Sediment transport in small streams is related to riparian buffer width

A comparison between wide and narrow riparian buffers

Rasmus Staaf

Bachelor Thesis • 15 credits
Swedish University of Agricultural Sciences, SLU
Faculty of Forest Science
Department of Forest Ecology and Management
Jägmästarprogrammet
Bachelor Thesis in Forest Science • Nr 2022:07
Umeå 2022

Sediment transport in small streams is related to riparian buffer width. A comparison between wide and narrow riparian buffers

Transport av sediment I små bäckar är beroende av bredden på kantzonen. En jämförelse mellan breda och smala kantzoner

Rasmus Staaf

Supervisor:	**Eliza Maher Hasselquist, Swedish University of Agricultural Science (SLU), Department of Forest Ecology and Management**
Examiner:	Nils Henriksson, Swedish University of Agricultural Science (SLU), Department of Forest Ecology and Management

Credits:	15 hp
Level:	First cycle, G2E
Course title:	Bachelor Degree Thesis in Forest Science
Course code:	EX0911
Programme/education:	Forest Science – Master’s Programme, Jägmästarprogrammet
Course coordinating dept:	Department of Forest Ecology and Management
Place of publication:	Umeå
Year of publication:	2022
Title of series:	Bachelor Thesis in Forest Science
Part number:	2022:07

Keywords:	Riparian Zone, Protective Zone, Headwater Stream, Forestry, Clear – cut Harvest, Organic Sediment, Inorganic Sediment, Near Stream Logging

Swedish University of Agricultural Sciences

Faculty of Forest Science

Department of Forest Ecology and Management

Abstract

This study aims to provide information about how different widths of riparian buffers affect the quantity and quality of sediments transported in a small stream after a clear – cut harvest. Small streams have critical influences on downstream rivers and excessive transported sediments can have large negative effects on the aquatic system. A small stream located 45 km north-west from Umeå, Sweden was studied. Traps were used to catch sediments transported along the stream bottom at the end of 100 m long sections of stream that either had a narrow (5m) or wide (15m) riparian buffer or was located within intact forest. The sediment collected was separated into coarse sediment, fine sediment and very fine sediment.

A narrow riparian buffer was found to cause significantly ($p < 0.05$) heavier amounts of coarse transported sediments than a wide riparian buffer after a clear – cut harvest. A narrow riparian buffer caused heavier weights of transported sediments from the pre-harvest and the un-harvested control than the wide riparian buffer. After a clear – cut harvest, the amount of inorganic transported sediments weighed significantly ($p < 0.05$) more than the amount of organic transported sediments. Additionally, it was found that a wide buffer could produce larger amounts of coarse organic transported sediments than a narrow buffer – at least during a wind and rain storm.

With the results from this study, and with support from previous studies, it is suggested that a wide riparian buffer should be used when a clear – cut harvest is made. The wide riparian buffer will better meet the Swedish management objectives regarding sedimentation than a narrow one.

Keywords: Riparian Zone, Protective Zone, Headwater Stream, Forestry, Clear – Cut Harvest, Harvest, Organic Sediment, Inorganic Sediment, Near Stream Logging.

Table of contents

List of tables

List of figures

Abbreviations

SMO	Swedish Strategic Management Objectives
BA	Basal Area
VFS	Very Fine Sediments
TEA	Trollberget Experimental Area
SLU	The Swedish University of Agricultural Science
SE	Standard Error

Introduction

In the forested area of Sweden small streams are important in an ecological and biogeochemical perspective. The small streams make up 70-80% of the total length of the stream network and have critical influences on the downstream rivers (Ågren et al. 2015). These important streams, also called headwater streams, transport nutrients, provide habitat for aquatic organisms and produce sediments (Wohl 2017). Wohl (2017) also points out that these streams are often not recognised as important parts of the stream network and therefore often lack legal protective measures such as riparian buffers. Because they are not seen as important, small streams have a greater risk of being negatively affected or destroyed by land use.

In order to ensure good quality and function of streams, the protection of the riparian zone is important (Hasselquist et al. 2020). The riparian zone is the landscape surrounding a stream and is the border between the aquatic and terrestrial environment (Naiman & Décamps 1997). The riparian zone acts as a filter when upslope water, sediments and nutrients flow through this zone, and this filtering capacity has a regulatory effect on the aquatic system, e.g., protection from excessive nitrogen input (Mayer et al. 2007).

Sweden has Strategic Management Objectives (SMO's) to ensure that the forests are sustainably managed with enough environmental consideration (Andersson et al. 2013). This consideration includes the protection of riparian zones during harvesting. During harvesting, a forested strip of vegetation near the stream should be left untouched, and is referred to as a riparian buffer. The SMO's state that the buffer should sustain ecosystem attributes such as shading, biodiversity, provision of dead wood and food and the reduction of sedimentation (Skogsstyrelsen 2013)

The sedimentation reduction is one important ecosystem attribute that the SMOs are supposed to protect. Excessive sediment transportation in streams can have large negative effects on the aquatic system, fish eggs and fry survival can be reduced (Sutherland et al. 2002), invertebrate community composition can be changed (Kreutzweiser et al. 2005), and hydrological exchange processes can be degraded (Brunke & Gonser 1997). The buffer can provide good protection from excessive sedimentation; buffer widths ranging from 10 to 20 meters have been shown to produce relatively little sedimentation (Gomi et al. 2005). However, studies have showed that harvesting within the buffer is possible and up to 50% of the basal area (BA) can be removed without increased sediment input in streams

(Kreutzweiser et al. 2009). Croke et al. (1999) showed in experiments that compacted disturbed surfaces such as roads and tracks are the dominant sources of sediment input and that actual tree harvest has minimal effect on sedimentation. Kreutzweiser et al. (2009) suggests that harvesting within the riparian zone may be possible if soil disturbance is kept on a minimal level.

