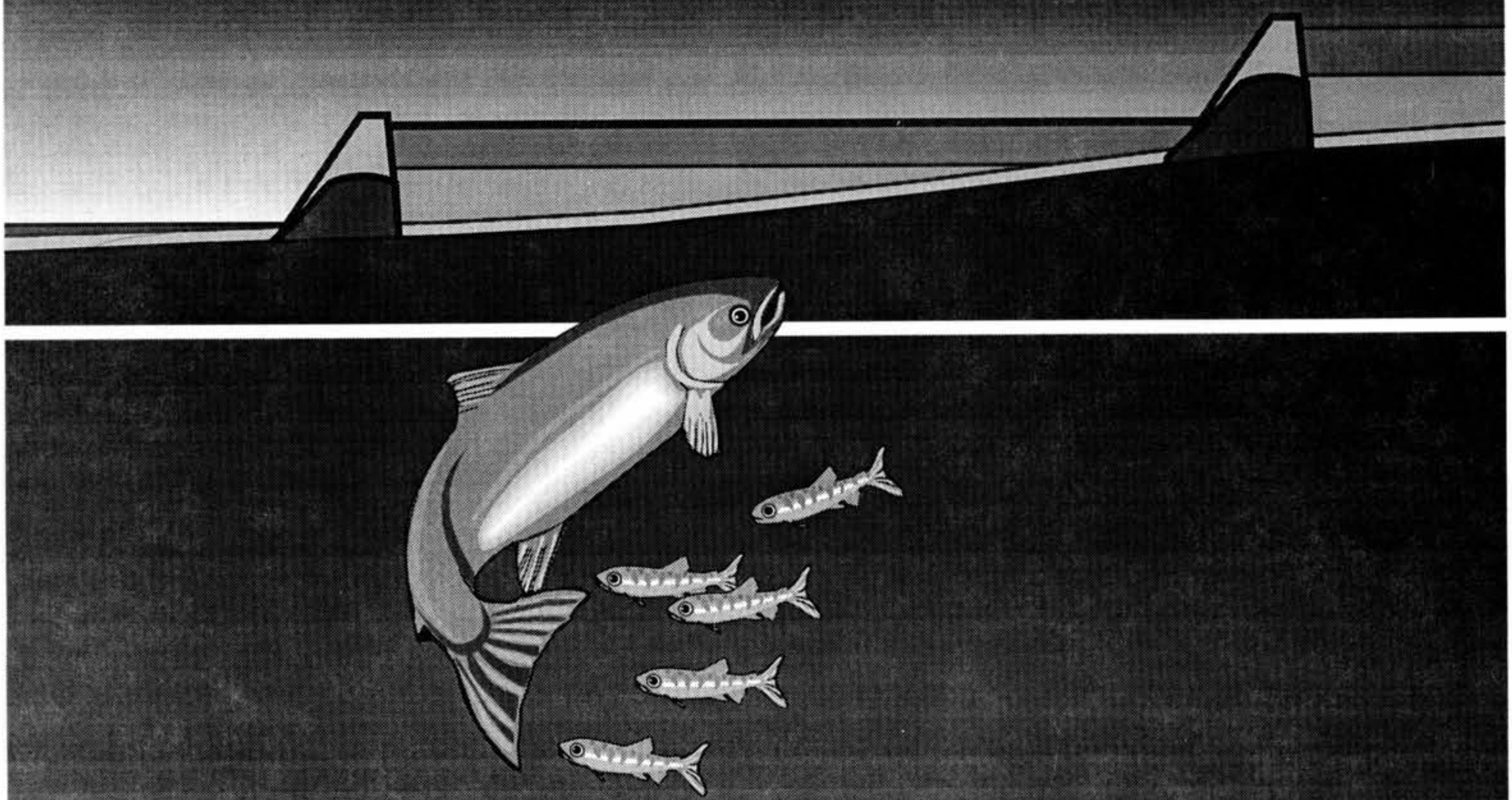
US Army Corps
of Engineers
Walla Walla District

1992 Reservoir Drawdown Test
Lower Granite and Little Goose Dams

Appendix R
Impacts of Experimental Dewatering of Lower Granite and Little Goose Reservoirs on Benthic Invertebrates and Macrophytes



December 1993

PNL-8807
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C. E. Cushing

September 1993

Prepared for the U.S. Army Corps of Engineers
under a Related Services Agreement
with the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830

Pacific Northwest Laboratory
Richland, Washington 99352

Battelle

PNL-8807

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IMPACT OF EXPERIMENTAL DEWATERING OF LOWER GRANITE AND LITTLE GOOSE RESERVOIRS ON BENTHIC INVERTEBRATES AND MACROPHYTES

C. E. Cushing

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EXECUTIVE SUMMARY

An investigation into the effects of dewatering on the benthic fauna in Lower Granite and Little Goose reservoirs was undertaken. Benthos in both the soft bottom regions of the reservoirs as well as those inhabiting the rock rip-rap along the shoreline were studied. These organisms provide an important food resource for both migrating salmonids and resident fish species; thus, impacts of contemplated dewatering schemes require evaluation.

