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Effects of kraft mill effluent on riffle community metabolism in a large river

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EFFECTS OF KRAFT MILL EFFLUENT ON RIFFLE COMMUNITY METABOLISM IN A LARGE RIVER

By

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Plexiglass chambers, placed in situ, were used to measure community oxygen metabolism of riffle sites above and below a kraft mill discharge in the Clark Fork River. Metabolism was measured during November 1984, and April and August 1985, to study seasonal variations in effects of the kraft mill discharge program on riffle community metabolism. Longitudinal trends in riffle community metabolism were then compared to water quality trends observed in the river during the study period. Although discharge of kraft mill effluent influenced the water chemistry of the Clark Fork River, daily metabolic rates of the riffle communities were unaffected downstream from the effluent mixing zone. Enhanced metabolic rates and nutrient concentrations were observed at riffle sites upstream of the kraft mill discharge, which suggested that an upstream source(s) of nutrients was affecting community metabolism in the study area. In addition, statistical confounding of environmental versus diel metabolism data was observed. Subsequent analyses of hourly oxygen production rates by the riffle communities supported the conclusion that nutrients derived from sources upstream of the study area masked effects of the kraft mill effluent.

An in situ chamber experiment was designed to help identify the causal pathways in which kraft mill wastewaters were influencing riffle community metabolism. Net community primary productivity was reduced in chambers dosed with a 1:1 mixture of effluent and river water, compared to chambers containing only river water. It was concluded that riffle communities downstream of a kraft mill outfall were potentially more heterotrophic, simply due to light attenuation by effluent color.

A light-dark bottle experiment was used to examine the metabolic characteristics of various mixtures (1:1, 1:20, and 1:200) of kraft mill wastewaters and river water. Diel changes in the metabolic characteristics of these mixtures showed that the effluent was biologically active, laden with a dynamic microbial community.

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I. INTRODUCTION

The wastewaters of the kraft process contain a myriad of toxic compounds, nutrients, and organic matter (Kelso et al. 1977; Leslie 1977; NCASI 1978; Kinae et al. 1981; Leung and Sell 1982; NCASI 1985). Previously, significant environmental impacts on receiving waters have occurred due to the toxicity, biological oxygen demand, or light-attenuating properties of untreated or primary-treated wastewaters (Spindler and Whitney 1960; Parker and Sibert 1973; Walden 1976; Stockner and Cliff 1976; Moore and Love 1977). Secondary treatment of these wastewaters, however, has significantly reduced the toxicity and oxygen demand of treated wastewaters (Rainville et al. 1975; Nestman et al. 1984; Leuenberger et al. 1985) so that other characteristics of the wastewaters may be more important in influencing the ecology of streams. Nutrient stimulation of algal productivity has been observed in laboratory streams with the addition of secondary-treated, kraft mill wastewaters (Williams 1969; Bothwell and Stockner 1980; NCASI 1985). Also, organic matter in the kraft mill effluent may be a source of allochthonous energy for organisms in the stream (NCASI 1978).

Unfortunately, system-level effluent impacts are extremely difficult to predict, due to the complicated composition of kraft mill wastewaters and the complexity of abiotic and biotic interactions within stream ecosystems. Pollutants contained in kraft mill wastewaters may interact either synergistically or antagonistically when influencing the structure and function of the stream ecosystem (Kamra et al. 1983). In addition, kraft mill pollutants may interact with pollutants from other sources or with the water chemistry of the stream to cause an impact.

Compounding these problems in assessing environmental impacts, a number of recent stream studies indicate that the structure and function of stream communities frequently varies among streams (Winterbourn et al. 1981; Busch and Fisher 1981; Cushing and Wolf 1982; Cushing et al. 1983; Minshall et al. 1983; Bott et al. 1985) or even among different reaches of the same drainage (Vannote et al. 1980; Naiman and Sedell 1980; Naiman 1983). These differences are due to the local influences of riparian zone vegetation, tributaries, climate, lithology, and/or geomorphology (Hynes 1975; Minshall et al. 1983, 1985; Bruns et al. 1984). Hence, it may be inappropriate to infer functional responses of a particular stream community to a pollutant using data from laboratory bioassays (Cairns

1981; Kimball and Levin 1985) or from other stream systems. Indeed, different stream ecosystems have responded differently to the addition of the same industrial effluent (Carter and Lamarra 1983).

Interpretations of the functional responses of a particular stream ecosystem to the addition of kraft mill wastewaters have been further hindered by the generally dynamic nature of stream ecosystems. Seasonal variations in hydrologic conditions (e.g. streamflow, water temperature, and channel morphology) affect the concentrations of water quality variables (Hines et al. 1977; Wallace et al. 1982) and affect the energy dynamics of stream ecosystems (Hall 1972; Naiman 1983; Bott et al. 1985). Temporary changes in the concentrations of nutrients and organic matter in a stream due to spates (Houston and Brooker 1981; Casey and Farr 1982; Cummins et al. 1983; Roberts et al. 1984; Webb and Walling 1985) also can obscure the effects of a pollutant on a stream ecosystem.

If stream function changes temporally and spatially, then the environmental factors influencing the structure and function of the stream community at one time or place, may not be important factors at another time or place. Therefore, the effects of kraft mill effluent on the stream biota may also change temporally and/or spatially.

To study functional responses of a stream community to the discharge program of a kraft mill, I measured community oxygen metabolism (cf. Odum 1956; Hall and Moll 1975) of riffle communities using chambers (Wetzel 1969; Kowalczewski and Lack 1971; Hansmann et al. 1971; Rodgers et al. 1978; Bott et al. 1978; Pennak and Lavelle 1979; Osborne and Davies 1981; Jeppesen 1982; Boyle and Scott 1984) placed in situ. Riffle communities were chosen because these communities were generally known to be primary sites of instream autotrophic production (Margelef 1965; Hynes 1970). Since recent stream studies (Minshall 1978; Busch and Fisher 1981; Cushing and Wolf 1982) indicated that instream autochthonous production was a major energy source for streams within dry biomes of the western United States, changes in riffle community metabolism due to the discharge of kraft mill effluent could have a profound impact on the energy and material dynamics of the entire stream reach. If the nutrients in the effluent exerted a significant impact on the riffle communities, the net community primary productivity of the riffle communities downstream of the kraft mill outfall was expected to increase (Stockner and Shortreed 1978; Elwood et al. 1981; Peterson et al. 1983; 1985). Conversely, if the kraft mill wastewaters contained significant concentrations of toxic substances, the net community

primary productivity and/or respiration of the riffle communities downstream of the kraft mill outfall was expected to decrease (Maki and Johnson 1976; Moore and Love 1977). Net community primary productivity might also decrease due to color of the kraft mill wastewater attenuating light (Parker and Siebert 1973; Stockner and Cliff 1976; NCASI 1985). If organic matter in the kraft mill effluent exerted a significant impact on the river communities, the respiration of the riffle communities downstream of the kraft mill was expected to increase, due to either : 1) the biological oxygen demand (BOD) of the bacteria cells in the kraft mill wastewaters; or 2) the development of a more heterotrophic community which could utilize this allochthonous source of energy.

To detect these possible trends in the Clark Fork River, I initiated synoptic studies (cf. Hines et al. 1977) in which water quality, insolation, and metabolism data were collected at selected riffle areas above and below the kraft mill outfall. These data were collected during autumn, spring, and summer to examine the following hypotheses: 1) different environmental factors affected riffle community metabolism seasonally; 2) the relative importance of a particular environmental factor on riffle community metabolism varied seasonally; and 3) the effects of the effluent discharge program on the riffle biota and

on water quality changed seasonally. During August, water column metabolism of the river was measured to examine: 1) the relative importance of benthic processes and water column processes to riffle community metabolism; and 2) the effects of the kraft mill discharge program on water column metabolism.

To supplement the synoptic studies, I designed an *in situ* chamber experiment and a water column metabolism experiment to help identify the causal pathways (cf. Rosenberg and Resh 1981) in which kraft mill wastewaters influenced riffle community metabolism. To relate changes in metabolism to water quality characteristics of the treatments used in the experiments, water chemistry variables were analyzed for some of the treatments.

II. STUDY AREA

The Clark Fork River

The Clark Fork River is the largest river in western Montana. It originates near the city of Butte as Silver Bow Creek, drains the west slope of the Continental Divide, and eventually empties into the Columbia River via Lake Pend Oreille and the Pend Oreille River.

Like most other rivers in the world, the Clark Fork River drainage has been subjected to a variety of anthropogenic disturbances. These disturbances have included fires (Barrett 1981), mining (Bailey 1976; Woessener et al. 1984; Ray 1985), agriculture, logging (USDA 1977), alteration of the stream channel (Weisel 1972), hydroelectric dams (Stanford and Ward 1979), and urbanization. In addition, the drainage basin is frequently subjected to natural fires caused by lightning strikes during the summer. When evaluating the impact of the kraft mill on the Clark Fork River, the effects of these other disturbances to water quality must also be considered.

The kraft mill is about 230 km downstream from the origin of the Clark Fork River. The study area is

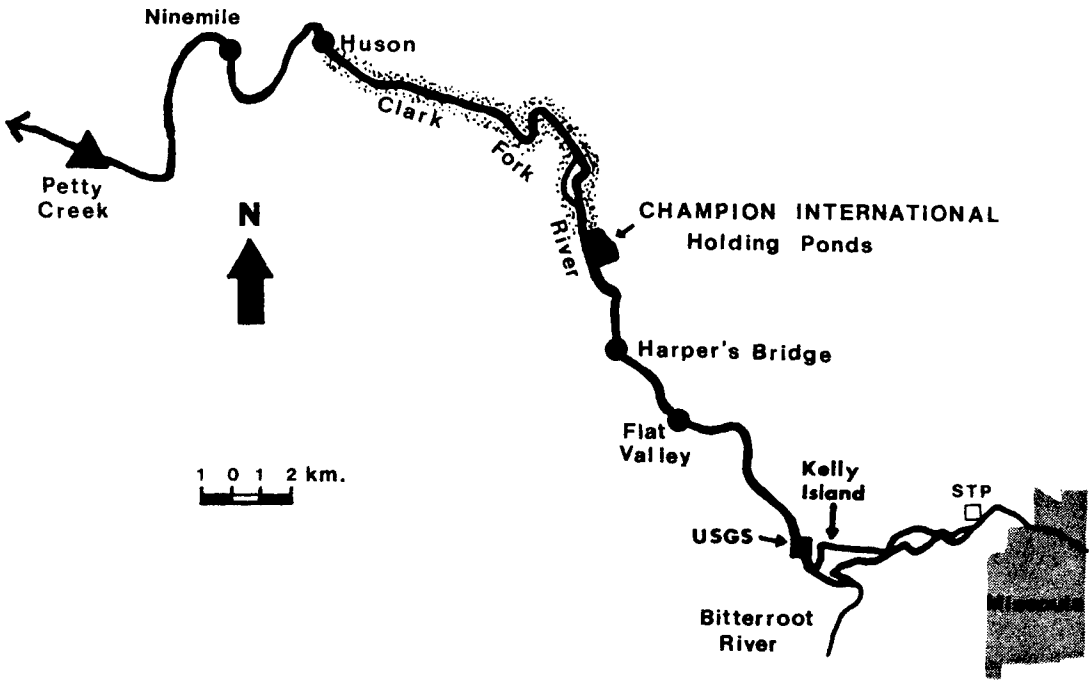

FIGURE 1. Study sites on the Clark Fork River with reference to the kraft mill, a USGS gaging station, and the Missoula sewage treatment plant (STP). The circles are locations of the synoptic study sites. The triangle is the location of the experimental work. The stippled region represents a 14 km mixing zone established for the kraft mill wastes by the Montana Department of Health and Environmental Sciences (Dr. Loren Bahls, Montana Water Quality Bureau, pers. communication).

downstream of a major confluence of the Clark Fork with the Bitterroot River in the Missoula Valley (Figure 1). The river has a cobble substratum that is interspersed with sand and silt. This stretch of the river has frequent riffles and long runs, but few pools. Depositional areas are mostly found along the banks of the river and in the backwater areas and sloughs created by

sideflows and the meandering nature of the river. Riparian vegetation, although generally well developed, does not span or shade much of the river channel within the study area. Consequently, the substratum receives direct solar insolation year round.

During most of the year, the average monthly flow of the Clark Fork River fluctuates between 50 to 100 m^3 s^{-1} at the USGS gaging station below Missoula (Figure 1). During the spring freshet, flow increases to an average monthly rate of about 510 m^3 s^{-1} (Shewman et al. 1984). This increased flow is caused by melting snow and the increased precipitation which occurs during spring and early summer.

The Kraft Mill

The kraft mill is located approximately 24 km from Missoula, near the village of Frenchtown. The mill is one of the largest in the world and has production capacities of 1850 tons of product per day (MDHES 1985). The mill produces unbleached linerboard and lesser quantities of bleached kraft paper. Wastewaters from these kraft processes are first treated by a mechanical clarifier to remove most of the suspended solids and then the wastewater is treated in aerated stabilization basins to reduce BOD

and color. After this secondary treatment, the wastewaters are then either disposed by infiltration into the groundwater from 48.6 hectares of rapid infiltration basins, or stored in holding ponds to be eventually discharged directly into the Clark Fork River (Figure 2).

While stored in the holding ponds, wastewaters also seep into groundwater and the Clark Fork River. The seepage rate is dependent upon the amount of wastewaters in the 202 hectares of holding ponds, but the paper company has estimated that the seepage rate can reach 43,500 cubic meters per day when the ponds are full (MDHES 1985).

The amount of wastewaters discharged directly into the Clark Fork River changes seasonally and is subject to criteria (MDHES 1985) based upon the flow of the Clark Fork River, instream dissolved oxygen concentration, and instream color. Due to these restrictions, most of the stored wastewaters are discharged directly into the river only during the high flow conditions of spring runoff. Approximately 30 to 40% of all the wastewaters annually produced by the kraft mill are disposed by the direct discharge method (MDHES 1986).

