sites are separated

		Fine organic cover %	Fine inorganic cover %	Coarse cover %	Woody debris, counts
North df = 7	µ	40,86	17,69	37,06	5,67
	min	11	0	0	1
	max	89,5	42,5	79,5	12
	SE	23,59	17,67	27,58	3,61
	R^2	0,17	0,02	0,21	0,10
	p-value	0,27	0,72	0,21	0,40
South df = 7	µ	33,03	21,52	40,17	7,44
	min	9	2	0	3
	max	63	50	68,5	17
	SE	19,15	17,51	21,55	4,74
	R^2	0,01	0,01	0,002	0,11
	p-value	0,81	0,81	0,92	0,39

In the north one trend can be seen, although non-significant; positive relationship between coarse substrate cover and increasing buffer width (figure 5).

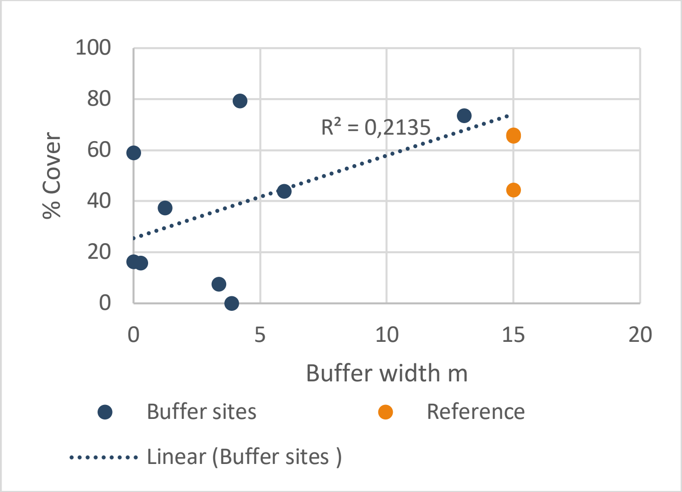

Figure 5 Coarse cover in the northern sites (regression analysis) as a response to increasing buffer width. Reference sites as visual comparison not included in the regression.

3.6 Water chemistry

The regression analysis of water chemistry as a response to changes in buffer width did not show any significant result (table 5). In the south a negative non-significant trend was observed between water pH and increasing buffer width (table 5).

Table 5 Results from water chemistry regression analyses, measure variables as a response to increasing buffer width. Mean (µ), min, max, standard error (SE), coefficient of determination (R^2) and *p*-value are presented. Northern and southern sites are separated.

		DOC (mg/l)	N-tot (mg/l)	P-PO4 (µg/l)	pH
North df = 7	µ	17.15	0.36	3.78	6.02
	min	4.90	0.16	1.03	5.30
	max	32.51	0.63	7.74	6.76
	SE	9.23	0.14	2.22	0.59
	R^2	0.004	0.01	0.06	0.01
	p-value	0.86	0.77	0.52	0.82
South df = 7	µ	21.40	0.79	2.71	6.43
	min	9.09	0.42	1.38	4.91
	max	34.50	2.53	4.17	7.25
	SE	7.59	0.69	1.00	0.62
	R^2	0.16	0.03	0.11	0.37
	p-value	0.28	0.63	0.39	0.08

4. Discussion

The purpose of this thesis was to investigate whether there is a relationship between the size of riparian buffer zone along headwater streams and the physiochemical conditions in these streams. Light in the riparian zone and air temperature were the only measurements that showed significant responses to buffer width. Number of other measurements indicated trends, although not statistically significant. This is most likely caused by the low number of replicates (9) I had for the regression analyses. However, it is also possible that some physiochemical variables do not respond to buffer width, or the responses are detectable only for a short period after harvest.

4.1 Light in the riparian zone

As expected, buffer width had a significant negative effect on light condition above the channel. This have been showed in several previous studies (Elliott and Vose 2016; Kiffney, Richardson and Bull 2003). However, the shading effect of the buffer do not only depend on the width; the character and composition of the vegetation is important as well. A narrow but dense buffer with shrubs and smaller trees will give more shade then wide buffers with only mature but thin trees (DeWalle 2010). In this study it seems that deciduous trees provided similar shading as coniferous. Southern sites have higher number of deciduous trees in each buffer category (except moderate buffers) but still have similar canopy closeness as northern sites, which are dominated by coniferous trees (Figure 2). Compared to reference sites, a buffer of 13 m seems to be enough in the northern sites to protect from elevating solar radiation and in the south a buffer of 20-35 m seams enough (figure 1).

The average values from the light intensity loggers tested for correlation against the average canopy openness, measured with densiometer, showed a significant correlation, but not perfectly linear. This can indicate that these two measurements can act as surrogates but they are not perfectly matching. This is because the densiometer account for heterogeneity of the site (readings were made along the entire 50 m section) whereas the logger account for record over time but only on one spot in the middle of the section.

4.2 Air temperature

The response in air temperature to changes in buffer width was also expected. Brosofske et. al. (1997) studied microclimate in small stream before and after harvesting and found that a buffer zone of 45 m was needed to prevent effect of clear-cutting on microclimate condition in the riparian zone. Spittlehouse et. al. (2004) compared air temperature in forested areas to clear-cut areas and found the open areas to be warmer during the day and slightly cooler at night, compared to forested areas. Open areas tend to have a larger range between minimum and maximum temperature (Brosofske et. al. 1997; Spittlehouse et. al. 2004) which can also be seen in the results of this thesis, for example in the converging trends of range temperature along the buffer width gradient (figure 3). Compared to reference sites a buffer of 13 m seems to be enough in the northern sites to protect from elevating temperature and in the south a buffer of 35 m seams enough (figure 3).

