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Drs. Craig MacPhee, M. A. Brusven and C. Douglas Gordon
Project Investigators
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The Effects of River Fluctuations Resulting From Hydroelectric Peaking on Selected Aquatic Invertebrates

by

Craig MacPhee
Fisheries Resources

and

M. A. Brusven
Entomology

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Water Resources Research Institute
University of Idaho
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John S. Gladwell, Director

ABSTRACT

Near-shore variation in number and weight of riffle insects was shown to be affected by changes in depth (15, 30 and 45 cm) and current velocity, interacting with date and station of sampling. This differential littoral distribution of riffle insects resulted in variation of the littoral community structure. In the non-fluctuating system, community diversity and diversity per individual decreased with increasing depths to 45 cm and current velocity to 1.1 m/sec. Fluctuating flows appear to reverse the order of the community structure, i.e., community diversity and diversity per individual increase with increasing depth to 45 cm and current velocity to 1.1 m/ sec. A flow reduction exponentially increased the number of drifting insects in zones adjacent to the exposed substrate in the shoreline. Insects tested in the laboratory demonstrated variability in temperature-exposure tolerances. The case-bearing caddisfly, *Dicosmoecus* sp., was generally more tolerant than the stonefly, *Pteronarcys californica*, at most temperature regimes. Older age-class nymphs of the latter were more tolerant than younger nymphs. Shore migration studies indicated stoneflies were much more successful in maintaining contact with the water column during flow reductions than caddisflies and mayflies; mayflies were most vulnerable.

ACKNOWLEDGMENTS

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FOREWORD

The Water Resources Research Institute has provided the administrative coordination for this study and organized the interdisciplinary team that conducted the investigation. It is the Institute's policy to make available the results of significant water related research conducted in Idaho's universities and colleges. The Institute neither endorses nor rejects the findings of the authors. It does recommend careful consideration of the accumulated facts by those who are assuredly going to continue to investigate this important field.

PREFACE

A hydroelectric power facility such as that at Dworshak Dam is used for hydroelectric peaking and results in rapid changes of downstream river levels. The ecological impact of these fluctuations in water level and water quality on aquatic organisms must be determined to find the optimum relationship between power production and aquatic habitat.

The North Fork of the Clearwater River contributes about 37% of the flow in the Clearwater below Ahsahka. Since the filling of Dworshak Reservoir, the North Fork is subject to almost complete regulation with the spring runoff being stored and then released during the normal low flow seasons. With the initial three power units already installed, the minimum and maximum planned releases range from 30 to 340 cubic meters per second. Unrestricted powerplant peaking operations could result in rapid fluctuations between the two release extremes and could cause a change in the water level in the lower Clearwater (that portion of the river below the North Fork) of up to 0.9 meters. If total potential generating capacity were to be installed, unrestricted peaking could result in downstream fluctuations of up to 2.1 meters.

The natural water temperatures of the lower Clearwater varied from approximately -1°C in February to over 24°C in July and August prior to the existance of Dworshak Dam. The multi-level power penstock intake and release system at Dworshak Dam will allow regulation of the water temperature of the river below the reservoir. It would be possible to closely match the natural temperatures in the main stem of the river during parts of the year. Alternatively, if reservoir withdrawals were taken only from the lower levels, the natural maximum summer water temperatures in the lower river could be reduced by about 8°C (from 24° to 16°C). During the winter months the releases would be about 3°C to 6°C warmer than the natural river temperature.

Existing benthic algal and insect populations have become genetically adapted over a long period of time to the existing environmental regime of the river. With increased velocities and sharp temperature fluctuations at critical periods of their life cycles, it is to be expected that numbers, and perhaps an abundance of algal and insect forms, might decrease. A decline in available food organisms could adversely affect the resident fish populations in the lower Clearwater.

The first two-year phase of this project has provided valuable background information on water fluctuations on the Clearwater River during the filling of Dowrshak Reservoir. Simulation studies in the field and laboratory have also produced important results on ecological resilience of shoreline benthos. Because fish and benthic populations are collectively influenced by water level changes, it is necessary to understand their relationships. The continuance of this project through December 1975 will provide an opportunity to establish these relationships.

The research from this OWRR sponsored study provided experience which contributed to the securance of a National Marine Fisheries Service contract. The project sponsored by the Fisheries Service involved the effects of a rapidly and sequentially lowered discharge on benthic insects as related to the catchability and feeding habits of fishes in the area. Furthermore, the hydro-peaking project is part of a many-faceted Snake River flow study that involves a number of resource agencies and other cooperating parties.