The buffers around small streams in Sweden, if present at all, are usually less than 5 meters wide and consists only of 1-2 rows of trees (Kuglerová et al. 2020). Mäenpää et al. (2020) questions the ecological function of narrow buffers as massive windthrows is a major risk. Spruce-dominated, narrow buffers are more likely be affected by windthrows, and thus, are more likely to cause more excessive sediment transport than wide buffers (Hasselquist et al. 2021). The SMOs are supposed to ensure that a buffer exists and that this buffer provides important ecosystem attributes for example reduction of sedimentation (Andersson et al. 2013). However, there is little information how to manage the buffer to meet the objectives (Chellaiah & Kuglerová 2021). When it comes to sedimentation in streams, Chellaiah and Kuglerova (2021) found no relationship between sedimentation and buffer width. However, they acknowledge that they might have missed the peak in sedimentation caused by harvesting, as their study was made 3 – 8 years after harvesting. Sedimentation could have peaked just after harvesting when the soils are still loose. For example, Macdonald et al. (2003) found that suspended sediments in streams have been found to return to normal amounts within 3 years or less.

In this study, I measured how clear-cut harvest protected by wide and narrow buffers affected sediment transport. The SMOs regarding sedimentation can be interpreted as there will be no (or minimal) difference in sedimentation before and after harvesting. The results from this study can help us better understand if a wide or narrow buffer best meet these SMOs. In contrast to Chellaiah and Kuglerova (2021), this data is collected directly before and after harvesting and will, thus, give a better view on what is happening directly after harvesting regarding sedimentation.

1.1 Aim

The study aims to provide information on how riparian buffers of different widths can affect the quality (i.e., inorganic vs. organic sediments) and quantity of sediments transported in a small stream impacted by clear-cut harvesting.

1.2 Research Questions

1. What is the difference in the amount and size of sediment as well as quality (i.e., inorganic vs. organic) transported in a narrow riparian buffer compared to a wide one?
2. Does a narrow (5m) or a wide (15m) riparian buffer better prevent changes in sediment transport after harvest and thus better meet the SMOs?

1.3 Hypotheses

1. I hypothesize that a narrow (5m) riparian buffer will cause more sediment transport (i.e., inorganic + organic sediments) than a wide one (15m) after the adjacent stand is clear – cut harvested, but that the wide buffer will produce a larger amount of organic sediments.
2. I hypothesize that the amount of sediment transported in a narrow buffer will differ more from an unharvested control site than the wide buffer.

Method and Material

The area of this study was at Trollberget Experimental Area (TEA), which is a boreal forest approximately 45km northwest from Umeå, Sweden. In the fall of 2018 this area became an experimental area when water quality stations were placed there. This site is now used for various experimental projects including, forests harvesting, soil preparation and riparian buffer design. The forest surrounding the study stream is dominated by conifers such as Norway Spruce (*Picea abies*) and Scots Pine (*Pinus sylvestris*). In the area there are iron podzols that are dry to moist but closer to the stream there are more peat-like soils. The study stream is approximately 1 meter wide and belongs to the Vindeln River Catchment and has its outlet in the Gulf of Bothnia. The design of the experiment along the stream consisted of 3 sites (1,2 and 3), each with a 100m long section of a narrow (5m) buffer and a 100m long section of a wide (15m) buffer (Figure 1).

Lenka Kuglerova and Eliza Maher Hasselquist, both employees at the Swedish University of Agricultural Science (SLU) collected the data. In this study only data from site 1 and 3 were used, the data from site 1 to test the treatment (wide and narrow buffer width) and the data from site 3 as un-harvested control. The forest around site 1 was clear-cut in August the 15th and at site 3 there were still a forest surrounding the stream, with no recent forestry measures made. this provided a set up for a before – after – control – impact/treatment (BACI) experiment (Eberhardt 1976 see Conner et al. 2016). In October 2018 a wind and rain storm occurred that resulted in large amounts of windthrows both in the narrow and wide buffer (*SLU* 2022).

