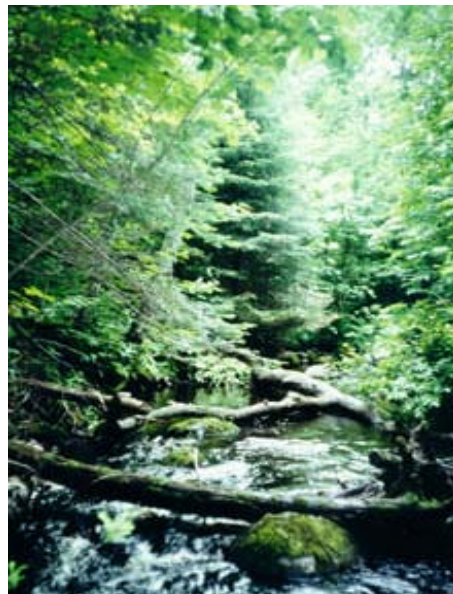


# **EVALUATING RIPARIAN AREA DYNAMICS, MANAGEMENT ALTERNATIVES AND IMPACTS OF HARVEST PRACTICES**

**Final Report to Minnesota Forest Resources Council  
11 December, 1998**

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## **Executive Summary**

### **Introduction**

Minnesota society places a high value on its forested landscapes and its numerous and diverse water resources. Terrestrial and aquatic ecosystems must be managed in ways that protect those values and balance production with conservation, reflecting the views expressed by local, state and national communities. Forest management prescriptions must be profitable and yet, must allow for (or guide) protection of riparian functions and values. This two-year project was funded by the Forest Resources Council to advance informed decision making in Minnesota's forested landscapes.

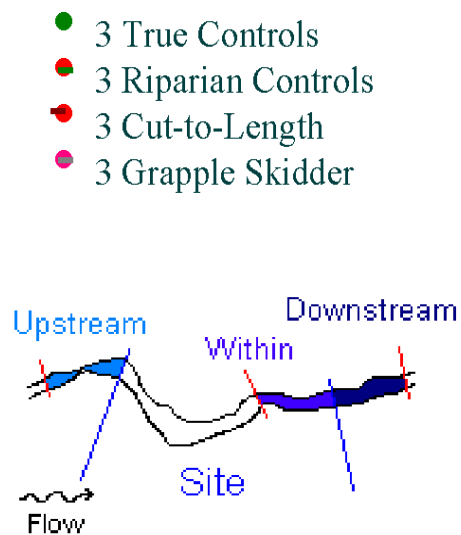
Six integrated sub-projects are included in this work. Each is described in the associated reports. This Executive Summary serves to describe the elements of experimental design common to all the sub-projects, and to highlight significant findings from the first two years.

### **Study Site Location and Experimental Design**

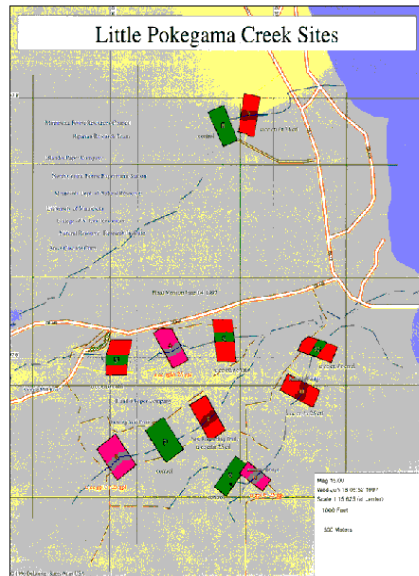
Two watersheds in two distinct Ecological Systems were selected in 1996. Pokegama Creek is on UPM Blandin Company land near Grand Rapids, in the Northern Minnesota Drift and Lake Plains Ecosystem. The second watershed, the West Branch of the Knife River on State, St. Louis County, and Potlatch Corporation lands is located west of Two Harbors. This site is in the Northern Superior Uplands Ecosystem. A third site was established in 1998 in the Cloquet River Watershed. This watershed includes the Langley River and Sullivan Creek in Lake County, on Potlatch Corporation and Forest Service lands and also is in the Northern Minnesota Drift and Lake Plains Ecosystem.

This project is an experimental manipulation, using a randomized block design, with 4 treatments in each of 3 blocks. On the Little Pokegama Creek watershed (Fig 1), 12 treatment stands were established, each 12 acres in size (6 acres on each side of the stream). The upland portions of 9

# Little Pokegama Creek



- 3 True Controls
- 3 Riparian Controls
- 3 Cut-to-Length
- 3 Grapple Skidder



stands were clearcut, using either a cut-to-length logging system (CTL) or a feller/buncher grapple skidder system (Full Tree). The riparian portions of 6 of these 9 stands also were cut, using the same system as in the upland, leaving a target residual basal area of 25 ft<sup>2</sup>/acre. The riparian areas of the remaining 3 cut stands (uplands cut) were left intact. The last 3 stands are true controls, with no harvesting in the uplands or riparian areas. In each stand, the riparian area consists of a 200 ft.-wide strip centered on the

stream (100 ft. on each side). The length of stream contained in each stand ranges from 450 to 650 lineal feet. Little Pokegama Creek sites were harvested in late summer-fall, 1997.

At the Knife River site, 12 stands were established using only one side of the river. Thus, the riparian area was delineated on only one side (a 100-ft. wide strip). The length of stream contained in each stand ranges from 450 to 650 lineal feet. Stand sizes vary from approximately 6 acres to over 16 acres. Treatments for the 12 stands are as follows: 3 true controls; 3 riparian controls (upland clearcut, riparian area uncut); 3 riparian clearcut (upland clearcut as well); 3 riparian residual (25 ft<sup>2</sup>/ac in riparian area, upland clearcut). The harvesting system to be used for all treatments is a feller/buncher with tree length skidding. This site uses a modified block design; 3 blocks contain each of the 3 cutting treatments, while 3 uncut controls are located in a separate block. Block 1 was harvested in winter 1997. The remaining blocks are to be harvested in winter 1998-1999.

The Cloquet River Watershed includes 12 stands established on 1 side of the river only. In this watershed, topography defines the riparian area (rather than using a fixed distance). Treatments are as follows: 3 true controls, 3 riparian controls (upland clearcut, riparian area uncut), 3 cut riparian areas having clumped residual distribution of approximately 50 ft<sup>2</sup>/ac, 3 cut riparian areas having uniform residual distribution of approximately 50 ft<sup>2</sup>/ac. The stands are harvested with a feller/ buncher with tree length skidding. We expect that harvesting will be completed by March 1999.

## Treatment definition

All of the following reports use a common terminology to reference treatments. Those terms are as follows:

|                  | Treatment                          |                   |
|------------------|------------------------------------|-------------------|
| Designation      | Upland                             | Riparian Area     |
| True Control     | Unharvested                        | Unharvested       |
| Riparian Control | Clear cut, either CTL or FT-system | Unharvested       |
| CTL              | Clear cut, either CTL or FT-system | CTL               |
| FT-system        | Clear cut, either CTL or FT-system | Full-Tree harvest |

## Results to date

### Water quality, stream organisms and their habitat

We identified significant direct effects among treatments on Little Pokegama Creek. Bridges on the lower edge of plots 10 and 11 had a significant negative impact on stream biota. At most of these latter sites, there was a significant increase in fine sediments and tolerant invertebrate taxa and a decrease in water quality as indicated by biotic indices. These changes were not directly related to treatments but could have a significant impact on trout populations in the streams. Shredding insects, which are critical in ecosystem function and are reliable indicators of ecosystem health, had reduced populations below the treatment sites. This suggests that other biotic effects may be present but masked by variance attributable to small sample size and/or the limited time frame of this analysis.

### Fish and In-stream habitat

In-stream habitat and fish community structure in the Little Pokegama Creek watershed degraded significantly between 1997 and 1998. During that time, substrate embeddedness, fines in the substrate, and boulder pools all increased; scores for the Index of Biotic Integrity and population density of the fathead minnow increased. Few if any treatment effects (i.e., those directly attributable to harvest practice) were evident based on this one-year post harvest data set. Results in this report are limited to Pokegama analyses; Knife River analyses will be reported elsewhere at a later date.

### Woody debris and coarse particulate organic matter

Woody biomass and Coarse Particulate Organic Matter (COPM) in the Pokegama River and Little Knife Rivers are comparable to the lower range of volumes reported for streams in the Pacific Northwest, Georgia, Tennessee and New Hampshire. We did not detect a significant treatment effect on CPOM in these streams. We feel that more than one year of observation would be required to detect any trends that are present. We also did not see short-term changes in coarse woody debris as a direct result of harvest activities in the upland. We believe that analyses over more coarse scales (e.g., watershed, landscape and cumulative effect scales) will be more

instructive in identifying any such pattern and its underlying significance.

### **Riparian vegetation**

Riparian areas in these watersheds contribute uniquely to local plant diversity. Herbaceous plant communities show distinct zonation across the riparian ecotone. Species richness appears to stabilize around 100 ft from the stream. The coincidence of highest species richness and occurrence of rarer species nearest the stream suggests that these areas deserve greatest attention with regard to reduction of direct harvesting impacts. Our preliminary post-harvest observations of vegetation suggest that floodplains and low terraces are least likely to be directly impacted by harvesting equipment during summer logging. Our early results indicate that regeneration of aspen is not greatly inhibited by overstory retention within partially harvested riparian management buffers. Retained trees in the harvested riparian buffers were usually clumped in patches, rather than dispersed uniformly across space. Clumped residuals result in more favorable competitive neighborhoods over a greater proportion of the stand.

Our early results quantifying leaf litter input to streams are surprising. These results suggest that nearly one-third of leaf litter originates more than twice the distance feet from the channel than would be expected from the literature. It appears that retention of 40 ft<sup>2</sup>/ac of overstory basal area within the riparian buffer is not sufficient for sustaining litter inputs at pre-harvest levels. The current suggested level of retention for managing intolerant species (25 ft<sup>2</sup>/ac) falls well below the level needed to maintain adequate litter input to achieve functional similarity to the uncut forest. However, our data are early and ongoing; we will link these results to those from in-stream collaborators to gain a better understanding of the significance of these results for the entire ecosystem.

### **Archeology and cultural artifacts**

We used replica archaeological deposits, using materials that closely replicate those typical of authentic archaeological sites in Northern Minnesota to simulate the effects of forest harvest. Approximately 5% of artifacts were lost or damaged during harvest of a Stand. Horizontal displacement of shallow materials and breakage of fragile materials are the most likely effects of harvest activities; those effects tend to occur only in areas directly trafficked by heavy equipment.

### **Harvesting system efficiency and damage to residual trees**

Full-tree (FT) harvesting systems exposed more organic and mineral soil than did Cut-To-Length (CTL) harvesting systems. The CTL system left considerably more slash on the site; that can be viewed as a detriment (e.g., fire fuel) or a benefit (e.g., erosion control, small animal habitat). In an FT-system, heavy equipment travels over a greater portion of the plot, including driving over slash. Un-trafficked slash is more evident on the CTL plots. There also is evidence of greater disturbance (e.g., rutting) in limited situations. Analysis is ongoing to identify the harvest and traffic patterns that lead to that level of disturbance.

### **Critical Effect Size**

Critical effects size ( $ES_{crit}$ ), a relatively new power analysis tool, is specifically designed to evaluate a reference/impact study design. As part of the environmental effects monitoring (EEM) program in Canada, it has recently been used to assess the adequacy of Pulp and Paper Effluent

regulations (Lowell 1997). One of us (JP) is working with the Canadian Pulp and Paper industry to refine application of critical effect size analyses; that provides us an excellent opportunity to develop a parallel application for Minnesota riparian areas.

The Canadian EEM program has been designed to achieve national uniformity in monitoring effluent effects, while taking into consideration site-specific factors. A critical aspect of any monitoring program is the management decision which is based on the magnitude of environmental impact that is deemed to be ecologically important (Mapstone 1996). Critical effect size ( $ES_{crit}$ ) analysis is used to set the “bottom line” for decisions by establishing the minimum effect that will initiate management action. It serves as a thematic tool that can be applied across disciplines (e.g., hydrology, water quality, ecology, fisheries, revegetation) to seek patterns that guide better decisions.

We are beginning to use critical effect size analysis as a tool to ascertain the efficiency of Minnesota’s riparian BMP’s. The critical effect size ( $ES_{crit}$ ) method typically focuses on the variation among sites within an ecologically similar area rather than on within-site variation or on variation between sites above and below a treatment. For a given response variable (i.e., taxa abundance, taxa richness), a two-part criterion is used: 1) *are the reference and impact area means significantly different at the 0.05 level (for the case where the alpha and fixed sample size can be determined)?* and 2) *Is the difference between the reference and impact means greater than a fixed critical effect size ( $ES_{crit}$ )?* The advantage to criterion 1 is that it is tailored to site-specific data and their variability. The advantage of criterion 2 is that it indicates whether the difference between the reference and impact means is a result of natural variability within a given habitat type. This latter element guards against potentially significant effects being overlooked because of the unusually high natural variability at some sites.

$ES_{crit}$  is set at the point where the mean for the impacted area is outside the normal range of values observed for unimpacted stations of the same habitat type in the reference area (e.g., a riffle habitat for benthic organisms in this study). Commonly accepted criteria for the reference condition is  $\pm 2$  SD or twice the coefficient of variation for the reference mean ( $\pm 2$  CV). Ideally, a study should be designed to provide a reasonably high probability of statistically detecting an effect if it has occurred. For macroinvertebrate analyses for example, the degree of variability among reference sites will depend on the scales(s) of patchiness in invertebrate distribution. The sample size required to meet the criterion (i.e., detecting effects  $\pm 2$  CV’s) can be determined using power analysis. In seeking to detect a negative impact, most biologists suggest that beta should be set to the same level as alpha (i.e., usually 0.05). That then sets the ‘power’ to 0.95.

