IMPACT OF SEDIMENTATION ON THE AQUATIC MACROINVERTEBRATES OF THE NORTH FORK OF THE LITTLE SNAKE RIVER

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Introduction

The North Fork of the Little Snake River is a steep, rough, regulated headwater stream located in the Colorado River basin in southwest and south-central Wyoming. A water development project, the Cheyenne Stage II Diversion Project began in 1983 in an effort to collect 23,000 acre feet of water annually from 30 tributaries of the North Fork of the Little Snake River for the city of Cheyenne, Wyoming. The North Fork and its tributaries support the largest known, essentially pure population of the Colorado River cutthroat trout, (*Salmo clarki pleuriticus* Cope) (Binns, 1977). This species is classified as "Endangered" (Utah), "Threatened" (Colorado) and "Sensitive" (Wyoming), and has been listed in the "Special Concern"category of the American Fisheries Society.

Earlier work on the effects of Stage I of the Cheyenne Diversion Project demonstrated that the Colorado River cutthroat standing crop had been reduced to 37% of its former levels (Jespersen 1981). While the factors resulting in this impact were not independently analyzed, Jespersen (1981) recommended that monitoring the impact of construction of roads, pipelines, and diversion structures should emphasize the potential damage caused by increased sediment on fish and macroinvertebrate populations. This recommendation appears to be well-founded based on the work by Brusven and Prather (1974), Leudtke et al. (1976), and others which has demonstrated that aquatic insects are sensitive and reliable indicators of sedimentary pollution and stream quality.

During the late summer of 1984, intensive rainfall in the construction area resulted in the deposition of a broad size range of sediments in a section of stream where flushing flow recommendations (removal of sediments by high discharge) had been made (Wesche et al. 1985). The introduction of this sediment into the North Fork presented an excellent opportunity to study the impacts of sedimentation and flushing flows on the aquatic macroinvertebrates in the North Fork of the Little Snake River as recommended by Jespersen (1981).

Beginning in July of 1985 and ending in September of 1987 collections of the aquatic macroinvertebrate community were taken to assess the impact of the addition of this sediment on the aquatic macroinvertebrate community. To best ascertain the degree of impact on the North Fork of the Little Snake River the objectives of the study were to: 1) describe the changes in selected biological indices (diversity, evenness, richness and abundance) between impacted and non-impacted sites; 2) determine the preferences of the aquatic macroinvertebrate taxa for selected substrate sizes; 3) determine the preferences of the aquatic macroinvertebrate taxa for mean water velocity; 4) determine the preference of the aquatic macroinvertebrate taxa for water depth.

Literature Review

Aquatic macroinvertebrates are a primary food source of most freshwater fish. Healy (1984) states that aquatic insects contribute substantially to world fishery production by providing the forage base for many freshwater fish populations. Elliot (1973) in studying the food of brown and rainbow trout (*Salmo trutta* and *Salmo gairdneri*) found that the aquatic insects (especially the orders Ephemeroptera, Diptera, Coleoptera and Plecoptera) were the dominant food items. Foster (1978) found that the preferred food for cutthroat trout (*Salmo clarki* Richardson) in the Snake River of Wyoming was also the aquatic insects, especially the orders Trichoptera, Ephemeroptera, Diptera and Plecoptera. Thus, if the aquatic insect community is disrupted the fish population will eventually become affected. Therefore, to maintain stream fisheries it is important to understand and protect their primary food source; aquatic insects.

Many streams are now being regulated to store or transport water. If, because of regulation, there is a reduction of the stream sediment transport competency, the net effect may an accumulation of sediment in the system. It is then of interest to not only the aquatic biologist but to fishery managers as well, if this addition of sediment will affect the aquatic macroinvertebrates and eventually the fish population.

Before the effects of sedimentation on the aquatic insects can be fully understood, it is important to understand the aquatic insect community prior to sedimentation. Three important physical factors influence the composition of benthic organisms: substrate, water velocity and water depth (Kimble and Wesche 1975). A general overview of the importance of each will be presented so that post-depositional changes in the aquatic macroinvertebrate community (qualitatively and quantitatively) can be more fully understood.

Aquatic Insect Substrate Preference

The substrate is the most important factor that influences aquatic insects' life histories. It determines to a large extent the microenvironmental conditions under which the insects live, and thus it profoundly affects their growth and survival (Minshall 1984). Each species, in accordance with physical adaptations, selects a different substrate and velocity in which to live (Hynes 1970).

Several investigators have shown that benthic insects have a preference for substrates composed of large particles, as evidenced by an increase in numbers over the sequence of increasing particle sizes from sand through large rocks. Pennack and Van Gerpen (1947) investigated the bottom faunal production of the North St. Vrain Creek in northern Colorado and compared it with the physical nature of the substrate. The four types of substrate they examined were bedrock (boulder surfaces), rubble, gravel and sand. They found evidence to support a pattern in which invertebrate abundance and biomass increases with increasing substrate size. Pennack and Van Gerpen (1947) found that Ephemeroptera are adapted to a wide range of substrates but have a preference for rubble. Plecoptera have a preference for rubble and Trichoptera have a preference for bedrock, but both orders were found in low numbers. Diptera showed a preference for bedrock, but it should be noted that the majority of Diptera that utilized bedrock were Simulium which used this substrate for attachment. They felt that the presence of Simulium in sand was fortuitous, since this genus has no means of attachment on shifting substrates.

Ward (1975) investigated the same sight as Pennack and Van Gerpen (1947). The substrate he examined was also bedrock, rubble, gravel and sand. Ward (1975) also found a progressive increase in total numbers and biomass from sand through rubble. Both Pennack and Van Gerpen (1947) and Ward (1975) found that numbers and biomass decreased when substrate size increased to bedrock. This finding, coupled with the low numbers found in less diverse substrates, suggests that the substrate selection by macroinvertebrates may be a function of (or at least complicated by) changes in substrate heterogeneity (Minshall 1984).

Kimble and Wesche (1977) studied the relationships between selected physical parameters and benthic community structure in Hog Park Creek, Wyoming. The substrate types they sampled were silt, sand and fine gravel, coarse gravel and rubble. They found that in silt substrate Diptera (primarily Chironomidae) accounted for the largest proportion of organisms; Trichoptera and Plecoptera were missing entirely, and Ephemeroptera and Coleoptera were present in very limited numbers. The fauna in sand and fine gravel were more varied than silt, with Ephemeroptera and Diptera making up the largest proportion of organisms. The number of Diptera varied between collection dates, and Trichoptera and Plecoptera abundance was relatively limited. The benthic fauna in coarse gravel was composed primarily of Ephemeroptera and Diptera. Trichoptera, Plecoptera and Coleoptera were poorly represented. In large rubble, Trichoptera, Ephemeroptera, and Coleoptera made up the most substantial portion of the fauna; Diptera varied while Plecoptera were low in numbers. These findings substantiated those of Pennack and Van Gerben (1947) and Ward (1975) in finding that the highest mean number and mean biomass of macroinvertebrates were found in rubble.

Rabeni and Minshall (1977), found in Mink Creek, a small stream located at the northern boundary of the Caribou National Forest, Idaho (elevation 1700 m) that the least colonization for most taxa of aquatic macroinvertebrates occurred on the smallest substrate sizes studied (0.5-0.7 cm diam.). Colonization was greater on the 1.0-2.0 cm size, reached a maximum on the 2.5-3.5 cm size, and was markedly reduced on the largest substrate size (4.5-7.0 cm). They attributed this difference to the ability of the smaller substrate to collect small detritus particles which are more readily utilized by the organisms.

Brusven and Prather (1974) conducted studies in the laboratory and field to determine the substrate relationships of five species of stream insects representing the orders Ephemeroptera, Plecoptera, Trichoptera and Diptera. Various combinations of pebble and sand were tested in the presence and absence of cobble. They found that substrate with cobble was preferred over substrate without cobble. The preference for cobble generally increased as the sediments around the cobble decreased in size. Substrate with unembedded cobble were slightly preferred over half-embedded cobble; completely embedded cobble in fine sand proved unacceptable to most species.

Lenat et al. (1981) in studying two upper Piedmont creeks in North Carolina interpreted patterns in species diversity by using a habitat reduction theory. This theory assumes that most benthic macroinvertebrates are confined to areas with rocky substrate. Partially embedded rubble substrate may act as an 'island' of productive habitat in the midst of a 'sea' of non-productive sand. Further additions of sediment reduces the amount of available habitat (i.e., rocky substrate), but does not affect measures of community structure (including taxa richness). An effect of sediment on the substrate is the congestion of, and therefore the loss of, interstitial space. Sediments falling onto eroding substrate fill up the interstices between the stones, thus depriving the cryptic animals of their hiding places (Hynes 1960).

<u>Aquatic Insect Water Velocity and Depth Preference</u>

The volume of flow, the relationship of velocity to depth, and the periodicity in timing of high and low flow, have important direct impacts on macroinvertebrates and indirect effects on other stream parameters. These indirect parameters include particle size, composition, and relative stability of the substratum, the amount of channel that is under water, food availability, and several other factors that occur on a macroscale level (Leopold et al. 1964).

Several studies have demonstrated the importance of water current on the distribution of benthic insects. Current velocity affects an insect's ability to gather food (Wallace and Merritt 1980), meet its respiratory requirements (Jaag and Ambuhl 1964), avoid competition and predation (Wiley and Kohler 1984), leave unfavorable environmental conditions (Corkum et al. 1977), and colonize favorable microhabitats (Minshall et al. 1983). Even within families and genera of insects, different species may have different current preferences (Hynes 1970). It is, therefore, almost impossible from field studies to define the current requirements of individual species in exact numerical terms. Nevertheless, in a given stream it is possible to show that as the current (e.g. measured on the surface, in mid-water, or as near as possible to the substrate) changes at a given rate of discharge, the fauna also changes (Hynes 1970).

The velocity of flow at any point in a channel is nearly inversely proportional to the logarithm of the depth. As a consequence of this relationship the mean speed of flow occurs at about 0.6 of the depth Also the mean of the speeds of flow at 0.2 of the total depth and 0.8 of that depth is the mean speed of the flow of water (Hynes 1970). It is these hydraulic factors (velocity and depth) that to a large degree characterize the substrate composition. In small mountain streams, faster water areas are normally characterized by a larger substrate and shallower water depths. For slower reaches of lesser gradient, the substrate size is diminished due to the deposition of smaller sediment particles and water depths are usually somewhat greater (Kimble and Wesche 1977).

Kimble and Wesche (1977) working on Hog Park Creek, Wyoming investigated the mean velocity and depth preference for Plecoptera, Trichoptera and Ephemeroptera. The greatest mean number and mean biomass were found at mean velocities of 0.152 m/s or higher. Mean depth data indicated a preference by these orders for depths of less than 0.305 m.

Gore (1978) took a total of 225 benthic samples at various riffles along the Tounge River in Montana during three separate weekly intervals in 1975. The stream velocities ranged from 0 to 129.4 cm/s; depths ranged from 5 to 45 cm. Gore (1978) found the conditions supporting the highest faunal diversity were 75 to 125 cm/s current velocity at 20 to 40 cm depth. The optimum condition appeared to be 76 cm/s at a depth of 28 cm over medium cobble substrates (i.e., rubble area of riffles).

Sediment and Stream Flora

One fundamental feature of plant communities is patchiness; they do not occur everywhere in a stream. There may be large bare areas in a stream caused by scour (removal of readily erodible material). If there is a large amount of sediment in the stream, the potential for scour is greatly increased.

River plants (macrophytes) alter their environment by forming soil. Their decay provides soil building material and they trap silt and build up mudbanks. This piling of silt may be unstable and the whole edifice may be periodically swept away by floods, carrying the original plant with it (Hynes 1960).

Although macrophytes are an important part of the bottom fauna, in that they provide some food for aquatic insects and are a substrate in themselves, the algae are the most important plants (Hynes 1960). Not only are they a primary source of food but are also major oxygenators of water. Hynes (1960) also states that the algal community is essentially sessile, it grows only on solid bottoms. Algae, like macrophytes, are also subject to scour. Silt not only smothers algae but also greatly lowers the light intensity and reduces algal growth (Hynes 1960).

Algae and macrophytes are an important food source for most aquatic insects. Merritt and Cummins (1984) listed the trophic levels for the aquatic insects. The vast majority are shredders, collectors, scrapers, or macrophyte piercers. Therefore, if the plant community is affected by the addition of sediments to the stream, it follows that the aquatic macroinvertebrates would be impacted.

Indeed, Nuttall and Bielby (1973) found that in rivers which were polluted by china-clay wastes, there was a low incidence of both plants and macroinvertebrates. However, they associated this low incidence of plants and insects with the deposition of fine inert solids derived from the clay extraction process, rather than turbidity or abrasion caused by particles in suspension. Egglishaw (1964) found a direct correlation between the numbers of invertebrates present in a stream riffle and the amount of plant detritus. The deposition of small sediments on a stream bed covers the available detritus and removes the aquatic insects' food source. Also, large substrates, in particular rubble, will tend to trap detritus more efficiently than will small substrates, such as sand.

The Effect of Short Term Depositions on Aquatic Insects

It is clear that the addition of sediment into a stream may have a negative impact on the aquatic community. However, in streams that are subject to periodic removal of the sediment either by natural runoff or mitigative practices (i.e., flushing flows) the impact may be reduced.

Barton (1977), in studying the effects of highway construction in a small mountain stream in southern Ontario concluded that severe and persistent sedimentation is required to induce distinct faunal changes. He found no change in numbers of riffle macroinvertebrates during or after construction. He felt that the invertebrates present during constructions activities may have remained in sheltered areas avoiding sedimentation effects or that organisms which may have been removed during construction were quickly replaced by drift.

However, short term effects may be serious. Tsui et al. (1979), when studying the effects of stream-crossing by a pipeline on the aquatic insects of a small mountain stream, concluded that sedimentation was the single most significant biological impact associated with the construction activity. From their results, it appeared that the sediment from the construction had a short-term effect on the water quality of the stream. A general reduction in the Shannon Weaver index of species diversity in benthic communities downstream from the crossing was observed, but the reduction was subtle and statistically insignificant. Tsui et al. (1979) suggested that based on the response of benthic communities observed in their study, the construction of the pipeline had a detrimental impact on the water quality and biota of the stream. However, the nature of this impact was both short-term and non-residual. They found that among Ephemeroptera, potential indicator species (i.e., those showing a strong negative response to sedimentation) included Baetis sp., Cinygmula sp., Epeorus (Ironopsis) sp., and Rithrogena sp.. Most of these species possess large gill surface areas which apparently make them susceptible to high silt loadings. Plecoptera species showing a negative response to silt included Alloperla sp., Eucapnosis sp., and Nemoura (Zapada) sp.. Among the Trichoptera, Ryacophila sp. appeared to be most sensitive to sedimentation. Data for the mayflies and stoneflies indicated a definite recovery trend; Ryacophila sp. showed a markedly slower recovery rate.

Lenat et al. (1981) studied the effects of sediment inputs from road construction on two upper Piedmont streams. They found that under high flow conditions, the benthic fauna occurred mainly on rocky substrates. As sediment was added to the stream, the area of available rock habitat decreased, with a corresponding decrease in density of benthic fauna. During high flow conditions, a stable sand community developed which differed qualitatively from the community with rocky substrates. The stable sand community was comprised of small grazing organisms capable of rapid colonization and reproduction. The average density of this community exceeded the density of benthic organisms in control areas.

Cline et al. (1982) examined the immediate and residual effects of localized highway construction activities on the aquatic macroinvertebrates on Joe Wright Creek, a high mountain stream in Colorado. They found that contrary to their expectations, effects to the aquatic insects were minimal. Where discernable changes occurred, recovery was rapid, despite 10-to 100-fold elevations in suspended solids. They argued that, "the relatively high inertia (ability to resist disturbance) and resilience (ability to recover from disturbance) of the lotic insect community was attributed to the following: (1) the rapid and persistent return of suspended solids to background levels following cessation of construction activities; (2) the absence of sedimentation during spring runoff when highest concentrations of suspended solids from construction occurred; (3) the steep gradient and virtual absence of pools in the study segment, which allowed the system to be flushed; (4) the presence of unimpacted upstream reaches; (5) the relatively short duration and localized nature of each construction disturbance."

Cline et al. (1982) found that generally Ephemeroptera, Plecoptera, Trichoptera, and Diptera (especially Chironomidae, Simuliidae, and Blephariceridae) contributed the majority of total macroinvertebrate density and biomass. However, at impacted sites, Ephemeroptera and Diptera accounted for a greater proportion and Plecoptera a smaller proportion of total density than at their corresponding reference locations. These differences were slightly greater in slow water than in fast water areas. Ephemeroptera contributed a larger proportion of total biomass at impacted sites, while other major groups did not exhibit consistent trends.

Mountain stream insects have evolved to withstand periods of high runoff with associated high levels of suspended solids (Ward 1984). If the major increases in suspended sediment due to construction activities occur immediately preceding or during spring runoff, it is perhaps not surprising to find only minimal effects on aquatic insects.

Conclusion

The effects of sediment on aquatic insects are varied. It has been shown by several investigators that aquatic insects show a preference for larger substrate sizes. Sedimentation embeds preferred substrate and therefore limits the usable area for insects. It also limits the amount of interstitial space which is utilized by some insects. Fine sedimentation affects the floral community by 1) reducing stable environment for attachment, 2) scouring, and 3) smothering by deposition. Sediment may also cover detritus and effectively remove an important food source for many aquatic insects. Sediment is readily transported during periods of increased flows. Not only does this cause a very unstable environment for the aquatic insects to inhabit but also increases the chances for scour and deposition (smothering) on both the insect and plant communities.

From the evidence provided, it is apparent that sediment has a highly negative impact on the aquatic macroinvertebrates. It not only robs them of preferred substrate size, it also damages them physically through scour and deposition and depletes their food source. If there is deposition over a large area of channel reach, not only should fisheries managers be concerned about the direct negative effects this deposition has on the fish, but also they should be aware of the secondary effects that are caused by the loss of the aquatic insects. However, if the deposition of sediment into a stream is not severe or persistent the aquatic macroinvertebrates may show a rapid recovery.

Removal of Sediments by Flushing Flows

This literature review illustrates some of the potential biotic impacts caused by the addition of sediment into a lotic system. The regulation of stream flow may cause an alternation in the natural regime of a system by affecting the channel morphology and conveyance capacity (Wesche et al. 1985). If there is a reduction of the stream sediment transport competency, the net effect may be an accumulation of sediment in the system, rather than the periodic removal (flushing) which occurs naturally during high discharge periods (spring runoff), for snowmelt dominated streams. Therefore, much research and developmental effort has been directed toward the determination of suitable instream flows to maintain fisheries habitat in regulated streams (Stalnaker and Arnette 1976, Wesche and Rechard 1980). There are several facets of the instream flow problem which have not been adequately investigated, one being the recommendation of flushing to simulate the peak runoff hydrograph characteristics of most unregulated streams (Reiser et al. 1985).

Reiser et al. (1985) reviewed 15 methodologies for flushing flow requirements in regulated streams. From these, they determined some basic considerations for evaluating flushing flows. Fundamental in the evaluation process is the initial determination of the need for a flushing flow. The determination should be based on:

1) The physical location of the water development project; is the project above or below the major sediment sources in the drainage?

2) The topography and geology of the project; is the drainage steep and open (susceptible to erosion) or flat and stable?

3) The susceptibility of the drainage to catastrophic events.

4) The sensitivity of important fish species and their life history stages to sediment depositional effects.

5) The extent of human-induced activities within the drainage which may increase sediment recruitment.

If a flushing flow is required, the timing, magnitude, and duration of the flush should be determined. Historically, important considerations for these included the species of the fish in the system and their life history requirements. To date, taxa and life histories of the aquatic macroinvertebrates have not been considered. Also important are the historical runoff period, flow availability, and water temperature.

The determination of the magnitude of the flows is the most important, yet most difficult and least understood aspect of flushing flows (Reiser et al. 1985). In general, the safest approach may be to use the highest discharge on record during the planning process. In this way, if refinements are later warranted to reduce anticipated biological impacts or minimize economic losses, they would likely result in a reduction rather than an increase in flows recommended (Reiser et al. 1985).

Methodology

Description of Study Area

The North Fork of the Little Snake River is a steep, rough, regulated headwater stream originating at an elevation of 10,400 feet (3050 meters) in the Sierra Madre Mountains of the Medicine Bow National Forest (Figure 1). Located on the west side of the Continental Divide, the North Fork flows southwesterly through large stands of subalpine fir (*Abies lasiocarpa*), Engelmann Spruce (*Picea engelmannii*), quaking aspen (*Populus tremuloides*) and lodgepole pine (*Pinus contorta*) as well as mountain meadows to the confluence of the Little Snake River approximately 20 Km downstream.

Site Location and Description

The study sites consisted of two control sites above and seven potentially impacted sites below the uppermost Cheyenne Stage I diversion structure (North Fork Diversion Structure). The sites were chosen to: (1) reflect a representative distribution of substrate type and flow regime; and (2) include areas that could be potentially impacted by construction activities (above and below road and bridge construction and confluences of regulated perennial tributaries). A tabulation of pertinent features of these collection sites is given in Figure 2 and Table 1.

At each site, six representative samples were taken using a .505 mm mesh Surber sampler each month from June to September, over a three year period beginning in 1985 for a total of 480 collections. The sampler enclosed an area of $0.1 m^2$. Collection

Table 1. Description of Study Area

Site	Dominant Substrate	Stream Width	Gradient
1	Rubble	11.0 feet	> 3.0%
2	Gravel	20.0 feet	1.0-3.0%
3	Sand	10.0 feet	0.1-1.2%
4	Rubble-Gravel	15.0 feet	1.0-3.0%
5	Bedrock-Rubble	21.0 feet	> 3.0%
6	Embedded Bedrock-Rubble 1985 to Bedrock-Rubble and Gravel 1987	22.0 feet	> 3.0%
7	Gravel-Rubble	22.0 feet	> 3.0%
8	Gravel-Rubble	19.0 feet	1.0-3.0%
9	Rubble-Gravel	19.0 feet	> 3.0%

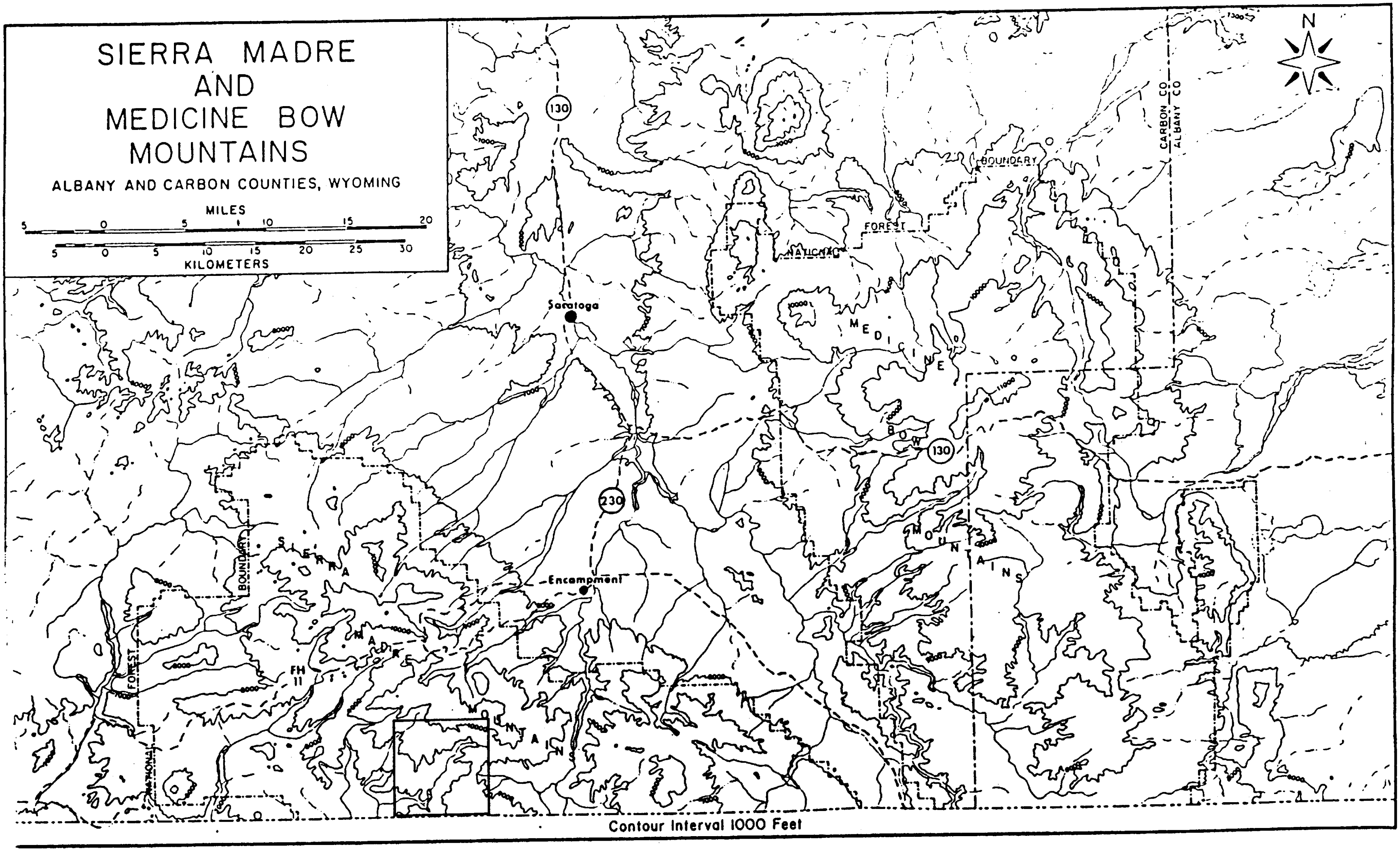

Figure 1. Physiographic setting of the Sierra Madre and Medicine Bow Mountains.

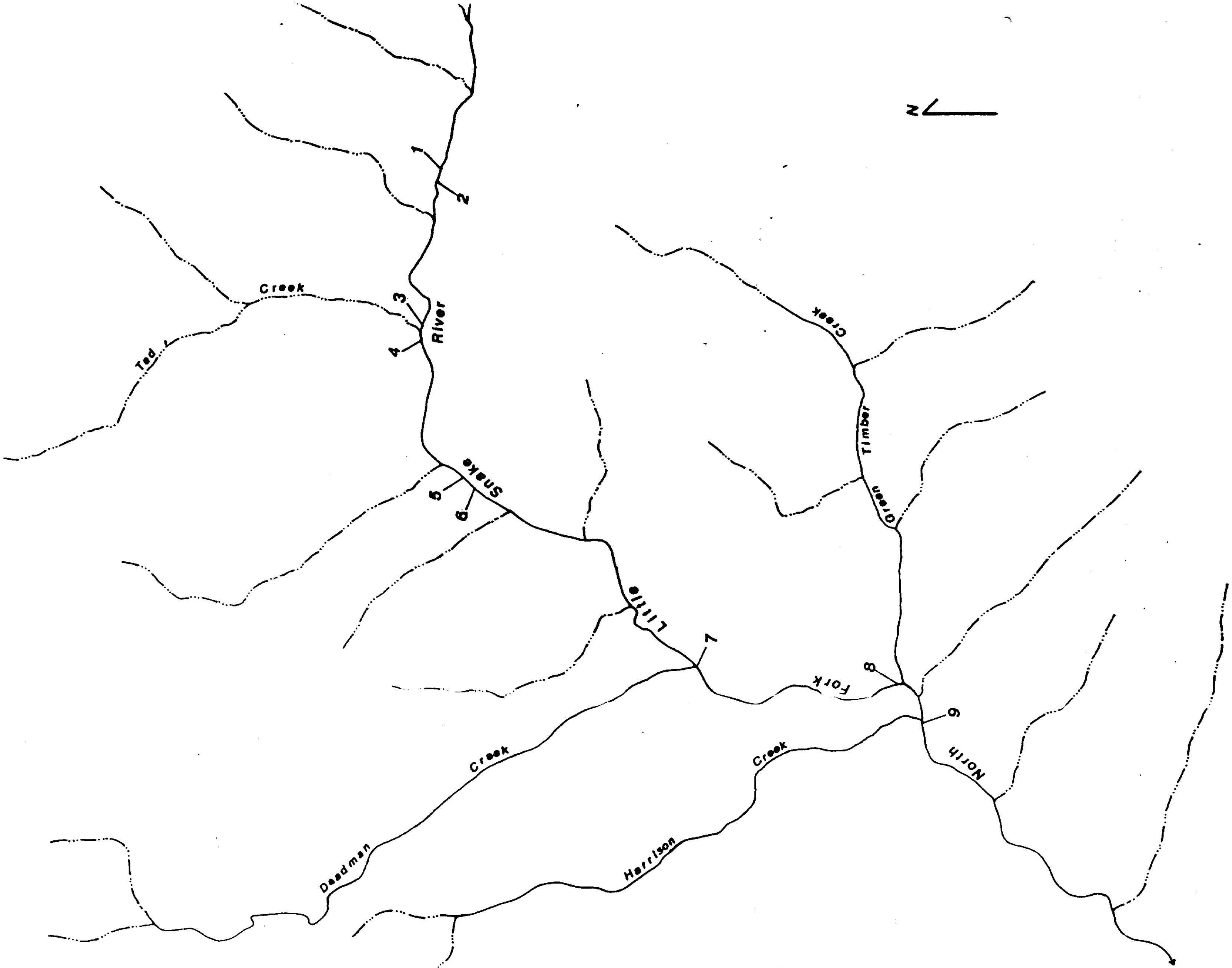

Figure 2. Site locations on the North Fork of the Little Snake River

dates for each site are listed in Table 2. Because of beaver impoundment of the stream, site number 3 was eliminated in September 1987. Samples were collected working from the bottom of the sample site upstream in order not to disturb the benthos and induce catastrophic drift. Because of the limitations of a Surber sampler, samples had to be taken where the current was neither too swift (> 2.5 ft/s) or the depth to great (>30.48 cm) to prevent backwash. The larger rocks and rubble were washed off in front of the net using the current to sweep the aquatic insects into the net. All larger rocks and rubble were retained for later measurement. Smaller gravels, sand, and silt were stirred for 10-15 sec. washing any remaining insects into the net. All larger rocks were then measured along their longest dimension. The mean rock size for the individual samples was determined by discarding the largest and smallest measured rock and taking an average of the remaining rocks. Substrate size was classified as to whether the sample was composed mainly of sand .83 to 4.71 mm, gravel 4.81 to 76.0 mm, rubble (cobble) 76.1 to 304.0 mm, or boulder (bedrock) 305.0 mm or greater (Platts et al. 1983). In June, July and September of 1987, each family that comprised at least 5% of the community associated with each substrate was classified as to substrate preference. Since there was not an equal number of samples taken for each substrate size, the number of organisms for each substrate was adjusted accordingly. Substrate preferences were assessed by a chi-square analysis. Preferences were considered significant at $p<0.05$.