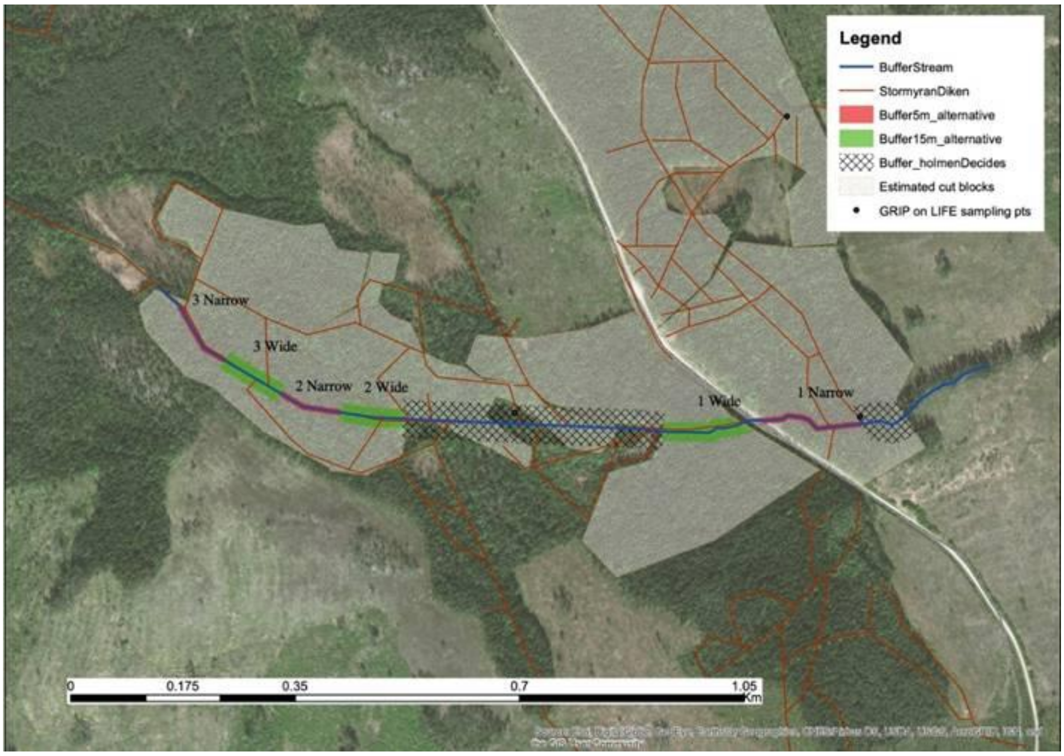

Figure 1. The study stream and the 3 different sites along it (1,2,3) where the samples were collected. Figure made by Lenka Kuglerova.

The method used when collecting the samples was inspired by the work of Kreutzweiser et al. (2009). Traps were used to catch the sediment transported along the stream bed. The traps consisted of plastic boxes that were 17 cm long, 17 cm wide and 5 cm deep. These were then dug into the bottom of the stream so that the top of the box was level with the stream bed. These were then weighed down by washed stones of a diameter between 1.5 – 2.5 cm. The tops of the boxes were open but with a 1.5 cm mesh net on them as an added measure to prevent traps from floating away. The open tops allowed sediments to be deposited but also re-suspended by a variable stream discharge. Three traps were placed in the middle of the stream in the end of the respective buffer widths in all of the sites. The samples were collected monthly, 2-June to 2-July, 2-July to 27-August, 27-August to 2-October and finally 2-October to 27-October. When the traps were emptied, the contents were transferred to a 1L storage container, moved to a freezer within 4 hours, and stored frozen until lab processing.

The processing in the lab is based on the work done by Kreutzweiser et al. (2009). It started with a separation of different sized sediments, coarse sediments (larger than 1mm), fine sediments (250 µm to 1mm) and very fine sediments (VFS) that were smaller than 250 µm. This was done by washing the sediments through sieves of 1 mm and of 250 µm, the amount of water used was noted. The sediments that were retained on the sieves were moved to labelled aluminium trays and later dried for two days at 60^{o}C. After two days the sediments were weighed and then put in a muffle furnace and were combusted in an increasing temperature, 1 hour to get to 100 ^{o}C, 30 minutes to get to 300 ^{o}C and 30 minutes to get to 500 ^{o}C. When the sediments had cooled, they were re-weighed in order to get the ash free dry weights (organic fraction) and the ash weights (inorganic fraction). Sediments that were washed through the 250 µm sieve were collected in a bucket and suspended by using a stir-bar on a magnetic stir-plate at a consistent speed. Later, a known number of 25mL aliquots were withdrawn at a constant depth using a 30mL syringe. The aliquots were then placed into a suction filter apparatus with a pre-ashed, 0.5-mm glass-fibre filter that had been stored in a desiccator before use. Aliquots were added to a point when the filter would not pass any more water. However, the filter would always pass water, just very slowly. The amount of water used could be adjusted based on the amount of sediment collected on the filter. In the case of water containing very fine, silty sediments that would almost immediately clog the filter at least 50mL for each sample was filtered. If 50mL of water was impossible to filter, a second filter was used so the total amount of water between the two filters were 50mL. The total subsample was then calculated from the number of aliquots filtered and the volume of water collected. The sediment collected was then dried for two days at 60 ^{o}C and was later combusted in a muffle furnace following the same procedure already described in order to provide organic and inorganic fractions of VFS. The data collected were later put in a raw-data excel file.

The collected data was analysed in two ways, with data from October and without data from October. This was done in order to exclude the extreme values caused by the storm in October, that could overwhelm the effect of the harvest and buffer width treatment.

The two data sets, with and without October were analysed in the software Rstudio. An Anova type 2 test was used to test the effects of buffer width and month on the weight of transported sediments. However, the data used sometimes showed no normal distribution, according to a shapiro test ($p<0.05$). This problem was fixed by transforming the data to logarithmic values using log10.

Results

An overview of how much sediments were transported during the studied months is visible in table 1. There was a significant difference in the weight of transported sediments between the month of October and the rest of the months ($p<0.05$), as seen in figure 2.

Table 1. Means of sediments transported during each month depending if there was a wide (W) or narrow (N) riparian buffer or in control (C). Numbers in parentheses denote the standard error. During October there was only one value for fine sediments in a wide buffer, hence no standard error. (-) denote the lack of standard error.

