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REGIONAL COPPER NICKEL STUDY
LEAF DECOMPOSITION

MINNESOTA ENVIRONMENTAL QUALITY BOARD
Author: Steven N. Williams
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PRELIMINARY DRAFT REPORT, SUBJECT TO REVIEW

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Abstract

Processing rates for aspen and red pine leaves were measured in first through fourth order streams in 1977. The purpose was to classify streams in the Regional Copper Nickel Study Area and attempt to determine the productivity of streams based on the predominant terrestrial vegetation in a watershed.

Artifical leaf packs were used to measure the weight loss during two eight week periods; one during June and July the other October and November. No significant difference ($P>.05$) in processing rates between stream orders was found, except for aspen leaves during the summer. Processing of aspen and red pine leaves was significantly more rapid ($P<.05$) in summer than fall. Average processing coefficients for aspen leaves for all stream orders were -0.02283 in summer and -0.00771 in fall.

The ratio of shredding to collecting invertebrates was higher in the fall for all stream orders and decreased with increasing stream order. Collector gatherers and collector filter feeders were the dominant functional groups at all stream orders on all dates. Shredders were most abundant in first order streams in the fall and least abundant in fourth order streams in the summer. The dominant shredder taxa were <u>Leuctra</u> during the summer and <u>Paracapnia</u> during the fall.

INTRODUCTION TO THE REGIONAL COPPER-NICKEL STUDY

The Regional Copper-Nickel Environmental Impact Study is a comprehensive examination of the potential cumulative environmental, social, and economic impacts of copper-nickel mineral development in northeastern Minnesota. This study is being conducted for the Minnesota Legislature and state Executive Branch agencies, under the direction of the Minnesota Environmental Quality Board (MEQB) and with the funding, review, and concurrence of the Legislative Commission on Minnesota Resources.

A region along the surface contact of the Duluth Complex in St. Louis and Lake counties in northeastern Minnesota contains a major domestic resource of copper-nickel sulfide mineralization. This region has been explored by several mineral resource development companies for more than twenty years, and recently two firms, AMAX and International Nickel Company, have considered commercial operations. These exploration and mine planning activities indicate the potential establishment of a new mining and processing industry in Minnesota. In addition, these activities indicate the need for a comprehensive environmental, social, and economic analysis by the state in order to consider the cumulative regional implications of this new industry and to provide adequate information for future state policy review and development. In January, 1976, the MEQB organized and initiated the Regional Copper-Nickel Study.

The major objectives of the Regional Copper-Nickel Study are: 1) to characterize the region in its pre-copper-nickel development state; 2) to identify and describe the probable technologies which may be used to exploit the mineral resource and to convert it into salable commodities; 3) to identify and assess the impacts of primary copper-nickel development and secondary regional growth; 4) to conceptualize alternative degrees of regional copper-nickel development; and 5) to assess the cumulative environmental, social, and economic impacts of such hypothetical developments. The Regional Study is a scientific information gathering and analysis effort and will not present subjective social judgements on whether, where, when, or how copper-nickel development should or should not proceed. In addition, the Study will not make or propose state policy pertaining to copper-nickel development.

The Minnesota Environmental Quality Board is a state agency responsible for the implementation of the Minnesota Environmental Policy Act and promotes cooperation between state agencies on environmental matters. The Regional Copper-Nickel Study is an ad hoc effort of the MEQB and future regulatory and site specific environmental impact studies will most likely be the responsibility of the Minnesota Department of Natural Resources and the Minnesota Pollution Control Agency.

INTRODUCTION

Previous studies have demonstrated that allochthonous inputs (organic matter from external sources) provide the primary energy source for small, heterotrophic streams (Teal 1957, Nelson and Scott 1962, Hynes 1963, Egglishaw 1964, Minshall 1967 and 1968, Mann 1969, Triska 1970, Vannote 1970, Fisher 1971, Kaushik and Hynes 1971, Hall 1972, Cummins et al. 1972 and 1973, Fisher and Likens 1972 and 1973, Petersen and Cummins 1974). Nelson and Scott (1962) reported that 66 percent of the energy available to primary consumers in a rock outcrop community was derived from allochthonous sources, primarily leaf matter. Vannote (1969) stated, "In a woodland stream the allochthonous detritus impact may support up to two-thirds of the annual energy requirements of primary consumer organisms." Over 99 percent of the annual energy input to Bear Brook was from allochthonous sources (Fisher and Likens 1972 and 1973). Teal (1957) attributed 76 percent of the energy at the primary consumer level to material of terrestrial origin, mainly leaf material.

Several authors have attempted to quantify the amount of allochthonous matter entering streams. Vannote (1969) estimated 1.37 g dry weight organic matter per day; Mathews and Kowalczewski (1969) and Kowalczewski (1970) 0.0489 g per square meter per day for the River Thames; and Hynes (1970) one kg per meter of bank length per year for a wooded valley stream. Fisher (1971) and Fisher and Likens (1972) approximated 1.70g per square meter per day; Liston (1972) 0.97g per square meter per day; and Petersen and Cummins (1974) 5.0 g per square meter per day for a small stream in Michigan.

Stream ecosystems undergo a transition in community structure from headwaters (1st and 2nd order) to higher stream orders involving changes in biological, physical, and energy conditions (Cummins 1975). Small, heavily shaded headwater streams rely on allochthonous material for the majority of their energy. As stream order increases, allochthonous energy sources decrease in importance while autochthonous sources (i.e. periphyton, macrophytes) increase. Corresponding changes take place in invertebrate community structure with increasing stream order. Headwater streams (1st and 2nd order) contain relatively large populations of shredding invertebrates capable of processing the greater input of organic matter. At higher stream orders there is a shift from shredders to collectors and filter feeders capable of assimilating the processed material washed in from upstream areas.

The importance of various types of detrital material to a stream is closely correlated with processing rates. Sedell et al. (1975) found that hardwood leaves were processed more rapidly than conifer needles and therefore became available as a food source much sooner. Hart and Howmiller (1975) found higher invertebrate biomass densities on leaves that were processed most rapidly. Woodall and Wallace (1972) working on several streams with different types of allochthonous inputs, at the Coweeta Hydrologic Laboratory, felt that the vegetation on each watershed was possibly the main factor affecting invertebrate species composition. They found that differences in the fauna of the streams in four watersheds could be explained by the availability of food or case-making materials, both of which are directly or indirectly controlled by watershed vegetation. Average monthly standing crops of invertebrates ranged from 716.3/m^2 in a white pine watershed to 1214.3/m^2 in an old field watershed.

Boling et al. (1975) list four major factors which contribute to detritus processing: 1) ingestion, processing and egestion by stream detritivores; 2) mechanical disruption of structured detritus by organisms eating or burrowing through detritus; 3) weakening and attrition of detritus due to microbial action; and 4) mechanical break-up and aggregation due to flowing water and the presence of obstacles. Studies to date have not tried to separate the effect of mechanical breakdown from that caused by micro-organisms and invertebrates, but have concentrated on the contribution made by invertebrates.

Hynes et al. (1974) suggest that the importance of leaf litter as a food for aquatic organisms probably lies in providing an energy source for microbial growth. They state "through the preference of animals for leaves that support micro-organisms, a vast resource of energy is profitably exploited in streams, leading to secondary and tertiary production." Kaushik and Hynes (1968, 1971) found that fungi were important primary decomposers of leaf material. Nelson and Scott (1962) found the ratio of the weights of detritivores and detritus higher than the ratio of herbivores to plants. They felt that detritus feeders obtain a portion of their food in the form of bacteria or some bacterial metabolic product.

Microbial metabolism can account for the processing of leaf litter in the absence of invertebrates (Mathews and Kowalczewski 1968, Triska 1970), but a twenty percent increase in processing was reported when shredders were present (Petersen and Cummins 1974). Jones (1975) stated that "ingestion of material by other animals (shredders) and excretion as faeces is thought to aid the decomposition process by producing a finely divided substrate which is more amenable to microbial attack." Short and Maslin (1977) found

(T.58N, R.10W, S.35) and its water flows into Birch Lake at T.61N, R.11W, S.25. The average stream gradient is 9.12 m/km.

Vegetation in the watershed consists of 15.49 percent white, red, or jack pine, 49.18 percent spruce-fir, 26.05 percent aspen-birch, and 6.08 percent nonforested land. Substrate types in the river bed vary from ledgerock to muck and detritus. Water temperatures vary from 25°C in summer to 0°C in winter months.