During the July and September collecting period for 1987,

Table 2. Aquatic Macroinvertebrate Collection Dates (month-day)

Site	Year 1985	1986	1987
1	7-27	7-26	6-15
	8-24	8-14	7-22
	9-15	9-11	9-13
2	7-27	7-26	6-15
	8-24	8-14	7-22
	9-15	9-11	9-13
3	7-27	7-26	6-16
	8-25	8-14	7-22
	9-15	9-11	
4	7-28	7-26	6-16
	8-25	8-14	7-22
	9-15	9-11	9-12
5	7-28	7-26	6-16
	8-25	8-14	7-23
	9-14	9-11	9-12
6	7-28	7-26	6-16
	8-25	8-14	7-23
	9-14	9-11	9-12
7	8-2	7-27	6-16
	8-25	8-14	7-23
	9-15	9-11	9-12
8	8-2	7-27	6-17
	8-24	8-14	7-23
	9-14	9-11	9-12
9	8-2	7-27	6-17
	8-24	8-14	7-23
	9-14	9-11	9-12

water depth and velocity were recorded for each sample at each site using a Marsh-Mc Birney Model 201 Current meter attach to a depth rod. Water velocity was recorded at 0.6 the water height. A total of 102 water depth and velocity samples were taken. Water depth and velocity preferences were calculated for the orders Ephemeroptera, Plecoptera, Trichoptera, Diptera, and Coleoptera for the months of July and September.

Hydrographs and sediment deposition data (quality and quantity) for the duration of the study at sites 2 and 6 were provided by the Wyoming Water Research Center (Laramie Wyoming).

Aquatic Macroinvertebrate Analysis

Benthic organisms collected in the field were preserved in 70% ethanol in labelled polyproylene containers. In the laboratory the organisms were picked from the debris under a binocular dissecting scope. After all the samples were picked, they were then identified to the most specific taxonomic group possible utilizing the most recent keys (Table 3).

Total number of individuals and taxa (family) were calculated. The Shannon (base 10) index of diversity, Shannon index of Evenness, total number of taxa, and total number of individuals were computed using the Ecological Measures software (Kotila 1986).

Flushing Flow Recommendations

Wesch et al. (1977) made recommendations for flushing flows for the North Fork of the Little Snake River and six of its tributaries. These recommendations were made because of the potential for additional sedimentation which might occur during

Table 3. List of Taxonomic Keys

Edmunds, G. F., Jr., S. L. Jensen and L. Berner. 1976. The mayflies of North and Central America. University of Minnesota Press, Minneapolis. 330pp.

Givens, R. D. and S. D. Smith. 1980. A synopsis of the western Arctopsychinae (Trichoptera: Hydropsychidae). Melanderia. vol. 35 24pp.

Jensen, S. L. 1966. The Mayflies of Idaho (Ephemeroptera). Master's Thesis. University of Utah, Salt Lake, Utah.

Lehmkuhl, D. M. 1979. How to know the aquatic insects. Wm. C. Brown, Dubuque, Iowa. 168pp.

Merritt, R. W. and K. W. Cummins (eds). 1984. An introduction to the aquatic insects of North America, Second Edition. Kendall/Hunt, Dubuque, Iowa. 772pp.

Pennak, R. W. 1978. Fresh-water invertebrates of the United States. Wiley, New York. 803pp.

Smith, S. D. 1968. The Rhyacophila of the Salmon river drainage of Idaho with special reference to larvae. Annals of the Entomological Society of America 61:655-674

Ward, J. V. 1985. An illustrated guide to the mountain stream insects of Colorado. Colorado State University, Fort Collins, Colorado.

Wiggins, G.B. 1977. Larvae of the North American caddisfly genera (Trichoptera). University of Toronto Press, Toronto. 401pp.

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construction of the Cheyenne Stage II Water Development Project and the presence of the endangered Colorado Cutthroat trout (Salmo clarki pleuriticus Cope) which inhabits the streams to be diverted. These recommendations were based on McLaughlin (1977), who recommended bankfull flow as a maximum flushing discharge. Generally, such a flow is characterized as the "channel forming" flow. It was anticipated that bankfull flow would maintain the integrity of the North Fork and its tributaries with regard to such morphological characteristics as channel width, depth and slope by continuing the natural sediment transport processes and by preventing the encroachment of vegetation into the channels.

The timing of the flushing flow releases was assessed with consideration for the following:

1) The life history of the Colorado Cutthroat trout. Flows were recommended to occur prior to any spawning activity to prevent both the subsequent dewatering of redds (flows released during spawning), or the dislodgement of eggs and alevins (flows released after spawning).
2) Historical runoff period. The timing of release flows corresponded to historical peak flows.
3) Water temperature. To the extent possible, the flushing flows occurred at low water temperatures. This took advantage of the higher viscosity of the colder water with the result that particles remained in suspension longer and were transported further downstream.

Flushing flow recommendations developed by Wesche et al.

(1977) called for a three-day annual release of 60 cfs during the spring runoff period. This recommendation was not intended for mitigative purposes in response to a sizeable sediment spill, but rather for routine channel flushing and maintenance during normal operating conditions (Wesche et al. 1987).

Principal Findings and Significance

Ecological Indices

For the years 1985, 1986, and 1987, the general pattern was for diversity, richness and evenness to increase from July to September (Table 4). There was no consistent temporal pattern of abundance exhibited by the macroinvertebrate community within or between years. This apparent lack of an seasonality in abundance is likely to be a function of sampling efficiency, life history phenomenon, and variation between species within families.

The most obvious, as well as interesting, occurrence for the three years is the decrease in both richness and abundance for all sites from 1985 to 1986 with a recovery from 1986 to 1987.

Site 6, the most heavily impacted site, reflected the same trends over time as the controls and other non-impacted sites. It is interesting to note however that in September 1986 this site had the lowest abundance (43 organism/ $0.10m^2$) of all nine sites for all three years. In September 1986, this site also had one of the lowest values for richness (10 families) for all nine sites for all three years, Site 1 in August (8 families) and September 1986 (9 families) being the lowest.

The site with the highest richness and abundance levels for all years was Site 8 in September 1985, with a richness of 21 families and an abundance of 509 organisms/$0.10m^2$. It should be noted that this site also had the lowest values for diversity (0.79) and evenness (0.67) for the nine sites surveyed in September of 1987. The site with the highest diversity (1.11) was Site 4 in September in 1987. Site 3 had the highest evenness

Table 4. Ecological Indices for Nine Sites Along the North Fork of the Little Snake River, 1985-1987

		Year and Month[a]								
		1985			1986			1987		
Site	Index	Jl	Ag	Sp	Jl	Ag	Sp	Jn	Jl	Sp
1	Diversity	0.50	0.94	0.95	0.76	0.64	0.83	0.44	0.77	0.96
	Evenness	0.51	0.80	0.85	0.73	0.71	0.87	0.40	0.67	0.83
	Richness	9	15	13	11	8	9	12	14	14
	Abundance	109	256	76	161	94	70	162	149	86
2	Diversity	0.90	0.96	0.98	0.63	0.82	0.89	0.54	0.81	0.98
	Evenness	0.77	0.84	0.81	0.74	0.71	0.86	0.49	0.73	0.79
	Richness	15	14	16	7	14	11	13	13	17
	Abundance	226	240	212	36	55	60	198	145	189
3	Diversity	0.83	0.91	0.97	0.67	0.93	0.88	0.71	0.71	0
	Evenness	0.65	0.76	0.87	0.74	0.81	0.92	0.58	0.63	0
	Richness	19	16	13	8	14	9	17	13	0
	Abundance	392	265	196	48	108	68	238	134	0
4	Diversity	0.64	1.05	1.08	0.65	0.87	1.07	0.72	0.75	1.11
	Evenness	0.58	0.82	0.88	0.68	0.78	0.87	0.57	0.65	0.85
	Richness	13	19	17	9	13	17	18	14	20
	Abundance	274	211	141	64	131	80	338	177	278
5	Diversity	0.77	1.00	0.94	0.72	0.91	1.10	0.79	0.79	1.07
	Evenness	0.66	0.77	0.73	0.75	0.77	0.91	0.64	0.76	0.87
	Richness	14	20	19	9	15	16	17	11	17
	Abundance	104	435	317	64	183	66	206	71	113
6	Diversity	0.79	0.84	1.00	0.71	0.93	0.91	0.77	0.86	1.06
	Evenness	0.69	0.67	0.80	0.66	0.79	0.91	0.59	0.80	0.86
	Richness	14	18	18	12	15	10	20	12	17
	Abundance	211	315	229	74	106	43	340	188	110
7	Diversity	0.86	1.09	1.00	0.71	0.97	1.04	0.96	1.00	1.02
	Evenness	0.71	0.85	0.79	0.71	0.82	0.89	0.78	0.87	0.84
	Richness	16	19	18	10	15	15	17	14	16
	Abundance	196	195	202	58	145	107	240	63	212
8	Diversity	0.94	1.06	0.98	0.60	0.96	0.99	0.83	1.01	0.79
	Evenness	0.82	0.85	0.74	0.57	0.79	0.89	0.71	0.82	0.67
	Richness	14	18	21	11	16	13	15	17	15
	Abundance	371	146	509	56	101	66	259	140	233
9	Diversity	0.83	1.00	1.02	0.73	0.95	0.98	0.81	1.03	1.08
	Evenness	0.67	0.80	0.80	0.70	0.85	0.83	0.64	0.88	0.86
	Richness	17	18	19	11	13	15	18	15	18
	Abundance	375	339	281	100	93	195	288	119	213

[a] Jn=June Jl=July Ag=August Sp=September

value for all three years (.92) in September of 1986.

Proportion by Order for 1985

At the nine sites in July of 1985 (Tables 5-13 and Figures 3-7) the order Ephemeroptera represented the greatest proportion of aquatic insects at sites 1-6 and 8, with the families of Heptageniidae or Baetidae comprising the largest percentage (31 and 13%, respectively) of all insects found. Site 3 was dominated by Diptera with Chironomidae being the predominant family (32%). Site 7 had an approximately equal number of Ephemeroptera (Baetidae and Heptageniidae 23%), Trichoptera (Glossosomatidae 29%), and Diptera (Chironomidae 26%), and Site 9 was dominated by Ephemeroptera (Heptageniidae and Baetidae 43%) and Trichoptera (Glossosomatidae 37%).

For the nine sites in August (Tables 5-13 and Figures 3-7), Ephemeroptera (Baetidae and Heptageniidae) was the dominant order in Sites 1, 3, 4, 7, and 9. Diptera (Chironomidae 13 and 46%) was dominant at Sites 5 and 6. Ephemeroptera (Heptageniidae 18%) and Plecoptera (Nemouridae 18%) were equally represented at Site 2 containing 28 and 27 % respectively. Diptera (Chironomidae 25%) and Ephemeroptera (Siphlonuridae and Ephemerellidae 28%) were the dominant orders at Site 8.

In September (Tables 5-13 and Figures 3-7), Ephemeroptera was the dominant order for Sites 1, 7 and 9 (Ephemerellidae and Heptageniidae) 4, (Ephemerellidae, Heptageniidae and Siphlonuridae) and 5, 6, and 8 (Ephemerellidae). Plecoptera (Nemouridae) dominated site 2, while site 3 was split between Ephemeroptera (Ephemerellidae and Heptageniidae) and Plecoptera

Table 5. Percentage of Abundance by Family for Site 1 in 1985.

Taxon	Month		
	July	August	September
EPHEMEROPTERA			
Ephemerellidae	2	7	18
Baetidae	0	20	3
Siphlonuridae	1	6	5
Heptageniidae	72	28	17
PLECOPTERA			
Nemouridae	3	12	17
Chloroperlidae	5	5	3
Perlodidae	9	17	21
TRICHOPTERA			
Rhyacophilidae	2	4	15
Hydropsychidae	0	1	0
Glossosomatidae	0	1	0
Limnephilidae	0	0	1
DIPTERA			
Chironomidae	5	9	7
Simuliidae	8	6	0
Ceratopogonidae	0	0	1
Tipulidae	0	0	1
COLEOPTERA			
Elmidae	3	3	11

Table 6. Percentage of Abundance by Family for Site 2 in 1985.

Taxon	Month		
	July	August	September
EPHEMEROPTERA			
Ephemerellidae	4	2	4
Baetidae	5	7	6
Siphlonuridae	1	3	1
Heptageniidae	35	18	13
PLECOPTERA			
Nemouridae	13	18	23
Chloroperlidae	8	8	5
Perlodidae	3	0	5
TRICHOPTERA			
Rhyacophilidae	6	9	8
Hydropsychidae	0	0	1
Glossosomatidae	0	0	0
Limnephilidae	0	3	1
DIPTERA			
Chironomidae	14	20	18
Simuliidae	6	0	0
Ceratopogonidae	1	0	0
Tipulidae	0	1	2
COLEOPTERA			
Elmidae	4	9	11

Table 7. Percentage of Abundance by Family for Site 3 in 1985.

Taxon	Month		
	July	August	September
EPHEMEROPTERA			
Ephemerellidae	1	11	12
Baetidae	9	28	4
Siphlonuridae	1	0	7
Heptageniidae	31	28	14
PLECOPTERA			
Nemouridae	7	4	13
Chloroperlidae	9	1	12
Perlodidae	1	4	10
TRICHOPTERA			
Rhyacophilidae	1	4	1
Hydropsychidae	0	0	0
Glossosomatidae	1	2	0
Limnephilidae	0	0	0
DIPTERA			
Chironomidae	32	5	20
Simuliidae	3	2	0
Ceratopogonidae	2	0	0
Tipulidae	1	0	3
COLEOPTERA			
Elmidae	1	7	2

Table 8. Percentage of Abundance by Family for Site 4 in 1985.

Taxon	Month		
	July	August	September
EPHEMEROPTERA			
Ephemerellidae	0	11	16
Baetidae	23	16	9
Siphlonuridae	0	4	15
Heptageniidae	16	22	15
PLECOPTERA			
Nemouridae	0	5	6
Chloroperlidae	4	6	7
Perlodidae	1	2	5
TRICHOPTERA			
Rhyacophilidae	1	3	6
Hydropsychidae	0	3	0
Glossosomatidae	0	5	3
Limnephilidae	0	0	0
DIPTERA			
Chironomidae	49	13	7
Simuliidae	0	1	0
Ceratopogonidae	0	1	1
Tipulidae	1	1	3
COLEOPTERA			
Elmidae	2	1	5

Table 9. Percentage of Abundance by Family for Site 5 in 1985.

Taxon	Month		
	July	August	September
EPHEMEROPTERA			
Ephemerellidae	2	13	34
Baetidae	32	7	5
Heptageniidae	34	3	4
PLECOPTERA			
Nemouridae	1	13	4
Chloroperlidae	2	4	5
Perlodidae	2	1	0
TRICHOPTERA			
Rhyacophilidae	2	2	2
Hydropsychidae	3	12	9
Glossosomatidae	3	3	3
Limnephilidae	0	0	1
Brachycentridae	0	1	0
DIPTERA			
Chironomidae	49	13	7
Simuliidae	0	1	0
Ceratopogonidae	0	1	1
Tipulidae	1	1	3
COLEOPTERA			
Elmidae	2	1	5

Table 10. Percentage of Abundance by Family for Site 6 in 1985.

Taxon	Month		
	July	August	September
EPHEMEROPTERA			
Ephemerellidae	6	5	28
Baetidae	12	7	6
Siphlonuridae	3	0	1
Heptageniidae	43	14	14
PLECOPTERA			
Nemouridae	2	2	7
Chloroperlidae	16	7	2
Perlodidae	0	0	1
TRICHOPTERA			
Rhyacophilidae	2	1	1
Hydropsychidae	1	6	8
Glossosomatidae	2	2	2
Limnephilidae	0	0	1
DIPTERA			
Chironomidae	10	46	11
Simuliidae	1	0	0
Ceratopogonidae	1	2	1
Tipulidae	0	1	0
COLEOPTERA			
Elmidae	1	3	8

Table 11. Percentage of Abundance by Family for Site 7 in 1985.

Taxon	Month		
	July	August	September
EPHEMEROPTERA			
Ephemerellidae	8	23	22
Baetidae	11	6	7
Siphlonuridae	0	2	0
Heptageniidae	13	11	21
PLECOPTERA			
Nemouridae	2	8	7
Chloroperlidae	1	2	3
Perlodidae	1	1	2
TRICHOPTERA			
Rhyacophilidae	1	5	1
Hydropsychidae	3	9	13
Glossosomatidae	29	6	2
DIPTERA			
Chironomidae	26	11	9
Simuliidae	1	0	0
Ceratopogonidae	0	1	1
Tipulidae	1	3	1
Blephariceridae	1	3	2
COLEOPTERA			
Elmidae	3	5	6

Table 12. Percentage of Abundance by Family for Site 8 in 1985.

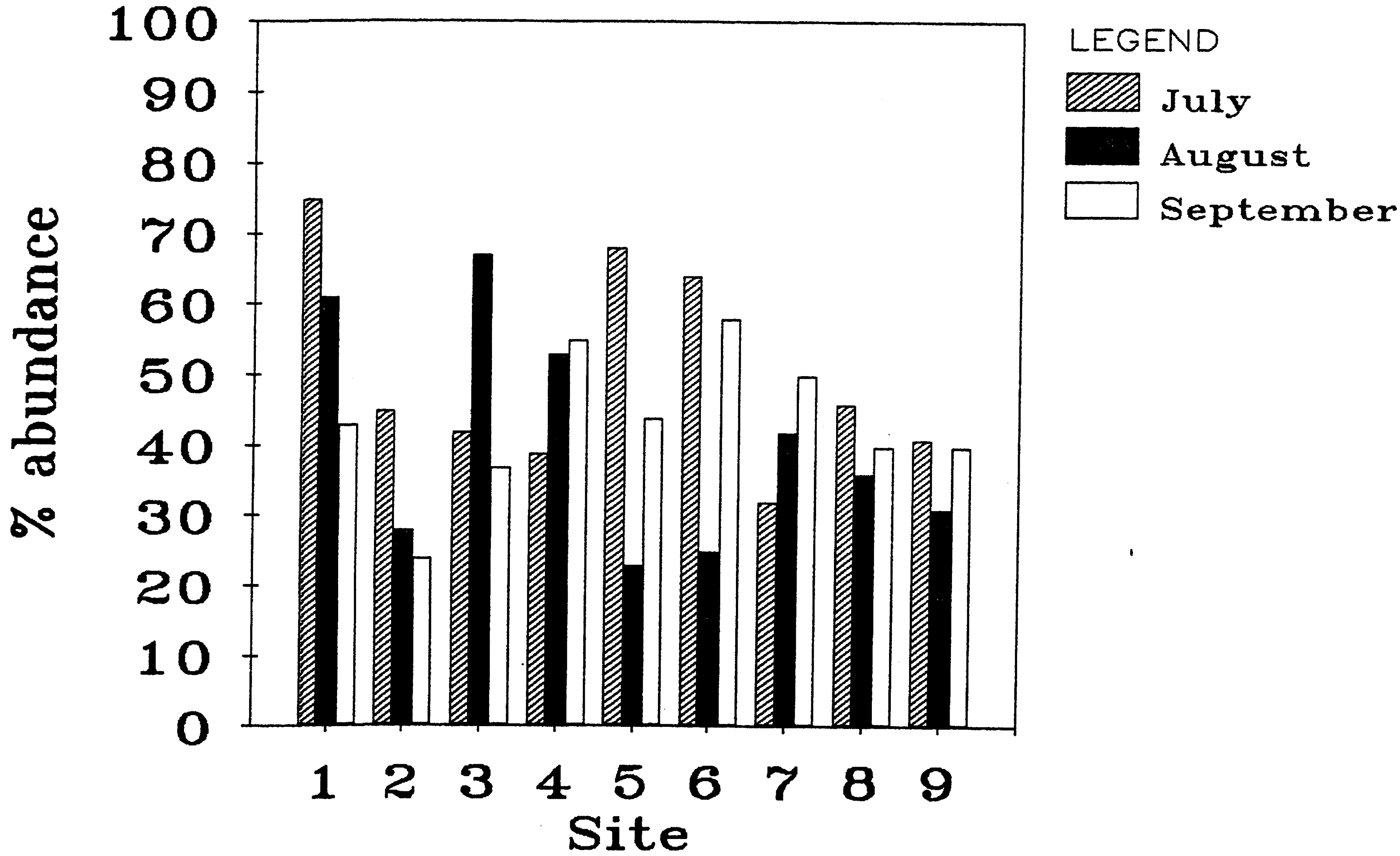
Taxon	Month		
	July	August	September
EPHEMEROPTERA			
Ephemerellidae	5	12	25
Baetidae	13	8	6
Siphlonuridae	14	12	0
Heptageniidae	14	3	8
PLECOPTERA			
Nemouridae	3	2	7
Chloroperlidae	1	1	1
Perlodidae	2	2	4
TRICHOPTERA			
Rhyacophilidae	1	3	1
Hydropsychidae	1	5	10
Glossosomatidae	12	1	3
DIPTERA			
Chironomidae	25	23	23
Simuliidae	0	0	0
Ceratopogonidae	1	6	1
Tipulidae	0	3	1
COLEOPTERA			
Elmidae	7	12	6

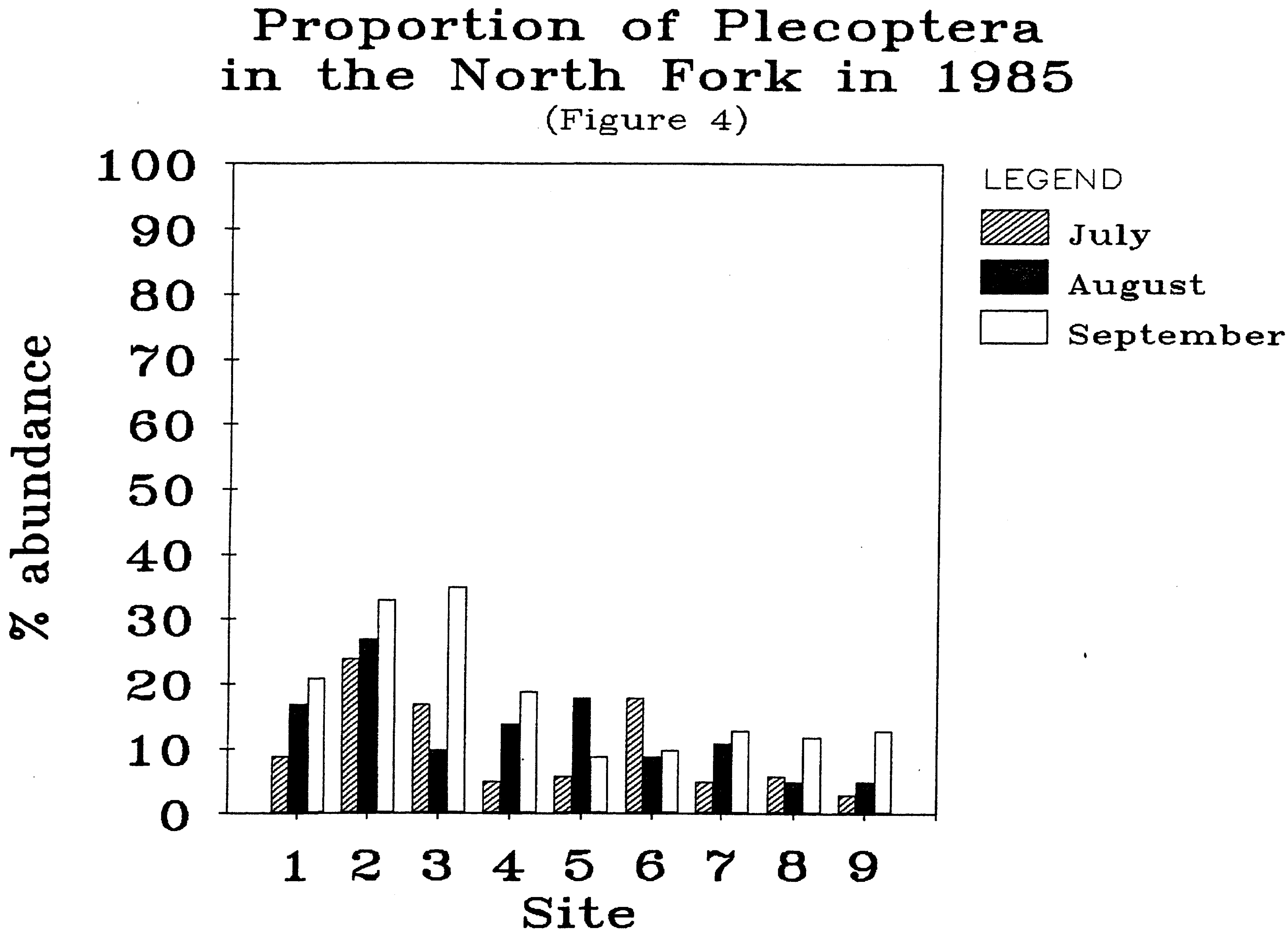
Table 13. Percentage of Abundance by Family for Site 9 in 1985.