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INTRODUCTION

This study was initiated to assess the effects of diel water fluctuations on the aquatic insects below Dworshak Dam on the Clearwater River. Because the study took place before the river was subjected to diel water fluctuations (July, 1971,to June, 1973), this objective was modified to include basic research on inshore distribution and drift of aquatic insects. This expanded objective has aided in our understanding of: (1) benthic community dynamics downstream from hydroelectric dams, and (2) the resiliency of specific insect species to diel water fluctuations. In downstream inshore areas, diel fluctuations of flow create a lotic counterpart similar to the marine "intertidal zone". The lotic "intertidal zone" will affect the flora and fauna by dewatering, possible desiccation, and other subtle changes.

The study occurred during a period of transition when the natural flow pattern of the lower Clearwater River was interrupted by the construction of Dworshak Dam. Closure of diversion tunnels on September, 1971, caused a reduction in discharge. In 1972 the discharge was controlled and altered as necessary to complete construction. Such alterations resulted in sporadic fluctuations of water levels. The lower Clearwater River may be subjected to diel fluctuations of flow if Dworshak Dam is operated as a peaking facility after completion of construction in 1973.

OBJECTIVES

Increasing demands for hydroelectric power production has stimulated concern about the ecological side effects to the stream biota. In an attempt to understand shoreline fluctuations for the purpose of providing criteria for regulating peaking operations, the following objectives were initiated:

1. To determine the effect of various temperatures and humidities on selected benthic organisms.
2. To monitor composition and numbers of benthos and drift organisms in the lower Clearwater River during the period of transition while Dworshak Reservoir is filled.
3. To correlate changes in numbers and variety of drift organisms in relation to the benthos in the lower Clearwater.
4. To determine differential migration rates of selected aquatic insects in relation to shoreline water fluctuation levels of a controlled flow regime.
5. To attempt to determine differential mortality of selected aquatic insects in relation to shoreline dewatering.

All objectives were essentially satisfied; research objective 5 was achieved in the laboratory.

METHODOLOGY

The methodology for accomplishing the objectives is divisible into three phases which are individually discussed.

Phase 1.

Four sampling stations were established on the main stem of the Clearwater River (two below and two above the confluence of the main stem and its north fork containing Dworshak Dam). The sampling stations were selected on the basis of similarity in substrate type, slope and current velocity.

During the summer and fall of 1971 and 1972 eight collections of benthic invertebrates were taken with a 0.1 m^2. Hess bottom sampler at water depths of 15 and 45 cm (and 30 cm in 1972).

In September and November, 1971, two collections of surface drift were made with 0.1 m^2 drift nets in three different zones having water depths of 30, 45 and 60 cm. One-hour samples were taken every three hours through a 24-hour period.

Closure of a diversion tunnel on September 27, 1971, to commence filling Dworshak Reservoir caused a reduction in flow. Drift nets were used to measure the effect of reduced discharge on drift insects before, during and after the closure.

Phase 2.

Two aquatic insect species in the orders Plecoptera and Trichoptera were tested; two size classes (small and large) of Pteronarcys californica (Plecoptera) were studied.

Insects were placed in petri dishes in a controlled temperature and humidity environment. Temperatures were maintained at five regimes, i. e., 5°, 10°, 15°, 20° and 32°C; relative humidity (65 - 80% range) was maintained with the use of anhydrous salts. Three substrate moisture conditions were tested (dry, damp and watered). Eight replications were made for each species in relation to age-class and substrate-moisture conditions. Insect behavior and mortality were noted at hourly intervals during the initial 10-hour period and at the conclusion of a 24-hour period.

Phase 3.

This phase of the project dealt with determining the rate of shoreline migration of selected aquatic insects under simulated conditions in the field. Three species in the orders Ephemeroptera, Plecoptera and Trichoptera were tested. Shoreline conditions were prepared in a small mountain stream with rake and shovel so that the variables of slope, substrate and wetness would be tested as factors influencing the abilities of insects to maintain contact with the water column. Three slope conditions (steep, moderate and flat) were tested. Two substrate conditions were simulated (sand and pebble and sand and pebble with cobble); two moisture conditions (wet and dry substrate) were evaluated. A 1.5 X 1.5 meter grid with $0.01m^2$ squares was used to record rates of movement. Four to 10 minute time periods were used to monitor direction and rate of movement. Tracking data were plotted on gridded recording sheets.

