Research Technical Completion Report
Project B-049-IDA

THE USE OF INVERTEBRATE INDICATORS FOR ECOLOGICAL RESILIENCY EVALUATION OF A FLOW REGULATED RIVER

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Donald F. Haber
Civil Engineering Department
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Merlyn A. Bruvsen
Department of Entomology
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Also we wish to thank the U.S. Army Corps of Engineers, Walla Walla Office for the help in obtaining cross sections and rating curves for the Clearwater River.

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ABSTRACT

A systems approach was used to determine certain biological and physical indicators which were used to characterize the benthic ecosystem in the Clearwater River below Dworshak Dam, Idaho. Using these indicators, a Hectare-Day Index was developed that resulted in a quantitative measure of impact of regulated flow on the benthic system.

For three selected periods, Summer 1978, Fall 1978 and Spring 1981 the reduction in the Hectare-Days Index when compared to an idealized constant flow for the same period was: 3.1% for the spring period, 5.5% for the summer and 5.5% for the fall period.

The analysis of field tests over the period 1977 through 1980 indicated mean insect density and species richness decreased as depth increased from < 60 to > 300 cm; the density and richness increased from velocities of < 6 cm/sec to > 60 cm/s; in the Clearwater River where cobbles, boulders and sand represented over 95% of the dominant particle sizes among the various habitats.

The rate of insect colonization on a sterile substrate was used to predict carrying capacity for main stem Clearwater River. Sixty days was predicted time required to attain full carrying capacity in the regulated reach. By point of contrast, 47 days were required for the unregulated reach (Middle Fork).

INTRODUCTION

Most of the major rivers and streams in North America are dammed, subjecting downstream reaches to regulated flows (Ward and Stanford, 1979). These downstream reaches are often adversely affected by frequent and extreme water fluctuations and changes in water temperature and water chemistry. Regulated flows potentially alter the biota of the stream and interfere with basic processes involving nutrient cycling and ecosystem stability.

The ability of organisms to persist is a mark of species and community resilience. The Clearwater River in north central Idaho provided an opportunity for assessing the response of benthic invertebrates to regulated flows and to test and evaluate the concept of resilience as a practical tool for local, State and Federal agencies to bring about a balance between energy production and the aquatic life within the river.

This study represents a continuation and expansion of earlier studies, bridging pre-impoundment and early post-impoundment eras on the Clearwater River (Walker, 1972; McPhee and Brusven 1973; Falter et al. 1973 and Brusven et al. 1974 and Brusven and Trihey 1978). The influence of regulated flows on the ecology of streams and rivers has been comprehensively reviewed by Baxter (1977) and Ward and Stanford (1979).

In this study, we define "ecological resilience" as the property of an ecosystem and/or its components to absorb external stress both natural and man made and to persist in such a manner that the biological components fluctuate within certain bounds. If the resilience bounds of the system decrease making the system more vulnerable, a previously absorbable external stress may cause functional relationships within the system to be drastically altered and potentially cause populations to decline and/or become extinct. We hypothesize that benthic insects because of their intermediate position in the plant-to-fish food chain, habitat specificity and sensitivity to environmental perturbations, are especially instructive in ecological resilience analysis of perturbed rivers. Further, that insight into the methodology and application of resiliency analysis in this study will provide a constructive approach to describe other perturbed systems. This study proposed to examine and evaluate resilience indicators which manifest simplicity and utility and to test them as indicators for assessing the impact of regulated flows in the Clearwater River.

CLEARWATER RIVER STUDY AREA

The lower 80.5 km of the main stem of the Clearwater River were investigated during this study (Figure 1). Seventy kilometers on the main stem are subjected to regulated flows from Dworshak Dam located on the North Fork Clearwater. Ten sites were established to monitor changes in benthic insects; most sites had an historical data base. The sites were selected on the basis of location, accessibility and sampling characteristics and correspond to R. km 5.6, 7.4, 8.3, 14.6, 21.2, 38.0 on the main stem Clearwater River (MSCR), R. km 72.9, 80.5 on the Middle Fork (MFCR) and R. km 0.2 and 0.3 on the North Fork Clearwater River (NFCR).

The lower main stem of the Clearwater River has habitats ranging from deep pools to high-velocity riffles. The width of the river in this reach is >150 m for most of its length. The gradient is low to moderate (1.1 to 1.8 m/km) with generally gradual, sloping shorelines. The bottom type is cobble or boulder in riffles. Sands are noticeably present on beaches and are variously intermixed with rubble in slower reaches of the river.

The flows in the Clearwater River are extremely variable and typically range from >70,000 cfs in May to 3,000 cfs in October. Winter and spring runoff is typically bimodal with moderate increases in discharge in December followed by a pronounced snow melt runoff in May and June. Water temperature in the Clearwater River vary from 0°C in January and February to >26° C in July and August.

Dworshak Dam, located approximately 1.5 km upstream from the confluence of North Fork with main stem of the Clearwater River, was built for hydroelectric power generation and flood control. Dam construction was initiated in 1965 and completed in March, 1973. While the dam has the capability of high-level peaking, its maximum power generation has not been fully realized. Load factoring has been and is currently used to generate daily fluctuations in hydroelectric power needs. This schedule has resulted in daily vertical fluctuations of <0.3 to ca. 1 m in the Clearwater River during most seasons of high electrical demand.

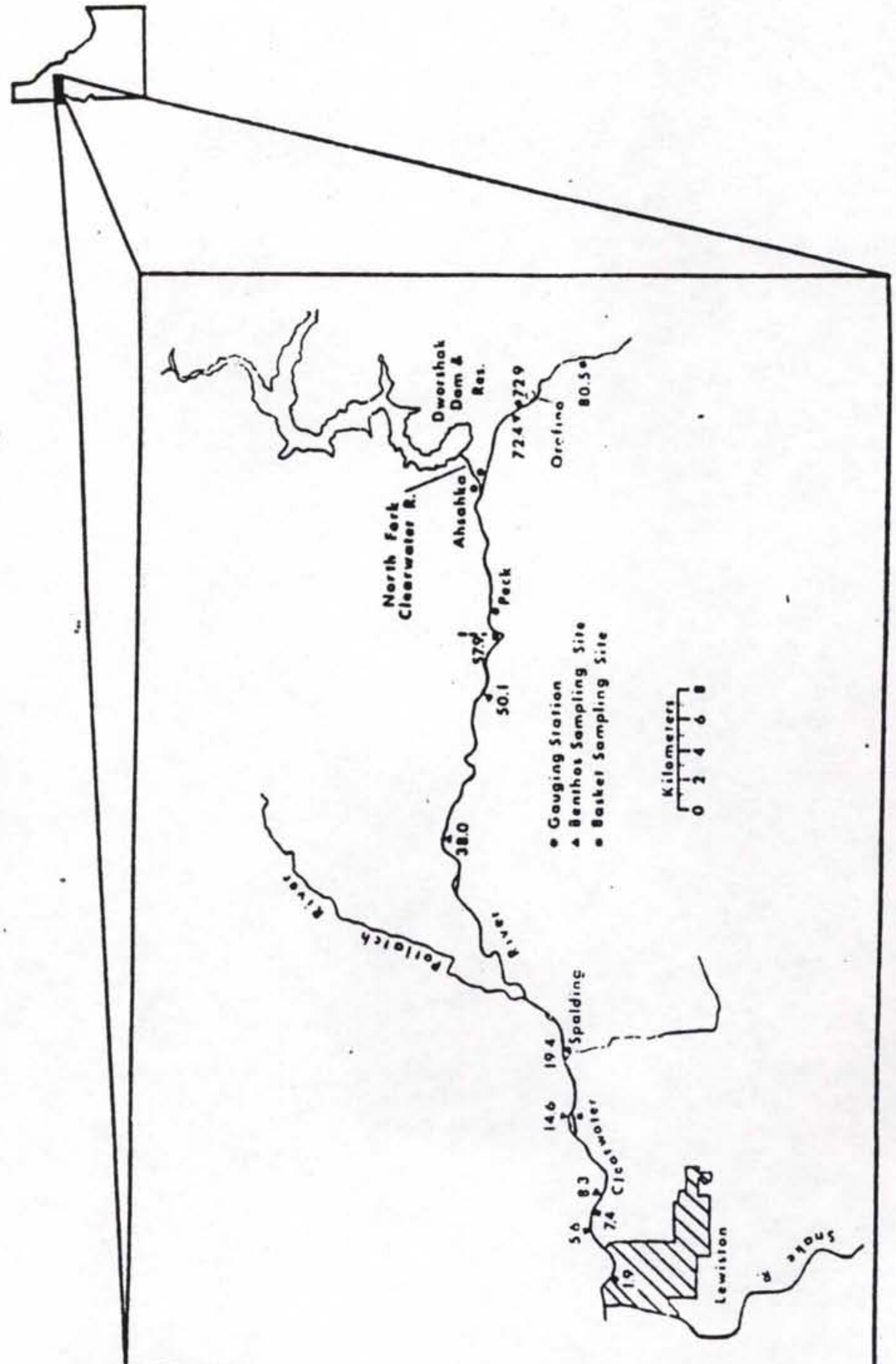


Figure 1. The Lower Clearwater River in Idaho, and Associated Collecting Sites

MATERIALS AND METHODS

System Boundaries

That portion of the Clearwater River from River Kilometer 80.5 to River Kilometer 1.9 and that portion of the North Fork of the Clearwater River from Dworshak Dam to the confluence with the main stem (approximately 1.5 KM) were considered as the length of the system boundary. The transverse boundary was the wetted perimeter at a flow of 200,000 cfs(5664 m^3/S). However, most of the impacts were in a wetted perimeter corresponding to 50000 cfs (1416 m^3/s).

River Channel Cross Sections

Three sources of river cross section information was used in this analysis. First, seventy-five river cross sections were obtained from the U.S. Corps of Engineers which performed an initial survey of the Clearwater River in 1960. These seventy-five cross sections were located within the ystem boundary and spaced approximately one-half mile apart. In addition, the corps had surveyed water surface elevations for various flows at the cross section locations. This information was also listed with the cross section data. The second source was a more recent less extensive survey (1978-81) performed by the research team for comparison with the 1960 data. The more recent data showed relatively little change in channel configuration. However, the most recent data was used whenever possible. Seventy-five channel cross section configurations in the 73.1 KM (45 miles) were determined. Figure 2 illustrates a typical channel cross section configuration for that reach.

Water Surface Elevation vs. Wetted Perimeter Analysis

Using the water surface elevation and flow data from the two surveys, a graphical relationship (rating curve) was determined for each characteristic cross section utilizing both the cross-sectional information and the rating curve the wetted perimeter at any flow for every characteristic cross section was determined. Finally, a wetted area was calculated by multiplying the wetted perimeter of a characteristic cross section with the length of the river stretch associated with that cross section. Thus, for a specified flow, the sum of all the wetted areas for the characters river stretches was used to represent the total wetted area.

The total wetted area for 44 discharges was then plotted and approximated by a best-fit log-log curve (Figure 4). The derivative of the best-fit curve was plotted to illustrate the changing slope of the wetted area vs. discharge plot or the decreasing values of the slope (d(wetted area)/d(discharge)) vs. discharge (Figure 5.)

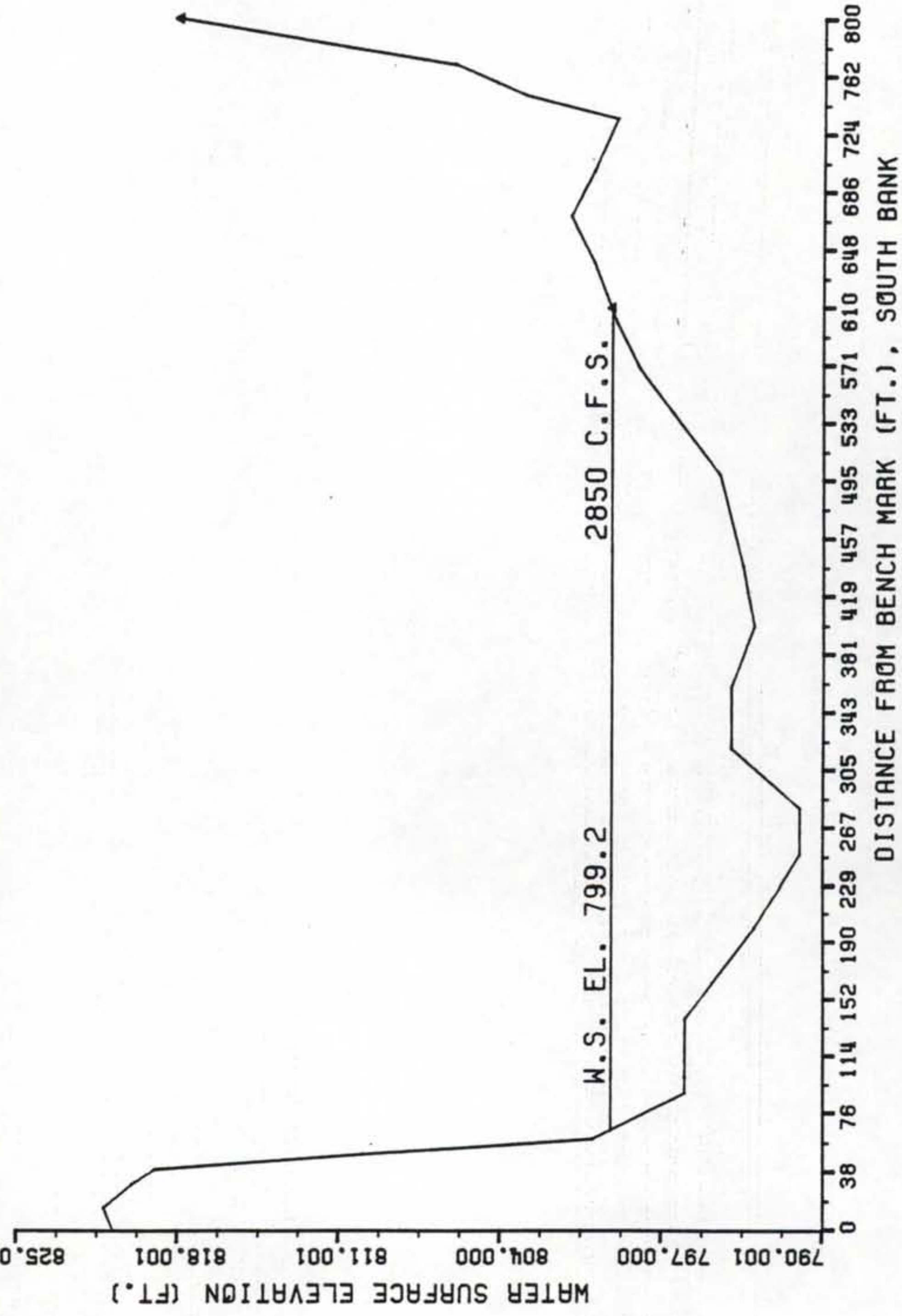


Figure 2. Clearwater River Cross-Section River Mile 15.28
Water Surface Elevation vs. Distance

Driving Variables

Physical and biological inputs to the system from outside the system boundaries were considered to be driving external variables. These inputs were applied to the system at the appropriate boundaries. For example, drift of insects into the river cross section at 80.5 KM was considered as an external biological input into the system. Similarly the flow across the river cross section boundaries at 80.5 KM and directly below Dworshak Dam were considered physical external inputs.

State Variables

State variables are assumed to be those which measure the level of a parameter such as the population of a specific insect or the amount of biomass of insects in a particular area. The state variables are generally associated with biological parameters where as most physical and chemical parameters are driving type variables.