Taxon	Month		
	July	August	September
EPHEMEROPTERA			
Ephemerellidae	5	9	22
Baetidae	10	6	6
Siphlonuridae	3	4	0
Heptageniidae	23	12	11
Leptophlebiidae	0	0	1
PLECOPTERA			
Nemouridae	1	1	8
Chloroperlidae	1	2	4
Perlodidae	1	1	0
TRICHOPTERA			
Rhyacophilidae	2	3	4
Hydropsychidae	2	13	16
Glossosomatidae	37	14	2
Brachycentridae	0	0	1
DIPTERA			
Chironomidae	12	24	15
Simuliidae	0	1	0
Ceratopogonidae	0	1	1
Tipulidae	1	0	1
COLEOPTERA			
Elmidae	3	7	4

Proportion of Ephemeroptera in the North Fork in 1985

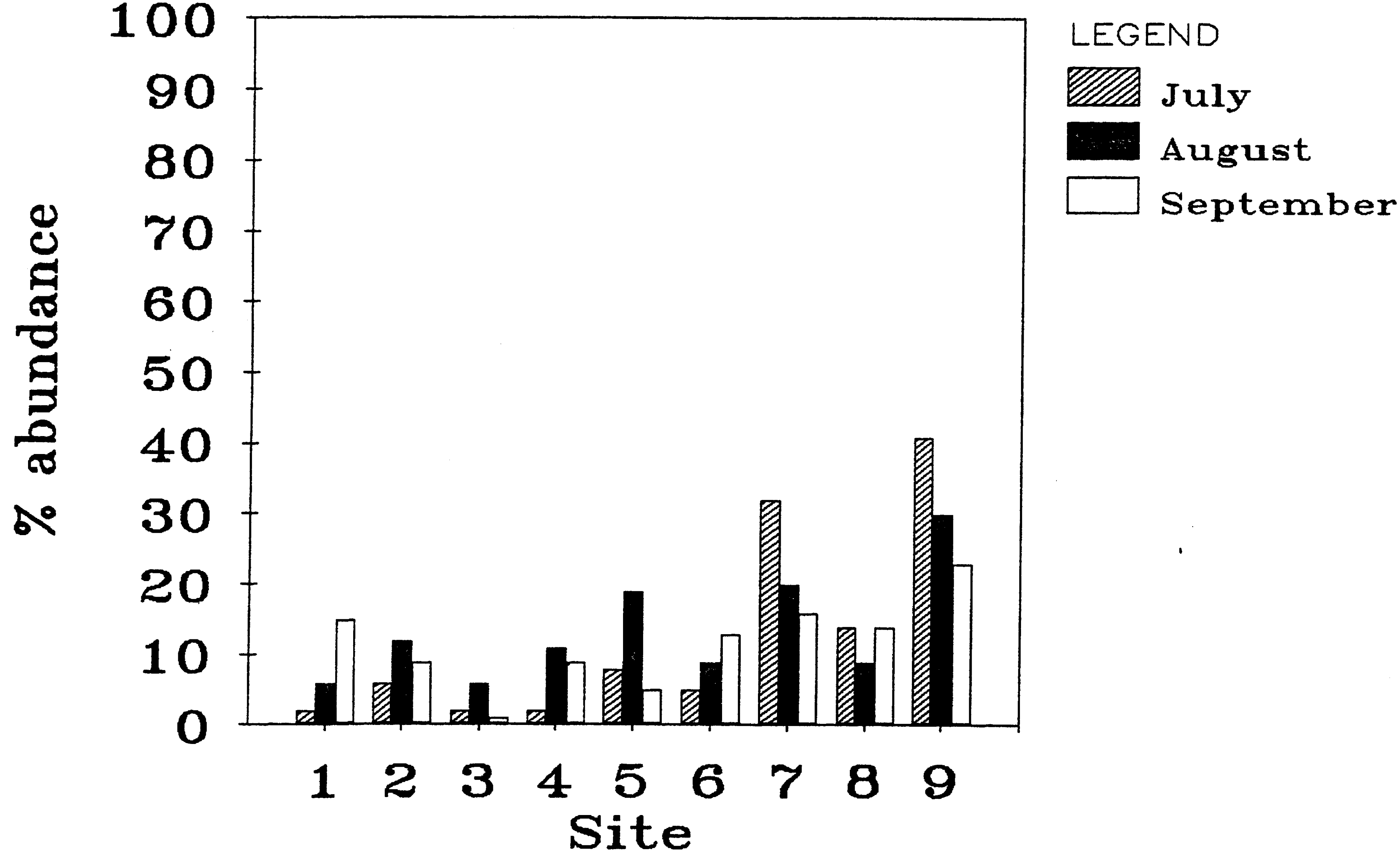
(Figure 3)

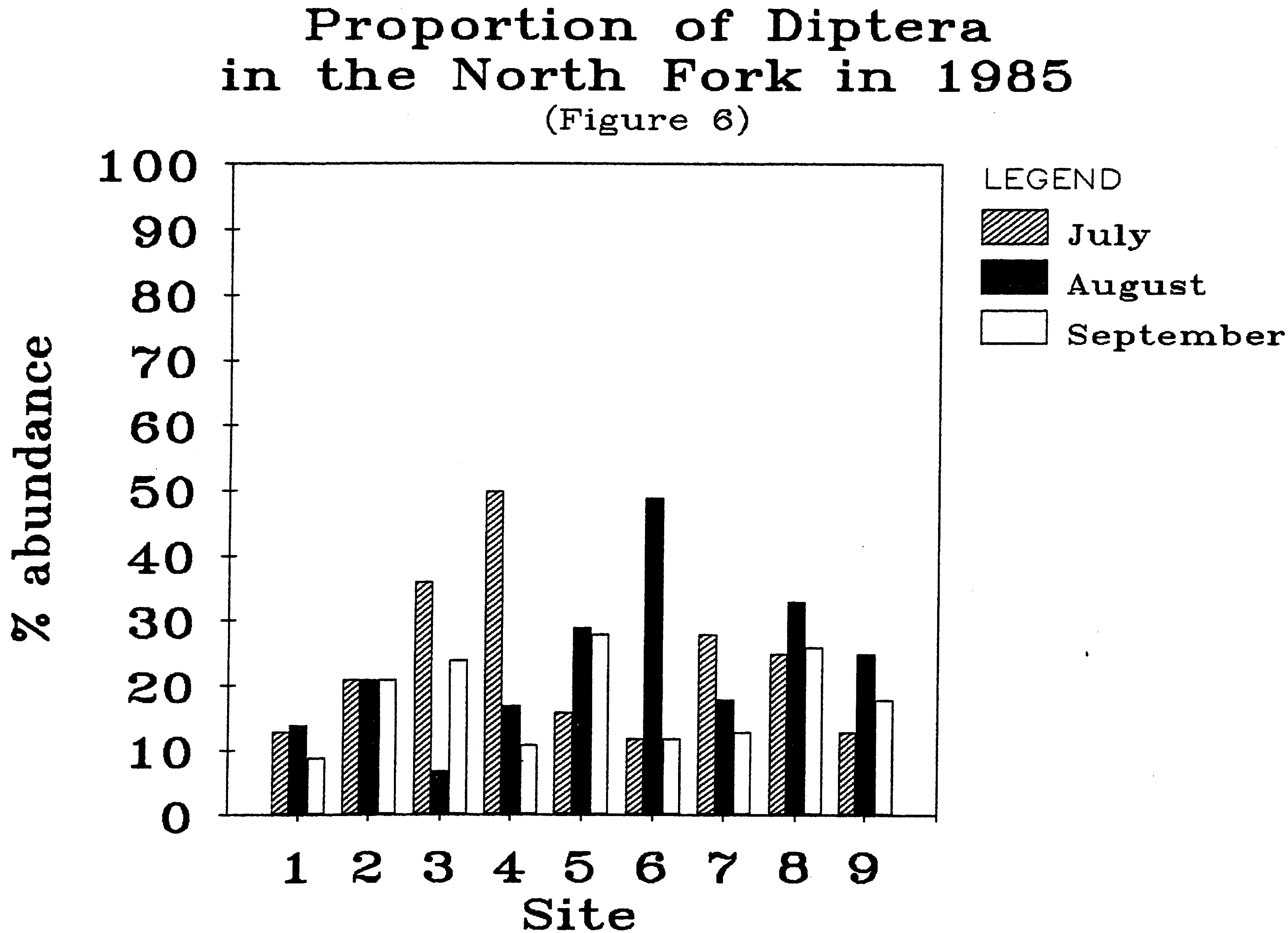


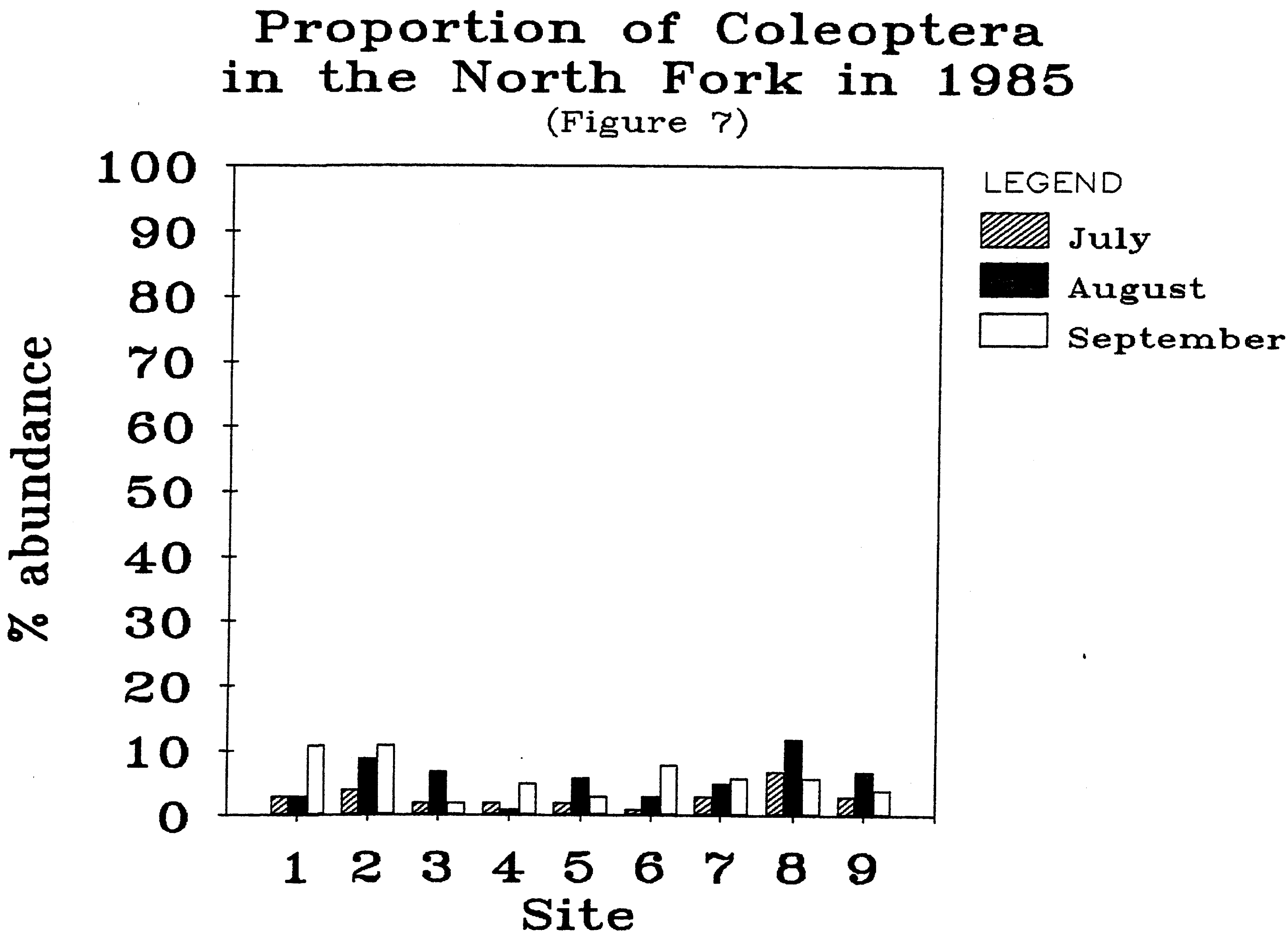

Proportion of Plecoptera
in the North Fork in 1985
(Figure 4)
% abundance
100
90
80
70
60
50
40
30
20
10
0
1
2
3
4
5
6
7
8
9
Site
LEGEND
July
August
September

Proportion of Trichoptera in the North Fork in 1985

(Figure 5)




Proportion of Diptera
in the North Fork in 1985
(Figure 6)
% abundance
0
10
20
30
40
50
60
70
80
90
100
1
2
3
4
5
6
7
8
9
Site
LEGEND
July
August
September



Proportion of Coleoptera
in the North Fork in 1985
(Figure 7)
% abundance
100
90
80
70
60
50
40
30
20
10
0
1 2 3 4 5 6 7 8 9
Site
LEGEND
July
August
September

(Nemouridae and Chloroperlidae).

Proportion by Order for 1986

At the nine sites in July of 1986 (Tables 14-22 and Figures 8-12) Ephemeroptera was the dominant order for sites 1-9. The families Heptageniidae and Baetidae represented between 50 and 78% of all organisms found, with the exception of site 2 where there were no Baetidae found. However, at site 2, Heptageniidae comprised 50% of all organisms found.

In August (Tables 14-22 and Figures 8-12), Ephemeroptera again was the dominant order for sites 2-9 with Heptageniidae (25%) and Baetidae (19%) being the major families represented. Though not the dominant order, Trichoptera represented 33% of insects found at site 8 with Glossosomatidae being the dominant family (29%). For site 1 Diptera was the dominant order with Simuliidae accounting for 55% of all insects found.

In September (Table 14-22 and Figures 8-12), Ephemeroptera dominated sites 1, 3, 5, 6, 8, and 9, with Heptageniidae (16%) and Ephemerellidae (14%) being the major families. At site 2, both Ephemeroptera (Ephemerellidae, Baetidae, Siphlonuridae and Heptageniidae 24%) and Diptera (Chironomidae 25%) were well represented. At site 4, though Ephemeroptera comprised 29% of all organisms, Plecoptera dominated, with the families Nemouridae (14%) and Perlodidae (13%) being well represented. For Site 7, Ephemeroptera had the largest proportion of insects (33%), but Trichoptera was well represented with 30% of all insects.

Proportion by Order for 1987

For the nine sites in June of 1987 (Tables 23-31 and Figures

Table 14. Percentage of Abundance by Family for Site 1 in 1986.

Taxon	Month		
	July	August	September
EPHEMEROPTERA			
Ephemerellidae	1	2	0
Baetidae	26	4	6
Siphlonuridae	0	0	4
Heptageniidae	36	16	29
PLECOPTERA			
Nemouridae	1	6	11
Chloroperlidae	9	0	7
Perlodidae	1	0	9
TRICHOPTERA			
Rhyacophilidae	4	5	6
Hydropsychidae	0	0	0
Glossosomatidae	0	0	0
Brachycentridae	2	0	0
DIPTERA			
Chironomidae	7	5	26
Simuliidae	12	55	0
Ceratopogonidae	0	0	0
Tipulidae	0	0	0
COLEOPTERA			
Elmidae	0	5	3

Table 15. Percentage of Abundance by Family for Site 2 in 1986.

Taxon	Month		
	July	August	September
EPHEMEROPTERA			
Ephemerellidae	0	2	2
Baetidae	0	4	5
Siphlonuridae	0	2	2
Heptageniidae	50	51	15
PLECOPTERA			
Nemouridae	3	9	5
Chloroperlidae	22	3	3
Perlodidae	0	2	10
TRICHOPTERA			
Rhyacophilidae	6	7	12
Hydropsychidae	0	0	0
Glossosomatidae	0	0	0
Brachycentridae	0	0	0
DIPTERA			
Chironomidae	11	4	25
Simuliidae	3	4	0
Ceratopogonidae	0	0	0
Tipulidae	6	2	0
COLEOPTERA			
Elmidae	0	6	20

Table 16. Percentage of Abundance by Family for Site 3 in 1986.

Taxon	Month		
	July	August	September
EPHEMEROPTERA			
Ephemerellidae	10	1	0
Baetidae	6	23	12
Siphlonuridae	0	1	15
Heptageniidae	44	27	21
PLECOPTERA			
Nemouridae	2	4	9
Chloroperlidae	27	9	6
Perlodidae	0	0	4
TRICHOPTERA			
Rhyacophilidae	6	7	2
Hydropsychidae	0	0	0
Glossosomatidae	0	1	0
Brachycentridae	0	0	0
Limnephilidae	0	1	0
DIPTERA			
Chironomidae	0	7	0
Simuliidae	0	8	0
Ceratopogonidae	0	0	0
Tipulidae	2	3	13
COLEOPTERA			
Elmidae	2	7	19

Table 17. Percentage of Abundance by Family for Site 4 in 1986.

Taxon	Month		
	July	August	September
EPHEMEROPTERA			
Ephemerellidae	8	3	3
Baetidae	17	34	6
Siphlonuridae	0	0	15
Heptageniidae	53	18	4
Leptophlebidae	0	0	2
PLECOPTERA			
Nemouridae	2	4	14
Chloroperlidae	6	4	8
Perlodidae	2	1	13
TRICHOPTERA			
Rhyacophilidae	2	2	5
Hydropsychidae	0	2	1
Glossosomatidae	0	2	0
Limnephilidae	0	0	0
DIPTERA			
Chironomidae	9	13	11
Simuliidae	2	13	1
Ceratopogonidae	0	0	0
Tipulidae	0	1	1
COLEOPTERA			
Elmidae	0	4	14

Table 18. Percentage of Abundance by Family for Site 5 in 1986.

Taxon	Month		
	July	August	September
EPHEMEROPTERA			
Ephemerellidae	0	2	20
Baetidae	9	24	5
Siphlonuridae	0	0	5
Heptageniidae	50	26	2
Leptophlebidae	0	0	2
PLECOPTERA			
Nemouridae	0	2	11
Chloroperlidae	5	3	8
Perlodidae	3	0	6
TRICHOPTERA			
Rhyacophilidae	2	3	5
Hydropsychidae	6	7	8
Glossosomatidae	0	4	0
Brachycentridae	3	0	2
Limnephilidae	0	0	0
DIPTERA			
Chironomidae	13	14	8
Simuliidae	9	10	0
Blephariceridae	0	1	5
COLEOPTERA			
Elmidae	0	2	12

Table 19. Percentage of Abundance by Family for Site 6 in 1986.

Taxon	Month		
	July	August	September
EPHEMEROPTERA			
Ephemerellidae	1	3	26
Baetidae	12	23	7
Siphlonuridae	1	3	0
Heptageniidae	55	28	19
Leptophlebidae	0	0	0
PLECOPTERA			
Nemouridae	1	2	7
Chloroperlidae	4	1	5
Perlodidae	4	8	2
TRICHOPTERA			
Rhyacophilidae	0	3	12
Hydropsychidae	0	0	12
Glossosomatidae	0	13	0
DIPTERA			
Chironomidae	7	8	7
Simuliidae	4	1	0
Ceratopogonidae	0	0	0
Tipulidae	5	0	0
Blephariceridae	0	2	0
COLEOPTERA			
Elmidae	3	4	5

Table 20. Percentage of Abundance by Family for Site 7 in 1986.

Taxon	Month		
	July	August	September
EPHEMEROPTERA			
Ephemerellidae	2	7	9
Baetidae	9	21	2
Siphlonuridae	0	0	1
Heptageniidae	53	19	22
PLECOPTERA			
Nemouridae	9	7	4
Chloroperlidae	3	1	8
Perlodidae	5	2	3
TRICHOPTERA			
Rhyacophilidae	2	1	8
Hydropsychidae	9	6	16
Glossosomatidae	0	14	5
DIPTERA			
Chironomidae	2	14	6
Simuliidae	7	5	0
Ceratopogonidae	0	0	0
Tipulidae	0	0	2
Blephariceridae	0	2	0
COLEOPTERA			
Elmidae	0	1	7

Table 21. Percentage of Abundance by Family for Site 8 in 1986.

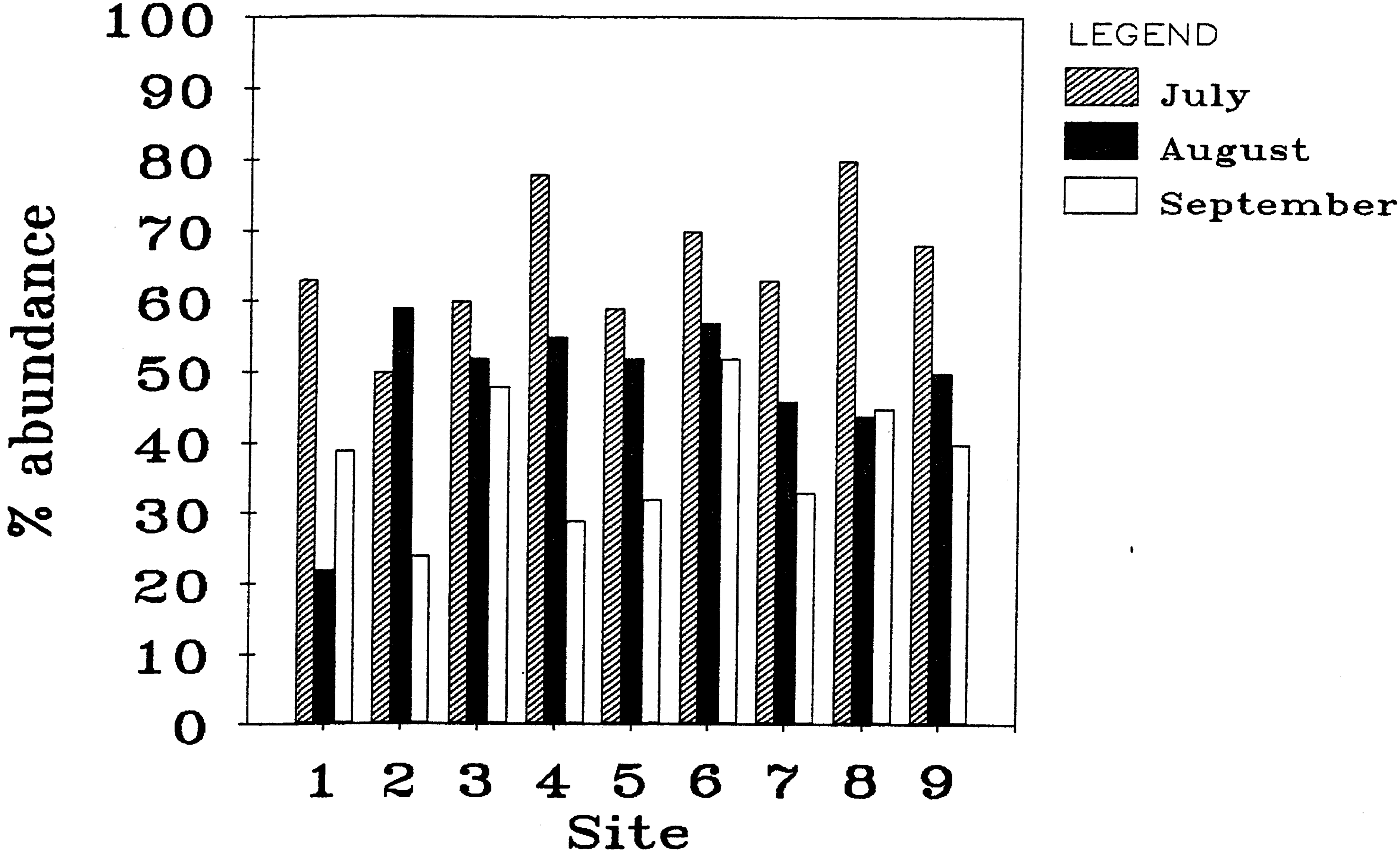
Taxon	Month		
	July	August	September
EPHEMEROPTERA			
Ephemerellidae	1	3	15
Baetidae	16	15	5
Siphlonuridae	1	13	3
Heptageniidae	63	13	15
Leptophlebidae	0	0	8
PLECOPTERA			
Nemouridae	2	1	5
Chloroperlidae	4	3	9
Perlodidae	0	2	0
TRICHOPTERA			
Rhyacophilidae	2	4	8
Hydropsychidae	4	0	3
Glossosomatidae	0	29	2
DIPTERA			
Chironomidae	4	5	0
Simuliidae	0	0	0
Ceratopogonidae	0	0	0
Tipulidae	2	1	0
COLEOPTERA			
Elmidae	2	7	22

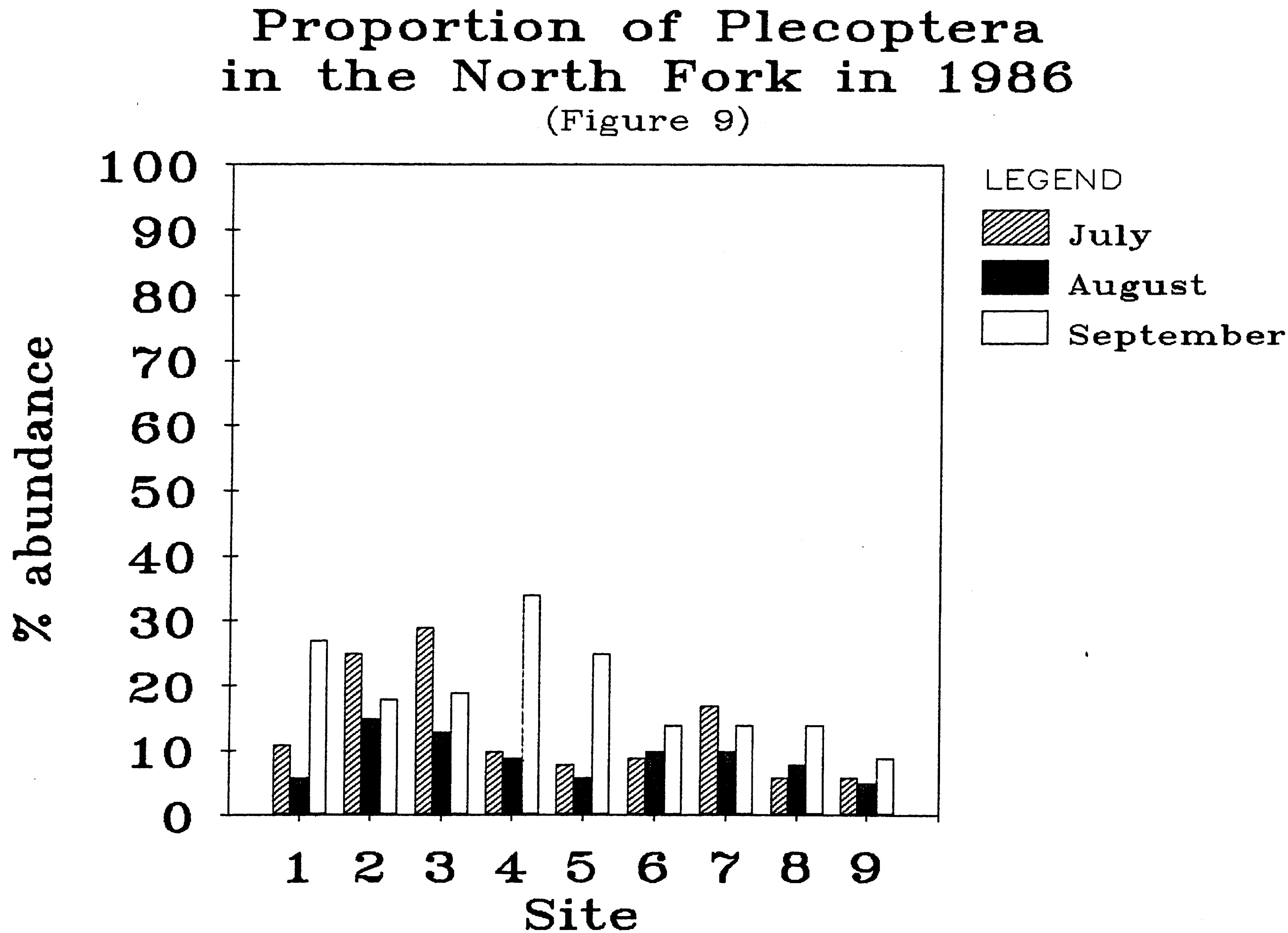
Table 22. Percentage of Abundance by Family for Site 9 in 1986.

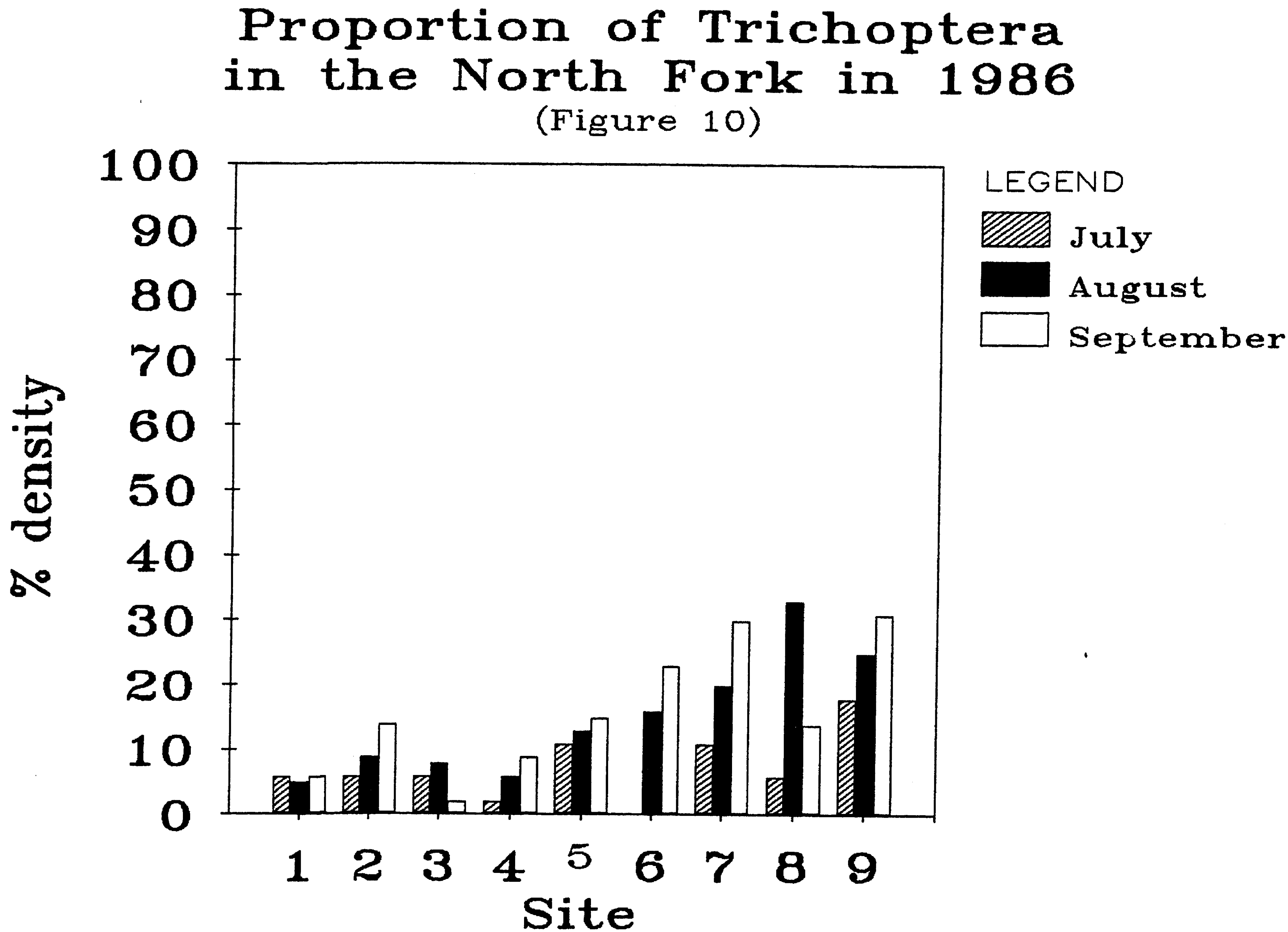
Taxon	Month		
	July	August	September
EPHEMEROPTERA			
Ephemerellidae	9	9	20
Baetidae	9	19	10
Siphlonuridae	0	0	0
Heptageniidae	50	23	11
PLECOPTERA			
Nemouridae	5	2	5
Chloroperlidae	1	2	2
Perlodidae	0	1	1
TRICHOPTERA			
Rhyacophilidae	6	2	5
Hydropsychidae	12	9	24
Glossosomatidae	0	13	2
Brachycentridae	0	1	0
DIPTERA			
Chironomidae	5	12	2
Simuliidae	1	0	0
Ceratopogonidae	0	0	0
Tipulidae	1	0	3
Blephariceridae	0	0	3
COLEOPTERA			
Elmidae	1	5	11