The quality of the kraft mill effluent reaching the river is dependent upon the method of disposal. The wastewaters in the holding ponds are usually anoxic and contain high concentrations of nutrients, biological oxygen

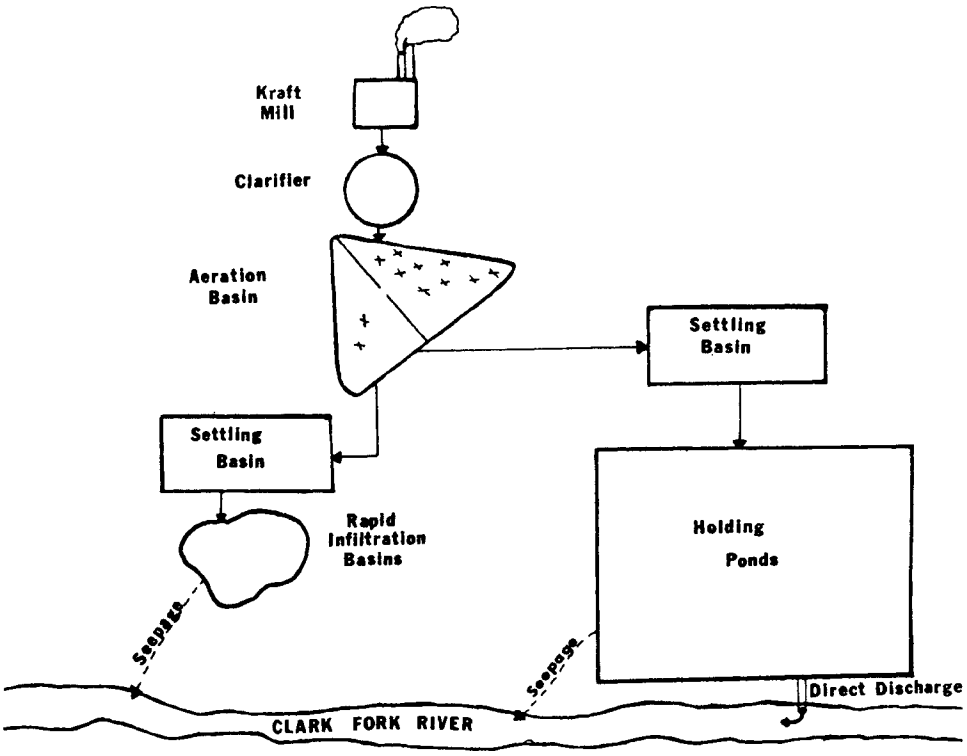

FIGURE 2. Schematic disagram of the kraft mill wastewater treatment system (modified from MDHES 1985).

demand, color, total suspended solids, alkalinity, sodium, chloride, and sulfates (MDHES 1974; Grimestad 1977). As the wastewaters seep into the groundwater, the concentrations of phosphorus, biological oxygen demand, color, total suspended solids, and possibly some dissolved organic compounds (see Bouwer et al. 1981) decrease 70 to 90 percent (MDHES 1974; 1986). These reductions are due to abiotic, physiochemical (Rice 1974) and /or microbial processes (Hutchins et al. 1984; Harvey et al. 1984) in the alluvium. Hence, wastewaters discharged directly into

the river have an inferior effluent quality than the wastewaters seeping into the river.

Location of Study Sites

For the synoptic studies of riffle community metabolism, data were taken at four riffle sites in the Clark Fork River (Figure 1). Two riffle sites, called Flat Valley and Harper's Bridge, were located about 10 and 6 km upstream of the kraft mill outfall. These sites, however, were located downstream of the Missoula sewage treatment plant, which adds secondary wastewater effluent to the river. The other two sites, called Huson and Ninemile, were located about 14 and 22 km downstream of the kraft mill outfall and were located below an established mixing zone for the kraft mill wastewater (Dr. Loren Bahls, Montana Water Quality Bureau, pers. communication).

The experimental work on causal pathways induced in the river by kraft mill effluents was conducted on a riffle area at the Petty Creek Fishing Access (Figure 1). The fishing access was located about 35 km downstream of the kraft mill and was downstream of all the riffle sites studied during the synoptic effort.

III. METHODS AND MATERIALS

Synoptic Studies: Metabolism Measurements Using Chambers

At each of the four sampling sites (Figure 1), four 0.125 m^2 benthic samples of cobbles and their associated biota (i.e. attached biofilms and zoobenthos) were collected from the river and were enclosed in plexiglass metabolism chambers (Figure 3). Substratum was carefully placed in the chambers and oriented such that the direction of water flow within in the chambers was similar to the direction of flow in the river. Benthic samples were collected from a river depth of 20-30 cm except during the higher flows of April. During April, the samples were collected from deeper depths (up to 70 cm) so that the same areas of the riffle sites were sampled throughout the study.

After moving substratum, each chamber was filled with river water and submersed near shore in areas having a river depth of 20-30 cm. Four identical chambers were used at each site for statistical replication. Water within the chambers was continuously circulated throughout the sampling period using TEEL Model 1P811A submersible pumps connected to 12V deep cycle RV batteries placed at the edge of the river.

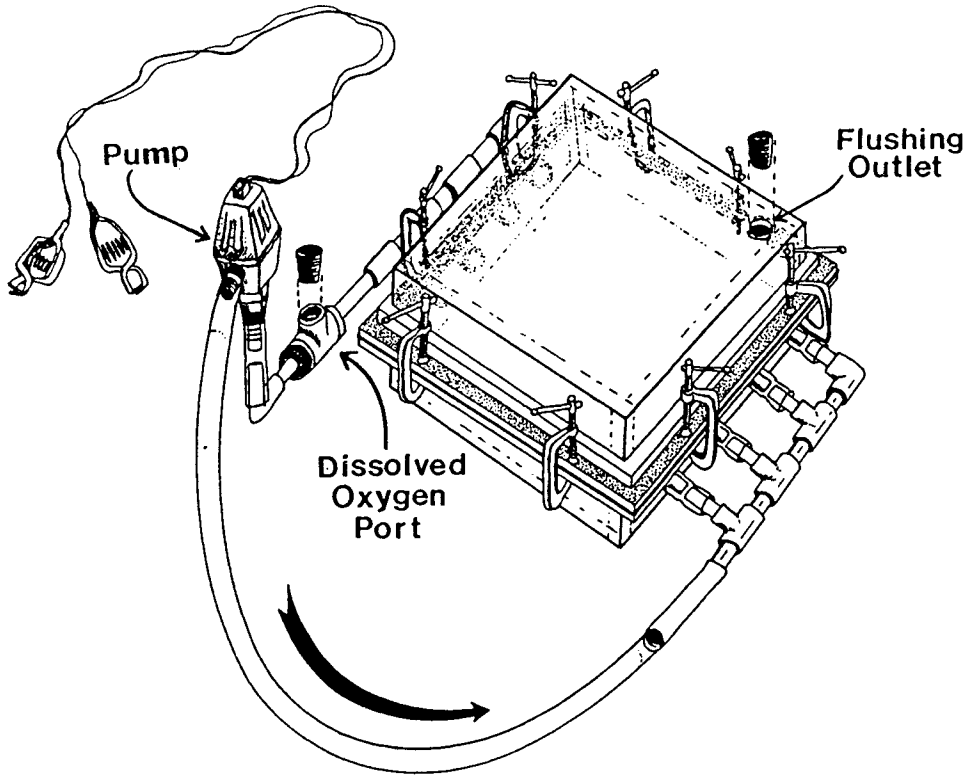

FIGURE 3. Design of plexiglass metabolism chambers. Inner dimensions are 35 cm X 35 cm X 18 cm.

Changes in dissolved oxygen within the chambers were then recorded over a 24 hour period with a YSI Model 54 dissolved oxygen probe. During the day, these dissolved oxygen concentrations were recorded every 15 to 30 minutes. During the night, measurements were recorded every 1.0 to 2.0 hours. The chambers were flushed periodically to keep the temperature and dissolved oxygen concentrations of the chambers within 2°C and 2.0 ppm of the ambient river temperature and dissolved oxygen concentrations,

respectively, and to replenish nutrients which might have become depleted during the incubation period. The longest incubation period before flushing was four hours, but sometimes high rates of oxygen production within the chambers necessitated flushing after only a 15 minute incubation period. After the sampling period, the river water in each chamber was drained and the water volume recorded.

Net community primary productivity was determined by summing the changes of dissolved oxygen concentration within the chamber during the photoperiod. An average respiration rate (mg O_2 hr^{-1}) was determined from the night-time decreases of dissolved oxygen. This respiration rate was assumed to be constant throughout the diel period (Odum 1956; Naiman 1983; Bott et al. 1985) so that diel respiration (R_{24}) was determined by multiplying the respiration rate by 24 hours. Respiration during the photoperiod (R_{pp}) was determined by multiplying the average respiration rate by the length (hours) of the daylight period. Gross primary productivity, net daily metabolism, and the P:R ratios were calculated from the respiration and net community primary productivity measurements (Naiman 1983) using the following equations:

1) Gross primary production (GPP) = net community primary production (NCPP) + respiration during the photoperiod (R_{pp}).

2) Net daily metabolism (NDM) = GPP - R_{24}.

3) Photosynthesis / Respiration (P:R) ratio = GPP/R_{24}.

Synoptic Studies: Measurements of Water Column Metabolism

During the August synoptic run, a series of light-dark bottle incubations were conducted concomitantly with the chamber metabolism measurements at each riffle site to measure water column metabolism (APHA et. al 1981) for comparison to benthic metabolism. Every 3 hours, four water samples were collected in clear BOD bottles and two water samples were collected in darkened BOD bottles using an antidiffusion device to avoid introducing bubbles into the BOD bottles during collection (Hall 1970). Two of the water samples in the clear BOD bottles (LB) and the two water samples in the dark bottles (DB) were then capped under water and placed in the river near the metabolism chambers. The other two water samples in the clear BOD bottles (IB) were immediately fixed with Winkler reagents and analyzed for dissolved oxygen concentrations (APHA 1981). After a three hour incubation period, the LB bottles and the DB bottles were fixed with Winkler reagents and analyzed for dissolved oxygen concentrations. After

averaging duplicate samples, net community primary productivity, and respiration of the water column for the incubation periods were determined by the following equations (Hall and Moll 1975):

1) Net community primary productivity = LB - IB.

2) Respiration = IB - DB.

To determine diurnal NCPP, the net community primary productivities of the incubation periods were summed. For the respiration results to be comparable to the chamber results, respiration was assumed to be constant over the diel period and an hourly respiration rate was determined from the respiration of the incubation periods. Diel respiration and gross primary productivity were then determined as previously described.

Response of Community Metabolism to Experimental Additions of Kraft Mill Wastewater

In the experimental approach, samples of Clark Fork River benthos were collected from the riffle area at the Petty Creek Fishing Access and were enclosed in six metabolism chambers as described above. But, instead of filling the chambers with river water, as in the synoptic

studies, experimental solutions were introduced into the chambers through the port for the dissolved oxygen probe (see Figure 3) via a special delivery system. Using this modification, three chambers were dosed with Clark Fork River water (the control) and three chambers were dosed with a 1:1 mixture of kraft mill wastewater and river water (the treatment). Dissolved oxygen concentrations in the chambers were recorded over a 24-hour period in a manner similar to that used in the synoptic studies, except that in this case, the metabolism chambers were periodically flushed with the appropriate treatment rather than with river water. The kraft mill wastewater used in the experiment was collected from the surface of a holding pond from which wastewater was discharged directly into the Clark Fork River.

The metabolism variables were estimated from the changes in dissolved oxygen concentrations as previously described for the synoptic studies.

Water Column Metabolism: Response to Experimental Additions of Kraft Mill Wastewater

To assess the influence of kraft mill wastewater on community metabolism within the river water column, a series of light-dark bottle incubations were conducted with three mixtures (1:1, 1:20, 1:200--wastes: river-

water) of the kraft mill wastewater and Clark Fork River. Untreated river water, collected at the same time and place as the treatments, was also incubated for experimental control. The light-dark bottle incubations were conducted as described for the synoptic studies, except the dissolved oxygen concentrations were determined with a YSI dissolved oxygen probe while the samples were mixed with a stir bar. Before recording dissolved oxygen concentrations, the probe was standardized against a value measured by Winkler titrations (APHA 1981). Incubations for all treatments occurred simultaneously.

Measurements of Physical Variables

During the diel sampling period, several physical variables of the riverine environment were also measured to determine their relation to concomitantly measured community metabolism. Conductivity and water temperature were measured hourly with a YSI S-C-T conductivity meter. Stream velocity near the point of benthos collection was measured every four to six hours with a Weathermeasure current meter or a General Oceanics current meter.

During November, incident photosynthetically active radiation (400 - 700 nm) was recorded every 15 minutes at each riffle site with a Li-Cor 188 light meter and a

quantum probe. Due to logistical problems with using the Li-Cor meter, a Kalsico photometer was used to record incident radiation every 15 minutes at each riffle site during April and August. Unfortunately, the conversion of the data from the Licor sensor to radiometric units was complicated and was dependent upon "...the spectral distribution curve of the radiant output of the source..." (Licor,Inc. pers. communication). Since changing cloud conditions would have changed the spectral distribution curve of the source, comparisons of light energy between November and April or August were not possible. To determine daily insolation rates, the instantaneous light measurements were assumed to be constant for the entire 15 minutes between measurements and the insolations over the 15 minute intervals were summed for the photoperiod.

During the experimental work, light was the only physical variable measured concomitant to the metabolism studies. The Kahlsico photometer was used to record incident light every 15 minutes.

Substratum Analysis

Benthic materials from the chambers were returned to the lab for subsequent analyses of total chlorophyll a and ash-free dry weights. The benthic materials were

frozen wet at -20°C to aide the extraction of chlorophyll (Marker 1980). Later, organic matter was scraped off the larger rocks. These scrapings, along with the smaller sized river bottom material, were placed in thick-walled plastic bags with 500 mls of absolute methanol to extract the chlorophyll (Tett et al. 1975). Samples were placed in a hot water (65°C) bath to boil for 5 minutes and then left in the dark for 24 hours (Sartory and Grobbelar 1984). Spectrophotometric measurements were made to quantify the chlorophyll content in each sample using a modification of Lorenzen's (1967) equation (Marker et al. 1980). Chlorophyll extractions were conducted within 2 - 7 months of freezing samples.

After the chlorophyll analyses were completed, the methanol was evaporated from the benthic samples and ash-free dry weights were determined. Benthic materials were first dried at 50°C for 48 hours and then cooled in a dessicator, weighed, and placed back in the drying oven for two hours. This procedure was repeated until successive weighings differed by only 2 mg. Samples were then ashed in a muffle furnace at 500°C for 12 hours (Cowan and Oswood 1983). After ashing, samples were cooled in a dessicator and reweighed. Due to the large amount of benthic organic matter collected from the riffle sites during November, only three samples were analyzed for

AFDW to obtain a seasonal estimate.