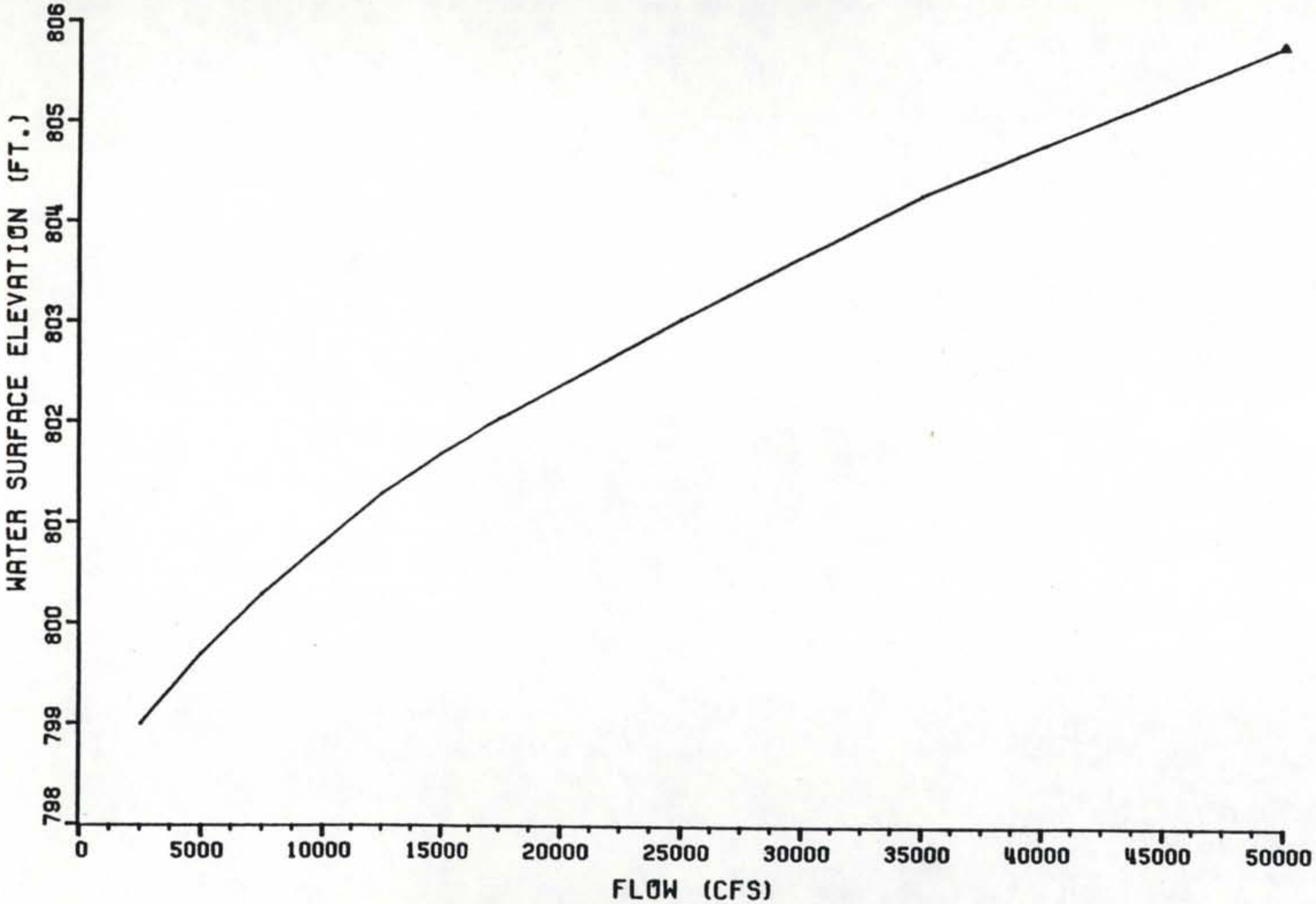


Figure 3. Typical Rating Curve-River Mile 15.28
Water Surface Elevation vs. Flow

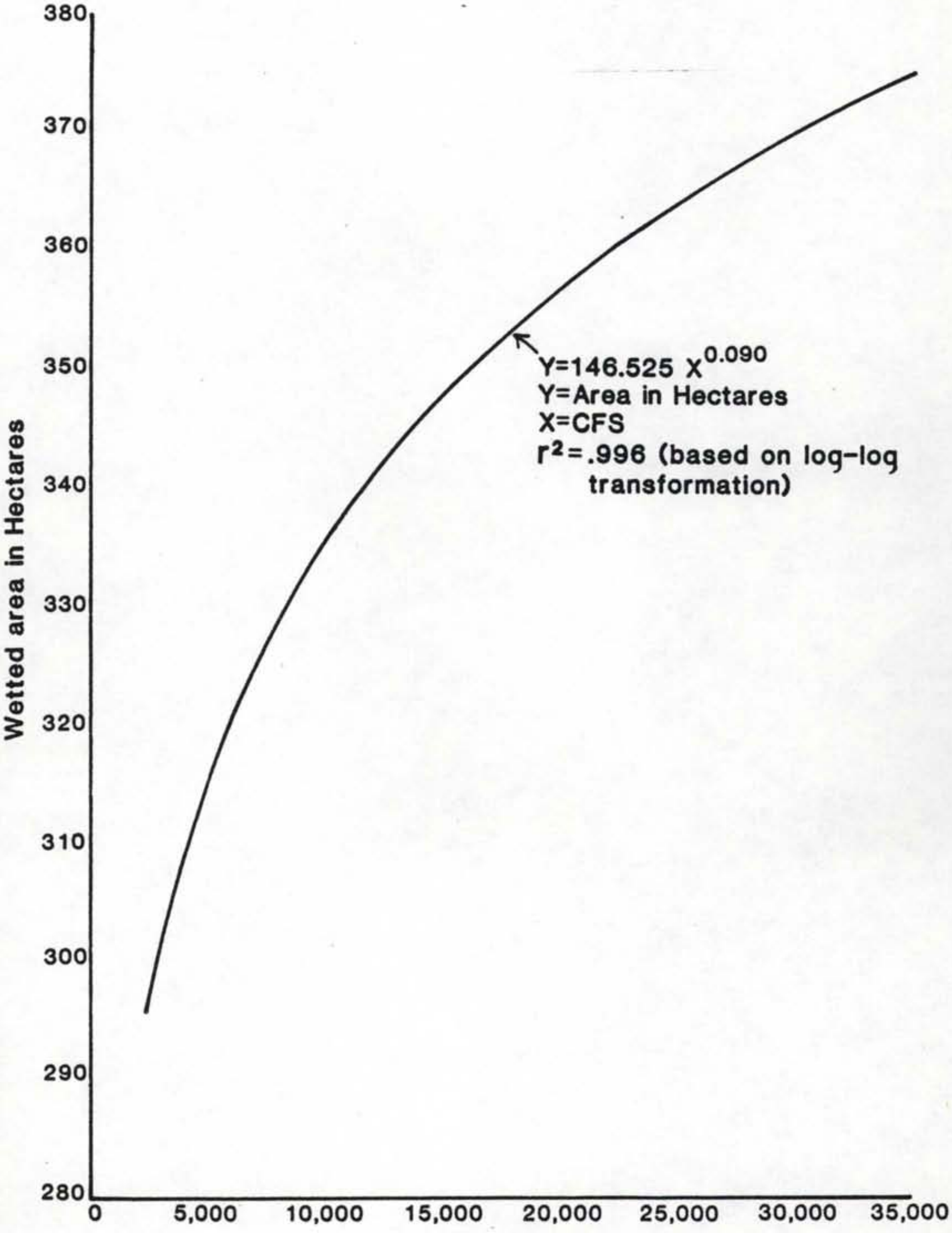


Figure 4. Total-Wetted Area vs. Discharge

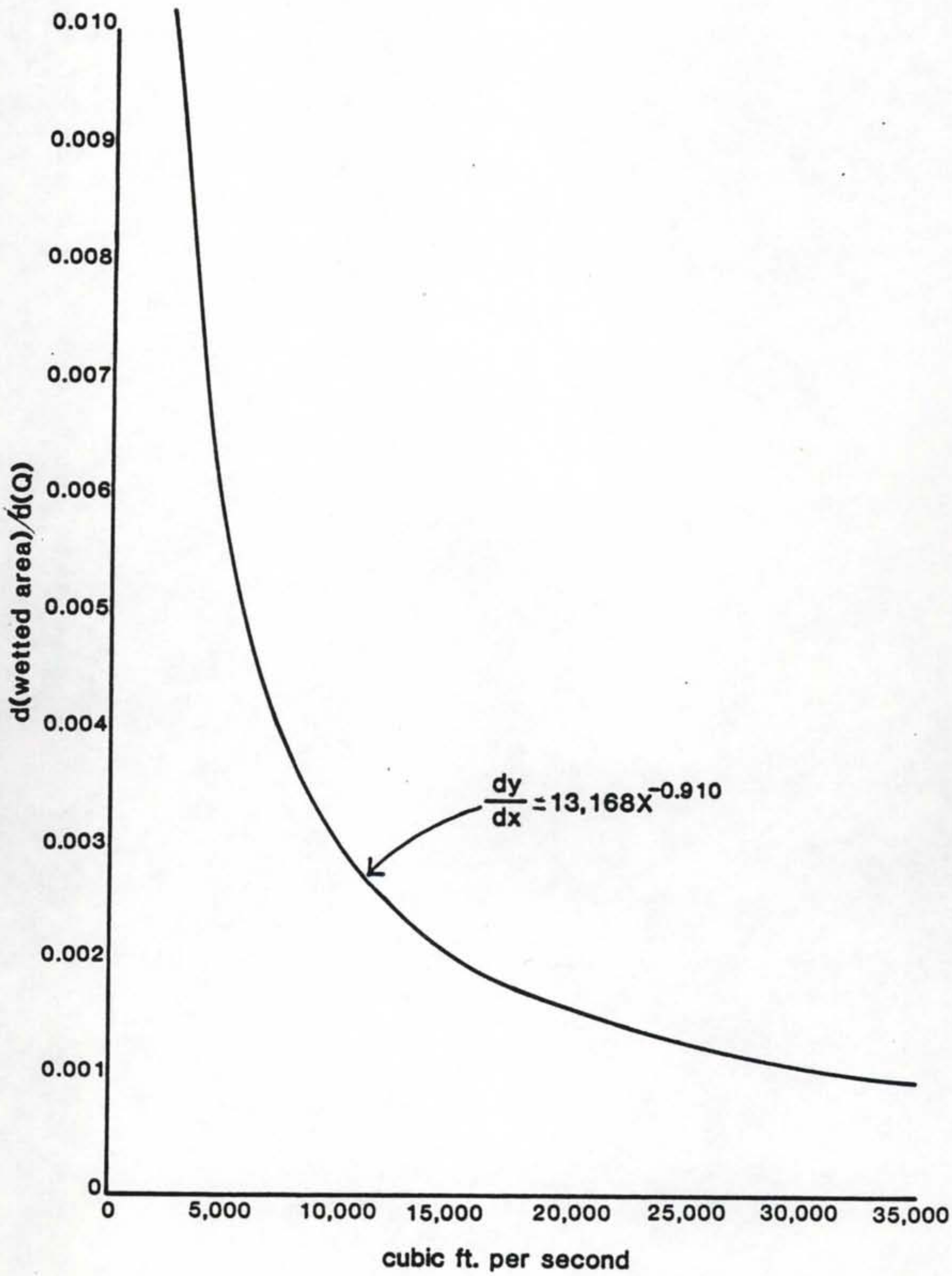


Figure 5. Change in Wetted Area vs. Change in Flow

Standing Crop - Shoreline Benthos

Benthic insects were collected with a Hess bottom sampler at water depths of 15, 30 and 45 cm. Three random samples were taken at each depth at each site on each sampling date. Water velocities at each depth were taken with an electronic current meter at 0.6 the depth. The substrate was classified employing a ranked system described by Brusven and Meehan (1979). Samples were preserved in 70% ethanol for sorting and identification in the laboratory.

In order to monitor the relative position of samples within the stream bed, distances were measured between a stake located above the high water mark and the existing water levels at the time of sampling. This method permitted referencing cross-sectional locations of bottom samples to existing discharge. Stake-to-water distances were compared with historical daily flow records from gaging stations, therefore, making it possible to assess the relative "permanency" of the watered zone where samples were taken.

Standing Crop - Deepwater Benthos

Deepwater benthos was sampled employing SCUBA techniques and a Hess bottom sampler. Six buoys were positioned equidistantly across a transect to mark the position of the samples. Water velocities were taken at each location at 0.6 the depth with an eletronic current meter; water depth and substrate characteristics were also determined. The substrate was described employing the method of Brusven and Meehan (1979). Two bottom samples were taken at each buoy position except on rare occasions when air reserves of the divers were deficient, then only a single sample was taken. Two divers were used during this sampling procedure.

Weighted belts were also used to provide more stable positioning of the divers on the bottom. SCUBA techniques were generally effective at depths of 8.5 m deep or more and when water velocities were <0.75 m/sec.

Insect Colonization Rates

Insect colonization rates on test rocks were determined by establishing rock grids in regulated (R. km 8.3) and unregulated reaches of the Clearwater River during August 1977 and 1978. Test rocks from the Clearwater River were autoclaved at 121°C for two hours to eliminate insects and epilithic algae, similar to the method described by Gersich and Brusven (1981). A test grid consisted of 20 rocks (displacement/rock = 404 cc   88 cc), individually placed approximately 30-45 cm apart in four transects of five rocks each. The grid was established at a depth of 0.3 m at low flow to insure against dewatering; each rock was marked with a fluorescent spot to aid in relocation. A single row of five rocks was sampled weekly, beginning with a downstream transect to avoid upstream disturbances to the grid from displaced sediments or accidental movement of other rocks in the grid. A nylon organdy net (250 m mesh size) was located immediately downstream from each rock sampled to insure capture of dislodged insects. Each rock was placed in the net upon removal from the grid and thoroughly scrubbed with a brush.

On each sampling day, five control rocks, similar in size and imbeddedness to test rocks, were sampled from the substate in near proximity to the grid. Control rocks were not subjected to dewatering, therefore, were assumed to support eplithic algal and benthic invertebrates at or near carrying capacity.

An ANOVA was performed on data derived from the rock grids. A least square means comparison was made on the basis of treatment, day and site. Regression analysis was performed on the data to predict colonization rates of sterile substrates, i.e. the time necessary for test substrates to approximate carrying capacity as reflected by standing crop on control substrates.

Water Temperature Analysis

Water temperature data for North Fork, Middle Fork and main stem Clearwater River were obtained from Water Resources Data for Idaho, Part 2 - Water Quality Records, U.S. Army Corps of Engineers - Walla Walla District, Dworshak Fish Hatchery temperature records and U.S. Geological Survey data tapes. The latter agency provided the primary source of temperature records for the main stem gaging stations at Peck (R. km 35.1) and Spalding (R. km 19.4). Pre-Dworshak Dam records on the North Fork were obtained from 1959-1971, post-Dworshak records from 1972-1978. Main stem CWR records spanned 1965-1978 at Peck and 1963-1978 at Spalding. Data, where appropriate, were key punched and run through a conversion program which 1) assigned a missing value indicator to any temperature over 90°F, 2) assigned a temperature of 32°F, and 3) converted all values to degrees Celsius (°C).

To relate water temperature to insect life cycles, water temperature data were analyzed as degree weeks. We define degree weeks as the accumulative mean weekly temperature above 0°C during successive weeks starting in January. In practice it was computed by meaning the mean high and low temperatures for a week and adding them successively to give an accumulative record for the year. For comparative purposes, the pre-Dworshak period of 1965-1971 and the post-Dworshak period of 1973-1977 were used and graphically portrayed both on an annual and seasonal basis. In the case of the latter, seasons were designated as 1) winter - December-February, 2) Spring - March-May, 3) Summer - June-August and 4) Fall - September-November.

RESULTS AND DISCUSSION

Physical Stream Characteristics

Water Temperature. Water temperature is one of the principal driving variables in the lower Clearwater River serving to alter biological processes as a result of thermal changes from Dworshak Dam. Pre- and post-Dworshak water temperatures clearly show a reversing trend in the main stem Clearwater River (MSCR) since the Dworshak Dam became operational (Figure 6); the first half of the year is warmer, the second half cooler. Equilibrium was attained at about the 27th week. A seasonal comparison of accumulative degree weeks for the North Fork and MSCR indicate that the winter months of December and February and summer months of June - August represent the seasons most responsible for deviation from pre-Dworshak temperatures (Figures 7-8). Pre-Dworshak temperatures in the NFCR during the winter months were approximately 45 degree weeks warmer, the summer months ca. 100 degree weeks colder. The ameliarating effect caused by the mixing of main stem and NFCR water is reflected in Figure 8 where degree week variations were reduced to nearly half of those recorded on the NFCR.

Colder temperatures during the summer months is largely attributed to temperature needs for Dworshak Fish hatchery located at the confluence of the NFCR and MSCR. The hatchery serves to mitigate the North Fork steelhead run that was lost because of Dworshak Dam. Colder temperatures during the summer potentially inhibit important biological processes involved in nutrient cycling and invertebrate life cycles. The critical nature of temperature alterations on the ecology of the river is best viewed in the long term rather than short term because of inherent recolonization

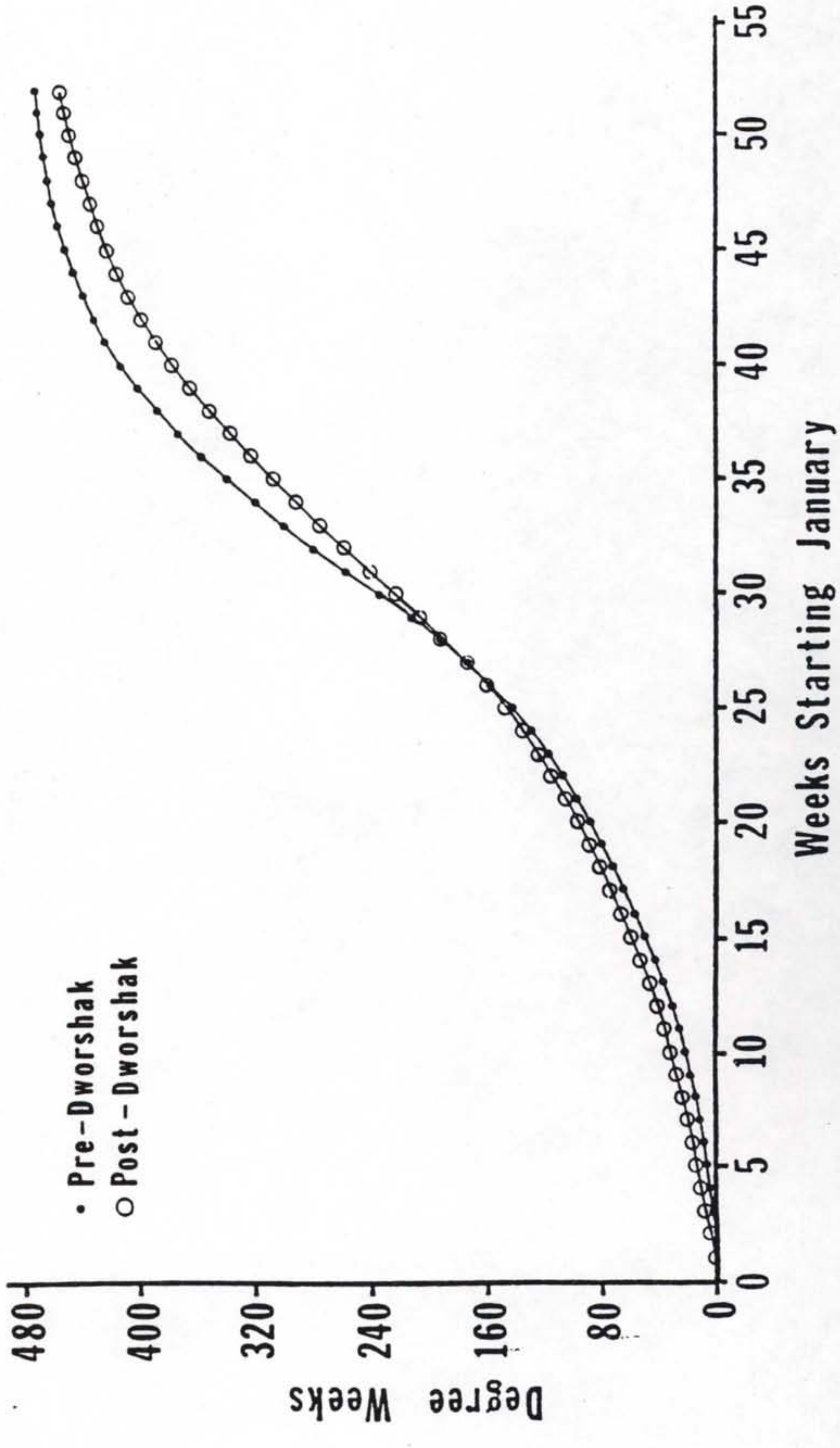


Figure 6. Mean Pre- (1965-1971) and Post-Dworshak Dam (1973-1977) Cumulative Degree Weeks (C) on the Main Stem Clearwater River, Idaho, Peck Gaging Station

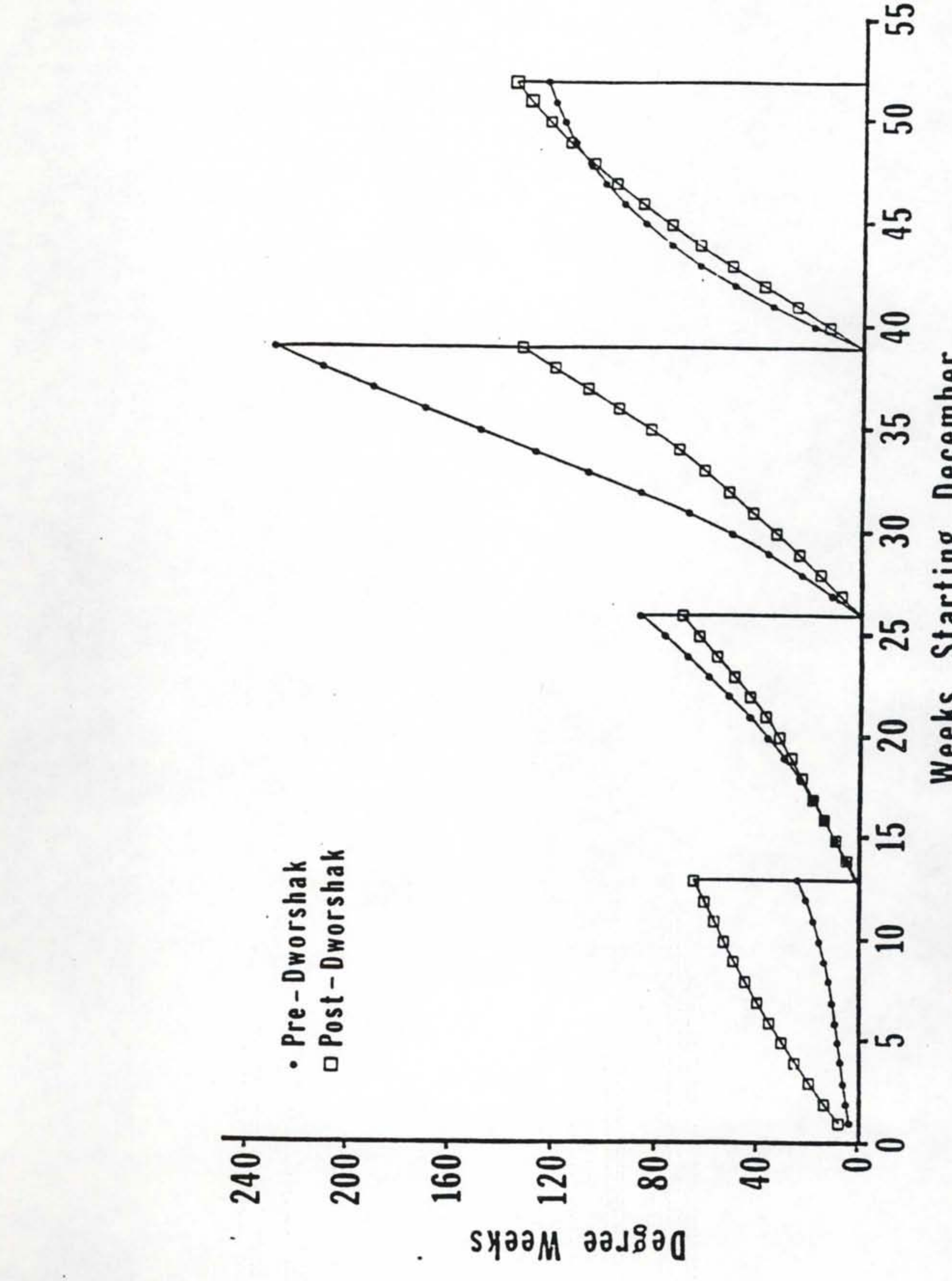


Figure 7. Mean Pre- (1965-1971) and Post-Dworshak Dam (1973-1977) Cumulative Seasonal Degree Weeks (C) on North Fork Clearwater River, Idaho

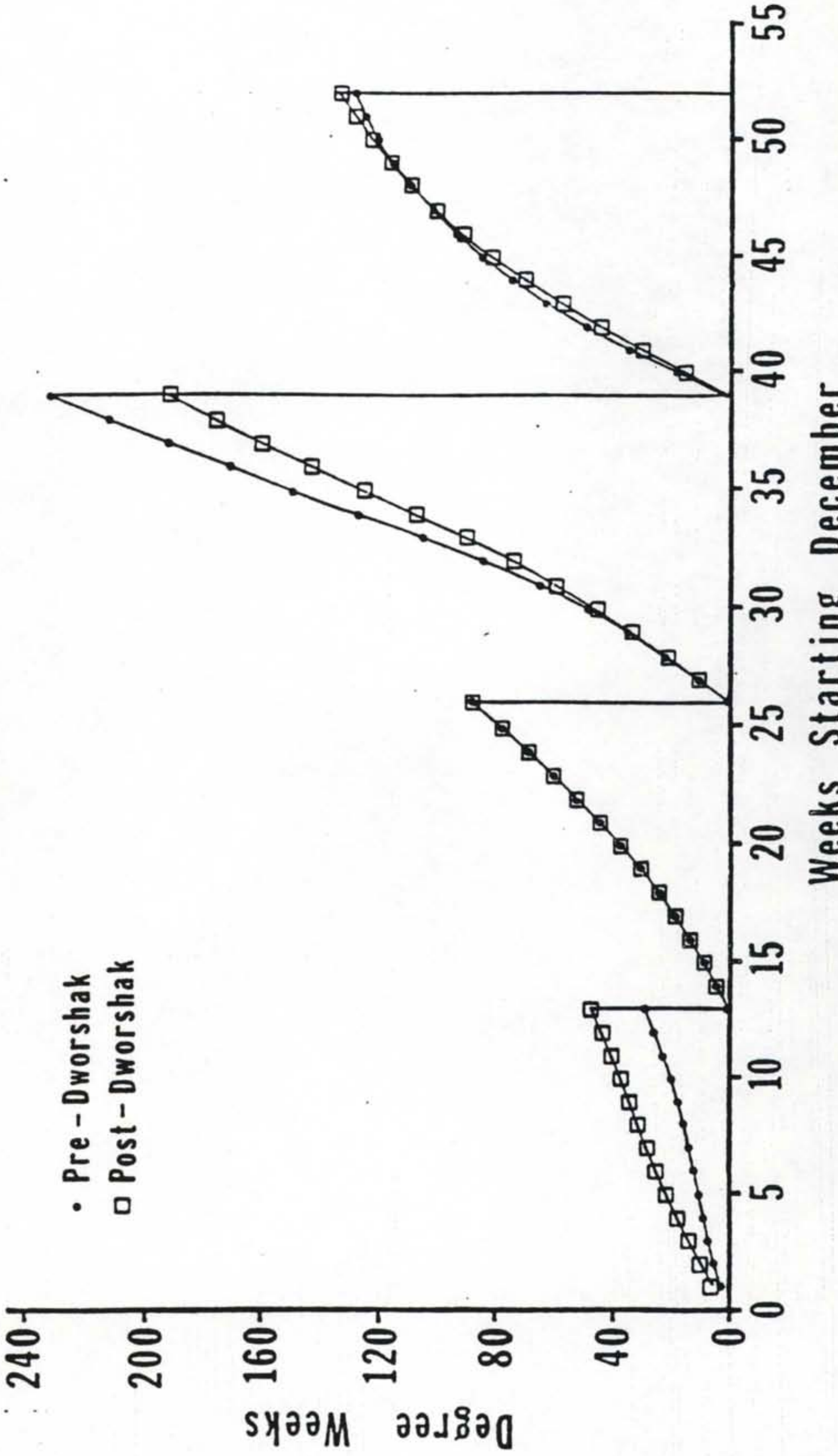


Figure 8. Mean Pre- (1965-1971) and Post-Dworshak Dam (1973-1977) Cumulative Seasonal Degree Weeks (C) on Main Stem Clearwater River, Idaho, Peck Gaging Station

capabilities and resilience qualities or organisms that only become apparent after studying a system for several years.