Proportion of Ephemeroptera in the North Fork in 1986

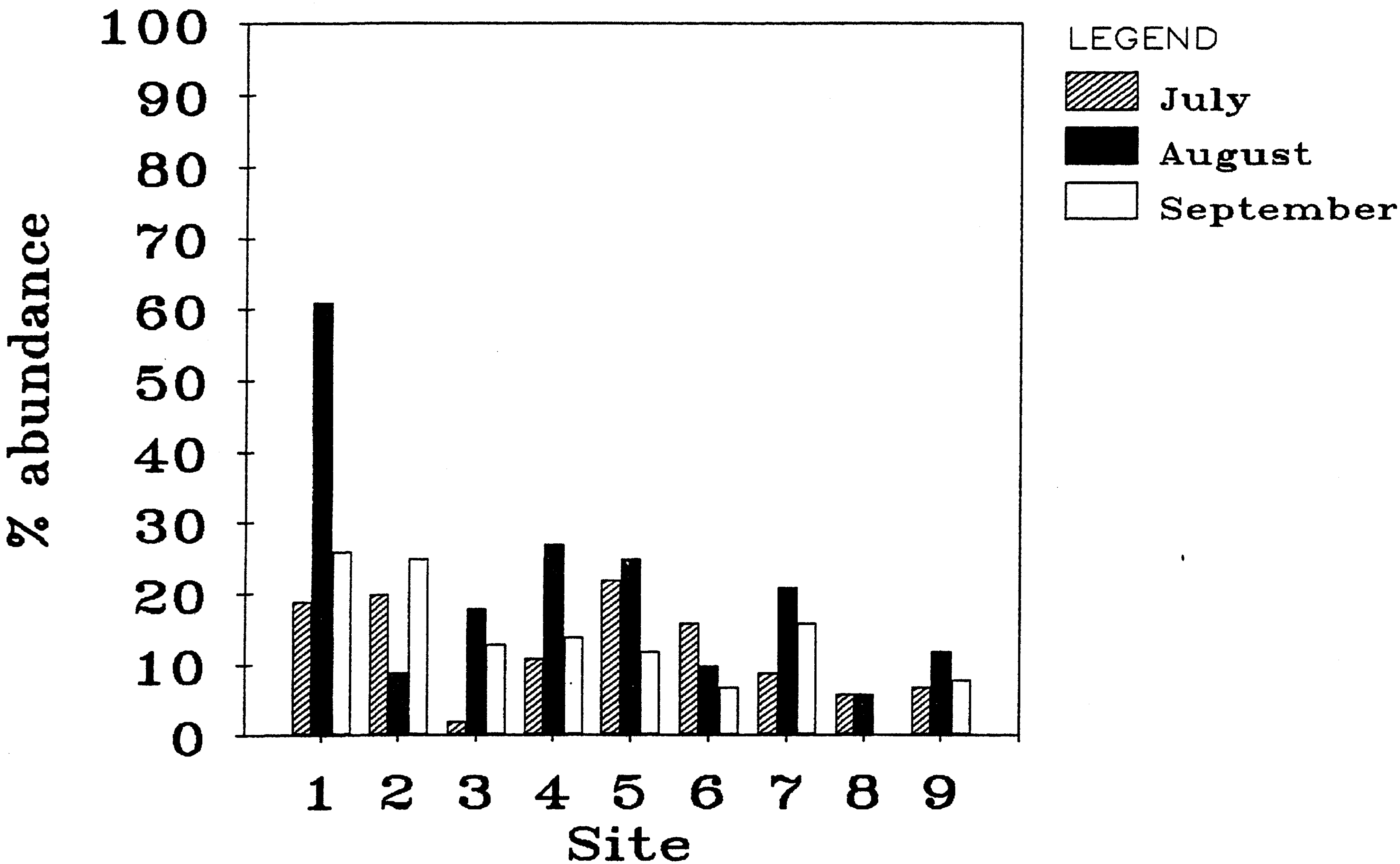
(Figure 8)

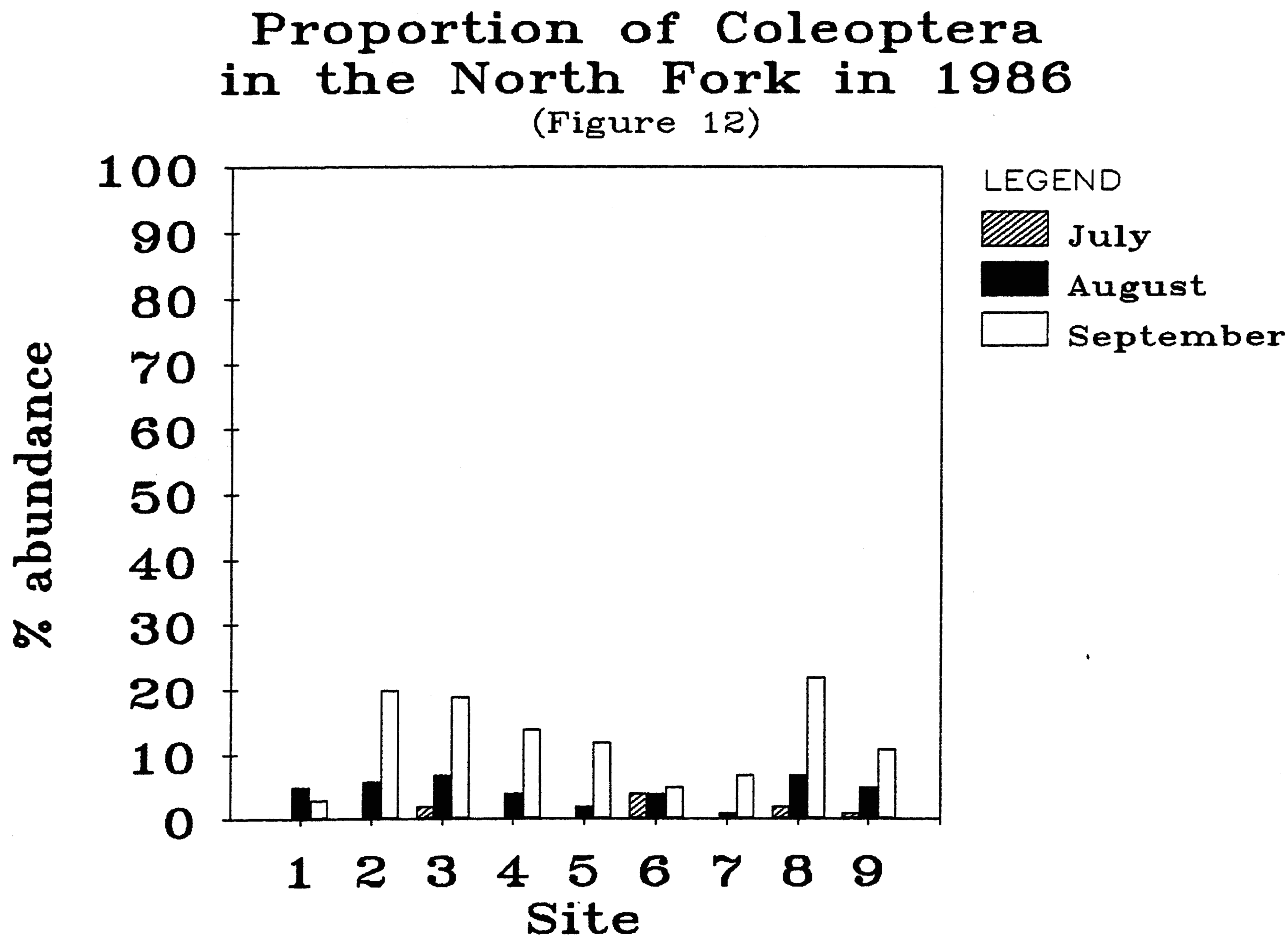



Proportion of Plecoptera
in the North Fork in 1986
(Figure 9)
LEGEND
July
August
September
% abundance
0
10
20
30
40
50
60
70
80
90
100
1
2
3
4
5
6
7
8
9
Site


Proportion of Trichoptera
in the North Fork in 1986
(Figure 10)
% density
100
90
80
70
60
50
40
30
20
10
0
1
2
3
4
5
6
7
8
9
Site
LEGEND
July
August
September

Proportion of Diptera in the North Fork in 1986
(Figure 11)





Proportion of Coleoptera
in the North Fork in 1986
(Figure 12)
% abundance
100
90
80
70
60
50
40
30
20
10
0
1
2
3
4
5
6
7
8
9
Site
LEGEND
July
August
September

13-17), Ephemeroptera was again the dominant order for sites 1-6, 8 and 9, comprising between 59-88% of all insects found. The families Baetidae and Heptageniidae comprised 39 and 36% respectively, of all insects found. Site 7 had a large number of Simuliidae 30% which made Diptera the dominant order.

In July (Tables 23-31 and Figures 13-17), the order Ephemeroptera dominated sites 1-7 and 9 with Heptageniidae and Baetidae being the dominant families. At Site 8, Diptera (Chironomidae) was dominant. Chironomidae was also well represented at Site 4 (27%) and Trichoptera (Hydropsychidae, Ryacophilidae, and Brachycentridae) comprised a large portion (28%) at site 9.

In September (Table 23-31 and Figures 13-17), Ephemeroptera dominated Sites 1, 4, 6, 7, 8, and 9 with Ephemerellidae being the dominant family (24%). Sites 2 and 5 were dominated by Plecoptera (Nemouridae and Chloroperlidae).

<u>Substrate Preference In June</u>

In the order of Ephemeroptera (Table 32, Figures 18-22), the family Ephemerellidae showed no significant substrate preference, although there was tendency to prefer gravel or rubble over bedrock and sand. The family Baetidae showed a significant substrate preference for either gravel or rubble, with few utilizing either sand or bedrock. The family Heptageniidae showed a significant substrate preference for either sand or gravel, however rubble was also relatively well utilized. The family Siphlonuridae showed a significant substrate preference for sand and was found on the other substrates in very limited

Table 23. Percentage of Abundance by Family for Site 1 in 1987.

Taxon	Month		
	June	July	September
EPHEMEROPTERA			
Ephemerellidae	1	5	2
Baetidae	75	2	1
Siphlonuridae	0	1	11
Heptageniidae	12	48	30
PLECOPTERA			
Nemouridae	1	3	14
Chloroperlidae	1	7	11
Perlodidae	1	0	7
TRICHOPTERA			
Rhyacophilidae	6	8	7
Hydropsychidae	0	0	0
Glossosomatidae	0	0	4
Limnephilidae	0	1	0
DIPTERA			
Chironomidae	2	18	6
Simuliidae	2	1	0
Ceratopogonidae	0	0	1
Tipulidae	1	1	1
COLEOPTERA			
Elmidae	1	3	5

Table 24. Percentage of Abundance by Family for Site 2 in 1987.

Taxon	Month		
	June	July	September
EPHEMEROPTERA			
Ephemerellidae	1	0	2
Baetidae	66	6	1
Siphlonuridae	0	0	5
Heptageniidae	16	32	23
PLECOPTERA			
Nemouridae	3	3	11
Chloroperlidae	3	14	20
Perlodidae	1	2	1
TRICHOPTERA			
Rhyacophilidae	2	6	11
Hydropsychidae	1	0	1
Brachycentridae	0	1	0
Limnephilidae	0	1	0
DIPTERA			
Chironomidae	2	28	12
Simuliidae	2	0	1
Ceratopogonidae	0	0	2
Tipulidae	1	2	3
Blephariceridae	1	0	0
COLEOPTERA			
Elmidae	3	5	4

Table 25. Percentage of Abundance by Family for Site 3 in 1987.

Taxon	Month		
	June	July	September
EPHEMEROPTERA			
Ephemerellidae	1	2	0
Baetidae	13	3	0
Siphlonuridae	3	2	0
Heptageniidae	57	51	0
PLECOPTERA			
Nemouridae	4	2	0
Chloroperlidae	8	15	0
Perlodidae	0	2	0
TRICHOPTERA			
Rhyacophilidae	0	2	2
Glossosomatidae	2	0	0
Limnephilidae	0	1	0
DIPTERA			
Chironomidae	2	16	0
Simuliidae	0	0	0
Ceratopogonidae	0	0	0
Tipulidae	3	3	0
COLEOPTERA			
Elmidae	3	1	0

Table 26. Percentage of Abundance by Family for Site 4 in 1987.

Taxon	Month		
	June	July	September
EPHEMEROPTERA			
Ephemerellidae	2	1	9
Baetidae	27	18	2
Siphlonuridae	0	0	8
Heptageniidae	46	37	12
PLECOPTERA			
Nemouridae	7	5	12
Chloroperlidae	7	3	14
Perlodidae	1	0	2
TRICHOPTERA			
Rhyacophilidae	3	3	3
Hydropsychidae	0	1	7
Glossosomatidae	1	0	2
Brachycentridae	0	1	1
DIPTERA			
Chironomidae	1	27	14
Ceratopogonidae	0	1	3
Tipulidae	1	1	2
COLEOPTERA			
Elmidae	1	1	6

Table 27. Percentage of Abundance by Family for Site 5 in 1987.

Taxon	Month		
	June	July	September
EPHEMEROPTERA			
Ephemerellidae	2	3	14
Baetidae	25	10	6
Siphlonuridae	0	1	2
Heptageniidae	43	44	5
PLECOPTERA			
Nemouridae	1	4	9
Chloroperlidae	3	6	18
Perlodidae	1	0	7
TRICHOPTERA			
Rhyacophilidae	7	7	3
Hydropsychidae	5	0	3
Glossosomatidae	1	0	7
Limnephilidae	0	0	2
DIPTERA			
Chironomidae	4	16	17
Simuliidae	0	7	0
Ceratopogonidae	1	0	2
Tipulidae	1	0	0
Blephariceridae	2	0	0
COLEOPTERA			
Elmidae	4	0	4

Table 28. Percentage of Abundance by Family for Site 6 in 1987.

Taxon	Month		
	June	July	September
EPHEMEROPTERA			
Ephemerellidae	3	3	23
Baetidae	22	8	6
Siphlonuridae	1	2	1
Heptageniidae	49	37	6
PLECOPTERA			
Nemouridae	3	0	11
Chloroperlidae	5	16	5
Perlodidae	2	3	5
TRICHOPTERA			
Rhyacophilidae	1	2	0
Hydropsychidae	2	9	9
Glossosomatidae	1	2	13
Brachycentridae	0	0	3
DIPTERA			
Chironomidae	4	13	5
Ceratopogonidae	1	0	1
Tipulidae	2	2	1
COLEOPTERA			
Elmidae	3	6	8

Table 29. Percentage of Abundance by Family for Site 7 in 1987.

Taxon	Month		
	June	July	September
EPHEMEROPTERA			
Ephemerellidae	2	5	17
Baetidae	10	17	5
Siphlonuridae	0	5	0
Heptageniidae	16	27	24
PLECOPTERA			
Nemouridae	5	6	5
Chloroperlidae	5	8	10
Perlodidae	1	0	3
TRICHOPTERA			
Rhyacophilidae	5	0	3
Hydropsychidae	7	2	9
Glossosomatidae	0	0	1
Limnephilidae	0	0	1
DIPTERA			
Chironomidae	5	3	6
Simuliidae	30	2	0
Ceratopogonidae	0	6	2
Tipulidae	1	8	2
Blephariceridae	10	0	0
COLEOPTERA			
Elmidae	1	5	9

Table 30. Percentage of Abundance by Family for Site 8 in 1987.

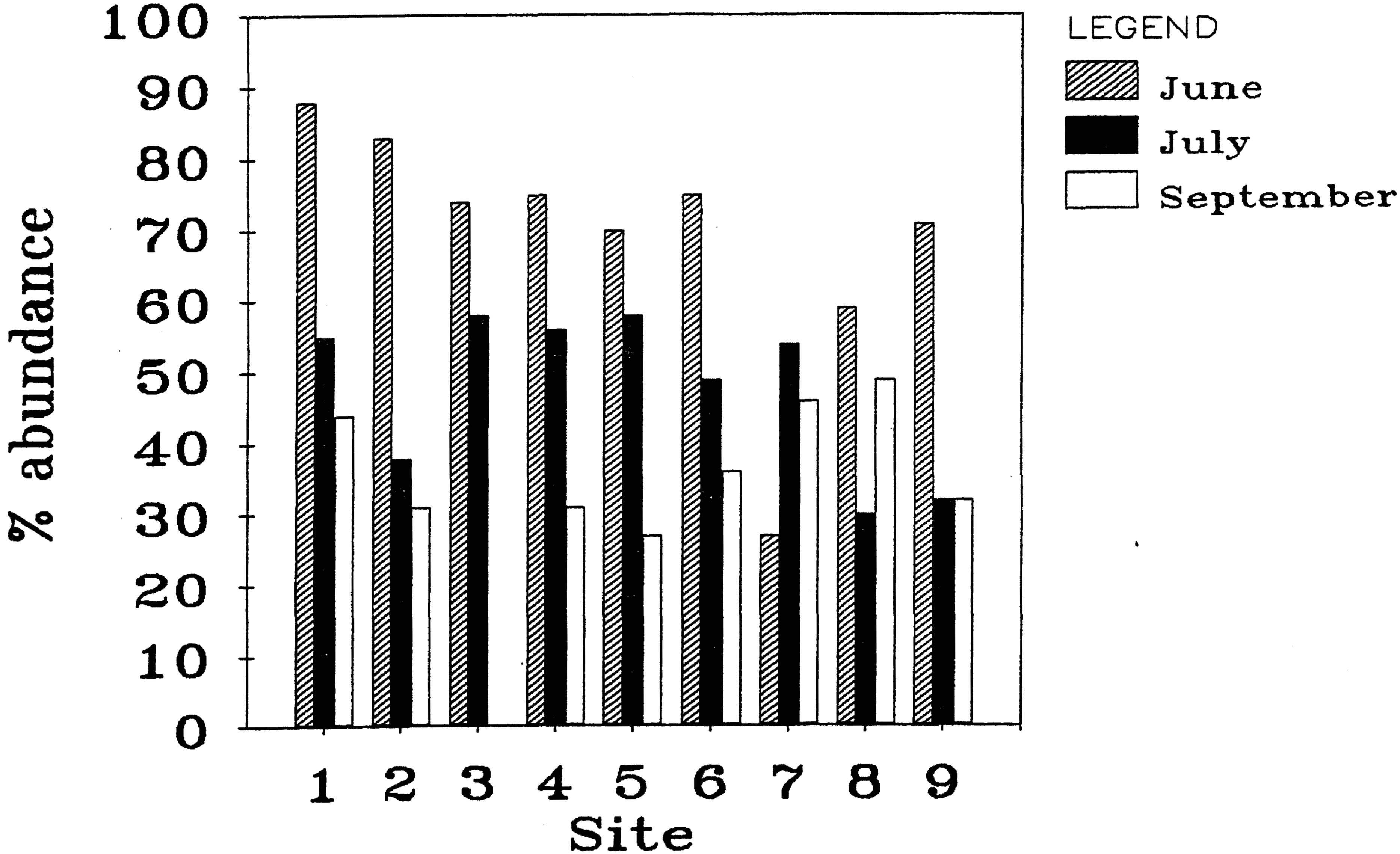
Taxon	Month		
	June	July	September
EPHEMEROPTERA			
Ephemerellidae	4	5	45
Baetidae	15	7	1
Siphlonuridae	0	10	0
Heptageniidae	40	8	0
Leptophlebidae	0	0	3
PLECOPTERA			
Nemouridae	2	3	1
Chloroperlidae	1	9	4
TRICHOPTERA			
Rhyacophilidae	6	3	3
Hydropsychidae	4	1	0
Glossosomatidae	0	2	3
Limnephilidae	0	2	0
DIPTERA			
Chironomidae	10	29	16
Ceratopogonidae	0	2	1
Tipulidae	0	3	7
Blephariceridae	13	0	0
COLEOPTERA			
Elmidae	4	13	14

Table 31. Percentage of Abundance by Family for Site 9 in 1987.

Taxon	Month		
	June	July	September
EPHEMEROPTERA			
Ephemerellidae	6	3	20
Baetidae	13	3	8
Siphlonuridae	1	5	0
Heptageniidae	51	22	3
PLECOPTERA			
Nemouridae	1	3	2
Chloroperlidae	3	7	2
Perlodidae	4	10	6
TRICHOPTERA			
Rhyacophilidae	3	13	8
Hydropsychidae	6	7	15
Glossosomatidae	0	0	4
Brachycentridae	0	7	2
Limnephilidae	2	2	1
DIPTERA			
Chironomidae	5	12	13
Ceratopogonidae	0	2	5
Tipulidae	1	3	4
Blephariceridae	4	0	0
COLEOPTERA			
Elmidae	3	13	10

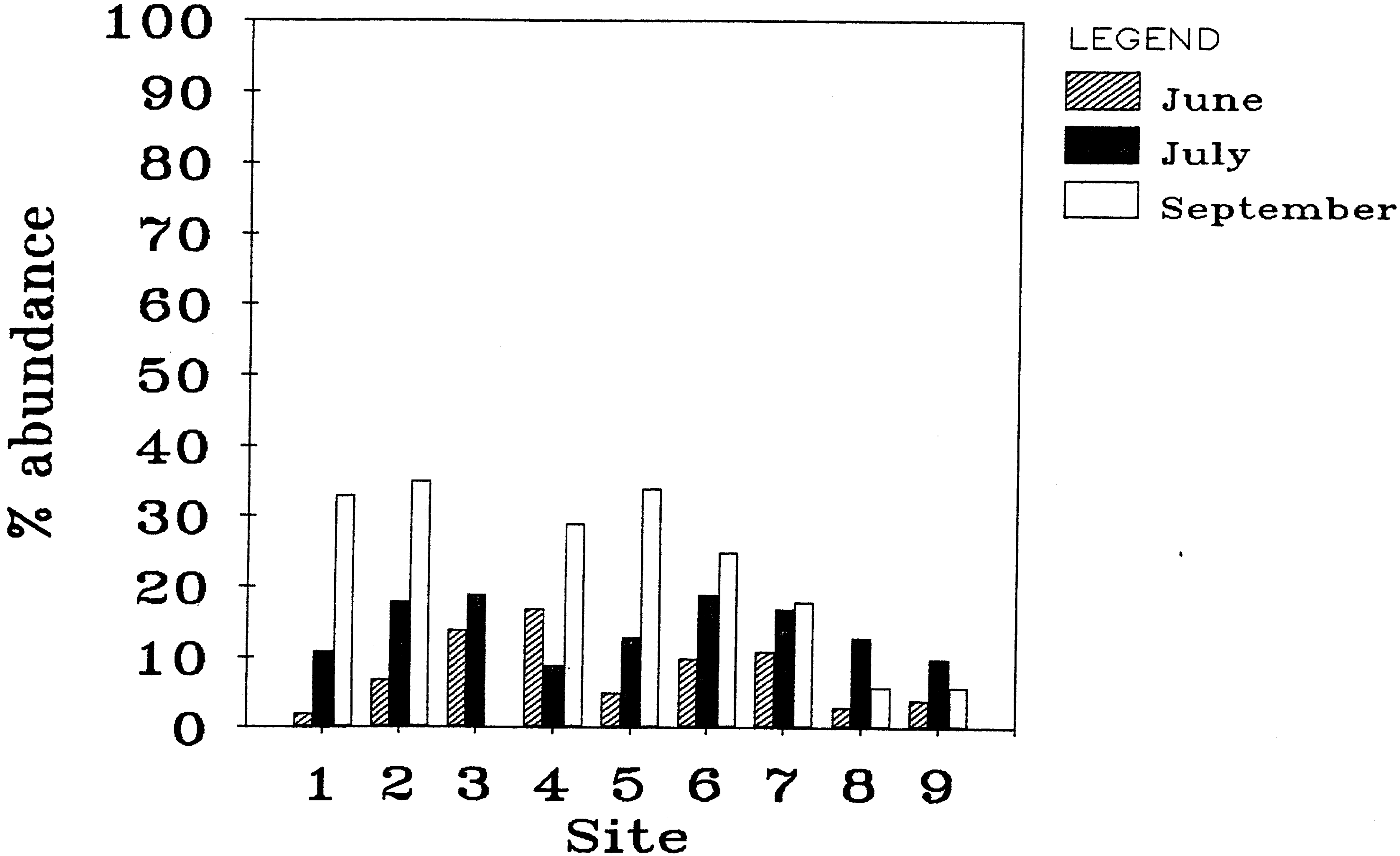
Proportion of Ephemeroptera in the North Fork in 1987

(Figure 13)



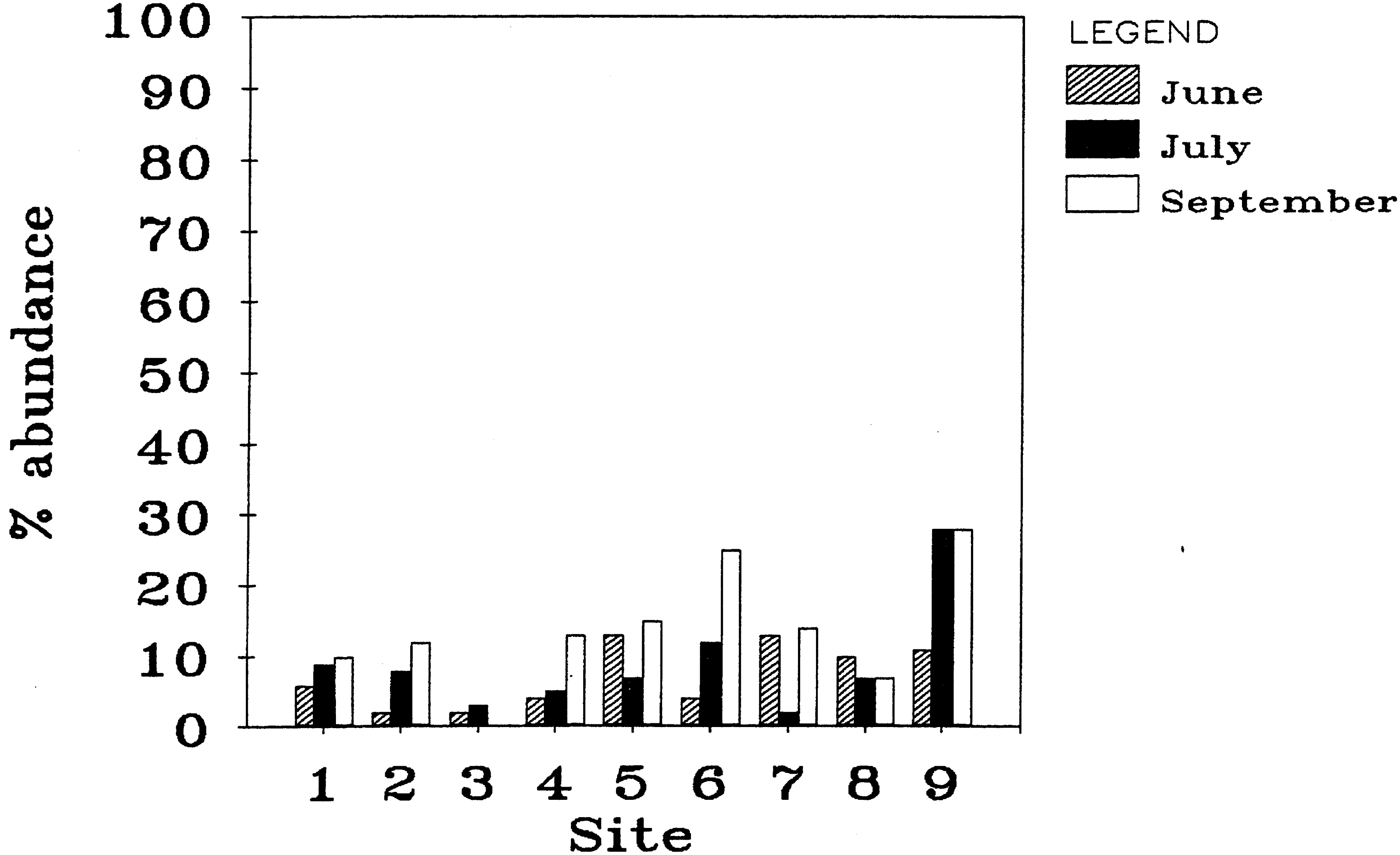
Proportion of Plecoptera in the North Fork in 1987

(Figure 14)