Measurement of Water Chemistry

To relate riffle community metabolism data to the water quality of the Clark Fork River, duplicate water chemistry samples were taken from each riffle area on November 30, 1984, and August 5, 1985. No water chemistry samples were taken during the April synoptic run due to the changing river chemistry associated with the onset of the spring freshet.

Earlier studies (DHES 1974; Grimestad 1977) indicated that kraft mill wastes contained high turbidity and large concentrations of sodium, chloride, sulfate, organic carbon, and total Kjeldahl nitrogen. Thus, these variables were included in a suite of variables (Table 1) analyzed to study potential effects of the wastewater discharge program on the water quality of the Clark Fork River.

Statistical Methods of Data Analysis

The variances of the net community primary productivity and gross primary productivity data were dependent upon the means. This situation, common in growth

TABLE 1. Methods for the measurement of water chemistry variables. Source: USEPA 1983.

Variables	Methods
Turbidity (TURB)	EPA 180.1
Hardness	
Calcium (Ca)	EPA 215.1
Magnesium (Mg)	EPA 242.1
Soluble Reactive Phosphorus (SRP)	EPA 365.3
Total Phosphorus (TP)	EPA 365.3
Ammonia (NH_3-N)	EPA 350.2
Total Kjeldahl Nitrogen (TKN)	EPA 351.3
Nitrate (NO_3-N) and nitrite (NO_2-N)	IC[1]
Dissolved silica (SiO_2)	EPA 370.1
Chloride (Cl)	IC[1]
Sulfate (SO_4)	IC[1]
Dissolved organic carbon (DOC)	TCS[2]
Nondissolved Organic Carbon (NDOC)	TCS[2]
Alkalinity (ALK)	EPA 310.1
Sodium (Na)	EPA 273.2

[1] IC refers to the Dionex Ion Chromatograph 16 (Dionex Corp 1979; Rawa 1979).

[2] TCS refers to the Oceanography International Total Carbon System (Menzel and Vaccaro 1964).

measurement studies, caused problems in satisfying the basic assumptions of statistical analyses. To remedy these problems, data were transformed using natural logarithms before determining tests of significance among seasons and sites in the synoptic studies and between treatments in the experimental studies. Unlike the primary productivity data, the variability of the respiration data were not dependent upon the means so these data were not transformed before conducting tests of significance.

In addition, results from a leaky chamber were deleted from further analyses so that only three chambers were used to estimate the metabolism variables at Ninemile during November. The deletion of these chamber results created some problems using analysis of variance (ANOVA) techniques due to unequal sample sizes. Therefore, interactions between site and season in the metabolism data were tested using an unweighted analysis of cell means (Snedecor and Cochran 1967). After significant interactions were detected, the appropriate one-way ANOVAs (Sokal and Rohlf 1981) were determined to test for seasonal differences at each site and for differences among sites within a particular season.

To study relationships among community metabolism variables and water quality variables, correlations were determined for variable pairs. Before determining these

correlations, net community primary productivity, gross primary productivity, chlorophyll a, and turbidity data were transformed into natural logarithms, because the variances of these variables were also dependent upon the means.

Since seasonal changes in correlations were suspected in the study's data set, correlations among the water quality variables and metabolism variables were also determined for each season separately. Unfortunately, by dividing up the data set into seasonal subsets, the resulting correlations were based on a small sample size ($n = 4$). Tests of significance, therefore, were limited to testing if correlations were significantly different ($p < 0.05$) from zero. The seasonal correlation matrices were then compared for similarities and contrarieties.

To study the relationship of light to hourly oxygen production by the benthos within the chambers, the changes in oxygen concentration during each incubation period were standardized to hourly oxygen production rates. In addition, hourly insolation rates were determined from the light measurements. These hourly oxygen production rates were then regressed on the corresponding hourly insolation rates. The resulting regressions were then compared among seasons and among sites by testing for the homogeneity of regressions (Huitema 1980; Sokal and Rohlf 1981).

ANOVA, regression, and correlation analyses were

conducted on a personal computer using the SPSSPC+ statistical package (Norusis, 1986).

T-tests were used to determine significant differences between treated chambers and control chambers in the experimental work to determine direct effects of effluent on community metabolism measures.

IV. RESULTS AND DISCUSSION

Synoptic Studies: Metabolism Measurements Using Chambers

Seasonal changes in longitudinal trends (Figure 4) caused significant interactions to occur in the analyses between sites and seasons for net community primary productivity ($p < 0.05$), diel respiration ($p << 0.002$), and gross primary productivity ($p < 0.002$). Net community primary productivity (NCPP) and gross primary productivity (GPP) generally increased 3X to 6X from November 1984 to August 1985, but the increase differed seasonally per site (Figure 4a and 4c). Diel respiration generally increased from November to August, but during April 1985, respiration increased at some sites and decreased at other sites (Figure 4b) relative to November.

The interactions between sites and seasons, coupled with the longitudinal trends in riffle community metabolism during each season, suggested that the discharge program of the kraft mill did not have a prevalent effect on these measures of riffle community metabolism in the Clark Fork River. Several reasons were possible for the absence of a prevalent effect:

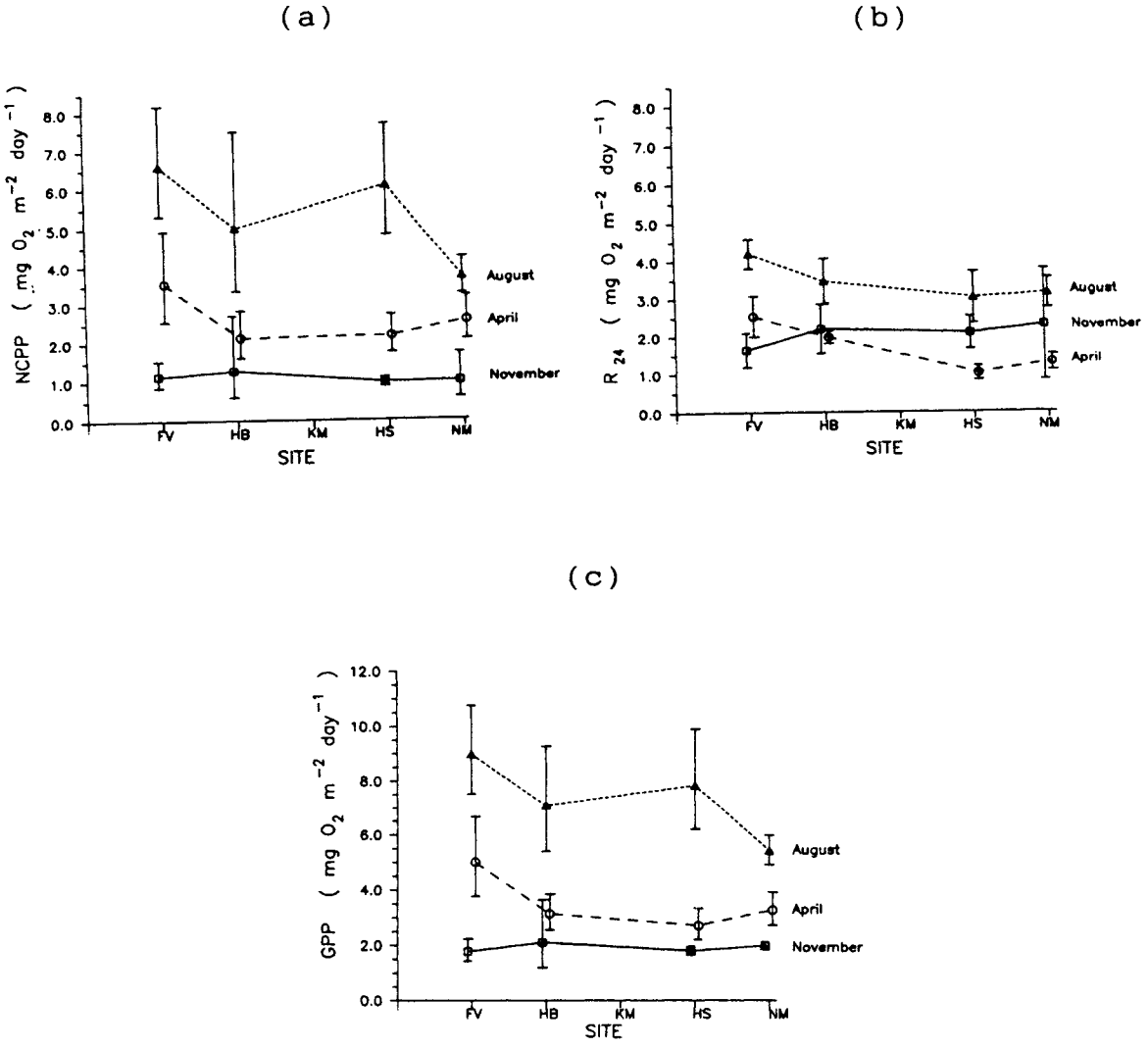

FIGURE 4. Comparison of seasonal trends in net community primary productivity (NCPP), diel respiration (R_{24}), and gross primary productivity (GPP) measured with benthic chambers at riffle sites above (Flat Valley (FV) and Harper's Bridge (HB)) and below (Huson (HS) and Ninemile (NM)) a kraft mill discharge (KM). Error bars represent 95% confidence intervals.

1) high natural variability within the study area or within the riffle community might have predominated the effects of kraft mill effluent on metabolism;

2) the chamber method might have provided only gross metabolism estimates which were insensitive to changes due to the addition of kraft mill wastewaters;

3) upstream pollution sources might have masked the effect of the kraft mill discharge program on riffle community metabolism; and,

4) the kraft mill wastewaters simply might have had no effect on riffle community metabolism.

To study these possibilities further and to discern the factors influencing riffle community metabolism, the metabolism variables were compared to the physical variables (e.g. light, stream temperature) measured concommitant to the metabolism measurements. The metabolism variables also were compared to water chemistry data collected during November and August.

Synoptic Studies: Seasonal Changes in Riffle Community Metabolism

The seasonal increases in community metabolism were significantly ($p < 0.05$) correlated with seasonal increases in stream temperature (Figure 5). No significant ($p > 0.05$) correlations were found, however, among seasonal rates of riffle community metabolism and insolation or chlorophyll a content. In an interbiome comparison study, Bott et al. (1985) noted that temperature, light, and chlorophyll influenced instream photosynthesis and respiration.

Seasonal differences in photoperiod did occur between November and August (Table 2). Unfortunately, the influence of these seasonal differences on NCPP and GPP could not be compared in this study because insolation was measured differently during November than during April and August. No seasonal differences in insolation were detected between April and August because the metabolism measurements were taken at about equal time intervals from the summer solstice.

Seasonal differences also occurred in the chlorophyll a content of the riffle areas (Figure 6). During April, the riffle sites contained significantly ($p < 0.05$) less chlorophyll a than the sites contained during November or August. The chlorophyll a content of the riffle sites

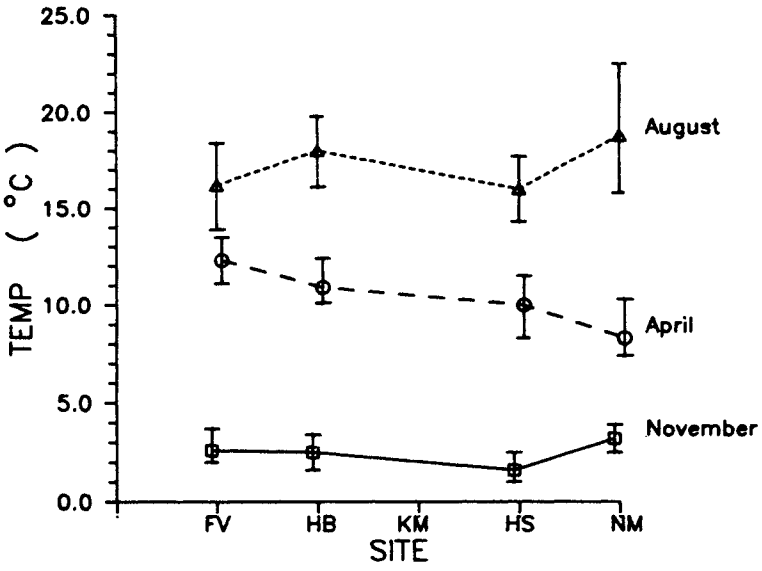

FIGURE 5. Comparison of seasonal trends in mean daily stream temperatures measured at riffle sites above (Flat Valley (FV) and Harper's Bridge (HB)) and below (Huson (HS) and Ninemile (NM)) a kraft mill discharge (KM). Error bars represent the daily range of temperatures.

during November were not significantly ($p > 0.05$) different from the chlorophyll a content of the sites during August. The decrease of chlorophyll a content from November to April caused the lack of correlation between chlorophyll a and the seasonal increases of community metabolism. This decrease of chlorophyll a content from November to April was due to the removal of organic matter from the riffle sites (Table 3) probably by ice scour (cf. Hynes 1970) or bedload scour during the onset of the spring freshet (cf. Tett et al. 1978). From April to August, both chlorophyll

TABLE 2. Comparison of photoperiod (hours) observed concomitant to riffle community metabolism measurements in the Clark Fork River.

Date	Flat Valley	Harper's Bridge	Huson	Ninemile
Nov	8.5	9.0	9.5	9.75
Apr	15.0	13.75	14.0	14.75
Aug	14.75	15.25	14.75	14.25

TABLE 3. Comparison of seasonal averages for ash-free dry weight (AFDW) of benthic organic matter collected during benthic chamber studies of riffle community metabolism. Standard deviations are in parentheses.