As an example, the estimated sample size (number of replicate sites per reference and impact area) for macroinvertebrates in the Pokegama Creek watershed, at the  $0.95 ES_{crit} \pm 2SD$  (i.e., 95% level) is eight. If the criterion were  $0.8 ES_{crit} \pm 2Sd$  (i.e., 80% level), five stations would be needed. In our FRC study, we have 12 reference and nine treatment sites per watershed. This falls comfortably within the 95% CI for macroinvertebrate analyses (typically a highly variable metric). We will develop this tool in more breadth (i.e., across disciplines) in further FRC riparian analyses in these watersheds.

# EFFECTS OF FOREST HARVEST ON AQUATIC MACROINVERTEBRATES, WATER QUALITY AND HABITAT

Mary Kay Fox and Jim Perry

## Abstract

We identified significant direct effects among all treatments on Little Pokegama Creek. Bridges on the lower edge of stands 10 and 11 had a significant negative impact on stream biota. At most of these sites, there was a significant increase in fine sediments, an increase in tolerant invertebrate taxa and a decrease in water quality as indicated by biotic indices. These changes were not directly related to the treatments but could have a significant impact on trout populations in the streams. Critical Effect Size, an analytical tool that incorporates regional variance proved useful in identifying other effects. Shredding insects, which are critical in ecosystem function and are reliable indicators of ecosystem health, showed a pattern of change among the treatment sites. This suggests that other biotic effects may be present but masked by variance attributable to small sample size and/or the limited time frame of this analysis.

There clearly is a need for longer term analyses at the Pokegama sites and for more detailed analyses at the Knife sites (no Knife River analyses are included here). It also is apparent that there is a potential for cumulative impacts that would not be identified by this site-specific analysis.

## Introduction

Aquatic macroinvertebrate communities are essential components of aquatic environments. They are important in trophic dynamics, they represent the link between primary and higher order production, and typically represent majority of the food available to fish species which in turn are important for human consumption and recreation (Benke, 1984).

Benthic macroinvertebrates have long been used in biological monitoring efforts because they are relatively sedentary, long-lived, diverse and often react predictably to human-induced disturbances in aquatic ecosystems (Perry and Vanderklein 1996, Rosenberg and Resh 1993). Biological (and other environmental) data obtained from reference areas can be compared to potentially stressed areas to quantify and diagnose impairment of aquatic ecosystems (Yoder 1991). Benthic invertebrates are useful diagnostic variables in such an analysis.

In the upper Midwest, very little is known about the effects that logging within riparian management zones has on macroinvertebrate communities or their habitat (Perry *et al* 1992). Predictions made in the Minnesota Timber Harvest GEIS, as well as most stream biological data about riparian management are based on information from high gradient areas such as the Appalachians and the Pacific Northwest (Gregory *et al.* 1991). As such, predictions in the GEIS remain tentative and untested; information pertinent to Midwestern streams is needed. We assessed benthic macroinvertebrate communities and habitat variables to evaluate forest harvest practices in the Little Pokegama River and the Knife River. The two sites represent two significantly different ecological types (i.e., Northern Minnesota Drift and Lake Plains Ecosystem and the Northern Superior Uplands Ecosystem), allowing us to broaden the inferential nature of our results.



## Objectives

The overall objectives in this study were to evaluate harvest treatment effects upon:

1. in-stream macroinvertebrate population and community responses, and
2. habitat alterations due to substrate changes from sediment inputs.

## Methods

We sampled two 100-meter reaches: one unit was above the upper boundary of the stand and a second 100 meter reach bounded the downstream border. On the lower boundary, 50 meters were within the stand and 50 meters were below harvest treatments. In true control stands, we sampled a representative 100 meter reach (Fig1). In-stream water quality variables, habitat and invertebrates were collected five times during this reporting period: June 15<sup>th</sup>, July 15<sup>th</sup>, Aug 15<sup>th</sup> 1997; May 15<sup>th</sup> and June 15<sup>th</sup> 1998. Site specific grab samples for conductivity, dissolved oxygen, temperature and streamflow were taken on each date at each site. Average velocity was recorded through each 50-meter reach. In-stream, continuously recording temperature loggers were placed above and below each stand at the Knife sites. At Pokegama sites, these were placed within the true control stands, and on the downstream reach of treatment stands.

**Figure 1** Field sampling design for benthos and aquatic habitat

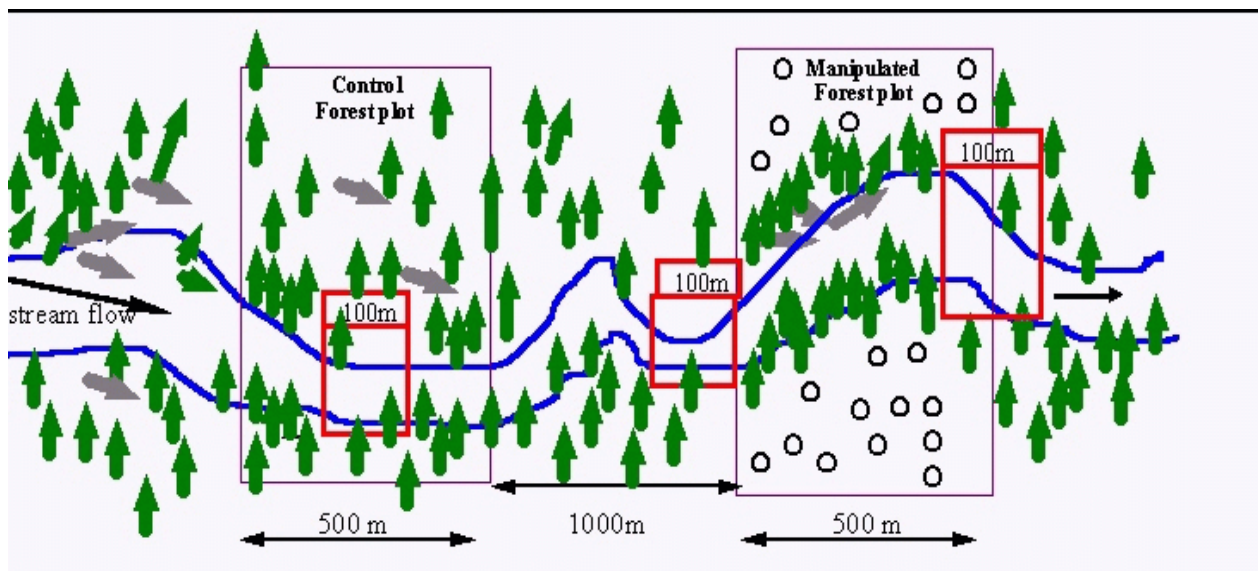


Figure 1: Designated sample study sites within the Riparian zone in relation to the manipulated forest plots (Manipulated forest plot: purple box, Stream study site: red boxes).

Substrate particle size, a useful measure of fish spawning resources and invertebrate community habitat, was assessed through Wolman pebble counts (Kondolf 1997, Wolman 1954) in pre-harvest and post harvest years on the impacted sites; pebble counts were not conducted on true control stands. Pebble count data are expressed as percentages (i.e., sands/muck: 0.062-1mm, gravel: 2-45mm, cobble: 46-180mm and boulder: 181-2048mm). Pebble counts were conducted on two separate riffle/pool sequences; mean counts were used in the analysis reported here.



We obtained quantitative samples of benthic macroinvertebrate communities with a 0.1m<sup>2</sup> Hess sampler, positioned randomly in sequential riffle areas. Invertebrate samples were ‘clean picked’ and identified to genus.

The Knife River was not harvested during the two years reported here. A full suite of pre-harvest data, following the design described elsewhere in this report, have been collected for the Knife. Those data are being analyzed similarly to those of the Pokegama River (Fox, MS Thesis, in preparation). The analysis presented here is for the Little Pokegama River watershed. The data reported here represent 180 samples and over 39,000 invertebrates among 99 taxa.

### **Biotic and abiotic variables**

Approximately four samples from each treatment stand (i.e., two from upstream and two from downstream), and two from each control stand were used in this analysis. The analysis follows a Reference/Impact study design, using a suite of biological, physical and chemical variables. We calculated several integrative biotic indices describing invertebrate populations and communities (e.g., mean abundance, community composition, % EPT [percent Ephemeroptera, Plecoptera and Trichoptera], Taxa Richness, Hilsenhoff’s Biotic Index and Family Biotic Index [FBI] [Hilsenhoff 1987], Functional Feeding Group [FFG] designations [e.g., %shredders, %filters, % clingers]). Those biological variables incorporate fifteen macroinvertebrate community and population descriptors. Summary statistics are in Table 1, Appendix 1.

Our physical variables included four substrate particle size categories (percent sand, gravel, cobble and boulders) and four riparian soil disturbance divisions (meters each as rutted, gouged, or mounded, and area covered) (data from Mattson and Thompson, this report). Original riparian soil disturbance data included both riparian and upland information. However, for this analysis only the riparian data set was used because our objective was to test riparian BMP’s. If the riparian buffer and associated areas are functioning ecologically correctly; upland impacts such as sedimentation should not reach the stream and affect the aquatic biological community. Chemical variables included four standard field water quality measures (i.e., dissolved oxygen, conductivity, degree-days [<sup>0</sup>C\*days] and velocity) and seventeen laboratory variables (data from Grand Rapids, USFS data) (Table 2, Appendix 1). Degree-days were calculated from recording thermographs which recorded hourly and were in place from July 1997 to April 1998 (providing >6,700 data points/stand).

### **Analytical approaches**

Five analytical approaches were employed to test for treatment effects on in-stream biological, physical and chemical variables: one- and two-way Analysis of Variance (ANOVA), simple and multiple linear regression. In addition, we used a Critical Effect Size (ES<sub>crit</sub>) technique with defined statistical procedures to evaluate our reference/impact framework. Both one- and two-way ANOVA’s were conducted on upstream-downstream (i.e., reference-impact) samples to test for differences due to treatment and location effects. Simple linear regression was used to develop relationships in which biotic factors (e.g., mean abundance, taxa richness, percent EPT) are predicted from substrate and chemical data.

## Critical Effect Size

Critical effects size ( $ES_{crit}$ ), a relatively new power analysis tool, is specifically designed to evaluate a reference/impact study design. This analysis is used to set the “bottom line” for decisions by establishing the minimum effect that will initiate management action Lowell (1997). We calculated critical effect sizes for three reference conditions for each biological variable (i.e., pre-impact [downstream 1997] reference sites, un-impacted (upstream) reference, true controls, and all reference conditions combined). The biological variables we use for  $ES_{crit}$  are mean abundance, taxa richness, percent EPT, family biotic index (FBI), and a functional feeding group representation (i.e., % Shredders and percent Clingers [following Karr and Chu1998]). Treatment and location effects then were evaluated using those biological descriptors. We report here results of the analysis of treatment effects (Tables 3 to 8, Appendix 1).

## Results

Significant treatment effects were apparent for each of the three harvest treatments (Riparian buffer, CTL, and FT-system).

***Riparian Buffer Treatment (Stands 3,5,12):*** The two-way analysis of variance (ANOVA) showed significant treatment effects for percent EPT ( $p=0.031$ ), percent Plecoptera ( $p=0.015$ ), and percent Diptera ( $p=0.054$ ). The decline in Plecoptera was primarily noted at stands three and twelve (Table1). Additionally, a oneway ANOVA for Stand 5 detected a significant increase in percent Diptera ( $p=0.036$ ); dipteran taxa increased by 26% with the largest change in the Simuliidae (31%).

***CTL Treatment (Stands 2,8,11):*** Filter feeders significantly declined below CTL stands (two way ANOVA,  $p=0.010$ ). The one way ANOVA showed a significant decrease in percent Simuliidae (a filter feeder), percent Plecoptera ( $p=0.054$ ), and percent Ephemeroptera ( $p=0.003$ ); total abundance increased but results were not significant ( $p=0.065$ ). Stand 11 had a significant decrease in filter feeders ( $p=0.071$ ) and Diptera ( $p=0.018$ ). This stand had a significant increase in percent muck/sand ( $p=0.04$ ) and the FBI decreased by one tolerance level indicating a decrease in stream water quality.

***Full Tree (FT-system)Treatment (Stands 4,6,10):*** Plecoptera declined significantly ( $p=0.03$ ) and Diptera increased but the increased was not significant ( $p=0.068$ ) below the FT-system stands.

Critical Effect size ( $ES_{crit}$ ) analysis by treatment identified a change in percent shredders but the change was not unidirectional (i.e., increased in some cases and decreased in others) (Table7, figure 3).

