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STREAMFLOW AND VELOCITY AS DETERMINANTS OF AQUATIC INSECT DISTRIBUTION AND BENTHIC COMMUNITY STRUCTURE IN ILLINOIS

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TABLE OF CONTENTS

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ABSTRACT

Stream flow characteristics, in particular velocity and depth, control channel substrates and directly or indirectly determine how aquatic insects are distributed and benthic communities are structured. A three year laboratory and field research program has been completed evaluating how streamflow affects aquatic insects in Illinois. Field studies related benthic community structure and species composition with boundary layer Reynolds number (R*) and evaluated microhabitat selection of several insect species on hydraulically defined artificial substrates. Hydraulic calibration of substrates was completed in laboratory flume studies using a thermistor based microprobe. A laboratory artificial stream was also used to determine habitat selection of net spinning caddisflies. Results indicated selection for defined microhabitats in several aquatic insect taxa. The artificial substrates proved to be a valuable tool in defining microhabitat characteristics occupied by aquatic insects. In studies to determine instream flow requirements, measures of mean column velocity were shown to be inadequate, determination of R* was preferred. The results of this research provide water resources managers with better tools to assess microhabitat modifications produced by changes in streamflow.

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List of Tables

List of Figures

1. INTRODUCTION

Instream flow needs are channel flows required to maintain beneficial uses such as aquatic life maintenance and propogation, recreation, or navigation. The importance of identifying instream flow requirements in water resources planning and management was recognized by the Water Resources Council (Water Resources Council, 1968; 1977). In particular the Council identified the need for research to determine the effects of stream flows on biological systems. Past ecological research has established a fundamental understanding of the nature of streams and the capacity of stream biota to modify life histories via migration, diapause, and emergence to adapt to the highly variable habitats in stream ecosystems. Seasonal flow variability is great, and low frequency events such as drought or severe flooding are all met by the stream ecosystem's natural resilience. Thus when flow modifications occur for short durations or severe changes occur infrequently the stream ecosystem can be maintained with little consequence to productivity. Unfortunately, conflicts arise when offstream demands for water produce instream flow conditions which exceed the ecosystem's capacity for recovery. With development of water resources for offstream use as well as flow modification for flood control or power production the instream flow needs of stream and river ecosystems have become a major issue in the management and protection of water resources values.

An essential component of stream ecosystems is the transfer mechanism between primary production and higher trophic level consumers such as fish. The transfer of carbon fixed in photosynthesis by either stream organisms or allochthonous production is effected by a group of aquatic organisms

dominated by aquatic insects. These organisms are the base of the consumer food chain in the stream and are essential to the resilience of the stream ecosystem and the maintenance of fisheries productivity to support recreational or other uses of stream biological resources. Although major attention has been paid to establishing instream flow needs of fish, only limited research has been directed to identifying instream flow needs for aquatic insects.

The objective of this report is to review the field investigations and experimental research designed to identify the effects of streamflow on aquatic insects and efforts made to improve existing instream flow needs assessment methods by the inclusion of aquatic insect needs in analysis programs. The methods used to identify aquatic insect flow relationships included descriptive and experimental studies conducted both in the laboratory and the field. Methodology advancements included development of new methods of measuring microhabitat characteristics, calibration of artificial substrates with defined hydraulic characteristics for use in field experiments, and assessment of new procedures do describe microhabitat characteristics from commonly made field measurements. Laboratory studies included experimental evaluation of habitat preference and velocity relationships in an artificial stream. Extensive field studies were conducted to evaluate substrate selection, colonization, and potential competitive interactions between aquatic insect species.

The following report is divided into sections which summarize the results of both laboratory and field studies. Section 2 reviews the development, verification and experimental use of a microvelocity probe used to better characterize aquatic insect habitat. Section 3 concerns the application of microvelocity probe measurement to three substrate types and the

development of a new measure of flow related habitat R*. Section 4 relates to aquatic insect communities in Illinois streams. Section 5 reviews the calibration of the artificial substrates used in field experiments. Section 6 contains the results of field experiments evaluating the effects of periphyton and sediment on substrate colonization. Section 7 identifies the instream current requirements of several species of aquatic insects. Section 8 reviews the effect of substrate particle size on aquatic insect distribution. The final section provides a summary and conclusions of the project.

2. AQUATIC INSECT MICROVELOCITY PROBE DEVELOPMENT, VERIFICATION, AND EXPERIMENTAL USE

2.1 PURPOSE

As part of the study of aquatic insect microhabitat conditions, it was necessary to develop a microvelocity probe and techniques for measurement of aquatic insect microhabitats. The purpose of initial efforts was the development of one or more microvelocity probe designs including detailed hydraulic consideration of the interrelationships between the primary habitat variables, depth, velocity, and substrate.

2.2 INTRODUCTION

The current velocities to which lotic organisms are exposed to is a primary factor affecting their distribution. It has been recognized that the actual current experienced by an aquatic insect is much less than that measured by standard current meters (Hynes, 1970). Furthermore, Railsback (1979) reported that simple measures of hydraulic parameters provided by available instream flow hydraulic models, mean column velocity, column depth, and substrate type (ref., PHABSIM) are not well suited for modeling conditions in the vicinity of the boundary layer (the region of flow on or near the substrate where flow velocity is reduced by friction. Additionally, the use of a simple linear relationship between the mean column velocity and a microhabitat current velocity, depth, viscosity, and substrate type involves parameters which are not independent at the insect microhabitat level.

For a given mean column velocity and depth, the theoretical velocity in the boundary layer may change as a function of surface roughness (a function of substrate type) (Streeter and Wylie, 1975). The interstitial velocity is also a function of particle size and shape. Velocity, depth,

and substrate type are not independent parameters in (microhabitats) selected by aquatic insects although the Incremental Methodology assumes that these parameters are independent. Although such an assumption may be valid for fish (Smith, 1979; Orth, 1982), and a model for aquatic insects has been proposed to predict habitat tolerances (Gore and Judy, 1981) the interdependence of all parameters is too great to be ignored. Depth, velocity and substrate type need to be combined in defining microhabitat characteristics in a hydraulically and biologically meaningful way before being used as habitat dimensions (Railsback, 1979).

Investigation of the interactions of velocity and substrate type have been limited due to the inability to measure velocity in the very small areas inhabited by aquatic insects. Velocity measurements have been taken in several ways: Gore (1978) and others have measured the average velocity at a sample site by holding the current meter at six-tenths of the distance down from the surface to the bottom; Cummins (1964), Minshall and Minshall (1977), and Ulfstrand (1967) held a current meter a short distance above the bottom; Eddington (1968) used a one cm diameter cup type meter to approximate the microvelocity near caddisfly nets, but this meter is still too large to accurately measure microhabitat; Rabeni and Minshall (1977) were able to approximate the interstitial velocity at one point in the substrate by using the rate of dissolution of salt tablets as a measure of velocity; and, Malas and Wallace (1977) recorded velocities adjacent to Parasyche and Diplectrona caddis larvae at the lower downstream side of rocks using a rubber bag current meter described by Gessner (1955). Georgian (1983) used a hydrogen bubble technique to study the hydrodynamic properties of caddisfly nets. Despite all of these attempts, researchers have not been able to readily quantify microvelocity at a precisely known

point as a direct function of depth, velocity, and substrate type. Defining such a function is critical for determining instream flow needs for aquatic insects.

We have developed an electronic microhabitat velocity thermistor probe for application to aquatic insect research which is small and sensitive enough to measure microhabitat velocities in the regions inhibited by benthic organisms. The thermistor probe itself is a modification of that described by Alavian (1981) who investigated the flow characteristics of warm water jets entering cold receiving waters. The development and modification of such a device provides the capacity to: determine a meaningful relationship between microhabitat parameters and benthic microvelocities; and to hydraulically calibrate aritificial substrates for additional studies of aquatic insect microhabitat needs. Such studies and relationships appear suitable as the basis for a practical means of modeling aquatic insect habitat. Thus, a principal objective of this study was the development of a microhabitat velocity probe.

2.3 THERMISTOR PROBES AND METHODS

The velocity probe employed in the following experiments is based upon the use of thermistors which measure velocity indirectly as the rate at which heat is lost from a heat source. In the following experiments, two slightly different procedures were employed, which consisted of modifications in the drive voltage and calibration techniques. These differences in procedures were necessitated by the measurement requirements placed on the probes and will be referred to as Series 1 and Series 2 procedures. It is important to note that both approaches employed the same thermistors and construction.

2.3.1 Probe Construction (Series 1 and Series 2)

Two thermistors are used in the probe, one a sensing unit and the other a reference thermistor. The fast response glass thermistors employed in this study (diameter 1.7 mm; 8000 r resistance at 25°C; No. GB38P12) were obtained from Fenwal Electronics (Framington, MA). The probe itself was built by inserting a thermistor into a small brass tube which was bent at one end to form a 90° angle. The sensor (i.e., semi-conductor) was sealed into position with silicone sealer and the leads to the sensor ran inside the tube and were attached to a Wheatstone circuit (Fig. 2-1). Two such thermistors formed two legs of the circuit.

2.3.2 Series 1 Probe Calibration and Operation

In the Series 1 probe (used for hydraulic calibration of artificial substrates) the circuit was provided with 16.5 V of electrical current (8.25 volts through each leg and thus to each thermistor). This voltage provided sufficient electrical current for the thermistor to generate temperatures greater than ambient conditions. The temperature of the sensing thermistor (and thus its resistance) is a function of the heat loss due to the velocity of the water and the ambient temperature. To compensate for the effects of the ambient temperature, the second thermistor (or reference thermistor) was encased in a brass circular block (diameter 1.25 cm) and placed into the same water (maintained a constant temperature between the two circuit legs). The out of balance of the voltage passing through the two legs to the two thermistors was a function of the water velocity at the point of the measurement (or in the vicinity of the sensing thermistor).

The Series 1 probe was used exclusively in a laboratory flume located in the Hydrosystem Laboratory at the University of Illinois

BRIDGE CIRCUIT

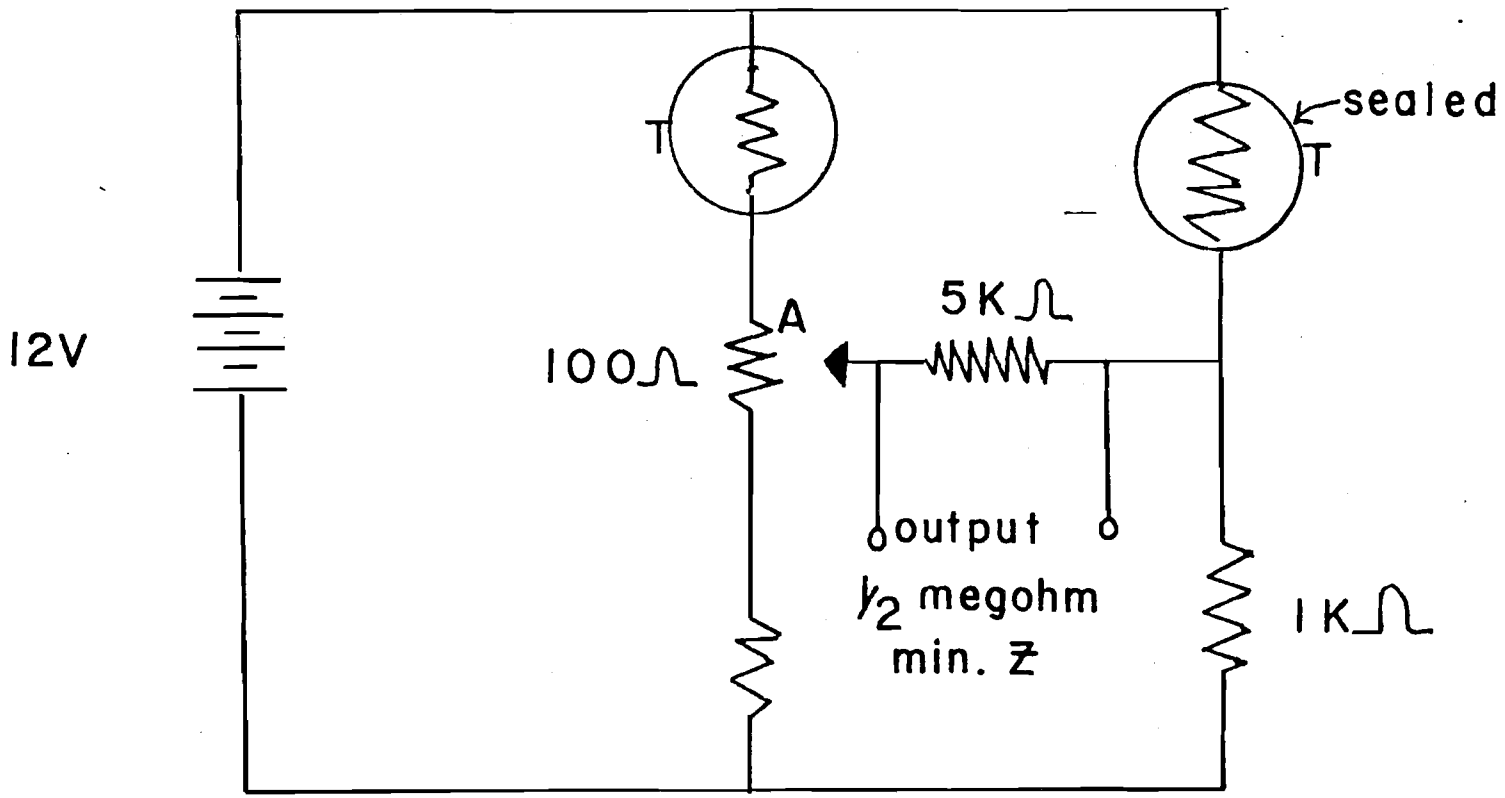


Figure 2-1. Wheatstone bridge circuit employed for use in thermistor probe.

Champaign-Urbana campus. Throughout the studies using the Series 1 probe, the water supply to the flume was maintained at 17°C, thus eliminating the need for ambient temperature adjustments and corrections when operating the Series 1 probe. The laboratory flume dimensions were 15 x 0.5 x 0.75 m and provided us with the capability of varying both water depth and velocity at a given point. The flume and probe set up employed are shown in Figure 2-2).

The initial calibration of the Series 1 probe is as follows. Both the sensor and reference thermistors were suspended in a 500 ml beaker containing flume water (temperature 17°C). The circuit was provided with 16.5 V of current using a voltage regulator and balanced to supply 8.25 V to each thermistor. When balanced, the voltage output from the system was equal to 00.0 mV. Voltage output was determined using a Fluke digital voltimeter. Following balancing of the circuit, power was shut off to the system (necessary as thermistors fuse when out of water due to heat generation) and the sensor thermistor mounted on a rack and pinion system to permit both horizontal and vertical movement. The reference thermistor was attached to the side of the flume and the water depth within the flume adjusted to 12.7 cm. Power (i.e., 16.5 V) was again supplied to the balanced circuit.

The sensor probe was positioned directly in front of a permanently mounted Marsh-McBirney flow meter sensing unit and the current velocity (read from the current meter) and the corresponding mV output from the circuit were recorded. The discharge of water through the flume was repeatedly adjusted to develop a response curve relating mV thermistor

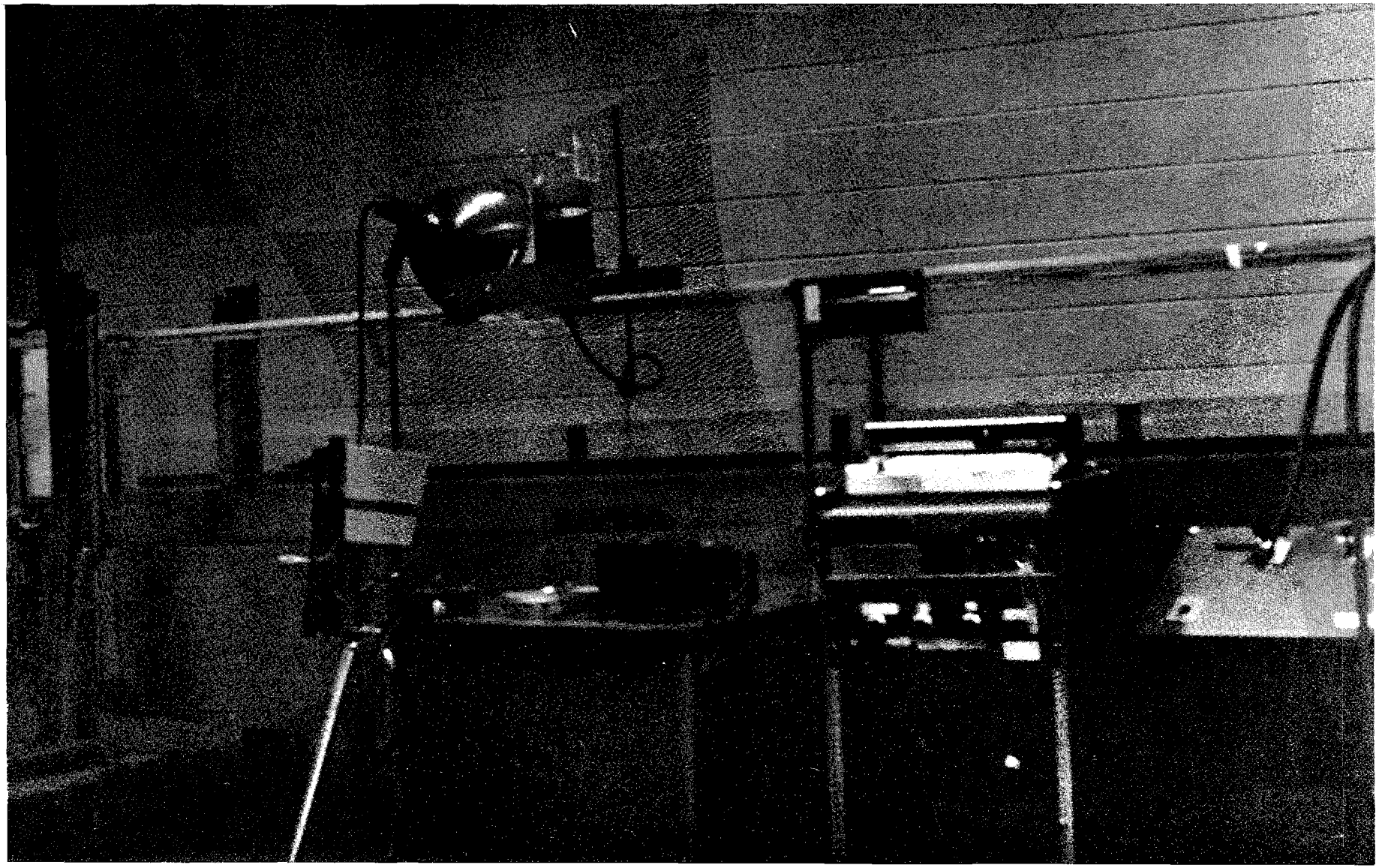


Fig. 2-2. Hydrosystem laboratory flume and research equipment (high speed camera, artificial substrates, rack and pinion probe support; dye reservoir, and voltage regulator with probe).

imbalance to water current velocity. A typical response relationship is presented in Figure 2-3. This relationship was mathematically related to current velocity using regression analysis and data transformation (Sokal and Rohlf, 1969).

As examination of Figure 2-3 indicates, the best probe response occurs at mean column velocities of less than 0.40 m/sec, which allowed the thermistors to maintain relatively constant temperature. Measurements in column velocities to 0.5 m/sec were valid using the Series 1 configuration. Beyond 0.5 m/sec, the rate of heat loss from the thermistor due to water current was more rapid than the reheating capabilities of the system. A range of current velocities from 0 to 0.5 m/sec is, however, adequate when experimentally examining aquatic insect microhabitat current conditions.

The preceding methodology was employed to hydraulically calibrate artificial substrates in water of a constant temperature regime. The exact procedures and experimental results are reported in a later section of this report. The Series 2 probe methodologies were designed to examine microhabitat flow characteristics where water temperature could not be maintained or assumed to be constant.

2.3.3 Series 2 Probe Calibration and Operation

In the Series 2 probe, which was developed to work at different water temperatures, the sensing thermistor was driven at 20 V. To compensate for the effects of ambient temperature, the reference (or second) thermistor was driven at a lower voltage of 0.5 V. At this low of voltage, no heat is generated by the thermistor and thus it does not respond to

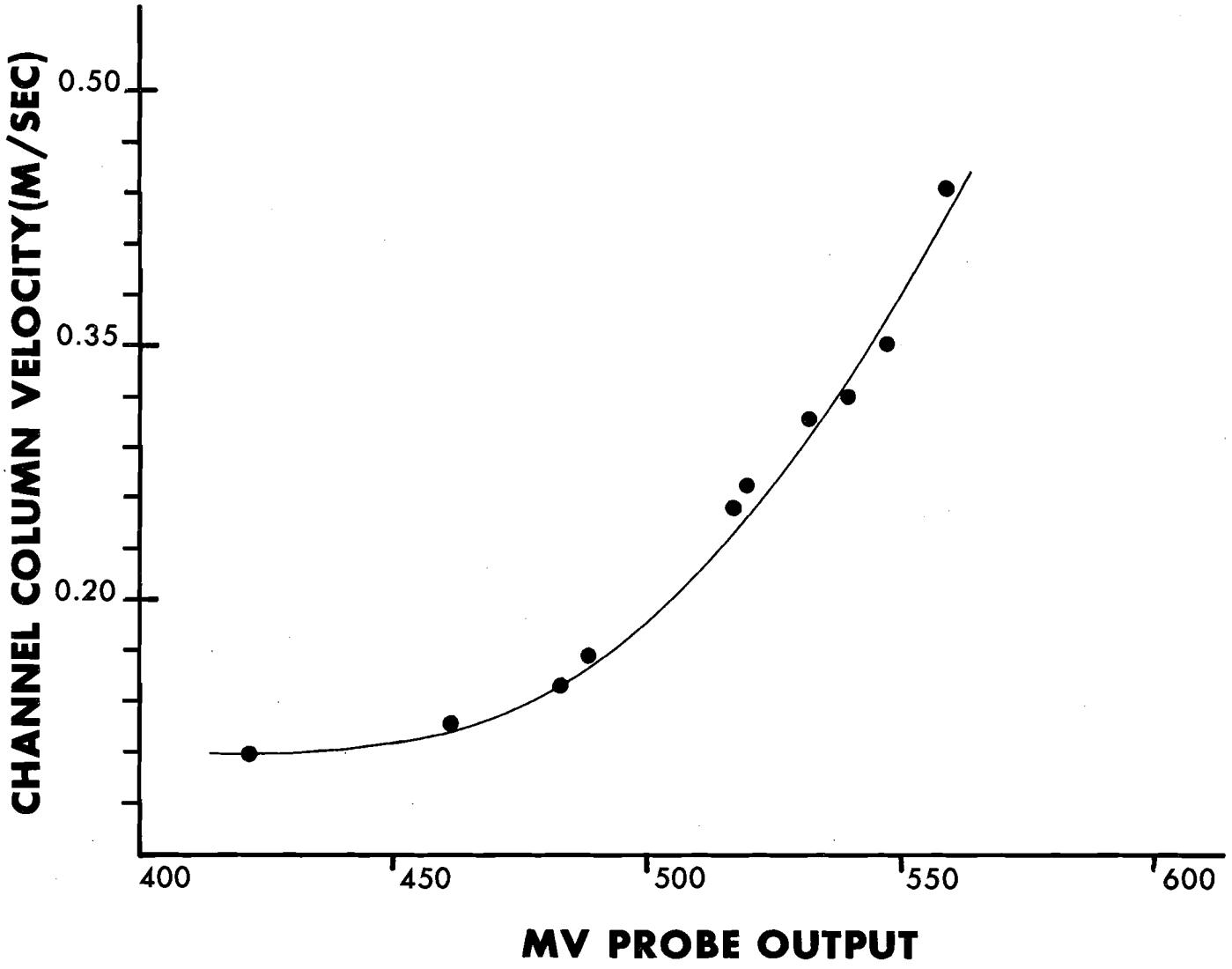


Figure 2-3. Microvelocity probe response to changing column velocity at 17° C

velocity, but only temperature. The signal of this compensating thermistor is substracted from the signal of the sensing thermistor, resulting in only a velocity component to the signal. This signal is amplified and sent to the Fluke digital output meter.

Once built, the first step in the probe calibration was to make both the sensing and compensating probes respond similarly to temperature. Because of the differences in the driving voltages, the two probes respond differently to temperature at zero velocity. Using a series of temperature calibrations in a water bath, it was determined that both probes responded linearly to temperature, though the response equation was different for each probe. To accurately compensate for temperature, the response of the two probes had to be matched to make the output to both thermistors equal to zero velocity for all expected temperatures. This can be done mathematically or electronically.

Mathematically, the difference between the two linear response curves is another linear function, found by subtracting the response of the compensating probe from that of the sensing probe. This gives the correction of the sensing output to make it match the compensating output, the correction being a function of temperature. Using the sensing probe response equation to substitute for temperature as a function of sensing probe output, the correction can be described as a linear function of the sensing output. For every measured value of sensing output, that value can be multiplied by a constant and added to another constant to make it respond to temperature as the compensating probe does.

Linear transformation of the sensing output can also be done electronically. Variable resistors were added to the output of both sensing and compensating thermistors, allowing the adjustment of the Y (voltage) intercept of each response curve, and a variable voltage divider was added to the sensing probe allowing the adjustment of its slope. Another circuit was also added to electronically subtract the compensating output from the sensing probe.

Matching the temperature response of the two probes was accomplished, at a low temperature, by adjusting the Y intercept controls so that the output of both thermistors was zero. At a higher temperature the slope control for the sensing probe was adjusted to make the sensing output match the compensating output. Several iterations of this process were necessary to make the responses match within a reasonable error (about 10%) over the range of temperatures expected in our experiment.

Once the temperature calibration was accomplished, velocity calibration was done using a rotating water tank. A cylindrical tank of water was rotated at a known angular velocity until the water inside rotated as a solid body. The velocity probe was mounted on an arm above the tank and lowered into it at various radial distances from the center. In this manner the velocity sensed by the probe could be measured as the angular velocity of the tank in radians per second multiplied by the radial distance in cm. The result was a semi-logarithmic relation between the output voltage and the velocity. The equation for velocity was found to be:

$$V = .131 \exp(86.2E)$$

where V is the velocity in cm per second, and E is the measured difference in voltage between the sensing probe and the compensating probe in volts.

The coefficient of correlation for this equation was .999. The range of the calibration was from zero to 50 cm per second, and response is accurate to at least two significant figures, even at velocities under 1 cm per second. This calibration curve was used for all subsequent velocity measurements.

2.4 THEORETICAL CONSIDERATIONS-HYDRAULIC PARAMETERS

The physical habitat parameters normally measured or simulated by hydraulic simulations (i.e., mean column velocity, depth, and substrate type) interact in a complicated and highly dependent fashion to determine conditions at the substrate surface. To produce a model which is both accurate and realistic is extremely difficult due to the inherently variable nature of fluid flow in streams, but useful relationships have been developed by open-channel hydrologists, some of which are applicable to the problem of microhabitat modeling. A method to use the mean column values of velocity and depth along with substrate type to model microhabitat is proposed here. This model served as a component of S. F. Railsback's master's thesis (1979).

A basic relationship of sediment transport theory is that a particle's potential for being moved is a function of the boundary layer shear stress (Simons and Senturk, 1977). Shear stress is the force parallel to the surface exerted on the bed particles, per unit area of bed surface. Shear stress is often quantified, not as an absolute value with units of force per unit area, but as a dimensionless ratio of shear stress to viscous stress known as the Reynolds number. For a substrate particle, the Reynolds number is evaluated as:

$$R^* = \frac{U^* D_s}{v} \qquad (1)$$

where: R* = boundary layer Reynolds number

U* = the boundary shear velocity

D_s = particle diameter

v = kinematic viscosity

For engineering purposes, U* is often approximated by:

$$U^* = \sqrt{gRS} \tag{2}$$

where: g = gravitational acceleration

R = the hydraulic radius

S = the slope

The hydraulic radius is defined as the channel's cross-sectional area divided by its wetted perimeter, and is often approximated by the depth. The R* thus becomes:

$$R^* = \frac{D_s\sqrt{gRS}}{v} \tag{3}$$

The Incremental Methodology models provide values for the mean column velocity and the Manning roughness coefficient n. The Manning equation is a commonly used empirical formula for calculating open channel flows. One form of this equation is:

$$v = \frac{Cm\ R^{2/3}\ S^{1/2}}{n} \tag{4}$$

where: v = mean column velocity

Cm = a constant with units: length $\frac{1}{3}$/time

n = the roughness coefficient which is higher for rougher beds.

Statzner (1981) uses a similar formulation to the Manning equation to develop an index of hydraulic stress.

A better approximation of the shear velocity may be obtained by using the Manning equation to approximate a value of S, using the known values of v and n. S is probably the most ambiguous term in the Reynolds number: slopes in hydraulic equations can refer to bottom slopes, water

surface slopes, or energy slopes (the energy loss per unit stream length). Solving the Manning equation for S and substituting into the Reynolds number equation yields:

$$R^* = \frac{D_s \, g^{1/2} \, R^{-1/6} \, Vn}{vCm} \qquad (5)$$

There are assumptions involved with this parameter, including: particles are assumed to be round in shape, and of uniform size for each substrate type. For many stream riffles, these assumptions are acceptable, since R* will be calculated individually for a number of points in a stream, not for the stream as a whole. The natural forces of sediment transport and erosion usually result in well-sorted gradients of substrate sizes, at least within the distances of a few feet that are modeled with the Incremental Methodology, and in many riffles the stones have been worn into semi-round shapes. In cases where the substrate is significantly out of round or nonspherical, a sphericity value between zero and one can be applied to estimate an effective diameter (Fair et al., 1968).

There is some question about the use of the Manning n factor in R*. The value of n is known to depend upon numerous factors, such as channel configuration and flow rate as well as the bed roughness. Thus, as n is a function of many factors, it may not be suitable to use a value of n determined for the channel as a whole to calculate R*. The IFG2 hydraulic model, employed in the Incremental Methodology (ref. PHABSIM) uses the value of n calibrated for each point in the channel for which a value of R* would be calculated. Such local values of n are probably sufficient for the calculation.

To demonstrate the characteristics of R*, sensitivity analysis has been performed by calculating the value of R* for a variety of hypothetical

Table 2-1 Sensitivity Analysis for R* (from Railsback, 1979) for various types of streams and stream habitats

Case	Ds (m)	R (Depth) (m)	Velocity (m/sec)	n	Temp (c)	R*
A	10^{-4}	1.50	0.10	0.030	20	1
B	0.02	0.50	0.20	0.035	20	495
C	0.05	0.20	0.50	0.040	20	4093
D	0.10	0.20	0.75	0.045	15	12139
E	0.15	0.20	1.00	0.050	10	23475

stream conditions. These results are reported in Table 2-1. In Table 2-1, Case A is typical of a large river or pool habitat, where the water is typically deep (R = 1.50 m) and slow (0.10 m/sec), with a fine sand bottom (i.e., n = 0.030). Case C is typical of a riffle in a midwestern stream: the water is shallow (0.20 m), moderately fast (0.50 m/sec), with a gravel substrate (n = 0.040). Case E represents a torrential mountain stream characterized by its shallow depth (0.20 m), very fast (1.0 m/sec) and cold water, with large cobble substrate (n = 0.050). Cases B and D (Table 2-1) represent intermediates between the extreme cases and a typical midwestern riffle.

3. MICROVELOCITY MEASUREMENTS IN VARIOUS SUBSTRATE TYPES AND FLOW CONDITIONS

3.1 PURPOSE

The Series 2 thermistor velocity probe provides the capability to measure local velocities at points on the benthos which are important to aquatic insects. The purposes of this investigation were: 1) to examine the utility of the Series 2 microvelocity probe in the laboratory at various velocities, depths, and on different substrate types; and 2) to evaluate the utility of the R* as a means for modeling aquatic insect microhabitat.

3.2 METHODS

Three substrate types were used to determine microhabitat conditions: large cobble with mean diameter of 10 cm; medium gravel with mean diameter of 5.4 cm; and, small gravel, 2.5 cm in diameter. For each substrate type, two different microhabitats were considered important: very near the surface of the rock and 0.7 cm above the surface, above the zone of low velocity near the surface of the substrate and approximately where a net spinning caddisfly might have it's net. The surface measurement was made by holding a Series 2 thermistor near the rock surface, so that the sensing element itself was half the diameter of the thermistor or 0.09 cm above the rock surface. This is within the range where many insects would have their gills.

A bed of each of the three substrate sizes was made in a large experimental flume with dimensions 49 m long, 1.8 m wide, and 1.2 m high. Flow rates up to .19 cubic meters per second were available in the flume, and by varying the flow and the elevation of the tailgate a variety of depths and velocities were produced. For each of these flows the depth

was recorded directly above the site of the microvelocity measurements in each rock size. The slope was determined by measuring the water surface elevation at each end of the rock bed. These measurements were used to calculate R* for each particle size and flow regime, using the approximation $U^* = \sqrt{gRS}$.