Season	November	April	August
Ash-free dry weight (g / m^2)	133.7 (10.1)	47.9 (14.0)	51.8 (19.7)
N	3	16	16

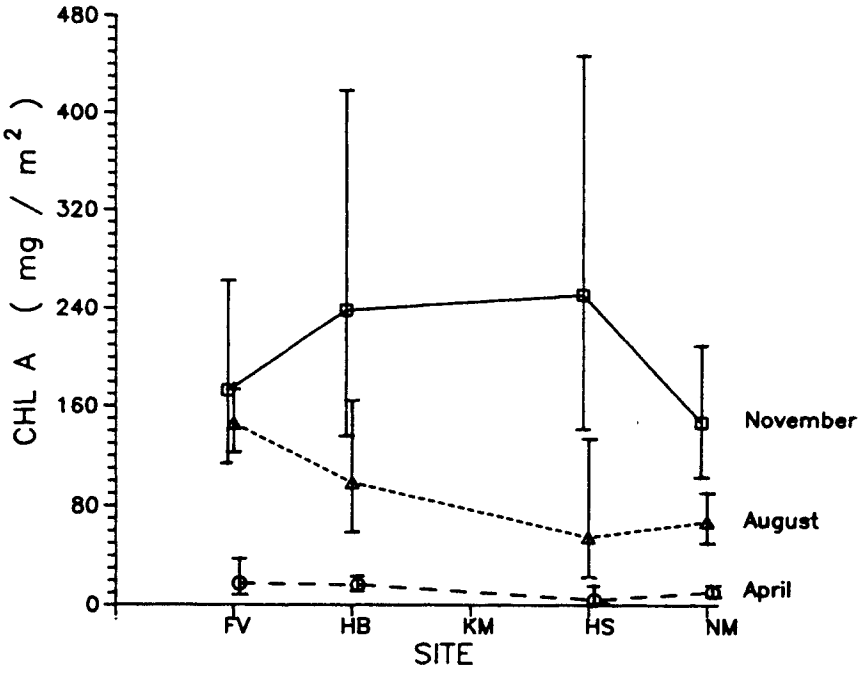

FIGURE 6. Comparison of seasonal trends in chlorophyll a content of riffle sites above (Flat Valley (FV) and Harper's Bridge (HB)) and below (Huson (HS) and Ninemile (NM)) a kraft mill discharge (KM). Error bars represent 95% confidence intervals.

a content and community metabolism increased at the riffle sites. Hence, part of the increase in riffle community metabolism during this period was probably due to the increased algal biomass in the riffle areas.

In addition to the seasonal changes observed in metabolism rates, a seasonal change in the relative importance of respiration to gross primary productivity was noted in the riffle communities (Table 4). These results indicated that a seasonal change occurred in the energetics (i.e. sources of energy and rates of energy transfer

TABLE 4. Comparisons of net daily metabolism and P:R ratios determined for riffle sites in the Clark Fork River.

Parameter	Date	Flat Valley	Harper's Bridge	Huson	Ninemile
Net Daily Metabolism ($mg\ O_2\ m^{-2}\ day^{-1}$)	Nov	+ 140	- 100	- 300	- 400
	Apr	+2480	+1160	+1710	+1980
	Aug	+4800	+3640	+4820	+2300
P:R	Nov	1.09	0.95	0.86	0.83
	Apr	1.98	1.59	2.69	2.52
	Aug	2.15	2.06	2.60	1.73

processes) of the Clark Fork River. During April and August, primary production dominated respiration at all sites, indicating that the riffle areas were gaining biomass from instream autotrophic production. In contrast, negative net daily metabolism values and the P:R (gross primary production : diel respiration) ratios indicated a predominance of respiration over primary production during November at all sites except Flat Valley. The heterotrophic conditions observed during November indicated that the riffle communities obtained energy from allochthonous sources or, more likely, from surplus biomass produced instream during the previous summer. Because

riffles and runs dominate the geomorphology of the Clark Fork River in this reach, the seasonal changes in energetics observed in the riffle communities probably occurred throughout the entire river bottom within the study area.

The seasonal changes in stream energetics implied that, perhaps, environmental variables exerted different effects on community metabolism during the different seasons. Indeed, the significant interaction terms for community metabolism among sites and seasons might have been due to different environmental variables exerting major control over community metabolism during different seasons. To examine this possibility, longitudinal trends in riffle community metabolism were analyzed for each season separately. These longitudinal trends were then compared to longitudinal trends in the environmental variables.

Synoptic Studies: Longitudinal Trends in Riffle Community Metabolism During November, April, and August

During November, net community primary productivity, gross primary productivity, and diel respiration did not differ significantly ($p > 0.05$) among sites (Figure 4). Chlorophyll a content also did not differ significantly from site to site (Figure 6) during November. No

significant ($p > 0.05$) correlations were detected among the riffle community metabolism variables and chlorophyll a, temperature, or light.

Net community primary productivity, however, was directly correlated ($p < 0.05$) with ammonia concentrations and gross primary productivity was inversely correlated ($p < 0.05$) with silicate concentrations of the river during November. Since NCPP and GPP did not differ significantly among sites, these correlations were not meaningful and their significance was considered to occur by chance.

During April, the Flat Valley site had a significantly ($p < 0.05$) higher NCPP, GPP, and diel respiration than the other three sites (Figure 4). The Harper's Bridge site also had a significantly ($p < 0.05$) higher diel respiration than the sites downstream of the kraft mill.

Chlorophyll a content (Figure 6) and ash-free dry weights (Figure 7) were significantly ($p < 0.05$) less at Huson than the other three sites during April. As a result, diel respiration at Huson might have been limited by the amount of algal biomass in the benthos of the Huson site when compared to the other riffle sites.

The community metabolism variables were not correlated with temperature, light, or ash-free dry weights (AFDW) during April, but GPP and diel respiration were significantly ($p < 0.05$) correlated with chlorophyll a

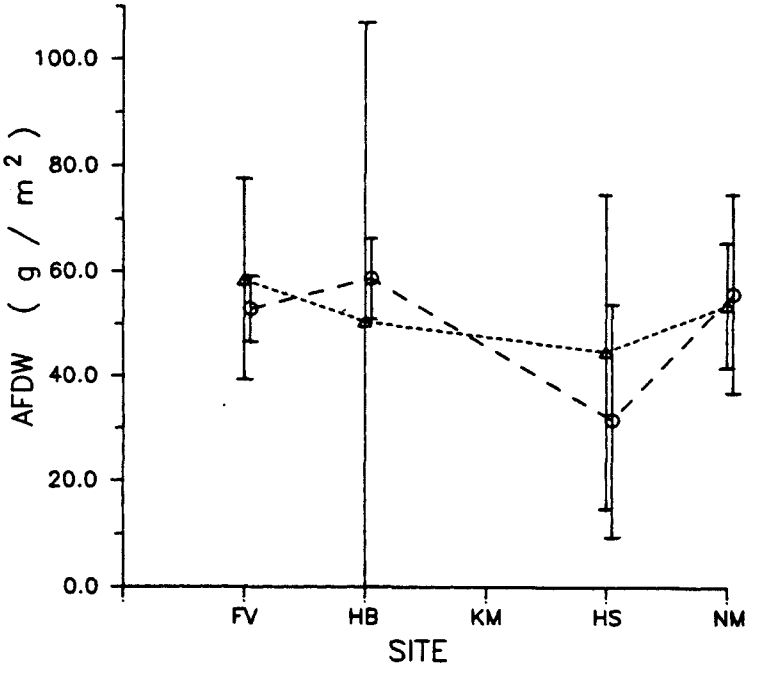

FIGURE 7. Comparison of seasonal trends in the ash-free dry weights (AFDW) of benthic organic matter collected from riffle sites above (Flat Valley (FV) and Harper's Bridge (HB)) and below (Huson (HS) and Ninemile (NM)) a kraft mill discharge (KM). Error bars represent 95% confidence intervals. The April data are represented with circles connected by dashed lines. The August data are represented with triangles connected with dotted lines.

chlorophyll a content suggested that algal respiration dominated diel respiration during April.

The longitudinal trends observed in the metabolism variables during April might have been related to the upstream addition of nutrients. No water chemistry samples were collected during the April synoptic studies due to the onset of the spring freshet, but data collected by the Montana Department of Health and Environmental Sciences

(Ingman 1985) just prior to spring runoff suggested a nutrient gradient existed in the study area that decreased downstream.

In other past studies (Spindler 1959; USEPA 1974), the Missoula wastewater treatment plant was implicated as a major source of nutrients upstream of the kraft mill. A recent study (Ver Hey 1986), however, suggested that septic tank failures also might be enhancing the nitrate concentrations of groundwater in the floodplain of the Clark Fork and Bitterroot Rivers. Kicklighter and Stanford (1985) did note that the Bitterroot River and possibly groundwater inputs contributed nitrates to the Clark Fork River.

During August, NCPP and GPP were significantly ($p < 0.05$) less at Ninemile than the other three sites (Figures 4a and 4c). Diel respiration was significantly ($p < 0.05$) higher at Flat Valley than the other three sites (Figure 4b).

Chlorophyll a content at Flat Valley was significantly ($p < 0.05$) greater than the chlorophyll a content at Huson and Ninemile during August (Figure 6). In addition, chlorophyll a content at Harper's Bridge was significantly ($p < 0.05$) higher than the chlorophyll a content at Huson. Ash-free dry weights, however, did not differ significantly ($p > 0.05$) among the riffle sites (Figure 7).

The riffle community metabolism variables were not significantly ($p > 0.05$) correlated with light or AFDW, but GPP and diel respiration were correlated ($p < 0.05$) with chlorophyll a content. Hence, the longitudinal trends in diel respiration appeared to be due specifically to the amount of algal biomass in the benthos of the riffle sites. A significant ($p < 0.05$) negative correlation was detected between NCPP and temperature.

The lack of correlation between light and NCPP during August was surprising because a short afternoon thunderstorm, which occurred during metabolism measurements at Harper's Bridge, produced a very notable effect on oxygen production in the metabolism chambers (Figure 8). Since the weather was clear during metabolism measurements at the other sites during August (Table 5), a correlation between light and NCPP was expected.

In addition, the nitrate concentration at Ninemile was below detection and a gradient of soluble reactive phosphorus (Figure 9a), nitrate (Figure 9b), and ammonia (Figure 9c) concentrations existed in the study area during August, but no correlations were detected among the metabolism variables and these water chemistry variables.

I suspected that the effects of the various environmental variables on the metabolism variables were confounded over the diel period. To explore the

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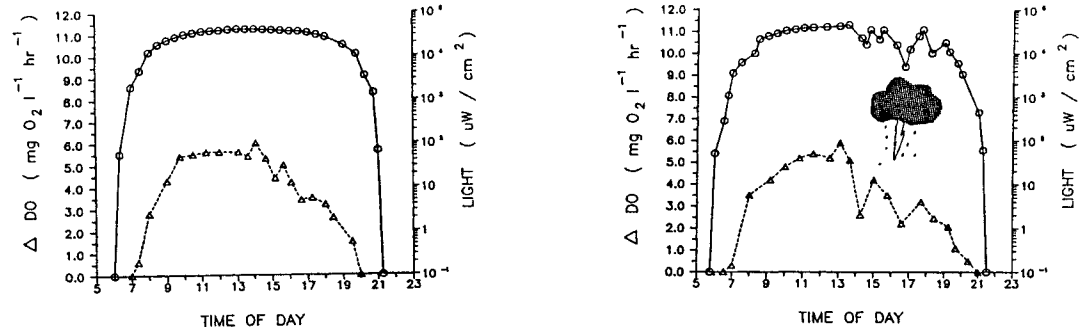
(b) HB



(c) HS

(d) NM

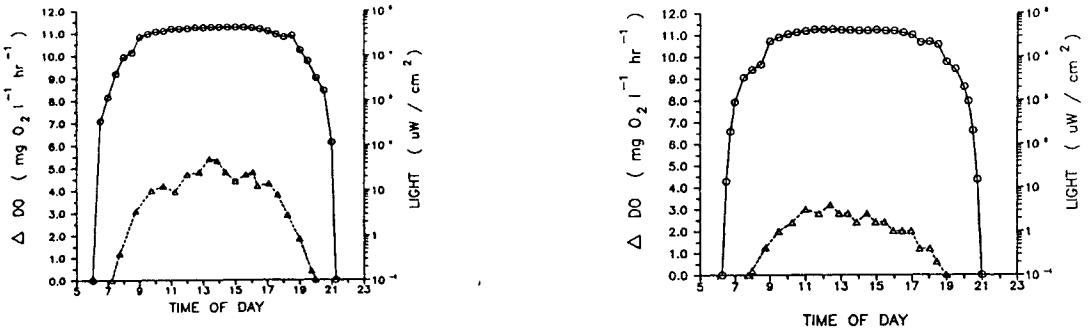


FIGURE 8. Comparison of diurnal oxygen production curves within benthic metabolism chambers and incident radiation rates measured at riffle sites above (Flat Valley (FV) and Harper's Bridge (HB)) and below (Huson (HS) and Ninemile (NM)) a kraft mill discharge. The diurnal oxygen production curves are represented by the triangles connected by the dashed lines. The incident radiation rates are represented by circles connected by the solid lines.

TABLE 5. Comparison of daily insolation rates of photosynthetically active radiation (PAR) (einsteins m^{-2} day^{-1}) and incident radiation (X106 Joules m^{-2} day^{-1}) measured in the field during the synoptic studies. Concurrent weather conditions are also given: Clear (C), Mostly Clear (MC)[1], Partly Cloudy (PC)[2], and Overcast (OC)[3]. Changing weather conditions are indicated with a double entry for the affected riffle site.

Variable	Date	Flat Valley	Harper's Bridge	Huson	Ninemile
Daily Insolation of PAR	Nov	13.3	8.10	6.52	8.44
Daily Insolation of Incident Radiation	Apr	13.3	7.61	14.5	11.5
	Aug	13.9	11.7	14.3	12.7
Weather Conditions	Nov	C-OC	PC-OC	OC	C-OC
	Apr	C-PC	PC-OC	MC	PC-OC
	Aug	C	MC	C	C

[1] Cloud cover < 25%.

[2] Cloud cover 25 - 75%.