## Differences between pre and post harvest years

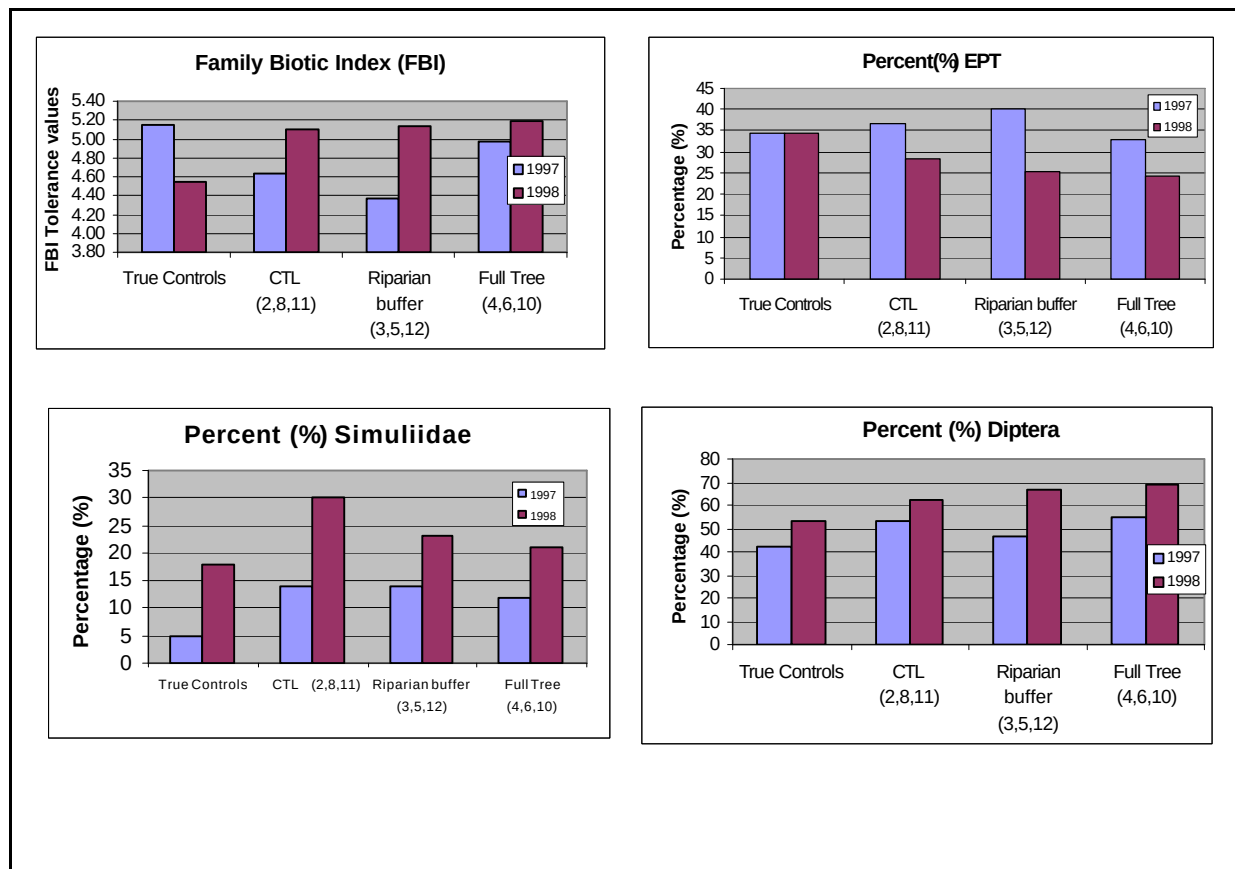
Although not directly related to treatment effects, significant year-to-year differences were evident. We developed regression equations on the basis of control and pre-harvest data; then used those to examine post-harvest conditions. In the pre-harvest data set, there was a significant

linear relationship between degree-days ( $^{\circ}\text{C}$ ) and: a) pre-harvest FBI ( $p=0.007$ , adjusted  $r^2=0.53$ ), b) percent collectors ( $p=0.017$ , adjusted  $r^2=0.40$ ), and c) EPT ( $p=0.039$ , adjusted  $r^2=0.36$ ). The four separate Pokegama streams and their associated stands accumulated different degree-days: stream 1 (stands 1,2) = 1853, stream 2 (stands 3,4,5) = 1712, stream 3 (stands 6,7,8) = 1795, and stream 4 (stands 9,10,11,12) = 1511. Because aquatic insects are exothermal, the high degree of variance among stream degree day accumulations can present a significant driving force in life history factors such as growth, reproduction and recovery rates. These degree-day differences may also be instructive in explaining the fish results presented elsewhere in this report.

There was a significant linear relationship between substrate and several biological community indicators. Percent gravel and cobble ( $p=0.001$  and  $p=0.013$ , respectively, adjusted  $r^2=0.74$ ) predicted macroinvertebrate mean abundance and taxa richness ( $p=0.003$  and  $0.006$  respectively,  $r^2=0.57$ ). Percent gravel ( $p=0.018$ , adjusted  $r^2=0.39$ ) was correlated with mean EPT abundance. Percent boulders ( $p=0.002$ , adjusted  $r^2=0.61$ ) was significantly correlated with the FBI. However, substrate was significantly different (increased percent sands  $p<0.001$  and gravel  $p<0.005$ ) between pre and post harvest years.

## Discussion

Among all treatments, there was an increase in percent Diptera and percent Simuliidae below harvested stands, and a decrease in percent EPT, percent Plecoptera, and FBI indicating reduced water quality (Figure2).



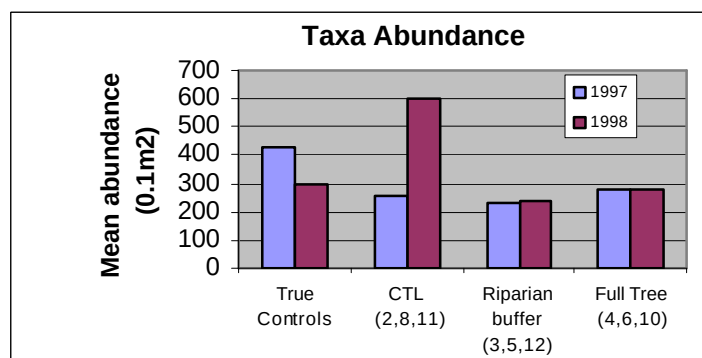
**Figure 2** Means macroinvertebrate population and community responses among harvest treatments.

Stands 9-12 are all located on one stream. It appears that sediment from bridges had a significant, site-specific impact on stream water quality and biota on the lower edge of stands 10 and 11. Below stand 11, there was a significant increase in percent muck/sand and invertebrate mean abundance; post-harvest FBI decreased by one tolerance level. The increase in taxa abundance is counter-intuitive. In fact, there was a decrease in sensitive species (percent EPT decreased by 71%) and an increase in more tolerant groups (i.e., Simuliidae increased 56%; Oligocheates increased 47%). Additionally, these three stands (10,11, 12) had the greatest amount of rutted soils within the riparian area. The Critical Effect Size ( $ES_{crit}$ ) for FBI on stand 12 exceeded the median variance for this variable, suggesting a possible cumulative effect. Treatment effects, which were statistically significant, in conjunction with the site-specific results give a weight of evidence that the bridge(s) have negatively impacted the stream. This has serious implications for the indigenous brook trout (*Salveninus fontinalis*) population, which is present only within the stream where stands 9 through 12 are situated.

Significant harvest effects were noted in our analysis of variance results (Figure 4). Critical Effect Size ( $ES_{crit}$ ) for percent shredders did demonstrate a change due to treatment effects. However, no apparent pattern (i.e., increase or decrease) was evident (Figure 3). Shredders break down coarse organic material and are large organisms of value as fish food. Patterns in their population are important to ecosystem function and as indicators; however, those patterns are not clear from this data set. These data do offer a quantitative reference for comparison in future years when the streams have been subject to these treatment effects on a longer term basis.

Critical Effect Size metrics developed here will provide a useful tool which could be generic across disciplines and therefore instructive in evaluating the weight of the evidence with regard to a treatment practice and/or a BMP implementation. This approach provides a more holistic, landscape view in assessing the ecological health of an aquatic ecosystem. It has been applied successfully elsewhere for freshwater zooplankton (Yan *et al.* 1996), phytoplankton communities (Finlay and Kaise, 1996) and for streamflow (Resh *et al.* 1988).

We identified significant direct effects attributable to treatments on Little Pokegama Creek. It is also apparent that there is a potential for cumulative impacts identified by site specific analysis. There clearly is a need for longer term analyses at the Pokegama sites and for more detailed analyses at the Knife sites.



**Figure 4.** Change in total insect abundance among treated plots and years.

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# EFFECTS OF FOREST HARVEST ON FISH AND IN-STREAM HABITAT

## E. C. Merten and R. M. Newman

### Abstract

Data and analyses here are limited to the Little Pokegama Creek watershed; Knife River data will be reported at a later date. Twelve species were collected from the study streams. In-stream habitat and fish communities were significantly different in 1998 compared to 1997. Changes included variables such as increased embeddedness, increased fines, decreased Index of Biotic Integrity scores and increased fathead minnow populations. However, very few if any effects were directly attributable to harvest practice in the time frame modeled here.

### Background

Numerous studies have documented effects of poor timber harvest practices on fish and in-stream habitat, mostly in mountainous areas of North America. Inputs of coarse woody debris, important for in-stream habitat, can be reduced for hundreds of years (Murphy & Koski 1989). Fewer fallen leaves may enter the stream, affording less food for the macroinvertebrates upon which most fish prey (Wallace *et al.* 1997). More light may reach the stream, favoring visual predators and raising water temperature (Barton *et al.* 1985). Erosion and sedimentation can increase (Erman and Mahoney 1983) and stream hydrology can be altered (Brooks *et al.* 1997). Some of these studies have found that fish populations initially increase following timber harvest, possibly due to better growth and feeding in warm illuminated waters, but then slip into a long-term decline when other changes take effect (Salo & Cundy 1987). However, the extent of all these effects depends heavily on watershed conditions (e.g., soils, geology, bank slope, stream gradient), and on timber harvest practices (e.g., buffer widths, time of year, stream crossings, equipment used) (Perry *et al.* 1992).

### Objective

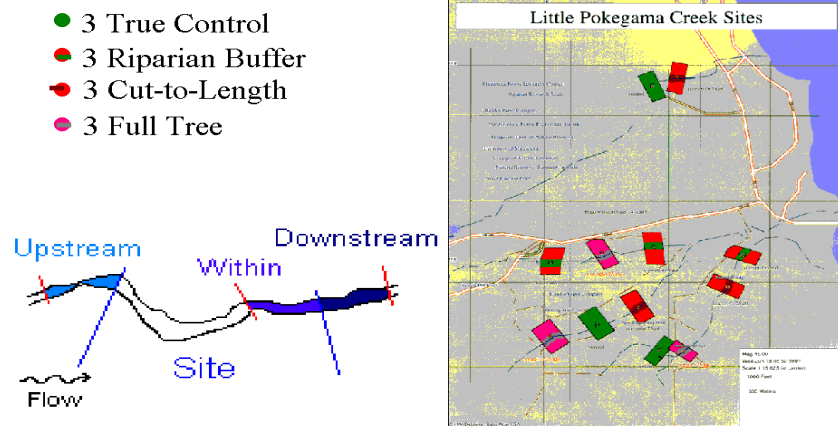
This project had two objectives:

1. Determine the degree to which forest harvest practices result in changes to fish habitats in coldwater streams, and
2. Determine the relationship between any habitat changes and changes in the fish communities of the streams.

### Methods

At each watershed, we collected data from 50 m stream reaches that were immediately upstream, within, and downstream from each of the twelve Stands (Fig 1). This design established two independent types of controls: true control sites and upstream reaches.

# Little Pokegama Creek



**Figure 1. Little Pokegama Creek sampling sites**

We collected pre-harvest data in 1997 and post-harvest data in 1998. Fish were surveyed by electrofishing all reaches twice each summer, once in late June or early July (early summer) and once in August. We made two passes with the electrofisher so that fish abundance could be estimated (mark-recapture or depletion estimates). We also measured numerous in-stream habitat variables in July of each year, including abundance of coarse woody debris, relative amounts of different substrates, mean width and depth, and total in-stream cover. We followed habitat sampling methods developed by the Minnesota Pollution Control Agency (Bailey *et al.* 1993), with some modifications. For example, stream substrate was characterized by ranking substrates within each of 35 randomly-located quadrats in each reach. The percent coverage of the near-stream tree canopy was measured during both years with a spherical canopy densiometer (Lemmon 1957) and windthrow trees which had fallen across the stream were counted in 1998.

Paired t-tests were first used to test for overall differences between years, with all sites combined. In this analysis, the 1997 value for each reach was paired with its 1998 value. Two different analysis of variance designs were used to test for harvest effects. The first design used all three types of controls (true control sites, upstream reaches, and pre-logging data) and was the most sensitive. Each site had two values, calculated with the formula:  $(1997_{upstream} - 1997_{impact}) - (1998_{upstream} - 1998_{impact})$  where impact refers to either the within reach or the downstream reach. The analysis used a reach factor (within or downstream) and a treatment factor (true control, riparian buffer, cut-to-length, or full-tree system). The reach factor and the interaction term were never significant. Statistically significant treatment effects would imply that at least one logging treatment responded differently from another from 1997 to 1998, and include the upstream reaches as controls at each site. The second design was similar but used post-logging data only; the formula was  $(1998_{upstream} - 1998_{impact})$ .



## Results

### Study areas

The Little Pokegama Creek watershed included four streams; one stream (sites 9-12) contained virtually all brook trout while the other streams contained six small non-game species but no trout. The brook trout stream also had more coarse substrates (e.g., boulders, cobble), while the other streams had mostly sandy substrates. The second watershed, the West Branch of the Knife River, had mostly coarse substrates and a wider channel. This stream contained brook trout as well as 11 small non-game species. The Knife River Stands were not harvested during this study period. Pre-impact (1997 and 1998) data from those sites are available (Merten, MS Thesis, In Preparation) and will be used to assess future changes. All the following analyses refer only to the Little Pokegama Creek watershed.

### Differences between years: Little Pokegama Creek

In-stream habitat conditions in 1998 were significantly different ( $p < 0.05$ ) than those in 1997 at all sites, based on paired t-tests. Between the two sampling years, stream substrate changed significantly, with more boulder pockets, greater embeddedness, fewer coarse substrates, more fine substrates (e.g., sand, silt), and lower substrate scores in 1998 (Table 1). These changes reflect lower-quality in-stream habitat for most fish. In 1998, the sites also had significantly lower Index of Biotic Integrity scores and more fish species in early summer and August; both of these conditions are indicative of degraded conditions for trout streams (Lyons and Simonson 1996). Brook sticklebacks were fewer in early summer 1998 than in 1997 (from 3.6 per reach in 1997 to 1.4 per reach in 1998) and fathead minnows were more prevalent in late summer. In fact, fathead minnows increased from 0.0 per reach in August 1997 to 8.9 per reach in August 1998, becoming the most abundant species at the sites. Fathead minnows are generally associated with low water quality, while brook sticklebacks usually indicate moderate water quality.