RESULTS AND DISCUSSION

To facilitate discussion of results obtained during this study, the results will be summarized as individual phases of the project.

<u>Phase 1.</u>

The biomass of benthic insects, especially Trichoptera, was generally greater in deeper (45 cm) than in shallower water (15 cm). The distribution of three species of Trichoptera and three of six species of Ephemeroptera showed regular increases in numbers with depth (Table 1). The other three species of Ephemeroptera and single species of Diptera and Coleoptera declined in numbers with depth.

Analysis of the benthos indicated that depth or factors associated with depth, along with current velocity, contributed significantly to the inshore distribution of species in terms of numbers and biomass.

Community structure near shore varied with depth. During the non-manipulated water levels of 1971, the distribution of individuals among the taxa in an insect community and the mean diversity that each individual contributed to the community (diversity per individual) decreased with increasing depth. The sporadic fluctuations in discharge in 1972 resulted in an increase in community diversity and diversity per individual with increasing depth. Both community diversity and diversity per individual indicate the

Table 1. Mean number (n=12) and weight (mg in parenthesis) of selected benthic insects per m^2 of substrate, at the 15, 30 and 45 cm water depths of stations 1, 2, 3 and 4, July to October, 1972.

	Water depth (cm)		
	15	30	45
Ephemeroptera			
Ameletus sp.	6.14	2.45	1.29
	(11.72)	(2.76)	(.53)
Baetis spp.	1.07	5.49	8.91
	(.27)	(3.86)	(11.02)
Rhithrogena undulata	23.04	32.38	35.05
	(45.48)	(95.11)	(111.99)
Heptagenia solitaria			
	(19.90)	(14.74)	(4.75)
Ephemerella margarita	4.80	16.59	16.77
	(5.21)	(32.56)	(38.75)
Paraleptophlebia bicornuta	9.32	3.76	1.15
	(25.84)	(3.11)	(.39)
Plecoptera			
Arcynopteryx sp.	5.53	11.57	9.23
	(31.39)	(97.14)	(95.11)
Trichoptera			
Hydropsyche sp.	22.58	56.84	59.22
	(232.60)	(733.25)	(843.89)
Cheumatopsyche sp.	21.97	78.56	87.18
	(127.88)	(525.72)	(569.41)
Brachycentrus sp.	7.99	26.47	28.95
	(52.74)	(242.19)	(279.01)
Diptera			
Tendipedidae	64.39	57.94	31.02
	(57.36)	(37.47)	(19.90)
Coleoptera			
Zaitzevia sp.	4.40	3.30	1.34
	(1.55)	(.87)	(.17)

relative stability of community; generally the more stable communities are associated with more complete utilization of the available niches.

No apparent difference in drift rate of immature insects occurred among the three sampled zones during stable flow conditions in September (Figure 1) and November, 1971.

Drift from zone 2 (water depth, 45 cm) is compared with benthos at station 3 (Figure 2). The September 26 values describe a 24-hour pre-treatment or control relationship before aquatic insects were affected by reduced discharge on September 27 (the September 27 and October 5 data represent treatment and post-treatment values, respectively). Although Baetis spp. comprised 53% of the drift samples, the percentage in benthos was only 0.5% (Figure 2). Hydropsyche sp. and Cheumatopsyche sp. contributed 15% and 50% of the benthos respectively, and together 7% of the drift on the control day and 2% during the day of flow reduction. Paraleptophlebia sp. accounted for 16% of the drift on the control day and 0.5% on the day of flow reduction as compared with 2% of the total benthic composition (Figure 2).

Closure of the diversion tunnel at Dworshak Dam resulted in a water level reduction of 30 cm at station 3. The water level reduction took place during daylight hours (1620 to 1700 hr.). Total drift rate of immature insects while the water level was receding did not differ from the controls