[3] Cloud cover > 75%.

confounding effects of the environmental variables on riffle community metabolism, I shifted my analyses of oxygen consumption and production from a daily time frame to an hourly time frame. Then, I compared the levels of

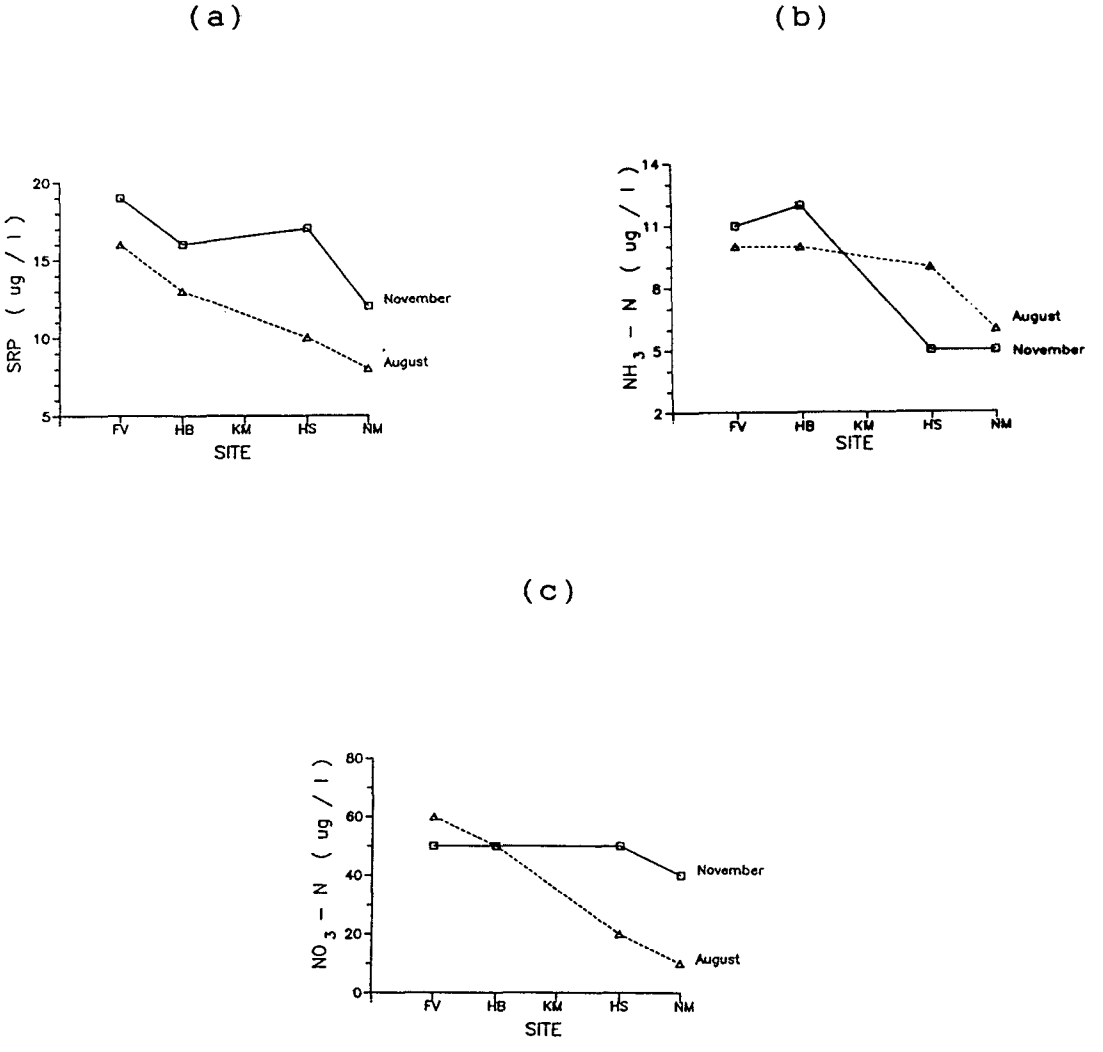


FIGURE 9. Comparison of seasonal trends in the concentrations of soluble reactive phosphorus (SRP), ammonia (NH3-N), and nitrate (NO3-N) among riffle sites above (Flat Valley (FV) and Harper's Bridge (HB)) and below (Huson (HS) and Ninemile (NM)) a kraft mill discharge (KM). Values recorded below the detection limit for nitrate (10 ug / l) and ammonia (5 ug / l) are plotted at the detection limit.

the various environmental variables to the relationship between light and the hourly oxygen production of the riffle communities. McIntire and Phinney (1965) used a similar analytical approach to study the relationship among community metabolism, light, temperature, and carbon dioxide concentrations in laboratory streams. Unlike the studies of McIntire and Phinney, however, I did not have control over the exposure of the riffle communities to varying levels of the environmental variables. Hence, the following interpretations are suggestive rather than definitive.

Synoptic Studies: Seasonal Variations in the Effect of Light on Oxygen Production by Riffle Communities

A nonlinear relationship existed between hourly insolation rates and the hourly production rates of oxygen within the chambers (Figure 10). This nonlinear relationship was consistent with the results of other investigators using chambers or *in situ* light-dark bottles (McIntire and Phinney 1965; Vollenweider 1969). To describe the nonlinear relationship, the chamber data were fitted with a logarithmic regression model. All the chamber data had a significant ($p < 0.05$) regression of hourly oxygen production on light except the November chamber data at Flat Valley and the November data from one

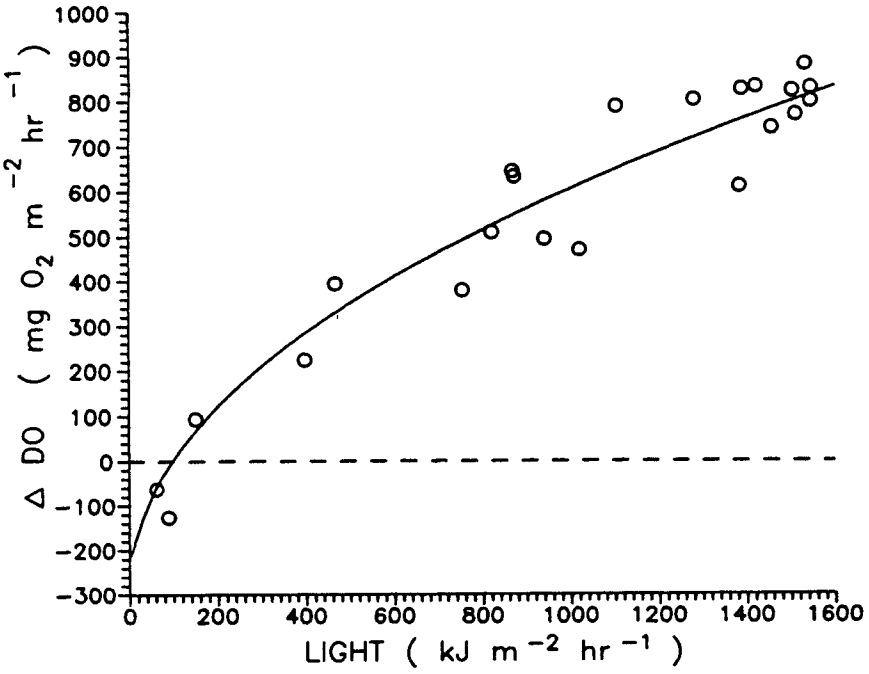


FIGURE 10. Hourly oxygen production rates within an <u>in situ</u> metabolism chamber as a function of hourly insolation rates.

chamber at Harper's Bridge. The absence of a relationship between light and oxygen production at Flat Valley during November might have been due to changing cloud conditions (Gallegos et al. 1977) coupled with taking light measurements every 30 minutes rather than every 15 minutes as was done at the other sites. The coefficients of determination of the significant regressions ranged from 0.53 to 0.98 among the various chambers.

To test for seasonal variations in the relationship of light to hourly oxygen production, the chamber oxygen data from all sites were pooled for a particular season and these data were regressed on corresponding hourly

insolation rates. A test for homogeneity of regression was conducted for the April and August data. The November chamber data were not included in the analysis because light was measured differently in November than April or August. The August chamber data (n = 313) had a signficantly ($p < 0.05$) greater regression slope than the April chamber data (n = 543).

The significance of the seasonal change in the logarithmic slopes became apparent when the logarithmic curves of the untransformed chamber data were plotted (Figure 11). The April data suggested that photosynthesis of the riffle communities became light saturated at fairly low insolation rates. In contrast, the August data suggested that photosynthesis of the riffle communities was still sensitive to changes in light even at high insolation rates.

To grossly compare the November metabolism data to the April and August data, a linear relationship was assumed to occur between the Licor light measurements and the Kahlsico light measurements. Comparison of light measurements obtained by the two instruments under the same light conditions indicated that a linear relationship did exist between these light measurements under overcast skies, but this relationship was subject to the errors described previously (see Methods and Materials). After the

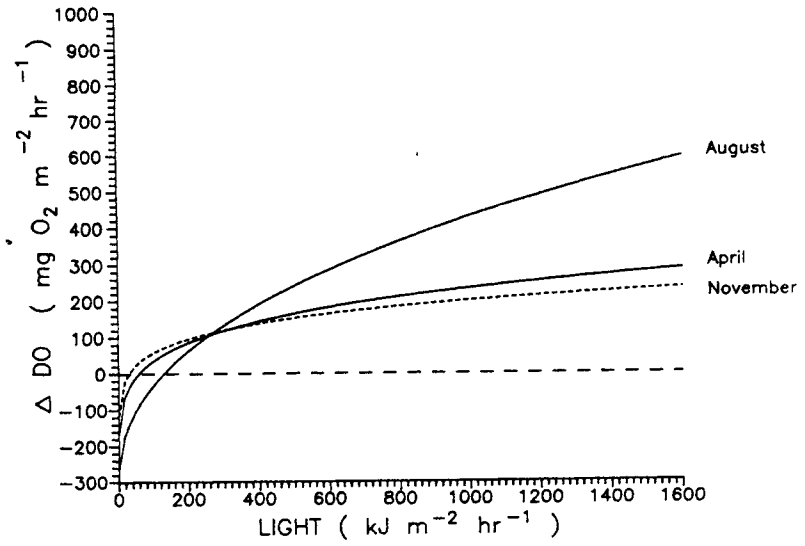


FIGURE 11. Comparison among seasons of hourly oxygen production within in situ metabolism chambers as a logarithmic function of hourly insolation rates. The dashed line represents light data which was measured differently than the data represented by the solid lines (see text).

November Licor data were transformed to the Kahlsico units, these data were regressed (n = 233) on the hourly oxygen production data measured during November. The resulting logarithmic curve was plotted with the logarithmic curves determined from the April and August data (Figure 11). The transformed November data suggested that photosynthesis of the riffle communities became light saturated at insolation rates similar to the photosynthesis of the riffle communities during April. Although the light-saturated production rates of oxygen did not greatly differ between

November and April, the riffle communities during November contained one to two orders of magnitude more chlorophyll a (Figure 6) than the riffle communities during April. As a result, the hourly production rate of oxygen per milligram of chlorophyll a was extremely low during November when compared to the hourly oxygen production rate per milligram of chlorophyll a during April.

The seasonal changes in the relationship between light and hourly oxygen production were believed to be due to seasonal changes in temperature. At low temperatures, the low rates of community metabolism were not very sensitive to changes in other environmental variables such as light. At high temperatures, however, the higher rates of community metabolism were more sensitive to changes in light and possibly were more sensitive to changes in other environmental variables (e.g. nutrients).

Synoptic Studies: Longitudinal Variations in the Effect of Light on Oxygen Production by Riffle Communities During November, April, and August

To explore the possibility that other environmental variables were influencing the relationship between light and oxygen production by riffle communities under warmer stream temperatures, the chamber data were pooled for a particular site during a particular season and

these data were regressed on corresponding hourly insolation rates. Then, the homogeneity of regression was tested among sites within a particular season.

No significant ($p > 0.05$) differences in regressions were detected among sites during November ($n = 39$ to 92) and August ($n = 65$ to 84). In contrast, significant ($p < 0.05$) differences in regressions were detected among sites during April ($n = 104$ to 168).

The regression of oxygen production on light had a significantly ($p < 0.05$) greater slope at the Flat Valley site than the regression slopes at the Huson and Ninemile sites during April. The regression slopes among the Harper's Bridge, Huson, and Ninemile sites were not significantly ($p > 0.05$) different. These results suggested that the hourly production of oxygen by riffle communities was sensitive to changes in environmental variables other than light during April.

The increase in stream temperatures from November to April could have explained the increased sensitivity of oxygen production to environmental variables during April as compared to November. Yet, if stream temperatures did increase the sensitivity of oxygen production to other environmental variables, then this effect would be expected to be most pronounced in August when stream temperatures were the highest. The homogeneity of regression slopes

among sites during August contradicted this interpretation, but certain assumptions underlying the regression analysis might not have been true.

In the regression analyses, the respiration rate was assumed to be constant throughout the diel period. In other metabolism studies, several investigators (Odum and Wilson 1962; Flemer 1970; Kelly et al. 1974; Schurr and Ruchti 1977) noted diurnal variations in the production of oxygen by lotic communities that were not explained by diurnal variations in light. Depletion of nutrients (Flemer 1970; Kelly et al. 1974) or diurnal changes in respiration rates (Odum and Wilson 1962; Kelly et al. 1974; Bidwell 1977; Yallop 1982) were suggested as possible causes for these diurnal variations in oxygen production. The tapering of the diurnal oxygen production curves measured under clear skies during August (Figure 8), might have been due to increased respiration rates during the afternoon. Hence, a more appropriate analysis of the chamber data might consist of dividing the data into two data sets (cf. Kelly et al. 1974), a morning data set and an afternoon data set, before conducting regression analyses and making comparisons among sites.

When testing the morning data set for the homogeneity of regression slopes among sites, no significant ($p > 0.05$) differences were detected in November ($n = 24$ to 48), but

significant ($p < 0.05$) differences were detected among sites during April ($n = 60$ to 76) and August ($n = 26$ to 36).

In April, Flat Valley had a significantly ($p < 0.05$) greater logarithmic regression slope than Ninemile (Figure 12). The logarithmic regression slopes of the other sites were not significantly ($p > 0.05$) different from each other, but the logarithmic regression slopes did decrease in a downstream direction. Correlation analyses of the logarithmic regression slopes with environmental variables indicated that the slopes were correlated ($p < 0.05$) with stream temperatures. The logarithmic regression slopes might have also been correlated to inorganic nutrient concentrations, but no water chemistry samples were collected during April.

During August, Flat Valley had a significantly ($p < 0.05$) greater regression slope than Huson or Ninemile (Figure 13). The regression slopes of the other sites were not significantly ($p > 0.05$) different from each other, but once again, the regression slopes did decrease in a downstream direction. Correlation analyses of the regression slopes with environmental variables indicated that the slopes were significantly ($p < 0.05$) correlated with nitrate concentrations. In addition, high (but not significant) correlations were found between the regression

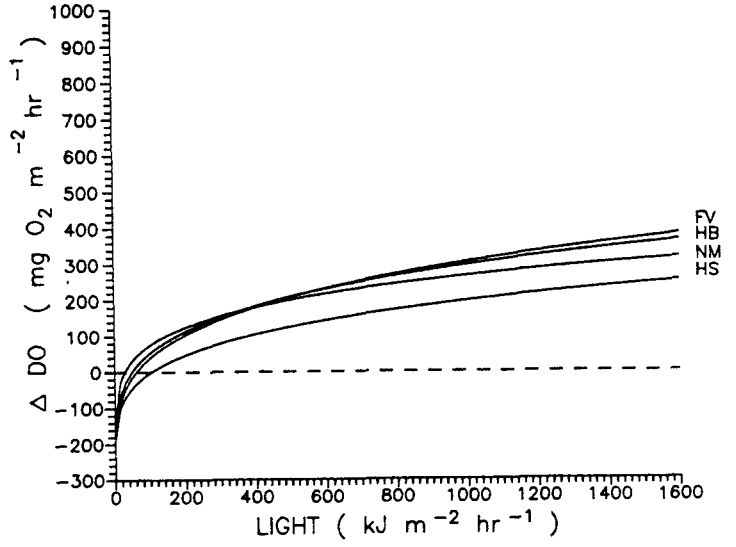


FIGURE 12. Comparison among sites of hourly oxygen production within in situ metabolism chambers as a logarithmic function of hourly insolation rates during April.