Inorganic + organic transported sediments									
Months	**VFS (g/L)**			**Fine (g)**			**Coarse (g)**		
	W	N	C	W	N	C	W	N	C
Jul	*0.18 (± 0.02)*	*0.27 (±0.02)*	*0.21 (±0.01)*	*0.81 (±0.09)*	*1.07 (±0.21)*	*0.12 (±0.01)*	*1.99 (±0.12)*	*1.47 (±0.15)*	*0.33 (±0.03)*
Aug	*0.28 (±0.02)*	*0.30 (±0.02)*	*0.24 (±0.02)*	*0.52 (±0.03)*	*0.65 (±0.08)*	*0.10 (±0.00)*	*1.46 (±0.14)*	*2.18 (±0.32)*	*0.14 (±0.01)*
Sept	*0.35 (±0.05)*	*0.22 (±0.03)*	*0.11 (±0.02)*	*0.48 (±0.05)*	*2.56 (±0.15)*	*0.15 (±0.03)*	*0.22 (±0.01)*	*6.15 (±0.80)*	*0.46 (±0.00)*
Oct	*0.73 (±0.17)*	*3.92 (±0.54)*	*1.26 (±0.17)*	*31.13 (-)*	*24.64 (±2.65)*	*11.71 (±2.05)*	*534.28 (±73.80)*	*633.28 (±54.23)*	*55.20 (±8.78)*

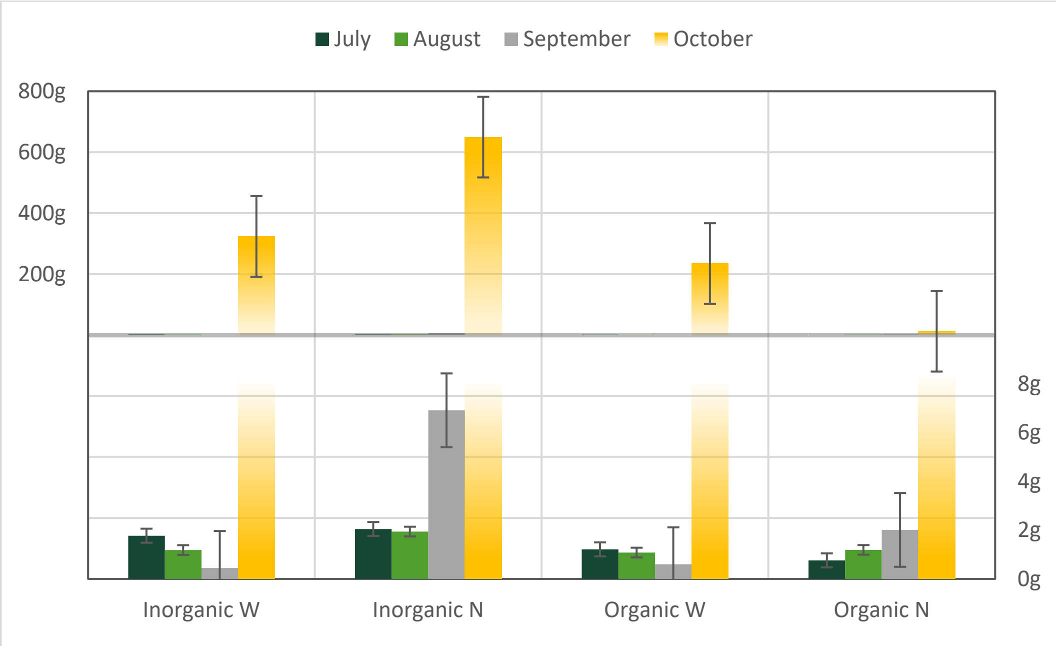

Figure 2. Average (±SE) weight of all sizes of inorganic (left) and organic sediments (right) transported in the study stream depending on whether or not it had a wide or narrow buffer. July and August show transport pre-treatment – when the forest was still standing, while September shows the results after the wide (W) and narrow (N) buffers were created when the adjacent forest was harvested. In October, there was a storm and the sediment transport was orders of magnitude higher, thus, the y-axis has a break in it to be able to include the values on the same graph.

Overall, I found a trend that a wide buffer transported less sediment than a narrow buffer among all months (Table 1, Figures 3, 4 & 5). After the clear-cut harvesting was made in the middle of August, a significant difference in weight of transported sediments between a wide and a narrow buffer was visible first in September (after harvest) ($p < 0.05$, Table 2, Figure 2). In September, a narrow buffer caused heavier amounts of coarse sediments to be transported than a wide buffer ($p < 0.05$, Table 2, Figures 3). No major difference was visible between a narrow and a wide buffer in July (before harvest) or in August (during harvest) ($p > 0.05$, Table 2).

A narrow buffer caused heavier amounts of fine sediments than the control in September and heavier coarse sediments in August and September ($p < 0.05$, Figures 3 & 4). A wide buffer caused heavier amounts of coarse sediments than the control in July and August ($p < 0.05$, Figure 3). There was no major difference of transported VFS between a narrow and a wide buffer or between any of the widths and the control ($p > 0.05$, Figure 5).