**Table 1. Mean sediment characteristics at the Little Pokegama Creek sites in July 1997 and 1998.**

| Date            | Boulder Pockets | Embeddedness | Coarse | Fine  |      |
|-----------------|-----------------|--------------|--------|-------|------|
| Substrate Score |                 |              |        |       |      |
| 1997            | 12.2%           | 62.1%        | 42.9%  | 49.1% | 12.3 |
| 1998            | 18.0%           | 72.5%        | 20.3%  | 71.7% | 9.9  |

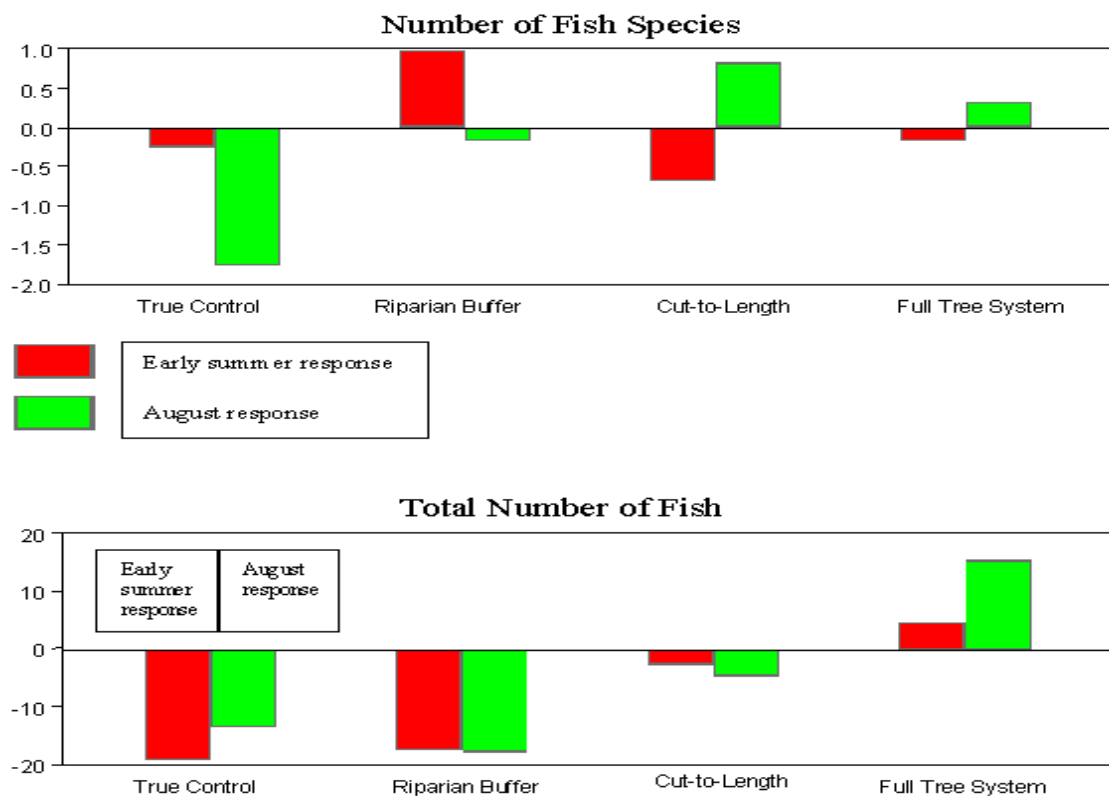
### Effects of harvest practices: Little Pokegama Creek

Site 9 was very shallow and nearly devoid of fish; therefore, it was omitted from analyses that included fish. Sites 10-12 were dominated by brook trout and contained very few non-game fish. None of the other sites contained brook trout. Thus, sites 10-12 were only used in the brook trout analysis and were excluded from analyses with the other fish. As such, replication was very low for the brook trout analysis (only sites 10-12) and required that the cut-to-length data be combined with the full-tree system data.

The larger analysis of variance design detected significant differences for some fish responses (Fig. 2 and Fig. 3). The following results were statistically significant ( $p < 0.05$  unless noted). With reference to this population of control and reference sites, sites with

riparian buffers were significantly different than other sites during the early summer sampling. In those riparian buffer sites, central mudminnow and fathead minnow populations experienced relative declines, but the relative number of fish species increased. More effects were evident in August: the true control sites gained relatively fewer fish species than all other sites, and the riparian buffer sites gained relatively fewer fish species than the cut-to-length sites. At the Ft-system sites, total fish abundance increased relative to the true control sites and to the riparian buffer sites, while central mudminnow populations increased relative to all other sites. Brook trout populations experienced a relative increase in the two riparian harvested sites compared to the riparian buffer site. Brook sticklebacks could not be analyzed in August due to a few unreliable abundance estimates. No significant changes occurred with Index of Biotic Integrity scores. The second, more limited analysis of variance design confirmed that, in August of 1998, control sites had fewer fish species relative to the riparian buffer sites and the CTL sites. No other significant effects were found.

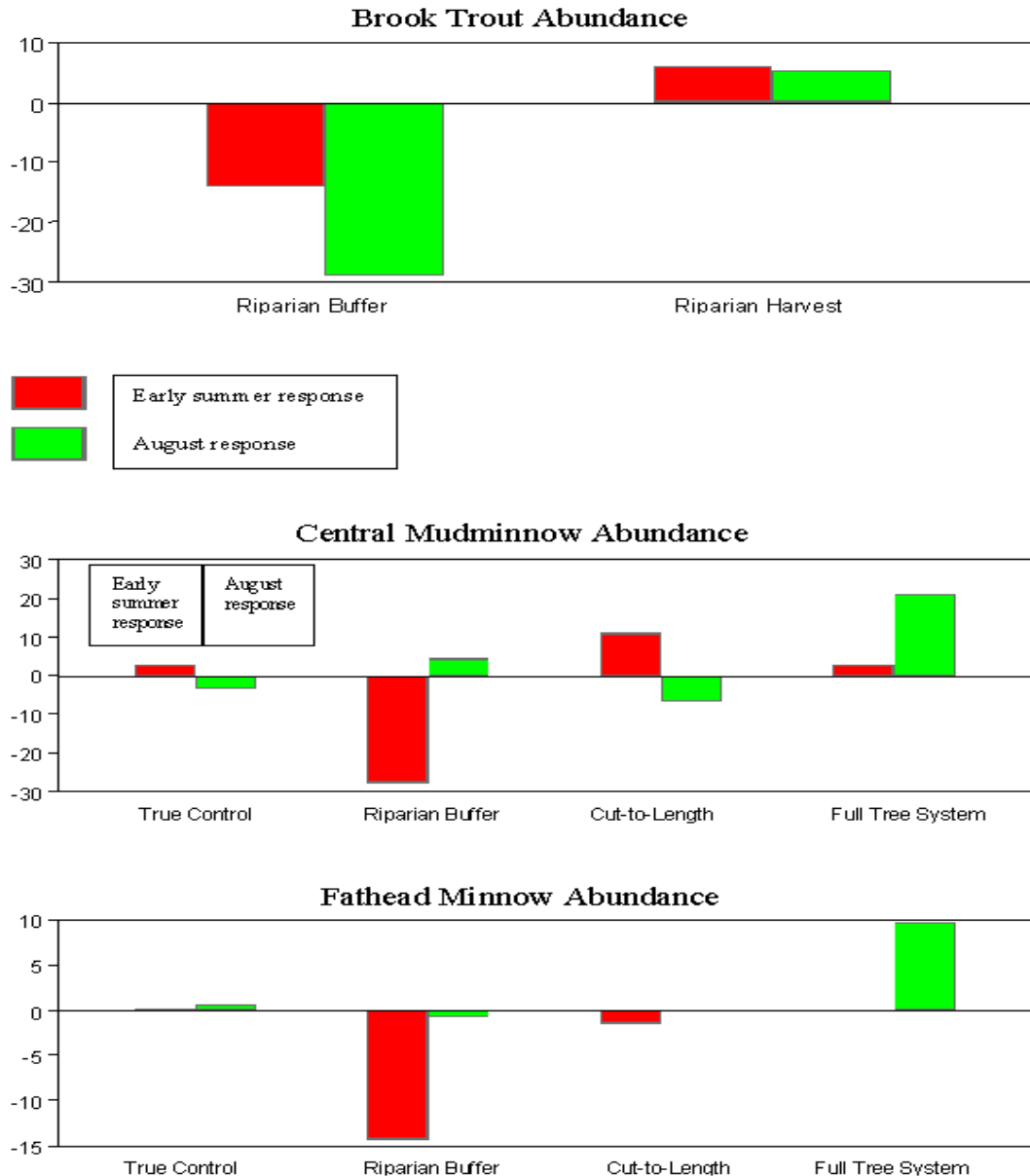
No significant treatment effects were found with in-stream habitat variables. Near-stream tree canopy coverage declined (not significantly) in all harvested sites and there were significantly more windthrow trees in the CTL and FT-system sites than the unharvested riparian sites ( $p < 0.1$ ). These results lead us to expect a reduction in shade and an increase in illumination.



**Figure 2** Values shown are the mean for each harvest treatment, using the formula (1997 upstream - 1997 impact) - (1998 upstream - 1998 impact). Negative values imply that the harvest treatment caused a decrease; positive values imply an increase.

## Interpretation and Further Study

The paired t-tests showed that a large amount of fine sediment had been delivered to the sites. This sand and silt may have originated from washouts of the logging road crossings upstream from several of the sites, although we cannot confirm this due to other possible year-to-year changes. The sediment was not confined to the harvested reaches but affected the entire lengths of the streams; it was not detected as an effect of this experimental harvest. The increased sediment may have contributed to the decline in brook stickleback populations and to the dramatic increase in fathead minnow populations between 1997 and 1998.



**Figure 3** Values shown are the mean for each harvest treatment, using the formula (1997 upstream - 1997 impact) - (1998 upstream - 1998 impact). Negative values imply that the harvest treatment caused a decrease; positive values imply an increase.

The analysis of variance results identified differences associated with timber harvest, and showed that these differences were more apparent during August than early summer. The true control sites were least altered in species composition (i.e., gained relatively fewer species), followed by the riparian buffer sites. The FT-system sites showed the greatest changes, generally gaining relatively more central mudminnows, total fish and number of fish species than the riparian buffer site. The FT-system sites may have experienced an increase in illumination relative to the other sites because of the pattern of removed trees. We cannot confirm that because illumination was not directly measured. Slightly warmer, more illuminated water could have enhanced fish growth in those sites and would allow fish to find prey more easily. Like fathead minnows, central mudminnows are tolerant species that indicate poor water quality (Lyons and Simonson 1996). The additional species and higher abundance of non-trout species in these harvested sites suggests a degradation of water quality.

The lack of apparent effects on in-stream habitat is consistent with results from other studies. Habitat changes are generally manifested over longer time spans than the one-year involved here (Meehan 1991). The changes in near-stream tree canopy coverage and windthrow trees demonstrate that both CTL and FT-system harvest in the riparian areas allow more light to reach the stream than under forested riparian conditions.

These initial data are in general agreement with previous studies showing increased fish abundance and numbers of species shortly after timber harvest. Further study will be necessary to determine whether these sites will exhibit long-term changes in the quality of their fish communities and their in-stream habitat.

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# WOODY DEBRIS AND COARSE PARTICULATE ORGANIC MATTER

## Lucinda B. Johnson and Carl Richards

### Abstract

Wood biomass in the Pokegama River and Little Knife Rivers is comparable to the lower volumes reported for Pacific Northwest mountain streams, blackwater streams in Georgia and uncleared streams in Tennessee. The number of debris accumulations in the Pokegama River is comparable to those of first order streams in forested areas of New Hampshire. Benthic CPOM values are similar to those reported from unharvested streams in the Coweeta Forest Experiment Station. Over the short time frame of this study, we did not observe a decrease in CPOM in these streams. More than one year of observation will be required to detect trends. As expected, we did not see short-term changes in coarse woody debris as a direct result of harvest activities in the upland. Results of the CPOM and CWD studies suggest that further study over longer time frames will be required to assess effects of harvest activities on the supply of organic matter in streams.

### Introduction

Coarse woody debris is a critical component of small to medium sized streams, directly influencing stream geomorphology and many ecosystem properties and processes (Harmon *et al.* 1984). Habitats created by CWD are varied (e.g., plunge pools, backwaters, eddies, interstices of debris dams and individual logs and are critical for fish as well as invertebrate species. They provide flow and predation refugia for fish, oviposition and pupation sites, a feeding platform for invertebrates and a substrate for biofilm production (Sedell *et al.* 1988, Shearer and Webster 1988). Increased channel complexity due to large woody debris is linked to habitat and biotic diversity (Angermeier and Karr 1984) as well as increases in the retention of organic matter. Changes in retention of CPOM alter nutrient fluxes through the biota and affect biotic processes and communities. Land use changes (including forest harvest), through their effects on the riparian zone, alter detrital inputs and thereby stream community structure and function. Forest harvest often results in a long-term decrease in the quantity and quality of coarse particulate organic matter and standing stock, size, and orientation of large woody debris in the stream channel (Hogan 1987, Hedin *et al.* 1988, Murphy and Koski 1989, Golladay, *et al.* 1989, Ralph *et al.* 1994).

In forests of the Upper Great Lakes region, very little is known about the characteristics of woody debris and other CPOM in streams. Although much of the region is in forested land covers, few investigations have attempted to quantify characteristics of CPOM in forested streams and the relationships between CPOM and other stream ecosystem components.

### Methods

Our objectives in this analysis were to:

1. Relate the distribution of Coarse Woody Debris in streams adjacent to alternative forms of forest harvest, and
2. Assess the degree to which harvested sites differed between years or among harvesting techniques.

## Methods

We quantified standing stocks of coarse particulate organic matter and coarse woody debris at harvested areas in the Pokegama, and Knife Rivers, and coarse woody debris at the Cloquet River sites. Coarse woody debris assessments were performed during low flow conditions during the summer of 1997 and 1998. CWD volume was measured using the line transect method (Wallace and Benke 1984). Three random transects were established in each flow regime (e.g., pools, riffles) represented within the sample reach. Logs  $\geq 2$  cm diameter and 0.5 m length that intersected the transect and fell within the bank-full channel were measured. Wood volume per unit area was calculated based on the formula:

$$\hat{X}_v = \left( \frac{\pi^2}{8L} \right) \sum_{i=1}^n d_i^2$$

where  $L$  = transect length and  $d$  = stem diameter intercepted by the transect. Volume per unit area was calculated for each transect and an average was derived for each reach and for each habitat type. In addition to volume measurements, counts of the total length of CWD  $\geq 0.05$  m diameter and  $\geq 1$  m in length were made at 10 m intervals within the reach and summarized as total meters of wood per  $\text{m}^2$  of stream bottom ( $\text{m}/\text{m}^2$ ) for each site. Debris accumulations  $\geq 1 \text{ m}^2$  in area were classified by type and counted. Benthic particulate organic matter (CPOM)  $> 1 \text{ mm}$  was collected from three locations on each transect using a  $0.1 \text{ m}^2$  Hess sampler. Samples were dried, weighed, ashed and reweighed to determine the organic matter content of each sample.