Benthic Invertebrates

Life cycles. Life cycles of benthic inverterbrates can be complex or simple. In non-perturbed systems most species are closely attuned to physical (especially temperature), chemical, and biological variables, e.g. food. In all cases the natural selection process had tended to optimize presence and density at times that meet the least resistance to survival. For purposes of illustrating life cycle variability, two mayfly species (*Ephemerella margarita* and *Ephemerella infrequens*) are graphically portrayed with regard to stream reach and time of year (Figures 9 and 10). Special reference is made to temperature (Figures 6-8) which is stream-reach related. *Ephemerella margarita* has a short life cycle, i.e. a short period of time is spent in the nymphal stage and a long time in the egg stage. Once the egg hatches, nymphal development is fast, usually taking about two months until the adults emerge. *Ephemerella infrequens*, on the other hand, has a long life cycle, characterized by a short egg incubation period followed by a long nymphal existence of 9.5 to 11 months.

Ephemerella margarita was relatively abundant in the Middle Fork and MSCR sites, but rare on the NFCR below Dworshak Dam. At the latter site, only a few early instar nymphs were taken in late August and September; no middle or late instar nymphs were collected during 1978-79. We conjecture that variation in nymphal occurrence is directly or indirectly related to temperature variations among the three reaches. Spatially, only 35 km spanned the primary intensive collection sites. Cooler temperatures during June-August on the MSCR undoubtedly retarded egg eclosion. Differences of two to eight weeks in development are apparent among similar nymphal age classes among the three reaches. The extreme cold temperatures on the NFCR during the summer (Figure 7) likely contributed to a delay in nymphal presence by about two months when compared to the MFCR. While no middle or late instar nymphs of this species were recorded in the NFCR, its absence in samples may be due to its overall rare nature on the NF or possible demise as it progressed through its nymphal development. Large numbers of this species in riffles above Dworshak Reservoir (unpublished data) strongly suggest that the environment created below Dworshak Dam has inhibited this species.

The mayfly Ephemerella infrequens has a somewhat different development with respect to stream reach. The start-up time for nymphs in the fall and winter months varied by 2.5 to three months. The earliest occurrence of the nymphs was recorded in the MFCR, the latest in the MSCR and NFCR. As the nymphs progressed through their three nymphal age classes during the winter, spring and early summer months, considerable reduction in nymphal variation occurred; approximately one month separated completion of nymphal development among the three reaches. We contribute this more synchonized summer nymphal development to the long nymphal presence spanning several months ultimately culminating to near developmental sychrony (at least for the MFCR and MSCR reaches) at about week 27 when degree weeks reached equilibrium (Figure 6). Unlike E. margarita, E. infrequens was abundant in the NFCR River, below Dworshak Dam and on many dates was the most abundant insect. We attribute this abundance to aquatic macrophytes (principally the moss Fontinalis) which were prevalent in the NFCR, but not at intensive sites at the other

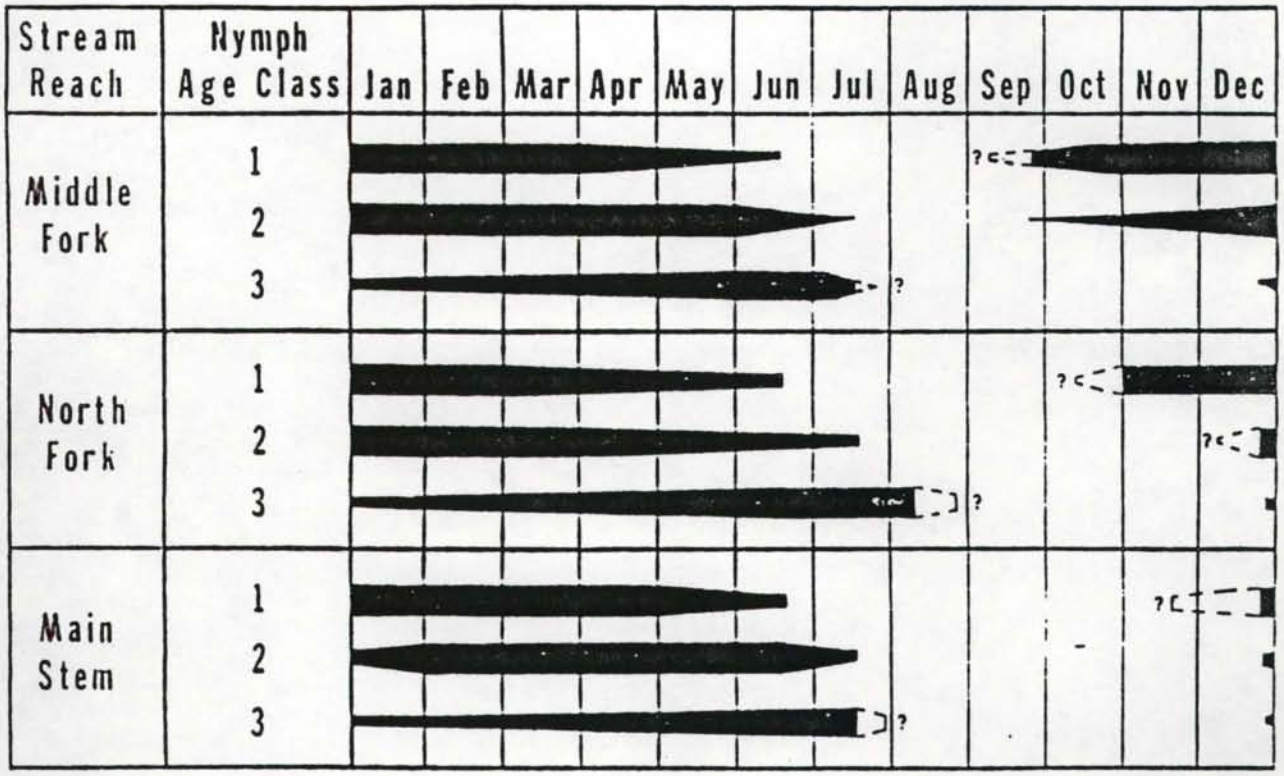


Figure 9. Seasonal Distribution of Three Nymphal Age Classes of *Ephemerella Infrequens* in Three Reaches of the Clearwater River, Idaho 1978-1979

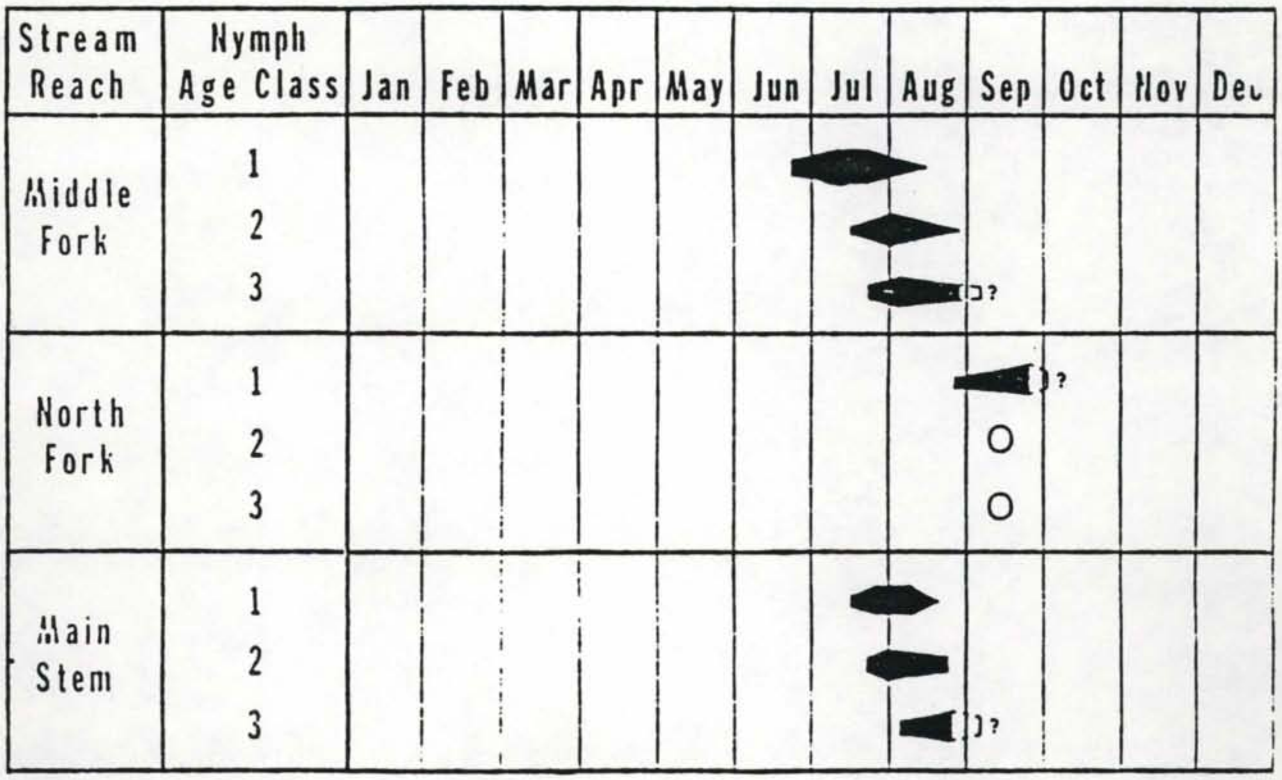


Figure 10. Seasonal Distribution of Three Nymphal Age Classes of Ephemerella Margarita in Three Reaches of the Clearwater River, Idaho 1978-1979

reaches. The insect is a collector-gather; the presence of mat-type filamentous mosses undoubtedly fostered large densities of this species by providing a place for attachment and enhanced its food gathering abilities.

Water Depth - Velocity - Substrate Relationship. Water depth in lotic systems functions independently or in conjunction with water velocity and substrate to influence the composition of benthic invertebrate communities. The mean composite insect densities from intensive study sites on the MSCR and MFCR were higher on shallow, near-shore regions, than depths >150 cm (Figures 11, 12). All shallow, near-shore samples included in the analysis were those which had at least a 30-day history of being permanently watered. The 15 cm depth supported a mean density of ca. 1500 insects, the 30 and 40 cm ca. 2200 insects (Figures 11). The near-shore regions of 15 cm or less approximated a more lentic habitat because of very low velocities. Deeper pools of 2.25 - >5 m supported the lowest insect densities, however, velocities often exceeded >1.5 m/sec. These data show that shallow, near-shore regions, contribute appreciably to the total invertebrate density in the river. Invasion of shallow water, which was for the most part near-shore, by regulated flows from Dworshak Dam could cause the displacement and/or demise of appreciable numbers of insects.

When plotting densities against five depth zones, mayflies, caddisflies and stoneflies all conformed to the same basic pattern of decreasing densities with depth (Figures 13-15). Only chironomid dipterans increased in density with depth (Figure 16). The latter relationship was engendered because of large densities of midges in the lower transition waters of the Clearwater River where depths were mostly >1m, velocities -

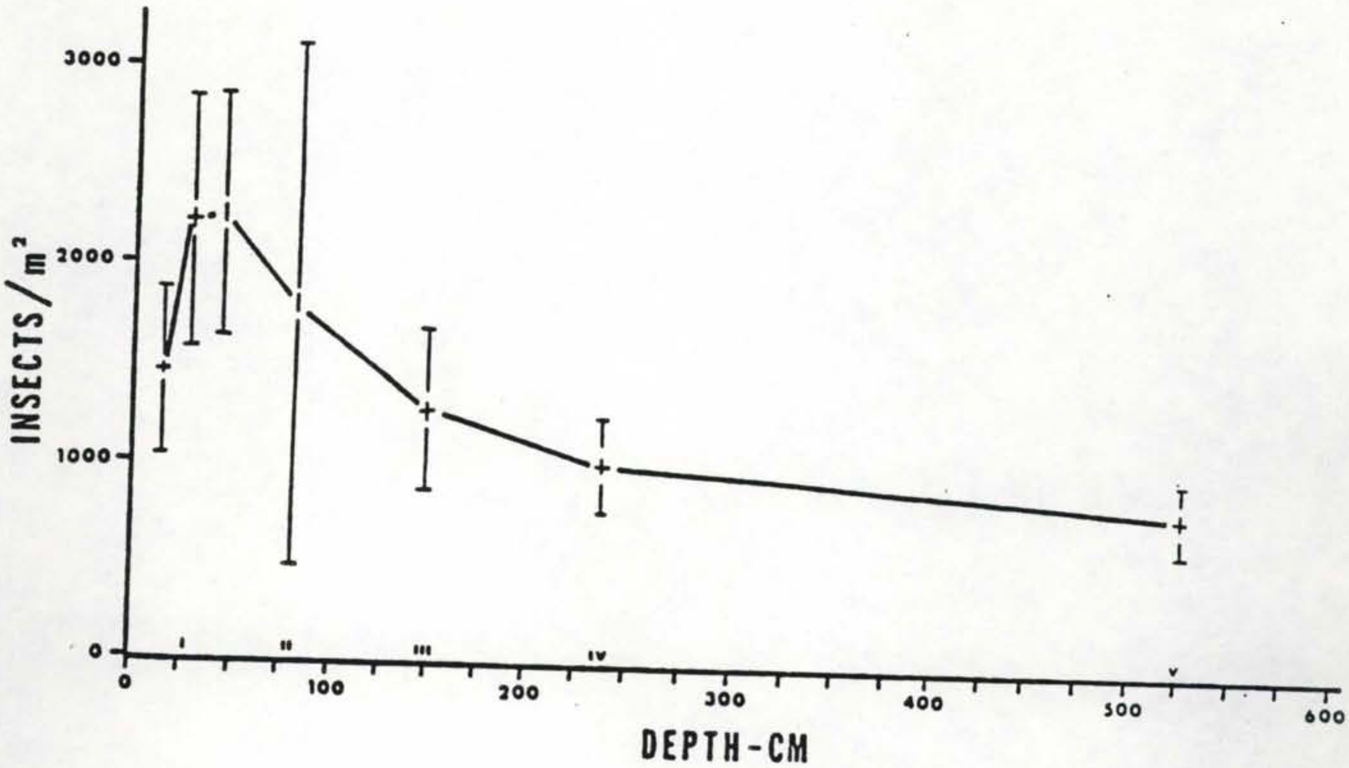


Figure 11. Mean Insect Density/M^2 for Different Depths in the Main Stem and Middle Fork Clearwater River, Idaho. July and August, 1977-1980. Vertical Lines = 95% C.I.

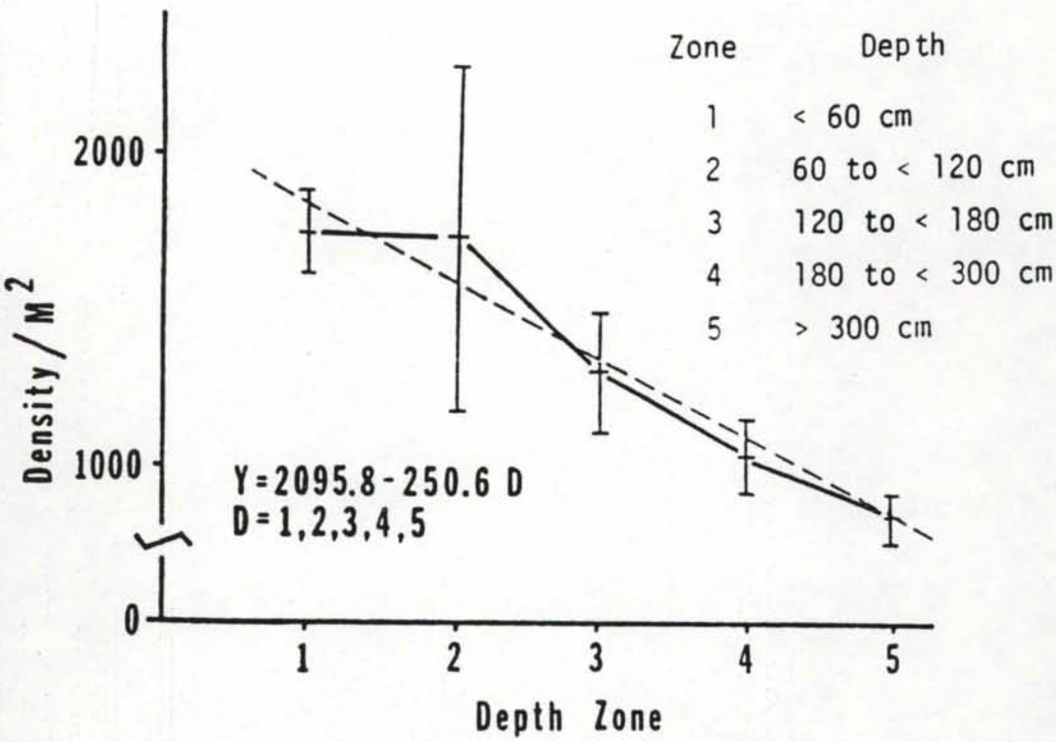


Figure 12. Mean Density/M^2 for Five Depth Zones in the Main Stem and Middle Fork Clearwater River, Idaho. July and August, 1977-1980. Vertical Lines = 95% C.I.

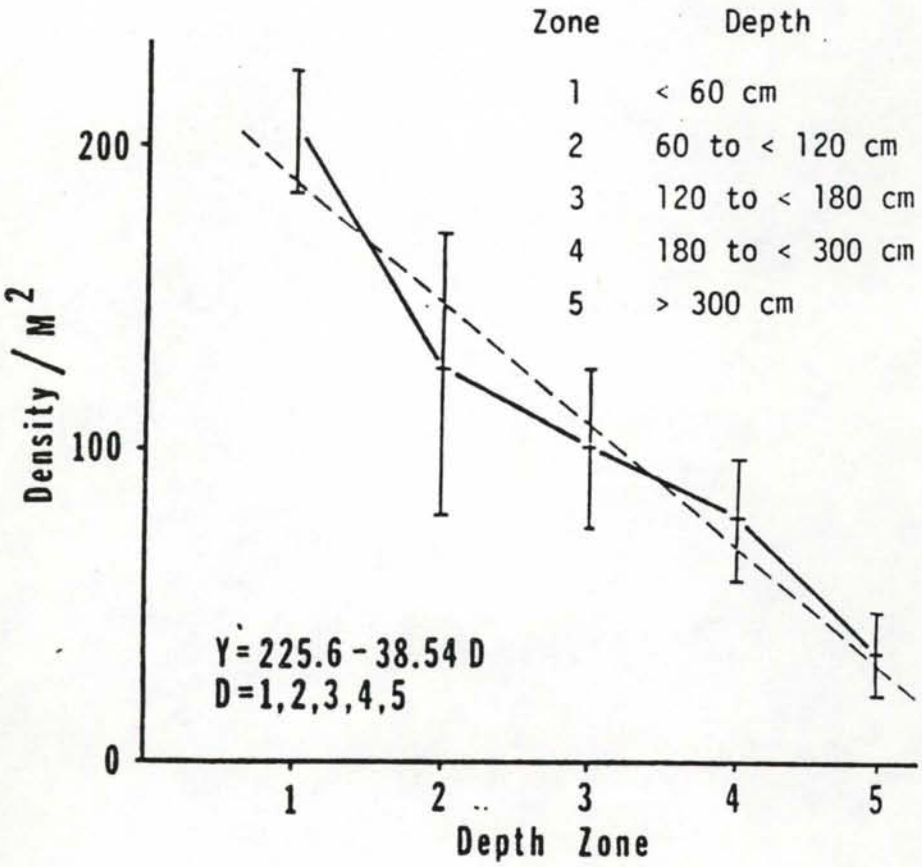


Figure 13. Mean Mayfly Density/M^2 for Five Depth Zones in the Main Stem and Middle Fork Clearwater River, Idaho. July and August, 1977-1980. Vertical Lines = 95% C.I.

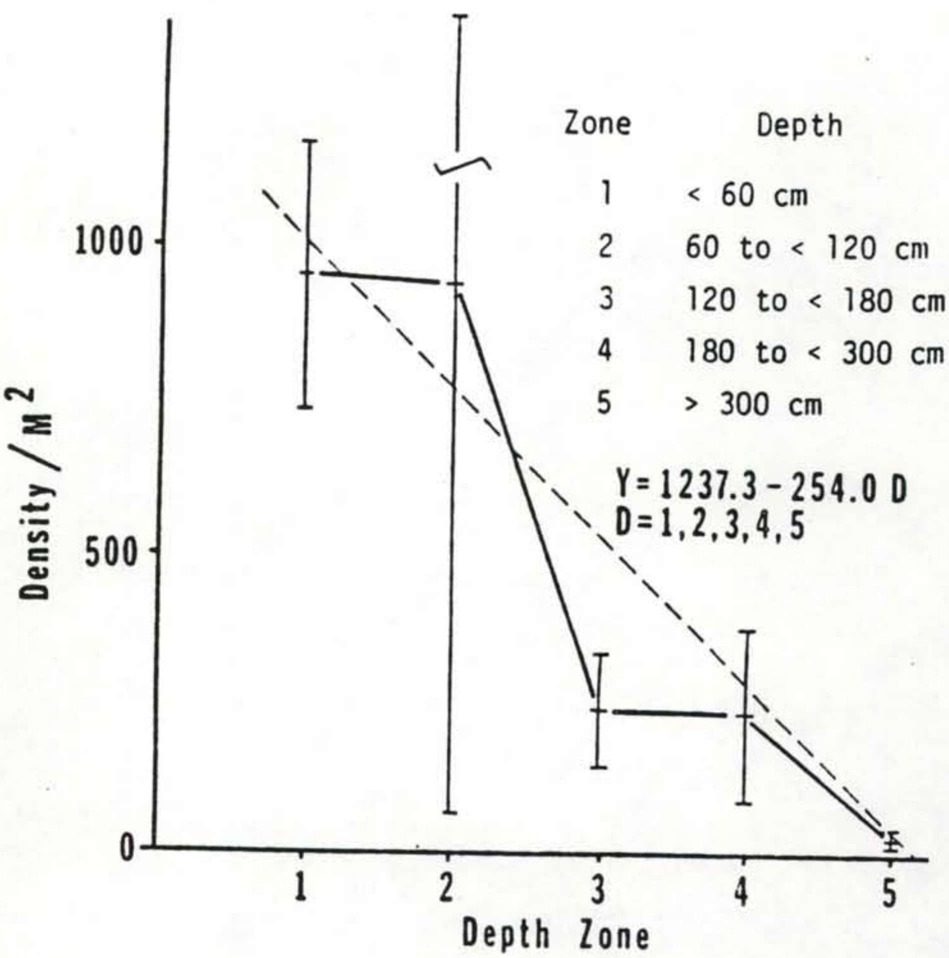


Figure 14. Mean Caddisfly Density/M^2 for Five Depth Zones in the Main Stem and Middle Fork Clearwater River, Idaho. July and August, 1977-1980. Vertical Lines = 95% C.I.