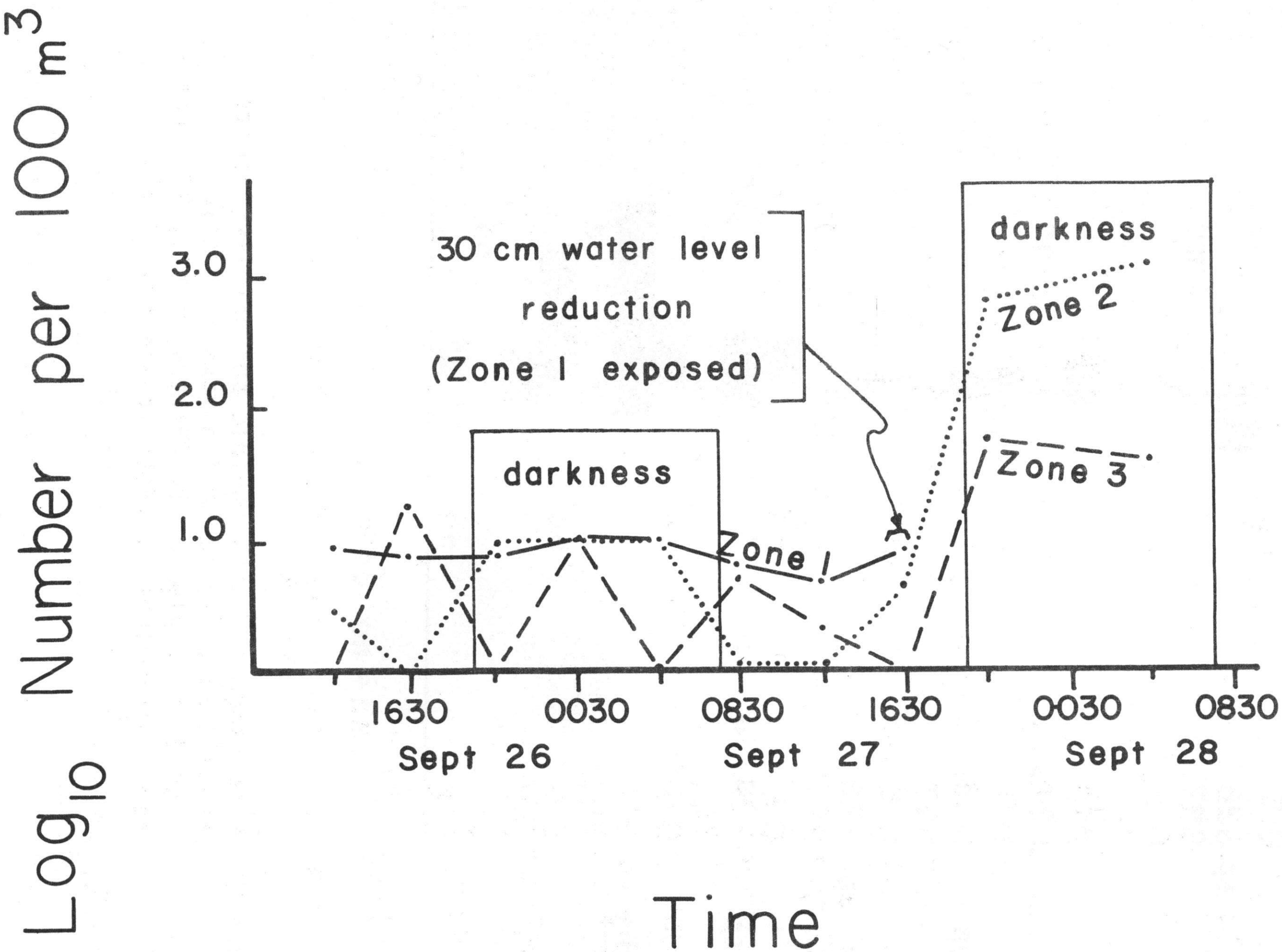

Figure 1. Number of drifting immature insects per 100 m^3 of water at station 3 before, during and after a 30 cm water level reduction (September 26 27 and 28, 1971).