There were only differences between inorganic and organic transported sediments during the month of October ($p < 0.05$, Figure 2). However, I found that there were differences between inorganic and organic sediments during other months when examining the sediment sizes individually. These differences occurred after harvest, for VFS in September ($p = 0.018$), for fine sediments in October ($p < 0.0001$) and for coarse sediments in October ($p = 0.00063$)

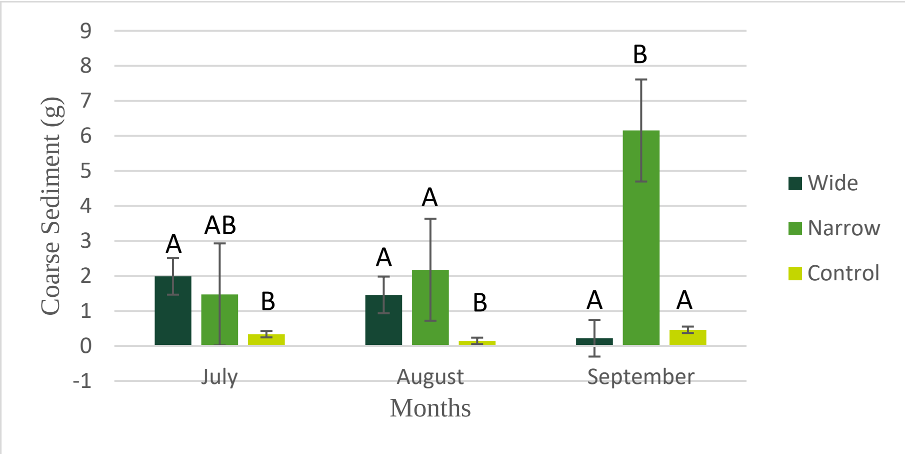

Figure 3. Average (±SE) weight of coarse sediments transported in the study stream depending on whether or not it has a wide or narrow buffer, compared to the control. July and August show transport pre-treatment – when the forest was still standing, while September shows the results after the wide and narrow buffers were created when the adjacent forest was harvested. Different letters denote significant differences (p < 0.05) within months (i.e., A differs from B, AB does not differ from A or B).

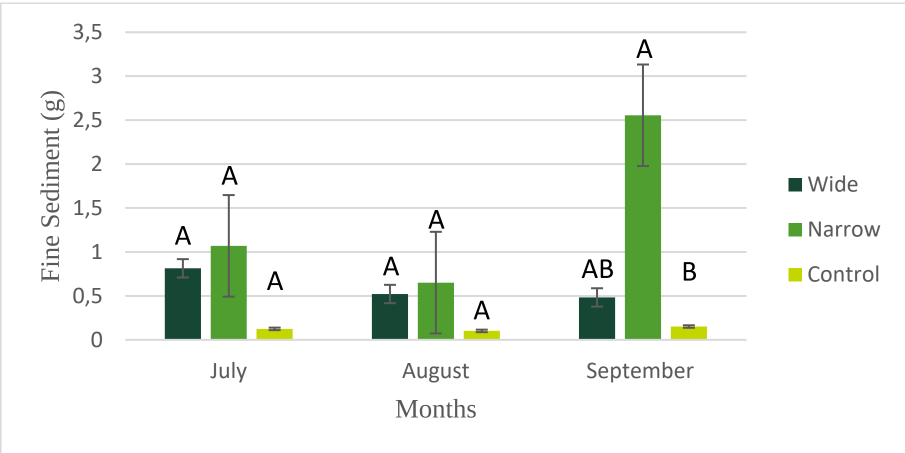

Figure 4. Average (±SE) weight of fine sediments transported in the study stream depending on whether or not it has a wide or narrow buffer, compared to the control. July and August show transport pre-treatment – when the forest was still standing, while September shows the results after the wide and narrow buffers were created when the adjacent forest was harvested. Different letters denote significant differences (p < 0.05) within months (i.e., A differs from B, AB does not differ from A or B).

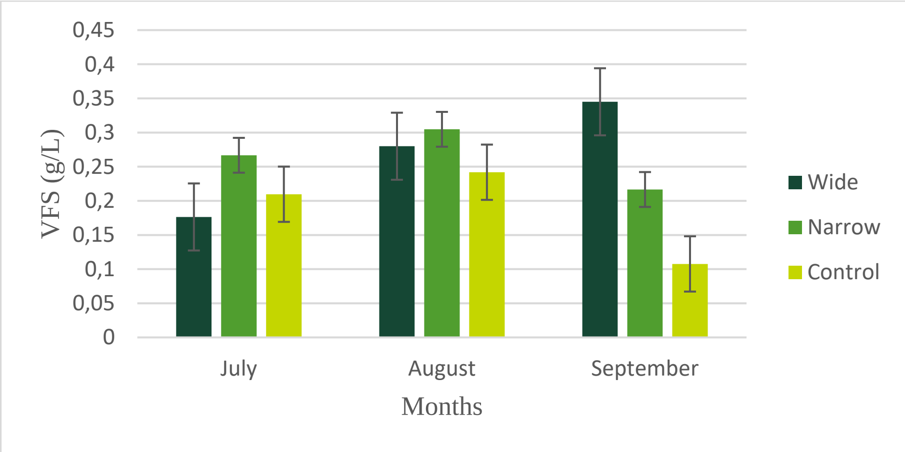

Figure 5. Average (±SE) weight of VFS transported in the study stream depending on whether or not it has a wide or narrow buffer, compared to the control. July and August show transport pre-treatment – when the forest was still standing, while September shows the results after the wide and narrow buffers were created when the adjacent forest was harvested. There were no significant differences within months ($p < 0.05$).