The St. Louis River Watershed is located south of the Laurentian Divide and has a drainage area of 350 km^2 upstream of Aurora, Minnesota, where it leaves the Study Area. Its major tributary, the Partridge River, has an additional 335 km^2 drainage area. The source of the St. Louis River is bog drainage above Seven Beaver Lake in St. Louis County. The river eventually flows into Lake Superior at Duluth, Minnesota. The watershed has 38.29 km of first order, 14.40 km of second order, 63.95 km of third order, and 6.67 km of fourth order streams. The average stream gradient is 5.72 m/km.

Watershed vegetation includes: 2.01 percent white, red, or jack pine; 34.78 percent spruce-fir; 46.04 percent aspen-birch; and 14.82 percent nonforested land.

Substrates in the river consist of boulder and rubble in the riffles and sand, muck, and detritus in areas of slower current velocity. Water temperatures vary from 25°C in summer to 0°C in the winter.

The Isabella River Watershed has a total drainage area of approximately 883 km^2 of which 132 km^2 is contained in the Little Isabella River Watershed.

a significant effect on nutrient availability to collectors when shredders were present. They noted that an increase in phosphorus uptake by collectors occurred, "probably because of a reduction in particle size, thereby increasing the amount of material available as food."

As part of the Regional Copper-Nickel Study, leaf decomposition rates in streams were used for four reasons:

1) to classify streams in the Regional Copper-Nickel Study Area (Study Area):

2) to provide baseline data for long-term monitoring of the aquatic environment;

3) to compare the processing rates of conifer and hardwood materials and their associated invertebrates; and

4) to determine the productivity of streams based on the predominant terrestrial vegetation in the watershed.

METHODS

Study Area

The Regional Copper-Nickel Study Area (Study Area) encompasses 5516 km^2 (2130 sq mi) in Lake and St. Louis counties in northeastern Minnesota (Figure 1). This area is divided into two major watersheds by the Laurentian Divide. Water north of this Divide flows through the Rainy River system to Hudson Bay. Water south of the Divide flows into Lake Superior. Sampling stations were located on the Stony River, Little Isabella River, Snake River, and Snake Creek north of the Divide, and the St. Louis River south of the Divide.

The Stony Watershed encompasses an area of approximately 632 km^2. Total stream miles in the watershed include: 104.98 km of first order, 81.41 km of second order, 53.02 km of third order, and 39.66 km of fourth order streams. The source of the Stony Watershed is on the north side of the Laurentian Divide

The Little Isabella River Watershed contains 19.06 km of first order streams, 18.98 km of second order, and 26.54 km of third order streams. The Little Isabella River has its source in a lowland area (T.59N,R.8W) near Isabella, Minnesota, and flows north to the Isabella River at T.62N,R.9W,S.34. Average gradient for the Little Isabella River is = 4.2m/km. Snake River and Snake Creek are also in the Isabella River Watershed. The Snake River has 9.21 km of first order, 10.29 km of second order, and 6.11 km of third order streams. Snake Creek has 2.49 km of first order streams, 1.36 km of second order streams, and 4.66 km of third order streams. Average gradients are 6.06 m/km and 1.51 m/km for the Snake River and Snake Creek respectively.

Vegetation in the Isabella River Watershed consists of 53.86 percent white, red, or jack pine, 24.58 percent spruce-fir, 18.55 percent aspen-birch, and 2.05 percent nonforested land.

Substrates vary from ledgerock and boulder in riffles to sand and detritus in areas of lower current velocity. Snake Creek and the headwaters of the Little Isabella River have cool water temperatures throughout the year and support brook trout populations. Summer water temperatures generally remain below 20°C. Water temperatures for the remainder of the watershed range from 25°C to 0°C.

Experimental Methods

Artificial leaf packs have been used by aquatic ecologists to evaluate leaf processing in streams (Petersen and Cummins 1974, Reice 1974, Paul, Benfield, and Cairns 1977). Mesh bags have been used by others to measure processing of leaf material (Mathews and Kowalczewski 1969, Park 1974, Hart and

Howmiller 1975), however, Petersen and Cummins (1974) suggest that complete processing would be hampered because of decreased microbial activity and the exclusion of large invertebrates. Petersen and Cummins (1974) and Reice (1974) used leaves fastened with nylon I bars to follow leaf pack processing which allowed measurement of processing under near natural conditions. This method may have overestimated processing because of the loss of large leaf fragments.

On May 8 and September 28, 1977, trembling aspen and red pine leaves were collected, air dried and frozen to prevent further degradation. Aspen leaves collected in September were picked from trees prior to abcission, those collected in May had been on the ground approximately seven months. Red pine leaves collected on both dates had been on the ground an undetermined length of time. During the present study, leaves were enclosed in nylon mesh bags (3 mm, Minnesota Fabrics Co., Minneapolis, MN) and anchored in streams. Aspen packs were constructed by placing 10 g of leaves on a square of nylon mesh, drawing the edges together and binding with a nylon wire tie. This formed a circular bag approximately 10 cm in diameter. Red pine leaves were bound with a nylon wire tie, rolled in mesh, and both ends of the pack bound with a wire tie to prevent leaves from slipping through the mesh before processing. In the present study, 10 g packs were selected as the size which would provide a comparable processing rate through all seasons based on the findings of Reice (1974).

Prior to placement in streams, three packs of each species were selected at random to measure moisture content. Leaves were dried at 105^{o}C for 24 h (Weber 1973) and weighed to the nearest 0.1 g.

Leaf packs were tied to the upstream side of logs anchored in riffle areas to simulate natural leaf pack formation. In May leaf packs were placed in riffle areas at each station. Aspen pack processing rates were also compared between riffle and pool areas at station SL-1 during summer. Leaf packs were placed in areas of lower current velocity in September to reduce the variability in weight loss between individual packs caused by mechanical fragmentation because of turbulence.

Twelve aspen packs were placed at each station on May 26 and October 6, 1977. In May twelve red pine packs were placed at one first order, two second order, and one fourth order station. Because the processing rates for red pine were found to be slow during the summer, their number was decreased to four per stream order in September. Three packs of each species were collected from each station at two-week intervals in the summer until all packs had been removed. Aspen packs were collected in the fall after 1, 2, 4, and 8 weeks exposure to evaluate changes in the rate of processing with decreasing water temperatures. Red pine packs were left in the stream for the full eight weeks in the fall.

Leaf packs were randomly selected at the time of removal, cut from the log, and placed in a plastic bag which contained 100 percent ETOH. At the laboratory leaves were removed from the mesh, rinsed with water to remove detritus and invertebrates, and placed in paper bags for drying. Invertebrates and detritus were then represerved. The leaves were dried at 105°C for 24 h then weighed to the nearest 0.1 g. After invertebrates had been sorted the remaining detritus was dried and its weight added to that of the leaves.

Invertebrates were identified to the genus level, or the lowest level practical and assigned to a functional group based on Cummin's (1978) classification. Chironomids were boiled in five percent KOH, mounted in CMCP-9AF, and identified to genus.

Data Analysis

The following formula was used to calculate the percent of leaf material remaining:

$$\%R = \frac{W_{(f)}}{W_{(i)}} \times 100$$

where W(i) is the initial weight of leaf material, and W(f) is the amount remaining after a given time. This assumes that the weight loss is a linear relationship, which is helpful for comparing sites and seasons. Leaf decomposition does not necessarily conform to a linear model and therefore an exponential decay model or processing coefficient (Petersen and Cummins 1974) was calculated using the formula:

$$\log_e \frac{W(tf)}{W(ti)} \; t = -k$$

Where W(ti) is the mean initial weight of leaf material, W(tf) is the mean weight of material remaining after time (t), and -k is the exponential decay coefficient.

Invertebrate data were analyzed by calculating the relative abundance of taxa in each functional group. Dominant taxa were chosen to be those taxa which were most abundant during a given season for each functional group.

RESULTS

Weight Loss

The mean percent of leaf material remaining after eight weeks exposure is shown in Figures 2 and 3. The differences between stream orders were tested using analysis of variance and significance levels are shown in Table 6. Differences in the amount of leaf material remaining for all stream orders were significant ($P<.05$) only for aspen leaves during the summer. First and third order streams were similar in the summer and second and fourth order streams were similar. The mean percent remaining for all stream orders was 39.84 percent in summer and 70.49 percent in fall for aspen; 81.9 percent in summer and 95.85 percent in fall for red pine. In the summer aspen packs were processed slowest in first order streams. In the fall processing was 20 percent faster in first order streams than other stream orders.