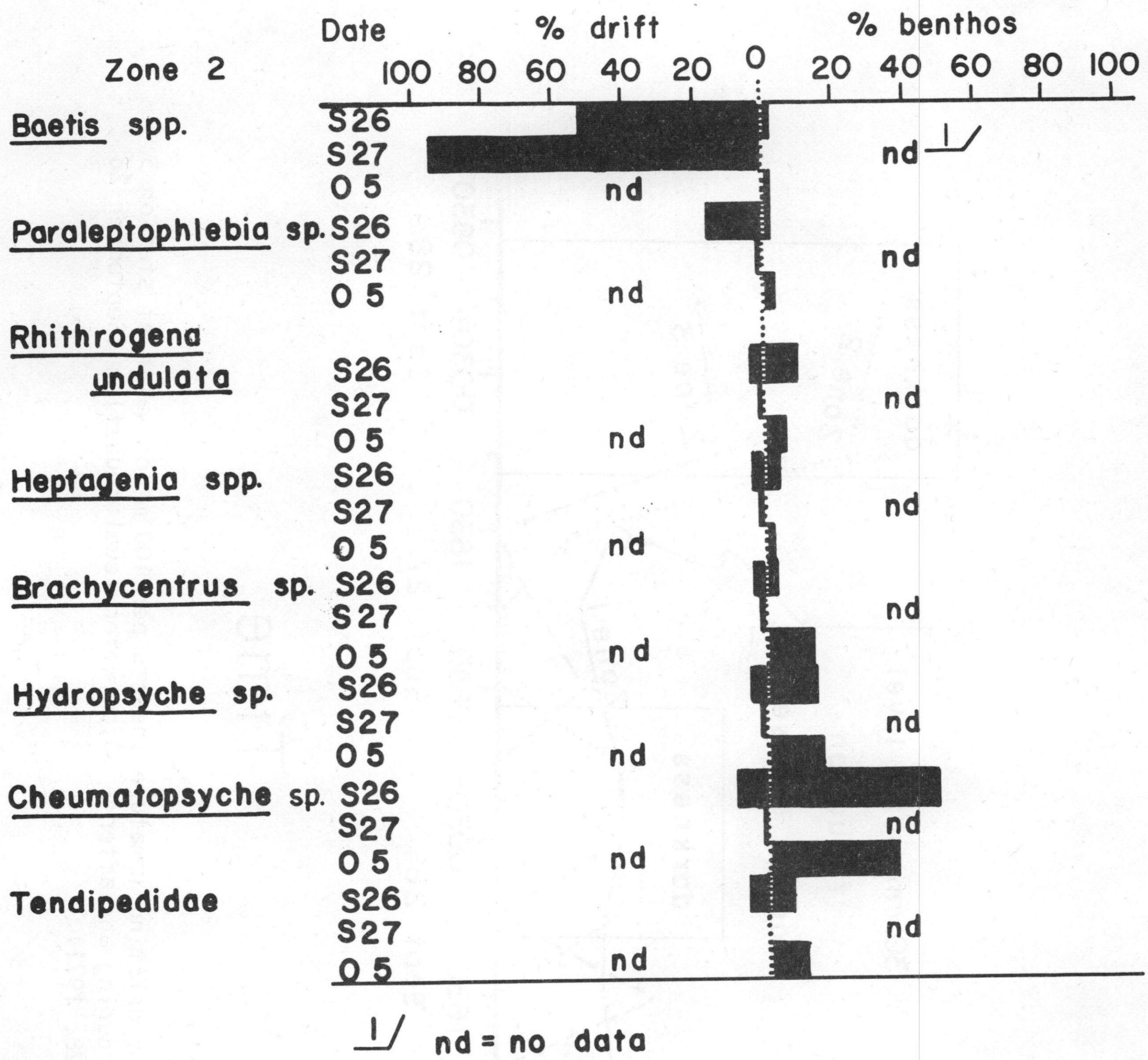

Figure 2. Percentage of total benthic and drifting insects among frequently occurring taxa at station 3, zone 2, on September 26 (Pretreatment), 27 (Treatment) and October 5 (Post-treatment), 1971.

Table 2. Percent survival of insects at 5 temperature levels, 65-80% relative humidity and watered substrate conditions during a 24-hour test period.

Insect	Temp. °C	Percent Survival — Exposure Time (hours) 1	2	3	4	5	6	7	8	9	10	24
Pteronarcys californica (large)	5	100	100	100	100	100	100	100	100	100	100	94
	10	100	100	100	100	100	100	100	100	100	100	100
	15	100	100	100	100	100	100	100	100	100	100	88
	20	100	100	88	81	81	81	81	81	81	81	31
	32	6	0	0	0	0	0	0	0	0	0	0
Pteronarcys californica (small)	5	100	100	100	100	100	100	100	100	100	100	100
	10	100	100	100	100	100	100	100	100	94	94	94
	15	100	100	100	100	94	94	75	75	75	75	56
	20	100	100	88	69	69	69	69	50	44	44	25
	32	0	0	0	0	0	0	0	0	0	0	0
Dicosmoecus sp. (large)	5	100	100	100	100	100	100	100	100	100	100	100
	10	100	100	100	100	100	100	100	100	100	100	100
	15	100	100	100	100	100	100	100	100	100	100	100
	20	100	100	100	100	100	100	100	100	100	100	100
	32	50	50	50	50	50	50	50	50	50	50	0

(Figure 1). However, after darkness the total drift rate of immature insects was 5 and 95 times greater, respectively, than the controls at zone 3 (outer zone) and zone 2 (middle zone) of station 3.