Microvelocities were measured with the Series 2 velocity probe at four points within each substrate bed. These points were on the top and side of two marked rocks, and microvelocity was measured near the surface (at .09 cm) and at .7 cm above the surface of the rock at each of these points. It should be noted that the obtained measurements may not be reflective of the actual insect microhabitat as point velocity measurements were taken only on the tops and sides of the substrates. Other factors, such as periphyton growth, which would be expected to alter flow characteristics and the fact that interstitial space measurements were not obtained would account for the possible limitation of extrapolating the results. As should be expected in measuring turbulent flow there was a great deal of fluctuation in microvelocity both between points on the substrate and over time at one point. Because of this variability, the microvelocity used in the results is an average of the values measured at each of the four points. The values measured at .09 cm and at .7 cm were analyzed separately.

3.3 RESULTS AND DISCUSSION

3.3.1 Evaluation of R* as a Microhabitat Indicator

Once R* and the corresponding microvelocities had been measured in the flume it was necessary to look for some relation between the two parameters. Because the values of both parameters ranged over several orders of magnitude the data was first plotted on log-log graphs. These

graphs, shown in Figures 3.1 and 3.2 show a large degree of scatter in the lower range of R*, but a significant degree of correlation at higher values. A possible explanation for the scatter is suggested by the observation that it appears when R* falls below about 1000. According to Shields (1936) the transition from turbulent to laminar flow occurs when R* falls below around 70. This transition region is not well defined (Simons and Senturk, 1977) and it may be that changes in the nature of flow due to the transition to the laminar flow regime may alter the relation between R* and microvelocity. The problem may also be related to the difficulty in accurately measuring low values of the slope.

In order to analyze the data, the values within this scattered range were deleted. For microvelocity measured at .09 cm, the equation found was:

$$MV = 0.0020(R^*)^{1.2}$$

where MV is the average measured microvelocity for each R*. The coefficient of correlation is .895 for this curve. For microvelocity at .7 cm the equation was:

$$MV = 0.0098(R^*)^{1.0}$$

The coefficient of correlation was .877.

Because the exponents of these two power functions were near 1, linear regression was also performed. For microvelocity at .09 cm, the line was found to be:

$$MV = 0.0075R^* - 3.9$$

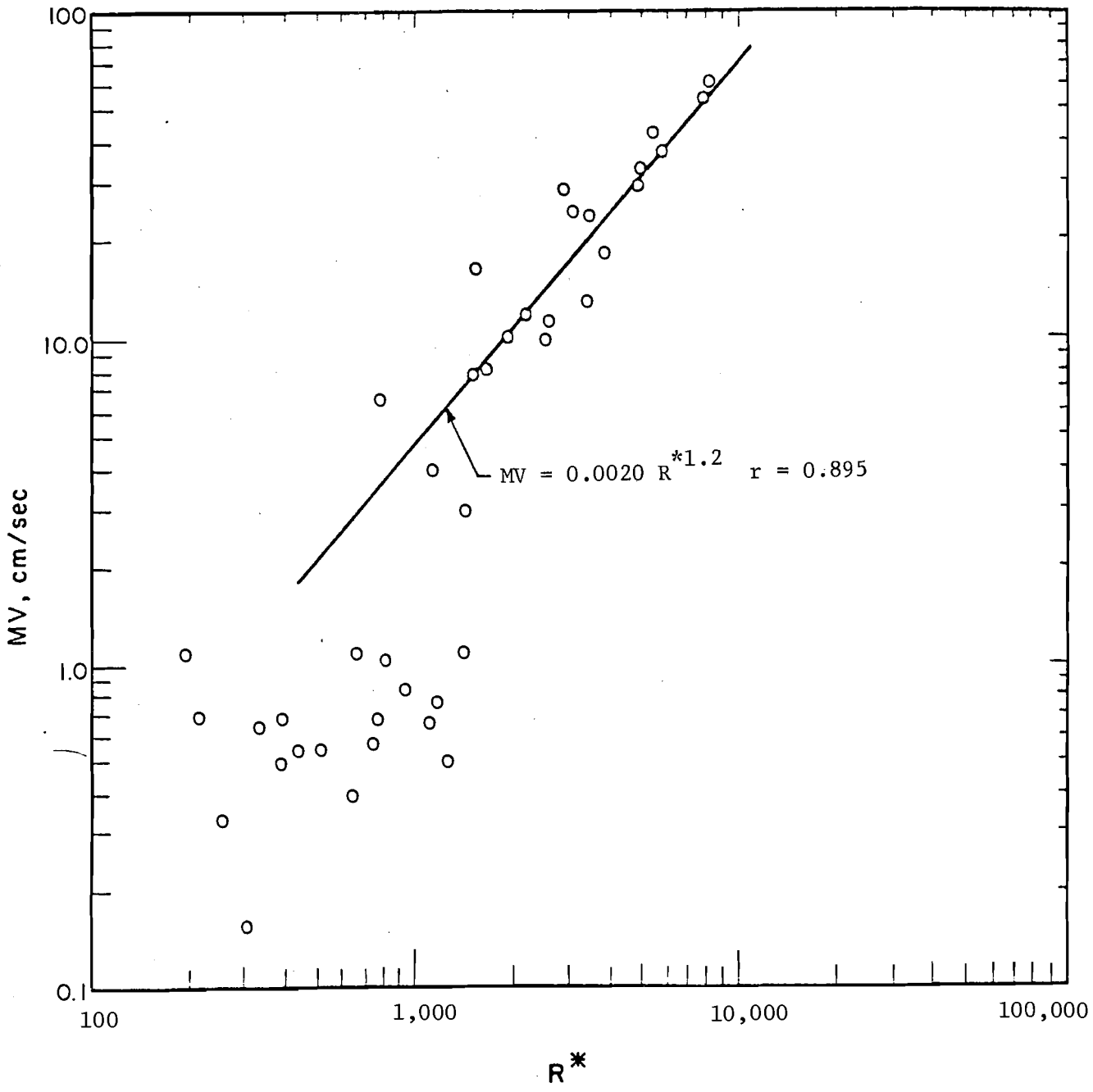


Fig. 3-1. Microvelocity at .09 CM vs. R^*

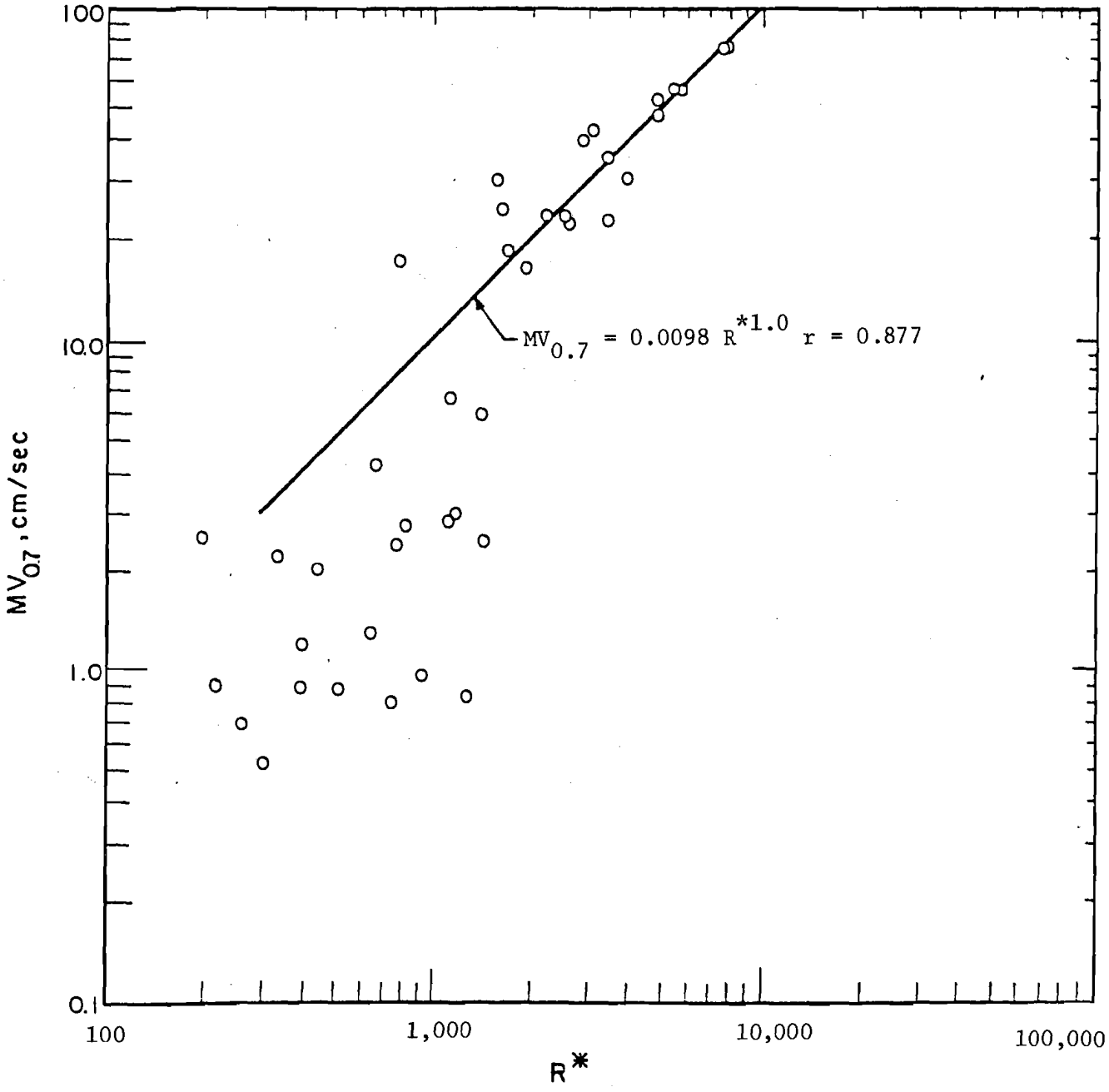


Fig. 3-2. Microvelocity at 0.7 CM vs. R^*

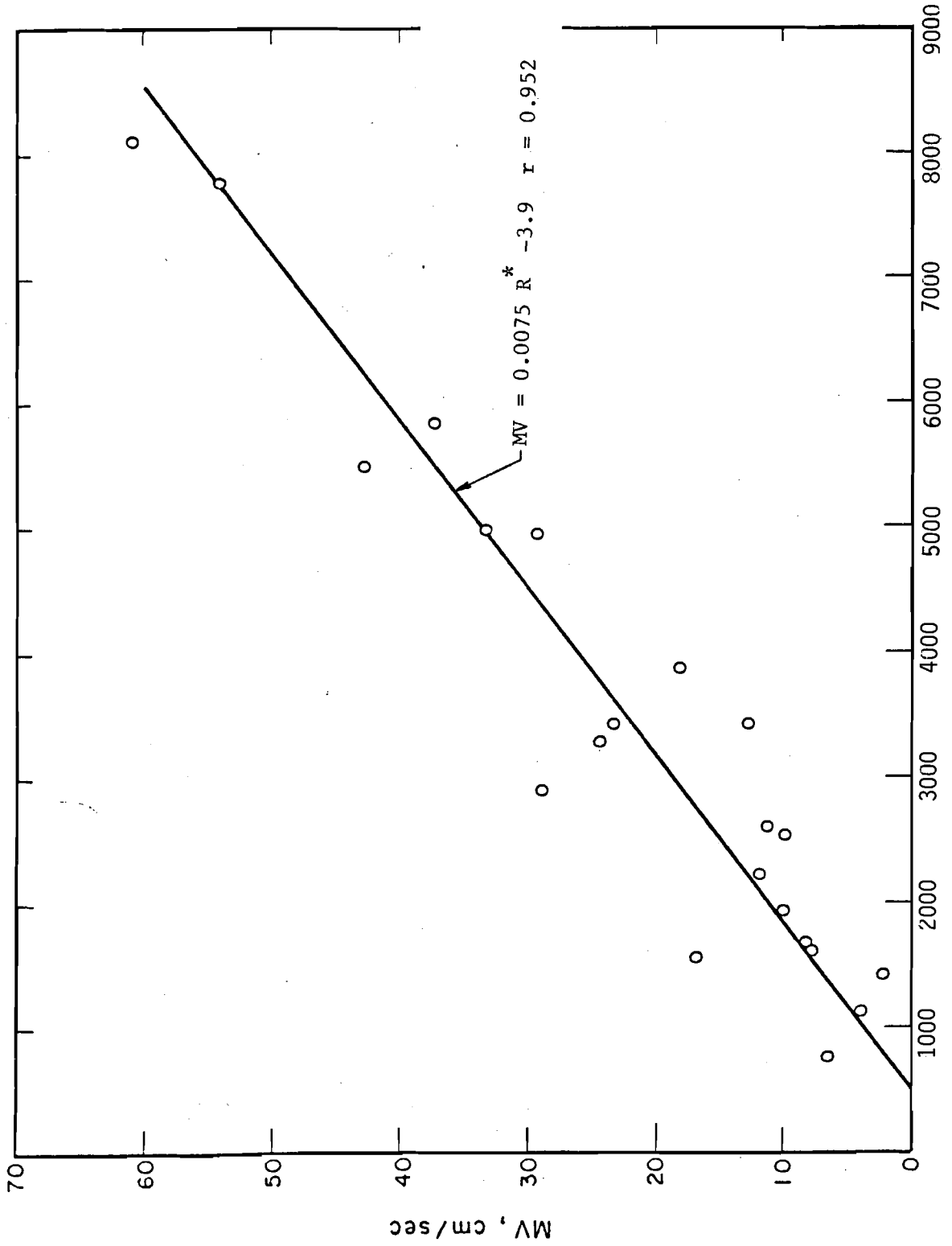


Fig. 3-3. Microvelocity at .09 cm vs R^* (linear plot)

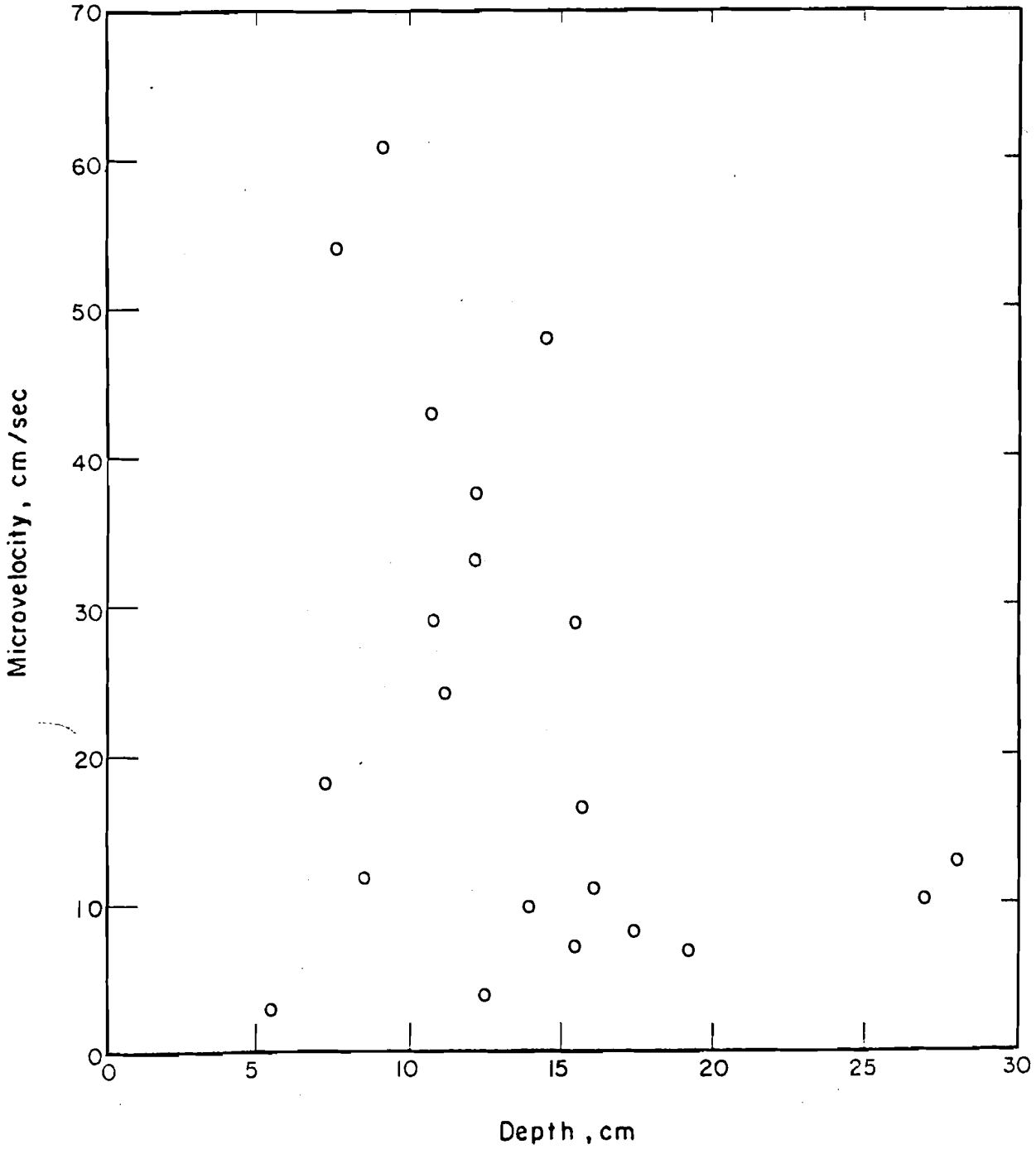


Fig. 3-4. Microvelocity at .09 cm vs depth

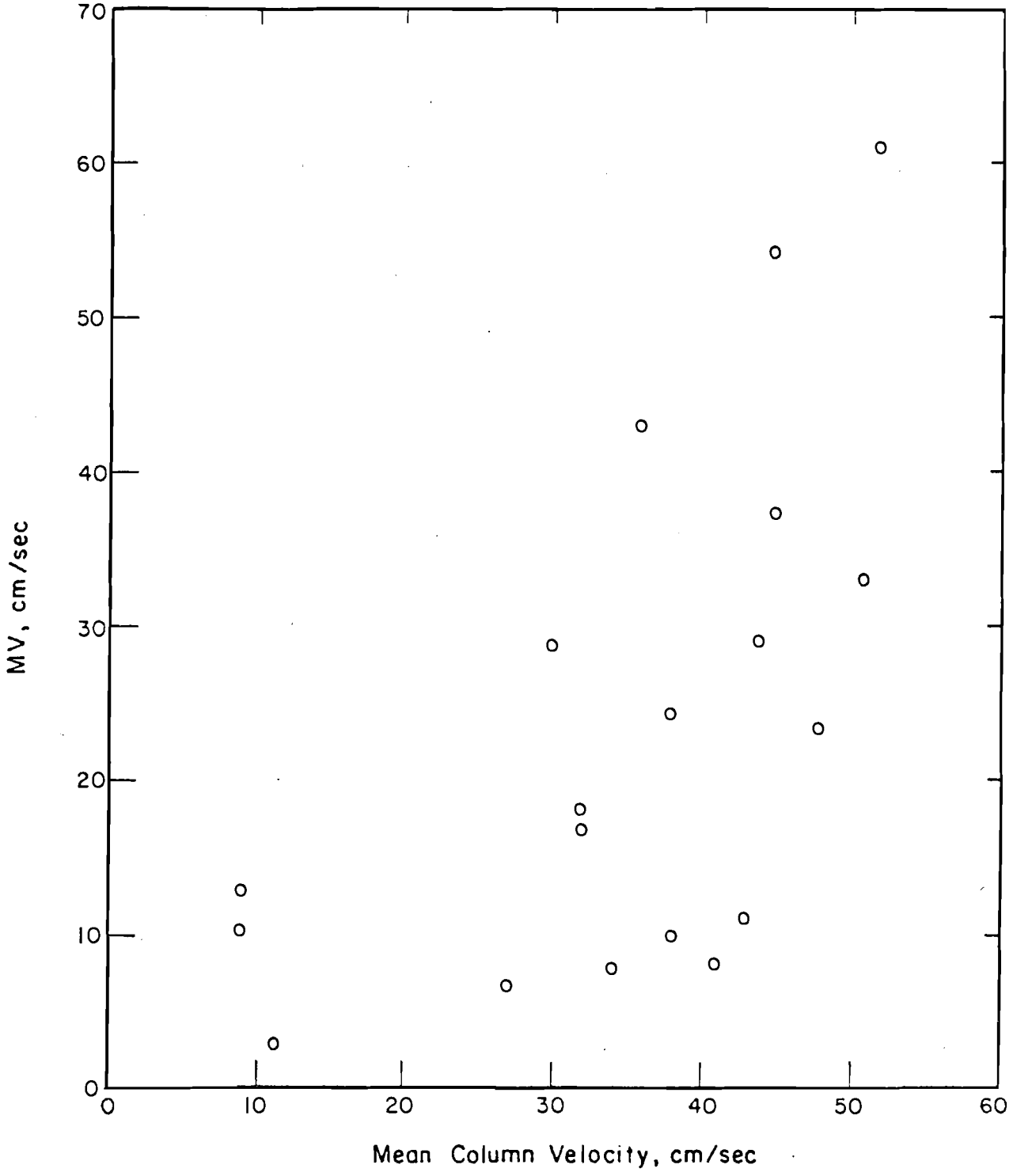


Fig. 3-5. Microvelocity at .09 cm vs mean column velocity

The plot of this line is presented in Figure 3.3 and Figure 3.5. The line for microvelocity .7 cm above the surface was:

$$MV = 0.0093R^* + 2.7$$

The coefficient of correlation were .952 and .947, respectively.

There is still scatter in these functions, but given the natural fluctuation in turbulent flow and difficulties in measuring microvelocity the correlation between R* and microvelocity is quite good.

It is emphasized that the measurements of microvelocity made in this experiment were made on the sides and tops of substrate elements, surfaces which are parallel to the direction of flow. Experimentation with the velocity probe indicated that the relation between microvelocity and R* would be different for microvelocities measured on different surfaces such as the front, back, or undersides of rocks. However, it should be remembered that the intent of a habitat indicator such as R* is not necessarily to find actual values of microvelocity but to provide an indication of the overall flow conditions within the substrate as was the purpose of this experiment. For R* values above about 1000, R* appears to accurately predict the flow conditions within the substrate and to be a useful tool for modeling aquatic insect habitat.

3.3.2 Comparison of R* to Depth and Velocity as Microhabitat Indicators

The most common parameters presently used to model habitat are, as previously discussed, depth, velocity, and substrate type. The data collected in this experiment also allows the correlation

of depth and mean column velocity with microvelocity. These two parameters were plotted against microvelocity in Figures 3.4 and 3.5, for measurements made at .09 cm. Points plotted were restricted as in the previous regression equations to values in the turbulent regime. It is obvious from these figures that neither depth nor velocity alone is an adequate predictor of microvelocity. Comparison to a plot of R* versus microvelocity on a similar linear scale (Fig. 3.3) shows the superiority of microvelocity prediction when the microhabitat parameters are combined into the boundary layer Reynolds number.

3.3.3 Example of R* Use for Studying Aquatic Insect Microhabitat

To further demonstrate the utility of R* as a descriptor of aquatic insect microhabitat, net-spinning caddisflies (Symphytopsyche cheilonis) were placed into a recirculating artificial stream channel (10 m long x 6.5 m wide) containing two substrate types, cobble and sand (n = 0.045 and 0.030, respectively). The organisms were allowed to disperse throughout the channel for a three week period and the water level adjusted once daily to maintain a constant depth; temperature was maintained at 15°C. At the end of this period, the mean column velocity (Pygmy Gurley meter) and water depth were determined for each 0.3 m length section and the substrate within each section sampled for S. cheilonis using a modified Surber sampler.

The results are reported in Figs. 3.6 and 3.7. These data indicate that S. cheilonis was found at all column velocities up to 16.0 cm/sec. The maximum mean column velocity within the channel was 16.5 cm/sec. S. cheilonis also occurred at water depths ranging from 2 cm up to 16 cm, although no larvae were collected at depths between 12 and 14 cm. The majority of larvae were collected within the 8-10 cm depth range (i.e., 48%) and at mean column velocities of 6-10 cm/sec (Fig. 3.7).

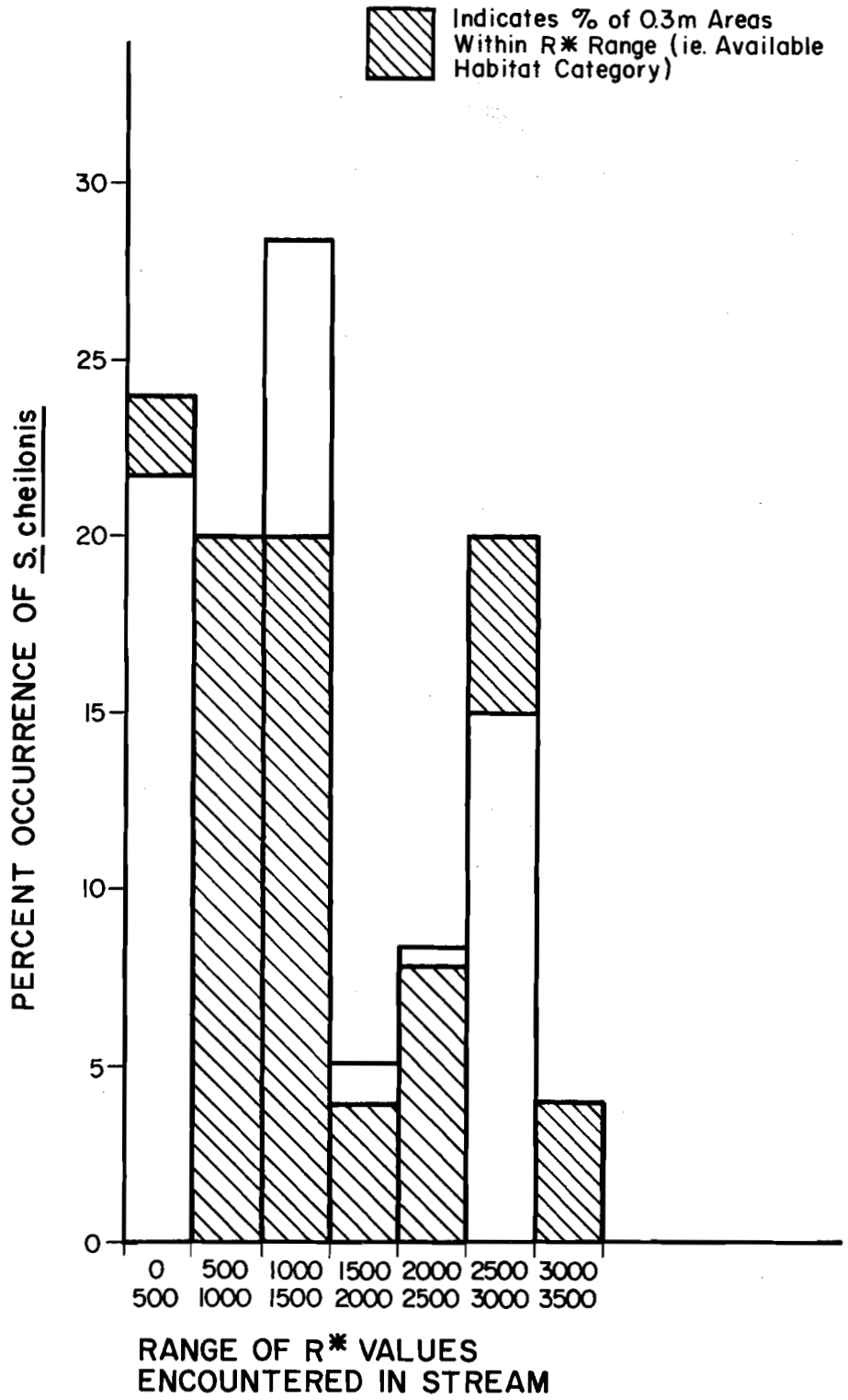


Fig. 3-6. The occurrence of S. cheilonis in a laboratory artificial stream with regards to existing R* and the percent occurrence of each R* category (lined bars) within the stream channel.

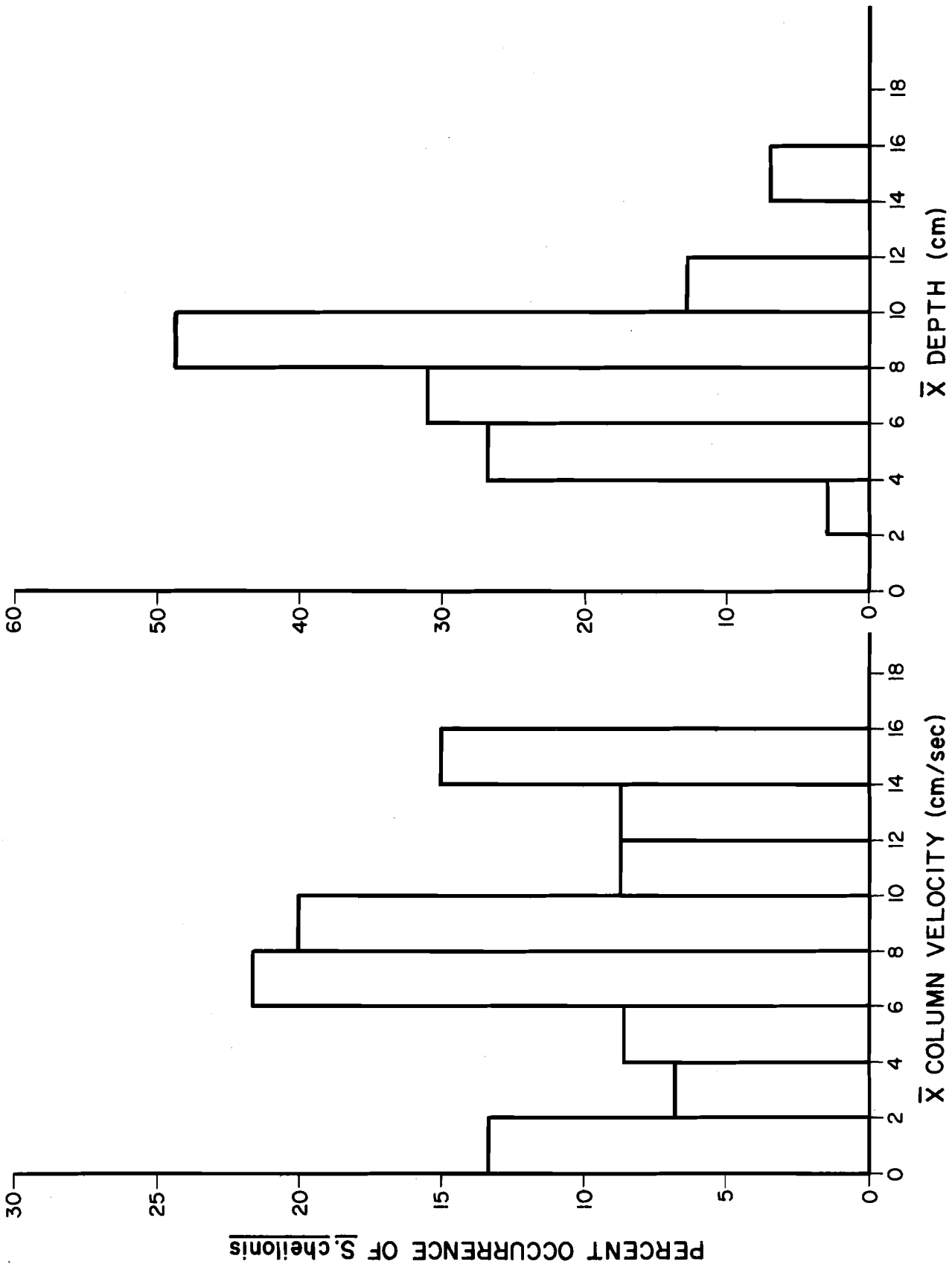


Figure 3-7. The occurrence of S. cheilonis in a laboratory artificial stream with regards to the mean column velocity and mean depth of each 0.3 m section.

Examination of Fig. 3-6 indicates that S. cheilonis occurred in sections of the stream channel with R* ranging from less than 100 up to a maximum of 3000. No larvae were found in regions of the channel where the R* value was greater than 3000 although 4% of the total available habitat had such boundary layer characteristics. Furthermore, examination of Fig. 3-6 indicates that in R* value ranges where S. cheilonis occurred (i.e., lower range 0-500; upper range 2500-3000), the percent occurrence was less than the area available when compared with the intermediate R* categories (i.e., 500-2500). This analysis indicates intermediate R* values contain greater numbers of larvae than would be expected based on habitat. This suggests a selection by the population towards the more intermediate R* values. Although habitat saturation was not demonstrated in this experiment, these data suggest that future experiments on competitive interactions for available habitat space in laboratory streams should concentrate on areas of stream with hydraulic characteristics within a R* value range of 500-2500.