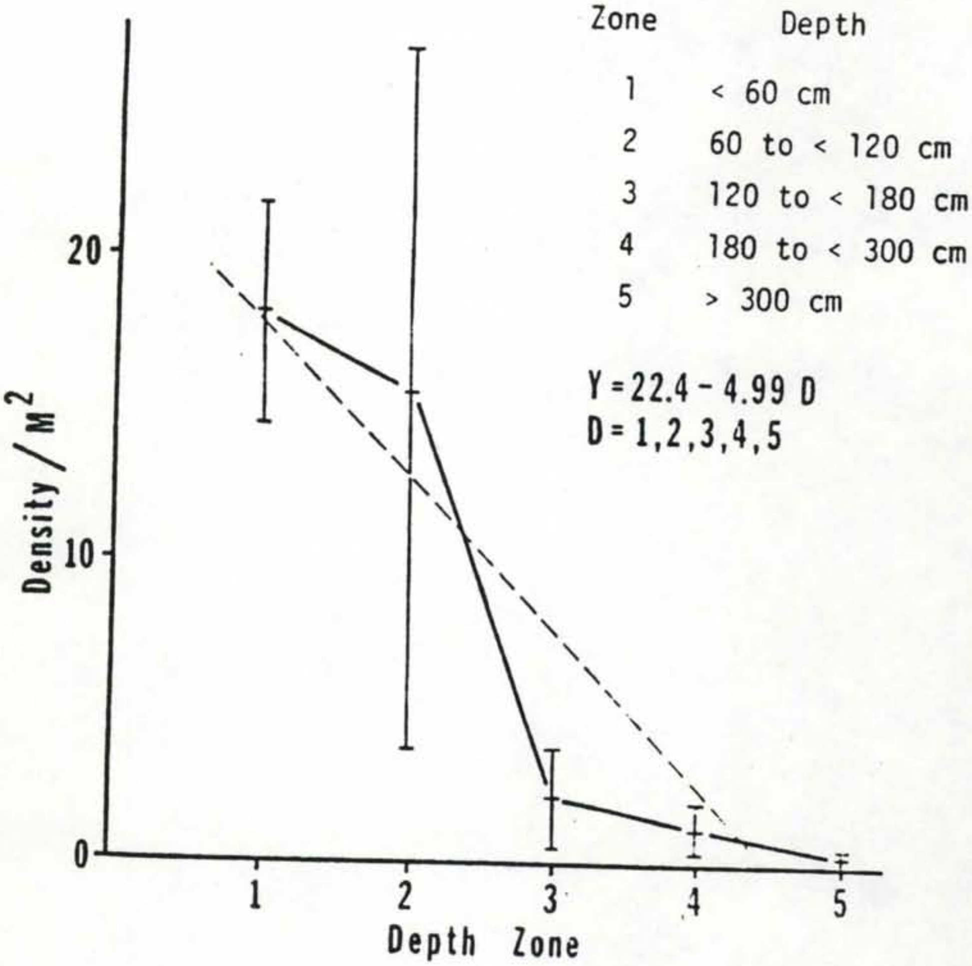


Figure 15. Mean Stonefly Density/M^2 for Five Depth Zones in the Main Stem and Middle Fork Clearwater River, Idaho. July and August, 1977-1980. Vertical Lines = 95% C.I.

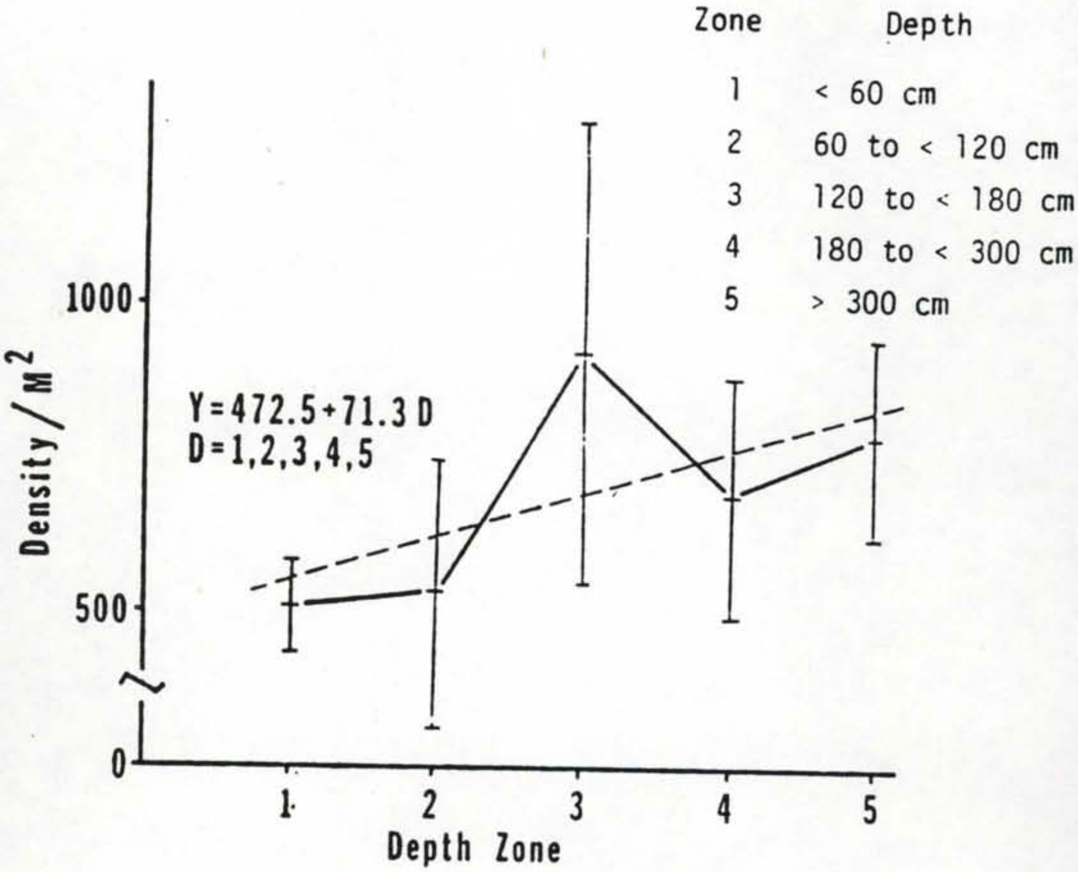


Figure 16. Mean Chironomidae Larvae for Five Depth Zones in the Main Stem and Middle Fork Clearwater River, Idaho. July and August, 1977-1980. Vertical Lines = 95% C.I.

slow (<30 cm/sec) and the substrate composed of sand and fine particulate organics.

Species richness, i.e. the mean number of species in samples taken from five depth zones, decreased with increasing depth (Figure 17). The largest number of species occurred in the shallow near-shore areas which are potentially most influenced by regulated flows. In the species richness computation, we treated chironomidae as a single taxon because of taxonomic uncertainties in species determinations.

The relationship of water velocity to insect density and species richness was as profound as water depth was to these same population characteristics (Figures 18, 19). Both density and species richness increased with increasing velocity from <6 cm/sec to >6 cm/sec. A mean density of ca. 1100 insects/m^2 was recorded for velocities <30 cm/sec and ca. 3500 insects/m^2 for velocities >60-90 cm/sec. We submit that while a curvilinear relationship is clearly reflected with regard to density and species richness to water velocity, this relationship may be secondary rather than primary. Water velocity was taken at 0.6 the depth and represents the mean velocity for a given water column. While this depth serves as a useful standard for hydrological purposes, it is not an effective descriptor of the velocities at the microhabitat level of benthic invertebrates. It has been pointed out that the velocity at rock-water interfaces is virtually zero and that interstitial flows within the substrate are very slow and measured in cm/min or /hr rather than cm/sec (Hynes 1970).

The annual hydrological cycle of rivers tends to maintain or change the physical character of the stream bed. Dynamic changes in stream morphology occur primarily during the spring run-off when flows are greatest

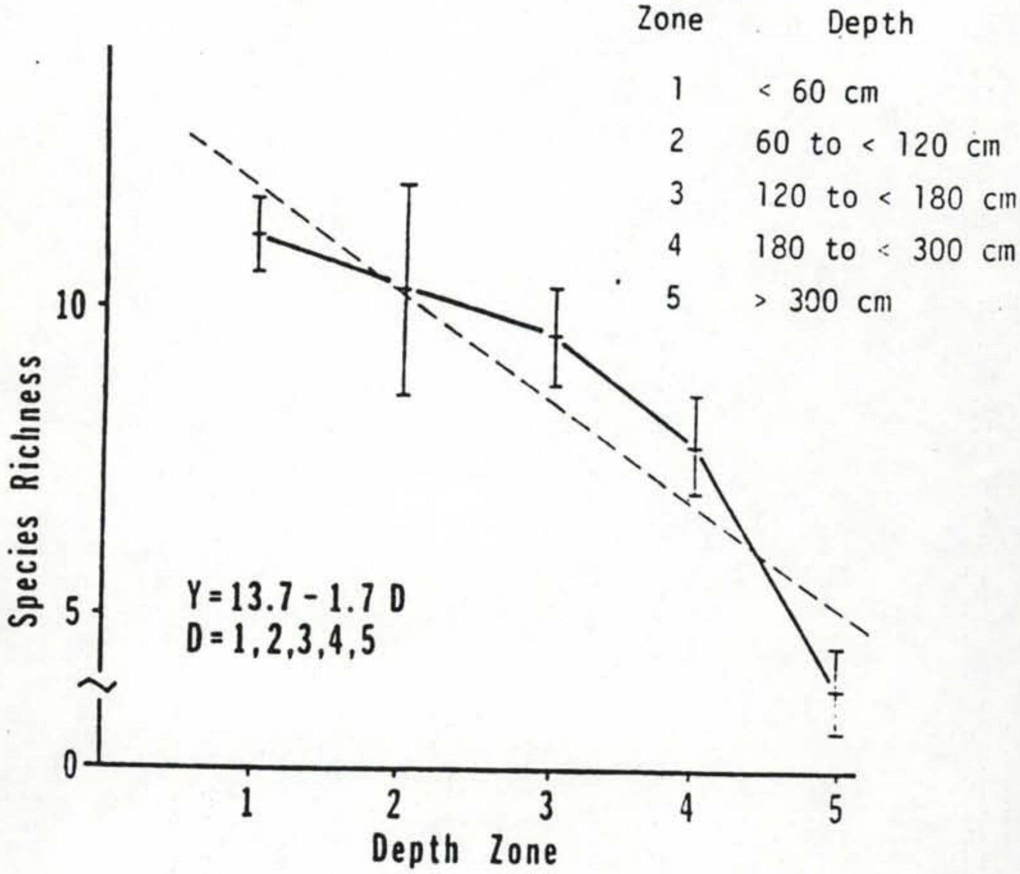


Figure 17. Mean Species Richness for Five Depth Zones in the Main Stem and Middle Fork Clearwater River, Idaho. July and August, 1977-1980. Vertical Lines = 95% C.I.

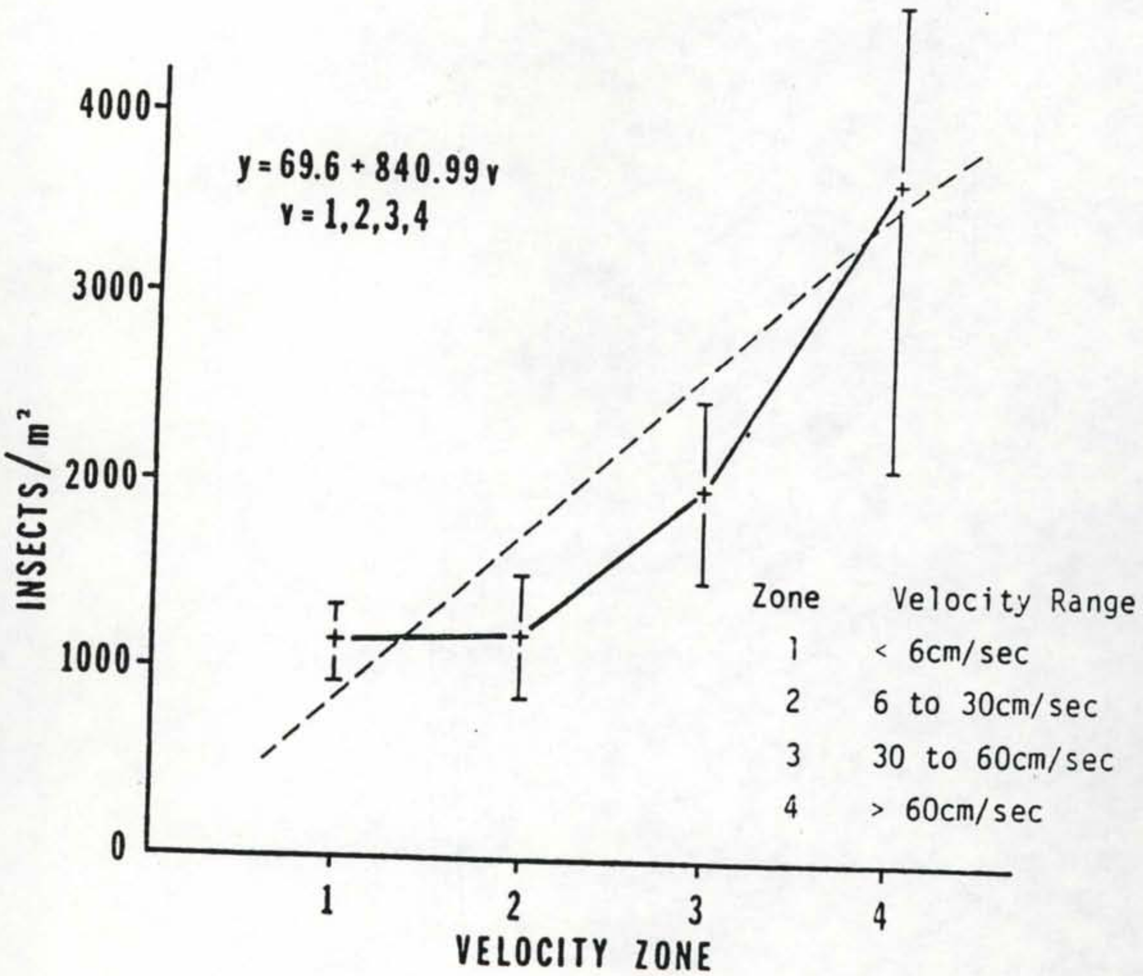


Figure 18. Mean Density for Four Velocity Zones in the Main Stem and Middle Fork Clearwater River, Idaho. July and August, 1977-1980. Vertical Lines = 95% C.I.

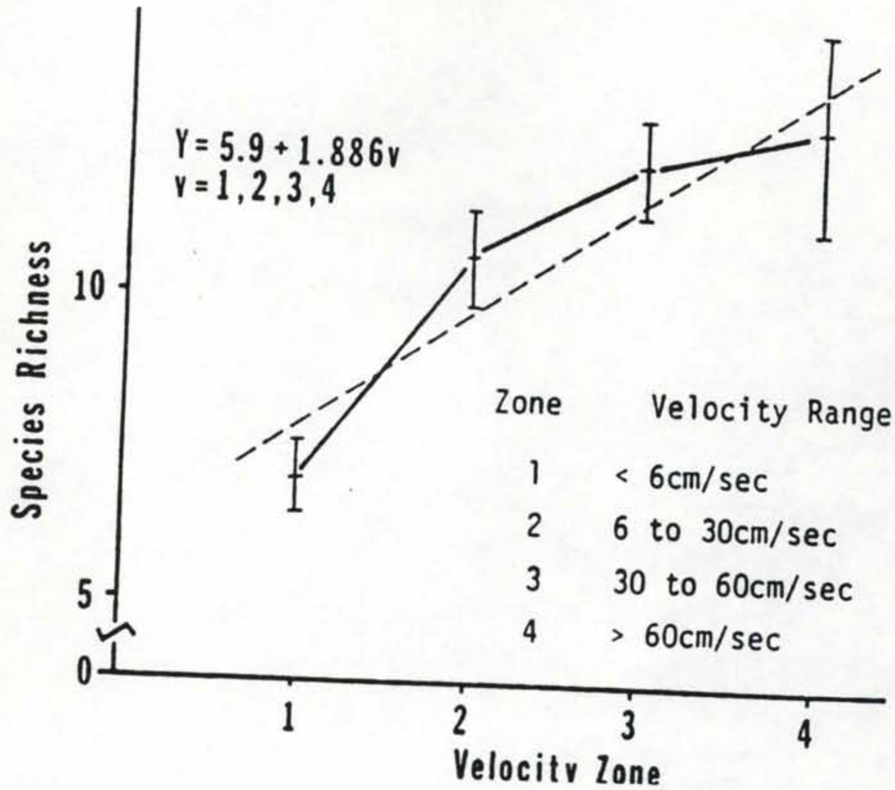


Figure 19. Mean Species Richness for Four Velocity Zones in the Main Stem and Middle Fork Clearwater River, Idaho. July and August, 1977-1980. Vertical Lines = 95% C.I.

or during unseasonable high flows caused by storm events or extreme changes in hydropower generation. During the remaining months of the year the stream bottom of many reaches enters into a relatively dynamic stable state with pool and runs becoming depositional rather than degredational. The invertebrate data included in this report comes largely from a post-runoff period and are reflective of the latter condition except for regular or irregular flow fluctuations from Dworshak Dam which under present operations were appreciably damped from the high flows encountered during spring runoff.

Because benthic invertebrates live largely out of the direct influence of currents, except when drifting, they are largely responding to the physical habitat, namely substrate that is seasonally conditioned and annually maintained by the energies of flowing water. The development of epilithic algae, macrophytes and deposition of particulate organics on or around substrate particles tends to provide a food base for the nonpredacious species in the invertebrate community which are by far the dominant members.

The nature of the substrate in zones of fluctuation is an important consideration when evaluating benthic invertebrate production in a flow regulated river. Three dominant substrate types (sand, cobble and boulder) make up nearly >90% of the shore regions subjected to regulated flows from Dworshak Dam. Sand (<1.5 mm) cobbles (127-254 mm) and boulders (>254 mm) made up 2, 53 and 45% of the shore regions, respectively. The substrate classification was based upon the size of the dominant particles proposed by Brusven and Meehan (1979). Highest mean insect densities from near-shore regions (15-45 cm deep) in the MSCR was recorded from large cobble substrates, the least from sand; sand had <2 insects/0.093 m^2 (Figure 20). Mayflies and caddisflies, two of the principal insect orders, showed different responses to substate. Mayflies had similar mean densities from cobbles and boulders, while cobble substrates promoted greater caddisfly densities. The latter relationship was largely contributed by the filter feeding caddisfly, Brachycentrus sp. and the net-spinning Cheumatopsyche sp. Many benthic insects may not be associated specifically with the dominant substrate, but the smaller particles, organics or algae surrounding the dominant types. For example, filter feeding insects tend to reside more on the surface of rocks where they can more effectively filter organic debris from the water. Collector-gatherers which characterize most of the mayflies and many dipterans feed on fine particulate food that settles out around and under dominant substrate particles.

Species richness enumeration in relation to the dominant substrate types was similar to density relationships (Figure 21) in that cobble and boulder substrate supported the higher mean species richness, sand and lowest. Seasonal variation likely exist for this parameter as with density, however, we believe the aforementioned results represent a reasonable index to these two important community characteristics. Additionally, substrate does not likely function totally as an independent variable with respect to insect distribution and abundance, but is closely associated with discharge parameters and permanency of watering.

Distributional Relationships. Cross sectional and stream reach distribution of benthic invertebrates are important when assessing the ecological resilience of invertebrates subjected to regulated flows. River cross-sectional distribution of benthic invertebrates provides

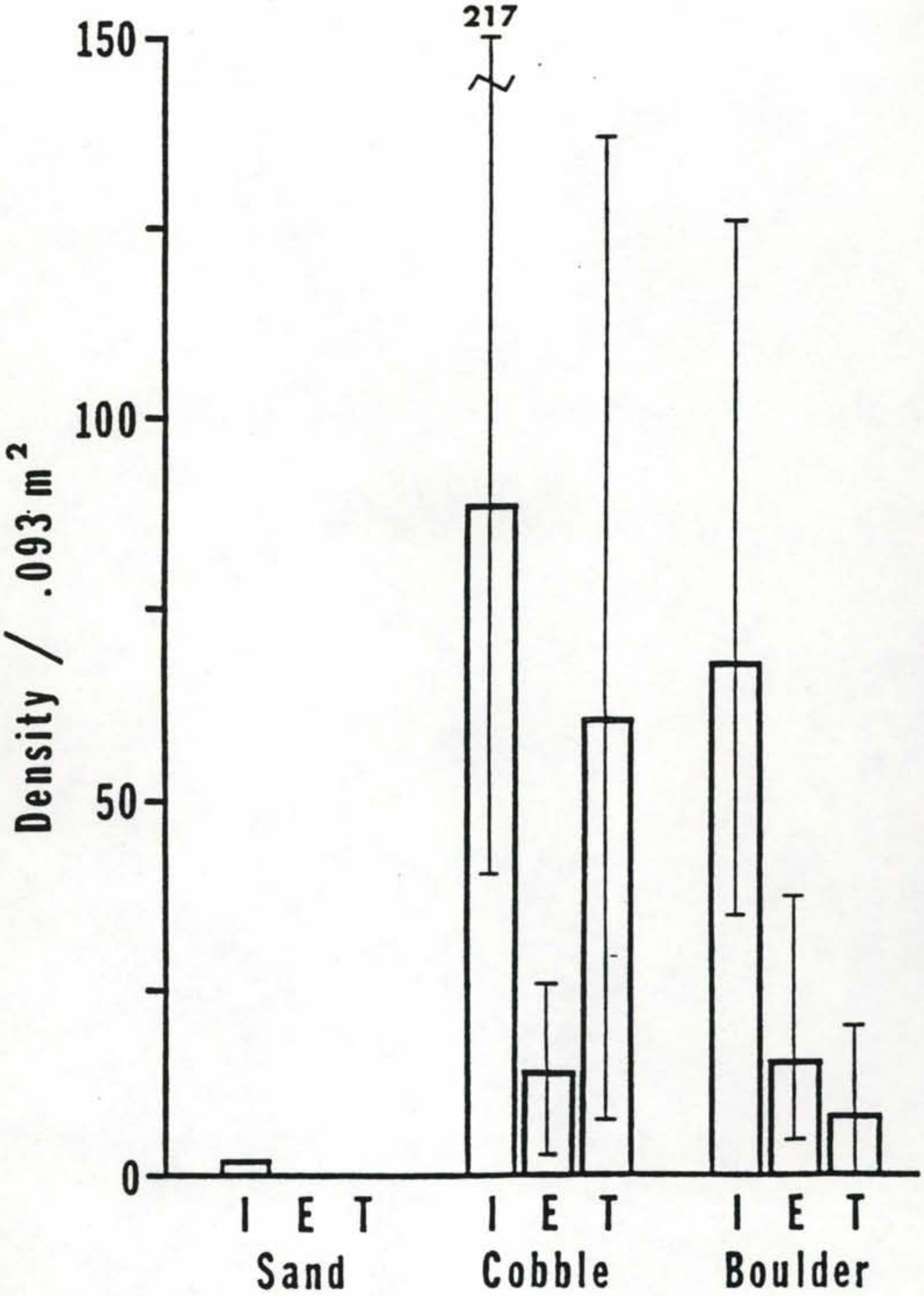


Figure 20. Mean Insect Density (I = All Insects, E = Ephemeroptera, T = Trichoptera)/0.093 M^2 From Sand, Cobble and Boulder Habitats, August 1978, Main Stem Clearwater River. Vertical Lines = Range of Variation Among Samples.