Distributional properties of all variables were assessed and appropriate transformations were applied to non-normal variables. Two-way analysis of variance (ANOVA) was conducted to test for differences due to harvest treatment and location within the reach. In addition, one-way ANOVA was conducted on data for adjacent and downstream samples only to test for differences due to treatment alone. Similarly, one-way ANOVA's were conducted to test for differences among samples at upstream, adjacent, and downstream locations in 1997 and 1998.

## Results

Two of the rivers studied were relatively similar in terms of the amounts and volume of woody debris (Table 1). The Pokegama had approximately  $0.72 \text{ m}$  of wood per  $\text{m}^2$  with  $0.6$  debris accumulations per  $\text{m}^2$ . In contrast, the Little Knife River had approximately  $0.5 \text{ m} / \text{m}^2$  of CWD, with  $0.04$  debris accumulations per  $\text{m}^2$ . Wood volume in the Pokegama River averaged  $0.030 \text{ m}^3 / \text{m}^2$  (or approximately  $15 \text{ kg} / \text{m}^2$ ). Benthic CPOM averaged  $248 \text{ g} / \text{m}^2$  over all sites in the Pokegama River in 1997 and  $375.6 \text{ g} / \text{m}^2$  in 1998.

### Pokegama Creek harvest treatments

Results of the two way analysis of variance showed no significant effects due to either harvest treatments or location within the reach. Furthermore, a one way analysis of variance testing the effects of treatments and locations, independent of one another also indicated no significant differences due to treatment or location in the reach. Although no significant differences are seen due to treatment or location in the reach, it is clear that average quantities of benthic CPOM increased between 1997 and 1998 in the reaches adjacent to and below the CTL treatment, while the control reach above the treatment remained the same. In the FT-system however, the control

reach experienced an increase in CPOM while the adjacent and downstream reaches were highly variable. Standing stocks of coarse woody debris and the number of debris accumulations did not exhibit any distinct trends.

## Discussion

Wood biomass in the Pokegama River and Little Knife Rivers is comparable to the lowest volumes reported for Pacific Northwest mountain streams (summarized in Gurnell *et al.* 1995), and are comparable to CWD volumes encountered in blackwater streams in Georgia (Wallace and Benke 1984) and uncleared streams in Tennessee (Shields and Smith 1992). The number of debris accumulations in the Pokegama River is comparable to those of first order streams in forested areas of New Hampshire (Bilby and Likens 1980), while the number of accumulations encountered on the Little Knife is comparable to those of second order stream in the same region of New Hampshire (Bilby and Likens 1980). Benthic CPOM values are similar to those reported from unharvested streams in the Coweeta Forest Experiment Station (Golladay, *et al.* 1989).

Previous research examining the influence of forest harvest on standing stocks of benthic particulate organic matter has found lower standing stocks following harvest (e.g., Golladay *et al.* 1989). Over the short time frame of this study, we did not observe such an effect. Organic matter is transported into streams by snow melt and overland flow from precipitation. Minnesota experienced a very warm summer during 1998, with low amounts of rainfall during the summer months. Consequently, it is unlikely that normal patterns of organic matter loading to the stream were present during the spring and summer of 1998. Little is known about the dynamics of forces regulating input and retention of large woody debris in low gradient streams. Since considerable annual variation is expected, more than one year of observation is required to detect trends. Bank erosion is believed to be the dominant mechanism causing trees to fall into the stream (Swanson and Lienkaemper 1978). Personal observations from the treatment watersheds suggests that beaver and previous logging activities (especially in the Cloquet River watersheds) also influence the presence of logs in the streams. Regardless of the specific mechanism resulting in input of logs to the stream, we do not expect to see short-term changes in coarse woody debris as a direct result of harvest activities in the upland. Rather, we would expect a long-term change that would perhaps become apparent obvious when viewed in a landscape context- that is, logging in the upper reaches of streams would restrict the long-term supply of logs to the river. Thus, as more harvest activities take place in the watersheds of small streams, we would expect to see fewer logs in downstream reaches over time. Results of the CPOM and CWD studies suggest that further study over longer time frames will be required to assess effects of harvest activities on the supply of organic matter in streams.

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**Table 1.** Means and S.E.M. for woody debris data for the Little Knife River and Pokegama River, 1997 and 1998.

| N = 30                                   | Year | Mean  | SEM   |
|------------------------------------------|------|-------|-------|
| <u>Little Knife River</u>                |      |       |       |
| Accum/m <sup>2</sup>                     | 1997 | 0.04  | 0.00  |
| Accum Size m <sup>3</sup>                | 1997 | 20.62 | 2.68  |
| Wood Abundance<br>m/m <sup>2</sup>       | 1997 | 0.48  | 0.06  |
| Diameter (cm)                            | 1997 | 12.81 | 0.73  |
| Length (m)                               | 1997 | 3.58  | 0.26  |
| Accum/m <sup>2</sup>                     | 1998 | 0.04  | 0.00  |
| Accum Size m <sup>3</sup>                | 1998 | 20.62 | 2.68  |
| Wood Abundance<br>m/m <sup>2</sup>       | 1998 | 0.48  | 0.06  |
| Diameter (cm)                            | 1998 | 12.81 | 0.73  |
| Length (m)                               | 1998 | 3.58  | 0.26  |
| <u>Pokegama River</u>                    |      |       |       |
| Accum/m <sup>2</sup>                     | 1997 | 0.63  | 0.05  |
| Accum Size m <sup>3</sup>                | 1997 | 1.91  | 0.19  |
| CWD volume (m/m <sup>3</sup> )           | 1997 | 0.030 | 0.006 |
| Wood Abundance<br>m/m <sup>2</sup>       | 1997 | 0.72  | 0.06  |
| Diameter (cm)                            | 1997 | 14.06 | 1.01  |
| Length (m)                               | 1997 | 1.88  | 0.13  |
| Ash-free Dry Mass<br>(g/m <sup>2</sup> ) | 1997 | 23.06 | 4.96  |
| Accum/m <sup>2</sup>                     | 1998 | 1.05  | 0.05  |
| Accum Size m <sup>3</sup>                | 1998 | 1.04  | 0.06  |
| CWD volume (m/m <sup>3</sup> )           | 1998 | 0.023 | 0.004 |

|                                          |      |       |      |
|------------------------------------------|------|-------|------|
| Wood Abundance<br>m/m <sup>2</sup>       | 1998 | 0.66  | 0.07 |
| Diameter (cm)                            | 1998 | 11.88 | 0.77 |
| Length (m)                               | 1998 | 3.18  | 0.31 |
| Ash-free Dry Mass<br>(g/m <sup>2</sup> ) | 1998 | 34.93 | 5.51 |
| Blowdown (# trees)                       | 1998 | 0.33  | 0.12 |

**Table 3.** Mean and S.E.M. for coarse woody debris and benthic particulate organic matter in the Pokegama River in 1997 and 1998. Two means are shown, the first is for the control reach upstream of harvest treatments, the other is the average of samples taken adjacent to and downstream of harvest treatments. Treatments are described in detail in the text and are abbreviated as: True Control; Riparian Control; Full-Tree (FT-system); Cut-to-Length (CTL).

| Treatment                        | Year | Volume m <sup>3</sup> / m <sup>2</sup> | Abundance m / m <sup>2</sup> | # Accum / m <sup>2</sup>    | CPOM g / m <sup>2</sup>  |
|----------------------------------|------|----------------------------------------|------------------------------|-----------------------------|--------------------------|
| True Control<br>n=3              | 1997 | 0.054 ± 0.025                          | 0.81 ± 0.10                  | 0.55 ± 0.05                 | 391 ± 252                |
|                                  | 1998 | 0.030 ± 0.011                          | 0.73 ± 0.10                  | 0.96 ± 0.07                 | 292 ± 63                 |
| Riparian Control<br>n = 3; n = 6 | 1997 | 0.035 ± 0.006;<br>0.015 ± 0.003        | 0.42 ± 0.22;<br>0.63 ± 0.70  | 0.64 ± 0.12;<br>0.78 ± 0.04 | 127 ± 20;<br>172 ± 64    |
|                                  | 1998 | 0.010 ± 0.003;<br>0.011 ± 0.003        | 0.50 ± 0.17;<br>0.45 ± 0.70  | 1.13 ± 0.19;<br>1.33 ± 0.04 | 284 ± 81;<br>212 ± 71    |
| Full Tree<br>n = 3; n = 6        | 1997 | 0.035 ± 0.028;<br>0.040 ± 0.018        | 1.15 ± 0.17;<br>0.75 ± 0.15  | 0.53 ± 0.11;<br>0.72 ± 0.18 | 474 ± 218;<br>181 ± 12   |
|                                  | 1998 | 0.010 ± 0.003;<br>0.032 ± 0.009        | 1.05 ± 0.25;<br>0.71 ± 0.17  | 0.97 ± 0.13;<br>1.02 ± 0.13 | 1019 ± 268;<br>331 ± 102 |
| CTL<br>n = 3; n = 6              | 1997 | 0.039 ± 0.006;<br>0.015 ± 0.006        | 0.91 ± 0.14;<br>0.60 ± 0.09  | 0.50 ± 0.03;<br>0.56 ± 0.09 | 454 ± 353;<br>141 ± 57   |
|                                  | 1998 | 0.030 ± 0.016;<br>0.023 ± 0.008        | 0.79 ± 0.18;<br>0.69 ± 0.18  | 1.04 ± 0.05;<br>0.95 ± 0.14 | 458 ± 266;<br>310 ± 74   |

**Table 2.** Means, medians and S.E.M. for woody debris data for the Pokegama River, 1997 and 1998. Treatments are described in detail in the text and are abbreviated as: True Control; Riparian Control; Full-Tree (FT-system); Cut-to-Length (CTL).

| Treatment        | Statistic  | Accum/m2 | Accum Size | Abundance | Diameter | Length | Accum/m2 | Accum Size | Abundance | Diameter | Length |
|------------------|------------|----------|------------|-----------|----------|--------|----------|------------|-----------|----------|--------|
|                  |            |          | m3m/m2     |           | (cm)     | (m)    |          |            |           | (cm)     | (m)    |
|                  |            | 1997     | 1997       | 1997      | 1997     | 1997   | 1998     | 1998       | 1998      | 1998     | 1998   |
| Control          | N          | 3.00     | 3.00       | 3.00      | 3.00     | 3.00   | 3.00     | 3.00       | 3.00      | 3.00     | 3.00   |
|                  | Mean       | 0.52     | 2.34       | 0.78      | 21.60    | 1.44   | 0.71     | 1.42       | 0.57      | 14.93    | 2.91   |
|                  | Median     | 0.52     | 1.92       | 0.76      | 21.33    | 1.70   | 0.69     | 1.45       | 0.48      | 13.00    | 2.96   |
|                  | Std. Error | 0.14     | 0.75       | 0.09      | 6.70     | 0.31   | 0.05     | 0.10       | 0.12      | 5.00     | 0.47   |
| Riparian Control | N          | 9.00     | 9.00       | 9.00      | 9.00     | 9.00   | 9.00     | 9.00       | 9.00      | 9.00     | 8.00   |
|                  | Mean       | 0.74     | 1.41       | 0.56      | 12.09    | 1.66   | 1.26     | 0.82       | 0.47      | 11.15    | 3.37   |
|                  | Median     | 0.78     | 1.28       | 0.57      | 11.29    | 1.46   | 1.29     | 0.78       | 0.44      | 11.20    | 3.30   |
|                  | Std. Error | 0.05     | 0.10       | 0.09      | 1.34     | 0.27   | 0.07     | 0.05       | 0.07      | 1.34     | 0.54   |
| Full Tree        | N          | 9.00     | 9.00       | 9.00      | 9.00     | 9.00   | 9.00     | 9.00       | 9.00      | 9.00     | 9.00   |
|                  | Mean       | 0.65     | 1.94       | 0.89      | 13.74    | 1.92   | 1.00     | 1.07       | 0.83      | 10.68    | 2.93   |
|                  | Median     | 0.60     | 1.67       | 0.82      | 12.25    | 1.97   | 1.00     | 1.00       | 0.67      | 10.14    | 2.67   |
|                  | Std. Error | 0.12     | 0.32       | 0.13      | 1.43     | 0.17   | 0.09     | 0.11       | 0.14      | 1.08     | 0.54   |
| CTL              | N          | 9.00     | 9.00       | 9.00      | 9.00     | 9.00   | 9.00     | 9.00       | 9.00      | 9.00     | 9.00   |
|                  | Mean       | 0.54     | 2.22       | 0.70      | 13.83    | 2.21   | 0.98     | 1.09       | 0.72      | 12.79    | 3.36   |
|                  | Median     | 0.54     | 1.86       | 0.65      | 13.36    | 2.13   | 0.95     | 1.05       | 0.60      | 12.10    | 2.51   |
|                  | Std. Error | 0.06     | 0.47       | 0.09      | 1.40     | 0.24   | 0.09     | 0.10       | 0.13      | 1.13     | 0.74   |

# **RIPARIAN VEGETATION: SPECIES DISTRIBUTIONS, TREE REGENERATION, AND STREAM LEAF LITTER CONTRIBUTIONS**

## **Brian Palik**

### **Abstract**

We investigated the distribution of woody and herbaceous plants and their recovery immediately post-harvest (i.e., in the first year). Plant species richness varies along an axis perpendicular to the stream channel. Forest harvest did not change plant community within our harvest stands. Although there was no significant impact of forest harvest on total regeneration, species specific rates did respond to treatments. Harvest resulted in a significant increase in aspen in post-harvest stands, most notably in cut-to-length treatments. Preliminary results also suggest that leaf litter dynamics may be more impacted than expected. For example, it appears that leaf litter entering the stream originates at greater distances from the stream channel and is more impacted by harvest than expected.