3.3.4 Discussion

The boundary layer Reynolds number R* has been shown to be a useful parameter in describing the microhabitat conditions for aquatic insects. The velocity within small gravel to cobble substrates was related to R*, for a range of R* values from less than 1000 to greater than 10,000, we feel the present hydraulic models adapted to instream flow modeling can easily be modified to calculate R*. The use of R* provides a sound starting place for the development of a habitat quality model for benthic organisms.

Although R* may be useful prediction of bottom velocity whether or not aquatic insects actually have strong preferences for certain microvelocity ranges must still be determined. There is evidence

in the literature that insects do segregate physical habitat based on velocity and substrate type (Allen, 1975; Cummins, 1964; Cummins and Lauff, 1969; Curry, 1962; Edington, 1968; Gaufin, 1962; Leonard, 1962; Williams and Hynes, 1973; Smith and Dartnall, 1980; Statzner, 1981). Unfortunately, it is often not possible to directly relate literature measurements of velocity and substrate to a microvelocity preference. Such preference ranges were determined by Statzner (1981) for his hydraulic stress index but these values were limited mainly to sand substrates.

Since R* has been shown to be directly related to microvelocity, macrohabitat measurements necessary to evaluate R* (e.g., measurements of depth, velocity, temperature and substrate assessment) may be taken instead. Using this information, functions of abundance versus microvelocity or R* may be determined for each target species. This suggested approach is similar to that proposed by Gore and Judy (1981) for a model to predict macroinvertebrate density in instream flow needs analyses. There have been many field studies undertaken for which this data has been collected (Bovee et al., 1978; Herricks and Furnish, 1980), and it may be reanalyzed to relate R* to the aquatic insect community.

As with fish, there are complicating factors caused by differences in niche dimensions of each life stages of a species. For example, Cummins (1964) showed that niche segregation by substrate size can occur between instars for some caddisfly larvae. The importance of life history in aquatic insect ecology is discussed at length by Wynes (1970).

There are other ecological complications that need to be considered as well, especially in the formulation of velocity and substrate preference functions for insects. There is some evidence in the

literature that the indirect effects of velocity may be more important than the actual current speed, and that actual tolerance ranges for velocity may be very broad. Eriksen (1966) investigated the indirect effects of velocity, especially the transport of oxygen to insects gills. Ulfstrand (1967) predicted wide tolerance ranges for direct effects of velocity because of the large natural fluctuation in streamflows, and hypothesized that a major role of substrate is in the provision of periphyton, detritus, and prey species for food. In one of the most careful studies of microhabitat to date, Rabeni and Minshall (1977) showed that for some insects a very wide tolerance range for velocity is demonstrated if suitable substrate is provided. This suggests that in some cases the most important function of velocity may be its role as a transporter and sorter of sediment to provide suitable substrate. Alternatively in Illinois, it may well be that the limiting factor in instream flow needs analyses for aquatic insects is the need for enough flow to prevent siltation of stone riffles.

The ability to model microvelocity by using the boundary layer Reynolds number R*, the generation of preference functions of insects for R*, provide an alternative approach to assessing aquatic insect habitat quality. Consideration of ecological factors with an assessment based on R* may provide a sound and readily applied methodology for modeling aquatic insect habitat.

4. A STUDY OF THE DISTRIBUTION OF AQUATIC INSECTS AS RELATED TO R* IN FIVE ILLINOIS STREAMS

4.1 PURPOSE

Previous investigators (Bovee et al., 1978; Gore, 1978) examined the distribution of invertebrates with regards to substrate and turbulence using three dimensional surfaces and centroid calculations. Froude number, microprofile index and diversity (or the abundance of a taxa) were employed as variables. This study was designed to extend habitat descriptions based on Reynolds numbers with information relating to shear stress (i.e., R*). The purposes of this study were: 1) the development of a field method for determining the instream flow requirements of aquatic insects; and 2) the generation of a suitable data base for examining the applicability of using R* as a means of modeling aquatic insect communities.

4.2 INTRODUCTION

Stream habitats have been described as ephemeral constructs of the constantly changing physical and chemical characteristics of stream flow (Herricks and Furnish, 1980), with discharge recognized as the controlling factor. Organisms inhabiting a stream system have evolved with the changing nature of their habitat. Despite the numerous behavioral and morphological adaptations of aquatic fauna, distributions are subject to alterations due to unnatural and catastrophic events.

A major area of study in stream ecology is determining the manner in which environmental parameters affect the distribution of aquatic organisms. The collection of data of this nature is important not only from a purely academic point of view, but sound data of this type contributes to an

understanding of instream flow requirements which is essential in stream management restoration, protection, and maintenance. Despite the fact that an extensive literature exists for benthic invertebrate ecology, the suitability of that literature for development of habitat/organism relationships which would be compatible with existing management tools such as the instream flow methodologies is limited (Herricks and Furnish, 1980).

4.3 STUDY SITES

Benthic macroinvertebrates were collected from five streams in Illinois from August, 1980 through August, 1981. Two of the streams, Big Creek and Hutchins Creek, were located in southeastern Illinois in the Shawnee National Forest. This area is characterized by mature deciduous forests and relatively steep stream gradients in rolling hills. Two other streams, Apple River and Kishwaukee River were located in the northwestern and northcentral portion of the state. The fifth site was located in the Salt Fork River, approximately 2 km upstream of the confluence with Jordan Creek in eastcentral Illinois. These five sites were selected for study due to the diverse physiographic characteristics and annual mean temperature regimes that they represented.

4.4 METHODS

Replicate benthic macroinvertebrate samples were collected periodically from each of the sampling sites from August, 1980 through August, 1981 using a standard Surber sampler (area 0.3 m^2; collection net 20 mesh/cm^2; agitation depth 5 cm). The samples were collected in a non-random fashion in order to sample as many of the habitat types (i.e., velocity, depth, substrate combinations) as possible. Organisms were preserved in 70% ETOH and returned to the laboratory for taxonomic identification.

Prior to agitation of the substrate enclosed by the sampler, but following sampler its placement, the mean column velocity in front of the Surber sampler and the total depth of the water were determined. Mean column velocity was determined by placing the sensing unit of a Marsh-McBirney flow meter at 0.6 of the total depth. Estimates of the average substrate particle diameter enclosed by the Surber and the water temperature (hand held thermometer) were also determined. These data were placed into the equation:

$$R^* = \frac{D_s \, g^{1/2} \, R^{-1/6} \, Vn}{vCm} \quad \text{(see eq. 5; Section 2)}$$

which was used to determine the Reynolds number for each sample.

The relationship of R* to species richness, total number of individuals, and the Shannon-Wiener species diversity (H') were determined using Spearman Rank nonparametric correlation analysis. Species diversity was calculated using the formula:

$$H' = -\sum_{i=1}^{s} p_i \ln p_i$$

where p_i is the proportion of individuals in the ith species of the community. The range of R* values inhabited by the most common taxa were also determined. Similarly, the relationship between mean column velocity and depth with the various community statistics were evaluated. Most common taxa were arbitrarily chosen to be those collected in greater than 10% of the total number of samples collected.

4.5 RESULTS AND DISCUSSION

A total of 217 macroinvertebrate taxa, the majority of which were aquatic insects were collected during the study (Table 4-1). The most abundant aquatic insect taxa belonged to the family Chrionomidae (order Diptera) and members of the orders Ephemeroptera (mayflies) and Trichoptera (caddisflies).

Table 4-1. Taxa collected during the study and the corresponding taxa codes.

038	AGYPETES ILLINOIS
001	CHEUMATOPSYCHE SP
002	CHIMARRA OBSCURA
030	CHIMARRA PROB. ATERRIMA
019	DIPLECTRONA MEATQUI
041	DOLOPHILUS SP.
024	GLOSSOSOMA SP.
003	HELICOPSYCHE BOREALIS
004	HYDROPSYCHE BETTENI
015	HYDROPSYCHE CUANIS
012	HYDROPSYCHE FRISONI
012	HYDROPSYCHE FRISONI
005	HYDROPSYCHE SIMULIUMS
013	HYDROPSYCHE Sp.
026	HYDROPTILA PROB. AJAX
035	HYDROPTILLA SP.
033	HYDROPTILLIDAE
021	LEUCOTRICHIA PICTIPES
036	MACRONEMA CAROLINA
018	MACRONEMA ZEBRATUM
040	NEOPHYLAX AUTUMNUS
022	NEURECLIPESIS SP!
037	OCHROTRICHIA RIESI
025	OCHROTRICHIA SP.
017	OCHROTRICHIA XENA
029	OECETIS SP.
020	ORTHOTRICHIA PROB. CRISTATA
031	ORTHOTRICHIA SP.
032	ORTHOTRICHIA TARSALIA
039	PHYLOCENTROPUS PLACIDUS
034	POLYCENTROPUS FLAVUS
006	PHCNOPSYCHE GUTTIFER
023	SYMPHITOPSYCHE BIFIDA
007	SYMPHITOPSYCHE BRONTA
028	SYMPHITOPSYCHE MOROSA
014	SYMPHITOPSYCHE SP.
008	SYMPHITOPSYCHE CHEILONIS
009	SYMPHITOPSYCHE SPARNA
101	ABLABESMYIA MALLOCHI
153	ABLABESMYIA SP.
131	BRILLIA SP.
102	CARDIOCLADIUS SP
134	CHIRONOMUS RIPARIUS
154	CHIRONOMUS SP.
103	CHIRONOMUS STATEGERI
160	CLADOTANYPUS SP.
163	CLADOTANYTARSUS SP!
133	CORYNONUERA TARIS
105	CRICOTOPUS BICINCTUS
106	CRICOTOPUS INTERSECTUS
104	CRICOTOPUS SP1.
139	CRICOTOPUS SYLVESTRIS SP GRP.
166	CRICOTOPUS TIBIALIS SP GRP.
108	CRICOTOPUS TREMULUS
107	CRICOTOPUS TRIFASCIA
109	CRYPTOCHIRONOMUS SP!
110	CRYPTOCHIRONOMUS FULVUS
111	DICROTENDIPES NEOMODESTUS
161	ENDOCHIRONOMUS SP.
112	EUKIEFFERIELLA SP
130	EUKIEFFERIELLA BAVARICA SP GRP.
114	EUKIEFFERIELLA POTTHASTI

Table 4-1. (Cont.)

113	EUKIEFFERIELLA DISCOLORIPES
115	EUKIEFFERIELLA PSEUDOMONTANA
116	EUORTHOCLADIUS (TYPE I. SOPONIS)
117	HETEROTRISSOCLADIUS SP
147	LABRUNDINIA SP.
164	LARSIA SP.
149	LAUTERBORNIELLA SP!
132	MICROPSECTRA SP.
118	MICROTENDIPES CAELUM
152	MICROTENDIPES SP!
146	NANNOCLADIUS SP.
156	NILOTANYPUS SP.
170	ORTHOCLADIUS CLARKEI
169	ORTHOCLADIUS DENTIFER
168	ORTHOCLADIUS ROBACKI
155	ORTHOCLADIUS SP.
119	ORTHOCLADIUS-CRICOTOPUS I (PROB. O. OBUMBRATUS)
120	ORTHOCLADIUS-Cricotopus II
121	PARAKIEFFERIELLA SP
142	PARAMETRIOCNEMUS SP.
122	PARATANYTARSUS SP.
150	PARATENDIPES SP.
145	PENTANEURA SP.
135	PHAENOPSECTRA FLAVIPES
123	PHAENOPSECTRA PROB! DYARI
157	PHAENOPSECTRA SP!
124	POLYPEDILUM CONVICTUM
125	POLYPEDILUM FAXXAX
167	POLYPEDILUM SCALAENUM
156	POLYPEDILUM SP.
143	POTTHASTIA LONGIMANUS
165	PROCLADIUS SP!
126	PSECTROCLADIUS PSILOPTERUS
127	PSUEDOCHIRONOMUS SP.
140	PSUEDOSMITTIA SP!
138	RHEOCRICOTOPUS SP.
136	RHEOTANYTARSUS SP.
141	SYNORTHOCLADIUS SP!
137	SYNORTHOCLADIUS SP!
148	TANYPUS GUERLUS GRP.
158	TANYPUS SP.
162	TANYTARSINI (TRIBE)
159	TANYTARSUS SP.
128	THIENEMANIELLA SP.
129	THIENEMANNIMYIA SP GRP!
171	TRISSOCLADIUS SP!
172	XENOCHIRONOMUS SP.EPHEMEROPTERA
201	AMELETUS LINEATUS
244	BAETIS BRUNNEICOLOR
229	BAETIS FLAVISTIGA
233	BAETIS FROMDALIS
203	BAETIS HERODES
204	BAETIS INTERCALARIS
202	BAETIS SP
232	BAETIS VAGANS
205	CAENIS SP.
206	CENTROPTILUM SP.
237	DANNELLA LITA
236	EPHEMERA SP.
218	EPHEMERELLA DEVELIENS
214	EPHEMERELLIDAE
221	EPHORON SP.
223	HEPTAGENIA MACULIPENNIS
230	HEPTAGENIA SP.

Table 4-1. (Cont.)

224	HEPTAGENIIDAE
207	HEXAGENIA SP.
208	ISONYCHIA SP.
240	LEPTOPHLEBIA SP.
235	PARALEPTOPHLEBIA SP.
242	PARALEPTOPHLEBIA GUTTATA
241	PARALEPTOPHLEBIA PRAEPEDITA
243	PARALEPTOPHLEBIA MOERENS
209	POTAMANTHUS SP.
231	PSUEDOCLOEN DUBIUM
216	PSUEDOCLOEN PARVULUM
234	PSUEDOCLOEN PUNCTIVENTRIS
213	PSUEDOCLOEN SP.
210	STENACRON GILDERSLEEVEI
222	STENACRON INTERPUNCTATUM
225	STENACRON MINNETONKA
227	STENACRON SP.
211	STENONEMA ARES (TERMINATUM)
239	STENONEMA EXIGUUM
228	STENONEMA FEMORATUM
220	STENONEMA ITHACA
238	STENONEMA MODESTUM (FORMERLY RUBRUM)
212	STENONEMA NEPOTELLUM (MEDIOPUNCTATUM)
219	STENONEMA PULCHELUM
217	STENONEMA SP.
215	STENONEMA TRIPUNCTATUM
226	TRICORYTHODES SP! PLECOPTERA
304	ACRONUERIA ABNORMIS
308	ALLOCAPNIA SP
305	ARCYNOPTERYX SP.
311	ATOPERLA SP.
310	BRACHYPTERA FASCIATA
307	CHLOROPERLIDAE
301	ISOPERLA CONFUSA
306	ISOPERLA SP.
309	PARACAPNIA SP.
303	PERLESTRA PLACIDA
302	TAENIOPTERYX NIVALIS COLEOPTERA
413	AGABUS SP.
414	BEROSUS SP.
407	DUBIRAPHIA SP.
412	DYTISCUS SP.
401	ELMIDAE
409	LIDDESSUS SP.
411	MYCROCYLLOPEUS PUSILLUS
406	PELTODYTES SP.
410	PSEPHENUS HERRICKI
403	STENELMIS CRENATA
404	STENELMIS DECORATA
405	STENELMIS HUMEROSA
402	STENELMIS SP. DIPTERA
503	ANTOCHA SP.
509	ATHERYX SP.
518	BEZZIA SP.
507	CNEPHIA SP.
505	DACTYLOLABIS SP.
517	DICTA SP.
510	HEMERODROMIA SP.
513	HEXATOMA SP.
516	PALPOMYIA SP.
511	POTAMYIA SP.
515	PROSIMULIUM MIXTUM
500	SIMULIDAE
501	SIMULIUM SP.
512	TABANUS SP.
506	TIPULA SP.

Table 4-1. (Cont.)

514 TROPISTERNUS SP. MISC.
601 ARGIA SP. (ODONATA)
602 ASELLUS SP.
620 COENAGARIONIDAE (ODONATA)
623 CORIXIDAE (HEMIPTERA)
613 CORYDALUS CORNUTUS (MEGALOPTERA)
615 DUGESTIA TIGRINA
616 FERRISA SP. (MOLLUSCA)
614 GYRAULUS SP.
607 HIRUDINOIDEA
608 HYALELLA AZTECTA
605 HYDRACARINA
619 HYPONEURA SP.
618 ISCHNURA RAMBURI (ODONATA)
604 NOTONECTA SP.
603 OLIGOCHAETA
612 PARAGYRACTIS SP. (LEPIDOPTERA)
611 PHYSA SP. (GASTROPODA)
610 PLANARIA
609 PSIDIUM SP.
617 SIALIS SP. (MEGALOPTERA)
621 VALVATA SP. (MOLLUSCA)
622 VIVIPARIDAE (MOLLUSCA)

Table 4-2. Community statistics for each of the 70 Surber Samples collected from Hutchins Creek (HC), Big Creek (BC), Apple River (AP), Kishwaukee River (KS), and the Salt Fork River (SF) and the corresponding R* value.

DATE	SITE	SAMPLE	NO. TAXA	NO. INDS.	H'	R*
101380	HC	1141	18	436	2.003	1596
101380	HC	1142	20	746	2.090	2923
101380	HC	1144	19	1053	1.841	318
101380	HC	1146	14	452	1.817	4790
101480	BC	1161	20	185	2.565	4360
101480	BC	1162	13	225	2.302	1199
101480	BC	1164	12	124	1.747	12185
101480	BC	1165	24	680	2.170	5980
101480	BC	1167	14	182	1.908	3005
102580	AP	1171	8	54	1.650	7914
102580	AP	1172	13	812	1.998	11074
102580	AP	1173	19	3818	1.802	16705
102580	AP	1175	26	923	2.298	16928
102580	AP	1181	14	458	1.887	8577
102580	AP	1182	27	1123	2.381	9256
102580	AP	1183	20	591	1.724	30037
102580	AP	1184	18	1355	1.956	9610
102580	AP	1185	17	317	1.917	6131
102580	AP	1186	12	634	1.316	2520
122180	KS	1231	19	747	2.039	15278
122180	KS	1232	13	519	1.345	14403
122180	KS	1233	9	52	2.076	4842
122180	KS	1234	11	443	1.330	10603
20381	SF	1261	34	886	2.129	17156
20381	SF	1264	22	763	1.531	9195
21981	HC	1271	8	1122	.560	2903
21981	HC	1273	20	725	2.253	61432
21981	HC	1274	7	169	.748	47062
21981	HC	1275	6	346	2.084	13400
21981	HC	1276	14	1937	.792	31399
22081	BC	1281	12	391	1.807	13241

Table 4-2. (Cont.)

DATE	SITE	SAMPLE	NO. TAXA	NO. INDS.	H'	R*
22081	BC	1282	8	71	1.821	33945
22081	BC	1283	27	490	2.646	22382
22081	BC	1284	21	110	2.275	12135
22081	BC	1285	24	505	1.327	12942
22081	BC	1286	22	308	1.958	3174
50381	BC	1301	7	189	1.135	3997
50381	BC	1302	9	126	1.516	8087
50381	BC	1303	13	199	1.527	4043
50381	BC	1304	12	411	1.472	3368
50381	BC	1305	8	468	.885	1189
50381	BC	1306	13	300	1.306	3193
51381	AP	1321	15	2421	1.234	9272
51381	AP	1322	9	1905	.829	16849
51381	AP	1323	13	1234	.731	4039
51381	AP	1324	14	1302	.712	10316
51381	AP	1331	14	751	1.650	10536
51381	AP	1332	14	355	1.533	8223
51381	AP	1333	19	6237	1.645	19386
51381	AP	1334	10	1643	.793	4574
51381	AP	1335	15	926	1.394	9733
51381	AP	1336	11	526	.938	8845
51381	AP	1337	9	1705	1.011	6601
70181	BC	1341	10	43	1.530	2778
70181	BC	1342	12	679	1.185	1799
70181	BC	1343	17	444	1.529	4682
70181	BC	1344	10	292	1.167	4287
70181	BC	1345	17	874	1.776	17283
70181	BC	1346	9	332	1.315	6520
70781	AP	1361	13	1820	1.036	8769
70781	AP	1362	11	617	1.794	7928
70781	AP	1363	16	1689	.767	18159
70781	AP	1364	9	626	.643	1890
70781	AP	1365	11	1097	.445	4655
70781	AP	1366	14	1069	1.619	21033
92281	SF	1391	14	439	1.526	5350
92281	SF	1392	18	837	2.082	19053
92281	SF	1393	21	2166	1.926	15315
92281	SF	1394	13	396	1.300	4012
92281	SF	1396	11	338	1.465	1073

Reynolds values (R*) ranged from a minimum of 318 to a maximum of 61,432 (Table 4-2). Both of the extreme ranges occurred in Hutchins Creek. The minimum R* value of 318 occurred in October of 1980, while the maximum R* value occurred in February, 1981. The total stream discharge during both periods was very similar; thus, the substantial variation in R* is reflective of the heterogeneity within the same reach. The principal difference in the minimum and maximum R* can be attributed to mean column velocity differences as Surber D in October, 1980 (Sample 1144) had a mean column velocity of 2.5 cm/sec, while Surber C (Sample 1273) had a mean column velocity of 66 cm/sec. The water depths at the two sites were 12.7 cm and 12.2 cm, respectively.

The mean R* for each of the five streams are reported in Table 4.3. The highest mean values were recorded in the Shawnee National Forest streams (i.e., Hutchins Creek mean R* = 18,425; Big Creek mean R* = 16,760). These two streams also had the highest standard deviations of R* values (Table 4-3) which further reflects the variability of microhabitats within a reach.

The remaining streams in the northern (i.e., Apple River and Kishwaukee River) and east central (i.e., Salt Fork) portion of the state had very similar mean R* values (Table 4-3) and similar variability (i.e., standard deviations). The slightly higher mean R* values in the south-eastern stream are reflective of the differences in the physiography and land form and are typical of the Ozark region streams. Despite the large differences in the average R* values between the five streams (Table 4-3), the values were not statistically different when analyzed using an analysis of variance in the R* within each stream. Thus, these data demonstrate

Table 4-3. Reynolds number statistics for each of the five rivers sampled during the project.

R* Parameters	Apple River	Big Creek	Hutchins Creek	Kishwaukee River	Salt Fork River
Mean	10,724.5	8,029.3	18,424.8	11,281.5	10,164.9
Standard Deviation	6,399.6	7,945.3	22,752.7	4,748.5	7,059.8
Minimum	1,890	1,189	318	4,842	1,073
Maximum	30,037	33,945	61,432	15,278	19,053

that while there is substantial variation in the R* value within the five streams, there are no significant intersystem variation.

The greatest mean species richness occurred in the Salt Fork River, while the lowest mean species richness occurred in the Kishwaukee River (Table 4-4). The Salt Fork River also had the highest individual species richness value with a total of 34 taxa occurring in one sample while the Hutchins Creek site had only six taxa in one sample (Table 4-4). No significant differences were detected in the species richness values between the five streams during the study which suggests a similar availability of microhabitats in all five streams.

Like the preceding results, no significant differences were found in calculated Shannon-Wiener H' values between the five streams (Table 4-5). The highest mean diversity value occurred in the Salt Fork River, while the lowest mean H' value occurred in the Apple River (Table 4-5). These results in conjunction with the preceding indicate that a similar diversity of macroinvertebrate fauna exists in streams with similar R* values.

A significant difference in the abundance of individuals within the samples was found between the five streams (Table 4-6). The results indicate that significantly more individuals occurred in the Apple River samples than occurred in the Big Creek samples (Table 4-7). The mean number of individuals in Big Creek was 331.7 per Surber, while the Apple River site had a mean of 1,333.6 individuals (Table 4-5). No other significant differences were found between the sites.

To meet the basic goals of this study, the calculated R* values were examined with respect to the various community statistics, depth, and velocity to determine if general trends existed between them. This was done using rank correlation analysis. The results of these analyses are reported in Table 4-8.

Table 4-4. Species richness statistics for each of the five rivers sampled during project.

Species Richness Parameter	Apple River	Big Creek	Hutchins Creek	Kishwaukee River	Salt Fork River
Mean	14.5	14.5	14.0	13.0	19.0
Standard Deviation	4.7	5.8	5.7	4.3	7.8
Minimum	8.0	7.0	6.0	9.0	11.0
Maximum	27.0	27.0	20.0	19.0	34.0
No. Samples	27	23	9	4	7

Table 4-5. Total number of individuals and corresponding statistics for each of the five rivers sampled during study.

No. Inds. Parameter	Apple River	Big Creek	Hutchins Creek	Kishwaukee River	Salt Fork River
Mean	1333.6	331.7	776.2	440.3	831.7
Standard Deviation	1248.9	214.7	538.7	289.7	629.6
Minimum	54.0	43.0	169	52	338
Maximum	6237	874.0	1937	747	2166

Table 4-6. Species diversity (H') statistics for each of the five rivers sampled during the project.

H' Parameters	Apple River	Big Creek	Hutchins Creek	Kishwaukee River	Salt Fork River
Mean	1.40	1.69	1.58	1.70	1.71
Standard Deviation	0.54	0.47	0.67	0.42	0.33
Minimum	0.45	0.89	0.56	1.33	1.30
Maximum	2.38	2.65	2.25	2.08	2.13

Table 4-7. Results of oneway analysis of variance on the various community statistics (species richness, total number of individuals, H' diversity) and the calculated Reynolds numbers with respect to river system and the subsequent A-posteriori comparisons (N.S. = not significant at $p<0.05$).

Parameter by Site	Anova Results	Duncan's A-posteriori Results
Species Richness	N.S.	
Total Number of Individuals	$p < 0.01$	BC KS HC SF AR
Shannon-Wiener Diversity (H')	N.S.	
Reynolds Number (R*)	N.S.	

Table 4-8. Results of Spearman rank correlation analysis with the various river parameters using 69 Surber samples and the corresponding correlation coefficient (rho). (N.S. = not significant at p = 0.05; * = significant at α = 0.05; ** = significant at α = 0.01.)

	Reynolds Number	Depth	Current Velocity
Species Richness	0.276(**)	0.129(NS)	0.101(NS)
Total No. Inds.	0.302(**)	0.015(NS)	0.132(NS)
H' Diversity	0.174(NS)	0.048(NS)	0.076(NS)

A highly significant relationship was found between R* and the species richness and the total abundance of macroinvertebrates. No significant relationship was found between the mean column velocity and depth when analyzed with respect to the community statistics. While a relatively linear relationship between R* and species richness and abundance exists in these data, there is likely a critical flow or R* value where this relationship no longer holds. Whether streams with such high R* values exist in Illinois is questionable. These data indicate that as R* increases one should also observe an increase in species richness and in total numbers of invertebrates. Such a relationship appears to be meaningful for the five streams examined in Illinois, but care should be taken in extrapolating these results to other regions of the U.S. This is particularly true of the moutainous west where very high shear stress values could be expected to reduce the abundance of macroinvertebrates. For the low gradient midwestern streams with lower velocity, such a relationship appears to be of general value in assessing stream condition and for simulation efforts. The use of the R* value is particularly applicable for adaptation to the existing IFGIM program as all of the information necessary for its determination is used throughout the various programs. The final component necessary for its use is the biological boundaries for each species. This would be similar to the fish "preference curves" presently employed in PHABSIM with the exception that only an upper and lower bounds are needed to determine if a taxa can or cannot occur within a given set of hydraulic conditions.

4.6 RANGE OF R* FOR INVERTEBRATE TAXA

To meet the final goal of this section, the range of R* values inhabited by the most common taxa collected throughout the study (those occurring in greater than 10% of the samples) were determined. These results are reported

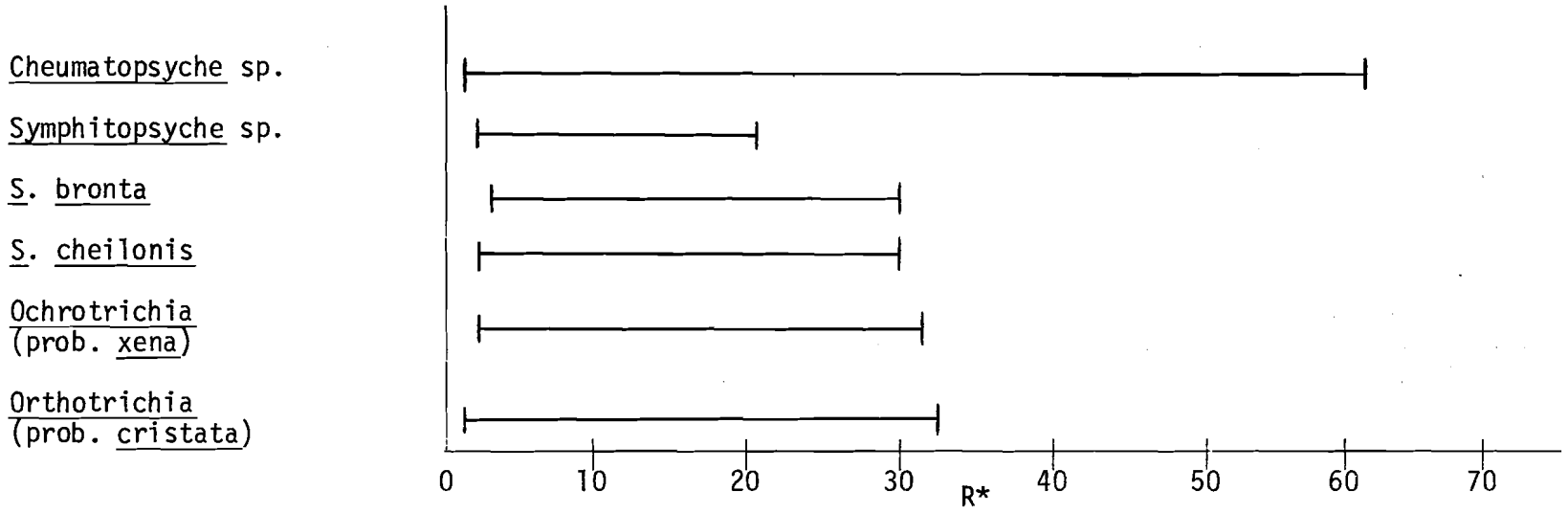


Figure 4-1. Range of R* values inhabited by the most abundant Trichoptera taxa. R* x 10^3.

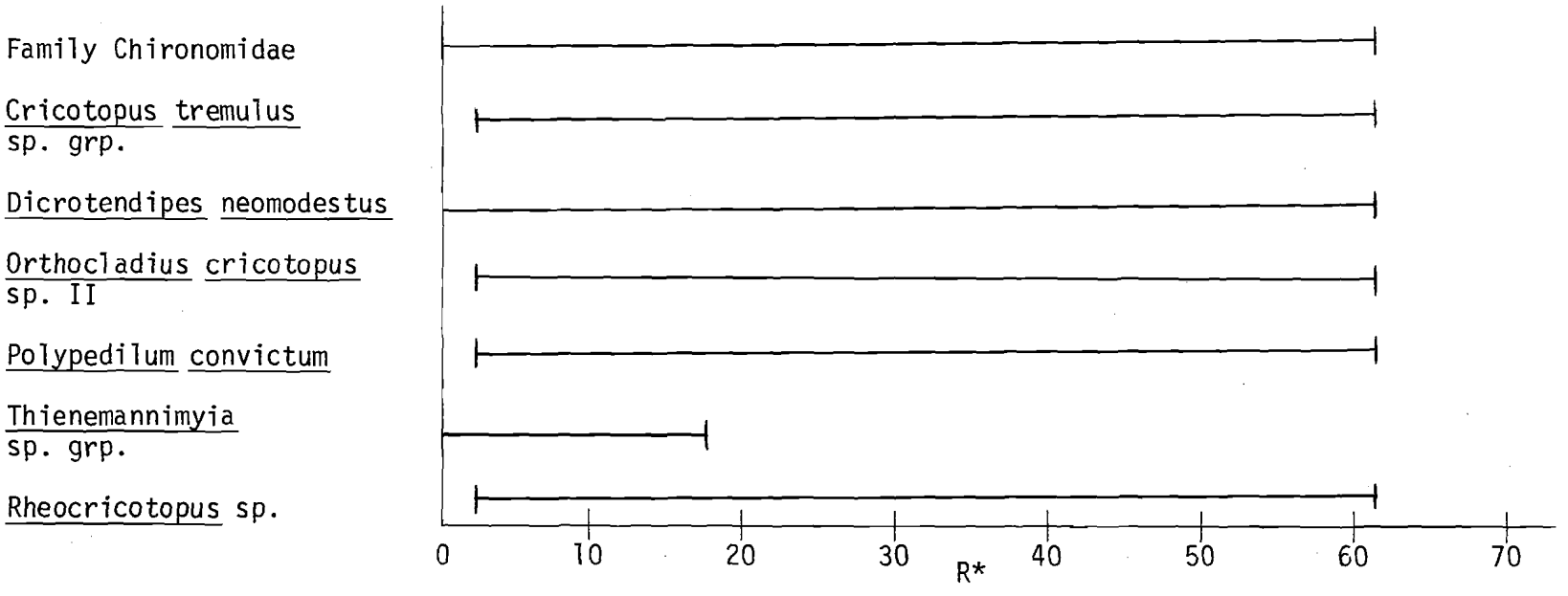


Figure 4-2. Range of R* inhabited by the most abundant Chironomidae taxa. R* x 10^3.