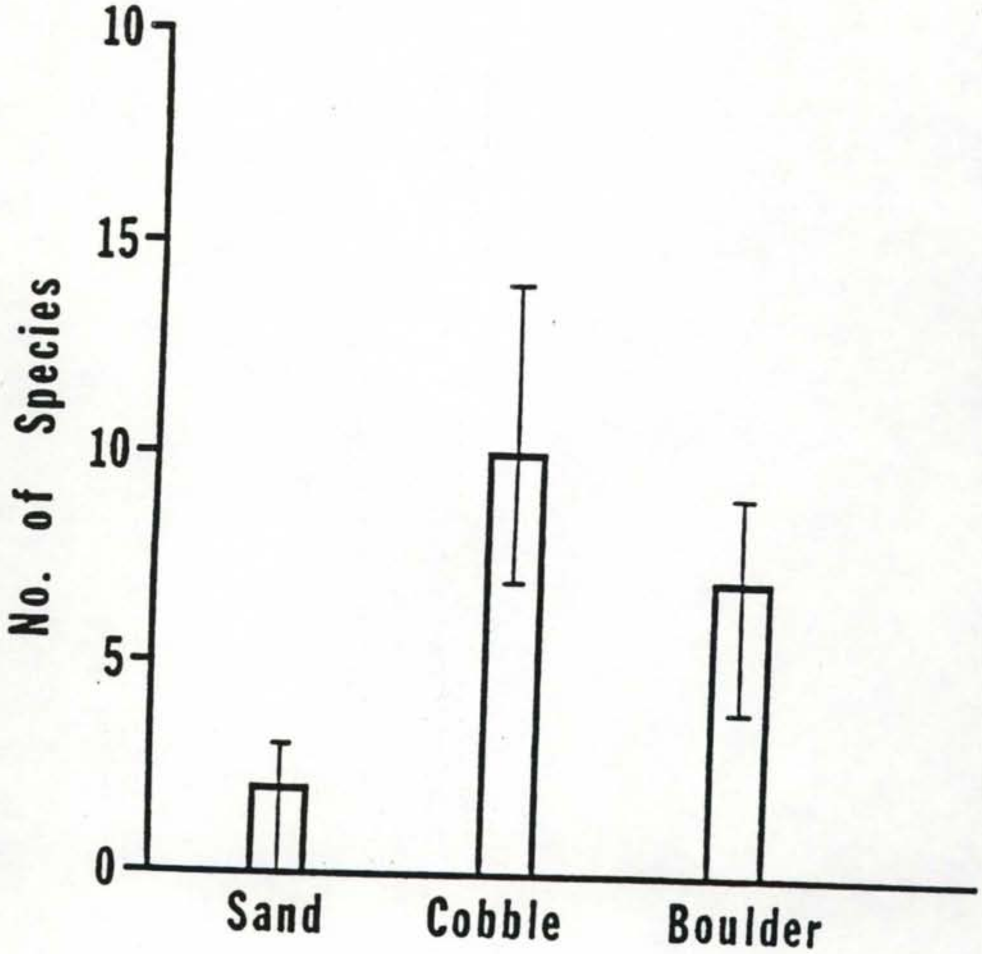


Figure 21. Mean Number of Species/0.093 M^2 Samples From Sand, Cobble and Boulder Habitats, August 1978, Main Stem Clearwater River. Vertical Line = Range of Variation Among Samples.

some of the most important criteria for managing a regulated river. Our results clearly show that stable, shallow-water regions, especially riffles, are major contributors to invertebrate density (Figures 11-16) and species richness (Figure 17) in the Clearwater River. The shallow water areas, therefore, tend to foster community heterogeneity, hence niche refinement through interspecific competition and partitioning of available resources. Additionally, these areas are important "seed" sources providing organisms for colonizing depauperate areas.

Biomass production from near-shore regions of 15, 30 and 45 cm deep was profoundly different among stream reaches (Figure 22). At the MFCR and MSCR reaches, biomass increased with depth, i.e. from 15 to 45 cm; at the North Fork it was relatively similar (ca. $1 g/m^2$). Invertebrate biomass was approximately 2.5 times greater on the MFCR than MSCR. Biomass enumeration was not done for samples taken from depths >45 cm, therefore, our interpretation is limited to the shallow, near-shore regions.

As with biomass, selected insect species showed considerable variation among stream reaches (Figure 23). The mayfly, Ephemerella infrequens attained its highest densities in the NFCR, a reach subjected to the full impact of regulated flows. This species functions as a collector gatherer. We believe it was enchanced because of the preponderance of aquatic moss in the North Fork which trapped fine particulate organics and fostered the collection and production of algae on its filaments. The collector-filtering caddisfly Cheumatopsyche sp. was abundant in both the MFCR and main stem, but sparse in the NFCR. The filter feeding caddis Brachycentrus sp. on the other hand was clearly more abundant in the MFCR than the other two reaches. We attribute these differences largely to inimical behavioral and physio-ecological attributes which allow the species to optimize food-gather tactics.

The functional group characteristics of the insect community among reaches are as profoundly different as the aforementioned population and community conditions (Figure 24). Over 95% of the NFCR insects are collector-gatherers; shredders, collector filterers, scrapers and predators were only limitedly present. The lack of diversity in functional group in the NFCR is not unexpected because >90% of the insect community was composed of midges (principally Orthocladinae) and the mayfly E. infrequens. The MSCR and NFCR supported a more even diversity of functional groups. Collector-gatherers were most prevalent in the MSCR, collector filterers in the MFCR.

Similarity indices are useful mathematical tools for comparing species or communities spatially. When used temporarily, they provide quantitative inferences to ecological resilience as we propose to use the concept. The proportional similarity index (PS) of Price (1975) was used to compare species or communities among key stream reaches. The proportional similarity values for insect communities among the three stream reaches, i.e. the NFCR, MSCR and MFCR, are graphically portrayed in the form of a dendrogram and clearly show differing similarities when chironomids were included or excluded in the analysis (Figure 25). In both cases, however, the NFCR was the most disassociated reach having a similarity value of 0.45 when midges were included and 0.03 when excluded from the computation. Because of the preponderance of midges in the community, their numbers greatly influence the index values. The NFCR is the reach that experiences the full impact of regulated flows and supports low species richness, but large numbers of midges and the mayfly, Ephemerella infrequens. It can be inferred that the highly perturbed conditions on the NFCR contributed to the lower PS values.

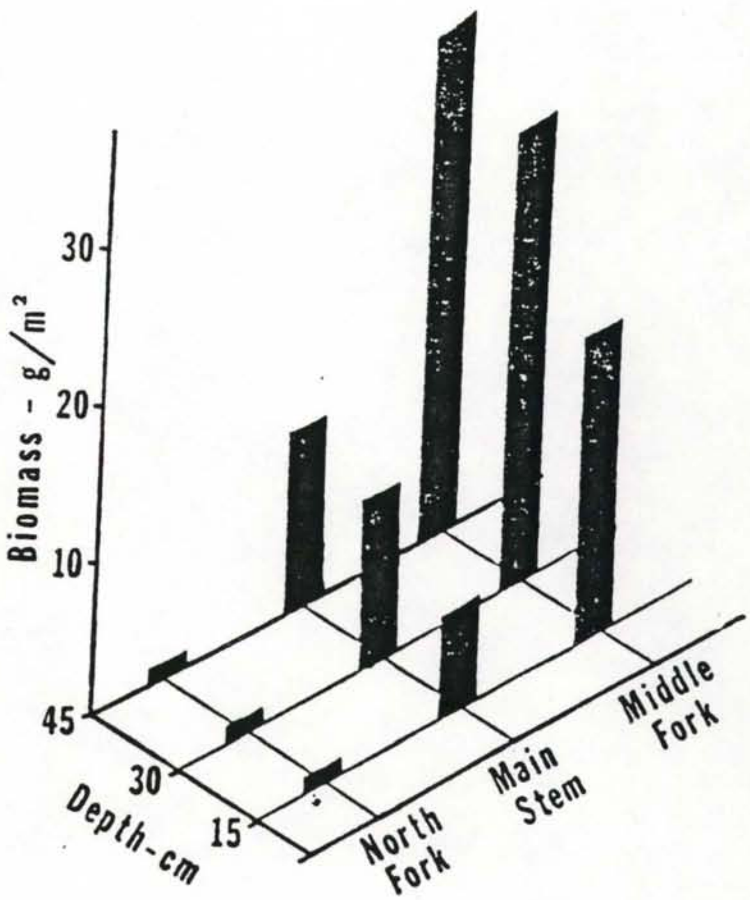


Figure 22. Mid-Summer Mean Invertebrate Biomass (G/M^2)
At Near-Shore Depths of 15, 30 and 45 CM

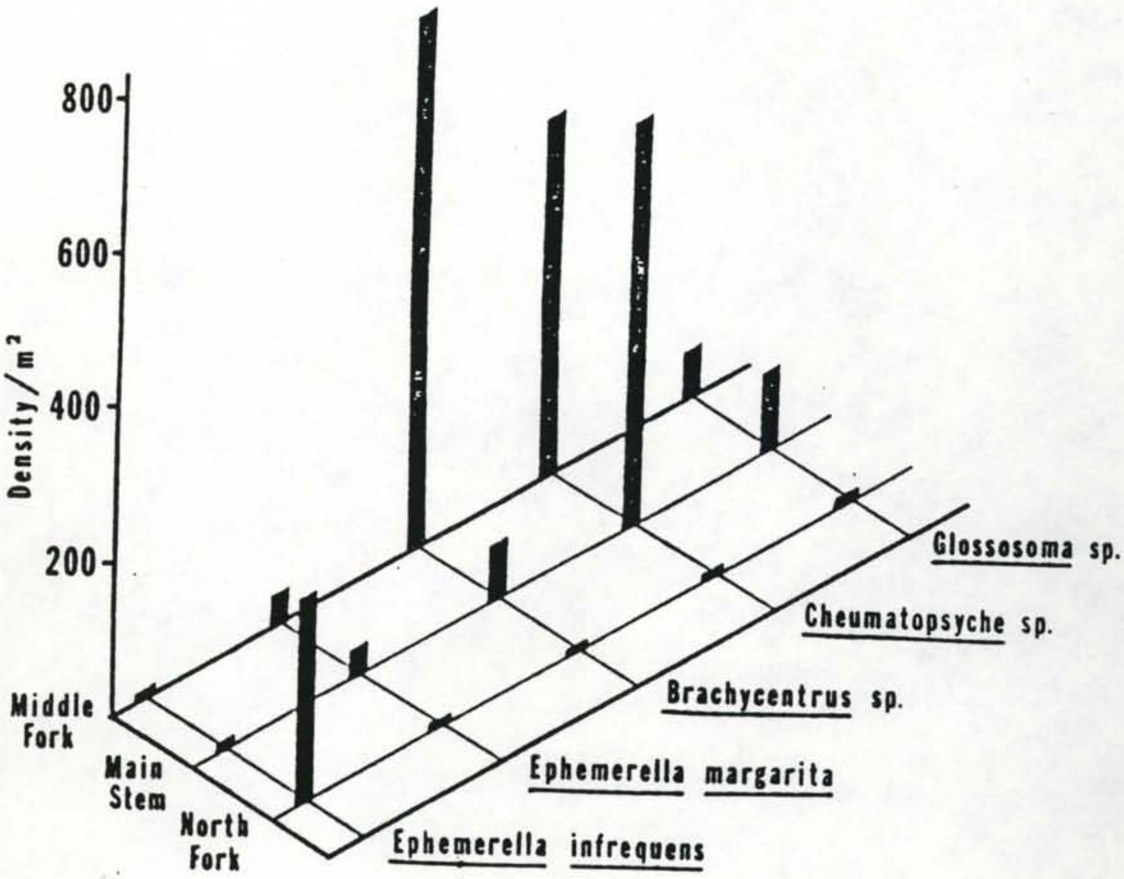


Figure 23. Insect Density/M^2 of Principal Mayflies and Caddisflies during July and August, from Three Reaches of the Clearwater River, Idaho

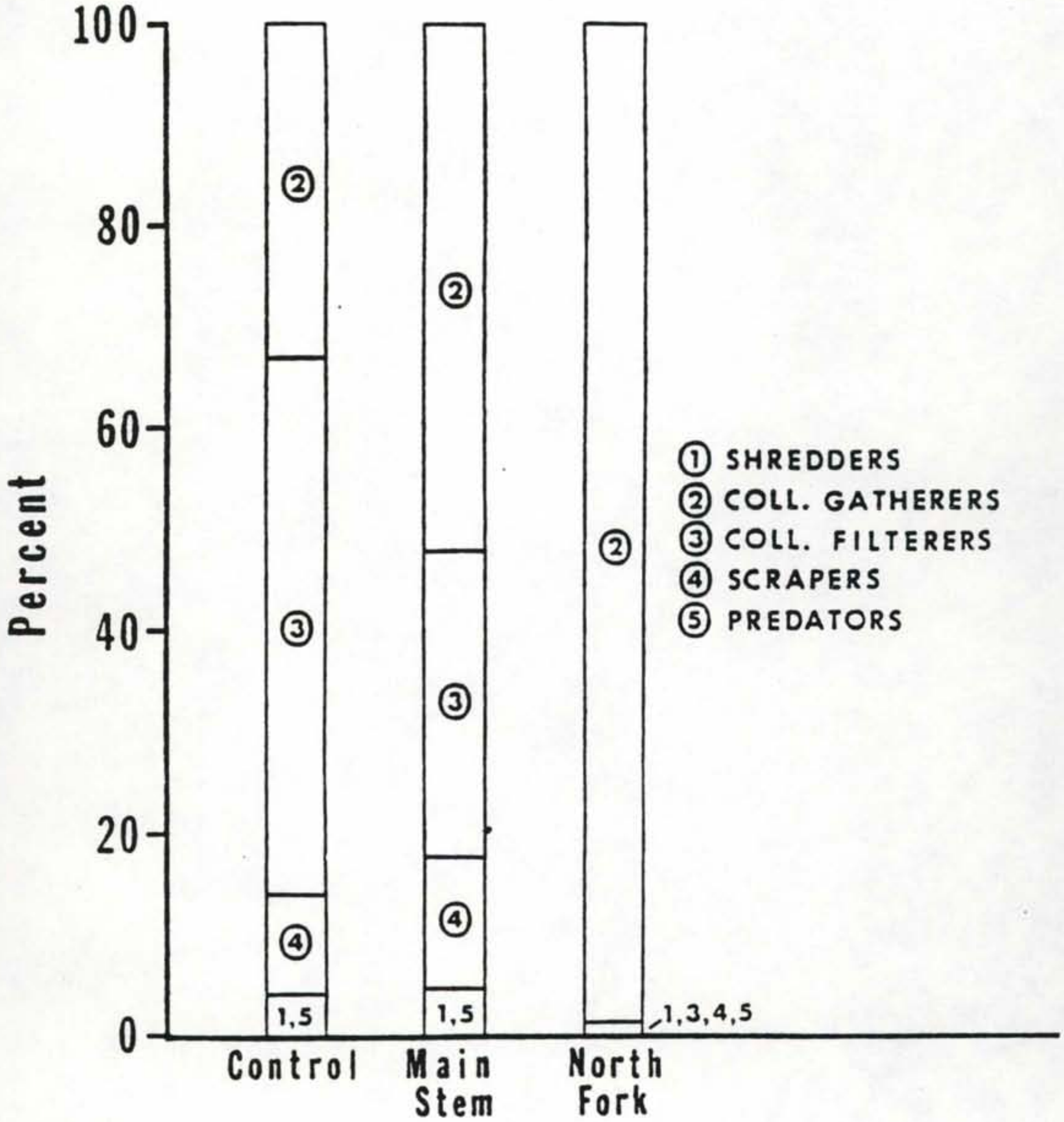


Figure 24. Percent Composition of Principal Functional Groups From Three Reaches in the Clearwater River, Idaho. July and August, 1977-1980.

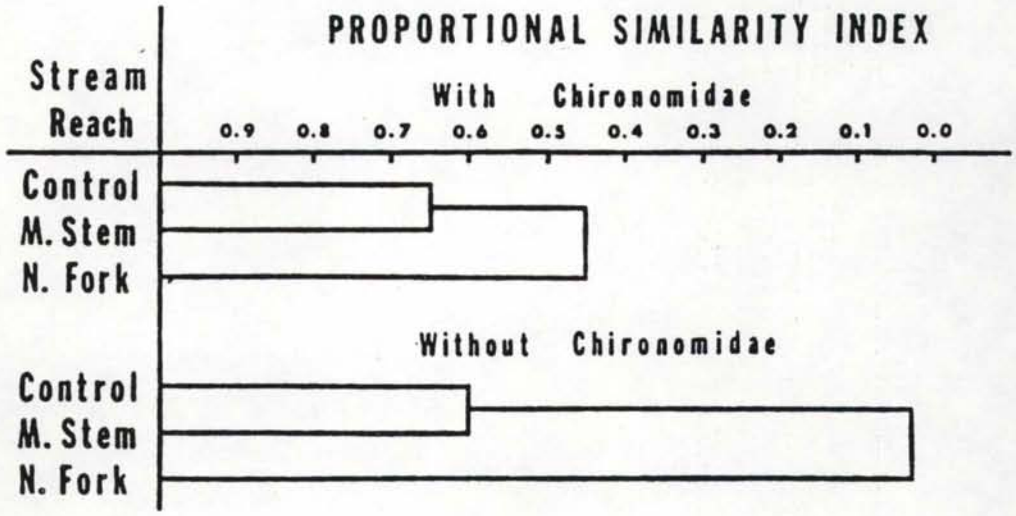
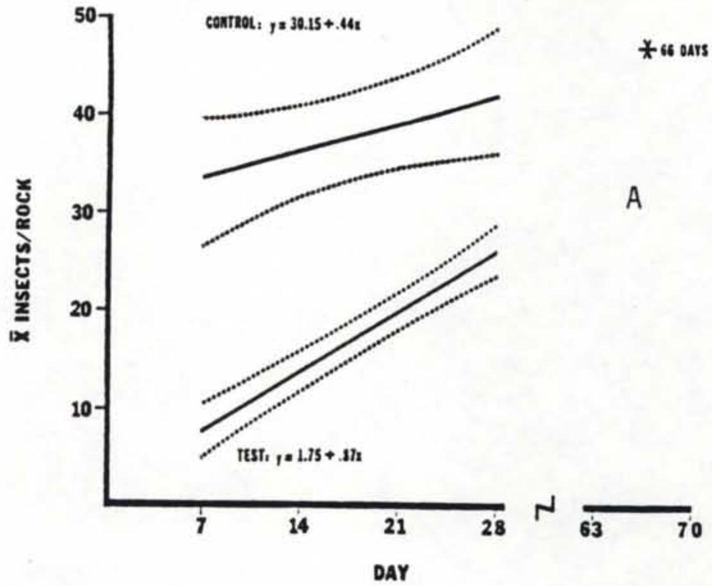


Figure 25. Proportional Similarity of Insect Communities With and Without Chironomidae Among Three Reaches of the Clearwater River, Idaho, July and August, 1977-1980.

Rate of Insect Colonization. Insect colonization during August 1977 and 1978, at flow regulated and unregulated sites, demonstrated that the control mean densities were similar throughout the test, except at the regulated site in 1978, where the density increased slightly; whereas, the densities on test rocks noticeably increased with time (Figures 26) Appreciable differences in density were noted between years; lower mean densities were recorded in 1978 than in 1977. We attribute these differences to inherent population fluctuations which occur in most natural ecosystems. At the end of 28 days, densities on the test rocks approached the standing crop of control rocks, however, test and control densities remained significantly different ($P<.05$) at both sites. Dominant insects on the rocks were chironomid dipterans, principally Chironomus sp., Orthocladius sp. and Procladius sp. Trichopterans, second in abundance, included Brachycentrus sp., Cheumatopsyche sp., Hydropsyche sp. and Glossosoma sp. During both years small densities of Ephemereoptera and Plecoptera colonized the rocks.