4.3 Water temperature

Since removal of riparian canopy have been showed to cause rising water temperature (Kiffney, Richardson and Bull 2003; Macdonald, MacIsaac and Herunter 2003) it was expected to see significantly lower water temperature in streams situated in the wider buffers. I have not found such results. There are two opposing factors effecting the water temperature, increasing radiation heating the water and increasing groundwater outflow (which is cold) because of the forest removal on the catchment (Buttle 2018). Groundwater outflow was not measured in this study so I could not quantify those opposing factors affecting water temperature. Further, it was not possible to analyze water temperature measurements conducted during the warmest months (June-August) due to drought. It is therefore unknown how water temperature condition would be in a normal Swedish summer (no drought) in these study sites. However, the week non-significant trend seen in figure 4, indicate maximum water temperature declines in response to increasing buffer width. This is an important factor for organisms living in small boreal stream, such as macroinvertebrates and a few fish species, which are often cold-water species (Degerman and Sers 1992). Thus, warming of the water may cause decline in cold-adapted organisms and shifts in the communities such as increasing abundances of algae, and *Chironomidae* a macroinvertebrate family (Kiffney, Richardson and Bull 2003; Nislow and Lowe 2006). Since this shift will further affect the food web it is important to protect streams from elevating temperatures (Kishi et. al. 2005).

4.4 Stream bed cover

The canopy is the primary soars of organic litter to the streams (Lidman et. al 2017), thereby it would have been expected to see a trend of larger proportion of organic stream bed cover the wider the buffer. There was no significant result supporting this.

Loading of fine sediment as an effect of forest harvest have been displayed by Kreutzweiser et. al. (2009) and is acknowledged in the Swedish forestry act (Skogsstyrelsen, 2014) as a problem which buffer management has to prevent. My results did not show that there is a relationship between buffer width and fine sediments on the streambeds. But a non-significant trend displaying a positive response of coarse stream bed cover to buffer width was found (figure 5). However, sediment transport was not measured, rather sediment deposition. It is still possible that the sites with no and thin buffer receive more sediments from the uplands, but these sediments may have been transported downstream. Therefore, for future studies it would be desirable to measure sediment deposition and export. It is well known that extensive sediment transport can affect organisms negatively, for example fish species which need clean riffle for spawning and filter feeding organisms such as macroinvertebrates and mussels (Burdon, McIntosh and Harding 2013; Österling, Arvidsson and Greenberg 2010; Sutherland, Meyer and Gardiner 2002). Therefore, for future studies it would be desirable to measure sediment deposition and export to understand the Swedish conditions regarding forestry operations affecting extensive sediment transport into streams.

4.5 Water chemistry

Water chemistry measurements is an important tool for acquiring knowledge on water quality in surface water bodies. Degradation of water quality will have cascading effect both in the ecosystem and for human water consumption. This is recognized by the EU in the Water Framework Directive, in which two of many important objectives set are; achieve good ecological status in all water bodies and guarantee a long-term sustainable supply of good quality water for human consumption (Directive 2000/60/EC).

Several studies report short-term increased levels of DOC after harvesting (Ahtiainen and Huttunen 1999; Laudon et. al. 2009; Schelker et. al. 2012). In addition, increased levels of DOC have been associated with decreasing pH levels (Jonsson et. al. 2017; Laudon and Buffam 2008). In this thesis, I found a weak (non-significant) trend of declining pH with increasing buffer width in southern Sweden. In the study by Jonsson et. al. (2017) streams in young forest (11 – 50 years) was associated with higher pH compared to streams in old-growth forest and clear-cut areas. My result do parallel with those findings.

Increased levels of N-tot, PO4-P have also been found in several studies (Ahtiainen and Huttunen 1999; Löfgren et. al. 2014), recovery to pre-logging condition may appear in about 5 – 6 years (Futter et. al. 2010). The non-significant result in this thesis regarding N-tot may indicate that some sites already had recovered since some of them was harvest >5 years ago.

A meta-analysis performed by Richardson and Béraud (2014) showed various results of the effects of riparian harvest on water chemistry, sometimes contradictive, for example both positive and negative response of nitrogen concentrations. They suggested that in some cases it could depend on difference in local environmental conditions as well as differences in measurement protocols and experimental design. A study by Blackburn et.al. (2017) explore the source of nitrogen in headwaters in the boreal part of Sweden (nutrient poor and peat rich) and found mobilization and mineralization in the stream and the wet part of the riparian zone, being the main source of nitrogen. In this thesis there is no significant result that can support forestry having impact om water chemistry. If this is a reliable result can be debated because the measurements consist of two grab samples per site in the autumn after an unusual hot and dry summer (SMHI 2019). Further, there may be conditions higher up in the catchment area that affect the watercourses i.e. a mire, lake, agricultural field or another clear-cut. One way to account for unknown site-specific environmental factors maybe to monitor the same streams before and after felling (Ahtiainen and Huttunen 1999; Schelker et. al. 2012). In addition, large-scale explanatory variables, such as whole catchment land use, may be needed to fully understand the terrestrial impact on fluvial system (Dodds and Oakes 2007).

In summery I found significant effect of buffer width on light conditions and air temperature. The results indicate riparian buffer along headwaters have the potential to protect the channel from increasing light and air temperature, a buffer width >13 m was found to be enough for maintaining the same conditions as in reference sites. Regarding rising water temperature, increasing sedimentation of stream bed and degradation of the water quality no significant effect was found. Potential reasons may be that riparian buffers on these particular sites did not mitigate impact from forestry or there was no measurable impact from forestry in these variables. Best management practice in Sweden regarding buffer width is still a subject for future studies.

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