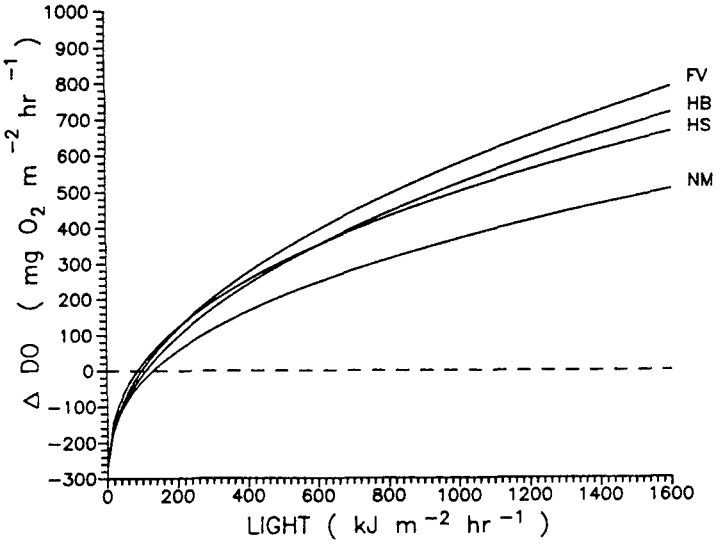


FIGURE 13. Comparison among sites of hourly oxygen production within in situ metabolism chambers as a logarithmic function of hourly insolation rates during August.

slopes and soluble reactive phosphorus concentrations of the river ($p = 0.06$); and between the regression slopes and the chlorophyll a content ($p = 0.09$) of the riffle sites. In contrast to the April regressions, the August regression slopes were not correlated to temperature ($p = 0.69$). Hence, the morning production of oxygen by riffle communities in the Clark Fork River appeared to be influenced by the concentration of inorganic nutrients during August.

When testing the afternoon data set for homogeneity of regression slopes among sites, no significant differences were detected during November ($n = 9$ to 44) and August ($n = 39$ to 48), but significant ($p < 0.05$) differences in regression slopes did exist among sites during April ($n = 44$ to 96). In April, the Flat Valley site had a significantly ($p < 0.05$) greater regression slope than Harper's Bridge, Huson, or Ninemile. The regression slopes of the other sites were not significantly ($p > 0.05$) different from each other, but the slopes did decrease in a downstream direction. Correlation analyses did not reveal any significant ($p > 0.05$) correlations between regression slopes and the environmental variables.

During April and August, the regressions of the morning data sets and the afternoon data sets were tested for homogeneity of regression slopes within a particular

site. No significant ($p > 0.05$) differences were detected between the morning and afternoon regressions except at the Flat Valley site during April. At the Flat Valley site, the afternoon regression slope was significantly ($p < 0.05$) greater than the morning regression slope during April.

The lack of significant differences between the morning regressions and the afternoon regressions during August was surprising because the morning regressions had heterogeneous regressions among sites whereas the afternoon regressions were homogeneous among sites. These results suggested that the variablity of the afternoon data might be different from the variability of the morning data. A test for the homogeneity of variances did detect significant ($p < 0.05$) differences between the variances of the morning data and the afternoon data at all sites except Harper's Bridge during April. The variances of afternoon oxygen production were found to be significantly ($p < 0.05$) greater than the variances of the morning oxygen production (Figure 14). The increased variability of the afternoon data suggested that some factor was interfering with oxygen production by riffle communities or with the measurement of oxygen production during the afternoon.

The factor causing the interference during the afternoon was not determined, but might include: 1) diurnal depletion of nutrients in the chambers or the river;

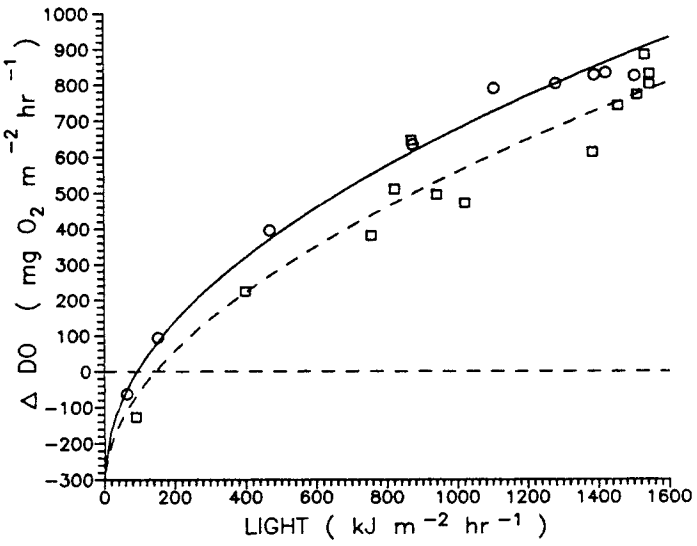


FIGURE 14. Comparison of hourly oxygen production within an in situ metabolism chamber as a logarithmic function of hourly insolation rates between the morning (solid line) and afternoon (dashed line) of August 17, 1985.

2) diurnal variations in the effect of photorespiration on apparent oxygen production; or 3) changes in the metabolic activities of other stream organisms. Regardless of the cause, the presence of the interference suggested that the metabolism data collected during the afternoon was questionable. Perhaps only metabolism data collected during the morning should be used for comparative purposes in synoptic studies, rather than diurnal measurements of metabolism.

Synoptic Studies: Water Column Metabolism

During August, no changes in oxygen concentrations were detected between the light and dark bottles in the water column incubations at any of the study sites. Since no changes in oxygen concentrations were detected, no estimates of water column metabolism could be determined using my methods. The kraft mill was not direct discharging wastewater during some of these measurements, but even when direct discharging did occur, no water column metabolism was detected. The low metabolism of the water column was substantiated by the low BOD5 and COD concentrations measured in this reach by the Montana Department of Health and Environmental Sciences during the summer of 1985 (Ingman 1985). The BOD5 and COD concentrations at these sites were also low during other periods of the year. These results indicated that the diurnal changes in dissolved oxygen observed in the Clark Fork River were due to benthic metabolism and not the metabolism of suspended or dissolved organic matter in the river water.

Effect of Kraft Mill Wastewaters on the Water Quality of the Clark Fork River

The longitudinal variation in the effect of light on morning oxygen production during August suggested that: 1) the metabolism of riffle communities was influenced by the water quality of the river; and 2) upstream sources of nutrients were masking any effects of the kraft mill discharge program on the Clark Fork River. It was possible that the rate of kraft mill discharge was too low to have a significant impact on the water quality of the Clark Fork River such that the discharge simply had no effect on riffle community metabolism. To examine this possibility, the direct discharge rates of the kraft mill were compared to longitudinal trends of water quality in the Clark Fork River within the study area.

The direct discharge rates of the kraft mill wastewaters changed seasonally (Table 6). During the low flow period of the Clark Fork River, kraft mill wastewater was discharged directly into the river at a rate of 1 part wastewater to 700-1000 parts river water except during the extremely low flow periods of summer. When the flow of the Clark Fork River dropped below 53.8 m^3 sec^{-1}, the kraft mill stopped direct discharging wastewater into the river. The potential environmental effects of discharging kraft mill effluent during the low flow period were corroborated by

TABLE 6. Rate of wastewater direct discharge by the kraft mill and the flow of the Clark Fork River at the USGS gaging station below Missoula during the synoptic studies.

Parameter	Date	Flat Valley	Harper's Bridge	Huson	Ninemile
Kraft Mill Wastewater Direct Discharge (m^3 / sec)	Nov.	0.102	0.093	0.102	0.088
	Apr.	0.572	0.198	0.530	0.544
	Aug.	0.0	0.088	0.093	0.0
Clark Fork River Flow at USGS Station below Missoula (m^3 / sec)	Nov.	80.1	79.6	72.5	81.5
	Apr.	164.3	124.2	176.9	162.4
	Aug.	53.6	71.6	76.7	55.1

longitudinal trends in sodium and chloride concentrations of the Clark Fork River (Figure 15).

The kraft mill effluent contained high concentrations of sodium and chloride (Table 7). Since sodium and chloride are biologically conservative elements (Stumm and Morgan 1981; Wetzel 1983), changes in sodium and chloride concentrations of the river were due mainly to the addition of kraft mill wastewaters, dilution processes, and possibly the addition of irrigation return waters. The concentrations of both sodium and chloride increased downstream of the kraft mill during November and August.

(a) (b)

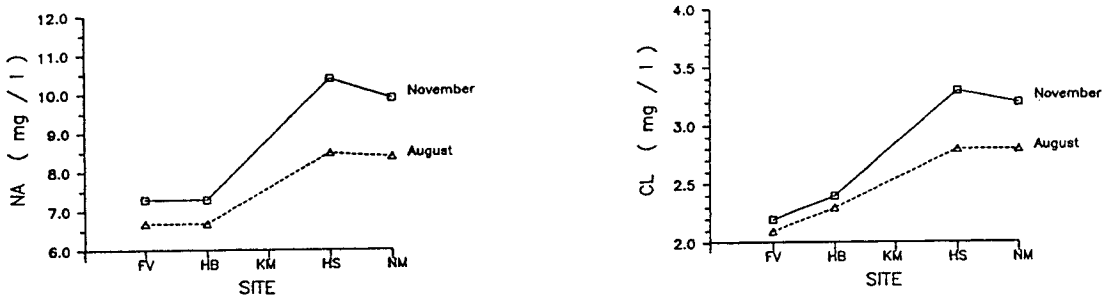


FIGURE 15. Comparison of seasonal trends in concentrations of sodium (NA) and chloride (CL) at riffle sites above (Flat Valley (FV) and Harper's Bridge (HB)) and below (Huson (HS) and Ninemile (NM)) a kraft mill discharge (KM).

The downstream increases of sodium and chloride during August, however, were less than the downstream increases of these variables during November. During August, the kraft mill was not direct discharging wastewaters into the river when water chemistry samples were collected, but wastewaters were still entering the river from groundwater seepage. During November, the mill was direct discharging wastewater into the river at a rate of 0.085 m^3 sec^{-1} when the water chemistry samples were collected. Since the changes in direct discharge rates were reflected in the concentrations of sodium and chloride in the river water downstream of the kraft mill, the water quality of the

TABLE 7. Comparison of water chemistry variables among mixtures of kraft mill wastewater and Clark Fork River water taken from the Petty Creek Fishing Access. Data are means of duplicate samples collected on September 3, 1985.

Variable	Full Strength	1:1	1:200	River Water
Turbidity (NTU)	23	20	2.0	0.83
Hardness (mg $CaCO_3$ / l)	215	171	133	135
Ca (mg / l)	61.2	47.9	36.6	37.0
Mg (mg / l)	15.2	12.6	10.2	10.3
SRP (ug / l)	287	145	4	8
TP (ug / l)	3710	1810	50	31
NO_3-N (ug / l)	< 10	< 10	< 10	< 10
NH_3-N (ug / l)	1460	1020	< 5	6
TKN (ug / l)	16300	7900	364	221
SiO_2 (mg / l)	40	22.0	11.7	10.2
Cl (mg / l)	141	74	4.2	3.5
SO_4-S (mg / l)	261	140	9.1	7.9
Na (mg / l)	623	295	12.5	9.4
Alkalinity (mg $CaCO_3$ / l)	682	406	133	129
DOC (mg / l)	40	31	2.7	1.7
NDOC (mg / l)	36	13	1.5	0.8

Clark Fork River appeared to be profoundly influenced by the discharge of kraft mill wastewaters.