The most significant increases in benthic insect colonization on test rocks were apparent on day 21; however, test densities did not attain carrying capacity during the 28-day study period. Colonization tests longer than 28 days were not possible because of the power peaking cycles emanating from Dworshak Dam during the summer and fall months. In order to predict an intercept point between test and control insect densities, a regression analysis was used to estimate the time necessary for the test rocks to approach carrying capacity (Figures 26). Assuming a linear colonization rate, approximately 66 days would be needed for test substrates to reach carrying capacity at the flow regulated site, and 47 days at the unregulated site. These colonization estimates are



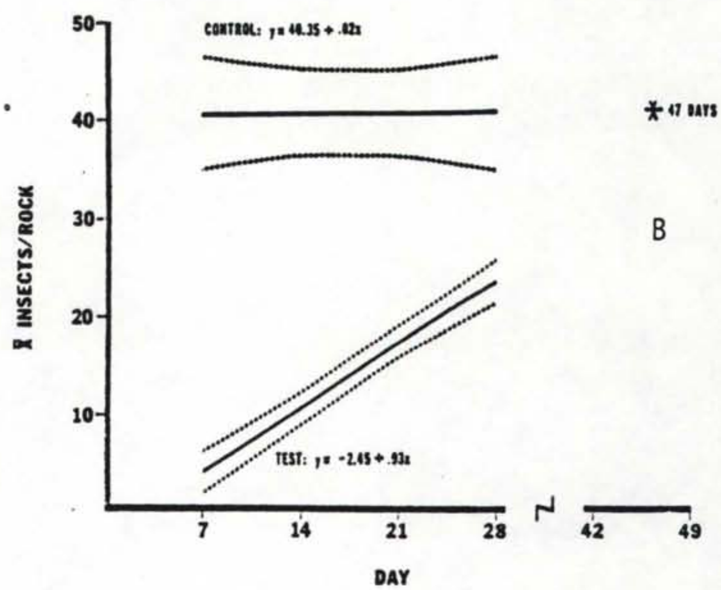


Figure 26. Predicted insect colonization rates (95% C.I.) for combined samples, August 1977 and 1978, at regulated reach (A) and unregulated reach (B) Clearwater River, Idaho.
* = test densities approach carrying capacity.

similar to those Shaw and Minshall (1980), obtained for benthic insects colonizing pebbles. In our study, the predicted carrying capacity of the control substrates at the unregulated site was relatively constant over the 28-day period (b=0.02), whereas, the predicted carrying capacity at the regulated site increased over the same period (b=0.44). We contend that these differences were likely due to flow fluctuations and colder water temperatures from Dworshak Dam. Some differences in community composition were noted between the test and control sites and appreciable differences in phenology were noted among several insect species, especially mayflies.

A nonlinear colonization rate may provide greater resolution of benthic insect response to newly watered substrate. Our studies indicate that high numbers of insects drift over newly watered, near-shore areas in the Clearwater River (Brusven and Haber, 1981; Brusven and Macphee 1976) but insects apparently either fail to settle out of the drift or do not remain in the newly watered areas, at least during the short term. Presumably, there is insufficient attached benthic algae or particulate organic matter to provide necessary requisites for a majority of the community. As food supplies increase one would expect the rate of colonization to also increase. We analyzed data from several studies on the Clearwater River (Gersich and Brusven, 1981; Stanton, 1978; Brusven, unpublished data) and determined that a logistic colonization model provided a reasonable fit to the data (Figure 27 & 28). The model was:

$$N_t = \frac{K}{1 + e^{c-rt}}$$

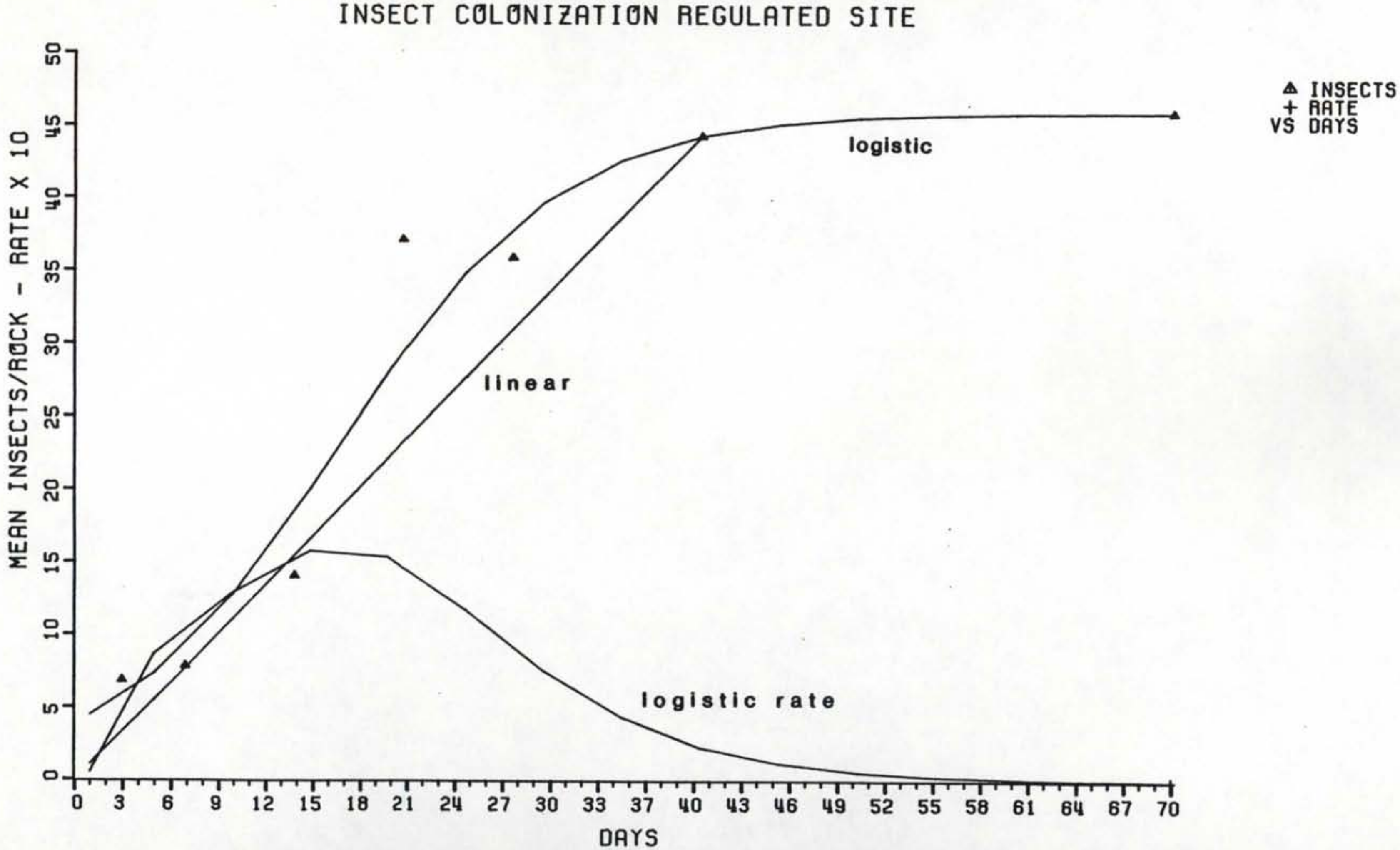


Figure 27. Insect Colonization (Mean Number/Rock) Assuming Linear and Logistic Models and Logistic Colonization Rate (Mean Number/Rock/Day) at Regulated Site

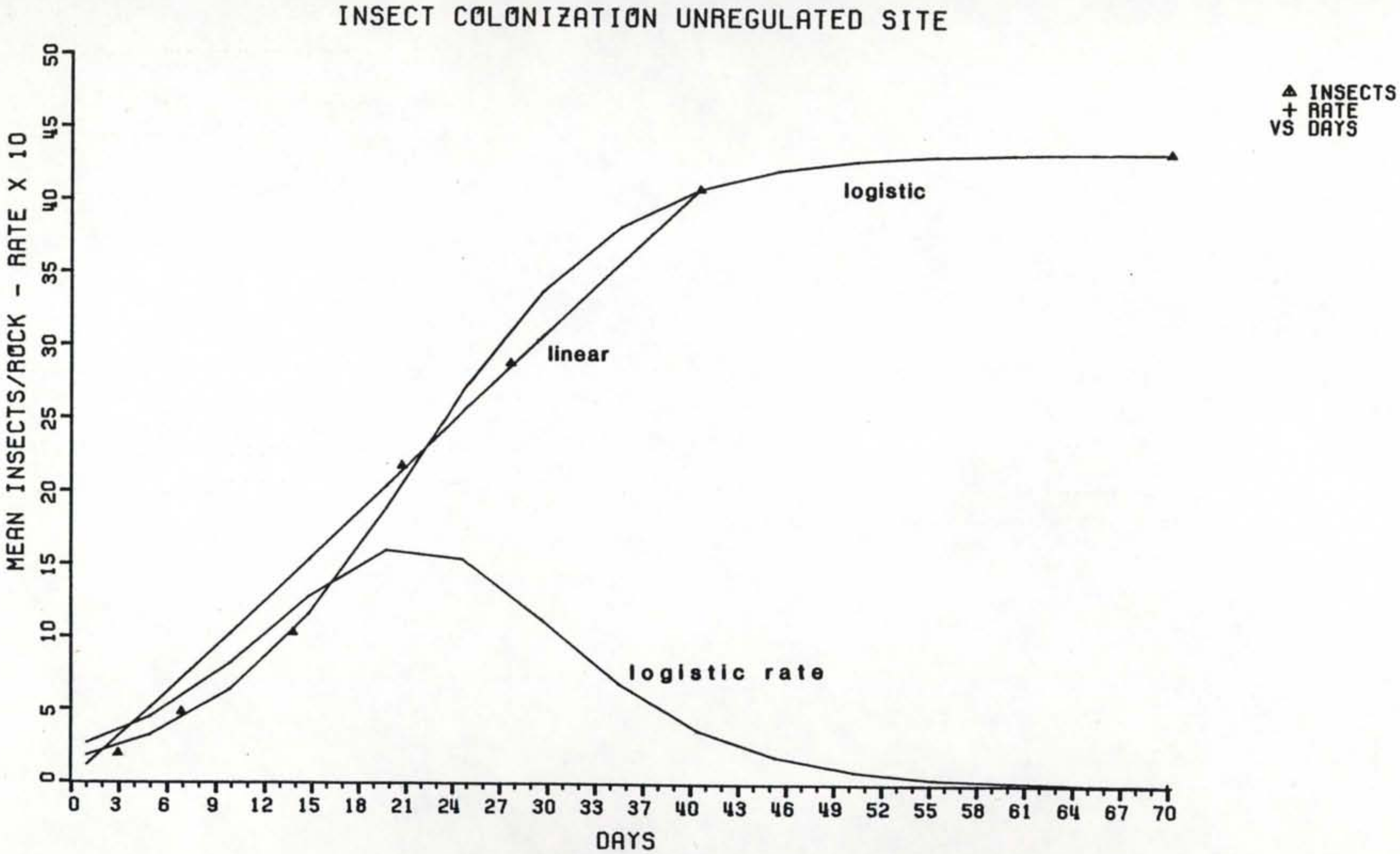


Figure 28. Insect Colonization (Mean Number/Rock) Assuming Linear and Logistic Models and Logistic Colonization Rate (Mean Number/Rock/Day) at Unregulated Site

which was linearized to the form

$$\ln \frac{K - N}{N} = c - rt$$

where

K = carrying capacity ($\bar{X}$ number insects/control rock)

N = number of insects/rock

ln = natural logarithm

e = base of the natural logarithm

c = parameter estimate (y intercept)

r = parameter estimate (slope of regression line)

Although 66 days (regulated site) and 47 days (unregulated sites) would be needed to attain benthic insect carrying capacity if a linear model is assumed (Gersich and Brusven, 1981) the logistic model predicts at least 94% colonization at both sites by day 40.

Community Composition. Community characteristics at intensive sites on the MFCR and MSCR were evaluated statistically by analyzing species richness values among and within sites (R. km 8.3, 38.0 and 72.4) on a yearly basis over a five-year period (1974-1976 and 1978-1979). The species richness values at R. km 8.3, 38.0 and 72.4 (control) indicated variation existed on a between-site, within-year basis (Figure 29). The species richness values during the five-year period ranged from 40 at R. km 72.4 (1976) to 9 at R. km 8.3 (1979)(Table 1). The X^2 values for the individual years were significant ($P<.05$) during 1978 and 1979 implying the control site (R. km 72.4) had higher richness values than the test sites (R. km 8.3, 38.0)(Table 1). The previous X^2 statistical analyses of species richness were performed on the actual richness values obtained at each of the three sites (R. km 8.3, 38.0 and 72.4). We acknowledge, however, that certain of the sampling sites had unique species which could bias the assessment of the effects of regulated flows by community comparisons employing species richness values as a resilience criterion.

Chi-square (X^2) statistical analyses performed on species richness among sites within each year indicated that the sites were statistically inseparable ($P<.05$) on the basis of species richness (Table 2). The relative percentages of the same species occurring at R. km 72.4 and R. km 38.0 or 8.3 are presented in (Figure 30). Although some species found at the control were not found at the downstream sites, the relative similarity of the communities was evident. Several species unique to the control reach (R. km 72.4) were rare and were not useful in discerning presence-absence relationships at sites below the influence of Dworshak Dam on the MSCR.

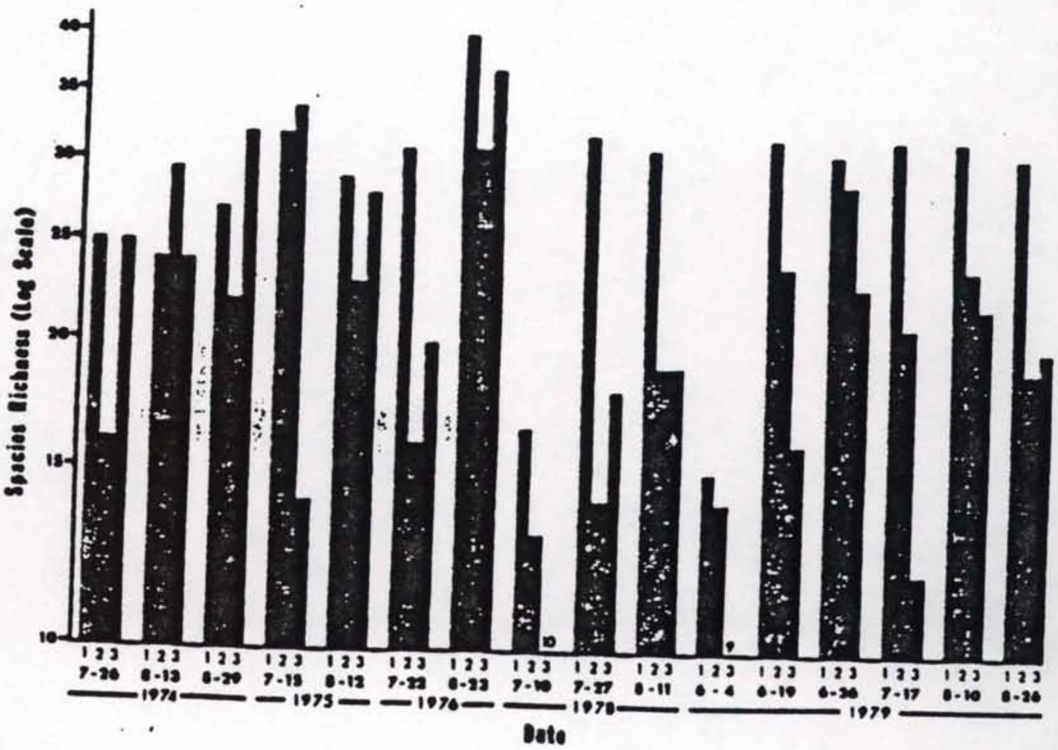


Figure 29. Species Richness Values for R. km 72.4 (1), 38.0 (2) and 8.3 (3) During the Summer Seasons 1974-1976 and 1978-1979, Clearwater River, Idaho. Chironomidae Included as a Single Taxon.

Table 1. Species richness and chi-square (X^2) values for comparisons among sites (R. km 72.4, 38.0 and 8.3) during the summer seasons 1974-1976 and 1978-1979, Clearwater River, Idaho. Chironomidae included as a single taxon.

	1974			1975		1976		1978			1979					
	7-26	8-13	8-29	7-15	8-12	7-22	8-23	7-10	7-27	8-11	6-5	6-19	6-30	7-17	8-10	8-26
Species Richness																
R. km 72.4	25	24	27	32	29	31	40	16	32	31	15	32	31	32	32	31
R. km 28.0	16	29	22	34	23	16	31	13	14	19	14	24	29	21	24	19
R. km 8.3	25	24	32	14	28	20	37	10	18	19	9	16	23	12	22	20
Yearly Site Comparisons																
Overall X^2		1.35		3.76		4.97			12.2**					18.8**		
R. km 72.4 vs 38.0									8.7**					5.8*		
R. km 72.4 vs 8.3									8.1**					18.3**		
R. km 38.0 vs 8.3									.1					3.6		

* = P<.05; ** = P<.01

Table 2. The species richness within each order at R. km 72.4, total number of species within each order at R. km 38.0 and 8.3 that were also found at R. km 72.4 and the chi-square (X^2) values comparing ordinal species richness among sites, Clearwater River, Idaho, 1974-1976 and 1978-1979. Chironomidae included as a single taxon.

	Ephemeroptera	Trichoptera	Plecoptera	Coleoptera	Diptera
Summer 1974					
R. km 72.4	19	11	6	4	5
R. km 38.0	14	7	3	2	5
R. km 8.3	13	7	2	4	3
X^2 Value	1.37	1.26	2.34	0.81	0.60
Summer 1975					
R. km 72.4	14	8	7	5	5
R. km 38.0	13	7	3	5	3
R. km 8.3	10	6	3	2	2
X^2 Value	0.70	0.29	2.48	1.50	1.42
Summer 1976					
R. km 72.4	19	12	5	5	5
R. km 38.0	14	6	3	3	3
R. km 8.3	15	8	3	3	2
X^2 Value	0.93	2.17	0.72	0.72	1.41
Summer 1978					
R. km 72.4	14	8	6	7	5
R. km 38.0	10	5	4	5	2
R. km 8.3	9	4	2	5	1
X^2 Value	1.00	1.52	2.00	0.47	3.21
Summer 1979					
R. km 72.4	20	13	7	9	7
R. km 38.0	15	8	6	6	4
R. km 8.3	17	5	2	5	3
X^2 Value	0.73	3.76	3.00	1.29	1.84

* = P<.05; ** = P<.01

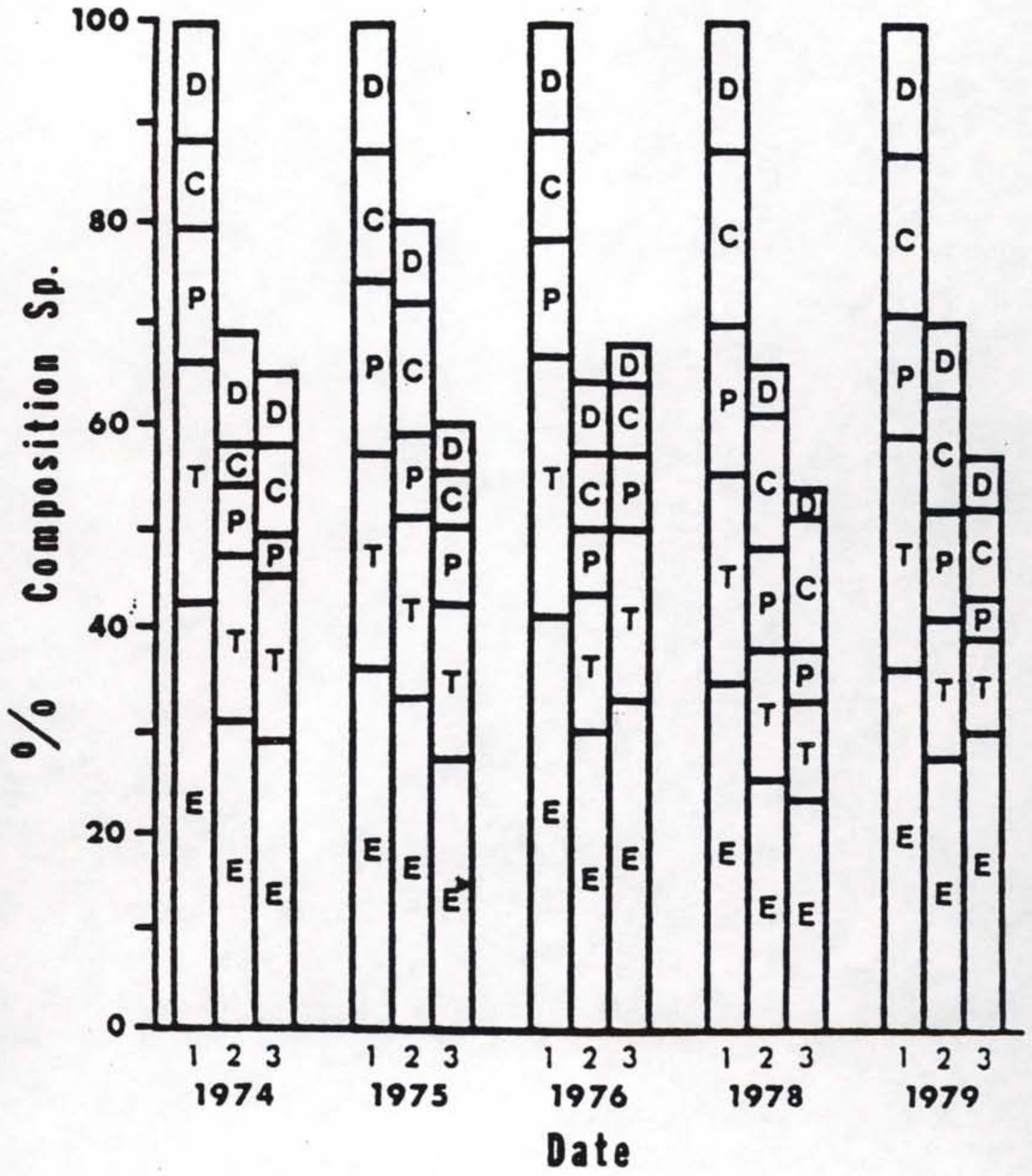


Figure 30. The percent species composition within selected orders (E=Ephemeroptera, T=Trichoptera, P=Plecoptera, C=Coleoptera, D=Diptera) at R. km 72.4 (1), 38.0 (2), and 8.3 (3), Clearwater River, Idaho, 1974-1976 and 1978-1979. The percentages represented were based on the total species richness at R. km 72.4 and only species obtained at R. km 38.0 and 8.3 that were also found at R. km 72.4 were included in the analysis. Chironomidae included as a single taxon.