### **Background**

Forested riparian areas support plant communities that are valued for many reasons. For instance, some elements of the riparian flora may be distinctly different from surrounding ecosystems, thus adding to biological diversity of the landscape (Pabst and Spies 1998). Riparian plants are central to sustaining functional connections between forests and aquatic ecosystems, for example, through contributions of organic matter to streams (Vannote et al. 1980). Riparian forests also are valued for their timber resources. In Minnesota, this is true simply because a large percentage of the timber resource is adjacent to water (Laursen 1996). Because of their timber value, riparian areas are vulnerable to management practices that can degrade important ecological contributions of riparian plant communities.

Best management practices (BMP's) are designed to protect ecological functions of managed ecosystems, while providing for utilization of timber resources. Current Minnesota BMP's, that are applicable to riparian areas, focus on water quality (MN DNR 1995). While not explicit in these BMP's, protection of other functions and values associated with riparian areas (e.g., biological diversity, organic matter inputs) are implied. Unfortunately, the efficacy of BMP's at protecting riparian functions is often untested. Additionally, the ability to manage riparian forests for timber, while adhering to the BMP's is questioned. This is of particular concern for intolerant species; management of aspen (*Populus grandidentata*, *P. tremuloides*) is an example. There is concern that adequate aspen regeneration is not possible when adhering to an important component of riparian BMP's, namely the retention of residual overstory. It is examination of trade-offs between protection of ecological functions (provided by riparian vegetation) and sustainability of timber management in riparian areas that is the intent of this research.

### **Objectives**

Specific objectives for this research component include:

1. Describing plant communities in riparian areas, with emphasis on identifying

- unique, non-woody riparian taxa and assessing impacts to riparian plants from different management approaches.
2. Examination of commercial tree species regeneration, particularly aspen, under riparian management treatments that include retention of overstory competitors.
  3. Quantification of coarse particulate organic matter contributions (leaf litter) to headwater streams from riparian forests managed using different approaches.

## Methods

### Vegetation Sampling and Analysis

Transects were established in all stands perpendicular to the dominant stream direction. The number of transects ranges from 4 to 8 per stand. Permanent sample points are established along the transects, centered on landform (e.g., floodplain, terrace, upland). The number of points per stand ranges from 16 to 42. At each point along transect in the Little Pokegama Creek Stands, herbaceous, seedling, shrub, sapling, and tree data were recorded (Table 1). Pre-harvest vegetation data were collected for the Little Pokegama

**Table 1. Sampling methods used for each vegetation layer.**

| Vegetation Layer        | Sampling Method                                                                                                                                                   |
|-------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Herbaceous <sup>1</sup> | 0.5 m <sup>2</sup> plot at each point, ocular estimate of coverage by species (% cover); 6 classes used, class 1 = trace-1% through class 6 = 60-100%             |
| Seedling                | 0.5 m <sup>2</sup> plot established at each point ; # of seedlings for each species recorded; Cloquet site: 0.75 m radius circular plot established at each point |
| Shrub                   | 1.5 m radius circular plot established at each point; # of stems by species recorded; Cloquet site: 1 m radius plots established at each point                    |
| Sapling and tree        | Point-quarter sampling used, centered on each point; Cloquet site 5 BAF prism used for saplings, 10 BAF prism used for trees                                      |

Creek and Knife River sites in summer 1997 and the Cloquet River site in summer 1998. Post-harvest data were collected at the Pokegama Creek site in 1998. No post-harvest data have been collected at the Knife River or Cloquet sites because logging is not complete. Pre-harvest data for these sites are not discussed in this report.

In addition to vegetation data, a pilot scale, stream litter input study is being conducted at the Pokegama Creek site. Overhead and lateral litter traps are installed in each replicate of the following treatments: control, riparian control, FT-system. Litter collections are

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<sup>1</sup>Little Pokegama Creek site only

conducted periodically throughout the year. ANOVA and ordination are the primary analytical tools used in this research. Detailed statistical results are omitted from this report, but are available on request.

## Results

### Distribution of Herbaceous Vegetation

Geomorphic surfaces of the riparian area at the Little Pokegama Creek site include narrow floodplains, fluvial terraces, terrace slopes and upland glacial terraces. Distance from the stream to the top of the terrace slopes generally exceeds 100 ft. (Fig.1). Plant species richness varies across that geomorphic gradient. Richness is highest near the stream, declining into the upland, with a break at approximately 100 ft (Fig.1). Plant composition varies among landforms and distance from the stream. For example, 10 of the 38 more common species are found primarily on floodplains and low terraces (Fig.2), while 8 occur mostly on slopes and in the upland. Dwarf enchanter's nightshade (*Circaea alpina*) was found exclusively on floodplains and low terraces (Fig.2).

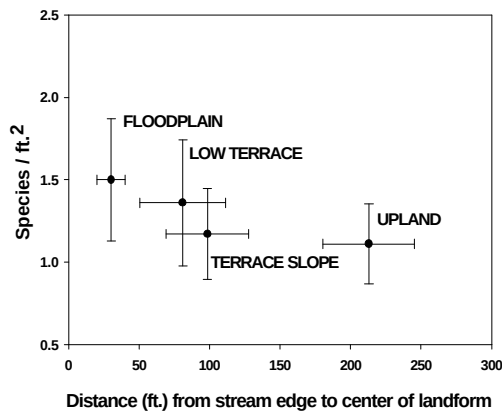


Figure 1. Species richness by distance from stream and landform. Horizontal and vertical bars are standard errors based on 48 to 72 samples.

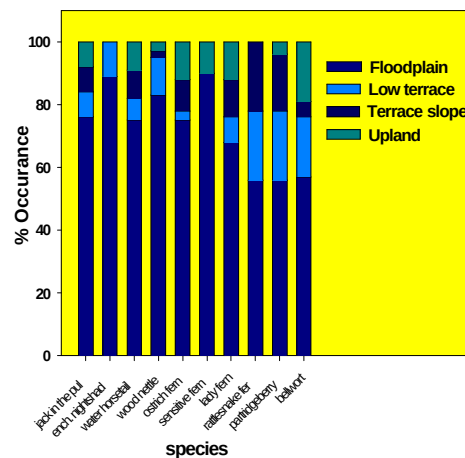


Figure 2. Species occurrence by landform.

### Changes in Overstory Structure

Pre-harvest basal areas were similar for all treatment stands, ranging from 120 to 145 ft<sup>2</sup>/ac. (Fig.3). Sugar maple (*Acer saccharum*) comprised the largest percentage of the pre-harvest overstory (26%), followed by paper birch (*Betula papyrifera*) at about 20%. Minor species include black ash (*Fraxinus nigra*), balsam fir (*Abies balsamea*) and basswood (*Tilia americana*). Aspen (*Populus tremuloides* and *P. grandidentata*) averaged about 11% of total pre-harvest basal area (Fig.4).

Basal areas of the stands having riparian areas harvested using the FT- system were reduced to an average of just over 40 ft<sup>2</sup>/ac (Fig.3). Stands that were harvested using the CTL system were reduced to approximately 35 ft<sup>2</sup>/ac (Fig.3). Post-harvest overstory composition is similar to pre-harvest composition, being dominated by sugar maple. In harvested riparian areas,

aspen basal area was reduced from about 13 ft<sup>2</sup>/ac to less than about 4 ft<sup>2</sup>/ac (Fig.4).

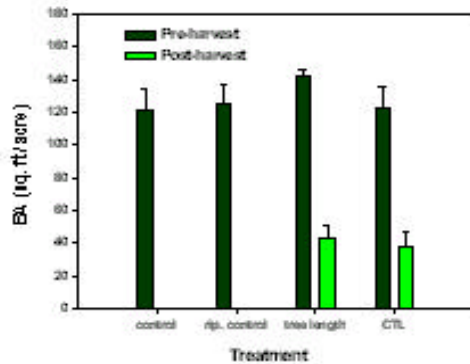


Figure 3. Overstory basal area by treatment.

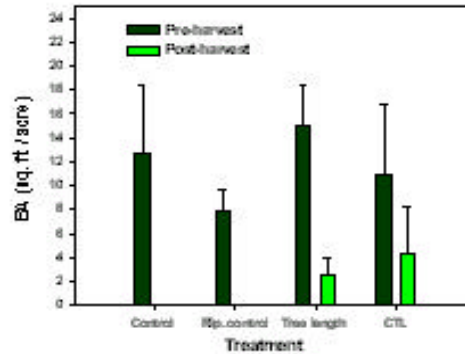


Figure 4. Aspen basal area by treatment.

### Regeneration Response to Overstory Treatments

There was no significant difference between total regeneration density before and after harvest across the treatments ( $p > 0.05$ ). Densities ranged from an average of 65,000 stems/acre in post-harvest controls to 91,000 stems/acre in post-harvest CTL stands. Species-specific regeneration density changed significantly for several taxa. Aspen regeneration density increased ( $p < 0.01$ ) for all harvest treatments, including the riparian control. Densities in the true controls remained essentially the same (Fig.5). The greatest increase occurred in stands harvested using the FT-length system, increasing from 5,000 aspen sprouts/acre to over 35,000 sprouts/acre.

Paper birch regeneration also increased in the partially harvested riparian treatments (Fig.6). The difference was not significant due to high variation. The largest increase occurred in the CTL treatments, with densities increasing from 500 to over 8,000 stems/acre (Fig. 6). Other species showed opposite trends. For example, sugar maple density decreased by approximately 50% in both harvested riparian treatments, dropping from around 40,000 stems/ac to less than 20,000 stems/ac.

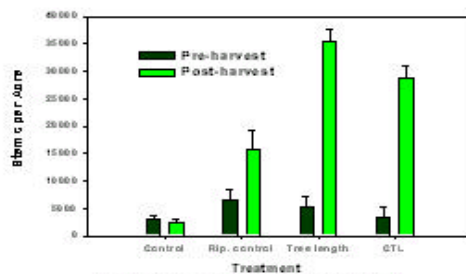


Figure 5. Aspen regeneration density.

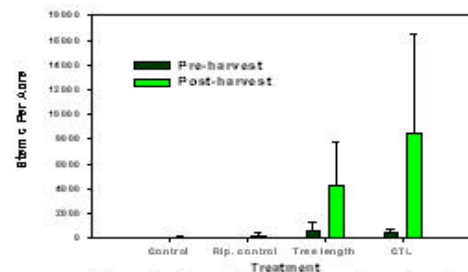


Figure 6. Paper birch regeneration density.



## Coarse Particulate Organic Matter Contributions

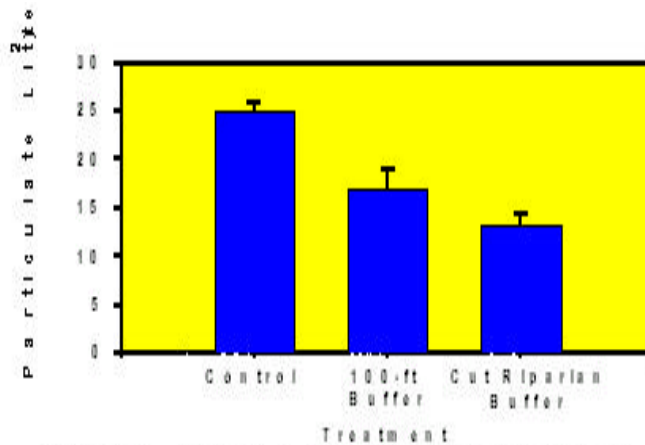


Figure 7. Stream Litter Input by Treatment

Preliminary results suggest that leaf litter input to the streams during 1997 varied significantly ( $p < 0.05$ ) among treatments. Litter inputs from the 100-ft. buffer, and from the partially harvested buffer, were 67% and 57% that of intact forest, respectively (Fig.7).

## Interpretation and Implications for Further Study

### Riparian plant distributions

Our pre-harvest sampling of herbaceous vegetation at the Little Pokegema Creek site suggests that these riparian areas contribute uniquely to plant diversity within the watershed. For instance, herbaceous plant communities show distinct zonation across the riparian ecotone. Species richness is highest near the stream, declining with distance into the upland. Richness appears to stabilize around 100 ft (30 m) from the stream. Plant community composition varies across the riparian ecotone. There is a group of species that are primarily riparian in their distribution. Nine species are best described as facultative (i.e., they are found primarily on valley floor landforms [floodplain, low terrace] but occasionally are found in the upland). One species is an obligate riparian taxon in the watershed, being found exclusively on floodplains and low terraces.

These data point out where the potential for greatest direct negative impacts from harvesting might occur. The coincidence of highest species richness and occurrence of rarer species nearest the stream, on floodplains and low fluvial terraces, suggests that these areas deserve greatest attention with regard to reduction of direct harvesting impacts. Interestingly, our initial post-harvest observations of vegetation suggests that floodplains and low terraces are least likely to be directly impacted by harvesting equipment during summer logging. This is a result of limited equipment access in areas that often have high surface soil moisture. However, this does not account for potential longer-term changes in plant communities due to indirect influences of harvesting, such as altered light regimes, microclimate, and hydrology. Our ongoing efforts are focused on continued monitoring of herbaceous plant communities in response to the harvest treatments.

### **Tree regeneration**

Our early results (one-year post harvest) indicate that regeneration of aspen (and paper birch) is not greatly inhibited by overstory retention within partially harvested riparian management buffers. Levels of first-year aspen sprouts in both the partially harvested riparian treatments (FT-system, CTL) are well within the range reported in the literature (17,600 to 90,000; Peterson and Peterson 1992). In fact, levels of aspen sprouting are high, even with retention of nearly twice the current recommendation of 25 ft<sup>2</sup>/ac when managing for intolerant species (MN 1995).

These results likely reflect the spatial nature of retention in the cut buffers and how this controls competitive effects of residual trees on resource availability. Retained trees in the cut riparian buffers were usually clumped in patches, rather than dispersed uniformly across space. The logger, largely due to topographic conditions, enforced this pattern. Steep slopes or wet soil prevented equipment access in parts of the riparian areas. Current ideas about the spatial nature of competition in two-cohort plant communities suggest that clumping of residuals should result in greater resource availability, and reduced competitive inhibition of regeneration than dispersed residuals, when measured across the whole stand (Palik *et al.* 1997). In other words, the same level of retention will result in greatly different competitive environments (averaged across the whole stand) depending on how the residuals are left in space. Clumped residuals result in more favorable competitive neighborhoods over a greater proportion of the stand.