The weight loss for pool-riffle samples at station SL-1 during the summer is compared in Figure 4. There was no significant difference ($P>.05$) in weight loss between the two samples for the total eight weeks of exposure. Variability in the amount of weight lost was higher in riffle samples than pool samples as shown by the 95 percent confidence intervals in Figure 4. Mean percent leaf material remaining for pool samples after 8 weeks was 21.84 and 18.57 percent for riffle samples.

Processing of aspen and red pine leaves was significantly ($P<.05$) more rapid in summer than fall (Figures 5 and 6). The average processing coefficients for aspen leaves for all stream orders were -0.02283 in summer and -0.00771 in fall (Table 1); summer values ranged from -0.01018 to -0.02803 and fall values from -0.00524 to -0.01320.

Invertebrates

Tables 2 and 3 show the mean total number of invertebrates collected per sample. In the summer the mean total number of organisms per sample increased with increasing stream order for both aspen and red pine packs. In the fall the total number of organisms decreased with increasing stream order. The mean number of organisms was higher in summer than in fall for all stream orders. In general, the number of invertebrates per red pine pack increased through the summer; invertebrates colonizing aspen packs, however, increased through the first four weeks in summer and decreased between four and six weeks.

The ratio of shredders to collectors for summer and fall sampling periods is shown in Figure 7. The shredder/collector ratio was higher in the fall for all stream orders. In the fall the ratio of shredders to collectors decreased with increasing stream order for aspen packs. In the summer the ratio was highest in second and third order aspen packs; lowest in red pine packs in fourth order streams.

The relative abundance of organisms in each functional group is shown in Table 4 and Figure 8. Shredders were most abundant in first order streams in the fall and least abundant in fourth order streams in the summer. Scrapers were found in the highest numbers in third and fourth order streams on all dates. Collector gatherers and collector filter feeders were the dominant functional groups at all stream orders on all dates, except first order streams in the fall.

The dominant taxa in each functional group is shown in Table 5. The dominant shredder taxa in the summer was the stonefly <u>Leuctra</u>. In the fall <u>Paracapnia</u>

replaced Leuctra as the most abundant shredder. Chironomids were found in high numbers at all sites on all dates. Dominant genera included Eukiefferiella and Polypedilum, both collector gatherers; Tanytarsus, a filter feeder; and Conchapelopia, a predator.

Water Level Fluctuations

Discharge data for the Dunka River are presented in Figure 9. The Dunka River drains an area of 128 km^2, which is approximately the same size as the drainage area of the Little Isabella River. Since discharge data were not available for the Little Isabella watershed the Dunka River was selected to document the water level fluctuations experienced during summer sampling. The Dunka River lies approximately 15 miles south of the Little Isabella River, and since drainage area and size are approximately the same, it was felt that water levels in the two rivers probably respond similarly to rainfall inputs.

Figure 9 shows that during the summer sampling period (June 1-July 21) water levels rose and fell three times. Peak discharges during the eight-week sampling period occurred in early June, immediately after placement of the samplers, late June and early July.

DISCUSSION

Weight Loss

Processing rates of leaf material in the present study do not conform to the stream order model proposed by Cummins (1975). If processing rates of leaf material were correlated with stream order then the rate of leaf degradation should increase with decreasing stream order as a result of higher shredder populations in lower order streams. Data from the present study show that differences in processing rates between stream orders were not significantly different even during the fall when populations of shredding invertebrates were highest.

Cummins (1974) suggested that the initial processing of conditioned leaves was through ingestion by large shredder species (Pteronarcys and Limnephilidae). Benfield et al. (1977) suggest that in the absence of large shredder species the major route of processing was the softening of leaf tissues by microbial decomposition, and subsequent fragmentation by mechanical breakage due largely to water currents. The dominant shredder taxa collected during the present study were all small particle feeders (i.e. Leuctra, Paracapnia) and their feeding activities could not account for the large weight loss, especially during the summer. Field observations indicate that water level fluctuations and subsequent changes in current velocity could account for the weight loss. The greater current velocities in the summer are reflected in the higher coefficients of variation for weight loss data and thus the higher processing rates.

The lower processing rates and decreased variability for red pine leaves during both sampling periods can be attributed to the differences in construction of red pine packs and the longer period of time required for conditioning of red pine leaves as discussed by Sedell et al. (1975).

The mean processing coefficients for aspen leaves in the fall is near the range reported by Petersen and Cummins (1974) for the fall; those in the summer are an order of magnitude higher. The higher processing coefficients in the summer can be attributed mainly to the greater mechanical breakdown.

Several other factors, however, may have contributed to the higher processing rates during the summer. Aspen leaves used during summer sampling had been on the ground for seven months prior to collection and were thus partially processed prior to being placed in the stream. This preprocessing may have allowed more rapid colonization by stream heterotrophs and invertebrates, thus leading to a faster processing rate for aspen packs in the summer. Higher water temperatures in the summer may also account for the increased processing rates. A significantly higher processing rate has been shown to occur with increased water temperatures (Petersen and Cummins 1974, Suberkropp et al. 1975, Paul et al. 1977).

Invertebrates

The colonization of leaf packs by invertebrates has been shown to increase with time as the leaves become conditioned by bacteria and fungi (Sedell et al. 1975). Data from red pine packs in the present study support this conclusion, however, invertebrate colonization of aspen packs functioned differently. The increasing number of invertebrates on aspen packs during the first four weeks is probably a result of increased conditioning of the leaves, but the decrease between the fourth and sixth week of exposure is not readily explainable. The decrease is not a result of insect emergence, because many groups only decreased in numbers and would have been expected to disappear had emergence been responsible. Two explanations are possible based on field observations: 1) the amount of leaf material remaining in the mesh bags had decreased to the point that sufficient substrate for invertebrate attachment was limited; and 2) high current velocities resulting from increased stream flow may have caused greater instability in the aspen packs forcing invertebrates to leave the packs and drift downstream. No decrease in the number of invertebrates on red pine packs was seen, probably because of the greater stability resulting from the different method of construction of red pine packs.

The mean number of organisms per sample increased with increasing stream order in the summer for both aspen and red pine packs. This increase may be a result of greater population size and a greater number of taxa in higher stream orders because of increased physical stability. In the fall the mean number of organisms per sample decreased with increasing stream order, indicating that a factor other than physical stability of the environment was determining the density of invertebrate colonization. The presence of larger amounts of leaf material in lower stream orders (Petersen and Cummins 1974) together with higher numbers of shredder invertebrates in lower order streams would explain the decrease in the number of organisms with increasing stream order.

Literature Cited

Benfield, E.F., D.R. Jones and M.F. Patterson. 1977. Leaf pack processing in a pastureland stream. Oikos 29:99-103.

Boling, R.H., Jr. 1975. Toward a model of detritus processing in a woodland stream. Ecology 56:141-151.

Cummins, K.W. 1974. Structure and function of stream ecosystems. Bioscience 24(11):631-641.

Cummins, K.W. 1975. The ecology of running waters theory and practice. Pages 277-293 in D.B. Baker, W.B. Jackson, and B.L. Prater (eds.) Proc. Sandusky River Basin Symposium. Tiffin, Ohio.

Cummins, K.W. 1978. Ecological tables. In R.W. Merritt and K.W. Cummins (ed) An introduction to the aquatic insects of North America. Kendall-Hunt Publ., Dubuque, Iowa.

Cummins, K.W., J.J. Klug, R.G. Wetzel, R.C. Petersen, K.F. Suberknopp, B.A. Manny, J.C. Wuycheck and F.O. Howard. 1972. Organic enrichment with leaf leachate in experimental lotic ecosystems. Bioscience 22(12):719-722.

Cummins, K.W., R.C. Petersen, F.O. Howard, J.C. Wuycheck and V.I. Holt. 1973. The utilization of leaf litter by stream detritivones. Ecology 54:336-345.

Egglishaw, H.J. 1964. The distributional relationships between bottom fauna and plant detritus in streams J. Anim. Ecol. 33:463-476.

Fisher, S.G. 1971. Annual energy budget of a small forest stream ecosystem, Bear Brook, West Thorton, New Hampshire. Ph.D. Thesis. Dartmouth College.

Fisher, S.G. and G.E. Likens. 1972. Stream ecosystems: organic energy budget. Bioscience 22:33-35.

Fisher, S.G. and G.E. Likens. 1973. Energy flow in Bear Brook, New Hampshire: an integrative approach to stream ecosystem metabolism. Ecol. Monogr. 43:421-439.

Hall, C.A.S. 1972. Migration and metabolism in a temperate stream ecosystem. Ecology 53:585-604.