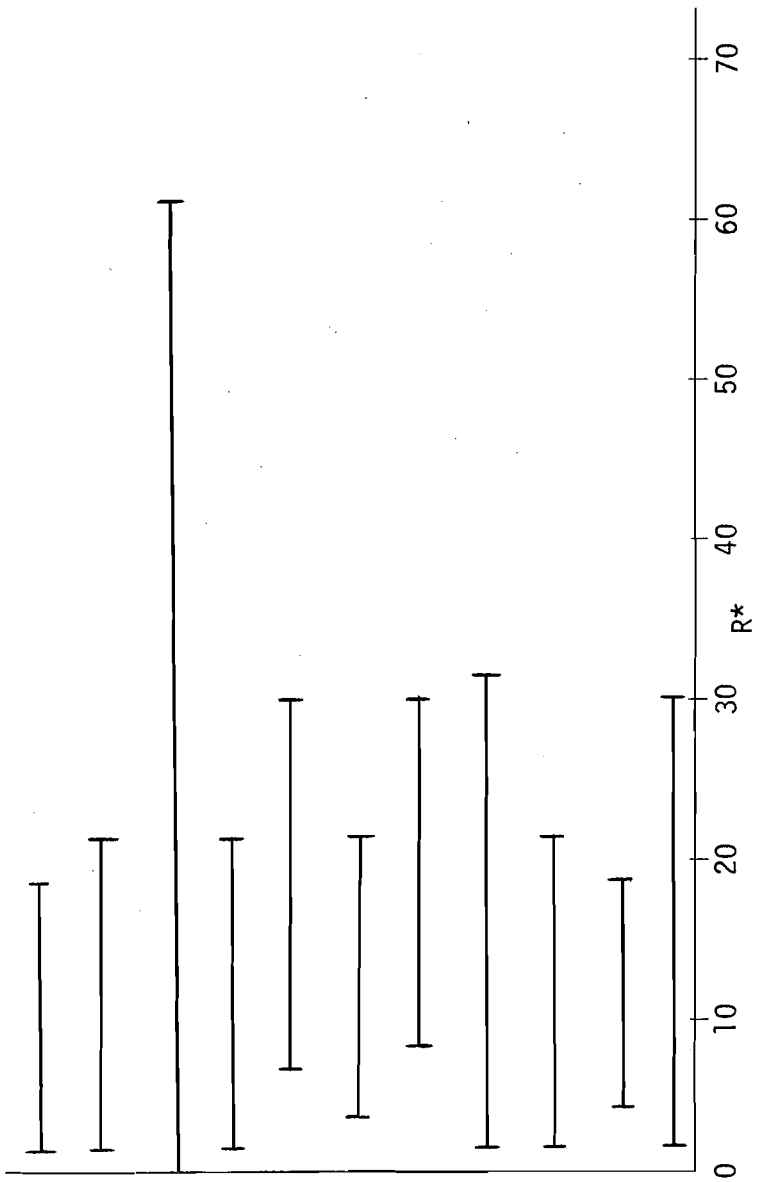


Figure 4-3. Range of R* values inhabited by the most abundant Ephemeroptera. R* x 10^3.

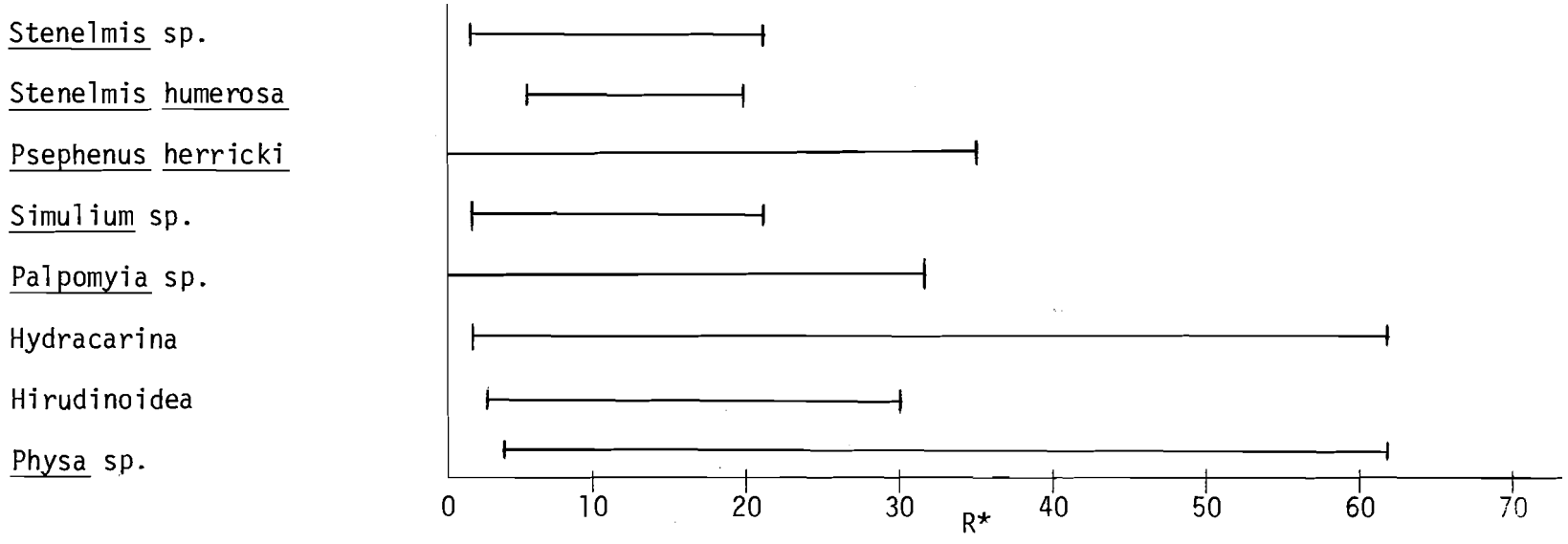


Figure 4-4. Range of R* values inhabited by the most abundant Coleoptera and Diptera (exclusive of Chironomidae) taxa. R* values x 10^3. Also numerous miscellaneous invertebrate taxa are included in the table.

in Figures 4-1 through 4-4. The R* ranges were determined for a total of 32 taxa of which six belonged to the order Trichoptera, seven to the family Chironomidae, eleven to the order Ephemeroptera, and three to the order Coleoptera (Figs. 4-1 to 4-4). The remaining five taxa were common miscellaneous fauna (Fig. 4-4).

In general, these results indicate that the majority of the Trichoptera require a minimum R* of 1000 and are limited to values of R* less than 30,000 (Fig. 4-1). The exception was Cheumatopsyche sp. which was found in R* regions of 380 to a maximum of 61,000 (Fig. 4-1). Thus, these data suggest that the majority of the Trichoptera fauna examined are found in intermediate R* regions. The difference between these results and laboratory studies of the same taxa, suggests that since the range of R* values in the laboratory were limited; the Trichoptera microhabitat distribution observed in the laboratory stream was only a partial representation of natural conditions.

The most generally distributed taxa were the family Chironomidae (Fig. 4-2). Only one taxa, Thienemannimyia sp. group showed a relationship with limited R* values. These results suggest that members of the genus Thienemannimyia are most commonly associated with areas of low shear stress such as depositional areas.

The majority of the mayflies, with the exception of Caenis sp. were limited to R* values less than 30,000. Caenis sp. was found to have an unusually wide R* tolerance while Stenacron minnetonka had a very narrow R* range.

The utility of this methodology for individual taxa will not be known until additional data is generated on the R* requirements; however, it does appear that such an index holds the promise of providing a better means of modeling benthic community responses to flow manipulations than does either depth or mean column velocity alone.

5. CALIBRATION OF ARTIFICIAL SUBSTRATES

5.1 PURPOSE

The purpose of this study was determination of microhabitat current velocities to which aquatic insects are exposed. A concrete substrate which could be calibrated to provide known microhabitat characteristics was developed. The purpose of the following studies was the hydraulic calibration of substrates.

5.2 INTRODUCTION

The current velocity to which lotic organisms are exposed is a primary factor affecting their distribution. While it has been recognized that the actual current experienced by an aquatic insect is much less than that measured by current meters (Hynes, 1970), the inability to accurately measure microhabitat velocities has long handicapped benthic stream ecologists. Of the many microhabitat current measuring devices developed, we have found that heated thermistors, similar to that described by Kalman (1966) and Alavian (1981), provide an accurate measure of microhabitat current velocities. The use of a simple linear relationship between the mean column velocity and a microhabitat current velocity, depth, viscosity, and substrate type may not accurately describe microhabitat because of the lack of independence between variables at the insect microhabitat level. We developed a method to estimate the current velocities inhabited by aquatic insects. The techniques require the calculation of a field Reynolds number (R*) for hydraulically calibrated substrates which are placed into a stream and permitted to colonize.

A standardized substrate was employed for the obvious reason of controlling at least one of the variables upon which the R* is based. The

following describes the substrates employed in this study, methods of hydraulic calibration using both high speed cinematography and thermistor probes, the results of the calibrations, and recommended field use and procedures.

5.3 METHODS

5.3.1 Substrates

Concrete substrates (Fig. 5-1) were chosen which generally were selective for Hydropsychid net-spinning caddisfly larvae (Trichoptera) and simulid black-fly larvae (Diptera). Previous investigations (Herricks and Unzicker, 1977; Furnish and Herricks, 1980) indicated that Hydropsychid caddisflies colonize and utilize the substrates, primarily in the notch regions (see below). The substrates (30 cm long; 15 cm wide; 6.4 cm high) consisted of four smooth faces (w, x, y, and z) with a slope of 30°, and three notches (I, II, III).

5.3.2 Calibrations

The substrates were hydraulically calibrated in a laboratory flume (15 x 0.5 x 0.75 m) where water temperature (for viscosity determination), depth, and mean column velocity could be controlled. The actual calibration consisted of two stages: a) an assessment of the flow patterns and vortices associated with the substrates; and, b) the collection of microhabitat point velocities at various locations on the substrate and at different flow condition.

The initial step involved in the calibration of the substrates consisted of describing the flow characteristics of the passing water and vortex formation. This was done by placing the substrate (Fig. 5-1) into the flume with Face w (the front) oriented perpendicular to the flow of

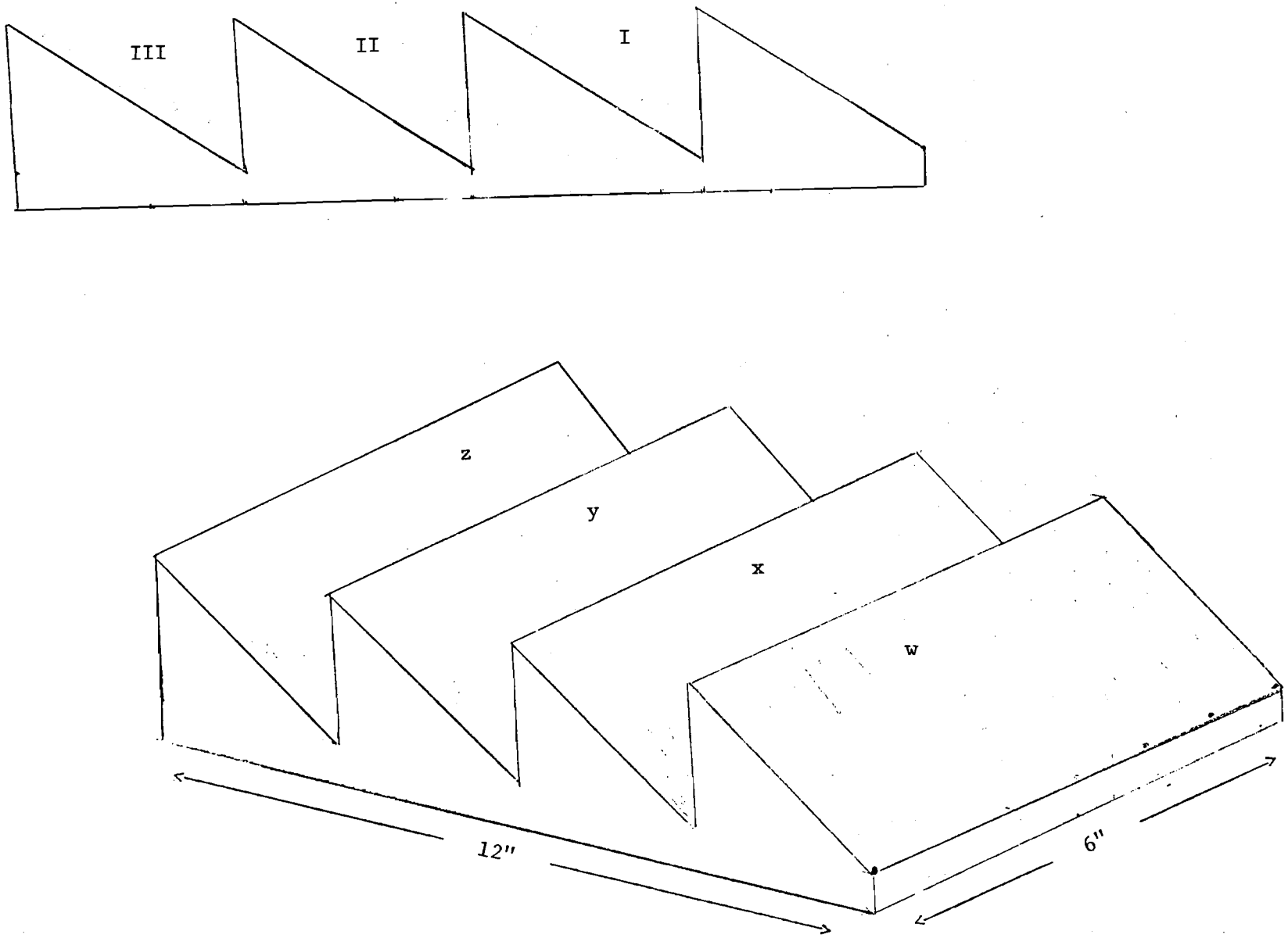


Fig. 5-1. General configuration of artificial substrates showing face designations (W-2) and notch designation (I, II, III).

the water. This is pictorially displayed in Fig. 5-2. During the cinematography calibrations, the water temperature was maintained at 17°C, the depth was 12.7 cm, and the mean column velocity maintained at 0.15 m/sec.

Two types of tracers were employed to study the flow characteristics, a liquid solution of potassium permanganate and a water-sawdust-potassium permanganate mixture. The liquid dye solution was placed into a reservoir mounted on a carrier with wheels directly above the flume channel (Fig. 5-2). This solution was released into the flume channel at the desired locations through a pitot tube mounted on a rack and pinion system. The rate of flow of the dye was controlled using a hose clamp. Sawdust particles were employed to replicate the path that a seston food particle may take in the vicinity of the substrates. These particles were released by hand approximately 3 m upstream of the substrates. It was found that the seston transport patterns corresponded very closely with the liquid dye results.

The flow patterns in the vicinity of the substrates were recorded on 8 mm film using a high-speed (64 cm/sec) movie camera (Fig. 5-2). The disperson of the tracers was filmed from a number of positions including the side, back, top, and front. The path of the dye past and around the substrates was later analyzed and a typical flow pattern diagram developed. These are represented in Figs. 5-2 and 5-3.

From the results of these investigations, it was possible to establish distinct hydraulic regions on the artificial substrates for further calibration and analysis. These are presented in Fig. 5-4 and are as follows. Each face, and back of each face (front of notch), were divided into 9 cells (regions) giving a total of 63 regions on each substrate.

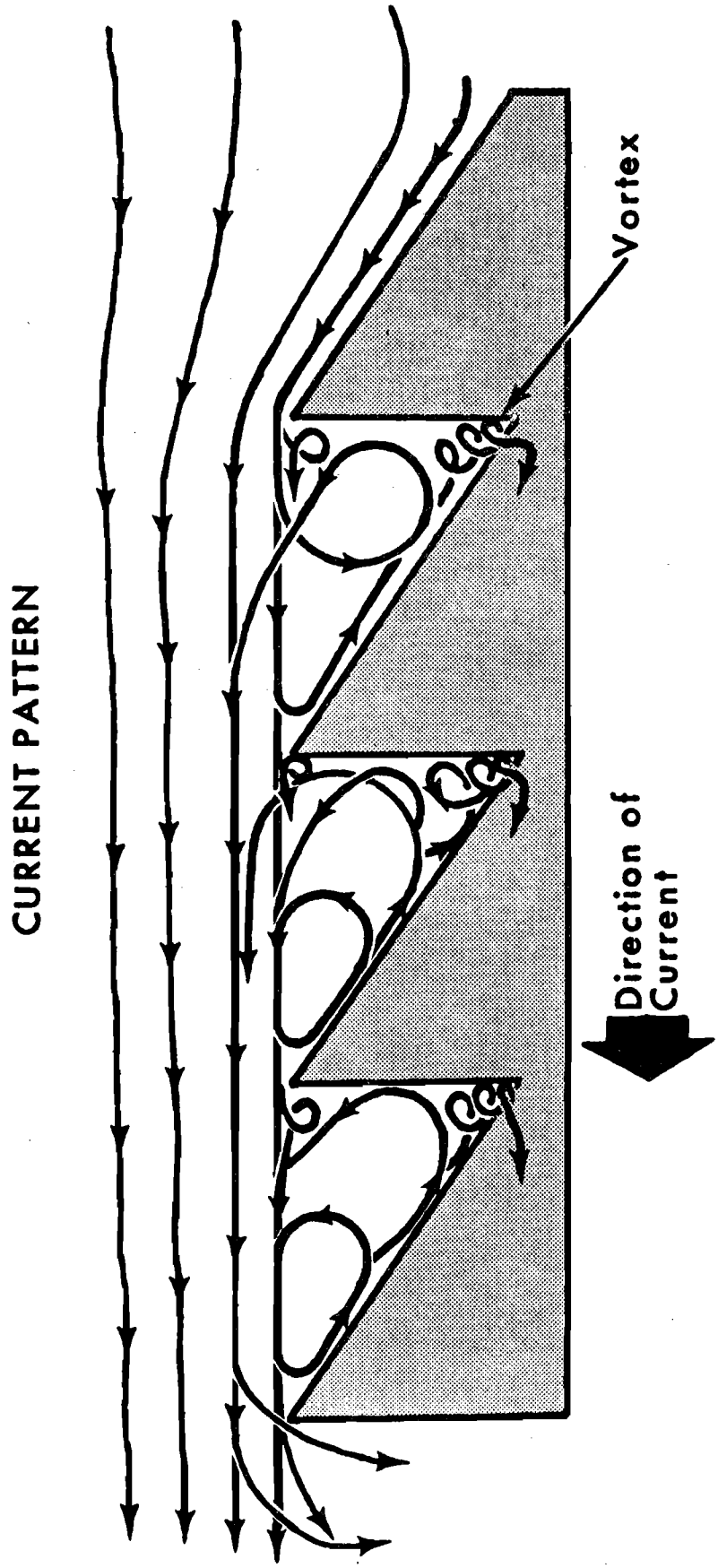


Fig. 5-2. Flow patterns over artificial substrates as indicated by high speed cinematography.

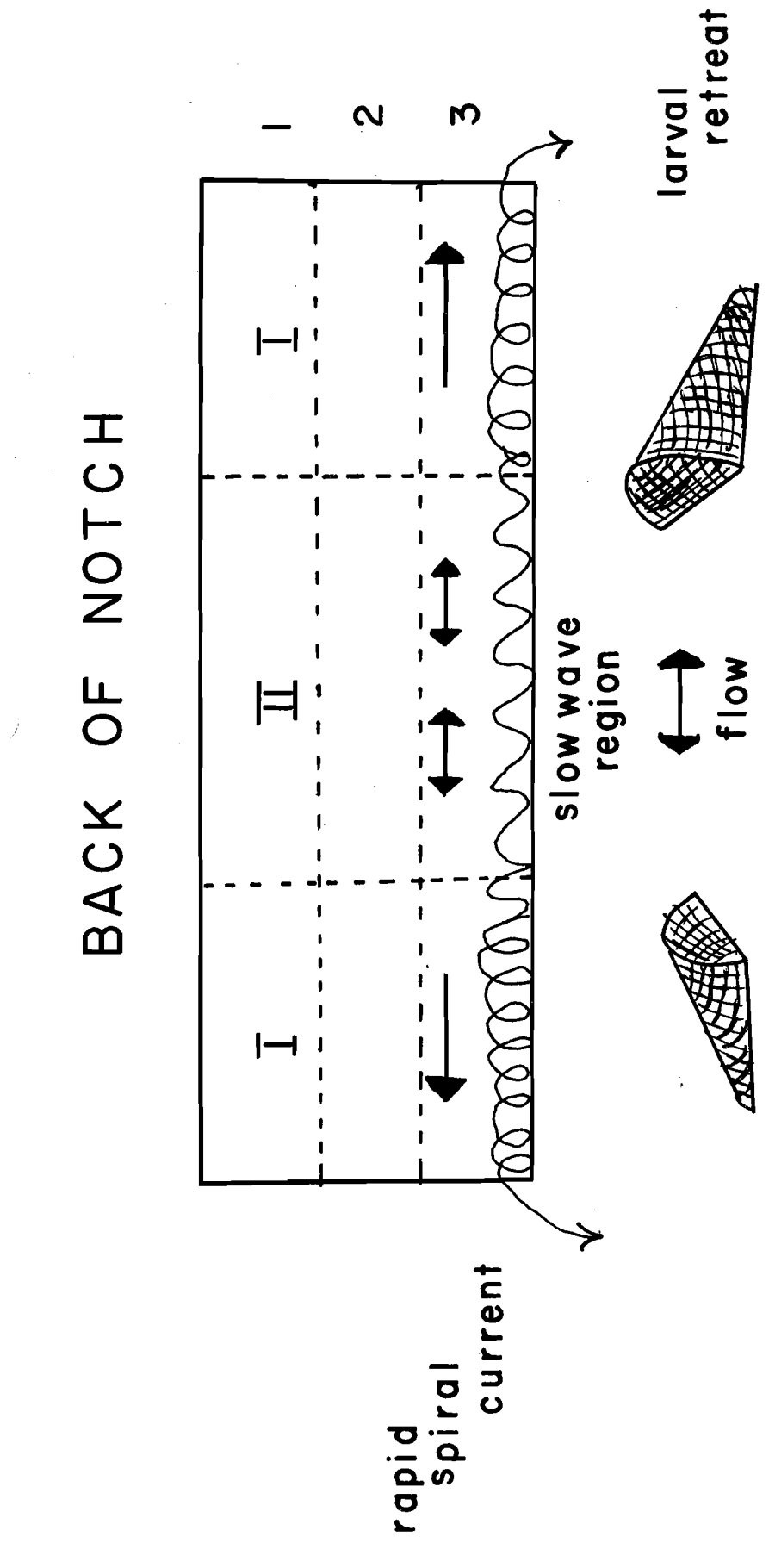
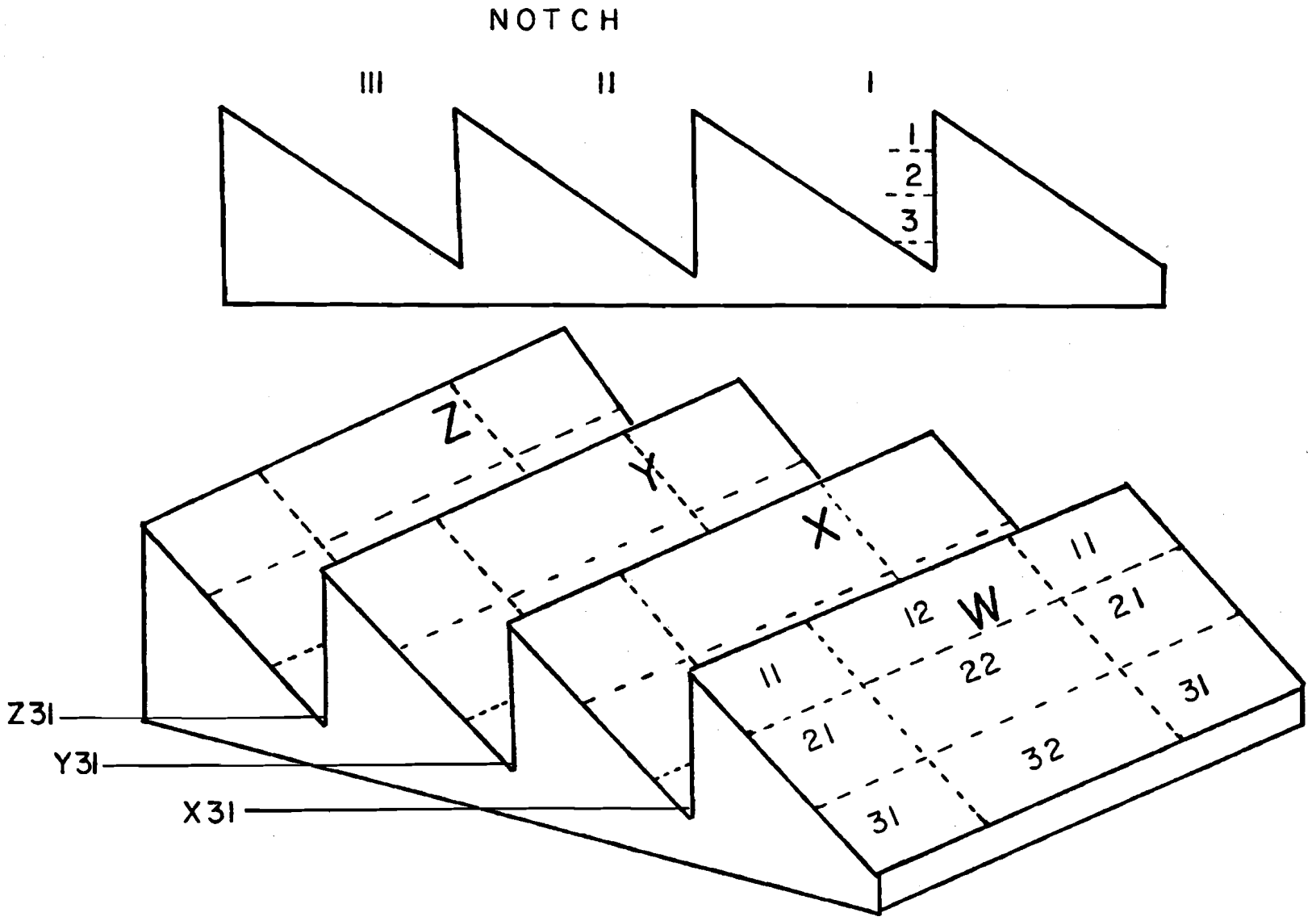


Fig. 5-3. Notch region designations and illustrating flow patterns and general net orientation.



SUBSTRATE REGIONS

Fig. 5-4. Substrate regions defined for microprobe velocity measurements on artificial substrates.

The lateral, or outside cells (e.g., Region 11; Fig. 5-4) were 4.0 cm wide and the middle cell regions (e.g., Region 12; Fig. 5-4) were 7.0 cm wide.

The tracer study also revealed the existence of distinct vortex patterns within the notches (Figs. 5-2 and 5-3) which could be important to filter feeding aquatic insects not only from the standpoint of velocity but of maximizing filter-feeding efficiency. Examination of these results suggested that at the bottom of the notch and at the outside regions (i.e., cell Regions 3-1) food particles become entrapped within the vortex and spiral rapidly around (approximately 3-4 times) before being discharged out the sides. In the middle notch region (i.e., cell Region 3-2) the particles very slowly migrate to the side regions (i.e., cell Region 3-1) before entering the vortex; or depending upon the size of the particle they will simply settle out.

The second step in the calibrations of the substrates consisted of developing equations relating the current velocities within each of the 63 substrate regions using the microvelocity thermistor probes to various flow conditions within the flume channel. This was done as follows.

The substrate was placed into the flume channel as previously described with the water temperature and depth (17°C and 12.7 cm respectively) held constant and the total water discharge through the flume adjusted to obtain one of the mean column velocities listed in Table 5-1. It is important to note that depth was controlled by adjusting the downstream tailgate of the flume, thus maintaining a constant water surface elevation. The column velocity (referred to here as the substrate column velocity) was determined by placing the support bracket on a standard

Table 5-1. The mean column velocities (cm/sec) employed in the substrate hydraulic calibrations and the corresponding Reynold's number (R*) at a depth of 12.7 cm and a temperature of 17°C.

Column Velocity (cm/sec)	R*
10.7	6,280
15.2	8,970
21.3	12,560
25.9	15,250
27.7	16,327
33.5	19,734

staff rod, which supported a Marsh-McBirney sensor probe, in the region W32 of the substrate. (This permitted a constant reference of column velocity in both the laboratory and the field.) After the discharge was adjusted, two current velocity measurements were taken within each of the 63 substrate regions using a thermistor probe mounted on a rack and pinion system. Each point velocity measure represents the current velocity at a distance of 0.9 mm above the substrate surface (i.e., the diameter of the sensor and its brass support) which is within the range of where an insect larvae would inhabit.

A Reynolds number was then calculated for each calibration run (see Table 5-1) using the formula:

$$R_e = \frac{CV \times H}{KV}$$

where: CV = substrate column velocity immediately upstream of the substrate (cm/sec)

H = total height of the substrate (i.e., 6.4 cm)

KV = kinematic viscosity (= 1.087×10^{-2} cm^2/sec @ 17°C)

By definition the Reynolds number is a dimensionless ratio of inertial to viscous forces. The above formula is substantially different than that offered previously for the calculation of R* (section 3.3) because a standardized substrate is being employed with distinct hydraulic characteristics as opposed to a heterogenous substrate mixture and variable hydraulic characteristics normally encountered in a natural stream bed. Using a standard substrate also permits the use of H as a length dimension in the analysis of the substrate (i.e., the substrate height).

Following determination of the R_e values, an equation was developed for each of the 36 substrate regions using regression analysis

with R_e as the independent variable and the measured mean point regional velocity the dependent variable. A complete list of the resultant equations which were used for the remainder of the study are reported in Table 5-2. The reported equations correspond with the cell regions in Figure 5-4.

The mean calibrated point velocity data were also used to determine if: 1) there were significant differences between Region I (later cells) and Region II (middle cells) within each notch (x, y, and z); and, 2) if there are differences in the Region I point velocities between notches x, y, and z. Answers to these two questions are particularly critical as they may explain differences in the location of insect larvae on the substrates.

An average velocity for each middle substrate region (e.g., W12; Fig. 5-4) and discharge valve was obtained by taking the mean of the two point velocities. Due to the similarities in the hydraulic patterns observed in the tracer-cinematography study and the similar agreement between the laboratory measured point velocities, a single mean value was calculated for the two lateral regions within a single plane (e.g., W11 and W11; Fig. 5-4).

To test the first hypothesis, a Mann-Whitney U-test was employed. The results, with the mean cell point velocities are reported in Table 5-3. These data indicate that a significant difference does exist in the microvelocity values within notches x and y. The examination of the mean point velocity values further indicate that the Region I values in notch x and notch y were significantly greater than Region II which corresponds to visual observations made during the cinematography dye studies. There were no significant differences found between Regions I and II in notch z, although the same trend of Region I being greater than Region II was apparent.

Table 5-2. Equations for determining mean point velocities on the 6.4 cm high artificial substrates with respect to regional location

Location	R^2	Equation
W11	0.91	$-2.57 + (.16 \times 10^{-2} R_e)$
W12	0.93	$-1.63 + (.14 \times 10^{-2} R_e)$
W21	0.95	$-1.94 + (.14 \times 10^{-2} R_e)$
W22	0.95	$-3.85 + (.14 \times 10^{-2} R_e)$
W31	0.91	$-1.43 + (.12 \times 10^{-2} R_e)$
W32	0.95	$-5.41 + (.12 \times 10^{-2} R_e)$
X11	0.93	$-5.99 + (.15 \times 10^{-2} R_e)$
X12	0.95	$-4.07 + (.13 \times 10^{-2} R_e)$
X21	0.97	$-.198 + (.14 \times 10^{-2} R_e)$
X22	0.94	$-4.97 + (.13 \times 10^{-2} R_e)$
X31	0.95	$-0.65 + (.26 \times 10^{-3} R_e)$
X32	0.90	$-0.31 + (.73 \times 10^{-4} R_e)$
Y11	0.99	$-5.76 + (.17 \times 10^{-2} R_e)$
Y12	0.97	$-7.91 + (.16 \times 10^{-2} R_e)$
Y21	0.99	$-5.28 + (.15 \times 10^{-2} R_e)$
Y22	0.98	$-7.35 + (.14 \times 10^{-2} R_e)$
Y31	0.75	$-1.03 + (.23 \times 10^{-3} R_e)$
Y32	0.85	$-0.29 + (.55 \times 10^{-4} R_e)$
Z11	0.99	$-6.36 + (.19 \times 10^{-2} R_e)$
Z12	0.98	$-4.47 + (.14 \times 10^{-2} R_e)$
Z21	0.96	$-8.11 + (.18 \times 10^{-2} R_e)$
Z22	0.97	$-9.22 + (.19 \times 10^{-2} R_e)$
Z31	0.79	$-1.38 + (.34 \times 10^{-3} R_e)$
Z32	0.70	$-0.86 + (.14 \times 10^{-3} R_e)$

Table 5-2. Continued

Location	R^2	Equation
A11	0.96	$-1.24 + (.32 \times 10^{-3} R_e)$
A12	0.91	$-3.36 + (.42 \times 10^{-3} R_e)$
A21	0.89	$-2.74 + (.52 \times 10^{-3} R_e)$
A22	0.98	$-1.26 + (.19 \times 10^{-3} R_e)$
B11	0.99	$-2.42 + (.43 \times 10^{-3} R_e)$
B12	0.97	$-1.89 + (.41 \times 10^{-3} R_e)$
B21	0.97	$-1.3. + (.36 \times 10^{-3} R_e)$
B22	0.95	$-0.57 + (.16 \times 10^{-3} R_e)$
C11	0.84	$-2.26 + (.42 \times 10^{-3} R_e)$
C12	0.93	$-5.07 + (.64 \times 10^{-3} R_e)$
C21	0.73	$-3.94 + (.54 \times 10^{-3} R_e)$
C22	0.91	$-2.39 + (.31 \times 10^{-3} R_e)$

Table 5-3. Statistical analysis of substrate calibration data for intrasite regional notch differences in mean calibration point velocity data. (Tests between Region I and II within notches X, Y, Z) using Mann Whitney U Test ($\alpha = 0.05$).