Further evidence that the discharge of kraft mill wastewaters effected the water quality of the Clark Fork River during low flow was provided by the longitudinal trends of turbidity and the concentrations of soluble reactive phosphorus (SRP), nondissolved organic carbon (NDOC), and total Kjeldahl nitrogen (TKN). During November, turbidity (Figure 16a) and the concentrations of SRP (Figure 9a) and NDOC (Figure 16b) in the river water increased downstream of the kraft mill. During August, no direct discharge of wastewaters was occurring when water chemistry samples were collected and no increased concentrations of SRP were noted downstream of the kraft mill; but, the concentrations of NDOC and TKN did increase downstream of the kraft mill (Figure 16). Perhaps, the benthic community of the river was fertilized by the enhanced SRP concentrations from groundwater seepage of the kraft mill wastewaters. The high rates of community metabolism, noted during August, would have caused the added inorganic nutrients to be rapidly incorporated into benthic biomass. Thus, the increased biomass could subsequently have been sloughed from the substrate and increased the concentration of particulate organic matter in the river. Alternatively, the increased concentrations

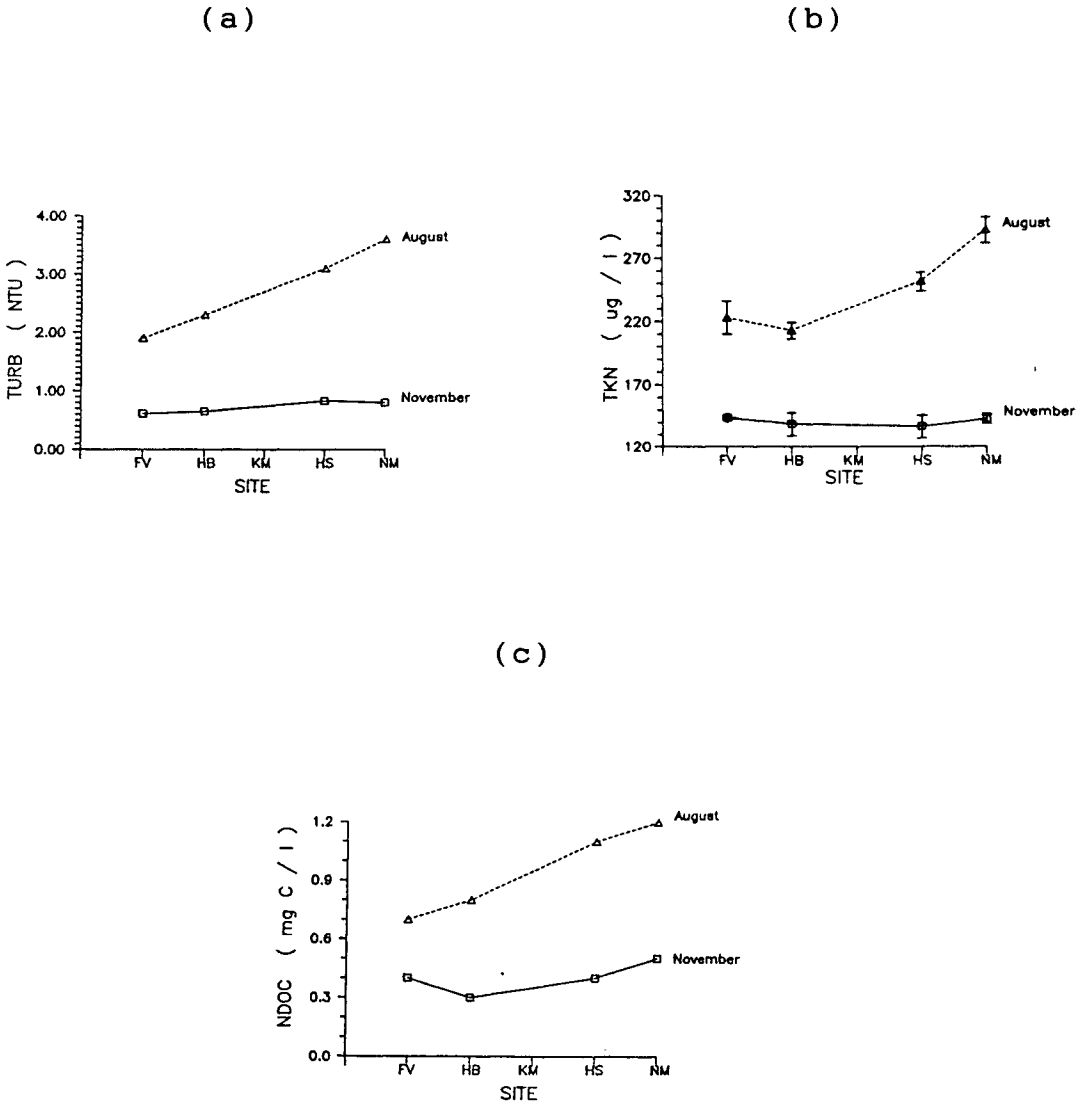


FIGURE 16. Comparison of seasonal trends in turbidity (TURB) and in concentrations of total Kjeldahl nitrogen (TKN) and nondissolved organic carbon (NDOC) at riffle sites above (Flat Valley (FV) and Harper's Bridge (HB)) and below (Huson (HS) and Ninemile (NM)) a kraft mill discharge (KM). Error bars represent the range of values from duplicate samples.

of particulate organic matter downstream of the kraft mill also might have been due to the abiotic flocculation of DOC to NDOC caused by changes in the physio-chemical properties (Lush and Hynes 1973, 1978; Wallace and Merritt 1980; Mullholland 1981; Jensen and Sondergaard 1982; Krueger and Waters 1983) of the wastewater as the groundwater seepage entered the river. Hence, the addition of kraft mill wastewaters into the Clark Fork River, either by direct discharge or groundwater seepage, did seem to influence the water quality of the Clark Fork River profoundly during low flow periods. These water quality results, coupled with the results of morning oxygen production by the riffle communities, suggested that the addition of nutrients by the kraft mill could increase riffle community metabolism in the Clark Fork River under conditions of "warm" (18 - 22°C) stream temperatures.

During April, the kraft mill discharged wastewaters directly into the river at a rate of 1 part wastewater to 250-600 parts of river water. The longitudinal trends of the morning oxygen production by the riffle communities during April (Figure 12) indicated that nutrients from this increased discharge rate did not increase metabolism of the riffle communities. Although the increased discharge of the kraft mill wastewaters would have increased the nutrient load to the river, the wastewaters also contained

color and possibly residual toxic compounds (Ingman 1985) which could have counteracted the fertilizing effects of the nutrients on riffle community metabolism. The results of the experimental work provided more insights into these possibilities.

Response of Community Metabolism to Experimental Additions of Kraft Mill Wastewater

The chambers dosed with the 1:1 dilution of wastewater had significantly ($p < 0.001$) less net community primary productivity and significantly ($p < 0.001$) less gross primary productivity than the controls (Table 8). The reduction in primary productivity observed in the chamber could have been due to two factors: 1) the concentration of residual toxic substances in the wastewater; or 2) the attenuation of light due to wastewater color.

Treated chambers did not have significantly ($p > 0.05$) different respiration rates compared to the controls. In addition, the chlorophyll a content of the substratum (which was shown to be positively correlated with respiration in the synoptic studies) was not significantly ($p > 0.05$) different between the treated chambers and the control chambers. These results implied that either 1) the respiration rate (including the

TABLE 8. Comparison of benthic metabolism variables using a treatment of a 1:1 mixture of wastewater and river water. Data are means (n = 3).

Variable	River Water (Control)	1:1 Mixture (Treatment)
Net Community Primary Productivity (mg O_2 m^{-2} day^{-1})	4270	750***
Diel Respiration (mg O_2 m^{-2} day^{-1})	2480	3160^{ns}
Gross Primary Productivity (mg O_2 m^{-2} day^{-1})	5460	2270**
Net Daily Metabolism (mg O_2 m^{-2} day^{-1})	+2980	- 890
P:R	2.20	0.72
Chlorophyll a (mg / m^2)	220	215^{ns}

*** $p < 0.001$

** $p < 0.005$

ns not significant ($p > 0.05$)

decomposition rate) of the 1:1 dilution was negligible when compared to the ambient benthic respiration in the river, or 2) the toxicity of the wastewater, which could have decreased respiration, was compensated by the additional respiration from the organic matter in the

kraft mill wastewater.

The greatest acute impact of the kraft mill wastewater on riffle community metabolism was on the net daily metabolism values and the P:R ratios of the control chambers compared to those treated with a 1:1 mixture of kraft mill wastewater and river water. The treated chambers experienced heterotrophic conditions, whereas autotrophy prevailed in the control chambers.

The results of this study contrasted with the observed nutrient stimulation of primary productivity due to the addition of kraft mill wastewater noted by Williams (1969) and Bothwell and Stockner (1980). Although the kraft mill wastewater used in this study contained high concentrations of nutrients (Table 7), these nutrients did not enhance primary productivity of the periphyton in the metabolism chambers in these short-term experiments. The difference in results might be due to the different concentrations of kraft mill wastewaters tested in the other studies. Williams (1969) used a 4% concentration of kraft mill wastewater and the greatest concentration tested by Bothwell and Stockner (1980) was a 25% concentration of kraft mill wastewater compared to a 50% concentration of kraft mill wastewater was tested in this study. Perhaps, different concentrations of kraft mill wastewater might allow different factors to be more significant in

influencing primary productivity of periphyton.

Leuenberger et al. (1985) found that chlorinated compounds were only partially eliminated by secondary treatment of bleached kraft mill wastes. Therefore, residual toxic substances in the wastewater might have reduced primary productivity when the chambers were dosed with a 1:1 mixture of kraft mill wastewater and river water.

Since periphyton use light energy to convert inorganic carbon into biomass, attenuation of light energy reaching the periphyton would reduce primary productivity. The dark color observed in the treated chambers indicated that the color of a 1:1 mixture of kraft mill wastewater and river water was adequate to attenuate light such that primary productivity in these chambers was reduced. Other investigators (Parker and Siebert 1973; Stockner and Cliff 1976; NCASI 1985) also found that primary productivity was reduced by the color of kraft mill effluents.

The absorbance of light by the dark color of the wastewater also caused the temperatures to increase more rapidly in the treated chambers than the control chambers. Since the chambers were flushed to keep temperatures within 3°C of the initial temperatures, the effect of temperature on metabolism in the experiment was minimized.

But, in a stream ecosystem, a high discharge rate of kraft mill effluent might increase water temperatures due to the color of the kraft mill wastewater. Increased stream temperature probably would increase respiration of the benthic communities downstream of the kraft mill discharge. Increased respiration coupled with the decreased primary productivity would have caused the development of a riffle community with heterotrophic characteristics. No such increases in stream temperature or respiration were noted below the kraft mill during the synoptic studies.

Water Column Metabolism: Response to Experimental Additions of Kraft Mill Wastewater

Perhaps the most surprising result of this study was the fact that the kraft mill wastewater had the capability for photosynthesis (Table 9). In addition, the metabolic characteristics of wastewater that had a "greenish tinge" were different from wastewaters that only had a "brown" color. The "green" wastewater was more biologically active than the "brown" wastewater (Table 10). Moreover, the wastewaters, which were sampled every four hours from the same location throughout a 24 hour period, changed from "brown" to "green" within that diel period. Since there was no known method of "controlling" the quality (brown

TABLE 9. Comparison of variables reflecting treatment effects on metabolism in the water column. Data are based on 3-hour incubation periods.

Variable	Composition of Solutions Used for Incubations				
	River Water	1:200	1:20	1:1 (Brown)	1:1 (Green)
Net Primary Community Productivity (mg O_2 l^{-1} day^{-1})	0.0	0.5*	1.3*	8.5*	8.5*
Diel Respiration (mg O_2 l^{-1} day^{-1})	0.0	0.0	1.4	3.6	12.6
Gross Primary Productivity	0.0	0.5*	2.0*	10.4*	15.3*

* Values were obtained on two effluents: "green" and "brown" (see text)

vs. green) of wastewater obtained from the same location in the holding ponds, experimental work was conducted on both green and brown wastewater, as available from the holding ponds.

No net community primary productivity or respiration was detected in the raw river water used as the experimental control (Table 9). These results were consistent with the light-dark bottle incubation results obtained from the other riffle sites (Flat Valley, Harper's Bridge, Huson, and Ninemile) during the synoptic study.

TABLE 10. Changes in dissolved oxygen concentrations of the 1:1 mixture of kraft mill wastes and river water during the water column metabolism experiment.

Time	Light Bottle (mg O_2 l^{-1})	Dark Bottle (mg O_2 l^{-1})	Effluent Quality
8:40-11:15	+0.6	-0.6	Brown
10:55-14:10	+1.0	-0.4	Brown
13:45-17:00	+1.7	-0.5	Brown
16:45-19:50	+5.9	-2.1	Green
19:35-22:45	-1.0	-1.4	Green
22:30- 2:05	-0.3	-0.4	Brown
1:40- 5:00	-0.4	-0.4	Brown
4:40- 7:35	-1.4	-1.4	Green

No diel respiration was detected for the 1:200 mixture of kraft mill wastewater and river water. Diel respiration of the 1:20 mixture was barely detectable. The respiration rate increased between the 1:20 mixture and the 1:1 mixture of kraft mill wastewater and river water, indicating that the respiration rate was dependent upon the wastewater concentration. The difference in respiration rates between the brown and green wastewaters for the 1:1

mixture of kraft mill wastewater (Table 9) indicated that wastewater quality was important to respiration rates. No difference in respiration was detected between green and brown wastewaters in the 1:20 dilution, however.

As the concentration of kraft mill wastewater increased, net community primary productivity increased (Table 9). The green effluent had a higher net community primary productivity rate than the brown wastewater (Table 10). Primary productivity was detected even in the 1:200 mixture of kraft mill wastewater and river water. This last result suggested that it might be possible for the kraft mill wastewater to produce organic matter by photosynthetic processes, even after the wastewater was discharged into the river. Since no water column primary productivity was detected at the riffle sites downstream of the kraft mill during the synoptic studies, this instream photosynthesis, if it occurred at all, probably was limited to the mixing zone.

When relating the results from the water column metabolism experiment to the results of the benthic metabolism experiment, the quality of the wastewaters must be considered. Only brown wastewater was used in the chamber experimental studies. Perhaps if green wastewater had been used during these studies, the addition of a 1:1 mixture of kraft mill wastewater and river water to the

metabolism chambers would have had different results. Comparisons of the hourly respiration rates between the benthic chamber experimental results and the water column experimental results (Table 11) indicated that respiration of the brown wastewater accounted for about 17% of the hourly respiration measured in the treated chambers. The hourly respiration rate for the green wastewater was 60% of the respiration in the treated chambers, indicating that respiration probably would have increased significantly if green wastewater was used in the chamber experiments. Since the green wastewater also had a higher primary productivity rate than the brown wastewater (Table 9), primary productivity rates in the chambers might have also increased. Hence, changes in the metabolic characteristics of the wastewater biota must be considered when assessing the impact of kraft mill effluents on stream ecosystems.

TABLE 11. Comparison of average hourly respiration rates among the benthic chamber experimental results and the water column experimental results.

Variable	Hourly Respiration (mg O_2 l^{-1} hr^{-1})
Benthic Chamber Experiment	
Control Chambers	0.69
Treated Chambers (1:1 Mixture of "Brown" Wastewater and River Water)	0.86
Water Column Experiment	
1:1 Mixture	
"Brown"	0.15
"Green"	0.52
1:20 Mixture	0.06
1:200 Mixture	0.00
River Water	0.00

V. CONCLUSION

Impact of the Kraft Mill on the Clark Fork River

Riffle community metabolism in the study area appeared to be influenced by the addition of nutrients from upstream sources. Elevated concentrations of inorganic phosphorus and nitrogen in the kraft mill effluent might have enhanced productivity, but this impact was apparently masked by high primary productivity caused by high nutrient concentrations of waters flowing into the kraft mill discharge area.

Although the impact of the kraft mill discharge program was masked by upstream sources, seasonal changes and longitudinal changes observed among the riffle sites during the synoptic studies provided additional information about potential impacts of the kraft mill discharge program. The effect of the kraft mill discharge program on riffle community metabolism probably changed seasonally. Cold temperatures during late autumn and winter limited community metabolism so that changes in water quality caused by the discharge program had a minimum impact on the riffle communities. As the stream temperatures increased, however, metabolism of the riffle communities became more

sensitive to water quality changes, indicating that the addition of kraft mill effluent would have a greater effect on the riffle communities during summer. The increased concentrations of TKN and NDOC in the river water downstream of the kraft mill during August indicated that the benthic community might have been fertilized by groundwater seepage of the kraft mill wastewaters. Hence, a discharge program that minimized the total input of kraft mill wastewaters, either by direct discharge or by groundwater seepage, during the summer would probably cause the least impact on the Clark Fork River.