Hart, S.D. and R.P. Howmiller. 1975. Studies on the decomposition of allochthonous detritus in two California streams. Verh. Internat. Verein. Limnol. 19:1665-1674.

Hynes, H.B.N. 1963. Imported organic matter and secondary productivity in streams. Proc. XVI Int. Congr. Zool. 3:324-329.

Hynes, H.B.N., N.K. Kaushik, M.A. Lock, D.L. Lush, Z.S.J. Stocker, R.R. Wallace and D.D. Williams. 1974. Benthos and allochthonous organic matter in stream. J. Fish. Res. Board Can. 31:545-553.

Jones, J.G. 1975. Heterotrophic micro-organisms and their activity. Pages 141-154 in B.A. Whitton (ed.) River ecology. Univ. of California Press, Berkeley.

Kaushik, N.K. and H.B.N. Hynes. 1968. Experimental study on the role of autumn-shed leaves in aquatic environments. J. Ecol. 56:229-243.

Kaushik, N.K. and H.B.N. Hynes. 1971. The fate of dead leaves that fall into streams. Arch. Hydrobiol. 68:465-515.

Kowalczewski, A. 1970. The leaf litter as a food source of aquatic organisms in the River Thames. Polskie. Arch. Hydrobiol. 17(30):133-134.

Liston, C.R. 1972. Contributions of allochthonous detritus to the energy regime of Doe Run, Meade County, Kentucky. Water Resources Laboratory, Univ. of Louisville, Louisville, Kentucky.

Mann, K.H. 1969. The dynamics of aquatic ecosystems. Pages 1-81 in J.B. Cragg (ed.) Advances in ecological research 6.

Mathews, C.P. and A. Kowalczewski. 1969. The disappearence of leaf litter and its contribution to production in the River Thames. J. Ecol. 57:543-552.

Minshall, G.W. 1967. Role of allochthonous detritus in the trophic structure of a woodland stream. Ecology 48:139-149.

Minshall, G.W. 1968. Community dynamics of the benthic fauna in a woodland spring brook. Hydrobiologia 32:305-339.

Nelson, D.J. and D.C. Scott. 1962. Role of detritus in the productivity of a rock outcrop community of a piedmont stream. Limnol. Oceanorg. 7:396-413.

Park, D. 1974. On the use of the litter bag method for studying degradation in aquatic habitats. Int. Biodetn. Bull. 10(2):45-48.

Paul, R.W., Jr., E.F. Benfield and J. Cairns, Jr. 1977. Effects of thermal discharge of leaf decomposition in a river ecosystem. Paper presented at the 20th International Association of Theoretical and Applied Limnology Meetings, Copenhagen, Denmark.

Petersen, R.C. and K.W. Cummins. 1974. Leaf processing in a woodland stream. Freshwater Biol. 4:343-368.

Reice, S.R. 1974. Environmental patchiness and the breakdown of leaf litter in a woodland stream. Ecology 55:1271-1282.

Sedell, J.R., F.J. Triska and N.S. Triska. 1975. The processing of conifer and hardwood leaves in two coniferous forest streams: I. Weight loss and associated invertebrates. Verh. Internat. Verein. Limnol. 19:1617-1677.

Short, R.A. and P.E. Maslin. 1977. Processing of leaf litter by a stream detritivore: effect on nutrient availability to collectors. Ecology 58:935-938.

Suberkropp, K., M.J. Klug and K.W. Cummins. 1975. Community processing of leaf litter in woodland streams. Verh. Internat. Verein. Limnol. 19:1653-1658.

Teal, J.M. 1957. Community metabolism in a temperate cold spring. Ecol. Monogr. 27:283-302.

Triska, F.J. 1970. Seasonal distribution of aquatic hyphomycetes in relation to the disappearance of leaf litter from a woodland stream. Ph.D. Thesis. Univ. Pittsburgh. 189p.

Vannote, R.L. 1969. Detrital consumers in natural systems. Pages 20-23 in the stream ecosystem an american association for the advancement of science symposium. Tech. Rpt. No. 7. Institute of Water Research, Michigan State University.

Weber, C.I. 1973. Biological field and laboratory methods for measuring the quality of surface waters and effluents. U.S. Environmental Protection Agency. 670/4-73-001.

Woodall, W.R., Jr. and J.B. Wallace. 1972. The benthic fauna in four small southern Appalachin streams. Am. Midl. Nat. 88:393-407.

Table 1. Processing coefficient, % remaining and coefficient of variation by stream order for aspen packs during summer and fall sampling.

STREAM ORDER	# OF SAMPLES		PROCESSING COEFFICIENT		MEAN % REMAINING		COEFFICIENT OF VARIATION %	
	Summer	Fall	Summer	Fall	Summer	Fall	Summer	Fall
1	1	3	-0.01018	-0.01320	56.89	54.93	----	43.5
2	6	6	-0.02803	-0.00524	24.13	74.93	41.8	9.6
3	5	6	-0.02037	-0.00580	49.30	78.01	46.1	11.6
4	9	3	-0.02604	-0.0066	29.04	74.10	53.6	13.9
Total for All Stream Orders			-0.02283	-0.00771	39.84	70.49		

Table 2. Mean number of invertebrates per aspen pack for four sampling periods at primary SCS sites.

DATE STREAM ORDER	6/9/77	6/23/77	7/7/77	$\bar{X}$	11/3/77	$\bar{\bar{X}}$ (annual)
1	275.98	115.02	----	195.5	400.51	263.84
2	142.99	885.84	426.17	485	375.83	457.71
3	852.84	764.39	415.43	677.55	323.77	589.11
4	948.72	1079.13	805.42	944.42	57.64	731.73
$\bar{X}$	555.13	711.10	549.01	605.08	289.44	

Table 3. Mean number of invertebrates per red pine pack for three sampling periods at primary SCS sites.

STREAM ORDER \ DATE	6/9/77	6/23/77	7/7/77	$\overline{X}$(annual)
1	69.37	195.00	----	132.19
2	----	----	----	----
3	304.11	284.82	516.96	368.63
4	312.91	736.32	550.84	533.36
$\overline{X}$	228.80	405.38	533.90	

Table 5. Dominant taxa in each functional group at primary SCS sites.

FUNCTIONAL GROUP	SUMMER	FALL
Shredders	Leuctridae, *Amphinemura*	*Paracapnia*, *Lepidostoma*
Collector-gatherers	*Eukiefferiella*	Eukiefferiella, Ephemerella
Collector-filter feeders	Simuliidae, Hydropsychidae	Simuliidae, *Tanytarsus*
Predators	*Conchapelopia*	*Conchapelopia*
Scrapers	*Physa*	*Physa*
Piercing herbivores	*Ithytricia*	*Agraylea*, *Hydroptila*