Substrate Region	10.7	15.2	21.3	25.9	27.7	33.5
$\bar{X}$ XI	0.313	1.555	2.726	3.339	3.789	4.569
$\bar{X}$ XII	0.065	0.405	0.470	0.802	-	1.352
		U = 1	P = 0.004**			
$\bar{X}$ YI	0.327	0.594	0.885	1.868	2.632	5.061
$\bar{X}$ YII	0.007	0.094	0.347	0.533	-	1.009
		U = 3	P = 0.015**			
$\bar{X}$ ZI	0.458	0.604	2.063	2.423	5.445	6.300
$\bar{X}$ ZII	0.007	0.164	0.185	1.210	-	2.752
		U = 6	P = 0.063 N.S.			

Due to the nature of the previous results, we are unable to group all of the individual notch data together and test for differences between notches. A Kruskal-Wallis one-way Anova test was employed in these two cases and the results reported in Table 5-4. The Null hypothesis (Ho:) being examined in this analysis was once again:

Ho: There are no differences in the Region I and Region II velocities between notches x, y, and z.

The results of these analyses indicate that there are no significant differences in the Region I and Region II microhabitat velocities between notches at any given R* value. Thus, any differences in species abundance and composition between notch region is not likely to be attributable to the speed of the current. Conversely, there may be significant effects of current on the distribution of organisms within a notch.

Using a standardized substrate provides a means for studying the microhabitat selection of aquatic insect larvae and using those results to identify a component of the instream flow needs. The use of standardized substrates was adopted and a field methodology developed (described below) for subsequent experimental studies.

5.4 APPLICATION TO THE FIELD

It is possible using the standardized substrate to evaluate microhabitat conditions selected by several taxa of net-spinning Trichoptera (which will be presented in a later section). The primary limitation of the technique is that it cannot be used when extensive algal growth developes on the substrates as this substantially alters the hydraulics (particularly the size of the boundary layer). In Illinois, we have found that such algal growths occur within 2 months of substrate introduction during the summer period.

5.4.1 Field Method

By placing the calibrated substrates into the stream with faces perpendicular to the direction of flow and recording the location of insect larvae on the substrates, we have been able to calculate the microhabitat velocities to which the larvae are exposed. This simply requires obtaining measurements of the water temperature for kinematic viscosity determination, and the column velocity in front of the substrate (as described in laboratory calibration section). It is important that the substrate column velocity be determined in the manner previously described or invalid calculations will be obtained. With these variables a R_e value is calculated which is then related to the microhabitat velocities within each substrate region using the previously described substrate regions (Table 5-2). This technique is also limited within the current velocities used during the calibration; thus, the minimum velocity in front of the substrate should be in the vicinity of 0.25-0.30 ft/sec (7.6-9.1 cm/sec). The results of substrate experiments are presented in Section 6.

Table 5-4. Kruskal-Wallis analysis for differences between XI, YI, and ZI, and XII, YII, and ZII using the mean point velocity calibration data on the artificial concrete substrates.

	Notch Point Velocity (Rank)		
Column Velocity (cm/sec)	XI	YI	ZI
10.7	1	2	3
15.2	7	4	5
21.3	12	6	9
25.9	13	8	10
27.7	14	11	17
33.5	15	16	18
R total =	62	47	62
H = 0.0035 (1649.50) - 57 = 0.73			N.S.
	XII	YII	ZII
10.7	3	1.5	1.5
15.2	8	4	5
21.3	9	7	6
25.9	11	10	13
27.7	-	-	-
33.5	14	12	15
R total	45	34.5	40.5
H = 0.05 (971) - 48 = 0.55			N.S.

6. SUBSTRATE COLONIZATION AND THE EFFECTS OF PERIPHYTON AND SEDIMENT

6.1 PURPOSE

Numerous environmental factors affect the colonization rates of benthic communities. The purpose of this study was to evaluate the standardized substrate examining: 1) the rate of colonization of the hydraulically defined artificial substrates; 2) the effects of periphyton development on the colonization rates, 3) the effects of sedimentation on the distribution of aquatic insects on the standardized substrates; and 4) examine differences in the rate of colonization of net-spinning caddisflies which may account for their distribution on the standardized substrates.

6.2 INTRODUCTION

Introduced natural and artificial substrates have been used to study invertebrate drift (Townsend and Hildrew, 1976), colonization (Sheldon, 1977; Osborne, 1983), distribution (Coleman and Hynes, 1970; Rabeni and Minshall, 1977), substrate preference (Cummins and Lauff, 1969; Friberg et al., 1977), insect behavior (Hildrew and Townsend, 1977), and recovery (Osborne, 1983). Evidence has been presented that colonization of solid surfaces by aquatic microorganisms is related to the physical characteristics of the attachment surface and to nutrient conditions in the surrounding medium (ZoBell, 1943; Jannasch and Pritchard, 1972; Hargrave and Phillips, 1977). Furthermore, colonization of submerged surfaces by epilithic organisms has been reported to occur in a defined sequence (Marshall et al., 1971; Floodgate, 1972; Hargrave and Phillips, 1977): 1) the initial reversible bacterial attachment phase, thought to last only a few hours; 2) the second irreversible stage dominated by bacterial secretion of polysaccharide

cementing compounds serving as a surface anchor; and 3) the final phase, characterized by cell growth and subsequent colonization by algae, fungi, and metazoans.

A study by Williams and Hynes (1976) demonstrated four sources of animals contributed to the recolonization and denuded substrates: drift; movement through the sediments, aerial sources, and upstream migration. Osborne (1981, 1982) postulated that for more nonmobile organisms (e.g., algae) drift was likely the primary source of colonizers.

Among others, Meier et al. (1979) have implicated the attachment of epilithic organisms and the deposition of detritus as factors determining the rate of colonization and the composition of macroinvertebrate communities. Furthermore, Weber (1973) and others have noted that the time of exposure was a critical factor in the development of a water quality and sediment loads have also been shown to be important in the development of aquatic communities (Meyer, 1979).

6.3 STUDY AREA

This study was conducted in Jordan Creek, a 2nd order stream with a drainage area of approximately 28 km^2 in the southern portion of Vermilion County, Illinois. Jordan Creek is part of the Vermilion River drainage basin and empties into the Salt Fork and Middle Fork Rivers.

Jordan Creek is roughly 17.6 km in length and flows through contrastint riparian habitats of equal lengths: an upper, open farm and pasture area; and, a lower wooded area (Larimore and Garrels, 1982). Frequent pools and riffles characterize the stream with the intermediate section (where this study was conducted) having a slope of 4.3 m/km. Larimore and Garrels (1982) reported an average annual discharge of 18 cfs with

current velocities during normal conditions ranging from zero to 1-1.5 m/sec. The predominant bottom material consisted of sand, rubble, and some rocks.

The location of the 50 m study reach was 100 m upstream of the beginning of the lower wooded section approximately 8.8 km downstream of the headwaters. This are was characterized by untilled farm and pasture land with little or no shrubs and trees.

6.4 PROCEDURES

6.4.1 Colonization Procedures

Thirty-nine 6" (15.2 cm) wide substrates (Fig. 5-1) and twelve 12" (30.4 cm) wide artificial concrete substrates were placed into a stream riffle on May 17, 1982. Four weeks prior to this, large rocks and boulders were removed and the riffle was smoothed by raking to obtain relatively homogeneous hydraulic conditions within the reach. Eighteen of the thirty-nine 15 cm substrates had been previously held in an artificial laboratory stream channel and allowed to colonize with periphytic algae for a period of three weeks prior to the beginning of this study. The algae used for pre-colonization was originally collected from Jordan Creek in the fall of 1981 and allowed and reproduce on natural substrates in the artificial stream channel in the absence of invertebrates. The fact that the composition of the laboratory periphyton assemblage was not identical to the spring Jordan Creek periphyton assemblage is not critical as the purpose of this experiment was to determine the effects of eliminating the first two steps and shortening the third step in the developmental sequence of the periphyton community (discussed in section 6.1) on the rate of aquatic insect colonization.

All 39 15-cm substrates (i.e., 21 uncolonized by periphyton and 18 periphyton colonized) were randomly distributed throughout the riffle area reach along with the 12 12-inch wide substrates. All of the substrates were positioned with the notches up and perpendicular to the direction of flow. The hydraulic conditions within the vicinity of each substrate are reported in Table 6-1 and 6-2. It is apparent that very little difference existed in the hydraulic conditions between the periphyton colonized with uncolonized treatments; while variations did exist within each treatment as would be expected (Tables 6-1 and 6-2).

To determine rates of macroinvertebrate colonization, replicate (2 or 3) substrates from each treatment were randomly removed on days 3, 5, 7, 11, 14, 18, 22, and 28. The substrates were removed by placing an adjustable plexiglass (17 cm x 5 cm x 1 cm) rectangle lined on the inside with rubber weather stripping around the substrate while still in the water. The plexiglass rectangle was equipped with three 1-cm diameter drain holes and corks in such a position to drain and rinse the sediment and other materials from each of the three notches (see Sediment Collection and Analysis section). Following attachment of the rectangular substrate samples, the substrates were removed from the water. Macroinvertebrates were either picked immediately from the substrates or from sediments collected from each other. All organisms were preserved in 70% ethylalcohol.

The macroinvertebrate assemblage was removed in the following manner: 1) picking directly from the substrates; 2) scraping and brushing all faces (also used for sampling chlorophyll and concentrations); and 3) rinsing with distilled water through the 3 drain holes.

Table 6-1. Periphyton colonized substrates, and the mean current velocities (cm/sec), depth (cm), R_e values within the study reach and the number of days the substrates were exposed.

Substrate	Mean Velocity	Mean Depth	$R_e(x10^6)$	No. Days
A-1	47.2	20	9.44	5
A-5	41.2	17	7.00	5
A-9	28.4	24	6.82	3
B-1	24.4	22	5.37	14
B-2	19.8	14	2.77	11
B-5	18.3	20	3.66	3
C-2	41.2	12	4.94	11
C-5	19.8	28	5.54	7
C-7	41.2	14	5.77	3
C-8	16.2	23	3.73	7
C-9	39.6	19	7.52	14
XC-1	23.8	20	4.76	18
XC-3	30.5	18	5.49	22
XC-4	10.7	16	1.71	11
XC-5	35.1	27	9.48	18
XC-6	22.6	21	4.75	18
XC-7	20.7	23	4.76	22
XC-8	20.7	22	4.55	28

Table 6-2. Periphyton uncolonized substrates and the mean current velocities (cm/sec), depth (cm), and R_e values within the study reach and the number of days substrate was exposed

Substrate	Mean Velocity	Mean Depth	$R_e(x10^6)$	No. Days
A-4	38.1	22	8.38	5
A-6	24.4	22	5.37	28
A-7	29.0	15	4.35	7
A-8	25.9	21	5.44	3
B-0	30.2	15	4.53	18
B-6	12.2	31	3.78	22
B-7	27.1	19	5.15	14
C-1	23.8	20	4.76	7
C-3	31.1	21	6.53	3
C-4	29.0	27	7.83	18
D-1	64.0	15	9.60	14
D-2	24.3	25	6.08	7
E-1	42.7	20	8.54	11
E3A	29.0	17	4.93	28
E-4	41.1	19	7.81	28
E-5	38.1	15	5.72	22
E-6	33.5	23	7.71	5
E-7	14.6	40	5.84	3
E-8	23.8	21	5.00	3
Y-4	30.5	25	7.63	18

6.4.2 Sediment Collection and Analysis

Sediment was collected into glass bottles immediately upon collection by rinsing the notches with distilled water through the small drain holes. The sediment from each notch was placed into individual glass wide mouth vials and returned to the laboratory for macroinvertebrate picking and substrate sediment weight determination. The sediment and water from each notch were placed into pre-weighed crucibles and dried at 120°C for 24 hours prior to weight determination.

In addition to the above, qualitative assessment of sedimentation consisting of none, little, moderate, and intense was made on each substrate during each sampling period. These results were related to the number of Hydropsychid retreats observed on the substrates using the Kolgomorov-Smirnov test. Hydropsychid retreats were also observed on each sampling data and substrate for this analysis.

6.4.3 Chlorophyll a Determination

In addition to the macroinvertebrate and sediment the chlorophyll a concentrations of the periphyton on each substrate face (i.e., w, xy, y, and z) were determined. (Note: Chlorophyll a concentrations did not begin until day 11 due to equipment problems.)

Samples for chlorophyll a determination were collected by scraping 1/4 of each substrate face with a razor blade and by brushing with a small hand brush. This material was rinsed into wide mouth vials with distilled water and the sample capped, placed in an ice chest and returned to the laboratory. Immediately upon return from the field ($\sim$4 hrs) the scraped material and water from each face was filtered through a 0.45 μm acetone soluble Millipore filter and placed into a centrifuge tube with a small amount of $MgCO_3$ to control acidity. The tubes were then frozen (-20°C) for a minimum of 3 days but not more than 2 weeks.

After freezing, the samples were removed and acetone added to dissolve the filters and extract the chlorophyll. Samples were placed into a centrifuge at 5500 rpm for 20 minutes and the supernatant analyzed with a spectrophotometer against an acetone blank. A mean chlorophyll a concentration value was then calculated for each substrate.

6.4.4 Community Parameters and Statistics

In the following analyses a Shannon-Wiener species diversity index was employed to determine the diversity on each of the substrates. The formula for the calculation of this index is:

$$H' = -\sum_{i=1}^{H} p_i \ln p_i$$

where p_i is the proportion of the ith taxa in the total community assemblage.

A community similarity coefficient was also calculated for each series of samples collected on each date to compare the development of the macroinvertebrates on the two substrate treatments. Community similarity coefficients are mathematical expressions of the degree of similarity of two or more communities in species composition or other structural characteristics. These coefficients may be calculated from data on simply the presence or absence of various species, or from detailed structural data such as density (as is the case here), dominance, or frequency estimates for the various species.

The most widely used coefficient of this type is the coefficient of community, the values of which varies from 0 for communities having no species in common, to 1.0 for communities identical both in species composition and in quantitative values for the species. Using quantitative data such as importance values for the various species, pairs of communities may be compared by calculating a coefficient of community (C) according to the formula:

$$C = \frac{2w}{a + b}$$

where: w = the sum of the lower of the two qualitative values for species shared by the two communities

a = the sum of all of the values of the first community

b = the sum of all values for the second community

For this analysis all of the replicate composition and abundance data for each treatment and date were combined and analyzed according to their total densities to obtain a coefficient of community.

6.5 RESULTS AND DISCUSSION

6.5.1 Colonization Results

The mean number of taxa and the mean number of individuals collected on the substrates for the periphyton colonized and periphyton uncolonized substrates with respect to days in the stream are reported in Table 6-3. In addition to the above, the table includes the results of the Shannon-Wiener diversity (H') calculations, while Table 6-6 contains the results of the coefficient of community similarity calculations (C).

Within three days of exposure, approximately 12 taxa occurred on the periphyton colonized substrates while only an average of six taxa occurred on the untreated substrates. Similarly, the periphyton exposed substrates had substantially higher numbers of organisms than did the unexposed substrates (Table 6-3). Examination of the C values further indicates that the taxa assemblages inhabiting the periphyton colonized and uncolonized substrates were more dissimilar than similar as indicated by C = 0.30 (Table 6-4).

These data suggest that the availability of periphyton, or the pretreatment of the substrates through colonization, significantly affects the rate at which macroinvertebrates colonize available habitat.

Table 6-3. Mean and standard deviations of the total number of taxa and individuals on the substrates and the range of H' values for the periphyton colonized and uncolonized artificial substrates.

Periphyton Colonized

Day	X Taxa	X Inds.	Range H'	N
3	11.7(2.5)	140.0(89.8)	1.65-1.96	3
5	7.0(4.2)	110.0(141.4)	0.63-1.31	2
7	12.0(7.1)	90.5(98.3)	1.77-1.88	2
11	9.0(5.6)	48.0(42.0)	0.96-1.90	3
14	13.5(5.0)	91.0(29.7)	1.91-2.32	2
18	17.0(1.4)	66.0(2.8)	1.82-2.54	2
22	12.5(2.1)	39.0(5.7)	2.11-2.45	2

Periphyton Uncolonized

Day	X Taxa	X Inds.	Range H'	N
3	6.0(3.1)	16.0(9.4)	0.64-1.92	4
5	5.0(5.7)	28.5(38.9)	0.00-1.09	2
7	9.0(2.0)	37.7(11.2)	1.50-2.04	3
11	10.5(7.8)	26.0(24.0)	1.58-2.39	2
14	17.0(0.0)	92.0(31.1)	2.02-2.22	2
18	18.7(4.9)	127.0(66.0)	2.05-2.43	3
28	14.0(12.0)	316.7(472.5)	0.69-2.40	3

Table 6-4. Coefficient of Community (C) using total densities for the periphyton colonized (P) and periphyton uncolonized (U) substrates with respect to sampling date and the total number of individuals within each treatment category P and U.

Day	(C)	(P)	(U)
3	0.30	325	64
5	0.35	215	57
7	0.59	181	113
11	0.07**	144	52
14	0.68	182	184
18	0.38	132	381
*22-28	0.59	86	98

*Days 22 and 28 combined due to limited samples within each treatment collected on both days.

**Attributable to the low number of individuals on the (U) substrates.

Examination of the individual taxa and their trophic relations suggest that periphyton development may not only be important as a food resource, but also in increasing the boundary layer and thus providing slightly more refuge from the current as the most abundant taxa were filter feeders and collector gathers. This is further supported by laboratory flume observations which indicated that periphyton slightly increases the boundary layer. Thus, the importance of periphyton development should not just be viewed from a trophic perspective as indirect evidence suggests it is important from a hydraulic perspective.

From day 3 through day 10, the mean taxa richness on the periphyton colonized substrates was greater than the untreated substrates, while the mean number of individuals were greater through day 14 when approximately the same numbers occurred on both treatments. These trends are graphically displayed in Figs. 6-1 and 6-2. Following these dates, the periphyton untreated substrates had both higher numbers of taxa and substantially higher numbers of individuals (Table 6-3). The differences towards the end of the study may reflect differences in the periphyton composition on the substrates as it is likely that the initial composition of algae used in the periphyton treatment was different than that which occurred in Jordan Creek during the spring.

The chlorophyll a data (Table 6-5) further suggests that periphyton development was higher and thus more advanced on the pretreated substrates. This, however, could reflect a reduced grazing pressure due to algal selectivity on the macroinvertebrate grazers.

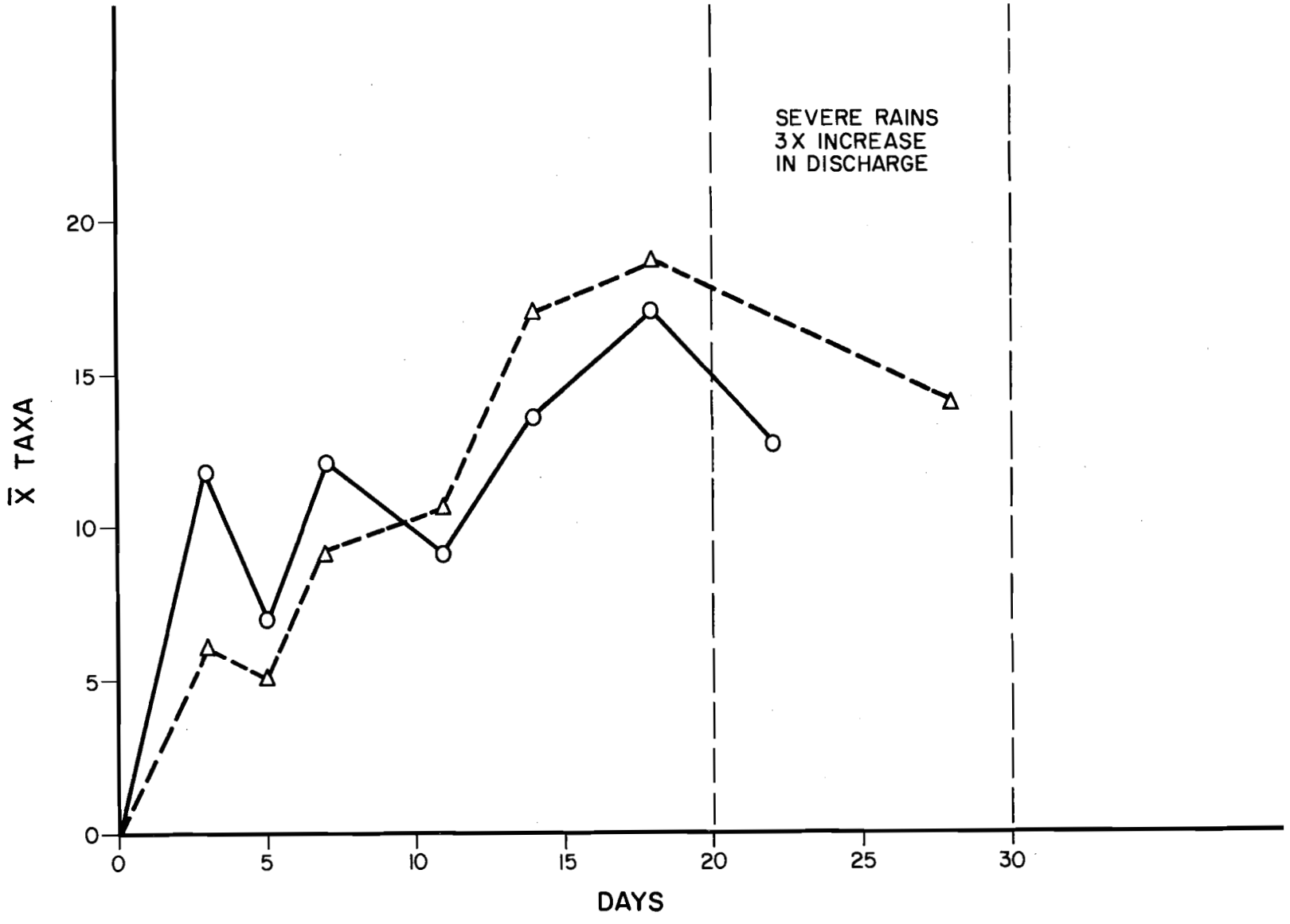


Fig. 6-1. Mean taxa richness on the substrates where (——) indicates periphyton colonized substrates and (---) indicates periphyton uncolonized substrates.

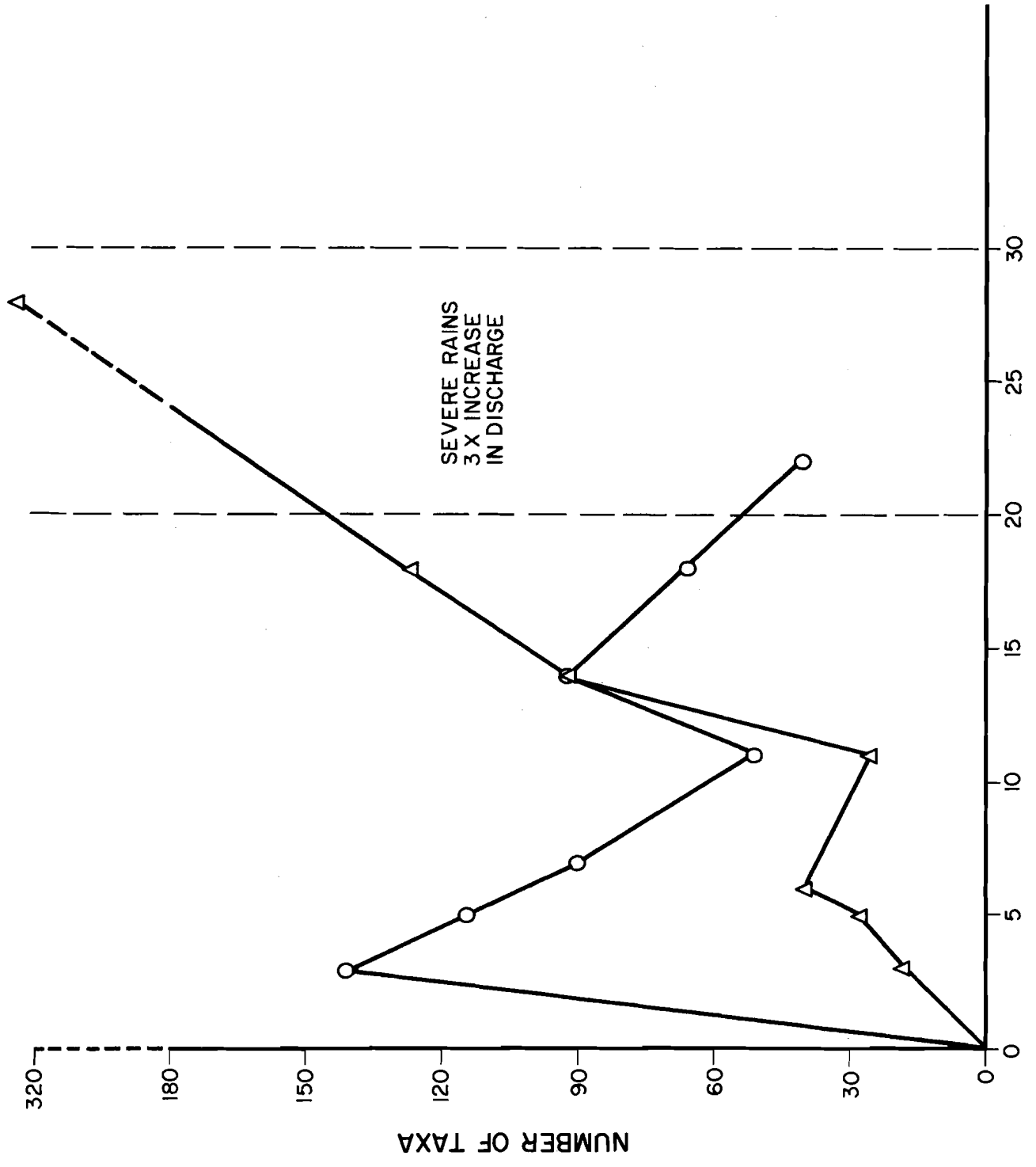


Fig. 6-2. Mean number of individuals on the substrates where (o) indicates periphyton colonized and (Δ) indicates uncolonized by periphyton.

Table 6-5. Mean chlorophyl concentration (mg Chla/substrate surface area) for uncolonized and periphyton colonized artificial substrates with respect to day of exposure

Day	Periphyton Colonized	Periphyton Uncolonized
3	-	-
5	-	-
7	-	-
11	86.4	-
14	70.4	52.4
18	117.2	154.4
22	217.2	148.4
28	274.0	193.6

From day 0 through day 18, the species richness of the assemblages tended to increase with the untreated substrates displaying the more classical MacArthur-Wilson colonization curve (Fig. 6-1). With the exceptions of day 11 samples, the community similarity between the two substrate treatments also increased. This suggests that the macroinvertebrate assemblages were becoming more and more similar with time. This trend continued through the end of the study with minor variations (Table 6-4).

By the end of the study, there were substantially higher numbers of individuals on the periphyton untreated substrates than the periphyton treated substrates. There were, however, similarities in the taxa richness (Figs. 6-2 and 6-1). This difference in species abundance rather than species richness is more likely attributable to the heavy rains which may have increased discharge and velocity washing organisms from the substrates. The effects of the increased discharge (due to heavy rains) towards the latter part of the study is best reflected in the lower taxa richness on both substrate treatments. These results correspond with those reported by Osborne (1983) concerning the effects of spring spates on lotic benthic communities.

Colonization is a subject that has been of interest to benthic ecologists for several years due to its' importance in the recovery process. The results of this study indicates that periphyton development substantially affects the rate of colonization of the insect community component. These data further suggest that increased stream discharge, due to heavy precipitation in the watershed has an adverse effect on benthic macroinvertebrate communities. Thus, in temporate stream environments, one should not expect to find benthic communities in equilibrium, but rather

in a constant state of flux responding to numerous high and low discharge pulses. Finally, these results indicate that colonization rates are still quite variable within a single riffle with relatively homogenous hydraulic conditions.

6.5.2 Hydropsychid Colonization

One may ask why some taxa occur where they do and are able to exclude others from the area, and how can so many morphologically and ecologically similar taxa coexist. A possible mechanism that would partially answer the above question when concerned with the taxa with similar instream flow requirements would be differences such as increased discharge and scour. Hutchison (1959) alluded to such a mechanism of coexistence for ecologically similar species in his classic "Concluding Remarks." This section addresses the question "do morphologically and ecologically similar taxa display differences in the rates of colonization which may account for their coexistence"?

For this analysis, three hydropsychid caddisfly taxa: Symphitopsyche bronta; S. cheilonis; and Hydropsyche betteni (Hydropsychidae: Trichoptera) were selected for study due to the importance of Hydropsychids in energy transfer in most lotic systems and the substantial amount of taxonomic information available. Specifics on the importance and life history of these taxa are reported elsewhere (e.g., Ross, 1944) and in a later section of this report; however, it is important to note that S. cheilonis and S. bronta are so morphologically similar in the larval stages that it was not until 1982 that characteristics were developed to distinguish between the taxa (P. Schuester, per. comm.). Similarly, H. betteni and the two Symphitopsyche taxa were formerly congeneric, but recently the former sub-genus Symphitopsyche was elevated to the generic level in the family Hydropsychidae (Ross and Unzicker, 1977).

All three taxa construct larval retreats and filter particles from the water column. A great deal of effort by Professor J. B. Wallace from the University of Georgia and others have concentrated on this aspect of hydropsychid ecology. These analyses include only 4th and 5th instars and the data was generated during the same period as the preceding colonization study using identical techniques. Besides these three taxa, other Hydropsychid taxa were also collected during the study (S. bifida, S. morosa; Cheumatopsyche sp. (three species identified from adult collections), H. cuanis, H. frisoni, H. simuliums, Macronema carolina, M. zebratum, Diplectrona metaqui, and S. sparna) but in insufficient densities during this period for inclusion in the analysis.

6.5.3 Hydropsychid Colonization Results and Discussion

The results of the hydropsychid colonization study is reported in Table 6-5 for both the periphyton colonized (P) and uncolonized (U) treatments. Throughout the study, S. cheilonis and S. bronta were substantially more dominant numerically on the substrates (approximately 3x) than H. betteni. This was similar to the distribution of the three taxa in the study reach during the colonization study which was determined by taking three Surber samples at the beginning of the study, two weeks into the study, and at the end of the study. For the following results to be meaningful, one must also assume that the abundance of each taxa was relatively constant in the study reach throughout the study. The Surber sample data further indicated that such an assumption was acceptable for these three taxa despite the variability associated for the total community due to alterations in stream flow. Immediately following the termination of the study on June 14, 1982, both H. betteni and S. cheilonis were rare in benthic samples but dominant in light traps indicating a period of peak emergence.

Comparison of the total percent abundance between taxa indicates that H. betteni is proportionally more abundant on the substrates from day 3 to day 14 than either S. bronta or S. cheilonis (Table 6-6). By day 14, 56.7% of all of the H. betteni larvae collected during the study occurred on the substrates, while only 16.8% and 19.3% of the S. bronta and S. cheilonis larvae were collected. Thus, these data indicate that H. betteni colonizes the substrates more rapidly than does either S. cheilonis or S. bronta. Table 6-6 indicates that there is no difference in the colonization rates of either S. bronta or S. cheilonis for the 28 day duration of the study. These results suggest close ecological similarity between the two morphologically similar taxa. It is not clear whether the differences in colonization rates are due to differences in drift rates or other ecological phenomena (e.g., more rapid exclusion rates).