Species richness values were statistically analyzed within sites over the entire five-year test period (1974-1976 and 1978-1979). The X^2 value for R. km 72.4 indicated that the species richness valus at this site over the five-year period were statistically inseparable ($P>.05$)(Table 3). The X^2 values for within-site analysis of R. km 8.3 and 38.0 were significant ($P<.05$). Based upon the use of species richness as a resilience indicator, the insect communities examined on the MSCR, under the influence of Dworshak Dam, were relatively resilient to fluctuating flows during the past six years.

Table 3. Chi-square (X^2) values for within site comparisons with respect to species richness at R. km 72.4, 38.0 and 8.3, Clearwater River, Idaho, 1974-1976 and 1978-1979. Chironomidae included as a single taxon.

	R. km 72.4	R. km 38.0	R. km 8.3
7/26/74	25	16	25
8/13/74	24	29	24
7/15/75	32	34	14
8/12/75	29	23	28
7/22/76	31	16	20
8/23/76	40	31	37
7/27/78	32	14	18
8/11/78	31	19	19
7/17/79	32	21	12
8/10/79	32	24	22

X^2 Values	
R. km 72.4	5.6
R. km 38.0	18.5*
R. km 8.3	21.3*

* = P<.05; ** = P<.01

Resiliency Approach for Assessing the Impact of Regulated Flows in the Clearwater River.

In order to assess the impacts of regulated flows on benthic insects in the Clearwater River, a resiliency based approach to defining the clearwater ecosystem was developed (Figure 31). This methodology disaggregated the system into several levels. In the process of disaggregation, key variables both biological and physical that best represented the processes and components in the benthic insect ecosystem were identified. The first step was to break the system into subsystem components and list their potential attributes (Table 4). Having identified potential attributes, we developed an interactive matrix which indicated potential impacts of physical driving variables of the system on principal biological and physical attributes (Table 5). Where there was a directed interaction we established or inferred relationships. Further we assessed the desirability and feasibility of empirically testing these relationships. Conceivably, all the functional relationships indicated by the interactive matrix could be quantitatively determined. However, determining quantitative relationships for certain of the interactions was clearly unfeasible. The quantification of the remaining feasible relationships still represented a very complex and data-intensive problem. To reduce the data and complexity, an idealized benthic indicator was hypothesized. Based on the physical and biotic characteristics of the Clearwater River System we determined the ideal resiliency indicater should manifest the following characteristics:

- respond in a manner that is consistent with and representative of the population and/or community which it is associated. The responses (or nonresponses) should be both identifiable and quantifiable.

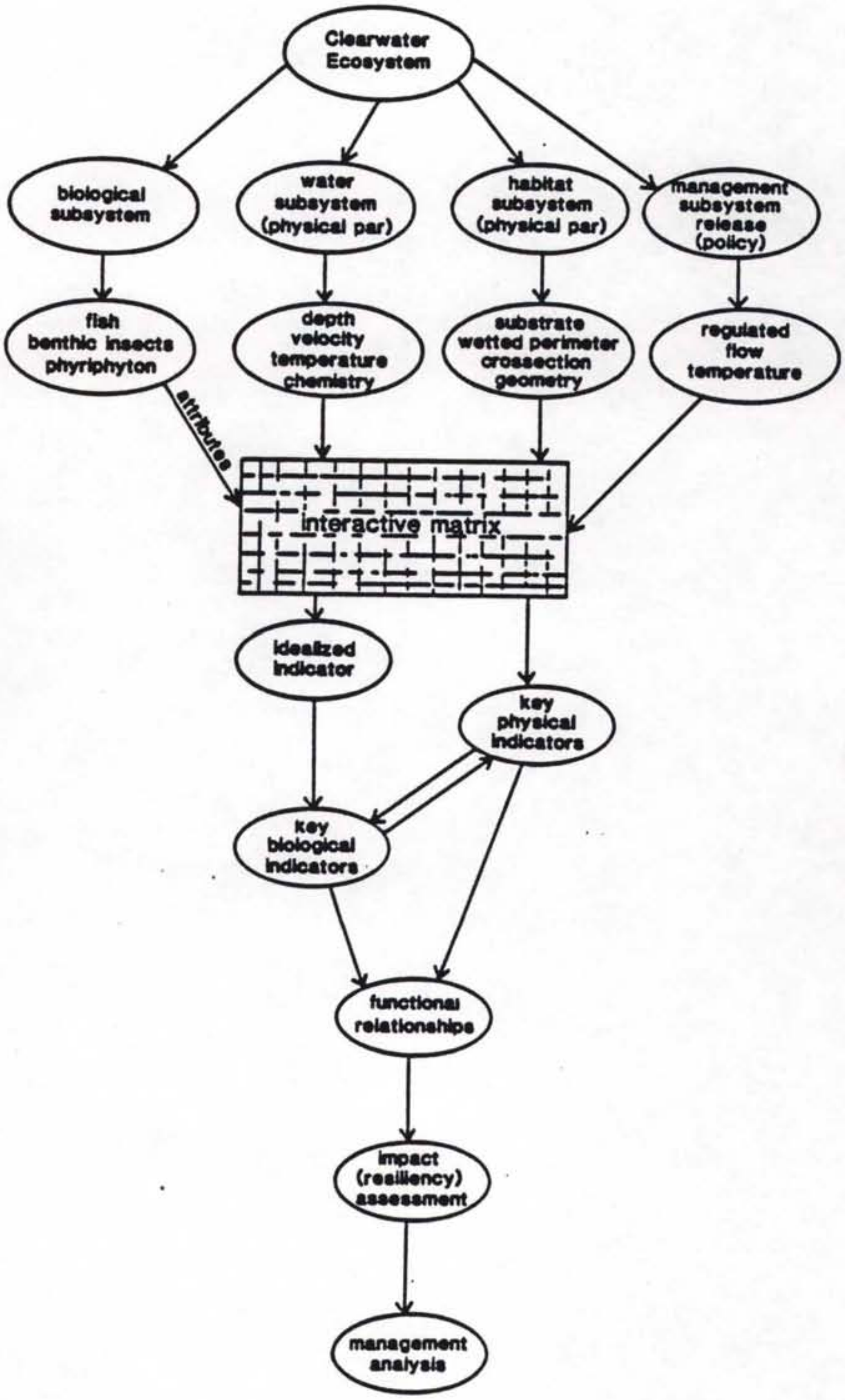


Figure 31. Diagram of the Resilency Methodology Used on the Clearwater River

TABLE 4

SUBSYSTEM COMPONENTS AND ATTRIBUTES OF THE LOWER CLEARWATER RIVER RESILIENCY STUDY

Component	Attributes
Climate & Weather	Air Temperature Relative Humidity Precipitation Cloud Cover Seasonality
Land Use	Mining Logging Grazing Farming Residential-Sewage Plants

Basin Morphology	Geological Considerations
	  Land Form
	  Mineral Composition

Water Chemistry	Temperature Turbidity Nitrates and Nitrites

Hydrology	Flow (natural & control)
	  Rate of change of velocity
	  Velocity
	  Wetted Perimeter
	  Exposed Shoreline
	  Depth
	  Turbulence
	  Scour/Deposition

Channel Morphology	Habitat Type Substrate Type Degree of Slope Cobble embeddedness Thalweg Gradient Thalweg Sinuosity Cross Section Shape Cross Section Roughness
Decomposers	Density Diversity and Abundance Biomass

TABLE 4 (continued)

SUBSYSTEM COMPONENTS AND ATTRIBUTES OF THE LOWER CLEARWATER RIVER RESILIENCY STUDY

Component	Attributes
Periphyton	Phenology
	Diversity and Abundance
	Density
	Biomass
	Photosynthesis
	Predation
	Other (?)
Macroinvertebrates	Diversity
	Density
	Biomass
	Species Richness
	Functional Status
	Mobility
	Survivability when flow impacted
	Colonization Rates
	Phenology
	Fecundity
	Ovipositional Behavior
	Metamorphosis
	Distribution
	Strandability
	Predation
	Other (?)
Vertebrates: Fish	Diversity and Abundance
	Density
	Biomass
	Food Habits
	Life History
	Predation
	Other (?)

TABLE 5

COUPLE MATRIX OF THE LOWER CLEARWATER RIVER RESILIENCY STUDY

Driving Variables / State Variables

	Habitat type	Substrate type	Degree of slope	Embeddedness	Air temp.	Relative humidity	Precipitation	Insolation	Volume	Water temp.	Turbidity	Nitrates & nitrites	Rate of vel. change	Velocity	Depth	Turbulence	Scour & deposition	Particle size	Decomposers: Density	Decomposers: Diversity	Decomposers: Biomass	Primary Producers: Diversity	Primary Producers: Density	Primary Producers: Biomass	Primary Producers: Photosynthesis	Macroinvertebrates: Diversity	Macroinvertebrates: Density	Macroinvertebrates: Biomass	Macroinvertebrates: Species richness	Macroinvertebrates: Functional status	Macroinvertebrates: Mobility	Macroinvertebrates: Survivability: LC_{50}	Macroinvertebrates: Strandability	Macroinvertebrates: Colonization rates	Macroinvertebrates: Phenology	Macroinvertebrates: Fecundity	Macroinvertebrates: Ovipositional behavior	Macroinvertebrates: Metamorphosis	Macroinvertebrates: Distribution	Vertebrates: Density	Vertebrates: Diversity	Vertebrates: Biomass	Vertebrates: Food habits	Vertebrates: Phenology
Habitat type																			X	X	X	X	X	X	X	X	X	X	X	X	X		X	X					X	X	X	X	X	
Substrate type	X			X												X			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X					X	X	X	X	X	
Degree of slope	X																														X	X	X	X										
Cobble & Embeddedness	X															X						X	X	X		X	X	X	X	X	X	X												
Air temp.										X																						X	X					X						
Relative humidity										X																						X	X					X						
Precipitation									X	X																																		
Insolation						X			X	X															X							X												
Volume Flow														X		X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X				X	X	X	X	X	
Water temp.										X									X	X	X	X	X	X	X	X	X	X			X				X			X						
Turbidity																						X	X	X	X		X	X		X													X	
Nitrates & Nitrites																						X	X	X	X																			
Rate of vel. change																										X	X	X			X	X	X		X			X	X					
Velocity	X														X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X				X					
Depth	X									X				X			X					X	X	X	X	X	X	X	X			X							X					
Turbulence	X																X								X																			
Scour & Deposition		X		X														X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

- has an identifiable relationship with each of the key driving variables that potentially has a significant impact on the resiliency.
- manifests identifiable and measurable position qualities within the community (e.g. food chain relationships).
- reflects the above responses and relationships throughout the physical bounds (space) and time frame of the impact analysis period.

The idealized indicator presented a framework against which measurable biological attributes could be compared. The following benthic indicators were determined as candidates to best fit the idealized indicator.

1. Total insect density /m^2
2. Species density /m^2
3. Biomass (insect)G/m^2
4. Species richness /m^2
5. Proportional similarity index (community analysis)
6. Functional group characterization

All of the five potential indicators were determined to have some of the characteristics of an idealized indicator. Hence, all of the five might be used as indicators individually or in conjunction with a total impact assessment.

The number of major physical variables were prioritized based on:

1. Historic Data
2. Survey of Literature
3. Recent field data analysis

As an example of the use of recent field measurements to delinate a major physical variable, species richness at a specific test site at a specific depth for a number of dates was evaluated (Figure 30). During the summer season, those sites where dewatering occurred within the 66 day colonization period, species richness showed a substantial reduction. Other species richness values in the summer season where there was no dewatering within the colonization period gave consistantly large values. Depth, substrate, velocity and their impacts on certain biological indicators given previously (Figures 11-21).

The major physical driving variables delineated were:

1. Depth,
2. Wetted Area,
3. Velocity,
4. Substrate,
5. Time, and
6. Temperature

From the above analysis, it is our opinion that the major impacts of regulated flow on benthic insects could be modelled by the six biological indicators and their relationships within the six physical variables. Clearly, the biological indicators and several of physical variables are not independent (i.e., wetted area, depth and velocity).

IMPACTS OF REGULATED FLOWS
A MANAGEMENT ASSESSMENT METHODOLOGY

From the previous resiliency analysis section, the total system impact was hypothesized to be represented by six key biological parameters and their relationship between the six physical driving variables. Since the biological indicators are not independent and are potentially highly correlated, a conceptual biological model is developed. The impacts of regulated flow policies on this biological model is represented by a quantitative model which uses an index representing major key physical driving variables as its impact measure.

CONCEPTUAL BIOLOGICAL MODEL

The fundmental assumption of the conceptual model of benthic insects in the Clearwater River is that continuously watered substrate enables aquatic insect populations to increases towards carrying capacity. As shoreline areas are watered, insect drift provides a ready source of colonists for the newly watered areas. Populations build towards carrying capacity and reach an equilibrium position in approximately 40 days. At that time insects settling in an area are balanced by those which depart via drift. If an area is dewatered, insects which escape stranding are available to colonize substrate not impacted by dewatering, provided that those areas have not reached carrying capacity.

Changes in flow due to natural cycles in the hydrograph or regulation by Dworshak Dam influence both the amount of hectares watered and the length of time that substrate is watered. These in turn affect the potential benthic insect production in the system. If no colonization occurs during daily fluctuations from Dworshak Dam, the key factors influencing benthic insect production (wetted hectares) are mainstem Clearwater River discharge and minimum flow releases from Dworshak Dam (Figure 32).

Dworshak Dam operation has altered mainstem Clearwater River water temperature in comparison to the pre-dam period. The effect is most pronounced during the summer months when both the North Fork and mainstem of the Clearwater River are substantially colder than they were prior to impoundment. However, we assume that the biological effects of altered water temperature in comparison to historical conditions have already occurred. We further assume that daily degree days do not vary among possible operating schedules for the dam.

Assumptions

1. Colonization of newly watered areas is linear and carrying capacity is essentially attained in 40 days.
2. Benthic insect carrying capacity is greatest in depths $\leq$ 24 - 48" is higher than at depths behond 48".
3. Benthic insects are totally eliminated from dewatered areas.
4. Benthic insects which escape stranding during dewatering can colonize areas which are not at carrying capacity i.e. those areas of stream bottom which have been watered for less than 40 days.
5. If carrying capacity is attained, surplus benthic insects enter transport to other areas via drift.
6. Areas which are rewatered are colonized by benthic insects at the same rate, regardless of the length of time the substrate has been dewatered.

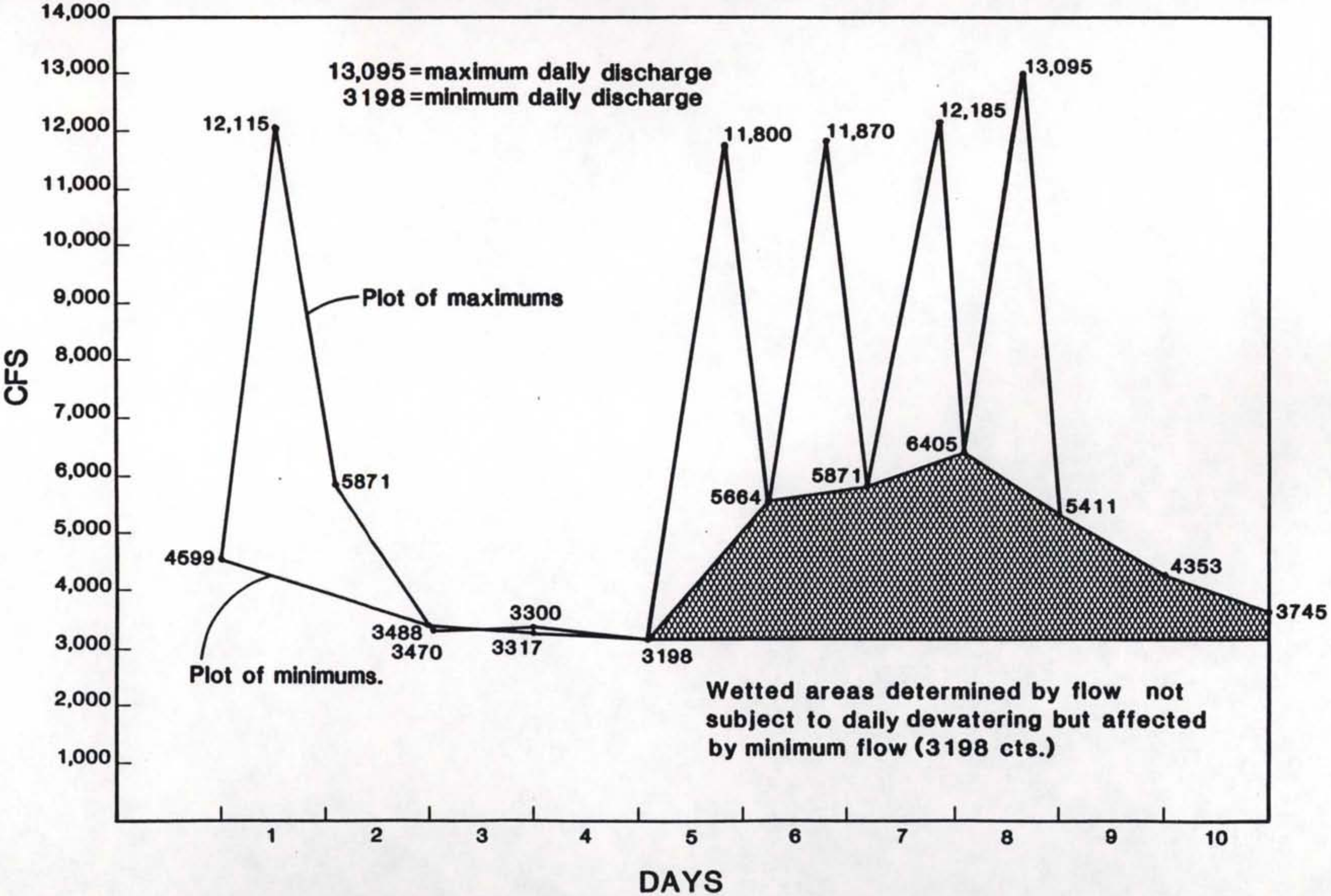


Figure 32. Daily Maximum and Minimum Flows at Peck, Idaho
9/1/78 to 9/10/78

QUANTITATIVE MODEL

The quantitative model presented here uses wetted area as the index to measure the impacts of regulated flows. With the assumptions presented in the biological model and further assumptions presented in this section it is our opinion that wetted area Index will give a comparative estimator (index) of the impacts of the regulated flow policies with respect to benthic invertebrates.

First, an ideal flow case is hypothesized. All other flows will be compared against this ideal flow. This approach allows a relative impact measure but does not attempt to derive absolute impact measures. Moreover, relative comparisons reduces certain physical parameter changes such as to aperature and water quallity charges. Assumptions derived from the comparative approach are:

1. Temperature and water quality regimes different flow regulation policies will be similar. The relative impacts due to these parameter changes are small when compared to dewatering.
2. The proportion of a type of substrate within the total wetted area remains essentially constant with differing flows.
3. The substrate does not change during periods of dewatering.
4. The stretches of river where cross sections did not change appreciably (55% of the length) represents the total length.

IMPACT CASE STUDIES

To illustrate the application of the quantitative model, three actual (historical) flow policies were examined. The Hydro graph for the three flow policies, Spring 1978, Summer 1978 and Fall 1980 were determined and converted to wetted area vs. time using the previously calculated area vs. flow relationship (Figures 33-35).

From the hydrographs, wetted area-hectare days were determined by the following procedure:

1. The area not dewatered for 40 days or more was determined. This area was assumed to be at carrying capacity. The number of days at carrying capacity was determined and a hectare-day index calculated.
2. All other areas were weighted according to the number of days since the area was last dewatered by the following equation.

$$\int_{o}^{tw} C(t) \quad \Delta A \, dt$$

where: $C(t)$ = carrying capacity relationship with time.

ΔA = number of hectares in the area where previous dewatering occurred at the same date.

t_W = the total time from the previous dewatering.

3. $C(t)$ was assumed to be a straight line from 0 to 40 days, that is, $C(t) = t/40$ where maximum carrying capacity is attained at 40 days.