Table 6. F values for comparison of stream orders

Aspen

Comparison of spring and fall samples

$F = 27.47$ df 1:13 $F_{.05} = 4.67$

Comparison between spring samples

$F = 3.88$ df 2:17 $F_{.05} = 3.59$

Comparison between fall samples

$F = 2.69$ df 3:14 $F_{.05} = 3.74$

Red Pine

Comparison of spring and fall samples

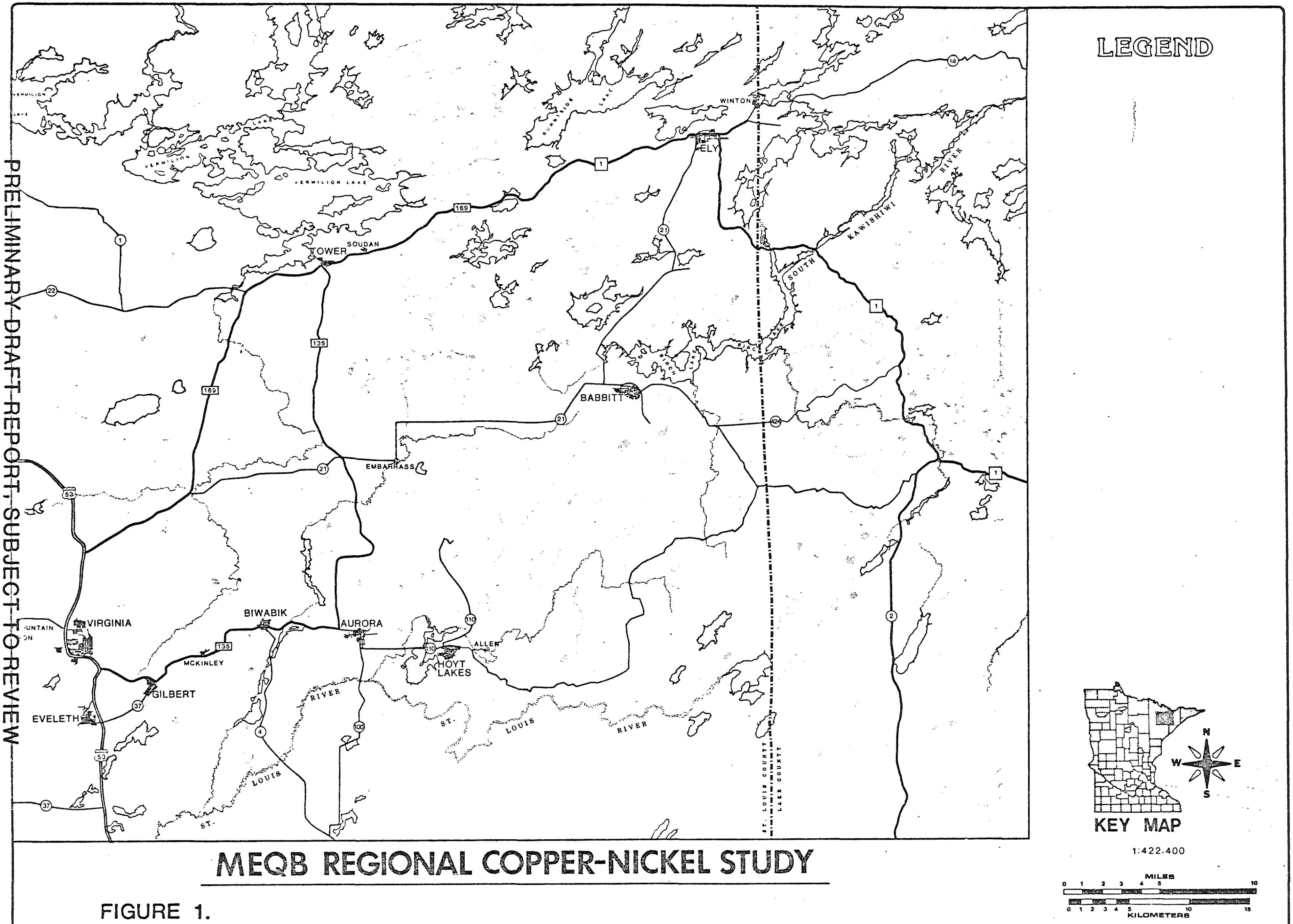
$F = 15.80$ df 1:13 $F_{.05} = 4.67$

Comparison between spring samples

$F = 2.45$ df 1:6 $F_{.05} = 5.99$

Comparison between fall samples

$F = 1.99$ df 1:4 $F_{.05} = 7.71$



MEQB REGIONAL COPPER-NICKEL STUDY

FIGURE 1.

igure 2. Mean % of leaf material remaining after 8 weeks exposure for aspen leaves.

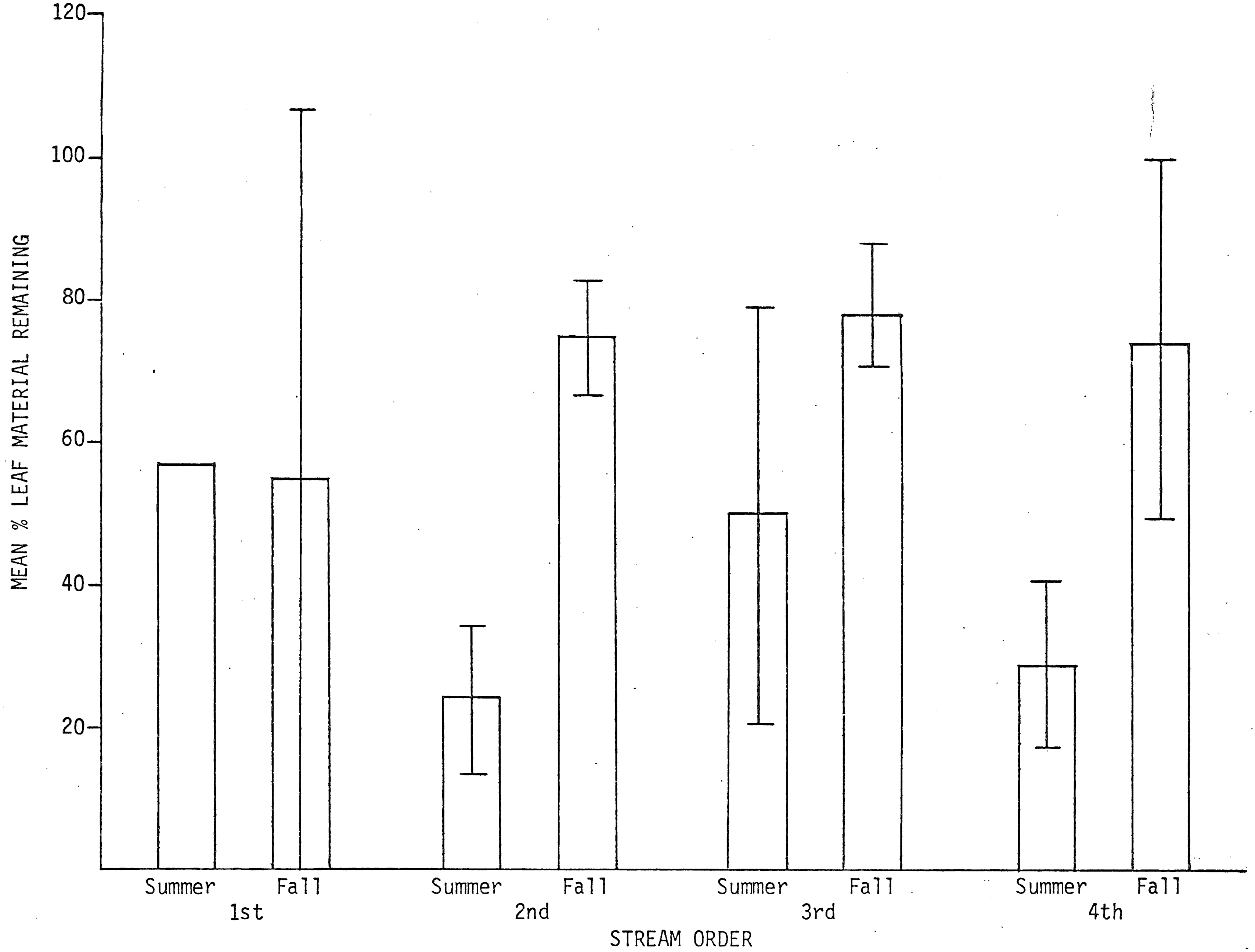


Figure 3. Mean % of leaf material remaining after 8 weeks exposure for red pine leaves.