Following day 14, both S. bronta and S. cheilonis occurred on the substrates in much greater proportions than did H. betteni. Thus H. betteni occurs in proportionally higher abundances early in the study than either of the two Symphitopsyche taxa suggesting: 1) more rapid colonization due to the greater adaptability of H. betteni to periodic environmental fluctuations; 2) existence of a mechanism permitting the coexistence of H. betteni with other confamilial and ecologically similar taxa; or 3) the influence of other mechanisms, both physical and biological on the populations of the 3 taxa. Whether either of the Symphitopsyche taxa can displace H. betteni following establishment on the substrates is not known. Alternatively, rapid colonization may be important to H. betteni if it is capable of excluding the Symphitopsyche taxa from suitable microhabitats already occupied, but unable to displace established Symphitopsyche. Thus,

Table 6-6. Percent of three net-spinning hydropsychid taxa occurring on each substrate throughout the colonization period and the percent of each on periphyton colonized and uncolonized substrates. Includes 12" substrates in totals.

Taxa	Total	Day 3	5	7	11	14	18	22	28
H. betteni (total)	53	5.7	11.3	13.2	7.6	18.9	20.8	9.4	18.9
H. betteni (p)	42	7.1	1.5	7.1	9.5	14.3	4.8	4.8	0.0
H. betteni (u)	42	0	4.8	2.4	0.0	7.1	9.5	0.0	19.1
S. bronta (total)	131	0.0	0.8	1.5	1.5	13.0	39.7	9.9	35.1
S. bronta (p)	103	0.0	0.0	1.9	0.9	11.7	11.7	4.9	4.9
S. bronta (u)	103	0.0	0.9	0.0	0.9	3.9	24.3	0.9	23.3
S. cheilonis (total)	182	1.1	1.7	6.0	0.6	9.9	33.5	14.3	33.0
S. cheilonis (p)	124	0.8	0.0	1.6	0.8	7.3	8.1	8.1	2.4
S. cheilonis (u)	124	0.8	2.4	4.8	0.0	4.0	23.4	4.0	31.5

*Note: The totals listed in the above table include several 12" substrates which were also employed in this study. The (p) represents the periphyton colonized substrates and the %'s reported on these substrates using a total obtained from p + u (= uncolonized periphyton substrates)

possession may be important in determining microhabitat selection of net-spinning hydropsychids and should be investigated if we are to better manage stream flow. Displacement or exclusion mexhcniams would be particularly important in stream systems which are habitat rather than food limited, as proposed by Cudney and Wallace (1980).

Comparison of the periphyton colonized and uncolonized substrate data (through day 14) for H. betteni (Table 6-6) suggests that H. betteni larvae were more abundant on the periphyton colonized when compared with the uncolonized substrates. After day 14, there was a shift in distribution favoring the uncolonized substrates. As indicated by Table 6-5, the chlorophyll a concentrations on the two substrate treatments were similar following day 14 suggesting that periphyton is an important microhabitat requirement of H. betteni. This supports earlier observations that algae is important as a food resource not only in seston production but through direct grazing (J. D. Unzicker, per. comm.).

Comparisons of the two substrate colonization treatments for S. bronta and S. cheilonis indicates little preference for either treatment during the study; nor were there significant interspecific differences demonstrating the ecological similarity between these two taxa. The lack of any preference for the substrate treatments compared with the observed preference of H. betteni for colonized substrates suggests that the two Symphitopsyche taxa may be habitat specialists. The Symphitopsyche taxa may have a greater dependency on seston while H. betteni both grazes and collects seston. In general the results of this study indicate that there are ecological differences between H. betteni and the two Symphitopsyche taxa, but no detectable differences between S. cheilonis and S. bronta. Such ecological differences will effect instream flow needs analyses.

6.5.4 Sediment Effects on the Distribution of Hydropsychid Larvae

A principal purpose of the following experiments section was to determine the effects of sedimentation on the distribution of aquatic insects. For this study all hydropsychid (Trichoptera: Hydropsychidae) larvae observed on the substrate were employed since their larval retreats could be easily viewed and counted without disturbing the location of the substrates in the stream. This, of course, precluded specific taxonomic identifications but permitted an overall assessment of sediment effects on the net-spinning taxa. Furthermore, a qualitative assessment of the amount of sediment within each notch could be made without disturbing the substrates. This data is amenable to nonparametric statistical analyses.

The qualitative analyses of hydropsychid sediment relationships is based on two assumptions: 1) that the occurrence of a hydropsychid retreat represents the existence of a single hydropsychid larvae; and 2) that a consistent qualitative assessment of sediment concentration could be made. With regards to the first assumption, we have periodically found either no larvae or more than one larvae (generally two, but never more than three) associated with a retreat. This being the case, one could expect the unusual cases of no larvae or multiple larvae within a retreat to average out given a large enough sample size assuming a normal distribution.

To insure that a meaningful qualitative sediment assessment was employed, a second analysis was conducted using the qualitative colonization data of larval counts and the substrate notch sediment data (see Methods section). Using this procedure, one could expect similar results between the two sediment analyses. If different statistical results are obtained between the qualitative and quantitative assessments, one must

assume that an insufficient sample size was used in the quantitative assessment, that the no larvae-multiple larvae retreats did not average to one, or that one or both of the two above assumptions were violated in the qualitative assessment.

6.5.5 Results and Discussion of Sediment-Retreat Distribution

Throughout the quantitative study, a total of 363 Hydropsychids were picked from the substrates. Sixty-nine of these were Cheumatopsyche sp. and the remaining belonged to either the genus Symphitopsyche or the genus Hydropsyche. Of the 363 larvae collected, 273 were collected in the notches and 90 collected from the faces. It was apparent that all of the hydropsychids collected from the faces (i.e., 90) were associated with irregularities in the substrate surfaces (i.e., depressions or small holes). These organisms were excluded from the present analysis, however, these observations did permit the development of an additional experiment (to be discussed later) concerning the availability of depressions on the distribution of hydropsychid caddisflies.

Of the 273 hydropsychid larvae found in the notches, 20.5% were located in notch I, 42.5% occurred in notch II, and 37% in notch III. Analysis using a X^2 test indicated that such a distribution was not significantly different from that which would be randomly expected. These findings correspond with the calibration results (Chapter 5) where no significant differences were found in the microhabitat current velocities between notches.

The sediment concentrations within the notches were quite variable, ranging from a minimum of 0.11 mg of sediment on June 8, 1982 to a maximum of 103.08 mg on May 31, 1982 (Fig. 6-3). Such variation in the amount of sediment is typical of riffle areas which can be characterized by containing both areas of deposition and erosion. Due to the fact that the sediment concentrations were continuous and not in discrete categories, the

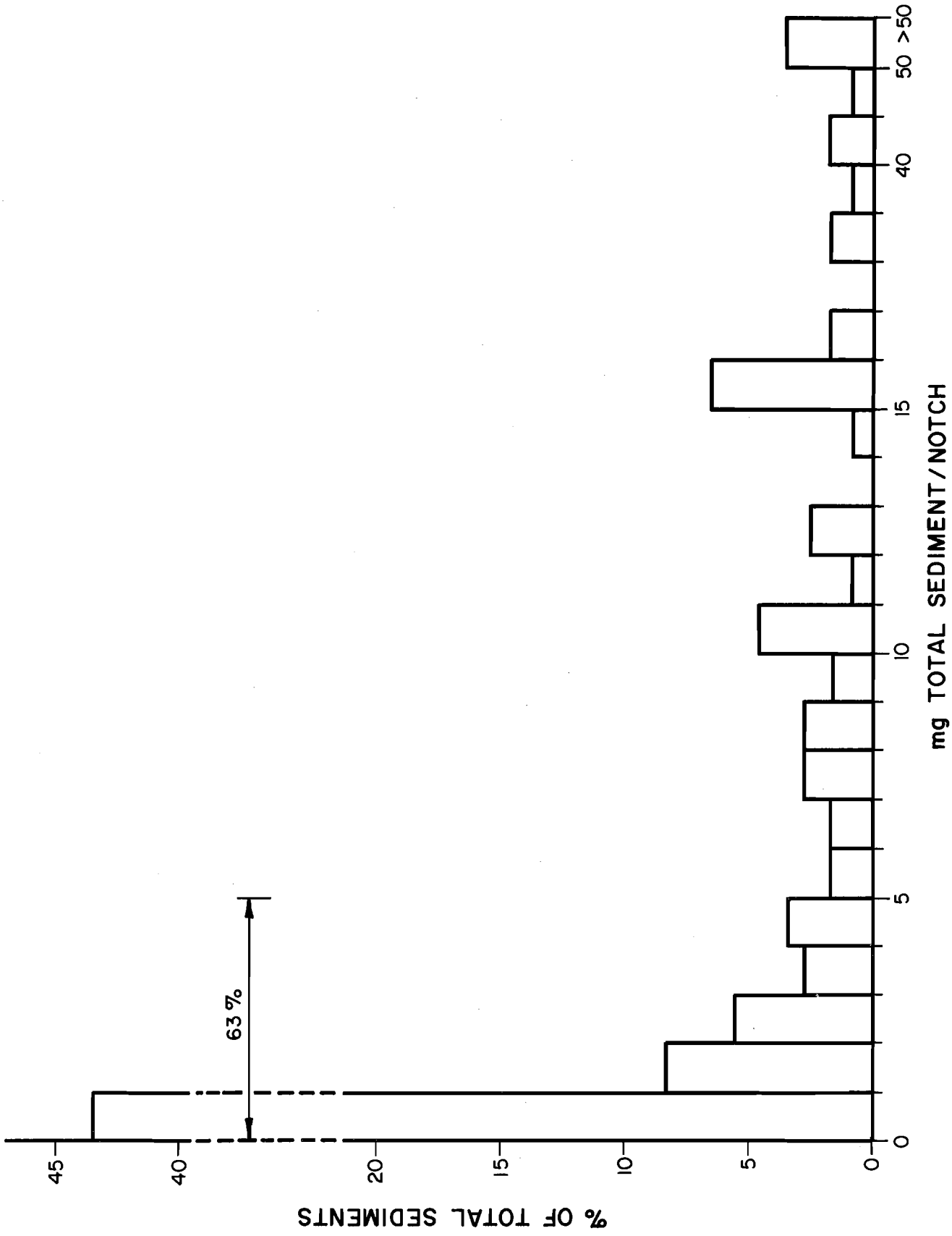


Fig. 6-3. Recent notches within each sediment category (habitat availability).

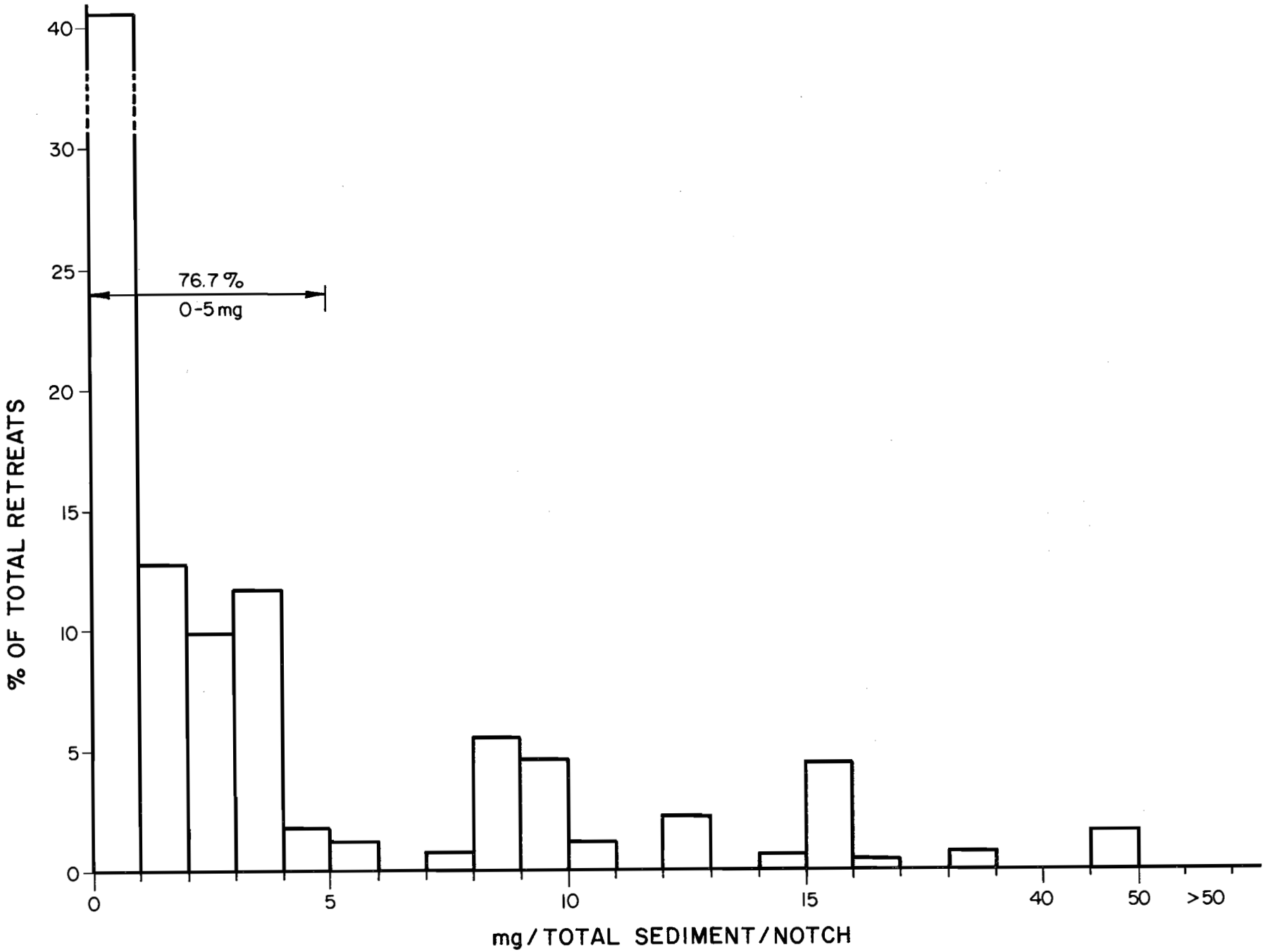


Fig. 6-4. Percent of retreats in different sediment levels.

sediment values were arbitrarily broken up into 23 discrete categories to simplify the analysis. The percent of the total number of notches within each category are graphically presented in Fig. 6-3.

The percent of the larvae collected from each of the sediment categories are graphically presented in Fig. 6-4. These data suggest a substantial skewness and selection for notches with low sediment contents as 76.7% of all of the larvae collected were found in notches containing 5 mg or less of total sediment. Thus, upon first examination it would appear that sedimentation does affect the distribution of hydropsychid larvae. This may not be the case, however, as one must ask if these results are a function of the habitat available, or of the distribution of habitat types within the study area. In essence, one must ask if 76.7% of the habitat notches available contain 5 mg or less of sediment and the distribution of the hydropsychids' is simply random with regards to sediment concentration. To determine if the above is the case, we are forced to examine the distribution of habitat types (i.e., Fig. 6-3), and statistically compare this distribution with the larvae distribution (i.e., Fig. 6-4). Such a comparison was made using the Kolmogorov-Smirnov test which is based upon the premise that "if two samples have . . . been drawn from the same population distribution, then the cumulative distribution of both samples may be expected to be fairly close to each other in as much as they both should show only random deviations from the population distribution" (Siegel, 1956).

No significant differences (i.e., $\alpha = 0.05$) were found in the distribution of the sediment-notch data and the larvae-sediment data which indicated that the caddisflies follow the same distribution as did the habitat sediment types. Thus, within the range of sediment concentrations

measured quantitatively in this study, no effects can be found on the distribution of hydropsychid larvae on the artificial substrates employed.

The qualitative study was undertaken to provide (described previously) a greater sample size with somewhat less effort. A total of 684 hydropsychid retreats were observed during the 28 day study and related to the sediment concentration. Of these 25% were observed in notch X, 38% in notch y, and 37% in notch z. Such a distribution is statistically identical to that obtained in the quantitative assessment.

In the following analysis, we tested the hypothesis that organisms are colonizing the substrates in a manner similar to their distribution within the environment based on quantitative data. The number of retreats within each notch and the percent of the total within each notch with regards to the four qualitative sediment categories are reported in Table 6-7, while the number and percent of the notches within each sediment qualitative category are reported in Table 6-3. Comparison of these two distributions, once again indicated that their were no differences in the number of retreats constructed and the distribution of sediment throughout the study area. Thus, the results of both the quantitative and qualitative analyses were the same which provides adequate evidence to suggest that sedimentation is not an important factor to the distribution of hydropsychid caddisflies on the standardized substrates.

6.6 SUMMARY

In summary, the results of these investigations indicate that: 1) preconditioning of artificial substrates by periphyton significantly increases the rate of macroinvertebrate colonization, 2) periphyton may not only be important trophically, but also hydraulically, as indirect evidence suggests it increases the boundary layer, 3) periphyton untreated substrates displayed a more classic MacArthur-Wilson colonization curve

Table 6-7. Number of retreats in each notch (% of total) with regards to estimate of sediment concentration.

	SEDIMENT CATEGORY			
Notch	None	Little	Moderate	Intense
X	61(36)	87(51)	12(7)	11(6)
Y	95(36)	125(48)	41(16)	0(0)
Z	96(38)	128(51)	27(11)	1(0.4)
$\overline{X}$	36.7%	50.0%	11.3%	2.2%

Table 6-8. Number of notches with each sedimentation level (ie. available habitat).

	SEDIMENT CATEGORY			
Notch	None	Little	Moderate	Intense
X	43(34)	59(46)	16(13)	9(7)
Y	53(42)	65(51)	8(6)	1(1)
Z	60(47)	57(45)	8(6)	2(2)
$\overline{X}$	41.0%	47.3%	8.3%	3.3%

than did periphyton pretreated substrates, 4) increased discharge tended to lower taxa richness, 5) colonization rates of macroinvertebrates are quite variable even in stream reaches with similar hydraulic conditions, 6) H. betteni appears to colonize available microhabitats more rapidly than does either S. cheilonis or S. bronta and appears to be more dependent on periphyton development than either of the Symphitopsyche taxa, 7) there are no detectable differences in the colonization rates and responses to the presence of periphyton between S. cheilonis and S. bronta, and 8) sedimentation does not appear to affect the distribution of hydropsychid larvae on our artificial substrates as organisms utilize available microhabitats in the same proportion as they occur in the environment.

7. INSTREAM CURRENT REQUIREMENTS OF FOUR SPECIES OF NET-SPINNING HYDROPSYCHID CADDISFLIES AND SIMULIUM SP.

7.1 PURPOSE

Ross (1944) recognized four distinct subfamilies of Hydropsychidae which includes: Arctopsychinae; Diplectroninae; Macronematinae; and Hydropsychinae. Individuals from three of these subfamilies (all but Arctopsychinae) have been collected from Jordan Creek, Illinois with four taxa (Symphitopsyche cheilonis, S. sparna, S. bronta, and Hydropsyche betteni), all belonging to the subfamily Hydropsychinae, occurring in the greatest abundance. These four taxa of hydropsychids were studied to determine the microhabitat current velocities which these four taxa inhabited; and further, to determine the interspecific overlap of one or more niche dimensions. Microdistribution is important in food preferences of caddisflies (Ulfstrand, 1967). Due to the existence of two distinct hydraulic zones on the artificial substrates (Section 5 - Cinematography Results) employed in this study, it was also possible to determine how flow patterns affected the distribution of the four species of hydropsychid caddisflies in relation to food sources.

7.2 INTRODUCTION

Two recently forwarded concepts, the river continuum (Vannote et al., 1980) and spiralling (Webster, 1975; Newbold et al., 1982) have had pronounced impacts on the direction of modern day stream research; particularly with regards to energy transfer and ecosystem maintenance. While these ideas are, in fact, developed within the early ecological and hydrological literature, Vannote and Webster have been able to synthesize and present this information in a relatively clear and coherent manner.

The concepts of the continuum and spiraling are particularly important when one recognizes the fact that streams cannot regulate the amount of input from the watershed (e.g., energy, nutrients, pollutants, etc.) while responding to any input through various internal mechanisms to maximize efficiencies. The importance of the watershed was recognized by Hynes (1975) in the classic lecture "The Stream and Its Valley." The mechanisms cited as important watershed/stream continuum maintenance factors may include spiraling or continuous downstream recycling of nutrients, utilization and conversion of all available forms of energy, and internal detoxification or flushing and dilution of toxicants within or through the system. Within the stream, these mechanisms are regulated, in part, by the biotic community through various means such as species adaptations and behavioral modifications. Added to the biological regulations are stream discharge and other related hydraulic parameters which provide an important rate determining component to the above internal mechanisms and processes. Thus, stream discharge cannot be overlooked as a major factor in the management, restoration, or protection of aquatic communities. Discharge affects the rates and processes of watershed/stream continuum factors directly.

Wallace (1979) has pointed out that net-spinning Trichoptera utilized the kinetic energy of streams as a food gathering energy subsidy, long before man ever dreamed of such energy applications. Earlier, Roback (1962) suggested that larvae of one family of net-spinners, the Hydropsychidae, comprise about 80% of trichopteran numbers in moderate to large North American streams. Thus, members of the family Hydropsychidae are an

important link in most stream food chains and there response to discharge modifications and alterations could be considered important to the functioning of the system in general.

Numerous investigators have examined aspects of the biology of hydropsychid caddisflies. These studies have ranged from microdistributional importance in regards to food preference (Ulfstrand, 1967) to the structure and dimensions of filtering nets (e.g., Wallace, 1975; Wallace, 1979; Wallace et al., 1977). While many have devised various means of examing the ranges of current velocities to which these organisms are exposed (Williams and Hynes, 1973; Wallace, 1975; Cudney and Wallace, 1980; Malas and Wallace, 1977) none have been able to determine actual microhabitat velocities to which the organisms are exposed. Some of the best data to date have been collected by Dr. J. B. Wallace and coworkers who employed a rubber bag current meter following that developed by Gessner (1955). While such a device does provide the current velocity in the general area of the larvae, it is questionable whether these readings are, in fact, the current velocities to which the organisms are exposed due to their large size and distance from the surface. Recent improvements in laboratory analyses have included observations of microhabitat characteristics through the use of hydrogen bubble techniques (Georgian, 1983).

Due to the limited amount of information on <u>microhabitat</u> current requirements of hydropsychid caddisflies this study was initiated to relate instream flow with aquatic insect microhabitat requirements. Throughout this section microhabitat current velocities will refer to the calculated speed of the water at a distance of 0.9 mm above the substrate surface. This is well within the area where a caddis larvae would be located.

7.3 STUDY AREA

The study was conducted in Jordan Creek, Illinois (described in section 6) in two study sites, A and B. Site A was the same as described in section 6. The hydropsychid fauna of the site was dominated by S. cheilonis and S. bronta. Site B was located approximately 2.5 km downstream from site A. The riparian vegetation in the vicinity of site B was well developed while site A was characterized by pasture and grazing land with few shrubs and trees and no canopy. Site B is typical of most eastern deciduous flora. The hydropsychid fauna at this site was dominated by S. sparna. H. betteni occurred at both sites, although not in the same abundance as the Symphitopsyche taxa.

7.4 METHODS

Artificial concrete substrates (Fig. 5-1) were placed into the stream at both stations A and B as described in section 5.4.1 at various times from July, 1982 through May, 1983. The substrates were permitted to colonize for a period of two weeks, but not more than three weeks. Prior to collection, the current velocity and temperature were recorded in the vicinity of each substrate using a Marsh-McBirney flow meter, and hand thermometer as described in section 5.4.1. This information was used to calculate a R_e value for each artificial substrate.

The substrates were removed from the stream and immediately examined for hydropsychid larvae and retreats. The location of each hydropsychid larvae was recorded and the larvae placed into a correspondingly labeled vial containing 70% ETOH. These samples were returned to the laboratory and the larve identified and the head-capsule measured for instar determination.

Due to the morphological similarity between S. bronta and S. cheilonis it was not possible to distinguish between these two taxa in the first and second instars. Therefore, only the third, fourth, and fifth instars were utilized in the following analyses for the three Symphitopsyche and one Hydropsyche taxa. The results of the instar frequency analysis are graphically displayed in Fig. 7-1.

Once the above information was compiled, the R_e value was used in calculating the microhabitat current velocities in the vicinity of each larvae using the equations in Table 5-2. This information was used in developing a frequency distribution 'vs' current velocity for each taxa.

A resource utilization index was calculated for each combination of taxa. The index followed that described by Schoener (1968). The calculations are as follows:

$$1 - 1/2 \Sigma|Pij - Pik|$$

where: Pij and Pik are the intensity of utilization of the ith resource by the jth and kth species.

7.5 MICROHYDRAULIC STUDY

As reported earlier, two distinct hydraulic regions were identified in each notch. These are graphically displayed in Fig. 5-3 and refered to as Region I (outside regions) and Region II (the inside or middle region). It is proposed that the existence of such different hydraulic regions would be important in the distribution of hydropsychid larvae. Essentially, this can be visualized as follows. If a food particle suspended in the water column (i.e., Seston) enters the substrate notch at Region I, it will cycle around, due to entrapment within a vortex, for 3-5 revolutions; thus, providing a larvae with 3-5 opportunities to entangle the particle within its net. Conversely, if the same particle were to enter the middle region

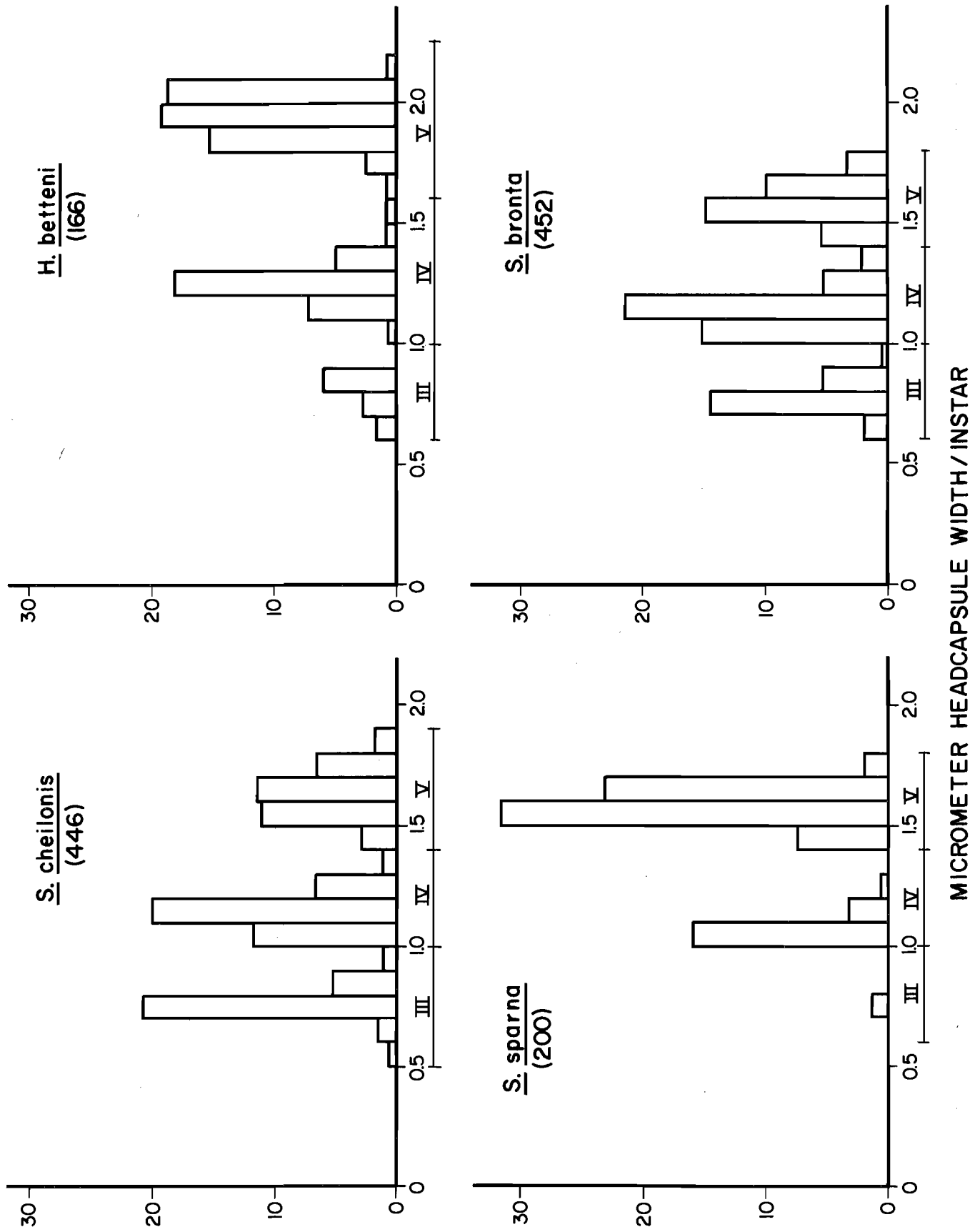


Fig. 7-1. Frequencies used for instar determination for four Hydropsychid taxa.

of the notch (i.e., Region II; Fig. 5-1) the particle will either slowly migrate to one of the two sides (Region I) or settle out giving the larvae only a single opportunity to capture the particle. Thus, by locating a capture net in Region I, a hydropsychid larvae would provide itself with 3-5 opportunities of capturing a food particle entering Region I, as well as providing an opportunity of collecting those particles which entered Region II. Therefore, if hydropsychids were to position their retreats for optimal filtering effectiveness, one would expect the majority of retreats to be located within Region I. The preceding was used as a hypothesis for this specific investigation.

7.5.1 Results and Discussion

The results of this investigation are reported in Fig. 7-2. These data indicate that: 89.6% of the H. betteni larvae; 78.3% of the S. bronta larvae; 84.8% of the S. cheilonis larvae; and 90.5% of the S. sparna larvae were found in Region I. These results demonstrated that Hydropsychid larvae in general maximize seston capture and filtering efficiencies by constructing filtering nets in areas where vortices form when given a choice between no vortex areas and vortex areas. Thus, microhydraulic patterns appear to significantly affect the distribution of Hydropsychid larvae.

Examination of the actual percent occurrence of larvae of the different taxa further indicates little interspecific variation. Such results suggest that hydropsychids as a group have similar flow requirements. Due to the high degree of intraspecific overlap that exists one would expect inter and intraspecific competition to be intense when such microhabitats are limiting. Cudney and Wallace (1980)

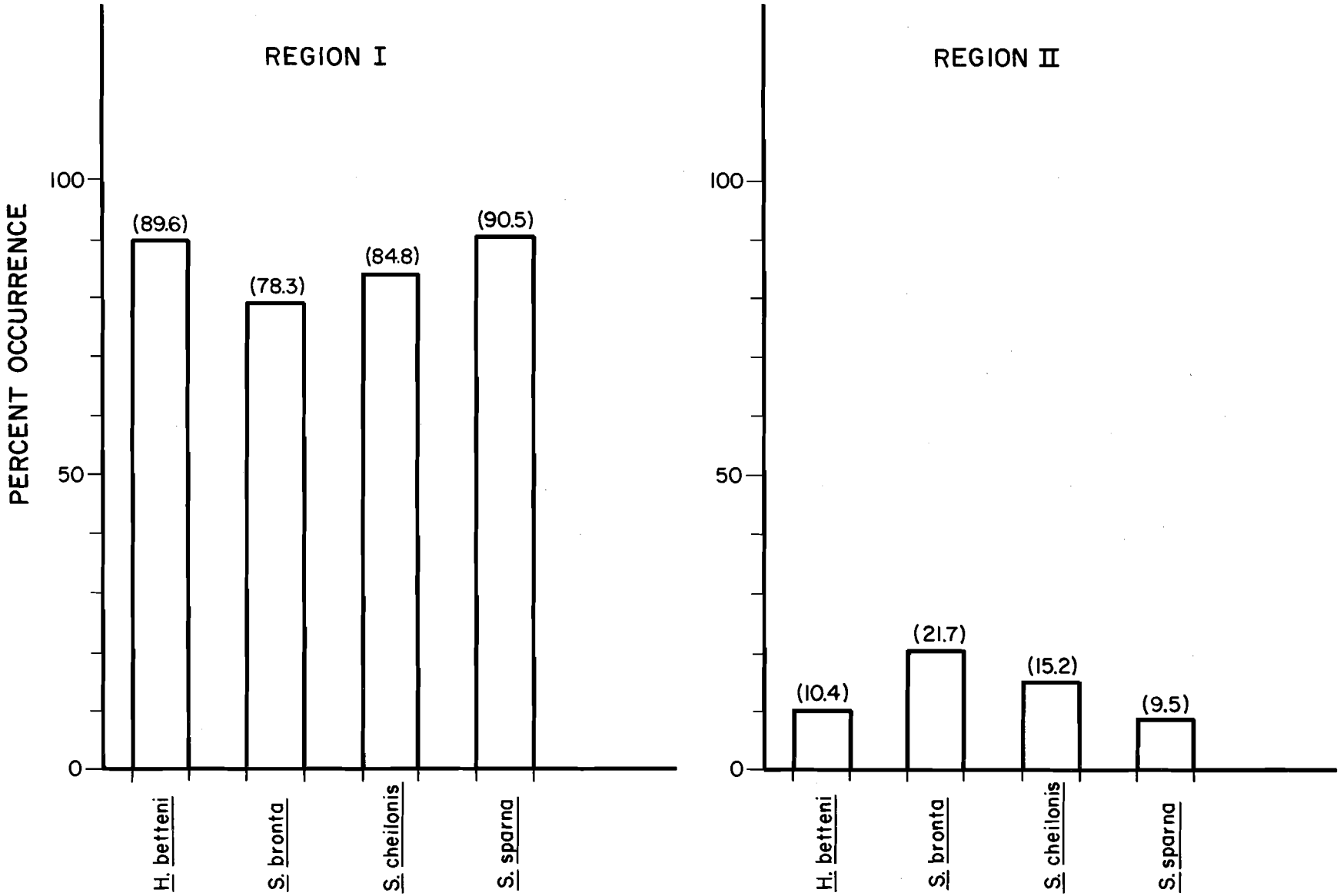


Fig. 7-2. Percent occurrence of total larvae in Regions Iand II during the Jordan Creek study. The above is based on the following sample size H. bettini (48); S. bronta (97); S. cheilonis (46); and S. sparna (126).

postulated the existence of such a limited resource. Intense competition could, however, be avoided if species were to partition microhabitats on the basis of current velocities.