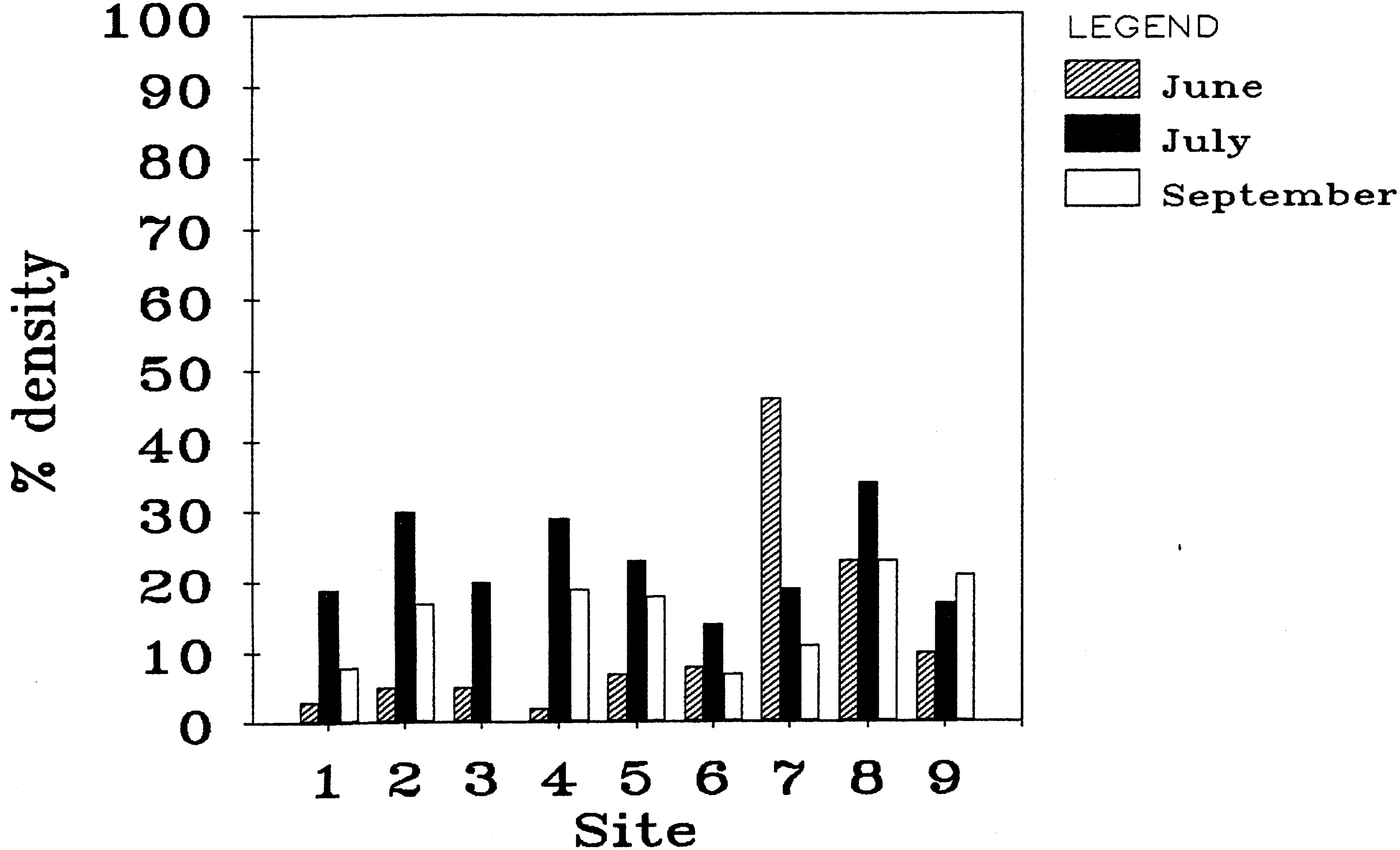
Proportion of Trichoptera in the North Fork in 1987

(Figure 15)



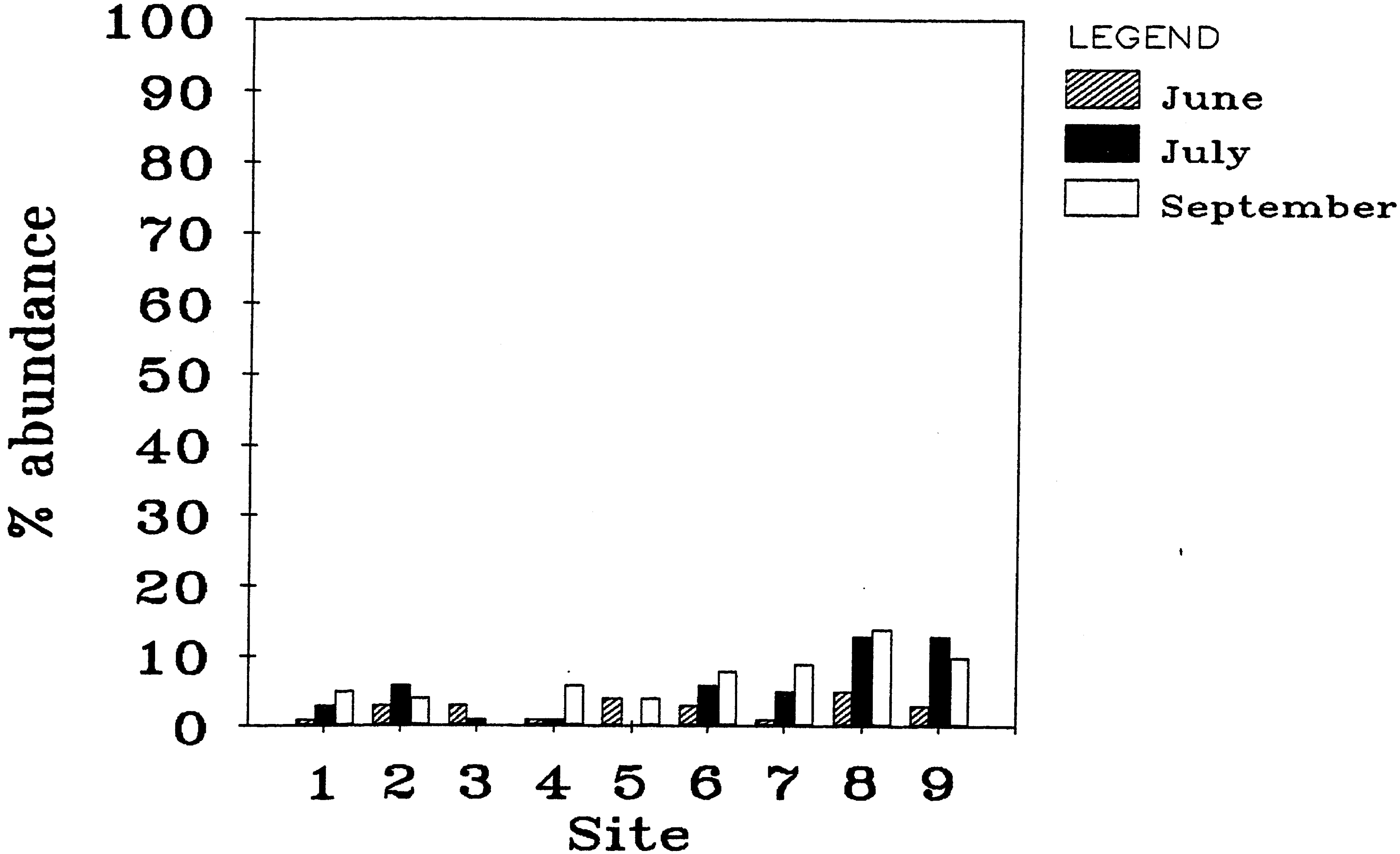
Proportion of Diptera in the North Fork in 1987

(Figure 16)



Proportion of Coleoptera in the North Fork in 1987

(Figure 17)



numbers.

In the order Plecoptera, the family Chloroperlidae had a significant preference for sand, and was found less frequently on substrates of increasing size. Nemouridae showed a significant substrate preference for either gravel and bedrock over sand and rubble. The family Perlodidae showed no significant substrate preference. However, this family was completely absent in sand, occurred in limited numbers on bedrock and was well represented on gravel and rubble.

In the order Trichoptera, the family Rhyacophilidae showed no significant substrate preference, although they were most abundant in gravel and rubble and were found in equal numbers on sand and bedrock. The family Hydropsychidae showed a significant substrate preference for either gravel or rubble; this family did not utilize sand and was found in very low numbers on bedrock. The family Glossosomatidae showed a significant preference for sand and bedrock; this family did not utilize gravel and was found only in limited numbers in rubble.

In the order Diptera, the family Tipulidae showed no significant substrate preference but was found in greatest numbers in sand and in equal numbers in gravel, rubble and bedrock. The family Chironomidae had a significant preference for rubble but was common in sand and gravel; this family occurred in low numbers on bedrock. The family Simuliidae showed a significant preference for either gravel or rubble with low numbers utilizing either sand or bedrock. The family Blephariceridae had a significant preference for rubble. Some

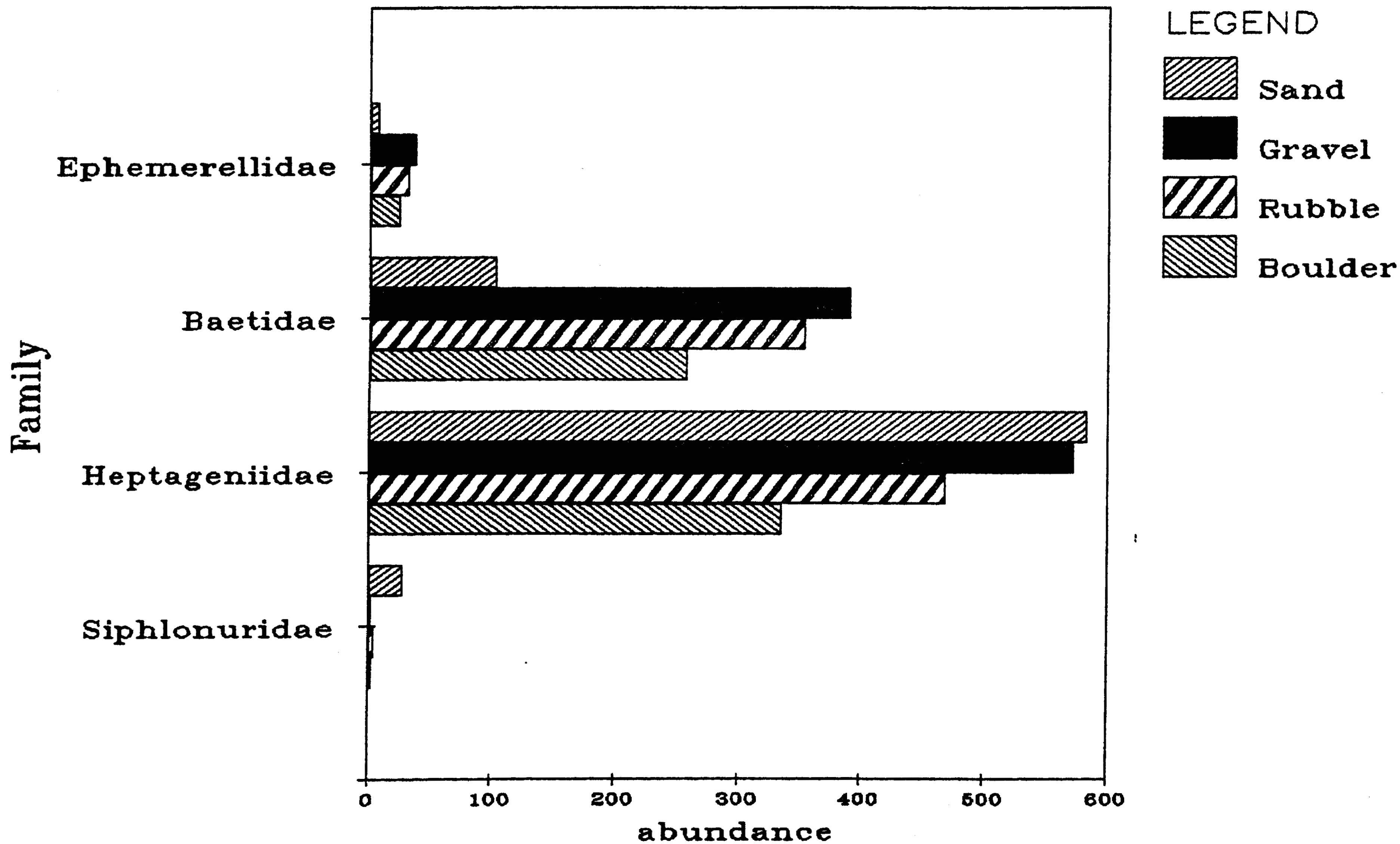
Table 32. Substrate Preference by Family for June 1987

Taxon	Substrate			
	Sand	Gravel	Rubble	Bedrock
EPHEMEROPTERA				
Ephemerellidae	2(8)*	15(38)	32(32)	7(25)
Baetidae	26(104)	154(392)	355(355)	74(259)
Siphlonuridae	7(28)	1(3)	5(5)	1(4)
Heptageniidae	146(584)	225(573)	469(469)	96(336)
PLECOPTERA				
Nemouridae	10(40)	20(51)	25(25)	14(49)
Chloroperlidae	32(128)	22(56)	45(45)	9(32)
Perlodidae	0	5(13)	12(12)	2(7)
TRICHOPTERA				
Rhyacophilidae	8(32)	21(53)	42(42)	8(28)
Hydropsychidae	0	16(41)	40(40)	1(4)
Glossosomatidae	3(12)	0	3(3)	2(7)
Brachycentridae	0	1(3)	1(1)	0
Limnephilidae	1(4)	0	5(5)	0
DIPTERA				
Chironomidae	8(32)	14(36)	58(58)	4(14)
Simuliidae	3(12)	22(56)	57(57)	1(4)
Ceratopogonidae	0	3(8)	2(2)	0(0)
Tipulidae	7(28)	5(13)	10(10)	3(11)
Blephariceridae	1(4)	3(8)	2(2)	0
COLEOPTERA				
Elmidae	10(40)	14(36)	25(25)	9(32)

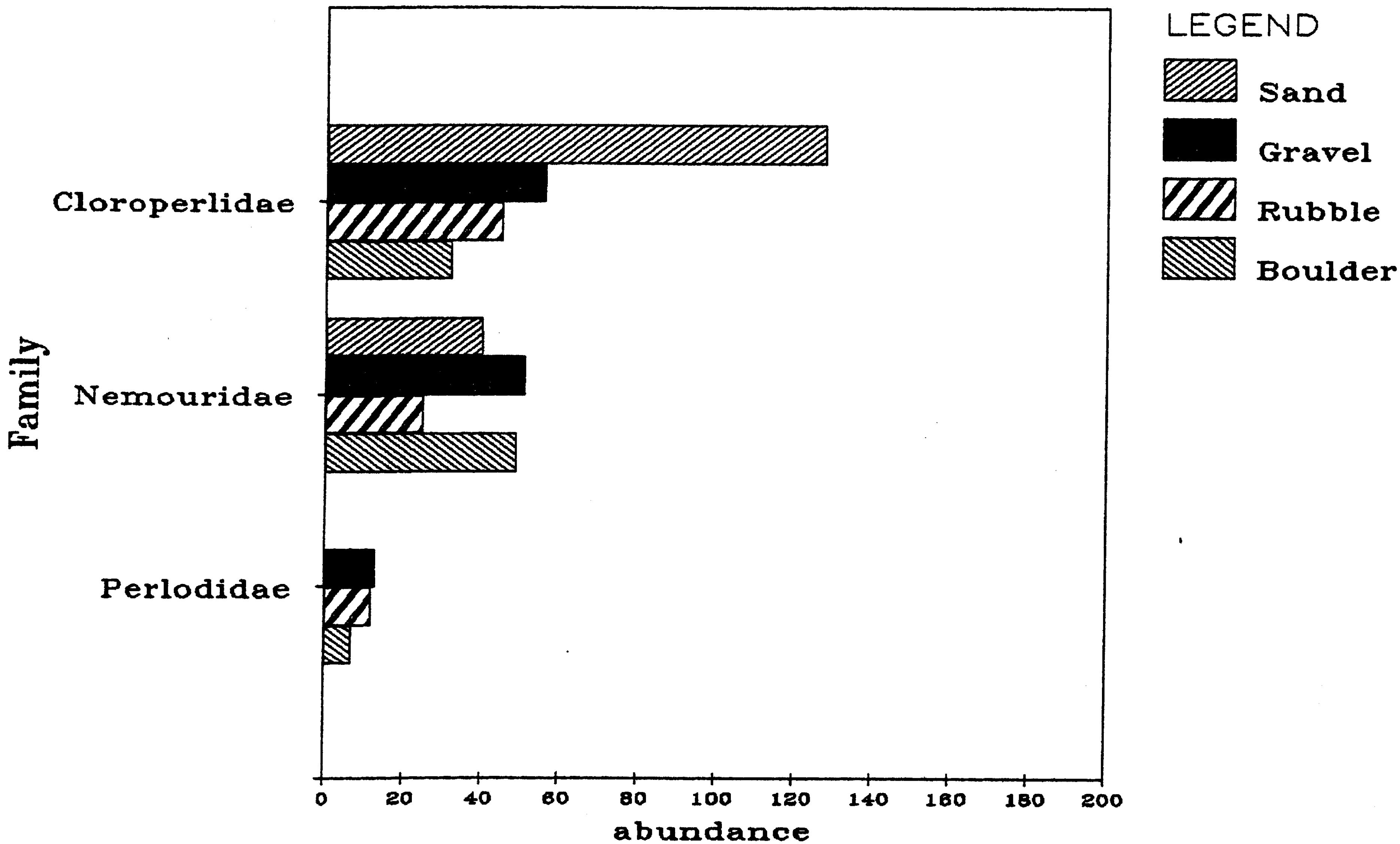
*( ) Adjusted data. See methods for explanation.

Substrate Preference for Ephemeroptera June 1987

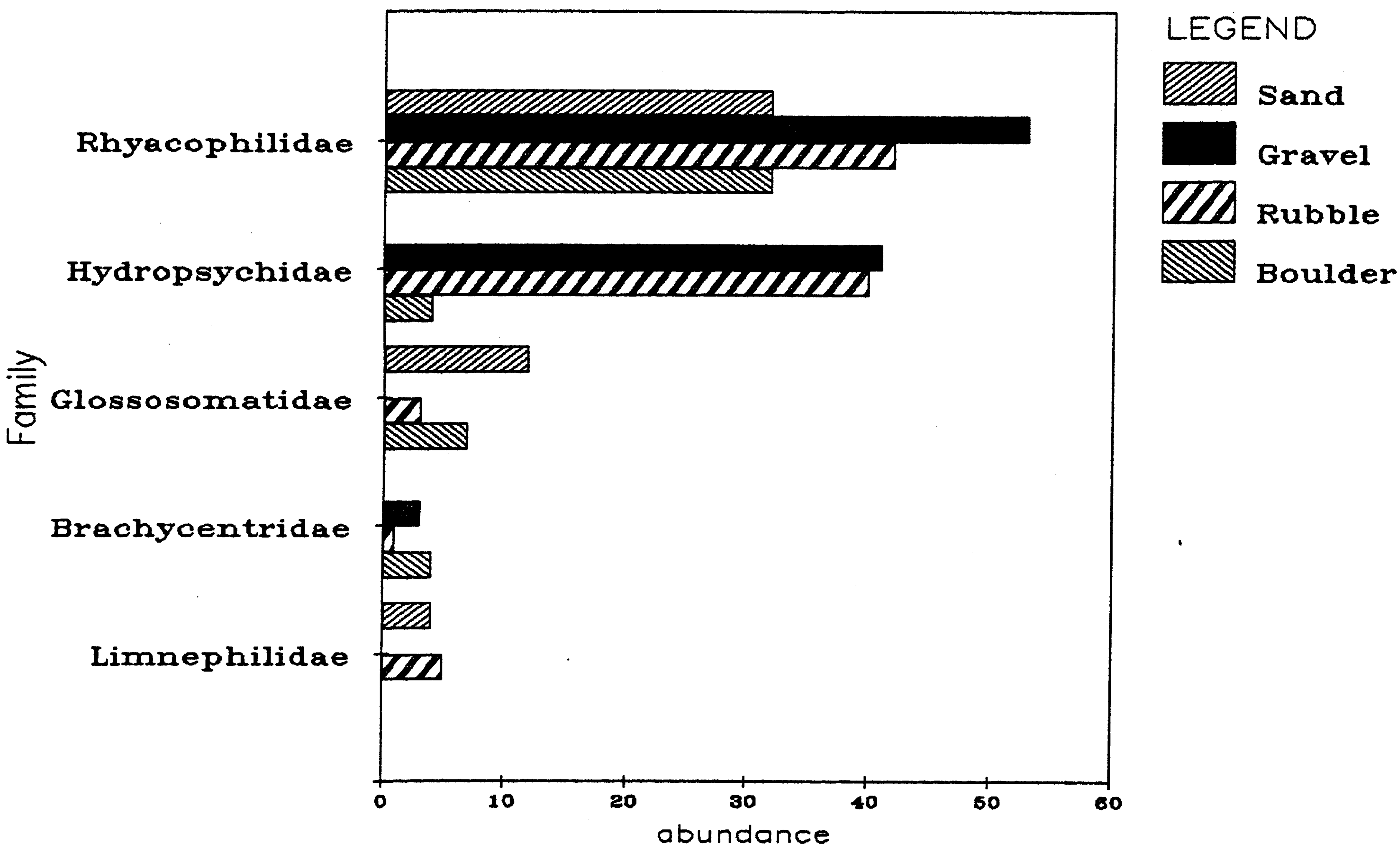
(Figure 18)



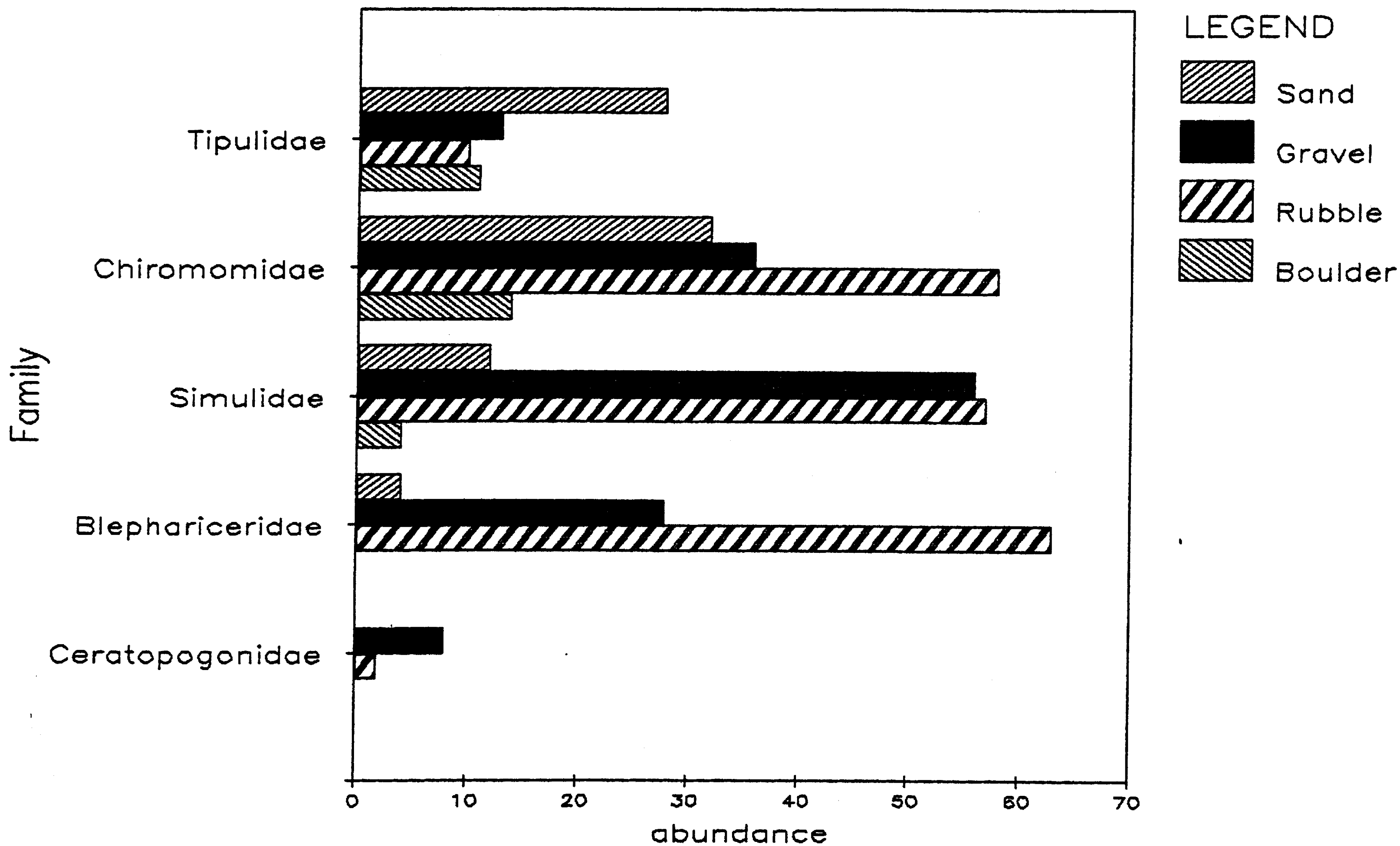
Substrate Preference for Plecoptera
June 1987
(Figure 19)



Substrate Preference for Trichoptera
June 1987
(Figure 20)

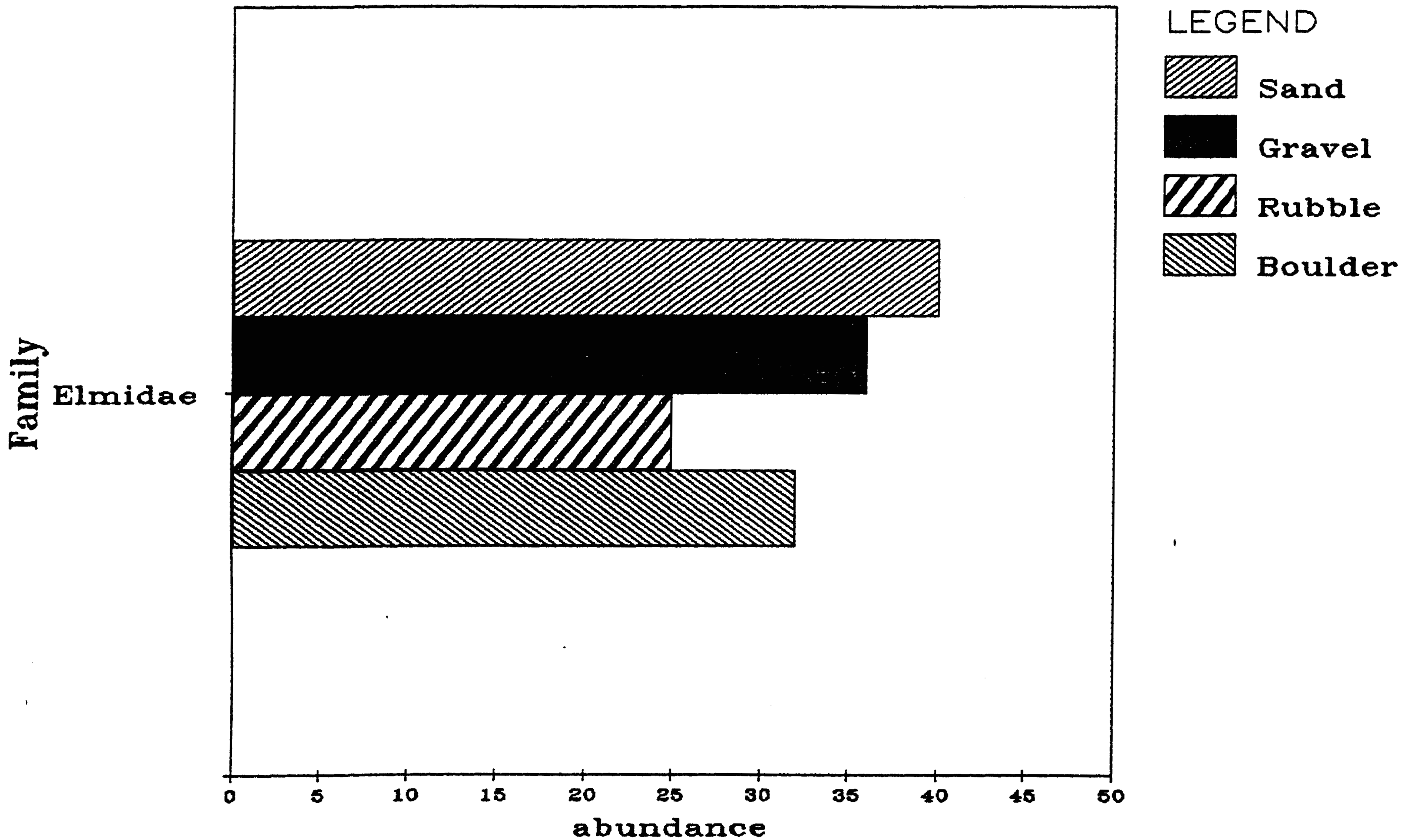


Substrate Preference for Diptera
June 1987
(Figure 21)



Substrate Preference for Coleoptera
June 1987

(Figure 22)



members of this family were found in gravel and sand, with no members found on bedrock. The family Ceratopogonidae showed no significant substrate preference but were found most often on gravel and only rarely on rubble. No members of this family were found in sand or on bedrock.

In the order Coleoptera, the family Elmidae showed no significant substrate preference and was distributed among all substrate types proportional to their frequency.

Substrate Preference in July

In the order Ephemeroptera (Table 33, Figures 23-27) the family Ephemerellidae showed no significant substrate preference but tended to utilize gravel and rubble more than sand or bedrock. The family Baetidae showed a preference for either gravel or bedrock. It was relatively well represented on rubble and was found in limited numbers on sand. The family Heptageniidae showed a very significant preference for both gravel and rubble, although it was common in sand and bedrock. The family Siphlonuridae showed a significant substrate preference for either sand or gravel and was found in very low numbers in rubble or bedrock.