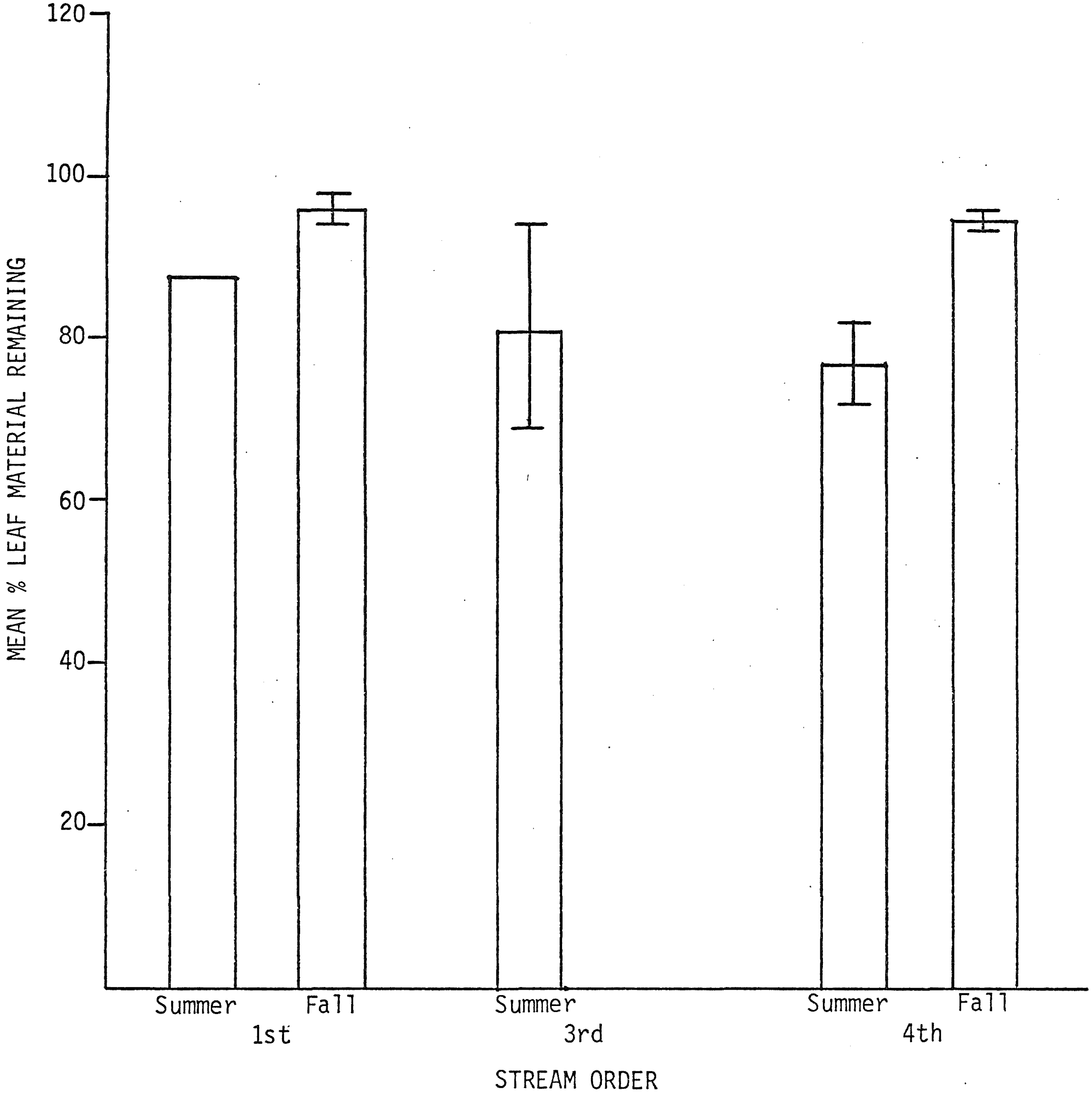


Figure 4. Comparison of pool-riffle samples at station SL-1 during summer, 1977.

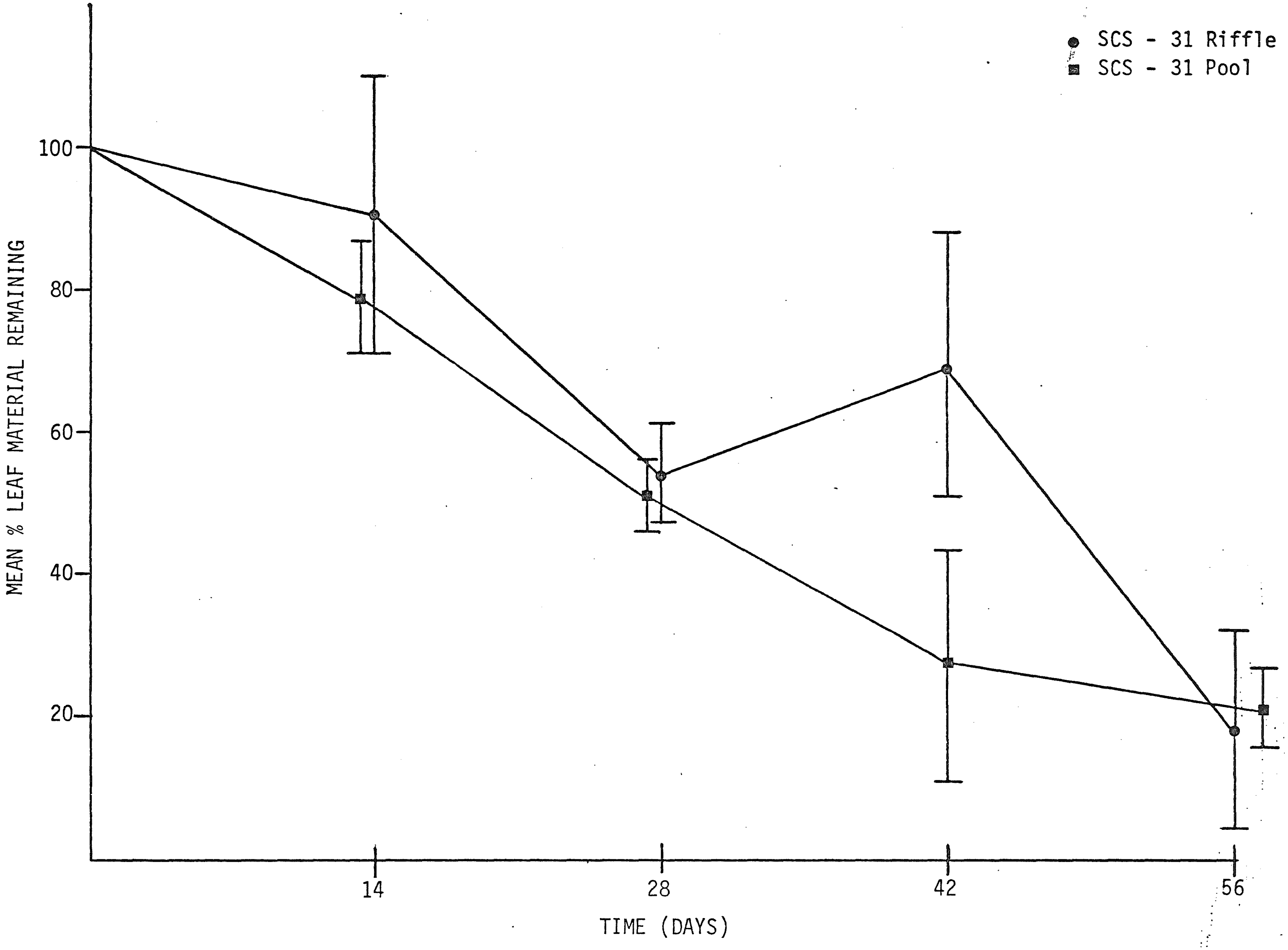


Figure 5. Mean % of leaf material remaining for all stream orders after 8 weeks exposure during summer, 1977.