7.6 MICROHABITAT CURRENT VELOCITY STUDY

This study was conducted to determine the microhabitat current velocities to which the four hydropsychid taxa of interest were exposed. This study in particular, may provide the most accurate and new information on the instream flow requirements of aquatic insects yet reported in the literature due to the use of the previously described thermistor probe and measuring technique. It, therefore, should not be surprising that some of the following information are substantially different than that previously reported in the literature.

This is not to say that previous workers were wrong and we are right; but rather, the following results reflect technological advancements and application in the area of aquatic insect microhabitat description and research. These points will hopefully become clearer with this and later sections where the artificial substrates were smoothed and holes drilled into the faces to provide a refuge from the flow.

It is important to note that the following results include only larvae collected within the substrate notches and not on the faces. While a few larvae were collected from the substrate faces, where current velocities were substantially higher, all of these larvae were associated with an imperfection in the substrate surface. The calculated microhabitat current velocities on the substrate faces where larvae were located are reported in Table 7-1. These data and their value will be discussed later with regard to the substrate hole experiment. The following results are concerned with only those larvae collected within the substrate notches.

Table 7-1. Microhabitat current velocities (cm/sec) calculated on substrate faces where Hydropsychids were found. All larvae were associated with a depression or imperfection in the substrate surface.

H. betteni (N=7)	*S. cheilonis* (N=5)	*S. sparna* (N=24)
9.7	20.0	25.0
59.7	7.9	33.3
78.1	9.8	8.0
81.8	57.3	6.8
62.6	65.1	22.8
83.0		33.4
54.6		16.4
		16.2
		31.2
		28.2
		8.6
		27.7
		19.7
		21.7
		63.4
		34.9
		31.2
		27.0
		68.8
		23.7
		49.8
		34.9
		26.9
		25.0

7.6.1 Results and Discussion

The microhabitat current velocities to which four species of hydropsychids were exposed (S. bronta, S. cheilonis, S. sparna, and H. betteni) were examined and the results presented in Figs. 7-3 and 7-4. These data indicate that some individuals of all four taxa inhabited areas of the substrate where microhabitat current velocities were less than 1 cm/sec. S. sparna and H. betteni were found to inhabit the highest curve velocity of 15 cm/sec. The maximum current velocities at which S. bronta and S. cheilonis were recorded were 10 and 11 cm/sec, respectively (Fig. 7-3).

Wallace et al. (1977) have previously reported the range of water velocities in the vicinity of hydropsychid capture nets for six different taxa. Unfortunately only one of these taxa, S. (formerly Hydropsyche) sparna, overlap with those in the present study. These authors reported current velocities (based upon 12 measurements in the Tallulah River) in the vicinity of S. sparna filtering nets from 28-103 cm/sec, substantially higher than the values reported in this study. The differences between Wallace's et al. results and this study may be attributed to the fact that current velocities were measured in the vicinity of the capture nets of the larvae in the former study while our calculated results are based upon equations generated for areas much nearer to the substrate surface (0.9 mm) in the areas where larvae inhabit. It is interesting to note the similarity between Wallace's et al. results for S. sparna and those reported in Table 7-1 (these will be discussed in a later section).

The data in Figures 7-3 and 7-4 indicate a substantial degree of overlap in the range of microhabitat current velocities between the four taxa. This is reflected in the calculated resource utilization indices

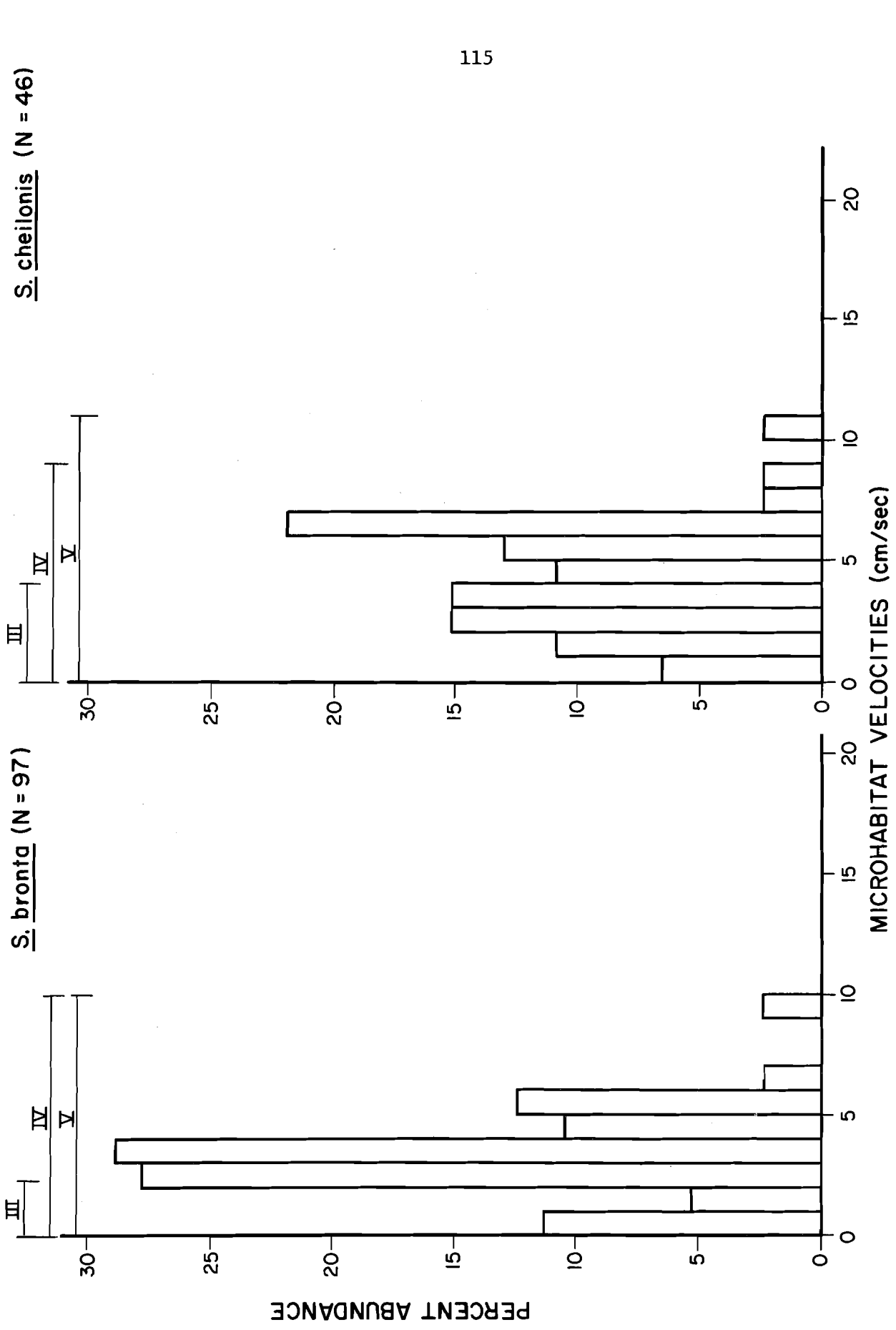


Fig. 7-3. Distribution of S. bronta and S. cheilonis within substrate notches with respect to calculated microhabitat current velocities and the distribution of instars.

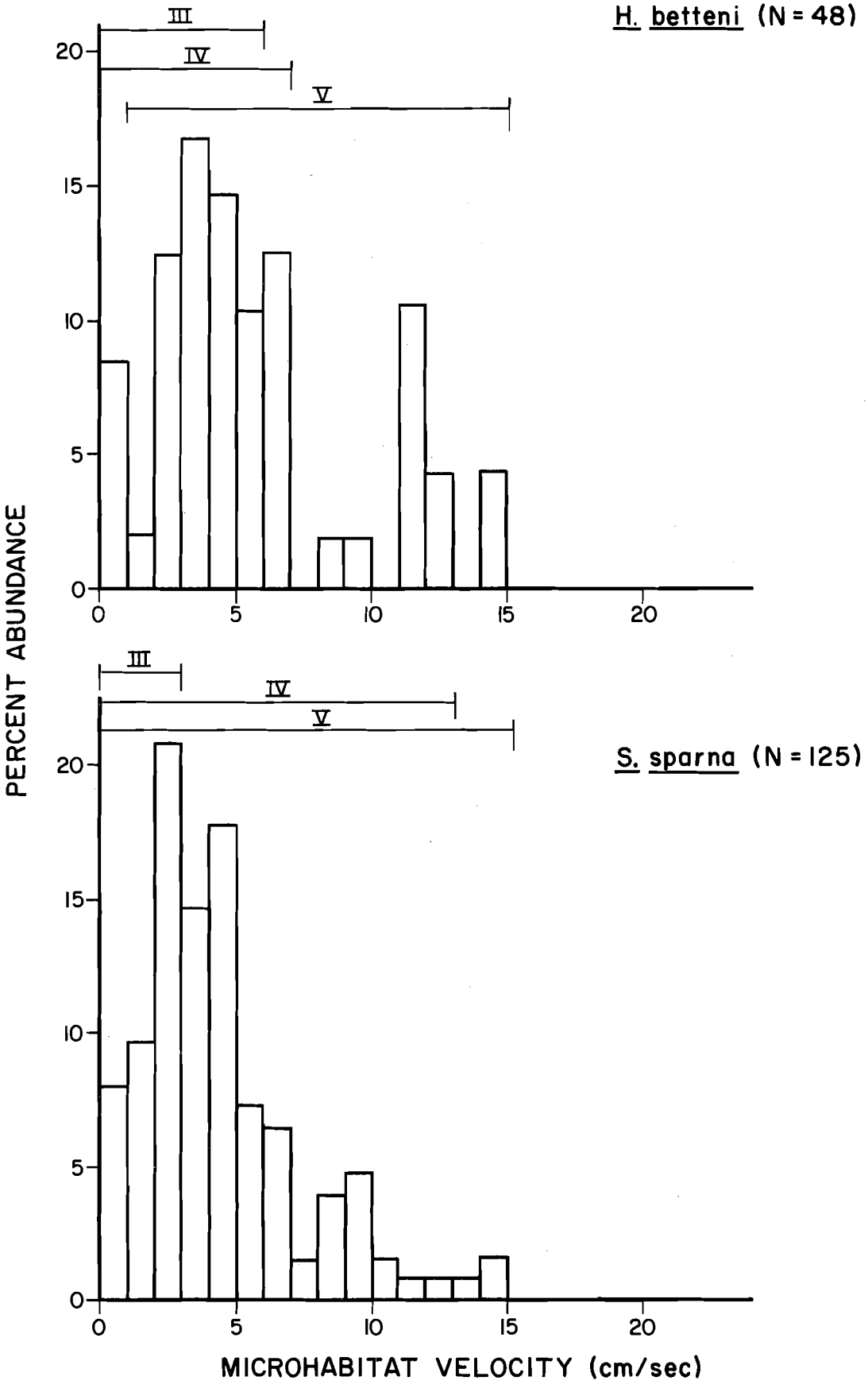


Fig. 7-4. Distribution of H. betteni and S. sparna within substrate notches with respect to calculated microhabitat current velocities and instar distribution.

(Table 7-2) for the six possible taxa pair combinations. These values ranged from a minimum overlap of 0.64 for S. bronta and H. betteni, to a maximum of 0.76 for S. cheilonis and S. sparna (Table 7-2).

An overlap of 0.7 or greater along any resource axis has been used as a cutoff to indicate significant competitive interactions if the resource becomes limiting. Accepting the 0.7 value, one could expect to see significant competition between S. sparna and the other three hydropsychid taxa and between H. betteni and S. cheilonis (Table 7-2) if habitats with appropriate microcurrent velocities to become limited.

Despite the high degree of ecological overlap (>0.7) between taxa microcurrent velocity distributions (Table 7-2), statistically significant differences were found between all of the taxa distributions when analyzed using the Kolmolgorov-Smirnov two sample test (Table 7-3).

As previously mentioned (section 7.3), the two study sites (A and B) were dominated by different Symphitopsyche taxa: S. cheilonis and S. bronta dominated site A, while S. sparna was numerically dominant at site B. H. betteni occurred in virtually equal abundances and was subdominant at both sites. Examination of the frequency distributions of the four taxa (Figs. 7-3 and 7-4) suggests that the aforementioned statistical distribution differences can be attributed to specialization within a limited range of current velocities. Both S. cheilonis and S. bronta, the two most morphologically similar taxa, were found in microhabitats with average velocities less than 11 cm/sec. Within this limited range (i.e., 0-11 cm/sec) approximately 57% of the S. bronta occurred in regions with microhabitat velocities of 2-4 cm/sec. Approximately 45% of the S. cheilonis

Table 7-2. Calculated resource utilization overlap for each pair of Hydropsychid taxa with respect to microhabitat current velocities and percent occurrence within each resource category.

	S. bronta	*S. cheilonis*	*S. sparna*	*H. betteni*
S. bronta	-	0.67	0.70	0.64
S. cheilonis	0.67	-	0.76	0.72
S. sparna	0.70	0.76	-	0.74
H. betteni	0.64	0.72	0,74	-

Table 7-3. Results of Kolgomorov-Smirnov 2 sample test on the Hydropsychid species pairs distribution. ** indicates significant difference at α=0.01.

	S. bronta	S. cheilonis	S. sparna	H. betteni
S. bronta	-	**	**	**
S. cheilonis	**	-	**	**
S. sparna	**	**	-	**
H. betteni	**	**	**	-

Note: Each 1 cm/sec category of current velocity was employed in the test in obtaining the above table.

larvae were collected in areas with microhabitat velocities of 5-7 cm/sec. These data appear to indicate a degree of microcurrent velocity specialization between these two morphologically similar taxa that could account for their co-existence at site A. Whether such minimal microhabitat specialization differences could be altered by human activity to the extent of eliminating one of the two categories (i.e., 2-4 or 5-7 cm/sec) and not the other and thus restricting the distribution of one taxa and not the other is questionable.

Both H. betteni and S. sparna were found in areas with microhabitat velocities as high as 15 cm/sec (Fig. 7-4). These two taxa also had a much more even distribution when compared with the distributions of S. cheilonis and S. bronta, in conjunction with its faster colonizing habits corresponds with its more general distribution between the two sites. Additionally, H. betteni is 10-15% larger within each individual instar than the three Symphitopsyche taxa. Assuming that filtering net mesh size is a direct function of larval head capsule size one could expect subtle differences in food resource overlap between H. betteni and the three Symphitopsyche taxa. This is presently speculative but follows findings of Wallace (1979).

The differences in Symphitopsyche species dominance between the two sites may, in part, be related to the distribution of microhabitat types within the two stream reaches as the majority of S. cheilonis and S. bronta were found in the 2-7 cm/sec range (Fig. 7-3 and 7-4). Differences in riparian vegetation and general topography between the two sites likely contribute to the disjunction in the longitudinal distribution of the Symphitopsyche taxa in Jordan Creek as well. These differences could also affect other stream characteristics such as temperature which may

account for the dominance of S. sparna at site B where a well-developed canopy could lower stream temperatures.

Besides interspecific interactions and segregations, intraspecific partitioning and instream flow requirements may also be important to the success or failure of a species population within a system. The distribution of three larval instars within each of the four species with regards to calculated microhabitat velocities are also reported in Figs. 7-3 and 7-4. The III instar data should be viewed with caution, due to the limited sample sizes. These results do, however, provide information on general microhabitat and flow preferences in species life history requirements.

Nets allow filter feeders to exploit food materials which are produced in many diverse habitats and made available to the larvae by the current (Wallace, 1979). The sizes of Trichoptera filter net meshes and their ecological importance have been the subject of numerous investigators (e.g., Schumacher, 1970; Wallace and Malas, 1975; Wallace et al., 1977). Wallace (1979) reported both significant inter and intraspecific differences in the mesh sizes of numerous hydropsychid taxa. Earlier, Wallace et al. (1977) reported a mean capture net mesh opening for S. sparna to be 110 x 160 µm in the IV instar and 180 x 270 µm in the V instar. In a later investigation, Georgian and Wallace (1981) reported the following mean mesh openings for S. sparna with regards to instars: I-39.3 µm; II-47.1 µm; III-87.3 µm; IV-141.1 µm; and V-232.1 µm. Such a correlation between instars and net mesh size was reported in all taxa examined. Georgian and Wallace (1981) also calculated the volume of water filtered through the nets per day and as would be expected, the latter values were found to be directly related to mesh opening as larger meshes would permit a greater volume of water to pass through.

The importance of mesh size to trophic relations and partitioning between and within hydropsychid taxa has been the subject of numerous investigations. Net mesh size and the feeding mechanism that hydropsychids have evolved is also likely to have an effect on microhabitat distribution of larvae since it would be unlikely that larvae with small meshed nets would be able to withstand the force (due to back pressure) of higher current velocities. Such a hypothesis appears to be generally true based upon the instar distribution of the four Hydropsychid taxa in this study (Figs. 7-3 and 7-4).

In all taxa, the higher current velocity (relative term to each taxa) categories contained only 4th or 5th instar larvae (Figs. 7-3 and 7-4). Further, 4th instar larvae occurred at higher current velocities than the maximum category in which third instar larvae were collected. All fifth instar Symphitopsyche taxa were collected from regions with microhabitat current velocities less than 1 cm/sec. Fifth instar H. betteni were found in microhabitat current velocities down to 1 cm/sec. Thus, these data suggest that the microhabitat distribution of hydropsychids is limited more by high current velocities than low and that instars do appear to be partitioning microhabitats.

7.7 SIMULID (SIMULIDAE:DIPTERA) CURRENT VELOCITY REQUIREMENTS

The ecology of Simulidae (black flies) have been investigated by several researchers (e.g., Merritt et al., 1978). Simulids are bowling pin shaped larvae normally found in flowing water on stones, vegetation, or other objects (Webb and Brigham, 1982). Like hydropsychids, simulids are filter feeders, but employ a different filtering mechanism. Simulids possess a

pair of fan-like cephalic appendages located on the anterior portion of their head by which they filter food particles from the water column. Anderson and Dickie (1960) reported few simulids in waters with large amounts of suspended soil particles and postulated that such materials clogged both their filtering fans and digestive tracts. While a great deal is known taxonomically about simulids due to their importance as a human pest, little is known of the exact microhabitat preferences or instream flow requirements of this taxa.

7.7.1 Purpose

This study was undertaken to provide preliminary information on the instream flow microhabitat requirements of simulids in Jordan Creek, Illinois. Such a study was felt important due to the commonly reported occurrence of simulids in only "swift" microhabitats.

7.7.2 Methods

Methods and procedures follow those described in the Trichoptera section of this report using concrete artificial substrates.

7.7.3 Results and Discussion

While conducting the study it was apparent that the simulid larvae colonized a different portion of the substrates than did the hydropsychid larvae. Instead of inhabiting the notches of the substrate like the hydropsychids, the simulids were restricted to the upper faces. This reflects filter feeding in an area directly exposed to stream flow rather than areas predominated by a vortex.

The results of the actual point velocity calculations for the simulids are reported in Fig. 7-5. These results are based on only a few number of larval occurrences due to the fact that the larvae appeared to emerge early in the study thus limiting sampling. It is also important to note that simulid larvae display a propensity to drift and are very early

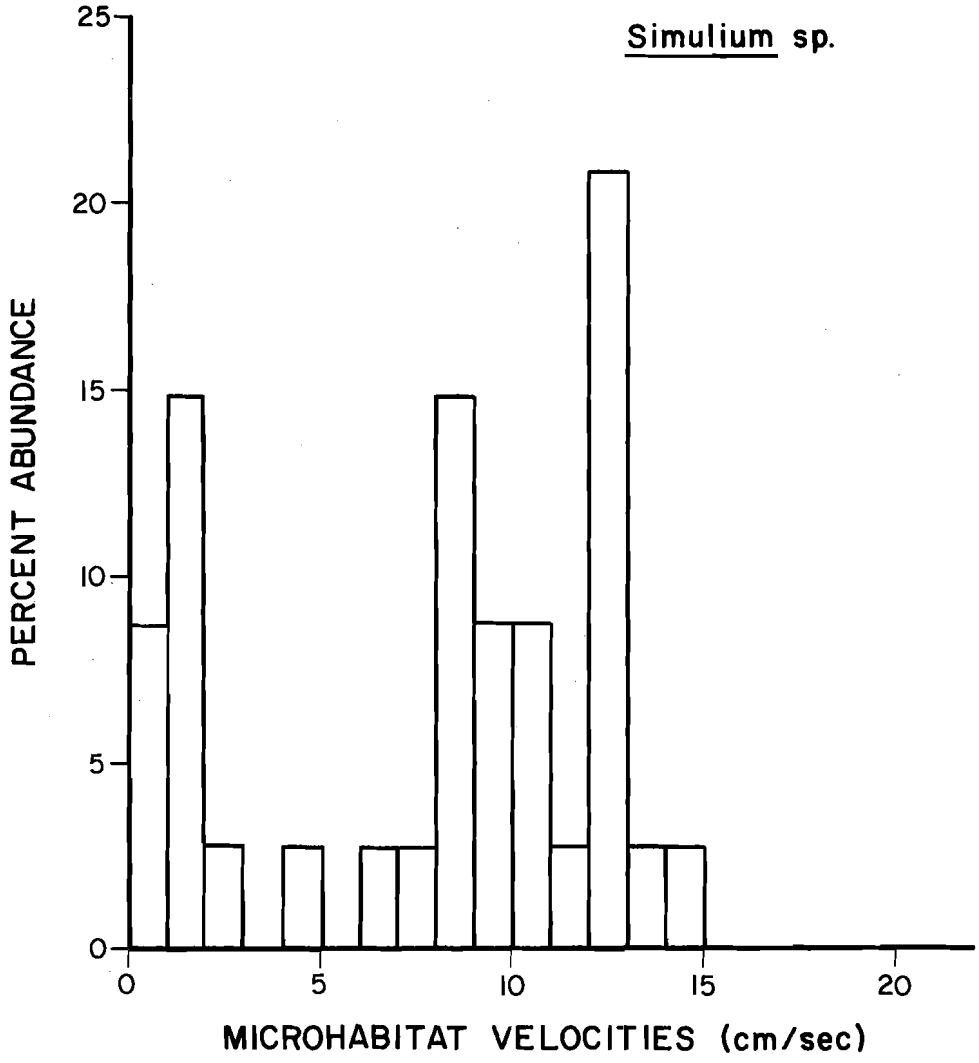


Fig. 7-5. Distribution of Simulium sp. on the artificial concrete substrates in Jordan Creek, Vermilion County, Illinois.

substrate colonizers (Osborne, per. observations). Thus, the meaningfulness of these results is limited without diurnal studies during periods of peak of peak instream abundance. These results do indicate, however, that Simulium sp. inhabits (at least temporarily) areas of substrate with current velocities similar to those of the hydropsychid larvae. Our values ranged from less than 1 cm/sec to 15 cm/sec. This is somewhat surprising given the fact that microhabitat regions with velocities up to 1.0 m/sec were reported on some substrates when simulids were present. Whether simulids can inhabit these regions for short or long periods is not yet known but should be examined in the future. It is also possible that attachment of simulids change hydraulic conditions enhancing further colonization.

7.8 SUBSTRATE HOLE EXPERIMENT

As mentioned earlier (section 7.6), some hydropsychids were periodically found on the faces of the artificial substrates where microhabitat current velocities were substantially higher than in the notches. In fact, microhabitat velocities on the upper regions of the face were at times higher than the mean column velocities (approximately 5-10% higher). Upon close examination, all larvae and retreats collected from the substrate faces were associated with imperfections in the substrate (e.g., cracks or depressions). Dr. J. B. Wallace (per. comm.) has also found hydropsychids on the face of apparently smooth rock out croppings where the mean column velocities were as high as 2 m/sec but closer examination of the sites revealed depressions which protected the hydropsychid larvae.

Based upon the results of our previous microhabitat current velocity studies (section 7.6), it was felt that existence of hydropsychid larvae on 'smooth' faces in such high current velocities would be unlikely. The apparent association of the larvae with imperfections in our artificial

substrates would further indicate that the texture or contour of the surface would be important in dictating the distribution of larvae. It was hypothesized that slight depressions in the substrate would provide a refuge for the larvae within the confines of the boundary layer and outside of the very fast current. To determine if this were the case, or alternatively: if Jordan Creek Hydropsychid taxa could inhabit substrate regions of very high (>30 cm/sec) microhabitat current conditions, the following experiment was conducted.

7.8.1 Methods

On July 14 and August 4, 1982, seven artificial concrete substrates were placed into Jordan Creek as previously described. Prior to their introduction into the stream, all substrate faces were made as smooth as possible using a paste made of glue, cement, and water. This provided us with a method of filling in all imperfections on the substrate surface and providing the organisms with a homogenous substrate texture. Three of the seven substrates were placed directly into the stream while the remaining four had six holes (depth 1/8") of two different sizes (large - 1/4" diameter; small 1/8" diameter) randomly drilled into each face. The distribution of hydropsychid larvae on the two substrate treatments (i.e., holes 'vs' no holes) were determined as previously described. This experiment was duplicated twice; for the purpose of replication and to determine the effects of time on distribution and colonization of the holes. Species indentifications were not made although the two dominant taxa during the experiments were S. bronta and S. cheilonis with H. betteni and two Cheumatopsyche species subdominant on the substrates.

7.8.2 Results and Discussion

The current velocities (mean column) and depth of the water in the vicinity of each of the substrates at the beginning of each of the two experiments are reported in Table 7-4. These values provide a similar R* for between treatment comparisons and the mean column velocities were sufficiently high in all cases to be used in the analysis.

On July 16, 1982, the first series of substrates were removed following a two day exposure and a total of 132 larvae counted (Table 7-5). Comparison of the mean number of larvae on the two treatments indicated that a substantially higher mean number of larvae occurred on the substrates with holes than those without (Table 7-5). This suggests that increasing substrate microhabitat available increases the abundance of larvae and that texture and contour are likely to be important in the distribution of hydropsychids. Similar results were reported in the August experiment with the no hole treatment having an average of 22.0 larvae while substrates with holes had an average of 35.0 larvae (Table 7-6).

At no time were larvae collected from the faces of the control treatments (i.e., without holes) (Tables 7-5 and 7-6). This further suggests that the higher number of individuals on the hole treatment was due in fact to the presence of the holes. These data further suggest that hydropsychids are unable to inhabit smooth faces where mean current velocities are greater than .30 m/sec. It appears that the holes provide a refuge for the organisms out of the stronger current and permit them to exist within the confines of the boundary layer.

Table 7-4. The substrate column velocity and water depth in the vicinity of each of the artificial substrates employed in the July 14 and August 4, 1982 experiments. Substrates followed by an H indicate those with holes in the face.

July 14

Substrate	Substrate Column Velocity (m/sec)	Depth (cm)
3H	0.30	18.0
4H	0.56	16.0
5H	0.26	17.0
6	0.51	16.0
7	0.39	17.0
8H	0.32	20.0
9	0.36	16.0

August 4

Substrate	Substrate Column Velocity (m/sec)	Depth (cm)
1H	0.33	17.0
2H	0.39	15.0
3H	0.54	15.6
4H	0.27	14.0
5	0.27	14.0
6	0.45	13.5
7	0.39	14.0

Table 7-5. Total number of larvae collected on the July 14, 1982 substrates and totals for each notch and face (B=1/4" hole; S=1/8" hole). Substrates collected on July 16, 1982.

	Number of Larvae						
Substrate	Notch 1	Notch 2	Notch 3	Face W	Face X	Face Y	Face Z
6	4	6	6	0	0	0	0
7	6	5	6	0	0	0	0
9	5	5	7	0	0	0	0

$\bar{X}$ No. larvae on substrates w/o holes = 16.3

Substrate	Notch 1	Notch 2	Notch 3	Face W		Face X		Face Y		Face Z	
				S	B	S	B	S	B	S	B
3H	3	5	5	1	3	1	1	0	0	0	2
4H	4	8	4	0	0	0	0	0	1	1	1
5H	4	7	10	1	0	1	2	0	0	2	0
8H	2	2	3	2	3	0	1	0	0	0	2

$\bar{X}$ No. of larvae on substrates with holes = 20.8

Percent of holes colonizes = 26%

Table 7-6. Total number of larvae collected on the August 4, 1982 substrates and the totals for each notch and face. (B=1/4" hole; S=1/8" hole). Substrates collected on August 17, 1982.

	Number of Larvae						
Substrate	Notch 1	Notch 2	Notch 3	Face W	Face X	Face Y	Face Z
5	4	8	9	0	0	0	0
6	7	8	7	0	0	0	0
7	7	9	7	0	0	0	0

$\bar{X}$ No. of larvae on substrates w/o holes = 22.0

Substrate	Notch 1	Notch 2	Notch 3	Face W		Face X		Face Y		Face Z	
				S	B	S	B	S	B	S	B
1H	10	10	7	3	3	2	2	2	3	3	3
2H	9	10	9	2	3	2	2	3	2	2	0
3H	7	6	5	1	1	1	2	3	3	2	3
4H	2	2	4	0	1	1	1	1	2	0	0

$\bar{X}$ No. of larvae on substrates with holes = 35.0

Percent of holes colonized = 61%

Comparison of the July and August experiments further indicate a difference in the amount of artificial refuges colonized as 61% were colonized at the end of two weeks and only 26% were colonized after two days.

The results of this study confirm our initial observations that hydropsychids require at least a pit or depression in the substrate surface when oriented in a manner that it received the full force of the current. The depression evidently provides a refuge within the boundary layer. As such, the calculated microhabitat velocities for the Trichoptera located on the faces of the substrates (Table 7-1) are likely overestimates of the true microhabitat velocities and do not reflect the true velocities.

8. SUBSTRATE PARTICLE SIZE AND THE DISTRIBUTION OF THE JORDAN CREEK EPHEMEROPTERA AND TRICHOPTERA

8.1 PURPOSE

The purpose of this study was to add to that body of existing literature on the effects of sediment particle size on the distribution of the aquatic insect fauna and provide a connection between microhabitat current experiments and commonly used instream flow needs analyses methodologies which incorporate substrate measurements.

8.2 INTRODUCTION

The importance of substrate particle size in structuring benthic invertebrate communities has long been recognized. Cummins (1964) has attributed what has become to be known as the "erosion-deposition" concept in stream ecology to Moon (1939). To a large extent, current velocity and depth within a given stream reach dictate the sediment composition. These three parameters cannot be easily separated or ranked as most important to least important in the manner in which they interact to provide a framework to available microhabitats for aquatic organisms. Aquatic insect utilize these microhabitats based upon morphological adaptations and evolved feeding mechanisms. Throughout this report, we have emphasized the importance of microhabitat current velocities in the distribution of hydropsychid caddisflies. This section deals with the importance of substrate particle size on the distribution of the mayfly and caddisfly taxa in Jordan Creek, Illinois.