*Table 2. Showing the P-values between the wide and narrow buffers and the p-values between the two buffer widths and control for each month. Significance level = $p < 0.05$ * denotes a significant difference.*

Difference between buffer widths (N,W) and control (C)	P-value VFS	P-value Fine	P-value Coarse
N-C July	*0.9997650*	*0.1502966*	*0.1390162*
N-C August	*0.9995226*	*0.1723582*	*0.0018405**
N-C September	*0.9946897*	*0.0084004**	*0.0156958**
W-C July	*0.9999961*	*0.1665189*	*0.0288950**
W-C August	*0.9993600*	*0.2360782*	*0.0058291**
W-C September	*0.7029403*	*0.4567621*	*0.9015044*
W-N July	*0.9941489*	*1.0000000*	*0.9905244*
W-N August	*0.9999996*	*0.9999998*	*0.9990654*
W-N September	*0.9849763*	*0.3660126*	*0.0013188**

Discussion

The most important findings in this study were that a narrow buffer caused more coarse sediments to be transported downstream after a clear – cut harvest than a wide buffer. I also found that a wide buffer better met the SMOs regarding sedimentation than a narrow buffer. With these results, my research questions could be answered and my hypotheses supported.

4.1 Difference in amount and size

In my first research question, I asked if there would be a difference in the amount and size of sediments being transported, depending if there was a narrow or wide buffer. October differed significantly ($p < 0.05$) in the weight of transported sediments from all the other months, regardless if there was a narrow or wide buffer. This difference can be explained by an extreme event - a wind and rain storm that occurred in the middle of October (SLU 2022). However, a narrow buffer caused heavier amounts of transported VFS and coarse sediments (Table 1) than a wide one. This suggest that a wide buffer is better in preventing sedimentation during storms than a narrow buffer, but none of the widths can prevent the excessive sedimentation caused by an extreme event.

When combining the results from figures 3 – 5 and table 2 where the storm was excluded, I found more transported sediments after harvest, regardless if a narrow or wide buffer was used. However, a narrow buffer consistently exported more sediments than the wide buffer and the un-harvested control site ($p < 0.05$). A narrow buffer caused significantly more transported coarse sediments than the wide buffer during September, after the harvest (Table 2). This difference between narrow and wide buffers could depend on a number of things, but because the difference mainly is in coarse sediments a probable explanation is likely windthrows. These windthrows and the disturbance of riparian soil from the exposed root wads could lead to large sized sediments entering the stream. This explanation is in line with Mäenpää et al. (2020), questioning the function of narrow buffers.

I found support for my first hypothesis, that a narrow buffer will cause more sediment transport than a wide one after an adjacent clear – cut. The difference was found in the weight of coarse transported sediments ($p < 0.05$, Table 2). However, when looking at figure 3 – 5 it is also shown that the weight of fine sediments differed between a wide and narrow buffer after harvest, although not significantly.

According to Gomi et al. (2005) buffer widths ranging from 10 – 20 m produced relatively little sedimentation and Croke et al. (1999) states that one of the dominant sources of sediment inputs are disturbed surfaces such as machine tracks. This together with the fact that a narrow buffer is more prone to windthrows (Mäenpää et al. 2020) are plausible explanations of my findings.

4.2 Differences between inorganic transported sediments and organic transported sediments

Additionally, my first research question asked if there was a difference between transported organic (OTS) and inorganic sediments (ITS) depending if there was a narrow or wide buffer. The finding that ITS are heavier than OTS for every month, as seen in figure 2 does not necessary mean that the amount of ITS is greater than OTS, only that it weighs more. Each ITS particle probably weighs more than an equally large OTS particle. The fact that the difference between ITS and OTS for the individual sizes occurred only after the clear – cut harvesting, suggests that an adjacent clear – cut might alter the sediment quality (i.e., inorganic vs. organic).

When comparing wide and narrow buffers for ITS and OTS respectively, the coarse OTS from the wide buffer weighed more than the coarse OTS from the narrow buffer after the storm in the month of October (Figure 2). This is the opposite of my previous findings, indicating that a narrow buffer causes heavier amounts of transported sediments. This can be explained by the storm in October and that there was more organic material available to enter the stream in a wide buffer than in a narrow one. My first hypothesis, stating that wide buffers will produce larger amounts of organic sediments than narrow buffers was partially supported. Wide buffers can produce larger amounts of coarse organic sediments than a narrow buffer – at least during an extreme event.

4.3 Best width to prevent changes in sediment transport

My second research question related to the Swedish management objectives (SMOs) regarding sedimentation which can be interpreted as there will be no (or minimal) change in the amount of transported sediments after harvest. To answer this, I determined which of the two buffers had more similar values of transported sediments to before clear – cut and control values. The control shows fairly stable monthly averages of transported sediments before the storm hit in October (Figure

3,4 and 5). I found support for the second part of my hypothesis, that a narrow buffer will differ more from the control than a wide buffer. When comparing how the wide and narrow buffer differs from the control, the narrow buffer seemed to cause significant differences in the amount of transported sediments more often ($p < 0.05$, Figures 3,4 and 5). After harvest (September), it is only the narrow buffer that differed from the control ($p < 0.05$, Figure 3). This suggests that a wide buffer is better in preventing changes in the amount of transported sediments after a clear – cut harvest, and thus, better meet the SMOs.