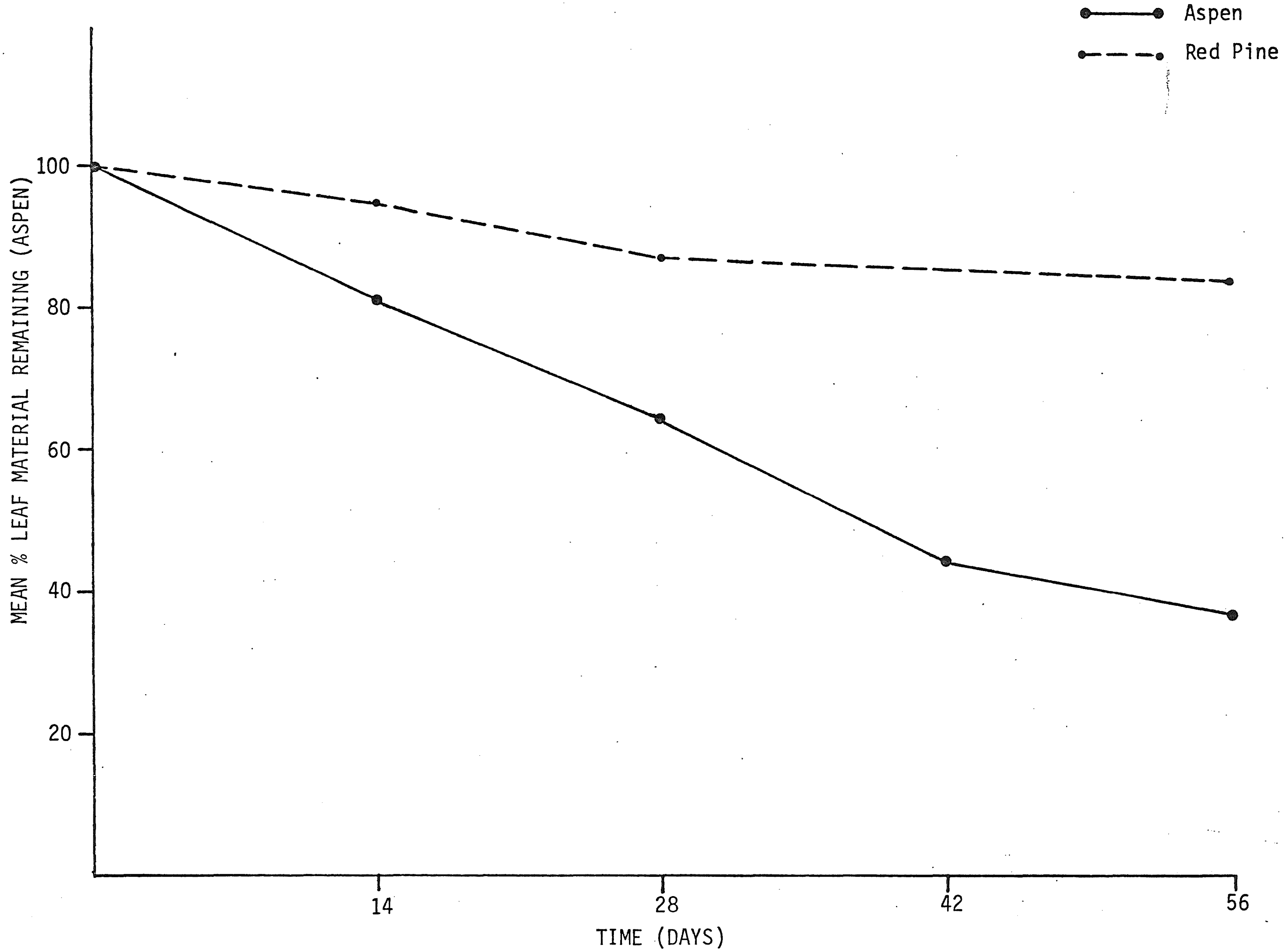


Figure 6. Mean % of leaf material remaining for all stream orders after 8 weeks exposure during fall, 1977.

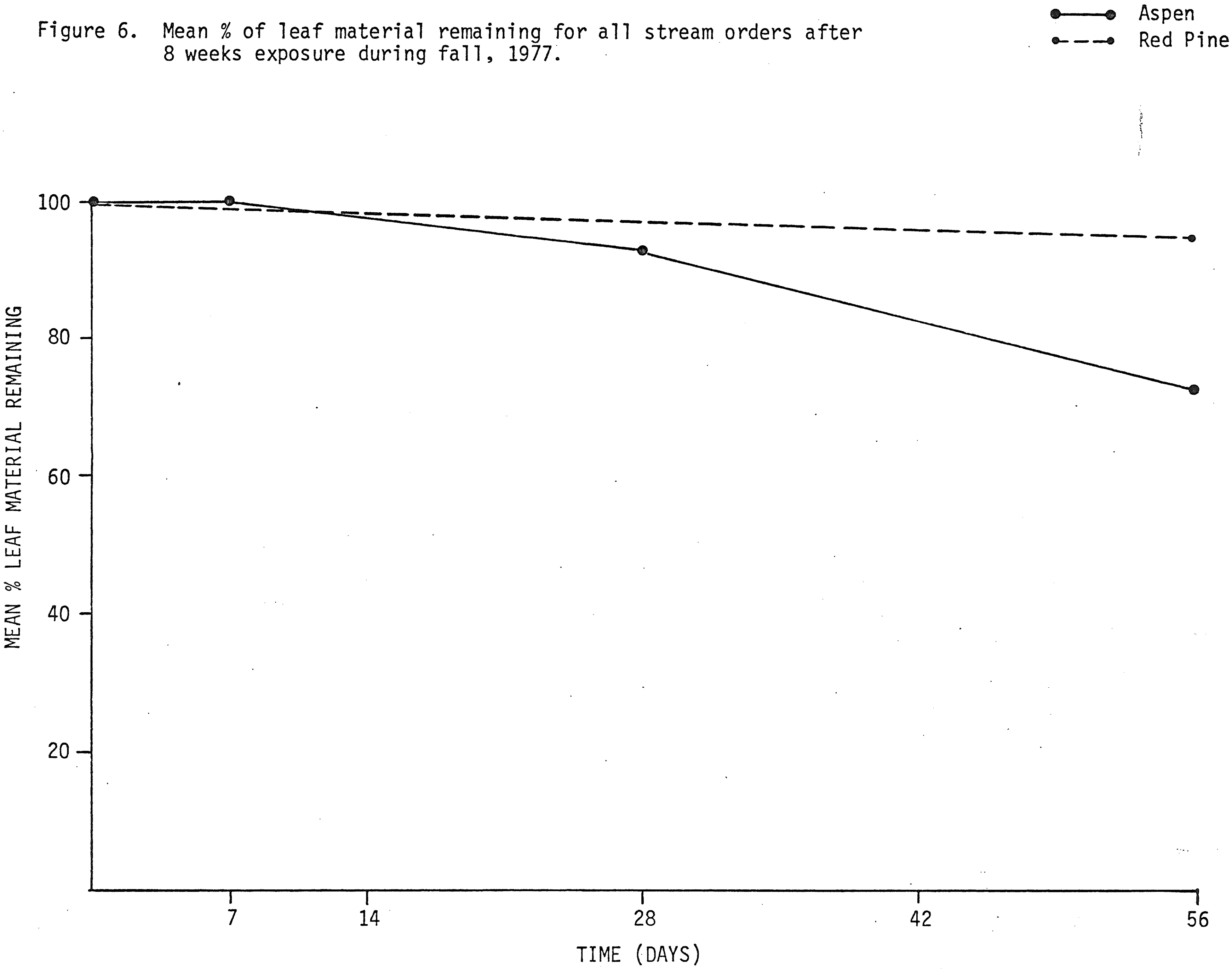


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Figure 7. Ratio of shredders to collectors for each stream order and each season.

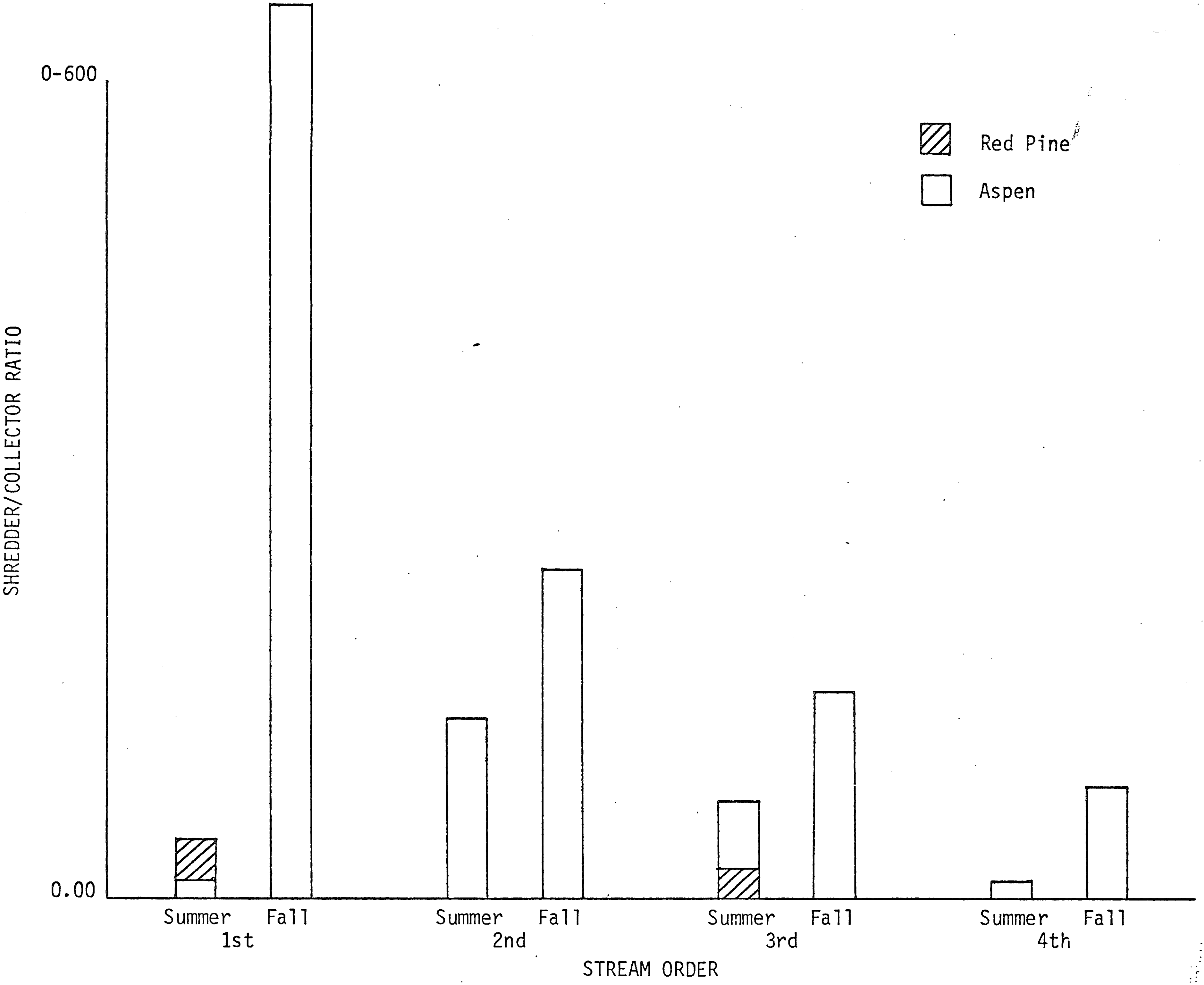

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Figure 8. Functional group composition of leaf packs after 4 weeks exposure