After reduced discharge the mayflies, Baetis spp., increased 180 times more than average and comprised 96% of the total near-shore drift. Although the mayflies, Paraleptophlebia sp., Rhithrogena undulata, and Heptagenia spp., and the caddisflies, Cheumatopsyche sp., Hydropsyche sp., and Brachycentrus sp., increased drift rates 10 to 40 fold while comprising less than 4% of the total drift.

Flow reductions were shown to stimulate exponential increases in the diel drift pattern of insects. Light intensity is the key factor in the phase-setting of drift periodicity; the drift amplitude is affected by current velocity, discharge and water temperature. On low-gradient littoral areas, increased drift rates after flow reductions apparently result from insects moving off the exposed areas and/or adjacent shallow water. Variable increases in drift among different taxa after flow reductions could result from differential abilities to escape.

Phase 2.

Results obtained during simulation studies in this research phase indicate that different insect species are variably affected by temperatures, substrate-moisture conditions and exposure. Pteronarcys californica (Plecoptera) showed high survival at temperatures of 5°, 10° and 15°C under all substrate-moisture conditions. This is most dramatically evidenced in data for watered substrate conditions (Table 2). Smaller forms of this species were more severely affected than larger members. Survival was generally greater on dry and damp substrates than watered substrates, possibly due to a breakdown in respiration. At 32° survival of both size classes of this species was low with mortality nearly 100% after 24 hours.

Dicosmoecus sp., a case-bearing caddisfly, showed considerably more resistance to exposure and higher temperatures probably resulting from its protective encasement.

The results indicate that the two species studied show appreciable "hardiness" at cool temperatures of 5 - 15°C on both dry and damp substrates. Twenty-four hour survival was generally 75% or better. As hydroelectric peaking often operates on a fluctuating 24-hour basis, even a 25% mortality/day of the remaining population could have substantial impact on a population when projected over an extended period of time. While the two species studied were relatively exposure tolerant, it is probable that other species, e.g., mayflies, because of their fragile nature, gill development and thin cuticle, would be more severely affected. Laboratory testing of this group did not permit a critical analysis of any of its species.

Phase 3.

Findings from this phase of the study provided information on mobility and behavior of selected aquatic species when dewatered. Three species were studied representing the aquatic insect order Plecoptera (stoneflies), Ephemeroptera (mayflies) and Trichoptera (caddisflies).

The plecopteran, Pteronarcys californica (Table 3), and the trichopteran, Dicosmoecus sp., showed moderate to high mobility on dewatered shores. The mayfly Ephemerella flavilinea demonstrated little ability to move when released on dewatered shores; mobility was similar on both dry and wet substrates. This latter group, however, effectively used surface interstitial flows to aid movement while the shore was in a state of being dewatered.

The stonefly and caddisfly studied showed a positive geotaxic response to slope. As expected, both net and gross rates of movement were greater on steep shorelines. In no case was there a net movement away from water on steep and moderately sloping shores, while average net movement toward or away from water was negligible. This indicates the insects tested had little orientation to the main stream channel and water when subjected to flat or shallowly sloping shores. If the shore was not ultimately re-watered, high mortality would be expected.

The presence of cobble on the shore as opposed to non-cobbled shores retarded movement of both the stonefly (Table 3) and caddisfly into water

Table 3. Average gross and net rate of movement by _Pyeronarcys californica_ on three slope conditions, two substrate types, and dry substrate conditions -- based on six replications.