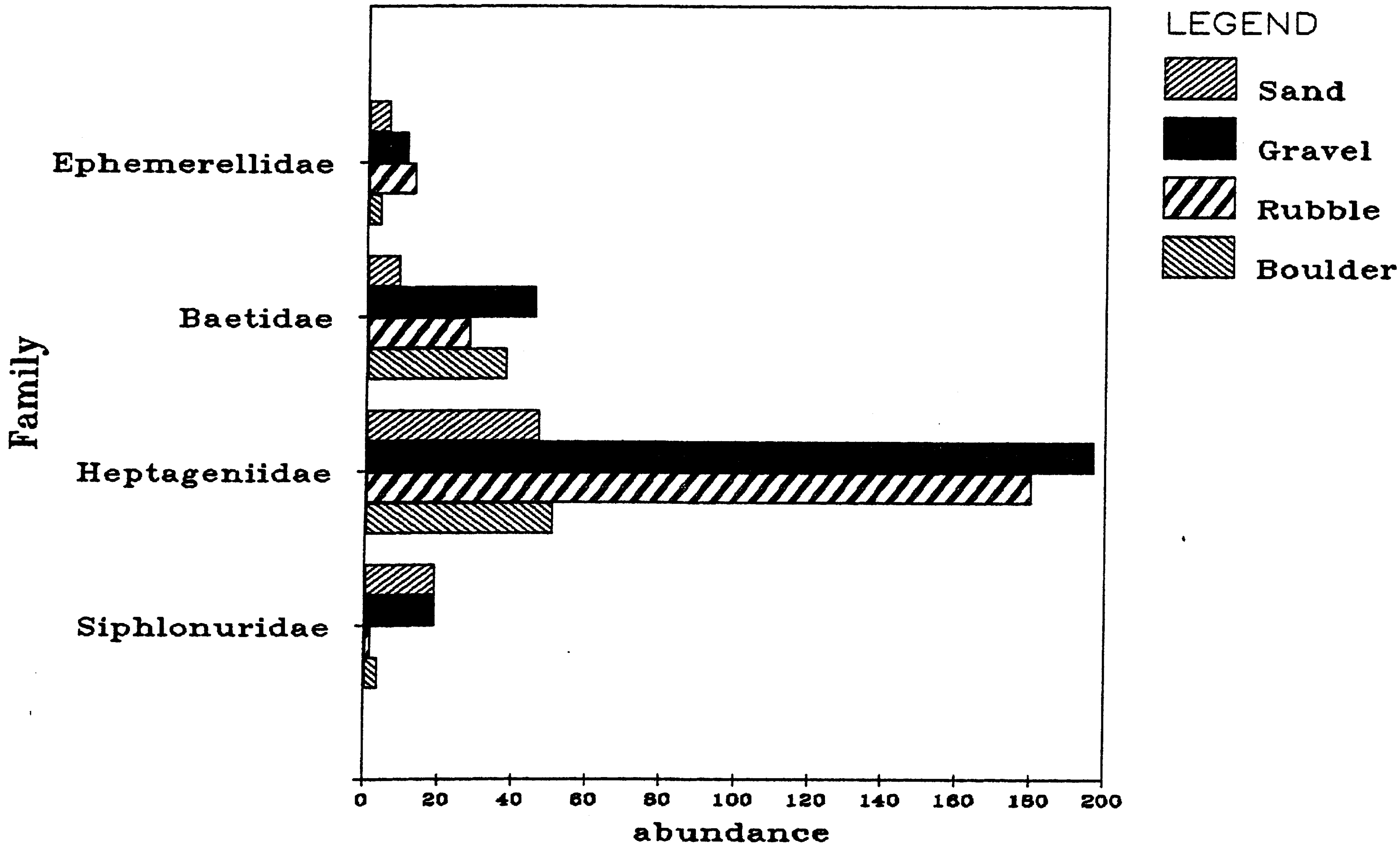
In the order Plecoptera, the family Chloroperlidae showed a significant preference for gravel; it was well represented in both sand and rubble and was found in limited numbers on bedrock. The family Nemouridae had a significant preference for both gravel and rubble over sand and bedrock. The family Perlodidae had a significant preference for either gravel or rubble; this family did not utilize sand or bedrock.

Table 33. Substrate Preference by Family for July 1987

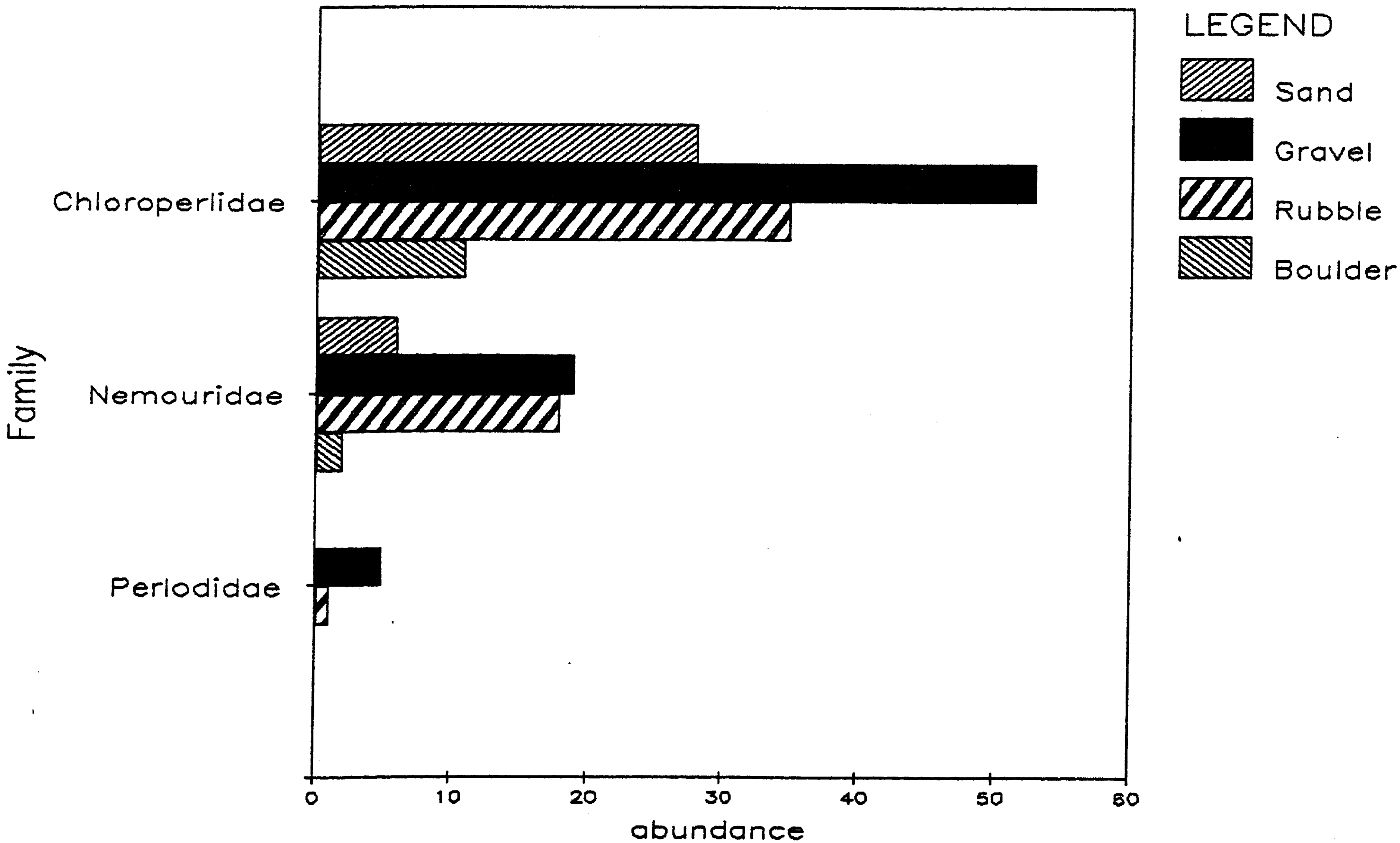
Taxon	Substrate			
	Sand	Gravel	Rubble	Bedrock
EPHEMEROPTERA				
Ephemerellidae	4(6)*	8(11)	13(13)	2(4)
Baetidae	6(9)	34(46)	28(28)	18(38)
Siphlonuridae	12(19)	14(19)	2(2)	2(4)
Heptageniidae	30(47)	145(197)	180(180)	24(51)
PLECOPTERA				
Nemouridae	4(6)	14(19)	18(18)	1(2)
Chloroperlidae	18(28)	39(53)	35(35)	5(11)
Perlodidae	0	4(5)	1(1)	0
TRICHOPTERA				
Rhyacophilidae	5(8)	15(20)	25(25)	4(8)
Hydropsychidae	0	3(4)	9(9)	0
Glossosomatidae	1(2)	0	4(4)	0
Brachycentridae	0	2(3)	0	1(2)
Limnephilidae	5(8)	0	1(1)	3(6)
DIPTERA				
Chironomidae	41(65)	80(109)	73(73)	4(8)
Simuliidae	1(2)	1(3)	5(5)	0
Ceratopogonidae	4(6)	4(5)	2(2)	1(2)
Tipulidae	12(19)	6(8)	6(6)	0
COLEOPTERA				
Elmidae	10(16)	19(26)	27(27)	0

* ( ) Adjusted data. See methods for explanation.

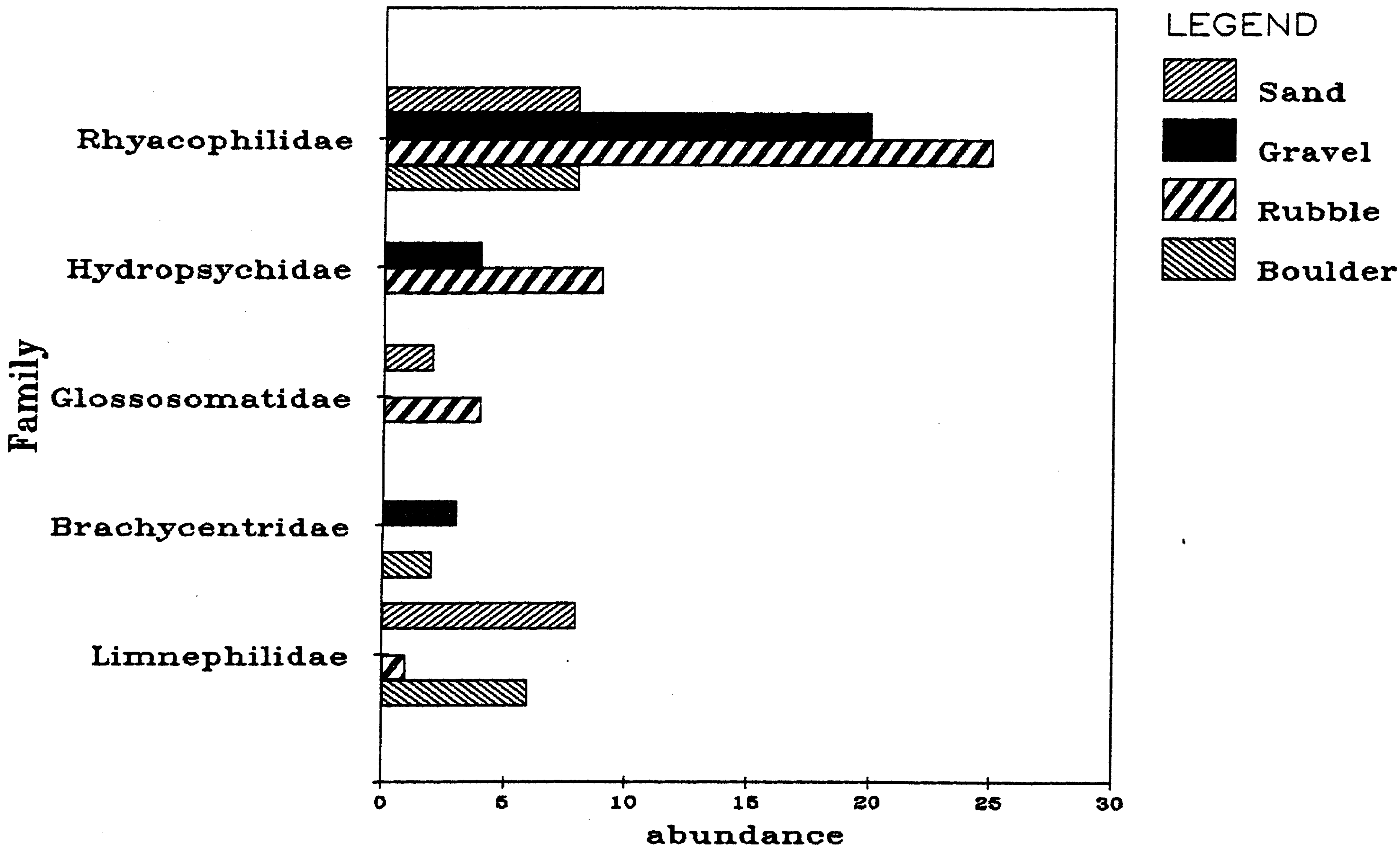
Substrate Preference for Ephemeroptera
July 1987
(Figure 23)



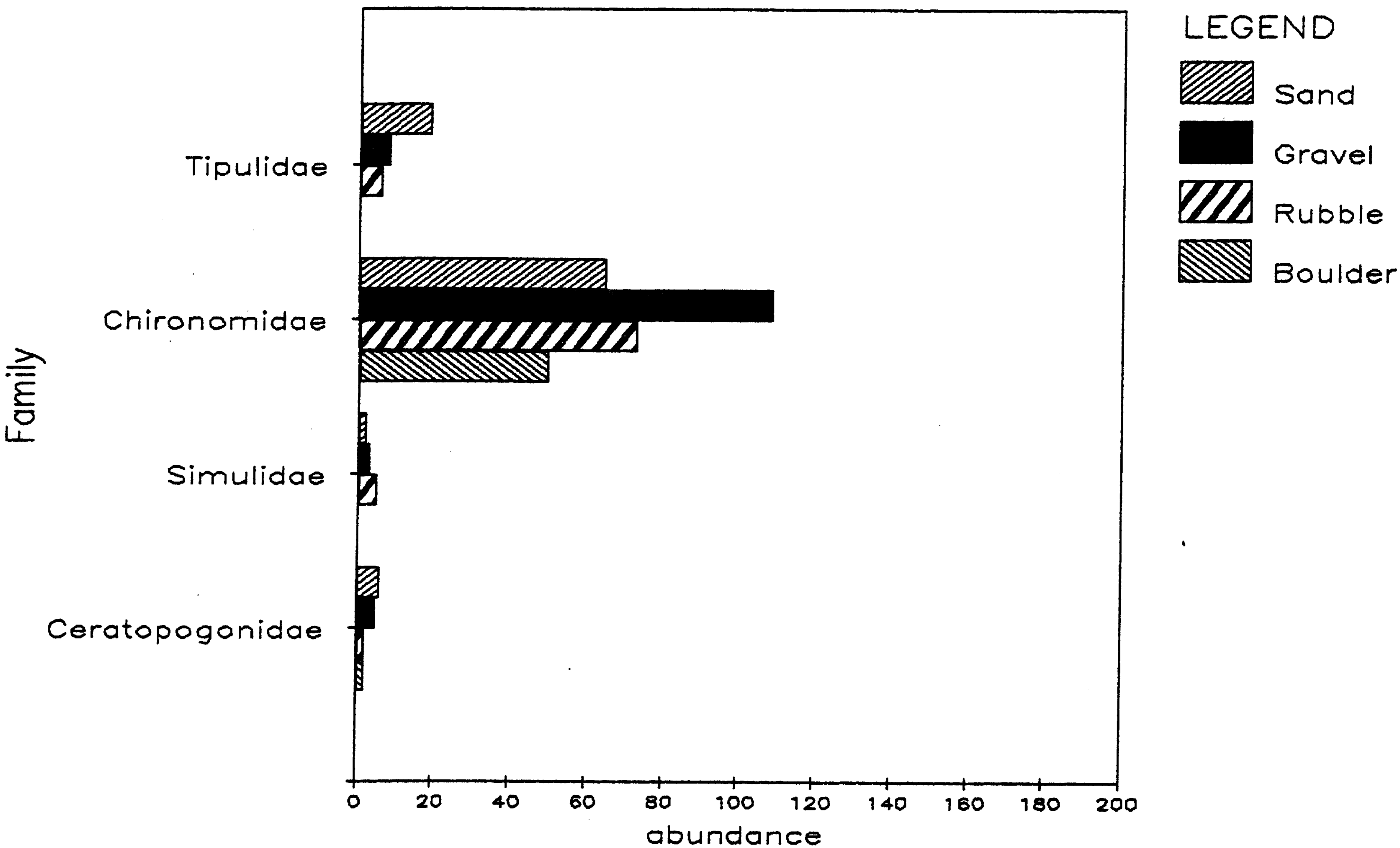
Substrate Preference for Plecoptera
July 1987
(Figure 24)



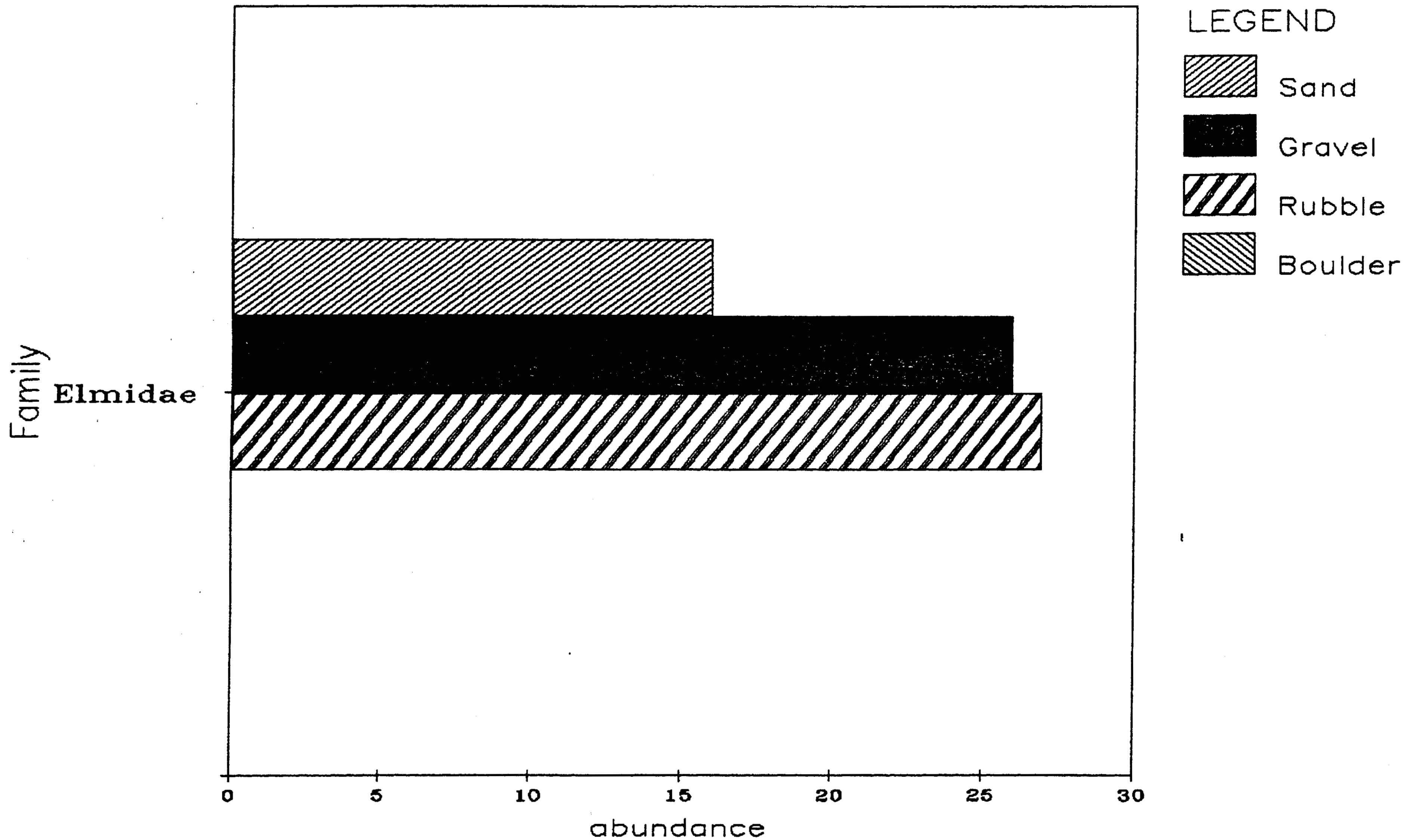
Substrate Preference for Trichoptera
July 1987
(Figure 25)



Substrate Preference for Diptera
July 1987
(Figure 26)



Substrate Preference for Coleoptera
July 1987
(Figure 27)



In the order Trichoptera, the family Rhyacophilidae showed a significant preference for either gravel or rubble and was found only in limited numbers on sand and bedrock. The family Hydropsychidae showed a significant preference for rubble; it was found in limited numbers on gravel and was not found on either sand or bedrock. The family Limnephilidae showed a significant preference for either sand or bedrock; this family did not utilize gravel and was poorly represented on rubble.

In the order Diptera, the family Tipulidae showed a significant preference for sand over gravel and rubble; it did not utilize bedrock. The family Chironomidae showed a significant preference for gravel but was well represented on sand, rubble and bedrock. The family Simuliidae showed no significant substrate preference. However this family was found in such limited numbers that it is difficult to determine a substrate utilization trend. The family Ceratopogonidae showed no significant substrate preference but was found in greater numbers on smaller substrates (sand and gravel) than on rubble or bedrock.

In the order Coleoptera, the family Elmidae showed a significant preference for either gravel or rubble, was well represented on sand but did not utilize bedrock.

Substrate Preference for September

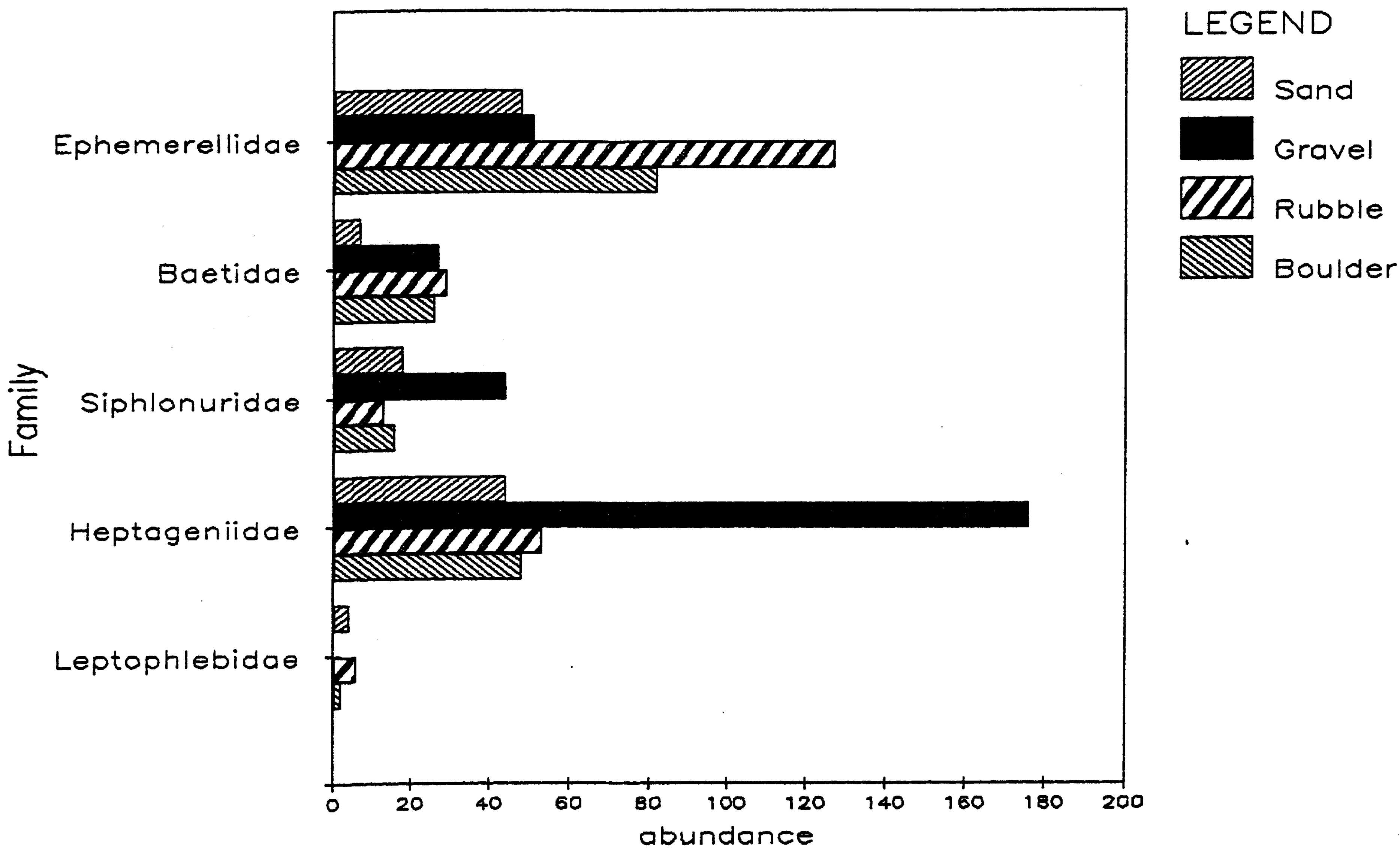
In the order Ephemeroptera (TAble 34, Figures 28-32), the family Ephemerellidae showed a significant substrate preference for rubble, was well represented on bedrock, and was common on sand and gravel. The family Baetidae showed no significant

Table 34. Substrate Preference by Family for September 1987

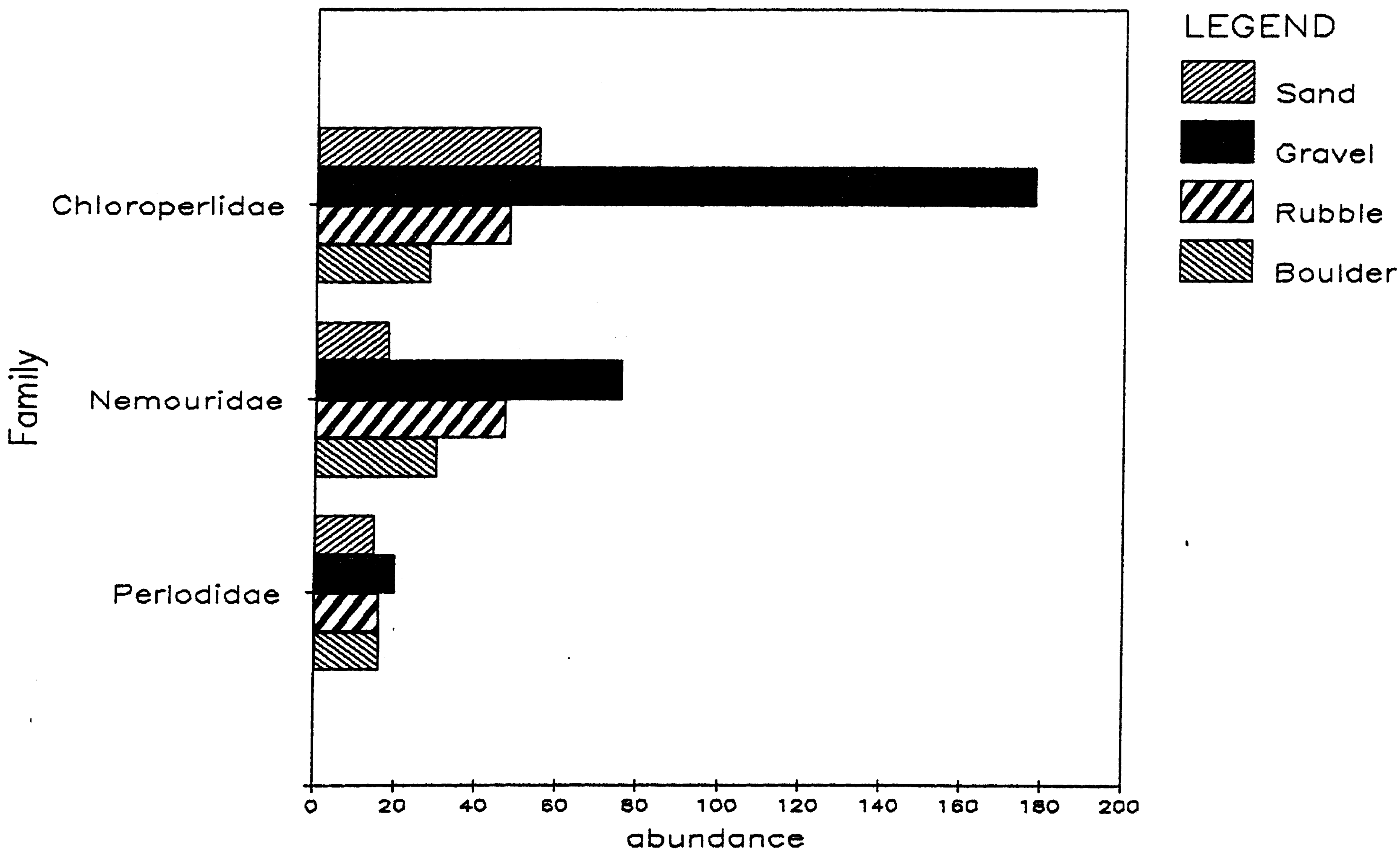
Taxon	Substrate			
	Sand	Gravel	Rubble	Bedrock
EPHEMEROPTERA				
Ephemerellidae	13(48)*	21(51)	127(127)	41(82)
Baetidae	2(7)	11(27)	29(29)	13(26)
Siphlonuridae	5(18)	18(44)	13(13)	8(16)
Heptageniidae	12(44)	72(176)	53(53)	24(48)
Leptophlebidae	1(4)	0	6(6)	1(2)
PLECOPTERA				
Nemouridae	5(18)	31(76)	47(47)	15(30)
Chloroperlidae	15(55)	73(178)	48(48)	14(28)
Perlodidae	4(15)	8(20)	16(16)	8(16)
TRICHOPTERA				
Rhyacophilidae	5(18)	21(51)	28(28)	14(28)
Hydropsychidae	1(4)	18(44)	40(40)	36(72)
Glossosomatidae	1(4)	15(37)	19(19)	15(30)
Brachycentridae	0	0	6(6)	4(8)
Limnephilidae	2(7)	1(2)	1(1)	1(2)
DIPTERA				
Chironomidae	14(51)	40(98)	80(80)	21(42)
Ceratopogonidae	8(29)	9(22)	11(11)	3(6)
Tipulidae	6(22)	6(15)	21(21)	7(14)
COLEOPTERA				
Elmidae	8(29)	17(42)	64(64)	25(50)

* ( ) Adjusted data. See methods for explanation.