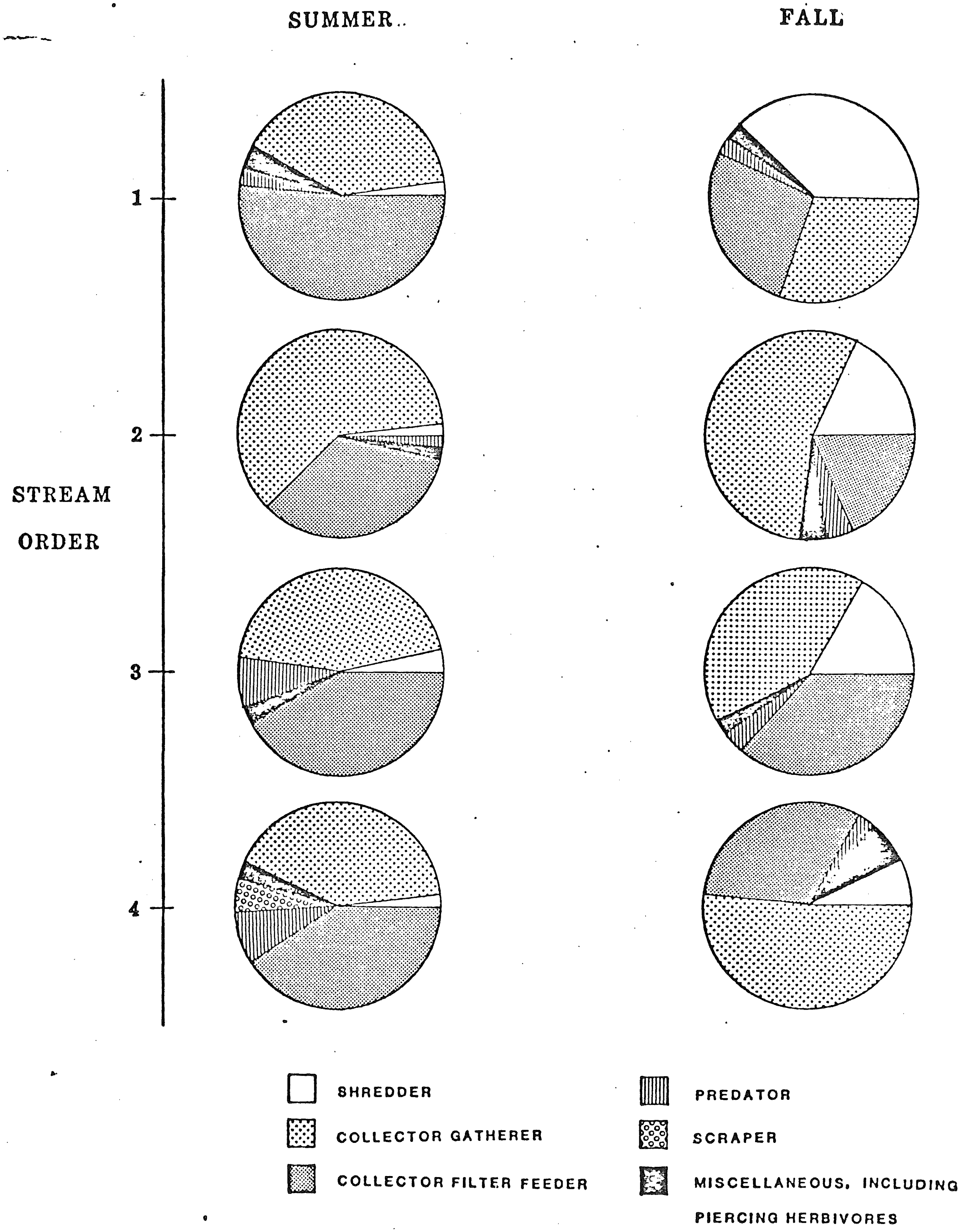

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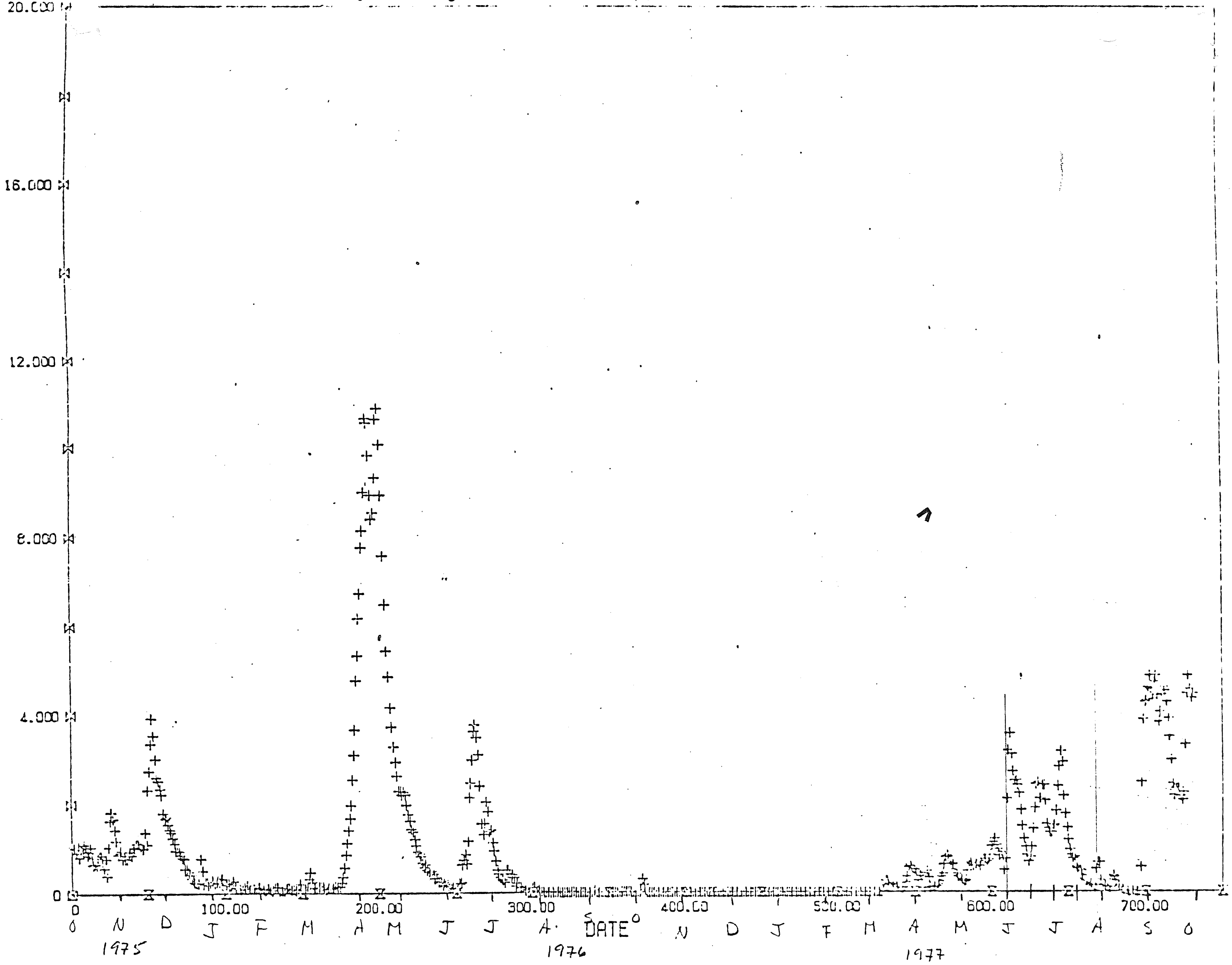
Figure 9. Mean Daily Discharges for the Dunka River



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