Experimental studies indicated that a 50% concentration of "brown" kraft mill wastewater reduced net community primary productivity of a riffle community in the Clark Fork River. This decrease in net community primary productivity was probably due to light attenuation properties of the kraft mill wastewaters. Hence, an increased rate of direct discharge of the kraft mill wastewaters could possibly cause the riffle communities to become more heterotrophic by decreasing instream autotrophic production.

The water column metabolism studies revealed that the metabolic characteristics of the kraft mill wastewater could change drastically within short time periods. More studies were required to understand the dynamic nature of

this biological community.

Riffle Community Metabolism as a Tool for Environmental Impact Analysis

The results of this study indicate that riffle community metabolism can be used effectively to detect water quality degradation. Other researchers have also suggested that stream metabolism measurements can be used as water quality indicators (Odum 1956; Hornberger et al. 1977; Lewis and Gerking 1979). However, I suggest that the metabolism measurements are more valuable when analyzed in conjunction with other water quality data. Whereas most water quality indicators (e.g. total phosphorus, dissolved oxygen, total suspended solids) only consider material aspects of an environmental impact, riffle community metabolism complements the traditional water quality indicators by addressing the energy aspects of an environmental impact under the constraints of prevailing environmental conditions. Hence, when comparing changes in metabolic rates with corresponding changes in the traditional water quality indicators, insights are provided as to how an impact by a "pollution source" occurs in the environment rather than merely detecting the presence of an impacting substance.

Because so many environmental factors influence riffle

community metabolism, I suggest that the use of metabolism measurements as a general water quality indicator would be spurious. Instead, the results of my study suggest that riffle community metabolsm may be a useful tool for defining and studying the functional attributes of a particular stream or river ecosystem and for studying the effects of a "pollution source" on functional variables (e.g. primary productivity, respiration). Modellers and water quality managers may thereby obtain relevant information about the important factors influencing the temporal and spatial variations in stream processes, which will complement correlative, cause-effect evidence of wastewater impacts.

The use of riffle community metabolism for environmental impact assessment, however, could be much improved over its use in this study. Because riffle community metabolism is sensitive to environmental changes (e.g. light, nutrient concentrations and bioavailability, temperature), metabolism measurements should be recorded simultaneously (rather than sequentially, as in the present study) upstream and downstream from a suspected pollution source. To separate water column metabolism from benthic metabolism, light-dark bottle incubations, or metabolism measurements using a chamber containing only river water, should be run simultaneously with chambers containing

benthos. Since river conditions continually change, both benthic and water column metabolism should be determined seasonally, if not more frequently. Water samples for chemical analyses should be collected on the same day that metabolism data were recorded. Incorporating these changes into the riffle community metabolism measurements could reduce the variance of the metabolism values so that interactions among the various water quality variables could be discerned more easily.

In addition to these considerations, attention should also be directed at the basic assumptions of the metabolism measurements. For example, respiration was initially assumed to be constant throughout the diel period in this study, but this assumption was shown later to be false. In cases where large changes in community metabolism are being compared (e.g. seasonal variations, effects of gross pollution) the violation of this assumption did not seem important, but when more subtle changes in community metabolism occur (e.g. the longitudinal trends within a particular season) the violation of this assumption was much more important. The results of this study indicated that perhaps metabolic (energy) measures other than diel quantification of primary productivity and respiration may be more appropriate for assessing the impact of a point source effluent on a river ecosystem.

APPENDICES

APPENDIX A. The following tables contain metabolism data and substratum data collected from each chamber used in the synoptic studies.

APPENDIX A.1. Comparison among metabolism chambers of net community primary productivity (NCPP, mg O_2 m^{-2} day^{-1}), diel respiration (R_{24},mg O_2 m^{-2} day^{-1}), gross primary productivity (GPP,mg O_2 m^{-2} day^{-1}), chlorophyll a content (CHLA, mg / m^2), and ash-free dry weight (AFDW, gr / m^2) measured during the November synoptic studies.

Chamber	Date	NCPP	R_{24}	GPP	CHLA	AFDW
FV01	841118	1250	1310	1770	161.0	----
FV02	841118	1030	1560	1650	134.0	----
FV03	841118	1390	2000	2180	166.0	----
FV04	841118	920	1690	1590	250.0	----
HB01	841124	650	1730	1300	298.0	139.0
HB02	841124	1230	2310	2100	146.0	----
HB03	841124	1620	2070	2400	234.0	----
HB04	841124	1950	2700	2960	318.0	----
HS01	841127	1030	1740	1720	298.0	----
HS02	841127	1030	2110	1860	150.0	122.0
HS03	841127	960	2410	191	262.0	----
HS04	841127	880	2090	1710	342.0	----
NM01	841121	800	2880	1910	139.0	140.0
NM02	841121	980	2320	1870	159.0	----
NM03	841121	1250	1700	1910	190.0	----
NM04	841121	----	----	----	112.0	----

APPENDIX A.2. Comparison among metabolism chambers of net community primary productivity (NCPP, mg O_2 m^{-2} day^{-1}), diel respiration (R_{24}, mg O_2 m^{-2} day^{-1}), gross primary productivity (GPP, mg O_2 m^{-2} day^{-1}), chlorophyll a content (CHLA, mg / m^2), and ash-free dry weight (AFDW, gr / m^2) measured during the April synoptic studies.

Chamber	Date	NCPP	R_{24}	GPP	CHLA	AFDW
FV03	850429	2820	2350	4190	11.6	57.1
FV04	850429	3180	2220	4480	11.8	51.6
FV05	850429	4470	2980	6210	25.6	48.0
FV06	850429	3930	2560	5420	27.5	54.6
HB04	850410	2370	2110	3450	12.1	54.3
HB05	850410	2580	1930	3570	21.2	55.7
HB06	850410	1860	1870	2820	17.2	65.1
HB07	850410	1780	2010	2810	15.9	59.4
HS03	850412	2640	1110	3240	8.9	43.6
HS04	850412	2220	1080	2800	1.4	43.8
HS05	850412	1910	1010	2460	3.7	19.5
HS07	850412	2010	850	2470	6.9	19.6
NM03	850426	2230	1400	2990	13.5	40.9
NM04	850426	2790	1370	3530	8.5	60.6
NM05	850426	2990	1310	3700	13.4	52.9
NM06	850426	2360	1100	2960	8.5	68.9

APPENDIX A.3. Comparison among metabolism chambers of net community primary productivity (NCPP, mg O_2 m^{-2} day^{-1}), diel respiration (R_{24}, mg O_2 m^{-2} day^{-1}), gross primary productivity (GPP, mg O_2 m^{-2} day^{-1}), chlorophyll a content (CHLA, mg / m^2), and ash-free dry weight (AFDW, gr / m^2) measured during the August synoptic studies.

Chamber	Date	NCPP	R_{24}	GPP	CHLA	AFDW
FV02	850817	6970	4140	9340	148.0	48.0
FV12	850817	5700	3900	7930	LE	49.1
FV11	850817	6140	4240	8570	LE	73.0
FV04	850817	7740	4490	10310	144.0	63.4
HB05	850804	6480	3210	8390	120.0	21.8
HB10	850804	5940	3390	7950	112.0	31.3
HB04	850804	3970	3210	5870	60.8	101.3
HB02	850804	4080	4000	6450	115.0	47.2
HS02	850814	5400	2610	6920	LE	30.5
HS12	850814	6920	3370	8890	LE	70.3
HS08	850814	5320	2690	6890	51.3	30.7
HS04	850814	6920	3410	8910	59.0	47.4
NM12	850829	3690	3060	5380	67.2	57.8
NM02	850829	3360	3280	5170	57.2	58.7
NM04	850829	4080	3370	5940	87.6	55.6
NM05	850829	3730	2810	5280	61.5	42.6

APPENDIX B. The following tables contain water chemistry data collected during the synoptic studies.

APPENDIX B.1. Water chemistry data collected from riffle sites in the Clark Fork River on November 30, 1984. Values for duplicate samples are presented.

Parameter	Flat Valley	Harper's Bridge	Huson	Nine-mile
TURB (NTU)	0.65 0.57	0.62 0.67	0.83 0.82	0.75 0.79
HARD (mg $CaCO_3$ / 1)	126 125	131 132	132 139	130 135
CA (mg / 1)	35.2 35.1	36.8 37.1	36.8 39.2	36.5 38.0
MG (mg / 1)	9.2 9.0	9.5 9.6	9.7 10.1	9.5 9.7
SRP (ug / 1)	1.9 1.9	1.6 1.6	1.7 1.7	1.2 1.2
TP (ug / 1)	3.7 3.4	3.3 3.4	3.6 3.6	2.9 3.3
NO_3-N (ug / 1)	50 50	50 50	50 50	40 50
NH_3-N (ug / 1)	13 8	12 12	9 < 5	9 < 5
TKN (ug / 1)	143 144	129 148	146 127	147 139
SIO_2 (mg / 1)	14.2 12.9	12.9 13.2	13.4 13.5	13.2 13.4
CL (mg / 1)	2.2 2.2	2.3 2.4	3.3 3.3	3.2 3.2
SO_4-S (mg / 1)	8.9 8.9	9.7 9.7	10.2 10.3	10.2 10.4
NA (mg / 1)	7.2 7.3	7.3 7.3	10.0 10.7	9.8 9.9
ALK (mg $CaCO_3$ / 1)	111 110	115 113	118 117	117 117
NDOC (mg / 1)	0.4 0.3	0.3 0.3	0.4 0.4	0.4 0.5
DOC (mg / 1)	1.1 1.0	1.4 1.5	1.6 1.2	1.3 1.6

APPENDIX B.2. Water chemistry data collected from riffle sites in the Clark Fork River on August 5, 1985. Values for duplicate samples are presented.

Parameter	Flat Valley	Harper's Bridge	Huson	Nine-mile
TURB (NTU)	1.9 2.0	2.3 2.3	3.3 2.8	3.4 3.7
HARD (mg $CaCO_3$ / l)	120 123	123 126	124 126	128 129
CA (mg / l)	33.1 33.9	33.9 34.4	33.9 34.4	34.8 35.3
MG (mg / l)	9.1 9.3	9.4 9.7	9.5 9.7	9.9 9.9
SRP (ug / l)	1.6 1.6	1.3 1.3	1.0 1.0	0.8 0.7
TP (ug / l)	4.2 4.2	4.0 4.0	4.1 4.1	4.3 4.6
NO_3-N (ug / l)	60 60	50 50	20 10	<10 <10
NH_3-N (ug / l)	11 8	8 12	10 8	6 5
TKN (ug / l)	210 236	206 219	244 259	303 282
SIO_2 (mg^2 / l)	14.8 14.2	14.0 14.4	13.8 13.8	13.2 13.2
CL (mg / l)	2.1 2.0	2.3 2.2	2.7 2.9	2.7 2.8
SO_4-S (mg / l)	5.6 5.5	5.6 5.7	6.2 6.3	6.2 6.2
NA (mg / l)	6.7 6.6	6.6 6.6	8.4 8.6	8.3 8.4
ALK (mg $CaCO_3$ / l)	119 123	124 121	127 129	130 129
NDOC (mg / l)	0.7 0.7	0.8 0.8	1.1 1.0	1.2 1.1
DOC (mg / l)	2.3 2.3	2.2 2.2	2.6 2.1	2.3 2.2

APPENDIX C. The following tables contain field data measured concomitant to the metabolism measurements.

APPENDIX C.1. Comparison of mean stream temperatures (°C) measured in the field during the synoptic studies. Ranges are given in parentheses.

Date	Flat Valley	Harper's Bridge	Huson	Nine-mile
November 1984	2.6 (2.0-3.7)	2.5 (1.6-3.4)	1.6 (1.0-2.5)	3.2 (2.5-3.9)
April 1985	12.3 (11.1-13.5)	10.9 (10.1-12.4)	10.0 (8.3-11.5)	8.3 (7.4-10.3)
August 1985	16.2 (13.9-18.4)	18.0 (16.1-19.8)	16.0 (14.3-17.7)	18.8 (15.8-22.2)

APPENDIX C.2. Comparison of mean stream velocities (cm sec^{-1}) measured in the field during the synoptic studies. Ranges are given in parentheses.

Date	Flat Valley	Harper's Bridge	Huson	Nine-mile
November 1984	114 (104-125)	87 (67-97)	97 (59-131)	62 (26-101)
April 1985	50 (32-68)	50 (35-67)	60 (41-74)	14* (8-20)
August 1985	34 (13-64)	12* (5-21)	36 (23-48)	33 (24-42)

experienced problems with Weathermeasure current meter

APPENDIX C.3. Comparison of mean specific conductance (umhos / cm^2) measured in the field during the synoptic studies. Conductivity values have been standardized to 25°C. Ranges are given in parentheses.

Date	Flat Valley	Harper's Bridge	Huson	Nine-mile
November 1984	234 (226-240)	262 (254-269)	261 (255-270)	256 (252-260)
April 1985	164 (154-170)	214 (199-222)	179 (144-189)	196 (186-200)
August 1985	239 (232-248)	248 (222-257)	247 (231-250)	271 (264-278)

APPENDIX D. Comparison among metabolism chambers of net community primary productivity (NCPP, mg O_2 m^{-2} day^{-1}), diel respiration (R_{24}, mg O_2 m^{-2} day^{-1}), gross primary productivity (GPP, mg O_2 m^{-2} day^{-1}), chlorophyll a content (CHLA, mg / m^2), and ash-free dry weight (AFDW, gr / m^2) measured during the in situ chamber experiment using a treatment of a 1:1 mixture of kraft mill wastewater and Clark Fork River water. Experiment was conducted on September 25, 1985.

Chamber	Treat-ment	NCPP	R_{24}	GPP	CHLA	AFDW
PC04	River	3950	2170	4990	213.0	32.2
PC08	River	4850	2790	6190	239.0	53.2
PC09	River	4070	2480	5260	208.0	52.6
PC02	1:1	580	3200	2110	225.0	44.0
PC05	1:1	1050	3520	2740	230.0	45.8
PC10	1:1	700	2770	2030	192.0	37.8

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