4.4 Comparison with already made studies

Chellaiah and Kuglerova (2021) found no trends that buffer width affects sedimentation and that sediment cover was similar in un-harvested reference sites. I found the opposite, that buffer width affects the amount of coarse sediments being transported. My study also shows, in contrast to Chellaiah and Kuglerova (2021) that a narrow buffer caused heavier amounts of transported fine and coarse sediments ($p<0.05$) than un-harvested control sites. The way the data was collected in the respective studies could be a reason why the results differ. Chellaiah and Kuglerova's (2021) results are based on visual snapshots in several streams, I studied one single stream but with data collected for whole months. Both studies have their respective pros and cons but one big advantage in my study is that I compared samples from the study stream that were collected directly before, during and directly after harvest. Chellaiah and Kuglerova (2021) might have missed the peak in excessive sedimentation caused by harvest, as their study was conducted 3 – 8 years after harvest.

My results are similar to Nieminen et al. (2005), stating that wide buffer sizes are more effective in reducing sediment concentrations than narrow ones. The questionable function of narrow buffers stated by Mäenpää et al. (2020) also matches with my findings. Mäenpää et al. (2020) compared 15m and 30m buffers and found that the narrower buffer was more susceptible to blow down. My findings that wide, 15m buffers are better in preventing changes in the amount of transported sediments than narrow buffers agree with Goomi et al. (2005), showing that buffers between 10 – 20 meter produce little excessive sediments.

Kreutzweiser et al. (2009) found that up to 50 % of the basal area in buffers could be harvested without any significant risk of increasing sediment input to streams. My study indicates that harvesting near the stream could lead to an increased sediment production. However, the two studies are difficult to compare. The buffer widths in the study of Kreutzweiser et al. (2009) ranged from 30 – 100 meters and these were harvested in late winter to minimize ground disturbance. The buffers in my study ranged from 5 – 15 meters and the adjacent forest was clear – cut in late summer. The combined results from the two studies suggests that no harvesting should be done closer than 15 meters to the stream and that careful harvesting can be done in extra wide buffers (30 – 100 meters).

4.5 Sources of error

There are a few things in my study that could have contributed to errors in the result. The study only examines one site with treatments along one stream. This results in few samples and difficulties in making reliable conclusions, especially when the standard error of the samples was relatively high (Table 1) and the data set contained many extreme values.

In this study, the samples were collected at the end of each buffer width. This results in not knowing for certain from where the collected sediments originate from. Sediments collected at one buffer width could possibly originate from upstream where other treatments have been made. A study where the collected weights at the end of the buffer width is subtracted with weights from the beginning of the buffer width should give more accurate results. Such a study would only show the weight of sediments that originate from that particular buffer width.

Another source of error could be that the narrow buffer is located downstream from a gravel road. Goomi et al. (2005) states that one of the external sources of sediments into streams are roads, Christie & Fletcher (1999) identified road fill materials as the main source of sediments in streams in areas that were harvested. The collected data from the stream in the narrow buffer could therefore be higher than normal due to the road upstream, making the comparison to the wide buffer located upstream from the road less reliable.

4.6 Conclusion

I found that riparian buffer width affects the amount of transported coarse sediments in a small stream after a clear – cut harvest. Furthermore, I found that a narrow riparian buffer caused heavier amounts of transported coarse sediments than a wide riparian buffer. My hypotheses were supported; a narrow riparian buffer caused more sediments to be transported than a wide riparian buffer, with one exception. A wide riparian buffer can cause heavier amounts of coarse organic sediment than a narrow one after a storm (likely needles, branches, and cones). Thus, a wide riparian buffer is preferred in order to best meet the SMOs regarding sedimentation.

With the results of this study and with support from previously conducted studies, I suggest using a wide riparian buffer of at least 15m when a clear – cut harvest is done next to a stream. Kreutzweiser et al. (2009) stated that harvesting within the riparian buffer is possible (up to 50% of the basal area) without risking increased sediment inputs in streams. If partial harvesting within riparian buffers is to be done, it is my suggestion that they should be done with great caution and thoughtfulness. If not, excessive sedimentation because of more windthrows (Mäenpää et al. 2020) and more disturbance of the soil surface could occur (Croke et al. 1999).

In order to get a better understanding of how riparian buffer widths affect transported sediments and which riparian buffer width should be used when harvesting more research is needed. My study is limited by few samples, short study time and that only one stream was studied. A similar study should be done over a longer period of time to see how long the effects of buffer widths lasts.

References

Brunke, M. & Gonser, T. (1997). The ecological significance of exchange processes between rivers and groundwater. *Freshwater Biology*, 37 (1), 1–33. https://doi.org/10.1046/j.1365-2427.1997.00143.x

Chellaiah, D. & Kuglerová, L. (2021). Are riparian buffers surrounding forestry-impacted streams sufficient to meet key ecological objectives? A Swedish case study. *Forest Ecology and Management*, 499, 119591. https://doi.org/10.1016/j.foreco.2021.119591

Christie, T. & Fletcher, W.K. (1999). Contamination from forestry activities: implications for stream sediment exploration programmes. *Journal of Geochemical Exploration*, 67 (1), 201–210. https://doi.org/10.1016/S0375-6742(99)00051-5

Conner, M.M., Saunders, W.C., Bouwes, N. & Jordan, C. (2016). Evaluating impacts using a BACI design, ratios, and a Bayesian approach with a focus on restoration. *Environmental Monitoring and Assessment*, 188 (10), 555. https://doi.org/10.1007/s10661-016-5526-6

Croke, J., Hairsine, P. & Fogarty, P. (1999). Sediment transport, redistribution and storage on logged forest hillslopes in south-eastern Australia. *Hydrological Processes*, 13 (17), 2705–2720. https://doi.org/10.1002/(SICI)1099-1085(19991215)13:17<2705::AID-HYP843>3.0.CO;2-Y