8.3 METHODS

Eighteen substrate containers (25 cm long x 12 cm wide x 6 cm high) made from plastic gutter spouting (Figure 8-1) were placed into Jordan Creek at both station A (the upstream station) and station B (the lower reach). Nylon mesh (7 mesh/cm) was glued to both ends of each container to permit current flow through the system. Three containers (replicates)

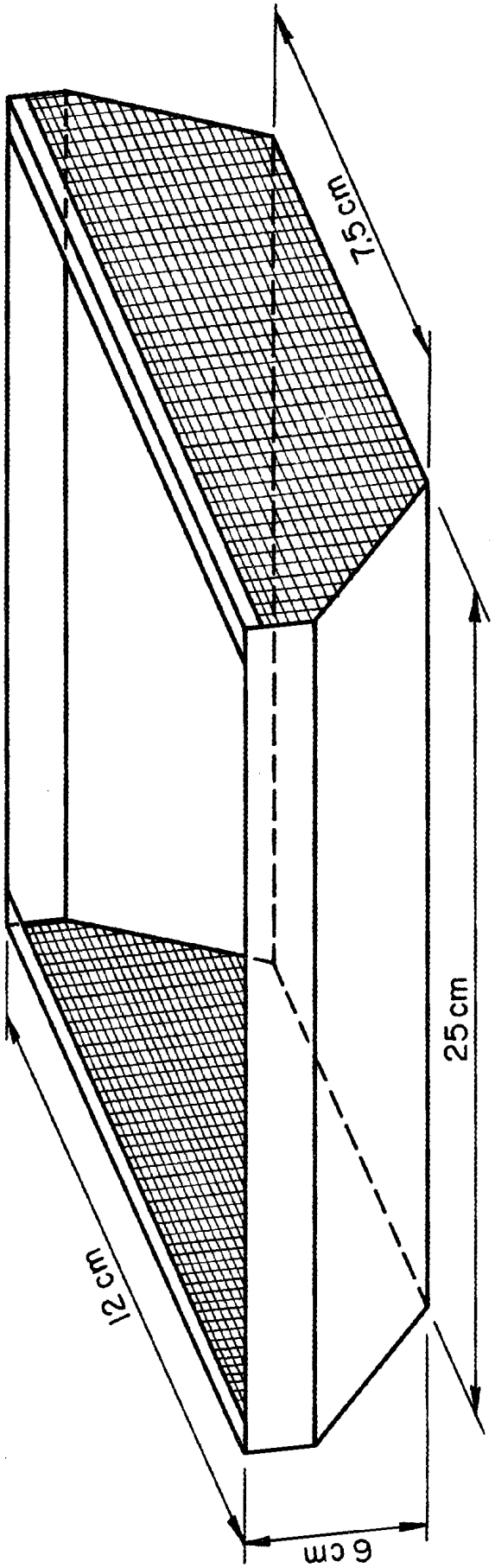


Fig. 8-1. Substrate containers employed in study.

for each of the six substrate treatments were filled with substrate materials previously collected from Jordan Creek. This material was dried and rinsed clean prior to this experiment. The range of the substrate particle sizes used in each of the six treatments are reported in Table 8-1.

Replicate treatments were placed into Jordan Creek at station B on October 12, 1982 and at station A on February 12, 1983 by digging a depression into the stream bed and placing the substrate containers containing the substrates so that approximately 2 cm of the containers remained above the bottom of the stream. The containers were oriented with the nylon mesh perpendicular to the stream flow. Current velocity within each study area were collected at 0.6 the depth and total water depth each determined at the beginning and end of each study.

The station B substrates were collected on November 8, 1982 by gently lifting the containers and while still under water placing a large white enamel pan under the container. In the field this material was placed into labeled Mason jars containing 70% ETOH. Organisms were sorted and the Trichoptera and Ephemeroptera fauna identified. The same procedures were employed in collecting the station A material on March 25, 1982.

8.4 RESULTS AND DISCUSSION

A total of 35 caddisfly and mayfly taxa were collected during the substrate experiments, which included 20 Ephemeroptera and 15 Trichoptera (Table 8-2). The most numerically abundant Trichoptera were: Helicopsyche borealis; Pycnopsyche guttifer; Ochrotrichia (prob. xena); Cheumatopsyche sp. (This taxa was represented by at least three species as determined by light sampling of adults); Symphitopsyche bronta; S. cheilonis; and S. sparna. The most numerically abundant mayflies were Baetis herodes; B. intercalaris;

Table 8-1. Substrate particle range employed in each of the six substrate treatments.

Treatment	Range of Sediment Diameter
I	>38.1 mm <76.2 mm
II	>26.7 mm <38.1 mm
III	>13.3 ,, <26.7 mm
IV	> 9.4 mm <13.3 mm
V	> 4.7 mm < 9.4 mm
VI	> 600 µm < 4.7 mm

Table 8-2. Total taxa list from substrate-aquatic insect distribution experiments.

Ephemeroptera:

- Ameletus lineatus
- Baetis sp.
- B. cingulatus
- B. harodes
- B. intercalaris
- B. phoebus
- B. pygmaeus
- B. vagans
- Caenis sp.
- Centroptillum sp.
- Ephemerella inermis
- Isonychia sp.
- Potamanthus sp.
- Pseudocloen sp.
- Stenacron gildersleevei
- Stenacron heterotarsale
- Stenonema terminatum
- Stenonema femoratum
- Stenonema mediopynctatum
- Stenonema tripunctatum

Trichoptera:

- Cheumatopsyche sp.
- Chimarra obscura
- Helicopsyche borealis
- Hydropsyche aerata
- H. betteni
- H. simulans
- Leucotrichia (prob. pictipes)
- Neureclipeus sp.
- Ochrotrichia (prob. xena)
- Orthotrichia (prob. cristata)
- Pycnopsyche guttifer
- Symphitopsyche sp.
- S. bronta
- S. cheilonis
- S. sparna

B. pygmaeus; Caenis sp. (thought to contain only one species), Stenacron gildersleevei; Stenonema terminatum; and S. mediopunctatum. These 14 taxa were employed in the Schoener's resource utilization index with substrate particle size used as the resource (see section 7). The results of these analyses are reported in Table 8-4 and 8-5.

The fewest mean number of individuals occurred in the 600 µm-4.7 mm particle size range with only 3.3 individuals per container (Table 8-3). The 26.7-38.1 mm sized particles had the highest densities of mayflies and caddisflies averaging 60.7 individuals/container (Table 8-3). Only 9 taxa were found in the 600 µm-4.7 mm treatments (Group VI) while the greatest species richness occurred in the 38.7-76.2 mm (Group I) treatment (Table 8-3). In general, taxa richness increased with substrate particle size (Table 8-3).

These results indicate that substrate particle size affects the taxa richness of the Trichoptera-Ephemeroptera benthic assemblage. Substrate particle size also affected the mean densities of aquatic insects, but in a different manner than occurred with taxa richness. Very few taxa and individuals were collected in the 600 µm-4.7 mm particle treatment which suggests that a drastic alteration in the structure and composition of the benthic insect community would occur if the substrate composition of the stream were to change from it's present composition to a more sandy type structure.

Alterations in substrate composition could occur in several ways including a reduction in stream discharge due to off-stream use (e.g., irrigation) or through elimination of the normal annual spring high-flow period in temperate regions such as the midwest. A reduction in discharge would likely lower current velocities which would permit smaller particles to settle out of suspension on to the stream bed. Elimination of the high water periods through the construction of impoundments could have a more

Table 8-3. General statistics on the distribution of Ephemeroptera and Trichoptera taxa with regards to substrate particle size in Jordan Creek, IL.

Treatment	$\bar{X}$ Number Ind. Per Container	Taxa Richness	N	Total Ephemeroptera Taxa	Total Trichoptera Taxa	$\bar{X}$ Number Ind. Ephemeroptera	$\bar{X}$ Number Ind. Trichoptera
600 μm - 4.7 mm	3.3	9	4	5	4	2	1
4.7 mm - 9.4 mm	26.8	21	6	10	11	17	10
9.4 mm - 13.3 mm	52.4	22	5	12	10	36	16
13.3 mm - 26.7 mm	43.2	20	5	12	8	27	16
26.7 mm - 38.1 mm	60.7	25	6	13	12	38	23
38.1 mm - 76.2 mm	47.3	27	6	14	13	32	15

Table 8-4. Schoneer's resource utilization index for seven Trichoptera taxa with regards to substrate particle size and frequency of distribution.

	Helicopsyche borealis	Pycnopsyche guttifer	Ochrotrichia xena	Cheumatopsyche sp.	Symphitopsyche bronta	Symphitopsyche cheilonis	Symphitopsyche sparna
Helicopsyche borealis	-						
Pycnopsyche guttifer	0.56	-					
Ochrotrichia xena	0.49	0.43	-				
Cheumatopsyche sp.	0.62	0.65	0.71	-			
Symphitopsyche bronta	0.64	0.73	0.55	0.88	-		
Symphitopsyche cheilonis	0.78	0.69	0.55	0.82	0.82	-	
Symphitopsyche sparna	0.62	0.68	0.73	0.89	0.77	0.78	-

Table 8-5. Schoneer's resource utilization index for seven Ephemeroptera taxa with regards to substrate particle size and frequency of distribution.

	Baetis herodes	Baetis intercalaris	Baetis pygmaeus	Caenis sp.	Stenacron gildersleevei	Stenonema terminatum	Stenonema mediopunctatum
B. herodes	-						
B. intercalaris	0.69	-					
B. pygmaeus	0.80	0.61	-				
Caenis sp.	0.71	0.68	0.83	-			
Stenacron gildersleevei	0.86	0.63	0.78	0.76	-		
Stenonema terminatum	0.70	0.66	0.50	0.52	0.73	-	
Stenonema mediopunctatum	0.79	0.72	0.59	0.60	0.79	0.84	-

pronounced effect on the system. Sediment normally accumulates within the stream during low flow periods such as late summer through the winter. This sediment is normally resuspended and transported downstream during periods of increased discharge. Such natural "cyclic" patterns (on an annual average) permits the restructuring and sorting of the bed material for another cycle. Elimination of such high flow periods would permit a continued accumulation of sediments. Without a flushing period, one could then expect a corresponding reduction in species richness, and possibly, the development of a more depositional type fauna. Therefore, management of such systems should include flushing periods which coincide with natural high flow periods if ones purpose is maintenance of existing benthic community structure and composition. The timing of artificially controlled high water periods is also important as stream organisms have generally evolved life history patterns to coincide with such annual cycles in stream discharge.

The distribution of the 14 most numerically dominant mayfly and caddisfly taxa with respect to substrate particle size are displayed in Figure 8-2. Examining the 14 taxa, one can perceive seven morphological categories based upon body size and shape. These seven categories (Table 8-6) are not simply construed by the investigators, but relate to general taxonomic and evolutionary relationships of the individual group members. For instance, Group I (Table 8-6) are all congeneric, while members of Groups II and III are all confamilial. It could be expected that members within each of these groups would have similar instream flow requirements due to similarities in morphology. In other words, one would

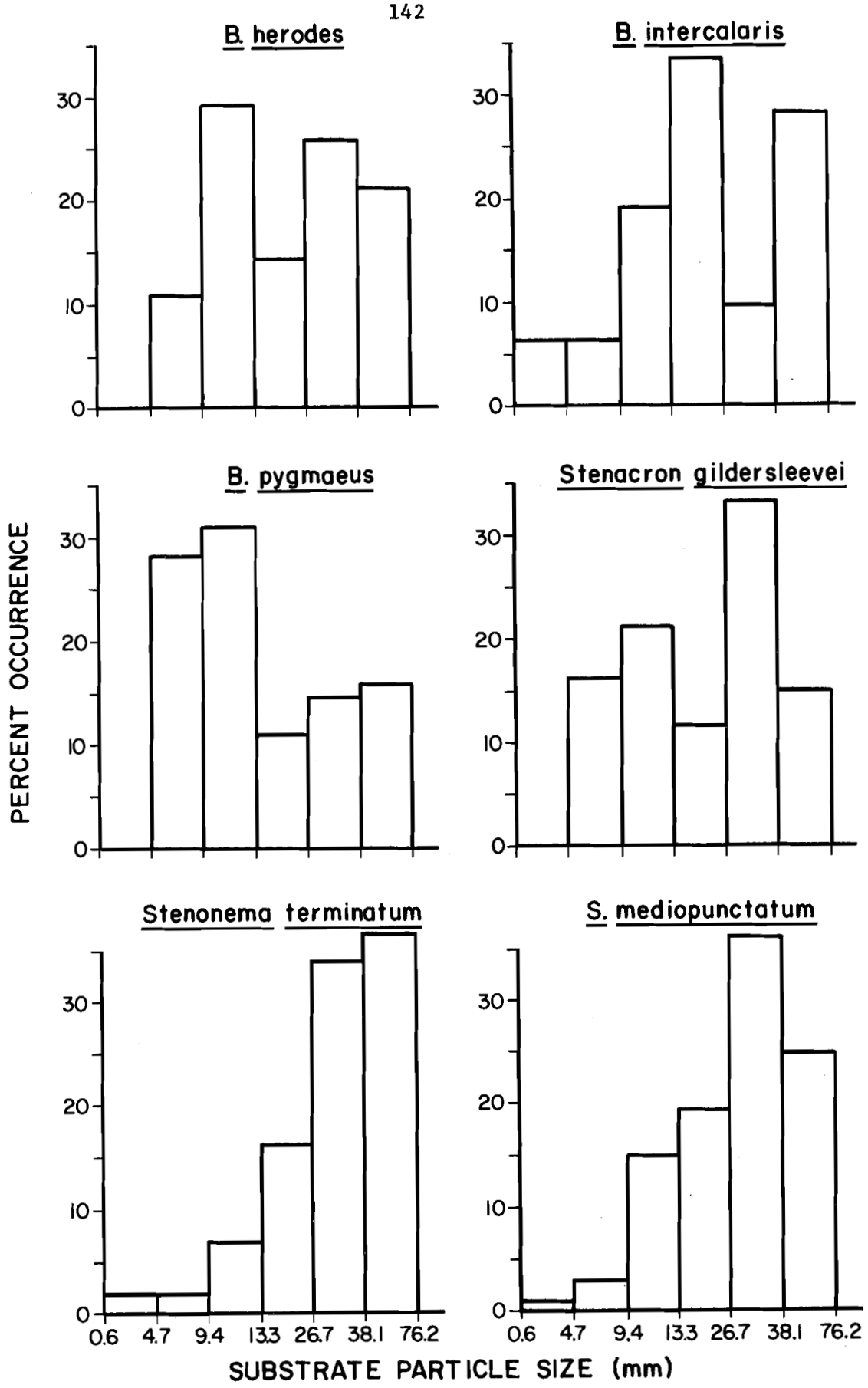


Fig. 8-2. Percent of total numbers of each taxa collection in the particle size for the Jordan Creek experiment.

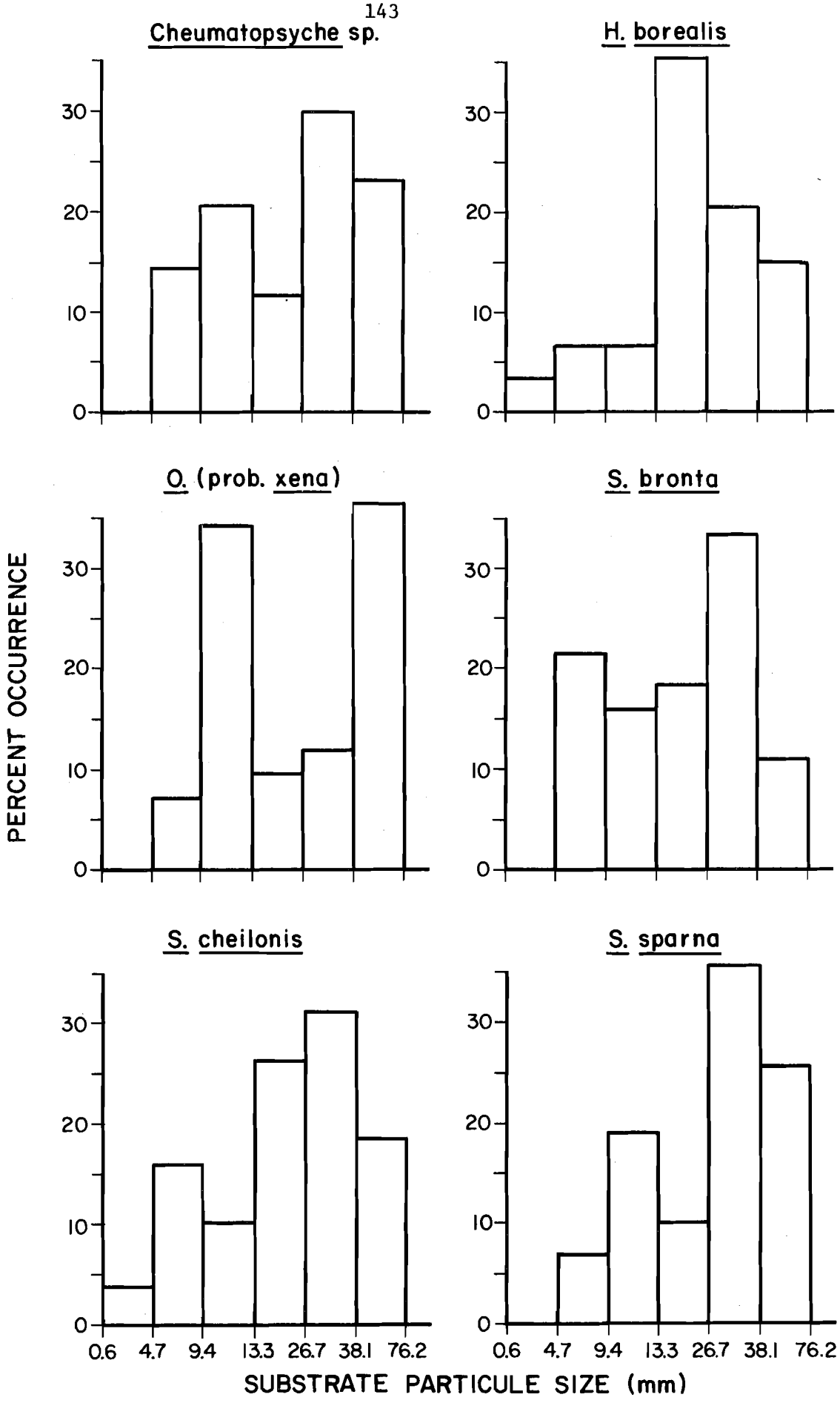


Fig. 8-2. Continued

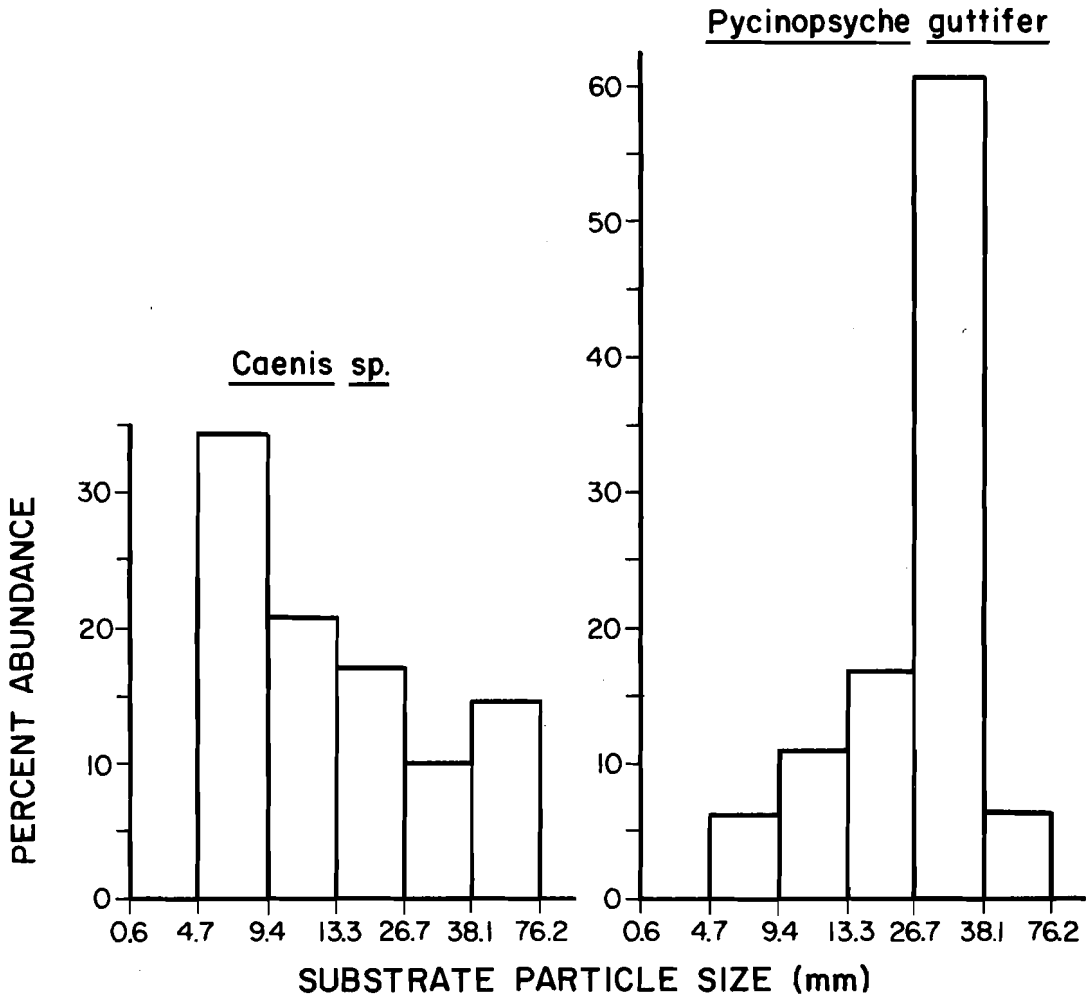


Fig. 8-2. Continued

Table 8-6. Categories of the 14 numerically dominant Trichoptera and Ephemeroptera taxa based on morphological similarities used in this study.

Group I	*Baetis herodes* *B. intercalaris* *B. pygmaeus*
Group II	*Stenacron gildersleevei* *Stenonema mediopunctatum* *Stenonema terminatum*
Group III	*Caenis* sp.
Group IV	*Cheumatopsyche* sp. *Symphitopsyche bronta* *S. cheilonis* *S. sparna*
Group V	*Helicopsyche borealis*
Group VI	*Pycnopsyche guttifer*
Group VIII	*Ochrotrichia* (prob. *xena*)

not expect large hydropsychid caddisflies to occur in silt dominated sediments. The above does not preclude the possibility of microhabitat partitioning by morphologically similar organisms as was seen in the previous study; rather, the importance of the level of analysis becomes one of scale, particularly with regard to existing methodologies and techniques in stream modeling and simulation. If we assume that alterations in substrate particle size or in stream discharge occur, one would more likely utilize a general change in benthic community composition, such as elimination of heptageneiid mayflies in relation to general changes or predictions in macrohabitat conditions in an ecosystem model. These general relationships are more likely to be of benefit in existing instream flow simulations than are species specific predictions when one is examining aquatic insects (Bovee, 1982).

Although the preceeding argument is based on several simplifying assumptions, it is useful when one is concerned with cost overruns and limited budgets. For these reasons, the results will be discussed from both a general and species specific distributional perspective. The end use of these data will depend on the questions asked and the precision required by the modeller.

The substrate utilization overlap indices between the seven mayfly taxa ranged from a minimum of 0.50 (B. pygacus x S. ares) to a maximum 0.86 (B. herodes x Stenacron gildersleevei (Table 8-5)). Overlap values within the family Baetidae ranged from 0.61 to 0.80 while in the family Heptageniidae (Group II) indices ranged from 0.73 to 0.84 (Table 8-5). The low overlap (0.69) between B. herodes and B. intercalaris appears to be the result of the more widespread distribution of B. intercalaris which was found in the smallest experiment test substrate range (0.6-4.7 mm)

and the substantially lower proportion of B. intercalaris in the 26.7-38.1 mm size class compared with B. herodes. Both of these taxa were found to co-exist both temporarily and spatially in Jordan Creek. Due to the propensity of these taxa (i.e., baetiids in general) to drift, it is difficult to determine if indeed they are partitioning substrate particle size from these data. The results in Table 8-7 do indicate that baetiids as a group are commonly found on substrates with diameters larger than 4.7 mm. Only B. intercalaris was found on substrates less than 4.7 mm in diameter.

The data in Figure 8-2 indicates that S. terminatum is utilizing the smaller substrate particles (less than 33.3 mm diameter) to a much less extent than are either Stenacron gildersleevei and S. mediopunctatum. The overlap for these three taxa is still quite high relative to one another (Table 8-5) which suggests that alterations in substrate particle size within the stream to the extent that one taxa in Group II (Table 8-6) is eliminated would have the effect of eliminating the entire Heptageniid component. The highest overlap between the Group II taxa (Heptageniids) was with the Hydropsychid caddisflies (Group IV) (Table 8-8). These data suggest that on the basis of substrate particle sizes heptageniid mayflies have similar requirements as do hydropsychid caddisflies, and would be expected to co-exist. Co-existence was indeed the case in Jordan Creek. It is important, however, that even while these two groups (i.e., heptageniids and hydropsychids) have very similar substrate requirements, their actual location on the substrates are quite different due to their morphological characteristics. Heptageniids are extensively dorsal-ventrally flattened which permits them to exist on the flat surface of the rocks while Hydropsychids require some form of refuge such as a pit or depression in the surface or a flow vortex (see previous section).

Table 8-7. Percent of each morphological group from Table 8-6 and their distribution in six substrate particle size classes.

Morphological Group	Substrate Particle Size (mm) 0.6 4.7	4.7 9.4	9.4 13.3	13.3 26.7	26.7 38.1	38.1 76.2
I - Baetidae	0.5	15.6	27.7	15.1	21.0	20.1
II - Heptageniidae	1.3	7.8	16.6	15.8	35.6	23.0
III - *Caenis* sp.	3.0	34.0	21.0	17.0	10.0	14.0
IV - Hydropsychidae	0.8	19.2	16.2	15.8	31.2	16.9
V - *H. borealis*	3.0	7.0	7.0	48.0	21.0	15.0
VI - *P. guttifer*	0.0	6.0	11.0	17.0	61.0	6.0
VII - *O.* (prob. *xena*)	0.0	7.0	34.0	9.0	12.0	38.0

Table 8-8. Resource utilization overlap indices for the seven aquatic insect groups listed in Table 8-6 with respect to their distribution in various substrate particle sizes.

	Group						
Group	I	II	III	IV	V	VI	VII
I	-						
II	0.81	-					
III	0.77	0.66	-				
IV	0.85	0.89	0.78	-			
V	0.65	0.66	0.58	0.71	-		
VI	0.59	0.74	0.50	0.70	0.56	-	
VII	0.76	0.73	0.58	0.66	0.50	0.44	-

In general, the majority of the Group I (Baetidae) mayflies were found in particle ranges of 4.7-26.7 mm while the heptageniids were more dominant in the 26.7-76.2 mm particle range (Figure 8-2). The most unique mayfly was Caenis sp. (Figure 8-2). The majority of the individuals of this taxa were found in the 4.7-9.4 mm range.

These data suggest that if the substrate particle present state we would initially see a corresponding decrease or elimination of the heptageniid mayflies. Continued reductions in substrate particle diameter would subsequently result in the elimination of the baetiid mayflies and result in an Ephemeroptera association dominated by Caenis sp. An elimination of the heptageniid component due to decreased particle diameter would likely result in a corresponding decrease or elimination of the hydropsychid caddisflies due to their similar instream substrate requirements. The dominance of the three mayfly groups (i.e., I-III) in the present suty and the distinct substrate particle diameter requirements of each further demonstrates that the two Jordan Creek study reaches are characterized by a diverse substrate distribution with both erosional and depositional type microhabitats.

The substrate overlap values between the seven Trichoptera taxa ranged from a minimum of 0.43 (O. xena x P. guttifer) to a maximum 0.89 (Cheumatopsyche sp. x S. sparna) (Table 8-4). The low overlap between O. xena and P. guttifer reflects the extreme differences in the size of these two taxa as P. guttifer is the largest caddisfly found to date in Jordan Creek, while O. xena was found most often in the intermediate and largest particle size categories (Fig. 8-2). Examining the distribution of P. guttifer reveals that the majority of these individuals (i.e., 61%) were collected from substrates with a diameter ranging from 26.7-38.1 mm. These results demonstrate that the size of the particles do not necessarily

dictate the size of the dominant taxa inhabiting the particles. Rather, the types of microhabitats created by the various size particles and the associated hydraulic patterns and textures are likely to be more important.

The very high overlap between Cheumatopsyche sp. and S. sparna is somewhat misleading when one considers that these two taxa appear to be partitioning their locations on the substrates (Braga, unpublished data). In artificial concrete substrate experiments and in various picking and hand collections during the study, Cheumatopsyche was generally found on the underside of the substrates while both Symphitopsyche and many Hydropsyche taxa were collected on the upper surfaces of substrates.

The overlap within the family Hydropsychidae (Group IV; Table 8-6) was relatively high, ranging from the previously mentioned 0.86 maximum to a minimum of 0.77 (S. bronta x S. sparna). As mentioned earlier, S. sparna and S. bronta were dominant in different reaches of the stream. The relatively high overlap in substrate particle distribution indicates that the differences in their distribution indicates that the differences in their distribution within Jordan Creek are not related to the distribution or abundance of substrate particles.

Examination of the general distribution of the Trichoptera within the different substrate categories indicates that the hydropsychids and P. guttifer were most common on substrates greater than 26.7 mm in diameter. H. borealis was most abundant on substrates ranging from 13.3-26.7 mm in diameter and O. xena on both very large substrates and substrates in the diameter range of 9.4-13.3 mm (Fig. 8-2). Thus, if the substrate particles in Jordan Creek were to decrease we would expect to observe an initial loss of the hydropsychids and P. guttifer with a reduction in the density of O. xena. Additional reductions in substrate particle size would be followed by elimination of H. borealis and subsequently O. xena.

9. CONCLUSIONS

The evaluation of instream flow requirements of aquatic insects required the development of new techniques and equipment to assess microhabitat conditions in streams. With quantification of microhabitat characteristics, it was possible to relate organism presence to a set of environmental conditions which could be associated with flow. Determination of actual instream flow requirements of aquatic insects requires the assessment of a number of habitat variables as well as other factors which control aquatic insect community organization and/or species preferences. The following summarize the accomplishments and findings of the research project.

1. A microvelocity probe, proven in hydraulic research and analysis, was modified for use in modeling aquatic insect microhabitat.

2. Microvelocity probes were used in analysis of flow characteristics in typical bottom substrates and artificial substrates and accuracy verified using sensitivity analysis.

3. The response of the microvelocity probe at various combinations of depth, current velocity, and substrate type was examined in the laboratory and response was verified with the use of high speed photography.

4. To compliment published instream flow requirements of aquatic insects and expand existing analysis methodologies, the utility of using the dimensionless Reynolds number, was evaluated as a means for describing aquatic insect microhabitat conditions. This value, R* was found to be related to microvelocity, permitting associative microhabitat measurements (e.g., depth, column velocity, temperature, and substrate type).

5. A field method was developed to determine flow requirements of aquatic insects based on R*. R* was found to be a better predictor of community statistics than either depth and velocity alone. Following the development of the field method, a preliminary data base was generated relating R* to a number of aquatic insect taxa in Illinois. R* was found to be significantly correlated with species richness and aquatic insect abundance in the five Illinois streams studied as a part of this project. R* may be used to describe general microhabitat conditions and provides a reasonable means of modeling benthic community responses to flow manipulations.

6. Laboratory methods were developed to hydraulically calibrate artificial concrete substrates for use in field experiments. Equations were developed to calculate microhabitat velocities in the vicinity of aquatic insects for 63 regions on the substrates. These equations permitted the determination of microvelocities using simple field measurements of temperature and stream velocity immediately in front of the substrates. Calibration illustrated distinct hydraulic regions which could affect the distribution of aquatic insects on the substrates.

7. Calibrated substrates were employed to examine the rate of aquatic insect colonization; the effects to periphyton development on aquatic insect colonization rates; the effects of sedimentation on the distribution of aquatic insects, and to examine the differences in the rate of colonization of net-spinning caddisflies. The results indicate the colonizing assemblages followed MacArthur-Wilson colonization predictions from day 0 through 18. Insects assemblages colonizing substrates precolonized with periphyton and uncolonized substrates were different initially but became more similar with time. Periphyton development substantially affects the rate of colonization for both a taxonomic and trophic perspective. Examination of the net-sponning caddisfly results indicated that 56.7% of the Hydropsyche betteni larvae were present on substrates within 14 days while only 16.8% and 19.3% of the two Symphitopsyche species observed. There was no detectable difference in the colonization rate and response to the presence of periphyton between S. cheilonis and S. bronta. Within the ranges of sediment measured inthis study there was no significant effect of sediment on the distribution of the caddislfy larvae.

8. The microhabitat current velocities which affected the distribution of several aquatic insects was determined. The hydropsychid caddisflies S. cheilonis, S. sparna, S. bronta, and H. betteni and simulid larvae observed to determine occurrence in defined microhabitats on calibrated artificial substrates. The results indicated that members of all four caddisfly taxa inhabited areas of the substrates where microhabitat velocities were less than 1 cm/sec. While S. sparna and H. betteni were found in the highest current microhabitat velocities of 15 cm/sec, S. cheilonis and S. bronta were recorded in 11 and 10 cm/sec respectively. A substantial degree of overlap occurred between the four caddisfly taxa. Simulid larvae were found in substrate regions with microhabitat velocities of 1 to 15 cm/sec. This study confirmed initial observations that hydropsychid larvae require a surface irregularity for protection when inhabiting regions with higher microhabitat current velocities.

9. Sediment particle size was shown to affect aquatic insect distribution. The distribution of the 14 numerically dominant mayfly and caddisfly taxa from Jordan Creek, Illinois was related to substrate particle size.

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