Substrate Preference for Ephemeroptera
September 1987
(Figure 28)

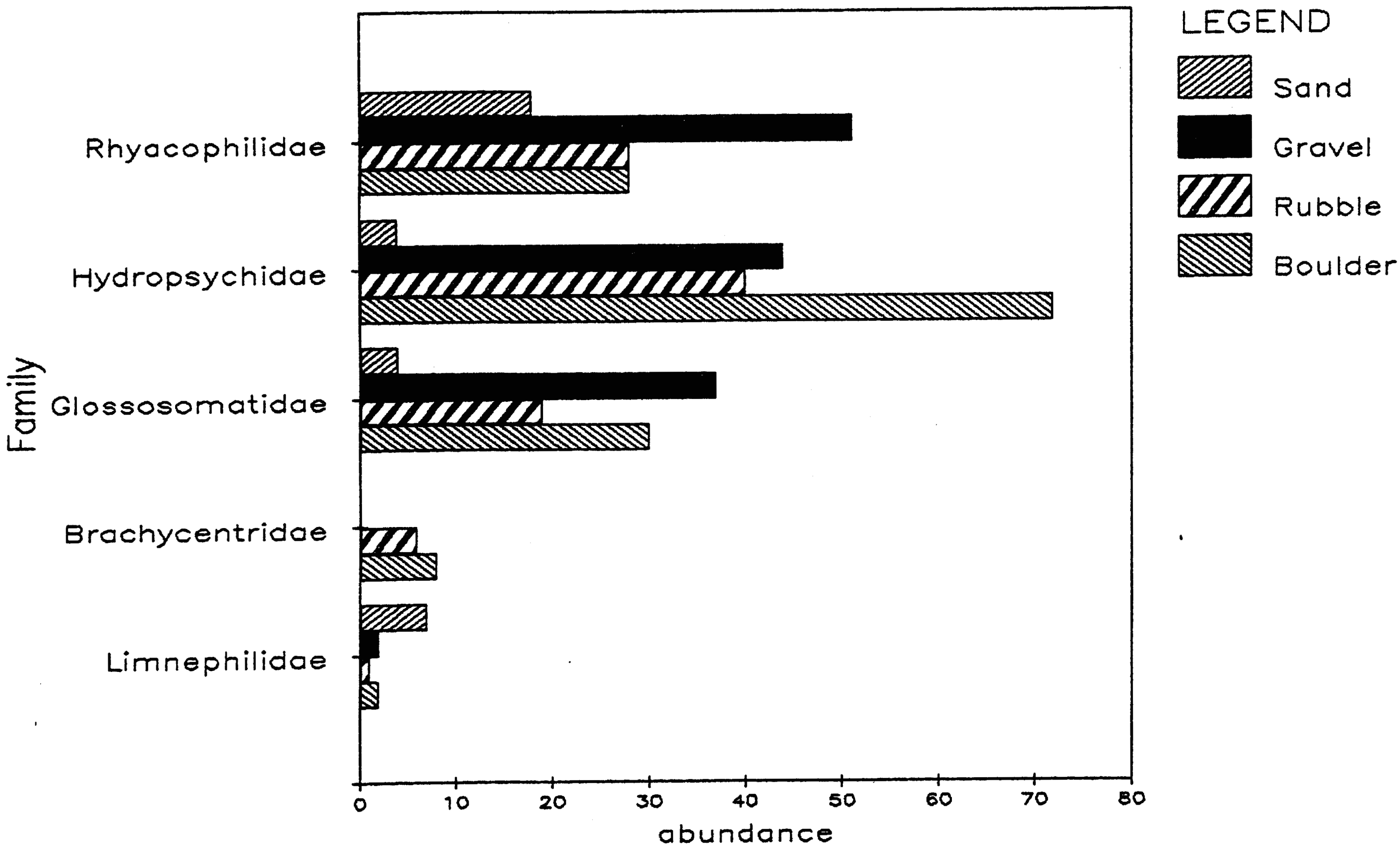


Substrate Preference for Plecoptera
September 1987
(Figure 29)

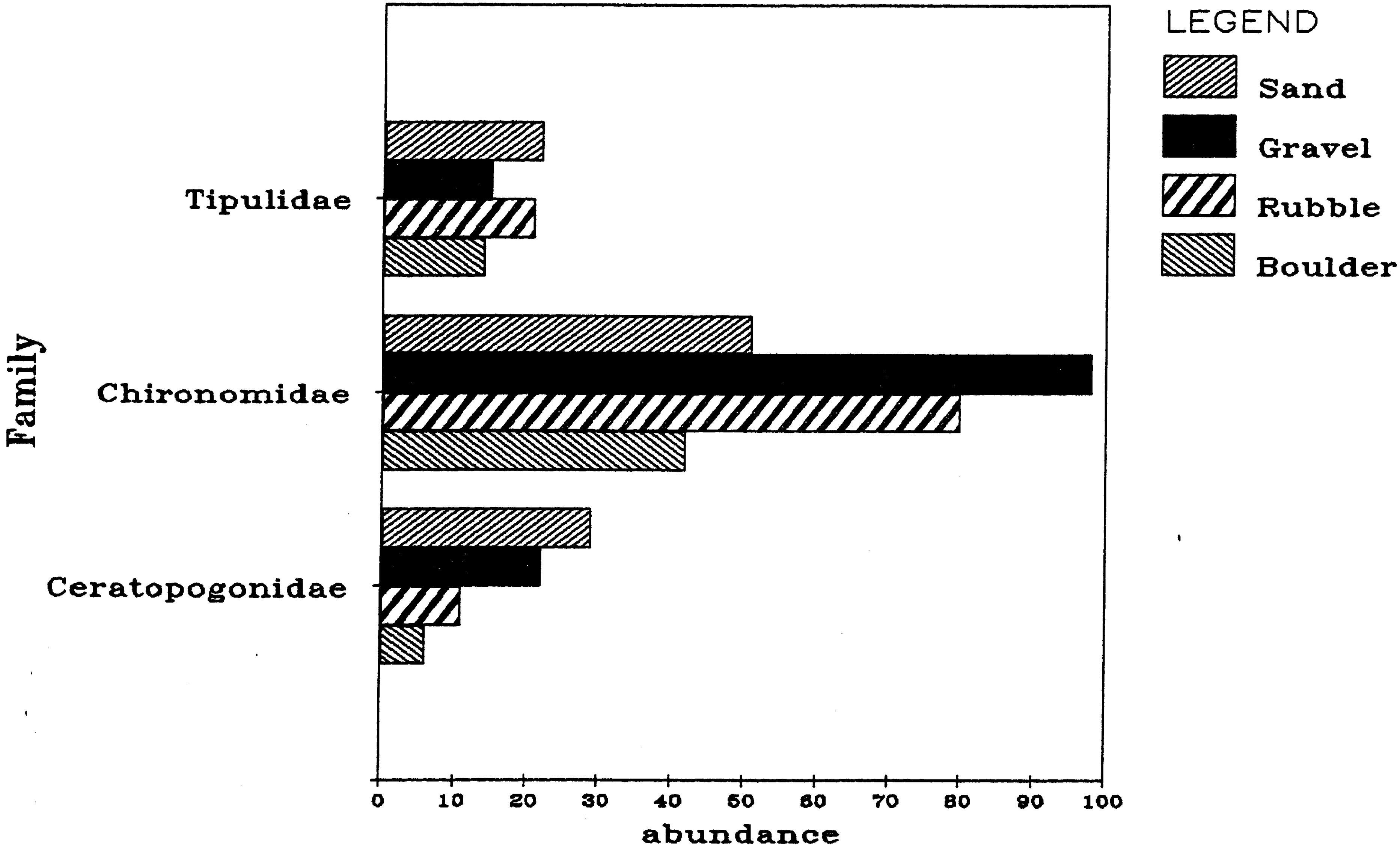


Substrate Preference for Trichoptera September 1987

(Figure 30)

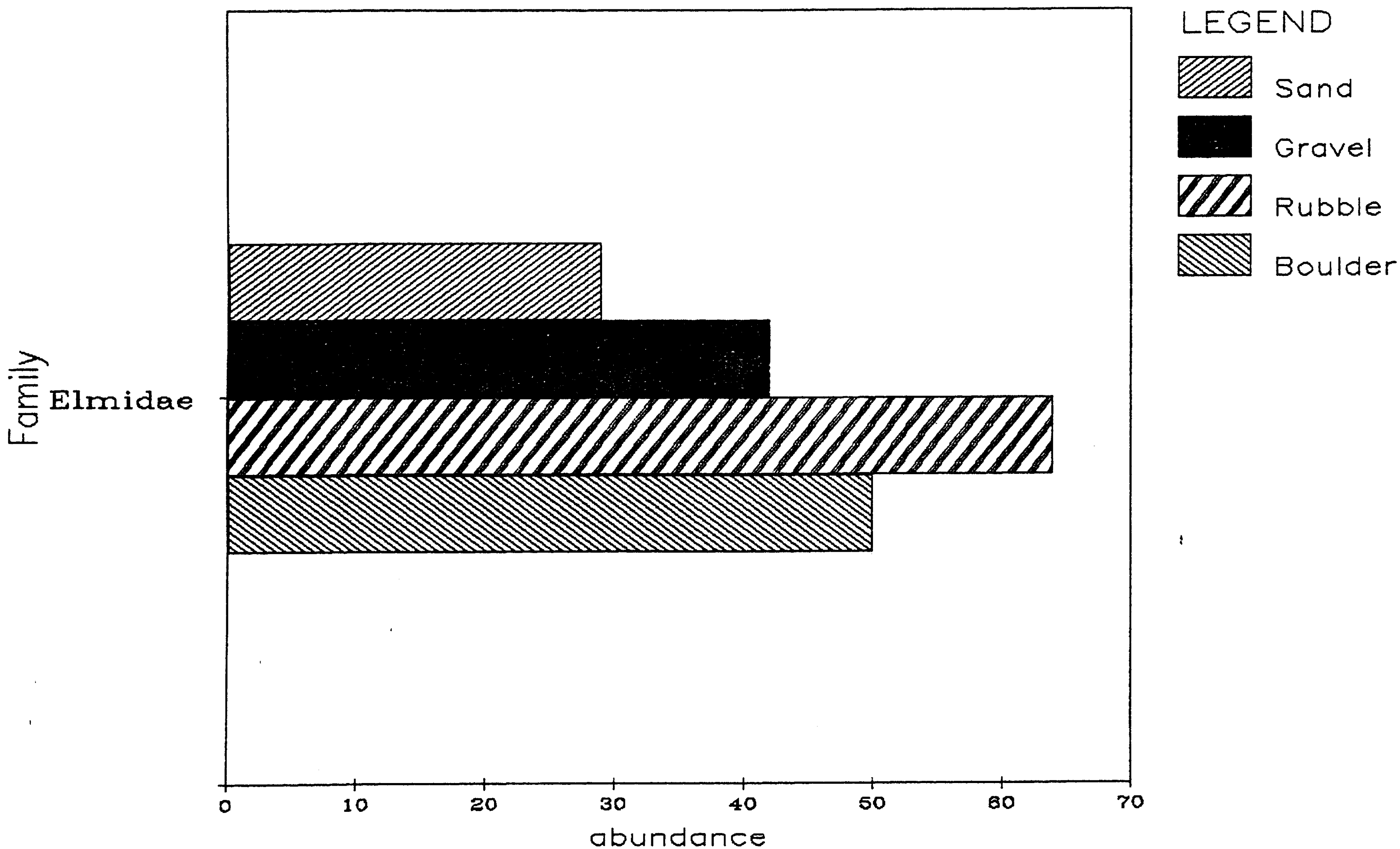


Substrate Preference for Diptera
September 1987
(Figure 31)



Substrate Preference for Coleoptera
September 1987

(Figure 32)



substrate preference, although it was well represented on gravel, rubble and bedrock and was found only in limited numbers on sand. The family Siphlonuridae showed a significant preference for gravel, but it was well represented on sand, rubble and bedrock. The family Leptophlebidae showed no significant substrate preference but was most frequently on rubble.

In the order Plecoptera, the family Chloroperlidae showed a significant preference for gravel, was common on sand and rubble and was only found in limited numbers on bedrock. The family Nemouridae showed a significant preference for gravel, was well represented on bedrock and rubble and was common on sand. The family Perlodidae showed no significant substrate preference and utilized all substrates proportional to their frequency.

In the order Trichoptera, the family Rhyacophilidae showed a significant preference for gravel, was well represented in rubble and bedrock and was common in sand. The family Hydropsychidae showed a significant preference for bedrock; although it was well represented in gravel and rubble and was found in limited numbers in sand. The family Glossosomatidae showed no significant substrate preference, but it was common in gravel, rubble and bedrock and found in limited numbers in sand. The family Brachycentridae showed no significant substrate preference, however, it utilized only rubble and bedrock and was not found on either sand or gravel. The family Limnephilidae showed no significant substrate preference but was found in greater numbers on sand than the other substrates.

In the order Diptera, the family Tipulidae showed no significant substrate preference. The family Chironomidae showed a significant substrate preference for both gravel and rubble but was common on sand and bedrock. The family Ceratopogonidae showed a strong substrate preference for sand, was common on gravel, less common on rubble and rare on bedrock.

In the order Coleoptera, the family Elmidae showed a significant substrate preference for rubble, although it was common on all substrates.

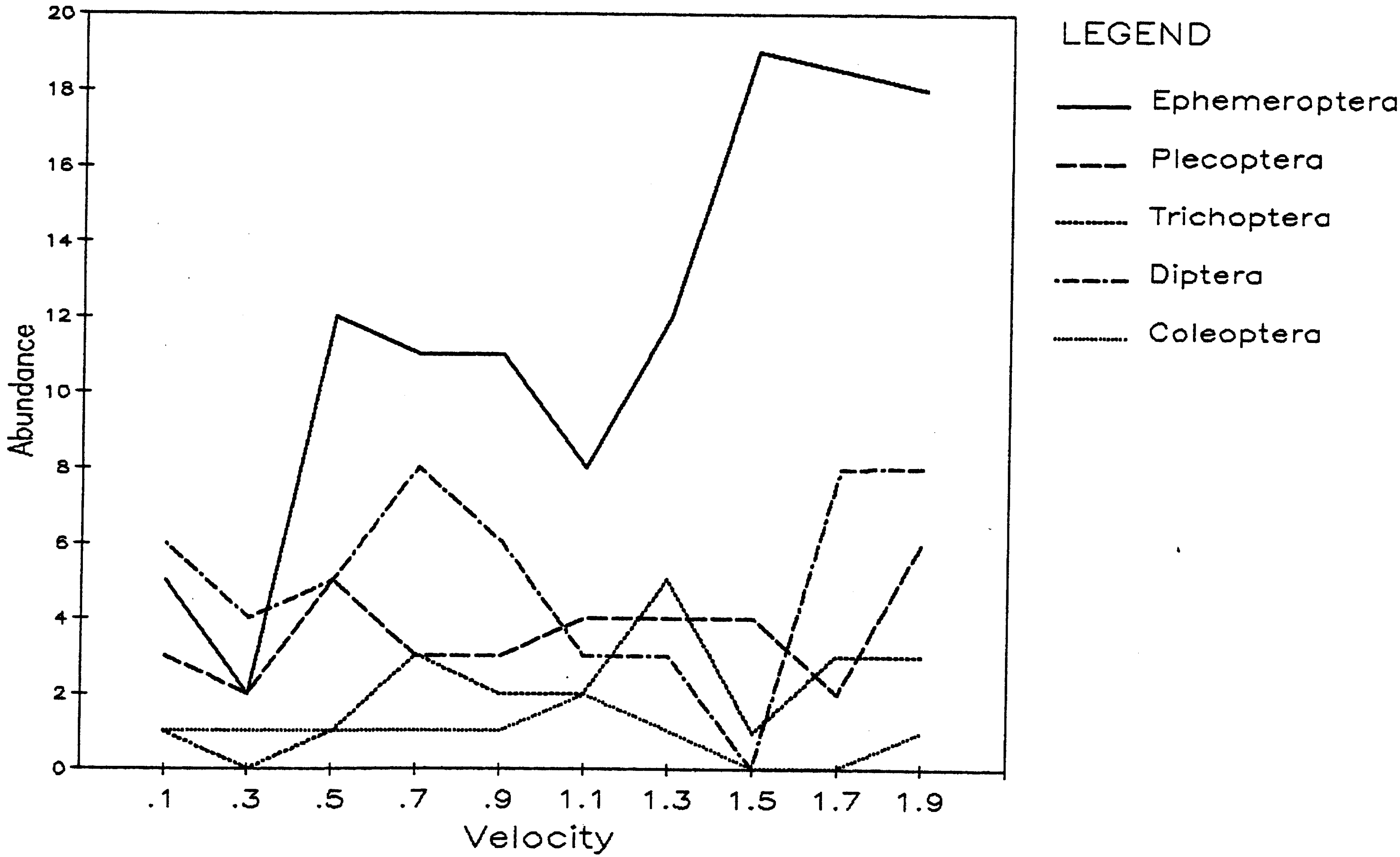
When total adjusted numbers are compared for insect substrate preference, gravel has the highest number (2,785), followed by rubble (2,206), sand (1,670), and bedrock (1,374).

<u>Water Velocity Preference by Order for 1987</u>

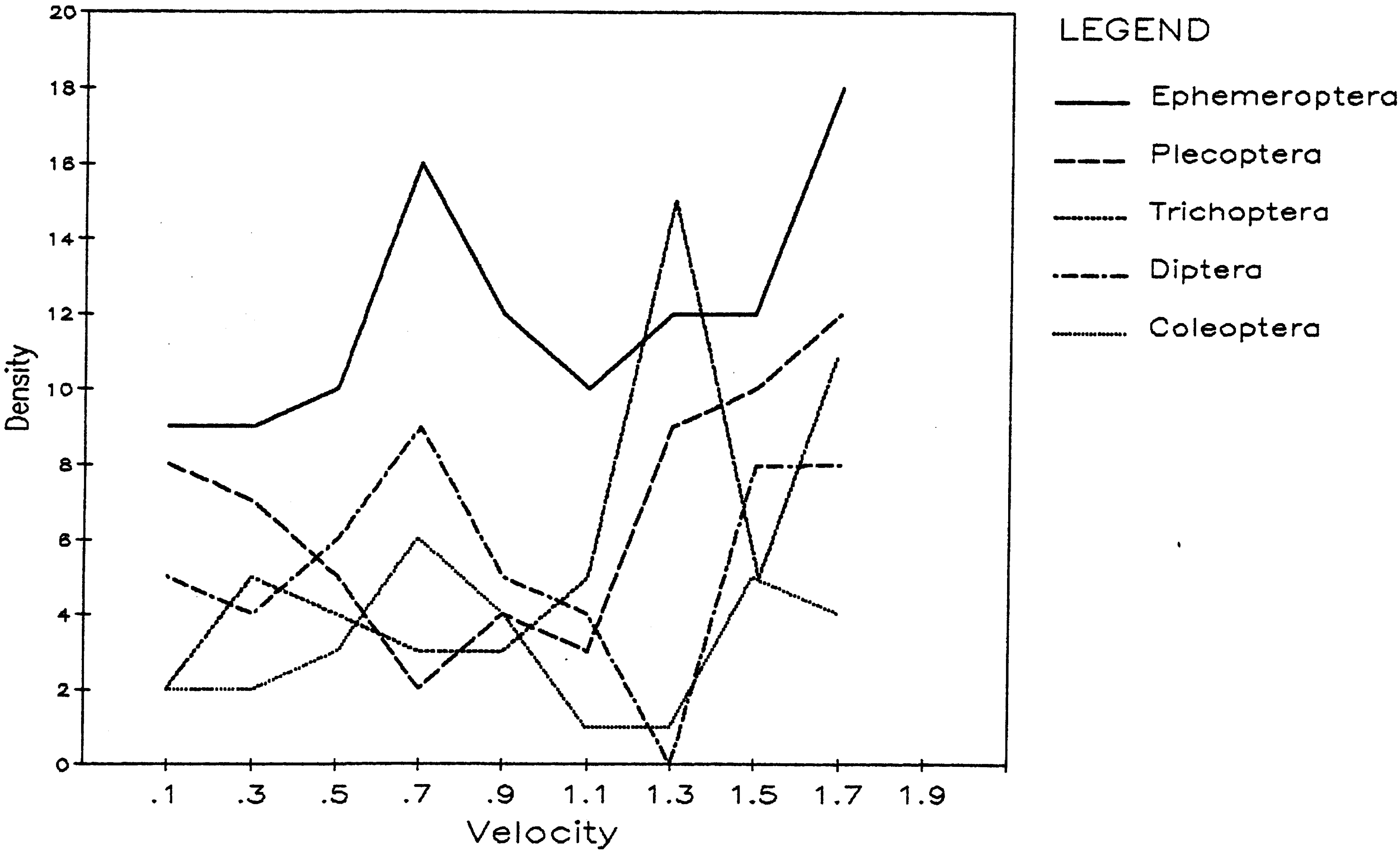
In July (Figure 33), the order Ephemeroptera showed a strong preference for higher velocities. As mean velocity increased from 0.4 ft/s to 2.0 ft/s (the highest velocity recorded) the number of Ephemeroptera increased. Trichoptera preferred velocities over 0.6 ft/s. Diptera showed a preference for mean velocities between 0.4 and 0.8 ft/s and mean velocities over 1.4 ft/s. Coleoptera and Plecoptera showed no mean velocity preference.

In September (Figure 34), Ephemeroptera again showed a preference for mean velocities above 0.4 ft/s. Plecoptera preferred velocities between 0.0 and 0.4 ft/s and velocities greater than 1.2 ft/s. Trichoptera were most abundant in mean velocities greater than 1.0 ft/s. Diptera preferred mean velocities over 1.4 ft/s but was well represented at all velocities. Coleoptera did not show a mean velocity preference.

Water Velocity Preference by Order
July 1987
(Figure 33)



Water Velocity Preference by Order
September 1987
(Figure 34)



Water Depth Preference by Order for 1987

For the month of July (Figure 35), Ephemeroptera showed a preference for water depths between 0.2 and 0.9 ft. Plecoptera preferred depths between 0.1 and 0.8 ft. Trichoptera showed a strong preference for depths between 0.75 and 0.95 ft. Diptera and Coleoptera showed no strong trends for any specific range of water depth.

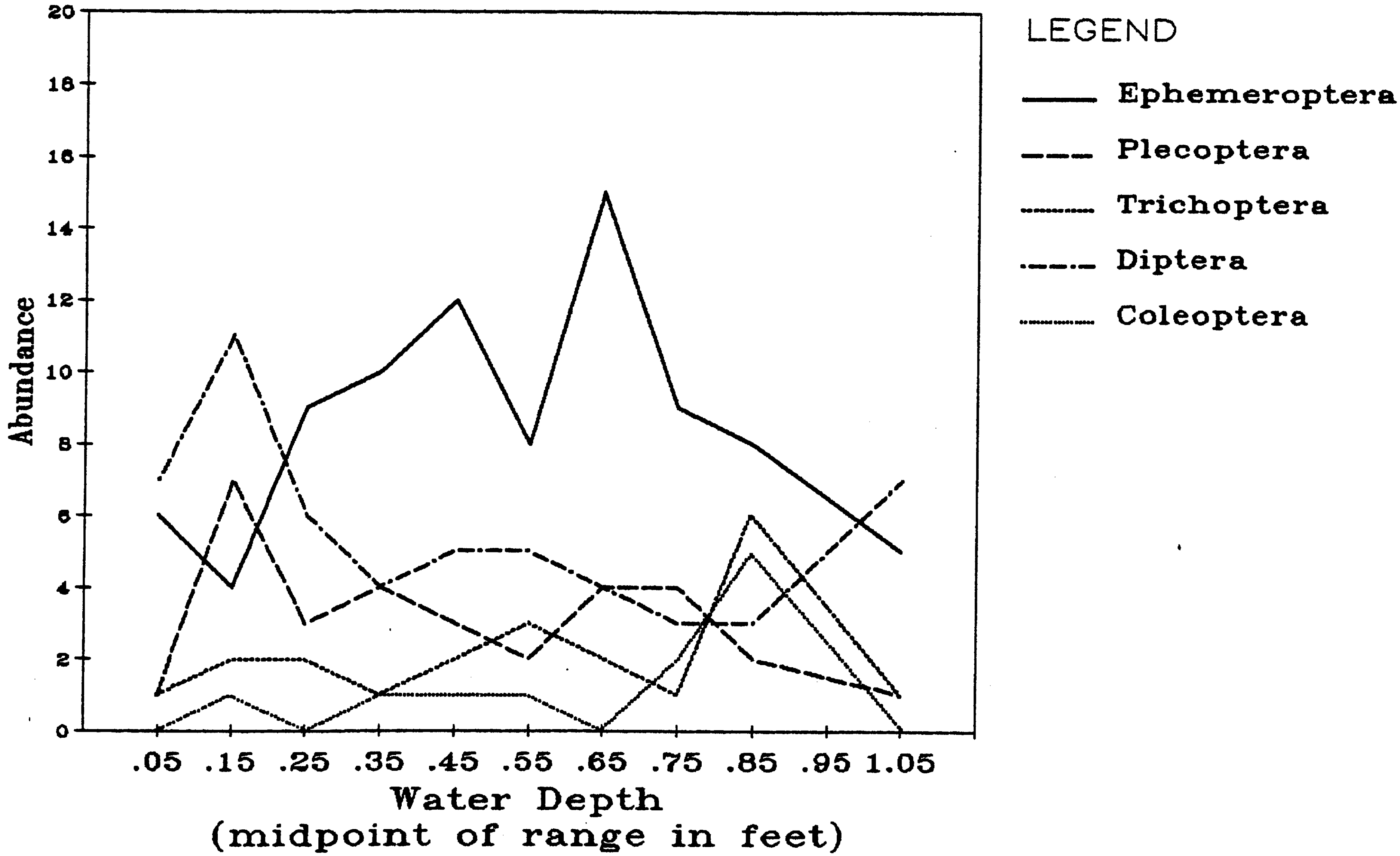
For the month of September (Figure 36) Ephemeroptera showed a slight preference for water depths between 0.2 and 0.3 ft. Plecoptera was most abundant between 0.2 and 0.8 ft. Trichoptera preferred depths between 0.2 and 0.9 ft. Diptera and Coleoptera again showed no specific water depth preference.

Evaluation of Mitigative Flushing Flows on the North Fork

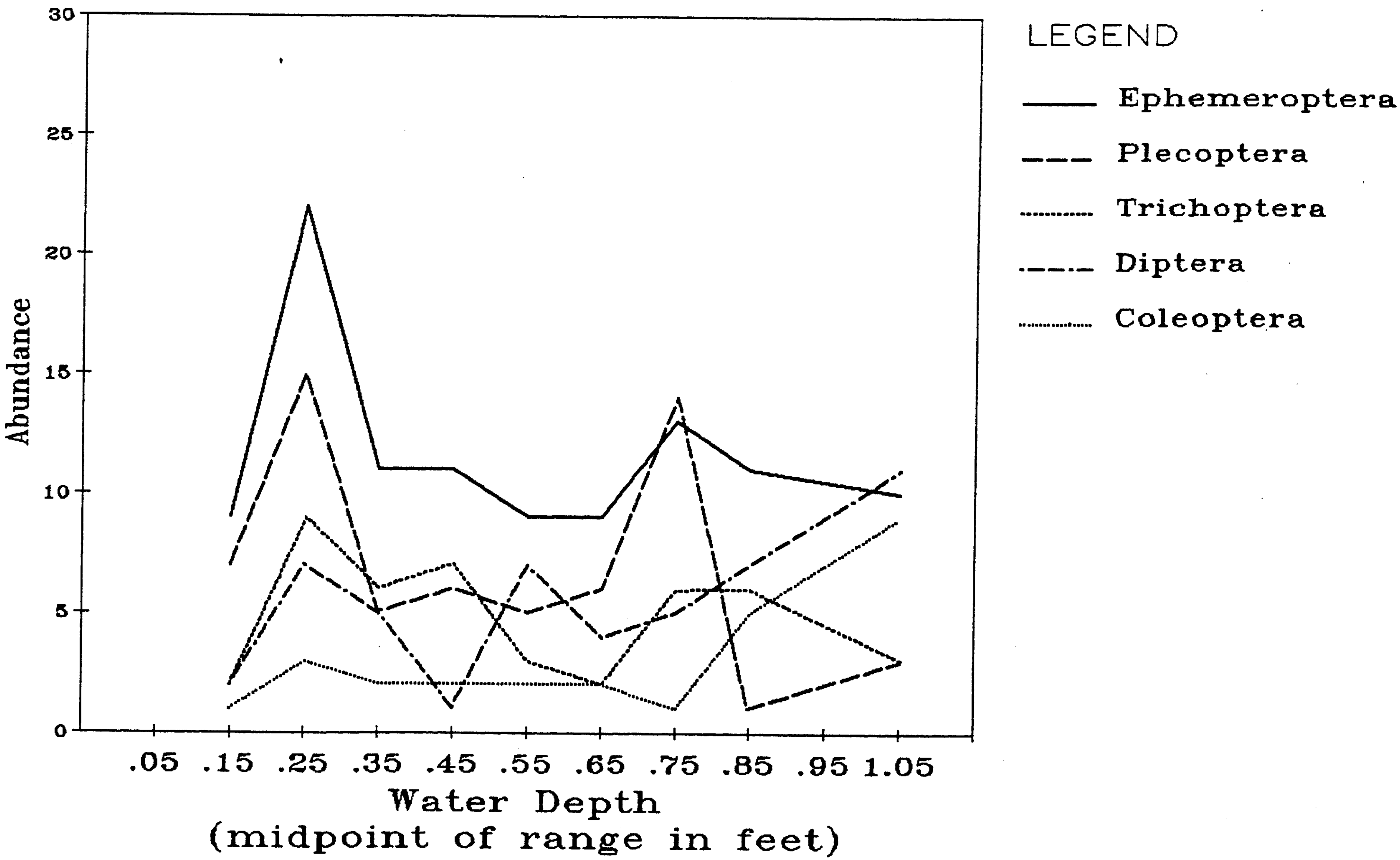
In 1984, the Wyoming Water Research Center initiated a research project entitled, "Development of methodology to determine flushing flow requirements for channel maintenance purposes". The area of study was the North Fork of the Little Snake River where Wesche et al. (1977) had recommended both maintenance and flushing flow regimes. Some of the objectives of the study were to document the rate of change through various channel characteristics resulting from aggradation/degradation processes under altered flow regimes and quantify the physical and hydraulic properties needed to transport deposited sediment through natural channels.