SLOPE	Gross Movement Rate (cm/min)[1]	Net Movement Rate (cm/min)[2]	Gross Movement Rate (cm/min)[1]	Net Movement Rate (cm/min)[1]
DRY SUBSTRATE				
	PEBBLE - SAND		PEBBLE - SAND - COBBLE	
Steep	+2.524	+1.336	+1.619	+0.830
Moderate	+2.619	+1.071	+1.520	-0.479
Flat	+1.948	-0.176	+1.593	-0.375
WET SUBSTRATE				
Steep	+3.855	+2.274	+2.053	+1.062
Moderate	+1.645	-0.195	+1.965	-0.909
Flat	+1.520	-0.287	+1.531	-0.058

[1] Average gross rate of movement (cm/min) in all directions from point of origin.
[2] Average net rate of movement (cm/ min) toward or away from water measured from point of origin; + represents movement toward water, - represents movement away from water.

as expected. Damp substrate did not appreciably increase or decrease rate of movement by insects when compared with dry substrate. Dampened sand grains occasionally adhered to the exoskeleton of some stoneflies causing momentary slowing of movement.

SUMMARY

1. Benthic community structure in inshore areas of riffles varied with depth. In non-fluctuating conditions of 1971, community diversity and diversity per individual decreased with increasing depth to 45 cm (maximum sampling depth).

2. The sporadic fluctuating flows of 1972 apparently resulted in a reversal of the 1971 community diversity and diversity per individual along the depth gradient. Community diversity and diversity per individual increase with increasing depth to 45 cm.

3. The loss of community diversity and diversity per individual in the shallow inshore zone means the community has changed to a more unstable form resulting in: (1) fewer species; (2) changes in the dominance relationships among the species; (3) changes in the energy entering the trophic level of insects; (4) changes in energy utilized by the insect trophic levels; and (5) changes in the available energy for higher trophic levels (fish) socially desirable to man.

4. Results indicated that depth or some factor or factors associated with depth, along with current velocity, contributed significantly to the inshore riffle distribution of species in terms of numbers and biomass.

5. There was no apparent difference in drift rate at 30, 45 and 60 cm depth zones in the inshore area during stable flow conditions.

6. Flow reductions were shown to stimulate exponential increases in the diel drift pattern of insects.

7. On low gradient inshore riffle areas, increased drift rates after flow reductions apparently result from insects moving off the exposed areas and/or shallow zones adjacent to the exposed substrate.

8. Uneven increases in drift among different taxa after flow reductions indicate differential abilities to move off of the exposed areas and susceptibility to flow reductions.

9. The relationship between benthic and drifting insects was variable among different species in both the non-fluctuating and fluctuating system.

10. Insects tested in the laboratory demonstrated variability in temperature-exposure tolerances. The case-bearing caddisfly, Dicosmoecus sp., was generally more tolerant than the stonefly, Pteronarcys californica, at most temperature regimes. Older age class nymphs of the latter were more tolerant than younger nymphs.

11. Shore migration studies indicated stoneflies were much more successful in maintaining contact with the water column during shore dewatering than caddisflies and mayflies; mayflies were most vulnerable.

CONCLUSIONS

The ability of insect populations to move laterally with water fluctuations or to withstand periodic exposure can be of prime importance to their survival under conditions of hydroelectric peaking. Very little research has been conducted regarding these parameters; although as the base power load is picked up by nuclear and fossil fuel plants, more and more hydroelectric installations will be operated on a peaking basis.

Research on critical tolerance limits and degree of mobility could establish to what degree the important insect species might be affected by fluctuations. For example, it might be established that if the decrease of water level was restricted to 0.5 feet instead of 1 foot per hour, any detrimental effects would be significantly reduced. Valuable insights should also be provided regarding the possible effects on insect populations resulting from the modification of normal temperature regimes. These effects could have a profound impact on resident and andromous fish.

Little is presently known about the biological effects of fluctuating stream flows; thus, a very real need for research becomes apparent as more and more hydroelectric dams are built, being built, and planned on the Snake and Clearwater Rivers. We feel that this is one area where personnel from the University of Idaho could, and should, develop a high level of expertise.

Several facts tend to focus attention on the need for continued study of the effects of fluctuating stream flows on the aquatic insects. First, aquatic insects are basic to the maintenance of resident fish populations. Second, a pre- and post-impoundment study of insect populations and their distribution can indicate if changes have taken place, but provide little insight as to why changes occurred. A continuous monitoring during the transition period is vital. Third, and perhaps most important, the operational policy for Dworshak Dam is being formulated and there is still time to provide inputs to maximize the optimum relationship between power production and aquatic habitat.

This project links resources from the Idaho Cooperative Fishery Unit, the Department of Entomology, and the Water Resources Research Institute. It also ties together and compliments on-going and proposed research of the Idaho Fish and Game Department and the U. S. Corps of Engineers.

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