In ongoing efforts, we will monitor new cohort development at the Little Pokegama Creek site. Additionally, we will begin post-harvest assessments of regeneration at the Knife River site (as harvesting is completed) and the Cloquet Valley site. The latter locations provide better tests of the effects of residuals on regeneration, since the experimental treatments include various levels and spatial patterns of retention.

### **Coarse Particulate Organic Matter Contributions**

Our early results on leaf litter input to streams are surprising. Conventional wisdom suggests that most litter entering streams come from within one-half tree height of the channel (O'Laughlin and Belt 1995), or 55-60 feet in this study. Our results indicate that nearly one-third of litter originates more than 100 feet from the channel. This result may reflect the steep topography of the study area, since leaves can travel greater distances down steep slopes. Our results also show that retention of 40 ft<sup>2</sup>/ac of overstory basal area within the riparian buffer is not sufficient for sustaining litter inputs at pre-harvest levels. These results are important for two reasons. First, they indicate that the functionally defined riparian area extends beyond the 100-ft width suggested by the current BMP. Secondly, they show that the current suggested level of retention for managing intolerant species (25 ft<sup>2</sup>/ac) falls well below the level needed to maintain functional similarity (in terms of litter input) to the uncut forest.

These results are tempered by several points. First, litter reductions are ephemeral. As the new forest develops, inputs will increase. However, the timing of this recovery is unknown. Second, watershed condition must be considered when speculating on the

importance of litter reductions. A single 200-foot reach with substantial reduction in litter inputs may be inconsequential if little of the watershed is in a young forest condition. Finally, the level of litter input to the stream that is required to sustain aquatic food webs in a pre-harvest condition is currently unknown. In ongoing work, we will continue to monitor litter inputs to the streams as the new forest develops. More importantly, we will link our data on litter inputs with those on stream detritus processing and aquatic invertebrate response to the riparian treatments.

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### **Products to date**

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1. Palik, B. J. Functional approaches to riparian definition and delineation. Presentation at the Ecology and Management of Riparian Areas Workshop, Minnesota Center for Continuing Education. Grand Rapids, MN. 1997.
2. Palik, B. J. Riparian Areas and Forest Fragmentation. Presentation at the Lake States Forestry Alliance Forum. Bloomington, MN. 1997.
3. Palik, B. J. 1997. Silvicultural approaches for riparian ecosystems. MN Department of Natural Resources Two Harbors Integrated Management Team.
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5. Ilhardt, B., B. J. Palik, and E. Verry. Defining riparian areas. Presentation at conference on Managing Riparian Forests in the Eastern United States. Columbus, OH. 1998.
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riparian areas. Conference on Managing Riparian Forests in the Eastern United States. Columbus, OH.

7. Palik, B. J., J. Robl., and E. S. Verry. 1998. Functional delineation of riparian areas. Annual Meeting of the Ecological Society of America. Baltimore, MD.

#### **Training Sessions and Tours**

1. One-day class on riparian silviculture. 1997-98. University of Minnesota Forestry Camp.
2. Managing riparian areas for multiple values. 1997. Workshop. Minnesota Center for Continuing Education.
3. Short-course: Silviculture Certification Training, USDA Forest Service. 1997. Riparian ecology and silviculture.
4. Tour: LCMR. 1997. Minnesota Riparian Management Experiment.

#### **Publications**

1. Palik, B. J. 1997. Riparian Forests: What's Water Got To Do With Them? *Minnesota Better Forests* 2: 8-10.
2. Palik, B. J. Zasada, and C. Hedman. 1998. Ecological considerations for riparian silviculture. In *Managing riparian areas of the eastern United States*. E. Verry and J. Hornbeck, (eds.). In press.
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# EFFECTS OF TIMBER HARVEST ON ARCHAEOLOGICAL SITES

Patricia Emerson

## Abstract

I investigated the effects of timber harvest activities on subsurface archaeological deposits. I constructed artificial archaeological deposits in timber stands scheduled for harvest, using materials that closely replicate those typical of authentic archaeological sites in Northern Minnesota. After harvest, I retrieved replica artifacts and documented the extent to which they had been displaced or damaged by harvest activities. Approximately 5% of artifacts were lost or damaged. Horizontal displacement of shallow materials and breakage of fragile materials are the most likely effects of harvest activities; those effects tend to occur only in areas directly trafficked by heavy equipment.

## Background

Understanding the precise manner in which archaeological deposits are affected by contemporary human activities is a vital part of efforts to devise strategies for mitigation of those effects. Although harvest impacts to archaeological deposits have been documented anecdotally, there has previously been no formal research on such effects in Minnesota. The present study was a first step in the process of collecting information relevant to the formulation of effective and practical recommendations for reducing the effects of forest management activities on cultural resources.

This research was based on a set of generally held assumptions about the nature of archaeological data -- particularly the concept of "site integrity", which for our purposes is defined as the extent to which artifacts and features or the stratigraphic relationships among them accurately reflect the human cultural behavior that created an observable archaeological deposit. A related concept is the theoretical definition of artifacts as conveyors of cultural information. In this view, objects are of value not *qua* objects but as carriers of meaning. The physical integrity of objects is important to the extent that it reflects the manufacture or use of the object in a cultural setting. Depending on the nature of the artifact, changes to its physical properties may lessen its potential to transmit information about past cultural behavior, thereby reducing the research value of the object.

The scientific value of archaeological evidence is thus diminished when stratigraphic relationships are disrupted or the physical properties of artifacts are changed. These effects could occur when activities such as heavy equipment traffic result in soil compaction, rutting, mixing of surface soils or removal of ground cover. Indirect effects such as increased potential for wind or water erosion could also result in loss of archaeological data.

While effects such as these can often be observed after the fact, quantifying the extent of data loss from specific management activities is challenging because of the nature of archaeological phenomena. Every site is a unique combination of cultural and natural characteristics that occurs nowhere else. "Before and after" studies of authentic archaeological sites cannot be conducted using conventional research techniques such as formal excavation, because pre-harvest data collection would destroy stratigraphic relationships and remove physical evidence from its original context.

Some U.S. researchers have addressed this difficulty by conducting studies of "replica" archaeological sites created specifically to document disturbance from management activities, including timber harvest and

other forest management practices. While some understanding of processes that affect site integrity has been gained, it is difficult to draw general conclusions from these studies due to regional variations in topography, soils, archaeological stratigraphy and harvest techniques.

This study ensured that experimental results parallel “real-world” situations to the extent possible. Three aspects of experimental design were particularly critical: the use of authentic materials for creation of replica archaeological deposits, pre-harvest field methods that resulted in minimal alteration of the physical properties of the soil column, and characterization of site disturbance in absolute measures of displacement and mechanical modification of replica materials.

## **Objectives**

This analysis had two principal objectives:

1. To determine if there are significant losses of, or damage to cultural artifacts in harvested sites, and
2. To determine if the type of practice used in conducting the harvest affects loss and/or damage

## **Methods**

### **Artifact preparation**

Our approach relies on use of replica artifacts. Here, "artifacts" refers to discrete, portable material objects made or used by humans, or generated as byproducts of human activities. A range of materials was selected to represent items typically found at archaeological sites in Northern Minnesota. It should be noted, that the assemblage included only a subset of the full range of functional classes, technologies and raw materials commonly observed in the archaeological record.

One focus of this study was the impact of mechanically induced change on the physical properties of archaeological materials. It was therefore important to represent properties of hardness and friability accurately; replica lithic and ceramic artifacts were prepared using authentic raw materials and techniques. Because faunal remains are an important component of PreContact sites, a selection of animal bone was also included in the set of replica materials.

Lithic artifacts were prepared from typical primary or secondary source materials: quartz, jasper taconite, Swan River Chert, Red River Chert, Knife River Flint, Cedar Valley Jasper and till cherts. Nodules or core fragments of each material were hand-knapped to produce debitage specimens in a range of sizes. No effort was made to replicate particular functional artifact classes. Replica ceramic vessels were produced from local clays and tempering materials, fired in an outdoor hearth. The fired vessels were broken, and an assemblage of sherds in various sizes and from various parts of each vessel was collected. Faunal material samples were extracted from specimens obtained opportunistically. Portions of crania, vertebrae, long bones and teeth from two mammalian genera (*Alces* and *Procyon*) were used; a subset of the raw bone specimens was thoroughly burned before use.

After the full set of replica artifacts was assembled, each item was assigned a catalog number and recorded on an index list. The items were then painted with fluorescent paint to aid in recovery, and catalog numbers were applied. To document original size and shape, sets of artifacts were placed on a photocopier and a series of copy sheets was produced. Images on the copy sheets were labeled with the appropriate catalog numbers.

## **Field Placement**

Six locations in the Little Pokegama Creek Watershed were selected for creation of replica artifact deposits. Four study plots were established in locations harvested with the FT-system; one plot was established in a CTL stand. A single control plot was established in a stand that would remain unharvested. In the following text, 'plot' refers to the location of replica placement; 'plots' are located in 'stands' (i.e., locations representing the various harvesting conditions). In selecting exact locations for the test plots, skid trail location and slash treatment prescriptions were considered. Other aspects of harvest strategies such as clumped versus dispersed residual trees were deemed negligible in terms of variation in effects to archaeological materials, so no effort was made to represent these attributes.

Provenience control at each study plot was established with the use of a grid template (i.e., an 8-by-12 foot tarp with forty-eight 3" (7.5 cm) diameter holes cut in it). The holes were spaced at 40 cm intervals on a 6-by-8 grid. At each study plot, the template was stretched out and pinned to the ground. The tarp location was recorded relative to benchmarks that included two local datum points (nails pounded into exposed tree roots) near each study plot. To further aid in documenting the grid position, template corners were marked on the forest floor with fluorescent paint, and large washers were placed within the top 5 cm of soil at two grid openings. A soil probe was used to remove columns of soil at the midpoints of the template's long edges, and the holes were filled with white aquarium gravel. Thus, several means by which the plot could be relocated were available, even if topsoil was severely disturbed by harvest activities.

Soil was removed from each of the openings in the template, artifacts were placed in the holes, and the soil was replaced and tamped down. It was often possible to retain the removed soil plug and place it back in the hole with little effect on the integrity of the soil matrix. Artifacts were buried between 3 and 20 cm below the ground surface. The placement depth of each item was recorded as depth below ground surface as well as depth below one of the local datum points.

## **Field Sampling**

Study plots were revisited after harvest and each template location was re-established relative to local datum points. At most plots, before the template could be repositioned, it was necessary to remove logging slash and other debris from the ground surface. Large logs were cut with a chainsaw or handsaw and moved; limbs that had become pressed into the ground surface were pried out and removed. Small branches and sticks, bark and leaf litter were removed with a garden rake.

One unanticipated effect of the harvest activities was discovered as data recovery progressed. At 4 of the 5 harvested plots, local datum points had been damaged by heavy equipment traffic. However, the other markers retained enough integrity to provide guidance in relocating the study plots. After the grid template was repositioned at each study plot, elevations were taken at each grid opening relative to the artifact placement datum. Although this vertical datum was often slightly misplaced from its original position, it was hoped that relative changes in the micro-topography of the plot area (e.g., the difference between elevation of the gravel columns) could be measured even if absolute changes could not.

After the template had been repositioned, grid openings were marked and excavated, limiting the horizontal extent of excavation to a circle 10 cm in diameter greater than the area excavated for artifact placement. Where the local datum used for artifact placement was unaffected by the logging (stands 1 and 3), the exact depth of artifact recovery was measured from this datum. Where the datum had been

compromised (stands 2, 4, 5, and 6), the vertical position of the artifact was measured in 5 cm arbitrary levels below ground surface. Thus, an artifact should have been found if it moved fewer than 5 cm horizontally from its original position. Similarly, vertical displacement by more than 5 cm would have been identifiable. Recovered artifacts were examined for evidence of damage, comparing them with their pre-placement photocopied images when necessary. The physical condition of each study plot (i.e., rutting, apparent compaction, extent and type of ground cover) was also noted and compared to pre-harvest conditions.

## **Results**

Inasmuch as the local datum points were almost universally compromised (typically bent), direct comparisons of depth below datum upon placement to depth below datum upon recovery were only possible in two of the stands. For the other four stands, comparisons of depth below ground surface were made, using the original ground surface elevations as a measure of accuracy. Post-harvest surface conditions were also recorded at each plot and compared to pre-harvest conditions.

### **Plot 1**

A control stand, located on an upland terrace in Stand 1 which was unharvested. The ground surface at data recovery was essentially unchanged from the surface at plot creation. All replica items were recovered, although proveniences for about one-third of them varied from placement depths by one to two centimeters. This degree of variation, is not significant for the purposes of this study and indicates that recovery techniques were reliable.

### **Plot 6**

This plot was located in Stand 6, near the edge of the riparian zone, in uplands that were clearcut with a feller-buncher. The logger had been instructed to create slash piles in this stand. Post-harvest conditions found the plot under a significant tangle of large limbs. Large sticks and branches were embedded (often frozen) in the slightly wet soil. In this plot, 4 of the original 48 replica items were not recovered, and 3 were found to be broken. About one-third of the items that were recovered were found at proveniences deeper than those of placement, but most of the changes were only in the range of 2 to 4 cm.

### **Plot 3**

This plot was located far from the riparian zone in Stand 4, in uplands that were harvested with the FT system. Slash was not deliberately piled by the logger in this stand. After harvest, the area was almost totally clear of vegetation and debris; only a few limbs had to be moved to expose the ground surface. A large rut ran along the edge of the plot, and in one place the sod had been dislodged and redeposited. Comparisons of relative surface elevations before and after harvest suggested that much of the study plot had been compressed by equipment traffic, although the damaged datum made an exact determination impossible. The observed surface compression resulted in many artifacts being recovered from proveniences that appear more shallow than placement depth. No recovered items were broken, but 17% of the original assemblage was missing; all of these items had initially been at depths less than 10 cm below ground surface.