The sediment spill on the North Fork occurred in the late summer of 1984. Because of the lack of adequate streamflow during this season, flushing flow releases and the study of the

Water Depth Preference by Order
July 1987
(Figure 35)



Water Depth Preference by Order
September 1987
(Figure 36)



response of the deposited material to the runoff hydrograph did not begin until the spring of 1985. Based on the 1985 investigation, the recommended mitigative flushing flow regime was implemented in 1986.

Wesche et al. (1987) reported that three major runoff peaks occurred during 1985 which equalled or exceeded the magnitude and duration of the 1977 flushing flow recommendation. Each peak had a maximum instantaneous discharge of 105 cfs while the maximum mean daily peaks ranged from 73 to 80 cfs (Figure 37). Snowpack in the North Fork watershed was well above normal during the winter of 1985-86. Combined with an agreement to pass all flow during the required three flushing periods, this resulted in flushing releases well in excess of the required 60 cfs in 1986. Peak mean daily discharges approached 250 cfs. Due to needed maintenance on the diversion system, additional flushes were also released in late June and early July. In 1987, a 3-day flush was released in late May which did not exceed 50 cfs.

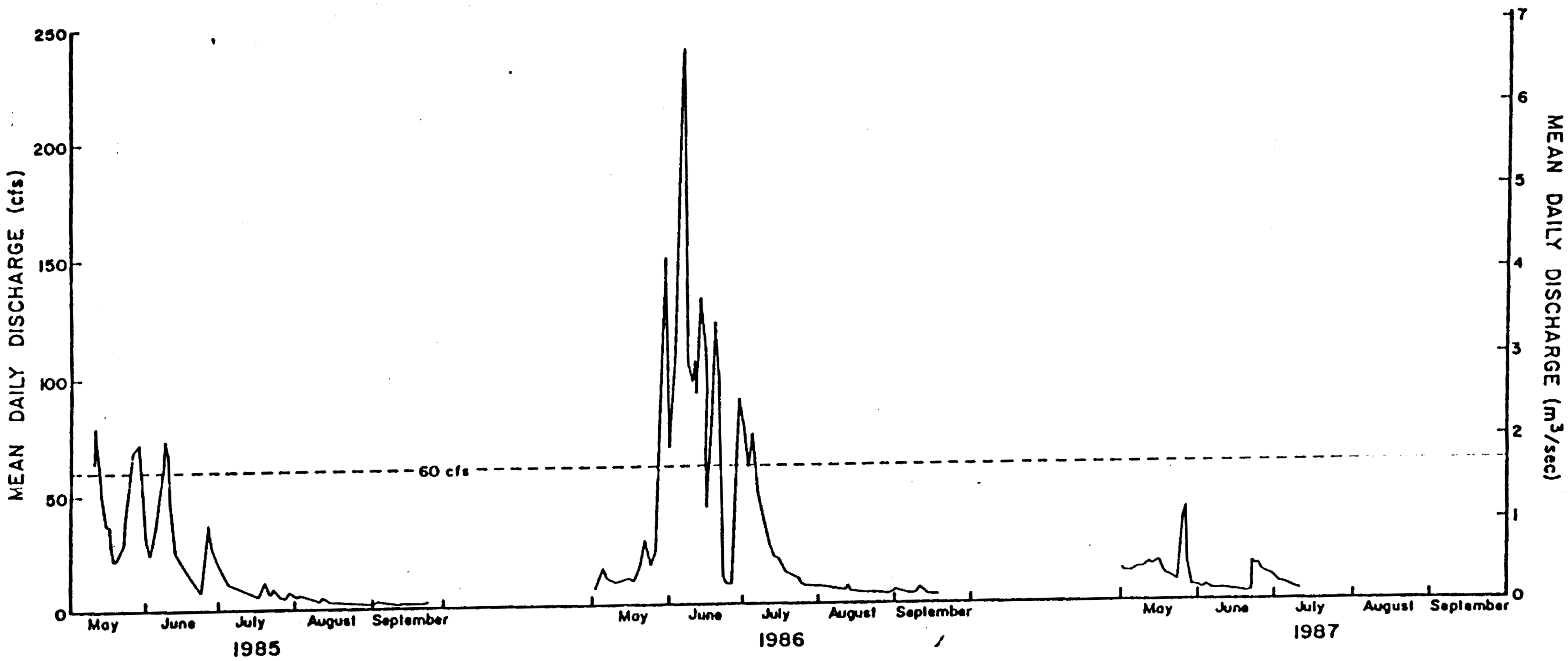


Figure 37. Hydrographs for 1985, 1986, and 1987 at Site 6, North Fork of the Little Snake River (Wesche et al. 1987)

Discussion

"From all the above considerations it well be clear that it is extremely difficult to obtain quantitative data on the benthic fauna of running water, and such data as can be obtained are bound to be very approximate. It is therefore at best a dubious procedure to multiply up from, say grams per one-tenth of a square meter to kilograms per hectare. Even though this may have to be done if we are to begin to understand the biological productivity of running water, we should not forget its very shaky foundations."

H. B. N. Hynes The Ecology of Running Water

Ecological Indices

For the years 1985, 1986, and 1987 the general trend was for diversity, richness, and evenness to increase from June or July through September. As the season progressed there was an increase in the number of families represented. Also, as the summer progressed the proportion of dominant families (especially Heptageniidae and Baetidae) decreased because of emergence. In temperate latitudes investigators who have sampled at various times during the year have found definite seasonal trends in faunal density (Gaufin 1959, Nelson and Scott 1962, Logan 1963, and Hynes 1961). All agree that under normal conditions the number of organisms decreases in spring and early summer, primarily because of the emergence of adults. Abundance rises again in late summer and autumn as larvae hatch from eggs, and then declines during the winter period since there is little or no recruitment (Hynes 1970).

Abundance and richness showed a marked decrease in 1986. This appears to be a function of erratic water flow. Sprules (1947), while studying insects emerging into traps on a stream in Algogonquin Park, found that a seven day flood, caused by the rupture of a beaver dam, resulted in his catching only about half the number of adults during 1940 as he had caught in 1939. Gaufin (1959) found that in the Provo River, Utah, a mountain stream with high runoff, the lowest faunal abundance was during the period from April to June. Some of this reduction was attributed to the difficulties of sampling during high water and some to the emergence of early species of Plecoptera, but most of the reduction was attributed to losses caused by wash out.

Site 6, the heavily impacted site, reflected the same general trends as all of the other sites. For this site all representative families were present for all three years. Site 6 had the lowest measure of abundance (43 organisms/0.10m^2) for all sites for all years. This may be a function of the erratic hydrograph for 1986 compounded by an unstable substrate (sand).

The site having the highest richness and abundance was site 8 in September of 1985. At this site and date all major families were represented and each was fairly abundant. This station is part of a braided channel and the lower flows along with a rubble substrate may have provided an optimum site. However, this site also had the lowest richness and evenness in September of 1987 for the nine sites. This could have been due to even lower flows in 1987 which allowed for a deposit of a fine layer of silt over the substrate. Rabeni and Minshall (1977) found that a light layer of silt reduced the abundance of seven taxa when added to trays of coarse substrate placed in a stream.

Proportion of Aquatic Macroinvertebrates

For the North Fork of the Little Snake River, Ephemeroptera, Plecoptera, Trichoptera, and Diptera contributed the majority of total macroinvertebrate density, although Coleoptera was well represented by the family Elmidae.

For all years, Ephemeroptera was the dominant order. The majority of this order was composed of the families Heptageniidae and Baetidae. The family Heptageniidae was composed mainly of Cinygmula sp. and Epeorus sp. in June, July, and August and shifted to Rithrogena sp. in September. All of these genera occurred in high abundance. The family Baetidae also composed a large majority of Ephemeroptera through August. Ephemeroptera continued to be a dominant order in September with the genera Rithrogena sp. (Heptageniidae) and Tibialis and Inermis (Ephemerellidae) appearing in high numbers.

When the orders of Plecoptera (families Chloroperlidae and Nemouridae) and Trichoptera (families Glossosomotidae, Brachycentridae, and Hydropsychidae) appeared in high numbers it appeared to be a function of finding high numbers of early instars.

In the order Diptera the family Chironomidae was quite prominent for all years at all sites. This is not surprising in that Cline et al. (1982) and Kimble and Wesche (1975), both found high numbers at their sites in high mountain streams. Hynes (1970) also indicates that a considerable number of Chironomidae are bivoltine. Simuliidae when found, were often in very high densities in a single sample. Alder (1988) has shown that the larvae of some species pack themselves tightly together in stream beds.

Substrate Preference

The types of substrate in the North Fork of the Little Snake River were divided into sand, gravel, rubble and bedrock. In general, the preferred substrate was either gravel or rubble.

In June, the families that showed either a preference for, or that were well represented in a sand substrate were Heptageniidae, Siphlonuridae, Chloroperlidae, Glossosomatidae, Chironomidae, Tipulidae and Elmidae. However, the only families to utilize this substrate throughout the summer were Tipulidae and Chironomidae. Both of these families have been shown to be able to utilize a sand substrate (Hynes 1970). The other families shifted from a sand to a gravel or rubble substrate in July and September. This is probably a function of life histories. Mackay (1969) in studying West Creek, a small stream in Quebec found the insect community in gravel to be the least specialized and included many species more common in other habitats. However, the interstices of the substrate sheltered early stages of Plecoptera, Trichoptera and Diptera especially during summer. She presumed that gravel forms an important reservoir from which other habitats are stocked. She suggested that the tendency of the young to move from gravel to leaves is because of insufficient food on the gravel habitats to support a large population of herbivores.

Mackay (1977) reported substrate preferences for three species of Limnephilidae (*Pycnopsyche gentilis, luculenta, scabripennis*) over most of their life cycles. While *Pycnopsyche gentilis* and *P. luculenta* did not show any substrate preference during their larval stages, *Pycnopsyche scabripennis* about to enter prepupal aestivation showed clearly positive and selective trends towards sand and gravel between 4 and 8 mm. Earlier instars of *P. scabripennis* showed no selectivity toward mineral substrate size.

All taxa examined utilized a gravel and/or rubble substrate. By far, these two substrate types had the larger numbers of macroinvertebrates when compared with sand or bedrock. In fact, the only family to show a preference for a bedrock (boulder) substrate was Hydropsychidae, which probably used this substrate as a point of net attachment for food collection (Usinger 1974).

For the present, it appears that although some aquatic insects actively chose specific substrates, most are substratum generalists (Minshall 1984). Even where definite preferences exists, these may change during the life cycle and remain undetected with the usual methods of analysis, especially with species where overlapping cohorts occur (which is the common case). However, the substrate preference for the aquatic macroinvertebrates in the North Fork of the Little Snake River substantiated the findings of Pennack and Van Gerben (1947), Ward (1975) and Kimble and Wesche (1975) which show a progressive increase in abundance from a sand to rubble substrate and then a decrease in total numbers when substrate size increases to bedrock. Minshall (1984) suggested that total abundance increases with a heterogeneous substrate (gravel and rubble) as compared to a homogeneous substrate (sand and bedrock). Although the highest abundance in this study was found to be in gravel, it should be noted that what this study considered to be gravel incorporated those sizes used by Pennack and Van Gerpen (1947), Ward (1975) and Kimble and Wesche (1975) designated to be rubble. If the hypothesis that increased substrate heterogeneity leads to a higher density of aquatic insects is correct, then there must be a size range where the substrate size becomes large enough so that it effectively becomes more homogenous that heterogenous. If this is the case, the size range of rubble used in this experiment may have been large enough to be associated with such a decline in numbers.

Water Velocity and Depth

Mean water velocity and depth preference were calculated for the months of July and September. Although most orders indicated a general preference trend for both velocity and depth, the results should be examined closely and qualified conclusions should be drawn regarding the influence of any single stream parameter. There are several reasons for apprehensions about the results of field studies of stream insects. Hynes (1970), Kimble and Wesche (1975), Minshall (1984) all note that in a stream environment, the hydraulic factors of water velocity, water depth and substrate type are closely interrelated. Current, for example, largely controls the substrate type. In small mountain streams faster water areas are normally characterized by a larger substrate and shallower water depths. For slower reaches of lesser gradient, the substrate size is diminished due to the deposition of smaller sediment particles and water depths are somewhat greater (Kimble and Wesche, 1975). Because in this study and in previous studies the effects of substrate velocity and depth are confounded, it is difficult to draw conclusions about the specific effects of any single factor.

Also, many workers have found that within even fairly uniform groups of animals, (e.g., Simulium [Adler, 1988]) different species have different current preferences. The result is that on rough substrates, where there is considerable local variation in current speed over quite short distances, a mosaic distribution of animals may occur (Hynes 1970). It can be concluded that current speed is a factor of major importance in running water, and that it controls the occurrence and abundance of species and thus the whole structure or the benthic community. However, its mode of action is highly variable in time and over short distances, and its effects are almost impossible to quantify except in general terms.

For the North Fork of the Little Snake River the orders Ephemeroptera, Plecoptera, Trichoptera and Diptera showed a preference for velocities over 0.6 ft/s. Coleoptera did not display a preference for water velocity. The preferred water depth for Ephemeroptera ranged between 0.2 and 0.9 ft. Plecoptera were most abundant between 0.2 and 0.8 ft. Trichoptera preferred deeper waters and were in greatest numbers around 0.9 ft. Coleoptera and Diptera showed no strong water depth preference.

Considering both velocity and depth, for the aquatic invertebrates in the North Fork, the optimum condition for highest abundance would be in velocities of above 0.6 ft/s at a depth ranging from 0.2 to 1.0 ft. Gore (1978) found the conditions of highest faunal diversity in the Tounge River in Montana appeared to be 2.5 ft/s at a depth of 0.8 ft. Because the North Fork is a much smaller stream than the Tounge River and during the study there were no velocities recorded above 2.0 ft/s it is difficult to compare the optimal velocities. However, the mean depths of the two studies compare favorably. This study substantiates the study of Kimble and Wesche (1975) in Hog Park Creek in which Trichoptera, Plecoptera and Ephemeroptera preferred mean water velocities greater than 0.5 ft/s and a depth preference of less than 1.0 ft.

Impact of sediment on the aquatic macroinvertebrates

During the late summer of 1984, a broad size range of sediments was deposited in a section of the North Fork of the Little Snake River. Unfortunately, there was no assessment of the immediate impact of the sediment on the aquatic macroinvertebrates. When this study began in July of 1985, the ecological indices (richness, evenness, diversity and abundance) suggested that the aquatic community, no matter how severely impacted, had largely recovered. However, visual assessment, sediment deposition records and qualitative samples (Wesche et al. 1987) clearly showed this area to have more embedded substrate than other sites on the North Fork. There may be several reasons that the aquatic macroinvertebrate community did not reflect these impacts. Given the length of time between the initial impact and the first aquatic community collection, recolonization may have occurred. Gore (1979) found Baetidae recolonizing a newly formed stream 14 hours after water was released into the channel. Hynes (1970), Gore (1979), Sheldon (1984) and others have shown that as food becomes available colonization will occur. Because of the localized nature of the impact and the presence of unimpacted upstream reaches, recovery could have been rapid.

In silty or sandy areas, any solid objects which are present become rapidly and often densely populated by lithophilic animals; the more shelter such objects provide, the denser the colonization (Hynes 1970). At site 6, the site of heaviest impact a cross section of substrate type was sampled. By sampling in this way, insects that were utilizing the available substrate would have been collected. This hypothesis would substantiate those findings of Lenate et al. (1981) who proposed that insects can utilize a reduced habitat. This finding is further confirmed by the finding that the family Hydropsychidae, was found at site 6 but was not found at site 3, a site that was composed completely of a sand substrate. Analysis of substrate preference showed that Hydropsychidae does not utilize a sand substrate. Therefore, these different substrate "islands" at the impacted site were acceptable to Hydropsychidae and presumably to the other insects as well. Also, the families Heptageniidae and Baetidae were well represented at every site and apparently are able to utilize all substrate types including the sediment deposited at site 6.

Hynes (1970) suggested an ecological principle in which the greater the diversity of the conditions in a locality the more diverse the species that make up the biotic community. The sudden addition of sediment into site 6 probably had an instantaneous detrimental effect on the aquatic fauna. However, in time (which may be very short, perhaps a matter of days), insects which were able to utilize the more diverse habitat, created by the deposition of a broad size range of sediment into the North Fork, may have colonized this area. Although the substrate at this site was dominated by sand in 1985 and 1986, other types of substrates were not eliminated. Therefore, the increased substrate diversity may have maintained species diversity. Because of the low number of taxa occurring in high Rocky Mountain streams (Ward 1986), it follows that those taxa utilizing the other sites in the North Fork would be found at site 6, thereby keeping between-site diversity, richness and evenness equivalent.

Barton (1977) and Cline et al. (1982) demonstrated no substantial long term impacts to the aquatic macroinvertebrates with the addition of sediment due to construction activities. These findings are substantiated by this study. The reason that there were no demonstratable impacts to the aquatic macroinvertebrates in the North Fork of the Little Snake River may include the following considerations: 1) the time lapse from the date of initial sediment impact to the first sample date, 2) the high springtime flow rates and flushing flows that removed sediment down from the impacted area, 3) the presence of substrates that were not completely embedded and were able to serve as islands for the aquatic community, and 4) the presence of unimpacted upstream reaches that allowed for quick recolonization.

Evaluation of Flushing Flows

Wesche et al. (1987) evaluated the effectiveness of their flushing flow recommendations. They concluded that in the North Fork, the magnitude and variability of stored sediment was much greater in low gradient pool habitats than in high gradient riffle-cascades. It was also determined that flushing flow releases on the North Fork had been successful in reducing stored sediment in the stream reaches most directly influenced by sediment spill. Below this zone of greatest impact, the amount of deposition quantity decreased and substrate quality increased in a downstream direction, indicating the effects of the spill were being moderated both temporally and spatially .

The use of flushing flows on the North Fork of the Little Snake River proved very effective in removing the finer sediment from site 6. Although biological indices showed no significant improvement in the aquatic community from 1985-1987, it should be clear from substrate preference that with the shift from an embedded substrate to that of a gravel-rubble substrate there is the potential in the system for greater diversity and abundance. The decline in the ecological viability of the community in 1986 which was apparently caused by the fluctuating releases is of some concern. Increases in discharge disturb the stream bed and

and result in the displacement of benthic populations (Lehmkuhl and Anderson (1972). Sprules (1947) had a 50% decline in benthic abundance after a seven-day flood event. Sediment input may also drastically increase during high discharge and have an adverse effect on the benthic community (Nuttall 1972, Ciborowski et al. 1977). The effects of both these factors (though not studied in this experiment) may have: 1) greatly increased downstream drift and 2) caused significant mortality to the aquatic insects by crushing, scour or other means related to high discharge. With proper timing of the flushes (accurately simulating spring runoff) it is felt that the flushing flows well preserve the North Fork as a suitable habitat for the Colorado Cutthroat trout. However, if improperly timed or mediated, these flows may seriously disrupt the macroinvertebrates and ultimately the trout.

<u>Considerations for Stream Diversion, Flushing Flows and the Aquatic Insects.</u>

From this study it can be seen that although the aquatic macroinvertebrate fauna was probably impacted by the sediment deposition in 1984 it had recovered by 1985. In 1986 the aquatic fauna was impacted by high water discharge but had recovered by 1987. Mountain stream insects have evolved to withstand periods of high runoff with associated high levels of suspended solids (Ward 1984). Therefore, it is not surprising that the aquatic macroinvertebrates in the North Fork of the Little Snake River recovered so rapidly from these impacts and it could be expected that they would recover from most natural types of catastrophe, even if the cause is anthropogenic.

When complete, the Cheyenne Stage II Diversion Project will alter the natural flows of the North Fork. From this study it appears that with flushing flows between 50 (1985) and 105 cfs (1987) the aquatic macroinvertebrates are not effected and these lower flows may even enhance the community as opposed to a discharges of up to 250 cfs which occurred naturally in 1986 which had a strong negative impact on the aquatic macroinvertebrates. From the data collected on water depth and velocity preference, the recommended minimum flow of 3.0 cfs for the North Fork is adequate for the aquatic insects.

However, both increasing and decreasing discharge induce drift of aquatic insects (Ward, 1984). Most colonization occurs from downstream drift of larvae (Gore 1979, Sheldon 1984). Though not addressed by this study, it is of interest to see that if after a flush (and subsequently increased invertebrate drift), those areas immediately below the diversion structures have a dramatic reduction in abundance and species composition caused by increased drift without upstream colonization.

Literature Cited

Adler, P. H. 1988. Black flies are busting out all over. Natural History. 97:34-40.

Barton, B. A. 1977. Short-term effects of highway construction on the limnology of a small stream in southern Ontario. Freshwater Biology. 7:99-108.

Binns, N. A. 1977. Present status of indigenous populations of cutthroat trout (Salmo clarki), in southwest Wyoming. Fisheries Technical Bull. No. 2, Wyoming Game and Fish Department, Cheyenne, Wyoming.

Brusven, M. A., and K. V. Prather. 1974. Influence of stream sediments on distribution of macrobenthos. J. Entomol. Soc., Brit. Columbia. 71:25-32. (abstr).

Cibrowski, J. J. H., P.J. Pointing and L. D. Corkum. 1977. The effect of current velocity and sediment on the drift of the mayfly Ephemerella subvaria Mcdunnough. Freshwater Biology 7:567-572.

Cline, L. D., R. A. Short, and J. V. Ward. 1981. The influence of highway construction on the macroinvertebrates and epilithic algae of a high mountain stream. Hydrobiologia 96:149-159.

Corkum, L. D., P. J. Pointing, and J. J. H. Ciborowski. 1977. The influence of current velocity and substrate on the distribution and drift of two species of mayflies (Ephemeroptera). Canadian Journal of Zoology 55:1970-1977.

Egglishaw, H. J. 1964. The distributional relationship between the bottom fauna and plant detritus in streams. Journal of Animal Ecology. 33:463-476.

Gaufin, A. R. 1959. Production of bottom fauna in the Provo River, Utah. Iowa St. Coll. F. Sci. 33: 395-419.

Gore, J. A. 1977. Reservoir manipulations and benthic macroinvertebrates in a prairie river. Hydrobiologia. 55:113-123.

Gore, J. A. 1979. Patterns of initial benthic recolonization of a reclaimed coal strip-mined river channel. Canadian Journal of Zoology 57:2429-2439.

Gore J. A. 1982. Benthic invertebrate colonization: source distance effects on community composition. Hydrobiologia 94:183-93.

Healey, M. 1984. Fish predation on aquatic insects, pp.255-288. In V. H. Resh and D. M. Rosenberg [eds.], The ecology of aquatic insects. Praeger, New York.

Hynes, H. B. N. 1960. The biology of polluted waters. Liverpool University Press, Liverpool 202pp.

Hynes, H. B. N. 1961. The invertebrate fauna of a Welsh mountain stream. Arch. Hydrobiol. 57:344-388.

Hynes, H. B. N. 1970. The ecology of running waters. University of Toronto Press, Toronto. 555pp.

Iwamoto, R. N., E. O. Salo, M. A. Madej, R. L. McComas, and Rulifson. 1978. Sediment and water quality: a review of the literature including a suggested approach for water quality criteria with summary of workshop and conclusions and recommendations. U.S. Environmental Protection Agency, Region 10, 910/9-78-048. U.S. Environmental Protection Agency, Seattle, WA. 253pp.

Jaag, O. and H. Ambuhl. 1964. The effect of the current on the composition of biocoenoses in flowing water streams, pp. 31-44. In: First International Conference on Water Pollution Research, London. Pergamon Press, Oxford. 341 pp.

Jespersen, D. M. 1981. A study of the effects of water diversion on the Colorado cutthroat trout (Salmo clarki pleuriticus) in the drainage of the North Fork of the Little Snake River in Wyoming. Master's Thesis, University of Wyoming, Laramie, Wyoming.

Kimble L. A. and T. A. Wesche. 1975. Relationships between selected physical parameters and benthic community structure in a small mountain stream. Water Resources Series No. 55, Wyoming Water Resources Institute, Laramie, Wyoming 64 pp.

Knighton, D. 1984. Fluvial forms and processes. Edward Arnold Ltd. London 218pp.

Kotila, P. M. 1986. Ecological Measures. Software Package. St. Lawrence University.

Lehmkuhl D. M. and N. H. Anderson. 1972. Microdistribution and density as factors affecting the downstream drift of mayflies. Ecology 53:661-667.

Lenat, D. R., D. L. Penrose, and K. W. Eagleson. 1981. Variable effects of sediment addition on stream benthos. Hydrobiologia 79:187-194.

Nuttall, P. M. 1972. The effects of sand deposition upon the macroinvertebrate fauna the River Camel, Cornwall. Freshwater Biology 2:181-186.

Nuttall, P. M., and G. H. Bielby. 1973. The effect of china-clay wastes on stream invertebrates. Environmental Poll. 5:77-86 (abstr).

Pennack, R. W. and E. D. Van Gerpen. 1947. Bottom fauna production and physical nature of the substrate in a northern Colorado trout stream. Ecology 28:42-48.

Platts, W. S., W. F. Megahan, and G. W. Minshall. 1983. Methods for evaluating stream, riparian and biotic conditions. U.S. Dept. of Ag. Forest Service, General Technical Report INT-138, Intermountain Forest and Range Experimentation Station, Ogden, Utah.

Rabeni, C. F. and G. W. Minshall. 1977. Factors affecting microdistribution of stream benthic insects. Oikos. 29:33-43.

Reiser, D. W., M. P. Ramey, and T. R. Lambert. 1985. Review of flushing flow requirements in regulated streams. Pacific Gas and Electric Co., San Ramon, California. 97pp. and App.

Sheldon, A. L. 1984. Colonization dynamics of aquatic insects. pp. 401-429. In V. H. Resh and D. M. Rosenberg [eds.], The ecology of aquatic insects. Praeger, New York.

Sprules, W. M. 1941. The effect of a beaver dam on the insect fauna of a trout stream. Trans. Am. Fish Soc. 70:236-248.

Stalnaker, C. B. and Arnette, J. L. (eds.) 1976. Methodologies for the determination of stream resource flow requirement An assessment. U.S. Fish and Wildlife Service, Office of Biological Services, Western Water Allocation, Washington D.C.

Tsui, P. T. P. and McCart, P. J. 1981. Effect of stream-crossing by a pipeline on the benthic macroinvertebrate communities of a small mountain stream. Hydrobiologia 79:271-276.

Usinger, R. L. 1974. Aquatic Insects of California. University of California Press. Berkely, California.

Wallace, J. B. and R. W. Merritt. 1980. Filter feeding ecology of aquatic insects. Annual Review of Entomology 25:103-132.

Ward, J. V. 1975. Bottom fauna-substrate relationships in a Northern Colorado trout stream: 1945 and 1974. Ecology. 56:1429-34.

Ward, J. V. 1984. Ecological perspectives in the management of aquatic insect habitat. pp.558-577. In V. H. Resh and D. M. Rosenberg [eds.], The ecology of aquatic insects. Praeger New York.

Ward, J. V. 1986. Altitudinal zonation in a Rocky Mountain stream. Arch. Hydrobiol/Suppl. 74:133-199.

Wesche, T. A., D. W. Reiser, W. Wichers, and D. Wichers. 1977. Fishery resources and instream flow recommendations for streams to be impacted by Cheyenne's proposed phase II development. Report to Wyoming Game and Fish Department, Cheyenne, Wyoming.

Wesche, T. A. and P. A. Rechard. 1980. A summary of instream flow methods for fisheries and related research needs. Eisenhower Consortium Bulletin No. 9. U.S. Government Printing Office: 1980-0-679-417/509, Washington D.C.

Wesche, T. A., V. R. Hasfurther, W. A. Hubert, and Q. D. Skinner. 1985. Assessment of flushing flow recommendations in a steep, rough, regulated tributary. Paper presented at Third International Symposium on Regulated Streams, Edmonton, Alberta, Canada.

Wesche, T. A., V. R. Hasfurther, and Q. D. Skinner. 1987. Recommendation and evaluation of a mitigative flushing flow regime below a high mountain diversion. pp. 281-298. In Dworsky R. F. [ed.] Water resources related to mining and energy - preparing for the future. American Water Resources Association. Bethesda, Maryland.

Wiley, M. J. and S. L. Kohler. 1981. An assessment of biological interactions in an epilithic stream community using time-lapse cinematography. Hydrobiologia 78:183-188.