As an example of this procedure, the area where no dewatering occurred over a 40 day period or more was determined by:

$$(\Delta A)\Delta t \qquad \Delta t>40$$

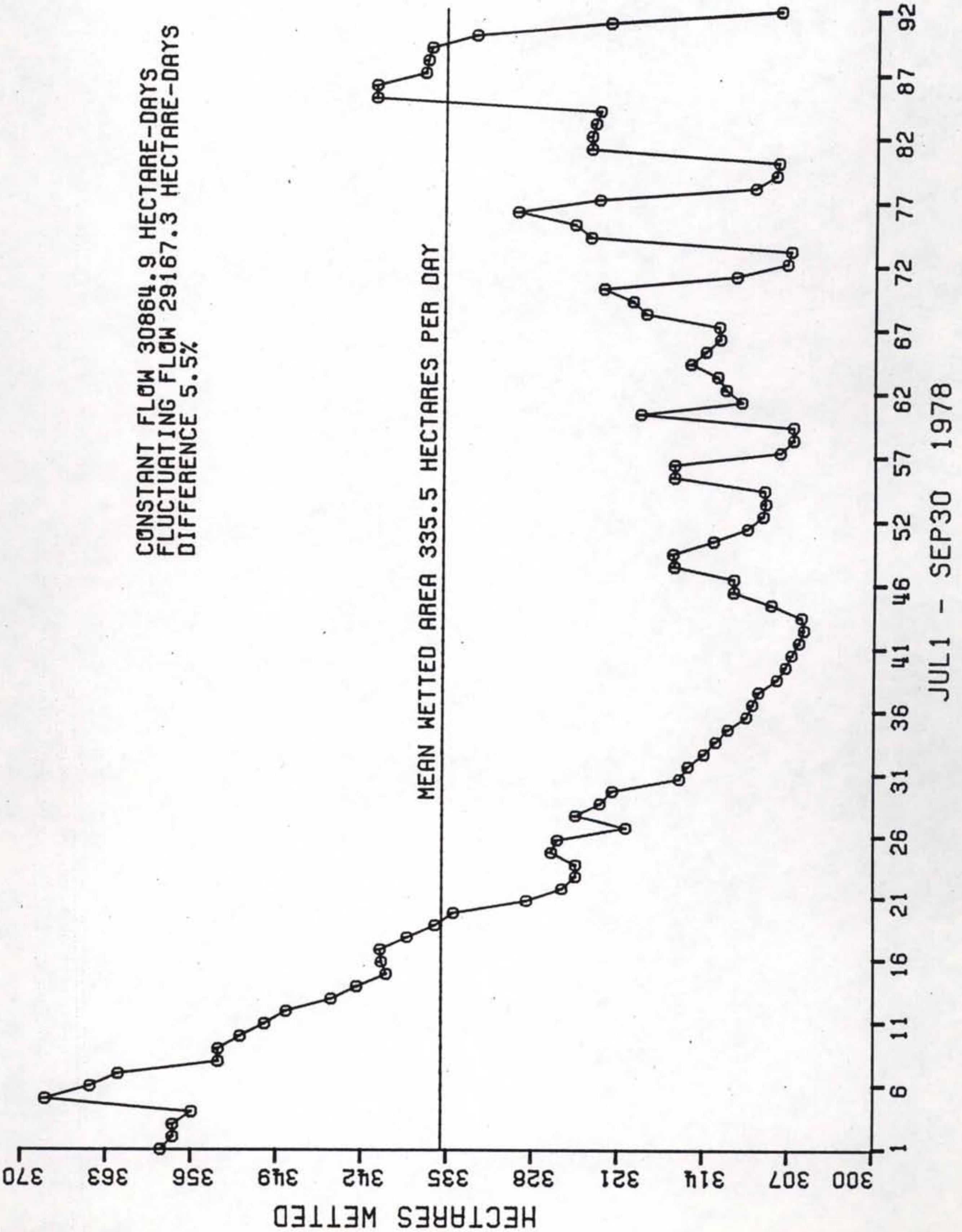


Figure 33. Hectare Wetted July 1 to September 30, 1978

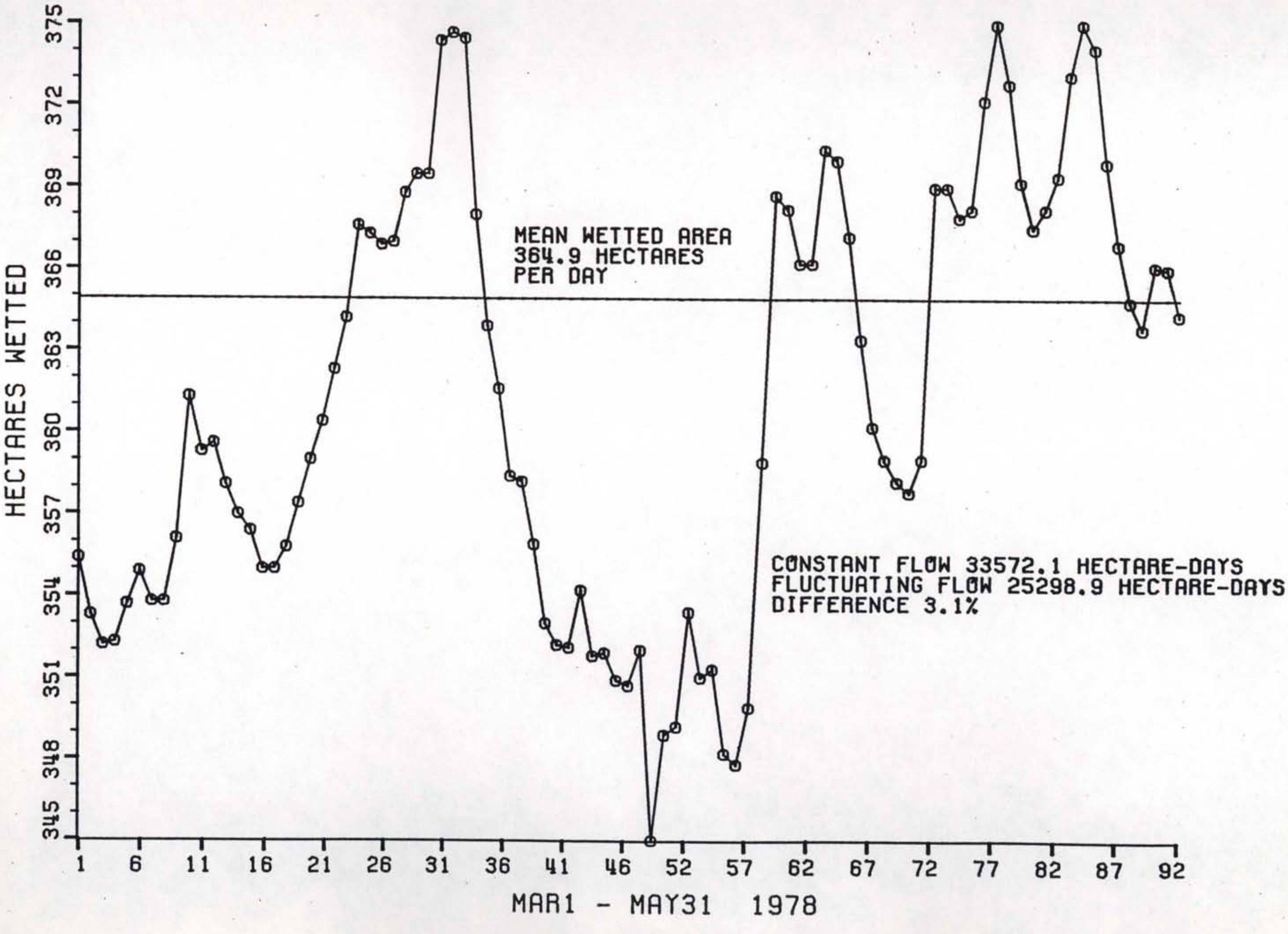


Figure 34. Hectare Wetted March 11 to May 31, 1978

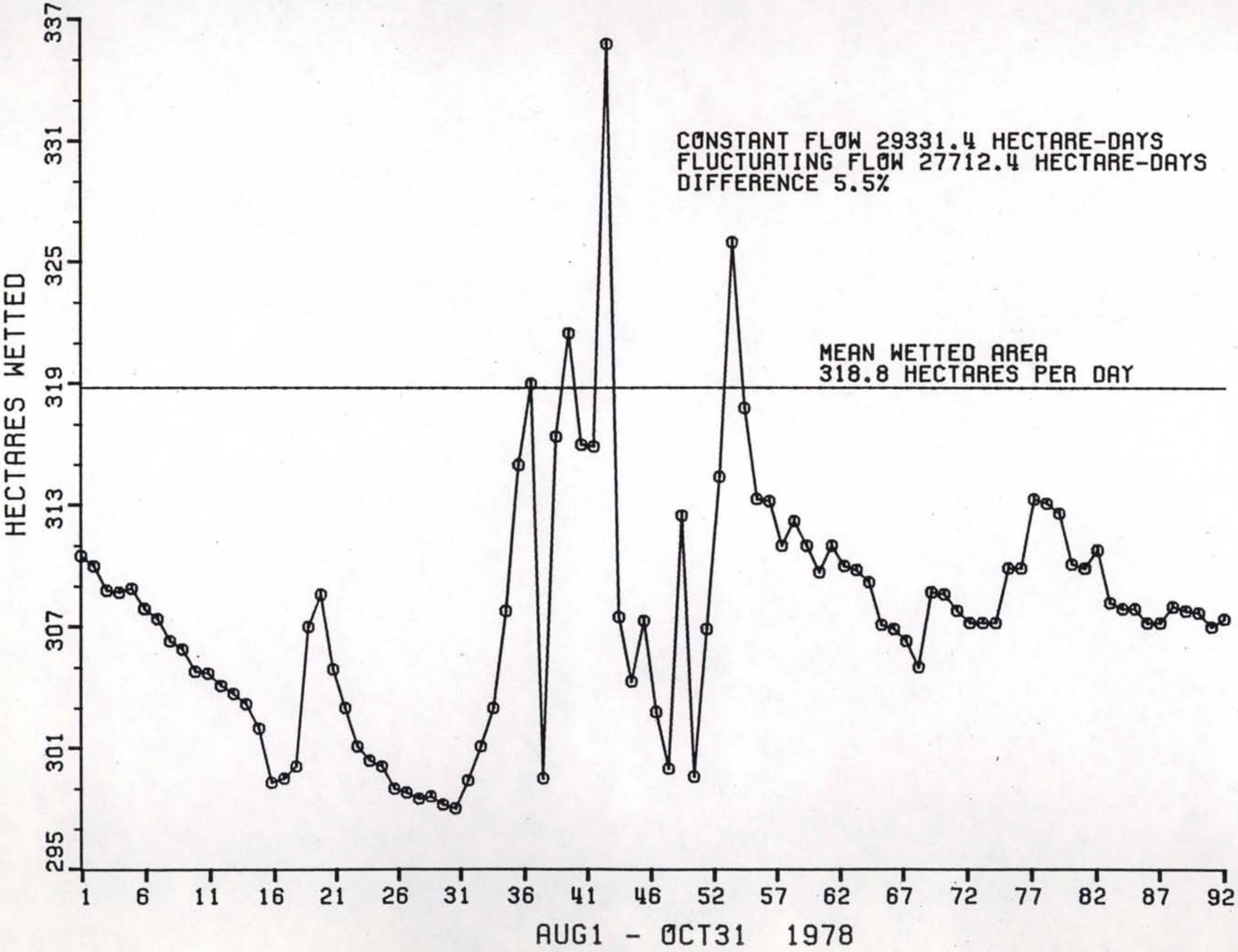


Figure 35. Hectares Wetted August 1 to October 31, 1978

Next, the areas where the time from the previous dewatering was the same were weighted by:

$$\int_0^t \Delta A \frac{t}{40}\, dt \qquad \Delta t \leq 40 \qquad \int_0^{tw} \Delta A \frac{t}{40}\, dt = \frac{\Delta A \quad tw^2}{2}$$

$$(\Delta A) t_w{}^2/2$$

The total of all hectare-days was determined and used as an index of the impact of fluctuating flows by comparison with the hectare-days calculated assuming a completely stable flow during the period. The stable flow was found by determining the total flow over the period and dividing by the length of time of the period considered.

RESULTS OF THE CASE STUDIES

For the summer of 1978, representing a falling hydrograph, the difference between the hectare-day index for fluctuating flows and a constant flow was 5.5% (Figure 33).

The major factor influencing the fluctuating flow index was the minimum summer flow, since the minimum summer flow determines the wetted area that was not dewatered during the entire period (95% of the total index). An increase in this minimum flow would increase the index by the following relationship.

$$\Delta I = t_p\ (146.5)(X_2{}^{-09} - X_1{}^{.09})$$

where ΔI is the increase in hectare-days

t_p the total time of the period

X_1 the period's old minimum flow

X_2 the periods new minimum flow

For example, if the minimum flow was increased from 3000 cfs to 4000 cfs the index would increase by 727 hectare days reducing the difference between fluctuating hours and a constant flow from 5.5% to 3%.

The analysis for the spring of 1978 representing a rising hydrograph resulted in the smallest impact, 3.1% (Figure 34). This result can be explained by the smaller relative size of the regulated peaking flow vs. the natural spring high runoff flows.

For the fall of 1981 which manifested a steady hydrograph, the difference between the ideal (constant) flow and the fluctuating flows was 5.5% (Figure 35.). Again the critical factor was the minimum flow during the period.

All of the previous analysis on the three case studies did not take into account a potential difference in carrying capacity with average depth. From the depth-biological indicator relationships (Figures 11-17), a definite trend is established with increasing depth. If this were factored into the hectare-day index, the impacts may be greater than indicated by the three case studies. However, there is also a natural flow fluctuation which would mitigate the influence of the regulated impact.

Figure 36 gives a comparison of the regulated flow on the main stem of the Clearwater River at Peck with the unregulated flow at Orofino during the fall of 1981. As can be noted, there was a definite fluctuation of the unregulated flow which is followed in general by the main stem. In addition, the main stem flow at Peck has considerably more fluctuations during the last 40 days than the unregulated flow at Orofino.

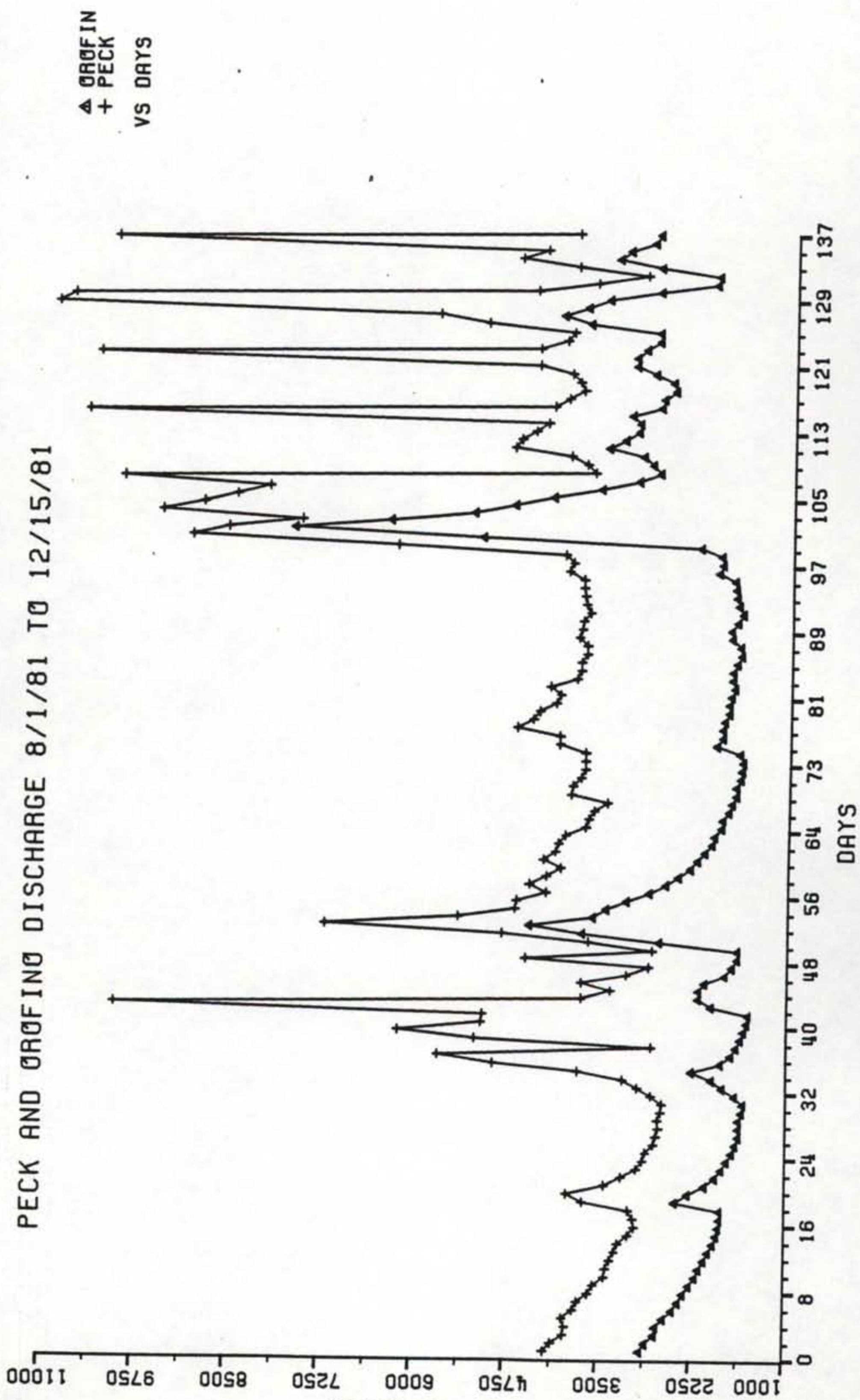


Figure 36. Peck and Orofino Discharge 8/1/81 to 12/15/81

SUMMARY

Water velocity, depth, substrate and temperature are important variables for assessing the impact of regulated flows on the macroinvertebrate community in big rivers such as the Clearwater River.

The resiliency methodology developed in the research resulted in the determination of the Hectare-Day Index. This index could measure the major impact of regulated flow, that is, dewatering substrate, on benthic production and carrying capacity of a conceptual biological model. Other impacts on the benthic model due to changes in temperature, water quality or substrate were considered to be of much smaller scale especially when comparing impacts in a relative sense.

Mean insect density (except for Diptera) and species richness decreased as depth increased from < 60 to > 300 cm; mean insect density and species richness increased from velocities of < 6 cm/sec to > 60 cm/-sec; in the Clearwater River where cobbles, boulders and sand represent over 95% of the dominant particle sizes among the various habitats, largest insect density and species richness occurred on cobble substrates, the least on sand.

Colder water temperatures from Dworshak Dam during the summer apparently inhibited the short and long life cycle development of the mayflies, _Ephemerella margarita_ and _E. infrequens_, respectively, by one or more months when compared to the life cycles of the same species occurring above the confluence of the NFCR. We contend that colder summer temperatures are at least partially responsible for the extremely low densities of middle and late instar _E. margarita_ on the NFCR below the dam; species among the other insect orders could be similarly affected.

Pre-Dworshak water temperatures in the NFCR during winter months were ca. 45 degree weeks (C°) colder than post-Dworshak temperatures; the summer months were ca. 100 degree weeks warmer. Mixing of MFCR and NFCR water caused a considerable amelioration of MSCR temperature, reducing the temperature differential to 18 and 39 degree weeks, respectively, for the two seasons.

Proportional similarity indices indicate the insect community on the NFCR below Dworshak Dam is highly dissimilar from locations above Dworshak Dam, the MSCR and MFCR. The dissimilarity is attributed to fewer species and a different density composition at the former site. We view the NFCR below Dworshak Dam as a useful indicator or advance warning system of possible cause-effect relationships of discharge and temperature on the MSCR should greater extremes of these variables occur during future power generation.

The rate of insect colonization on a sterile substrate, which may be construed as the equivalent of a newly water-shore zone, differed between the MSCR and MFCR. We predict 47 days are required to attain carrying capacity in the MFCR and 66 days in the MSCR in late usmmer. We believe colder temperature during the summer months is one of the principal variables affecting rate of colonization because of its association with primary production and benthic insect life cycles.

LITERATURE CITED

Baxter, R. M. 1977. Environmental effects of dams and impoudments. Ann. Rev. Ecol. Syst. 8:255-283.

Brusven, M. A. and D. F. Haber. 1981. Effects of Power Peaking Cycles from Simulated Fourth Generator Discharges on Benthic Invertebrates in the Clearwater River. Project Completion Report, U.S. Dept. of Interior, Fish and Wildlife Service. Contract No. 14-16-0001-80176. 54 pp.

Brusven, M.A. and C. MacPhee. 1976. The effect of river fluctuations resulting from hydroelectric peaking on selected aquatic invertebrates and fish. OWRT Tech. Compl. Rep., Project A-035-IDA, Univ. Idaho. 46 pp.

Brusven, M. A., C. MacPhee and R. C. Biggam. 1974. Effects of water fluctuation on benthic insects. IN Anatomy of a River. Pacific Northwest River Basins Report. Vancouver, WA p. 67-69.

Brusven, M.A., W. R. Meehan and R. C. Biggam. 1979. Interacting Effects of Substrate and Fluctuating Flows on the Distribution and Abundance of Aquatic Insects. Proj. Compl. Rep. No. 1702-13, USDA, USFS, Corvallis, OR. 42 pp.

Brusven, M. A. and E. F. Trihey. 1979. Interacting effects of minimum flow and fluctuating shorelines on benthic stream insects. Tech. Compl. Rep. Proj. No. A-052-IDA. Idaho Water Resources Research Institute. 78 pp.

Falter, C. M., W. H. Funk, D. L. Johnstone and S. K. Bhagat. 1973. Water quality of the lower Snake River, especially the Lower Granite Pool area, Washington-Idaho. Univ. Idaho-Wash. State Univ. joint research report to U. S. Army Corps of Engineers, Walla Walla District. 257 pp.

Gersich, F. M. and M. A. Brusven. 1981. Insect colonization rates in nearshore regions subjected to hydroelectric power peaking flows. J. Freshwater Ecol. 1:231-236.

Hynes, H. B. N. 1970. Ecology of Running Waters. Univ. Ontario Press, Toronto. 555 pp.

Price, P. W. 1975. Insect Ecology. John Wiley and Sons, Inc. New York. 514 pp.

Shaw, D. E. and G. W. Minshall. 1980. Colonization of an introduced substrate by stream macroinvertebrates. Oikos 34:259-271.

Stalnaker, C. B. and J. L. Arnette. 1976. Methodologies for the determination of stream resource flow requirements: An assessment. U.S. Fish and Wildlife Service Report, Office of Biological Services. 199 pp.

Stanton, J. E. 1977. Post-impoundment effects of regulated flows from Dworshak Dam on the Benthic insect community of the Clearwater River, Idaho. Unpublished M. S. Thesis, Dept. of Entomology, Univ. of Idaho, Moscow, ID. 80 pp.

Walker, R. 1972. Benthos and periphyton communities in riffles of the Clearwater River, ID. Unpubl. M.S. thesis. Univ. Idaho. 42 pp.

Ward, J. V. and J. A. Stanford. 1979. Ecological factors controlling stream zoobenthos with emphasis on thermal modification of regulated streams. IN Ward and Stanford (ed.). The Ecology of Regulated Streams. Plenum Press, New York and London. 398 pp.

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16. Abstract

A systems approach was used to determine certain biological and physical indicators which were used to characterize the benthic ecosystem in the Clearwater River below Dworshak Dam, Idaho. Using these indicators, a Hectare-Day Index was developed that resulted in a quantitative measure of impact of regulated flow on the benthic system.

For three selected periods, Summer 1978, Fall 1978 and Spring 1981 the reduction in the Hectare-Days Index when compared to an idealized constant flow for the same period was: 3.1% for the spring period, 5.5% for the summer and 5.5% for the fall period.

The analysis of field tests over the period 1977 through 1980 indicated mean insect density and species richness decreased as depth increased from < 60 to > 300 cm; the density and richness increased from velocities of < 6 cm/sec to > 60 cm/s; in the Clearwater River where cobbles, boulders and sand represented over 95% of the dominant particle sizes among the various habitats.

The rate of insect colonization on a sterile substrate was used to predict carrying capacity for main stem Clearwater River. Sixty days was predicted time required to attain full carrying capacity in the regulated reach. By point of contrast 47 days were required for the unregulated reach (Middle Fork).

17a. Descriptors

*Regulated Flow, Benthic Insects,*Benthic Colonization Rates, Impact Indicators, Flow, Velocity, Substrate, Water Temperature,*Species Richness, Density, Rating Curves, Hydro-Peaking Management, Resiliency.

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