### **Plot 4**

This plot was located in Stand 2, on an upland slope that drops off to the east. This stand was harvested with the CTL system. The logger did not complete harvest of this stand until late in 1997, so archeological data were not recovered until 1998. Post-harvest conditions found the area relatively clear of debris but



growing over with weeds. Equipment tracks were apparent, but the surface appeared to be compressed rather than rutted. Overall, the cut-to-length system had minimal visual effects on the study plot. The entire artifact assemblage was recovered and only one very fragile piece of burned moose vertebra had been broken. Eight items were recovered from proveniences more shallow than placement depth, but differences were all in the range of 1 to 5 cm, a difference not considered significant.

### **Plot 5**

This plot was located within the riparian zone in Stand 6, on a terrace with a slope of approximately 10%. Here, uplands were harvested with the FT-system and slash was piled; selective harvest was conducted in the riparian zone. The artifact grid was placed on a natural ramp down from the upland that was used as a skid trail. Post-harvest conditions found the plot totally denuded with what appeared to be substantial surface disturbance. Six of the original 48 replica artifacts were not recovered and 4 (2 ceramic sherds and 2 pieces of burned bone) were broken. All of the missing or damaged items had originally been in shallow (< 10 cm) proveniences.

### **Plot 6**

This plot was positioned on a slope of approximately 15%, in an upland portion of Stand 4 that was clearcut with the FT-system. No slash piling was done in this stand. Like plot 5, this study plot was situated on a natural ramp that served as a skid trail. Post-harvest conditions found the plot totally denuded, but with minimal apparent surface disturbance. Plot 6 had 5 missing items and 2 broken pieces of burned bone. Most of the lost or damaged items were originally at proveniences between 4 and 12 cm below the ground surface, slightly deeper than those of the items lost or broken at other study plots.

### **General effects**

Nine of the 219 recovered artifacts (4%) were moved a significant distance vertically, and much of the noted vertical displacement appears to have been due to changes in the elevation of the ground surface (compression, rebound, or addition or removal of soil) rather than actual migration of artifacts. In contrast, 21 items (9.6%) were not recovered and are assumed to have been significantly displaced horizontally. Losses were almost universally from shallow contexts (i.e., from depths less than 10 cm below ground surface at the time of placement). In both horizontal and vertical dimensions, artifact displacement did not occur in isolation. Typically, groups of adjacent artifacts were displaced, suggesting that significant disturbance was limited to discrete areas that were most heavily trafficked by harvest equipment.

Approximately one in twenty-two recovered artifacts (4.6% of total) exhibited some type of physical damage that can be attributed to logging activities. No lithic items or raw bone fragments were damaged; the broken pieces were all either ceramic sherds or burned bone. All damaged pieces were recovered within 5 cm of surface except for two items that were more than 10 cm below ground surface.

### **Interpretation**

Overall, the extent of effect to the replica archaeological deposits seen in this study was variable within study plots as well as across them. The harvest strategy employed does not appear to have been the sole determinant of effect, although the plot harvested with a cut-to-length system did suffer less disruption than the other study plots.

Although the disturbance pattern was not consistent, there was pattern in the localized nature of observed effects. That is, within each affected plot, some areas were essentially intact while other areas suffered

moderate to significant disruption. Assessment of surface conditions suggested that equipment traffic patterns were the most important factor in explaining the observed variations in artifact displacement and alteration. Areas directly trafficked by equipment – particularly by multiple passes -- were likely to sustain damage, while adjacent areas remained unaffected.

Thus, it is difficult to predict the extent of data loss for a given archaeological site in a harvest area, because the exact location of the disturbance will be largely determined by equipment operators as they move through the stand. Even if one could predict an average affected area of, for example, 10% of a total site area, this does not necessarily translate to loss of 10% of the data contained within the site. An archaeological site is a highly patterned assemblage of cultural and natural features in which there may be some areas that are almost devoid of data and other areas that contain dense deposits of artifacts or other materials that are critical to site interpretation. Therefore, disturbance of a small portion of a site, if it occurs in an area of high artifact concentration, may result in loss of a significant proportion of the total information contained within the site.

Of note in this regard is the fact that the faunal materials used in this study sustained more physical damage than ceramic or lithic materials. Faunal remains tend to be poorly preserved in archaeological contexts in Northern Minnesota, while being of particular value for such analyses as radiometric assay, dietary studies, seasonality determinations and paleoenvironmental reconstructions. Their apparent susceptibility to damage from equipment traffic must therefore be a significant consideration when assessing the potential for harvest activities to affect archaeological sites.

Although limited in scope, this study yielded results that begin to suggest which aspects of the harvest process are of most concern to protection of subsurface archaeological deposits. It also resulted in definition of an efficient and reliable protocol for the creation of replica archaeological deposits, although a minor revision is needed to better protect local datum points from damage by logging equipment. Application of the experimental design described here at additional harvest sites will expand sample size and allow for more detailed investigation of specific aspects of the effects observed in the present study. The DNR-Forestry Heritage Resources Program intends to conduct further research as opportunities arise on State Forest lands. In time, the body of accumulated data should provide a better understanding of how to accommodate cultural resource considerations within the framework of forest management in Minnesota.

# **TIMBER HARVESTING EFFICIENCY AND STAND DAMAGE**

**James A. Mattson and Michael A. Thompson**

## **Abstract**

The full-tree (FT) harvesting system exposed more organic and mineral soil than did the CTL system. The CTL system left considerably more slash on the site. The full-tree system traffics a greater portion of the plot. Untrafficked slash is more evident on the CTL plots. There is evidence of greater disturbance (e.g., rutting) in limited situations. Analysis is ongoing to identify the harvest and traffic patterns that lead to that level of disturbance.

## **Introduction**

Assessing the effects of forest operations on the site is an important first step in evaluating the significance of impacts on the health of the forest ecosystem. The majority of the effort devoted to operational questions in phase I of this project were devoted to studying the operational site impacts of the harvesting operations. Most riparian areas have a gradient of site conditions ranging from upland conditions away from the water body to conditions that may be characterized as wetlands near the water. Therefore, the most serious constraints placed on harvest system selection and operation, with the possible exception of unstable soils on steep slopes, are the conditions occurring closest to the water body where high soil moisture conditions are the predominant consideration.

Minimizing damage to residual trees and plants is critical in all-age management systems where partial cuts are applied on a regular basis. Logging damage most often occurs in the first log of the tree, which is usually the most valuable. The trees selected for saving in a partial cut are usually those species and individuals that have the most potential for growing high valued products. Any logging damage incurred can then have a significant impact on the long-term economics of the management system.

## **Objectives**

We posed two objectives:

1. Determine if the imposition of additional constraints in the riparian area would have an effect on the operational efficiency of the harvesting systems, and
2. Assess the extent and nature of damage to residual trees and the surface soils of sites harvested in different ways.

## **Methods**

Site impacts were studied over a gradient of conditions from the stream to the upland areas of the study plots, with the emphasis on the riparian areas.

## **Harvesting System Efficiency**

The harvesting systems used in this study were a conventional full-tree (FT-)system consisting of a feller-buncher, grapple skidder, and roadside slasher, and a cut-to-length (CTL) system consisting of a rubber-tired single grip harvester and a rubber tired forwarder. The specific equipment used in the full-tree system were a Timbco 425B tracked feller-buncher with a Quadco 22 inch high-speed saw head, and a John Deere 648E grapple skidder. The cut-to-length system

used either a Valmet 546 Woodstar Series II harvester, or a Ponsse Cobra HS10 harvester, in conjunction with a Valmet 546 Woodstar Series II forwarder.

Three different applications of the harvesting systems were evaluated. In the first treatment (plots 4, 6 and 10), the FT-system was used to harvest both the upland and riparian areas of the study plot. In the second treatment, the CTL system was used to harvest both the upland and riparian areas of the study plot. This system was used for plots 2, 8, and 11, except that the FT-system was used to harvest the upland portion of plot 2. This plot was harvested last, after the harvesting equipment had been moved to other jobs, and the contractor requested that we use the FT-system on the upland. In the third treatment (plots 3, 5 and 12), the CTL system was used to harvest only the upland portion of the study plot, leaving the riparian area uncut as a control.

Standard time and motion study methods were used to study a sample of the harvesting operation. The large size of the overall project (i.e., approximately 6000 cords of wood harvested, a large number of machines operating simultaneously) made it impractical to attempt to do a 100 percent time study. Most of the actual harvesting operation was a fairly straight-forward application of standard equipment, and the productivity and cost of the operation would not be expected to vary from established industry standards for productivity and cost. It was originally envisioned that the riparian area and the upland area in each study plot would be harvested separately, and the productivity and cost of the operation could be determined separately for the two areas. However, it quickly became obvious that the most efficient approach for the contractor was to simultaneously harvest the riparian area along with the associated upland area. Data were collected on a sample of the operations in both the upland and riparian areas. This information and supporting information on the normal efficiency of these systems and the additional constraints that working in a riparian area place on the harvesting system allow us to develop estimates of the productivity and costs of the operation, and to identify any additional costs incurred as a result of harvesting in the riparian area.

### **Residual Stand Damage**

After logging was completed in the study plots that had a harvesting operation in the riparian area, a 100 percent inventory of the residual trees in the riparian area was conducted. Damage to the crowns, boles, and roots was documented on all trees 5 inches dbh and larger. Damage to a total of 321 trees was recorded. Analyses to categorize all damage with respect to location, type of damage, and severity are ongoing. Ultimately, plot by plot analyses will look at differences that may be attributed to the harvest system.

### **Site Impacts**

We employed a field method we previously developed specifically for application to these settings. We visually assessed soil disturbance resulting from forest operations to evaluate the site impacts created by the harvesting operation. The method relies on three levels of assessment, with an associated height or depth measurement for some disturbance categories. The first level of assessment uses variables visible on the soil surface (e.g, litter, slash, mineral soil). The second level attempts to answer the question *What happened here?*, using categories such as undisturbed, trafficked and rutted.. The third level of assessment attempts to identify larger features of the site such as landings, roads and skid trails that define the patterns of impacts on the site. The method

can be used with any number of sampling schemes and is reproducible by different observers. The method does not produce absolute measures of site impacts, but is particularly appropriate for making comparative evaluations of different systems, such as was done in this project.

The impact evaluations done in this project were based on a series of transects established in each study plot. Twelve to sixteen transects, each nominally 100 meters long, were established in each study plot. Each transect began at the stream and extended out approximately parallel to the plot boundary. Transect locations were chosen to coincide with the transects established for measurement of vegetation on the plots so that collaborative analyses could be done between harvesting impacts and vegetative response. Along each transect at intervals down to 0.1 meter, the visible layer, disturbance evaluation, and main site features were recorded.

## Results

Preliminary information on the soil visible layer is summarized in Table 1. It appears evident that the FT-system exposed more organic and mineral soil than did the CTL system. This would be reasonable to expect since the grapple skidding involves dragging loads of full-trees or tree-length stems on the ground which would tend to scrape away the litter layer and expose the underlying soil layers. A second evident trend is that the CTL system left considerably more slash on the site. Slash, in this assessment system, is defined as accumulations of logging debris so thick that the underlying soil surface cannot be seen. This is typical of the operation of CTL systems (i.e., “windrows” of slash are left in the stand due to the pattern that the harvesters will typically follow as they work their way through the stand).

**Table 1. Soil visible layer by treatment (percent of total transect length)**

|          |                    | Riparian: Control<br>Upland: CTL | Riparian: FT<br>Upland: FT | Riparian: CTL<br>Upland: CTL |
|----------|--------------------|----------------------------------|----------------------------|------------------------------|
| Litter   | Riparian<br>Upland | 94.7<br>41.7                     | 78.4<br>51.7               | 67.0<br>49.2                 |
| Organic  | Riparian<br>Upland | 0.1<br>7.4                       | 6.7<br>15.7                | 5.3<br>5.7                   |
| Mineral  | Riparian<br>Upland | 0.0<br>0.5                       | 1.9<br>3.1                 | 0.4<br>0.4                   |
| Slash    | Riparian<br>Upland | 1.7<br>49.4                      | 9.5<br>28.4                | 23.8<br>43.7                 |
| Non-soil | Riparian<br>Upland | 3.5<br>1.0                       | 3.5<br>1.0                 | 3.5<br>1.1                   |

Preliminary information on the disturbance evaluation is summarized in Table 2. Again, some trends appear evident. The FT-system, again because of the skidder travel, tends to traffic a greater portion of the plot. Skidder loads are smaller, requiring more trips and, particularly in the uplands where travel is not restricted, skidders will tend to vary their traffic patterns, always

minimizing their travel distance. Untrafficked slash is more evident on the CTL plots, a product of the more patterned approach generally taken by a CTL system.

A third category undergoing further analysis is the one termed “disturbed” in Table 2. This category includes the most severe forms of site impacts such as rutting. The amounts of disturbance that were recorded appear to be within reasonable limits for typical harvesting operations (i.e., three percent or less). However, the FT-system did appear to generate about twice the amount of disturbance that the CTL system. This category analysis will provide the opportunity to develop mitigation strategies for any harvest effects that are identified.

**Table 2. Disturbance evaluation by treatment (percent of total transect length)**

|                       |                    | Riparian: control<br>Upland: CTL | Riparian: FT<br>Upland: FT | Riparian: CTL<br>Upland: CTL |
|-----------------------|--------------------|----------------------------------|----------------------------|------------------------------|
| Undisturbed<br>litter | Riparian<br>Upland | 93.9<br>11.5                     | 61.9<br>11.6               | 45.5<br>18.9                 |
| Trafficked            | Riparian<br>Upland | 0.0<br>47.0                      | 20.9<br>67.2               | 20.8<br>38.1                 |
| Disturbed             | Riparian<br>Upland | 0.0<br>1.7                       | 3.0<br>3.4                 | 1.6<br>1.6                   |
| Scarified             | Riparian<br>Upland | 0.9<br>9.2                       | 4.2<br>4.0                 | 9.0<br>10.2                  |
| Untrafficked<br>slash | Riparian<br>Upland | 1.7<br>29.7                      | 6.5<br>12.8                | 19.5<br>30.1                 |
| Non-soil              | Riparian<br>Upland | 3.5<br>1.0                       | 3.5<br>1.0                 | 3.5<br>1.1                   |