Gomi, T., Dan Moore, R. & Hassan, M.A. (2005). Suspended Sediment Dynamics in Small Forest Streams of the Pacific Northwest1. *JAWRA Journal of the American Water Resources Association*, 41 (4), 877–898. https://doi.org/10.1111/j.1752-1688.2005.tb03775.x

Hasselquist, E.M., Kuglerová, L., Sjögren, J., Hjältén, J., Ring, E., Sponseller, R.A., Andersson, E., Lundström, J., Mancheva, I., Nordin, A. & Laudon, H. (2021). Moving towards multi-layered, mixed-species forests in riparian buffers will enhance their long-term function in boreal landscapes. *Forest Ecology and Management*, 493, 119254. https://doi.org/10.1016/j.foreco.2021.119254

Hasselquist, E.M., Mancheva, I., Eckerberg, K. & Laudon, H. (2020). Policy change implications for forest water protection in Sweden over the last 50 years. *Ambio*, 49 (7), 1341–1351. https://doi.org/10.1007/s13280-019-01274-y

Kreutzweiser, D., Capell, S., Good, K. & Holmes, S. (2009). Sediment deposition in streams adjacent to upland clearcuts and partially harvested riparian buffers in boreal forest catchments. *Forest Ecology and Management*, 258 (7), 1578–1585. https://doi.org/10.1016/j.foreco.2009.07.005

Kreutzweiser, D.P., Capell, S.S. & Good, K.P. (2005). Effects of fine sediment inputs from a logging road on stream insect communities:a large-scale experimental approach in a Canadian headwater stream. *Aquatic Ecology*, 39 (1), 55–66. https://doi.org/10.1007/s10452-004-5066-y

Kuglerová, L., Jyväsjärvi, J., Ruffing, C., Muotka, T., Jonsson, A., Andersson, E. & Richardson, J.S. (2020). Cutting Edge: A Comparison of Contemporary Practices of Riparian Buffer Retention Around Small Streams in Canada, Finland, and Sweden. *Water Resources Research*, 56 (9), e2019WR026381. https://doi.org/10.1029/2019WR026381

Mäenpää, H., Peura, M., Halme, P., Siitonen, J., Mönkkönen, M. & Oldén, A. (2020). Windthrow in streamside key habitats: Effects of buffer strip width and selective logging. *Forest Ecology and Management*, 475, 118405. https://doi.org/10.1016/j.foreco.2020.118405

Mayer, P.M., Reynolds Jr., S.K., McCutchen, M.D. & Canfield, T.J. (2007). Meta-Analysis of Nitrogen Removal in Riparian Buffers. *Journal of Environmental Quality*, 36 (4), 1172–1180. https://doi.org/10.2134/jeq2006.0462

Naiman, R.J. & Décamps, H. (1997). The Ecology of Interfaces: Riparian Zones. *Annual Review of Ecology and Systematics*, 28 (1), 621–658. https://doi.org/10.1146/annurev.ecolsys.28.1.621

Nieminen, M., Ahti, E., Nousiainen, H., Joensuu, S. & Vuollekoski, M. (2005). Capacity of riparian buffer zones to reduce sediment concentrations in discharge from peatlands drained for forestry. https://jukuri.luke.fi/handle/10024/532590 [2022-02-23]

SLU (2022). *Reference measurements of the climate at the Experimental Forests at SLU*. https://www.slu.se/en/departments/field-based-forest-research/environment/climate-data/referenceclimate/ [2022-04-14]

Skogsstyrelsen (2013). *Målbilder för god miljöhänsyn - En delleverans från Dialog om miljöhänsyn*. (5). Jönköping: Skogsstyrelsen. https://cdn.abicart.com/shop/9098/art52/20785652-da5df6-1856c.pdf [2022-03-09]

Sutherland, A.B., Meyer, J.L. & Gardiner, E.P. (2002). Effects of land cover on sediment regime and fish assemblage structure in four southern Appalachian streams. *Freshwater Biology*, 47 (9), 1791–1805. https://doi.org/10.1046/j.1365-2427.2002.00927.x

Wohl, E. (2017). The significance of small streams. *Frontiers of Earth Science*, 11 (3), 447–456. https://doi.org/10.1007/s11707-017-0647-y

Acknowledgements

I want to thank my supervisor Eliza Maher Hasselquist for helping me with ideas and giving me feedback throughout my work. I also want to thank Lenka Kuglerova. She provided me with a map over the study stream and collected the data together with Eliza, thank you both.

Publishing and archiving

Approved students' theses at SLU are published electronically. As a student, you have the copyright to your own work and need to approve the electronic publishing. If you check the box for **YES**, the full text (pdf file) and metadata will be visible and searchable online. If you check the box for **NO**, only the metadata and the abstract will be visible and searchable online. Nevertheless, when the document is uploaded it will still be archived as a digital file. If you are more than one author, the checked box will be applied to all authors. Read about SLU's publishing agreement here:

- https://www.slu.se/en/subweb/library/publish-and-analyse/register-and-publish/agreement-for-publishing/.

☒ YES, I/we hereby give permission to publish the present thesis in accordance with the SLU agreement regarding the transfer of the right to publish a work.

☐ NO, I/we do not give permission to publish the present work. The work will still be archived and its metadata and abstract will be visible and searchable.