The results of these studies indicate that there were no significant, long-term impacts to the soft bottom benthos as a result of dewatering in Little Goose Reservoir. In fact, higher numbers of some taxa indicate that there may have been a washout of these organisms from Lower Granite Reservoir with subsequent deposition in the upper reaches of Little Goose Reservoir. This should be accompanied by a coincident decrease in these organisms in Lower Granite Reservoir. However, we did not have pre-dewatering samples from Lower Granite Reservoir with which we could compare post-filling samples to determine if the dewatering resulted in lower benthic populations.

For hyporheic and rip-rap benthos, data suggests that dewatering resulted in losses of species that have low mobility, such as molluscs, amphipods, Trichoptera, and tube-dwelling chironomids on rocks. Mobile species such as crayfish were able to follow the receding water to some degree, although many succumbed in the rocks and pools. It also appears that many of the sediment dwelling benthos were also lost as the surficial sediments dried out. It is probably safe to assume that a large percentage of the invertebrates inhabiting the dewatered areas were lost, but these populations probably were replenished after the area was resubmerged. This, of course, is related to how much of the soft bottom habitat is dewatered and how much remains covered with water and thus available as a source of recruitment.

The implications of these results are difficult to ascertain given the cursory nature of these studies. Losses of some benthic food organisms, and other benthic species, are inevitable, and impacts on those surviving the drawdown may affect their subsequent life histories. Impacts of future

drawdowns on benthic organisms will depend on such things as the duration, time of year, and magnitude of the drawdown.

ACKNOWLEDGMENTS

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INTRODUCTION

In March 1992, the U.S. Army Corps of Engineers conducted a test drawdown of Lower Granite and Little Goose reservoirs to determine what impact lowering the water would have on various physical aspects of the system, e.g., erosion, effects on turbines, etc. This drawdown test was part of the ongoing efforts to find ways to protect and enhance the salmon stocks of the Columbia and Snake rivers listed as threatened or endangered under the Endangered Species Act. The purpose of the drawdown would be to increase the velocity of water through the reservoirs, thus theoretically decreasing the time it takes for downstream migrant salmonids to reach the ocean. Several physical and biological studies were initiated to evaluate the impact of the drawdown. One such study, reported here, was an investigation of the impact of dewatering on the benthic invertebrates and macrophytes. These studies included an evaluation of the impact on 1) the benthic invertebrates inhabiting the soft bottom sediments in water up to 60 ft deep, 2) those organisms inhabiting the rip-rap hyporheos (=below substrata-water interface) along the shoreline, 3) any macrophyte beds, and 4) mollusc beds. Because of contract complications, the studies were not initiated until after drawdown of Lower Granite Reservoir had already started; thus, no pre-dewatering control samples were available. Some aspects were largely "reactive" in that cursory investigations were done after field observations documented certain impacts, e.g., the extensive *Corbicula* mortality.

Benthic invertebrates are an important food source for many fish species and are also important ecosystem constituents in terms of energy flow, nutrient dynamics, and secondary production. In Lower Granite and Little Goose reservoirs, they are consumed by migrating salmon (*Oncorhyncus* spp.) and steelhead (*Oncorhyncus mykiss*) as well as bass, sturgeon, and several other resident species (Bennett et al. 1988; 1990; 1991). Thus, it is important to ascertain the potential impacts of the extended periods of dewatering on the benthic community. In terms of overall importance to the ecosystems concerned, the benthos inhabiting the soft sediments could contribute a larger portion of energy to the food web than does that of the rip-rap, because of the soft bottom's greater area. Data on the soft bottom benthos are available

(Bennett et al. 1988; 1990; 1991), but quantitative studies of the rip-rap communities are lacking. Also, the larger area of soft bottom provides a significant source for recruitment following dewatering. However, this is directly related to the extent of water lowering. The greater the lowering of shoreline elevation, the closer the water channel will approximate the original river bed, thus exposing the soft bottom areas to drying and to the potential loss of the benthic fauna characteristic of this habitat.

Potential impacts on the benthic community include 1) desiccation and death, 2) scouring and transport by increased water current, 3) loss of habitat by scouring, 4) loss of organisms (e.g., Hydropsychidae) that abandon retreats and unsuccessfully attempt to follow receding water levels, and 5) forced migration, either by following the receding water levels or retreating into the hyporheic zone if it is available. Of these potential impacts, the first is of vital concern, and can be quantified by appropriate sampling. Observed changes in population densities of the soft-bottom fauna may be related to a combination of these impacts, i.e., desiccation and loss of habitat or conversion of the habitat so that it is no longer inhabitable.

Recovery of the benthic invertebrate community is complex. In the soft bottom habitat, some organisms may survive a temporary dewatering by migrating into the hyporheic zone where moisture is still present as long as the substratum is suitable for burrowing. Others may encyst or have other mechanisms to survive desiccation. Still other species, such as crayfish and some molluscs, are mobile enough to move with the receding water levels, as long as the rate of drawdown is not too rapid, and thus avoid desiccating conditions. However, this does not guarantee their survival; they may simply move to locations that eventually dry up, where they expire. At the time of the experimental dewatering in spring, recovery of this habitat should also be relatively rapid for the insects. New colonizers will be emerging and ovipositing in spring and summer, as contrasted to a dewatering during winter, when emerging insects are scarce or absent.

Aquatic macrophytes are important in aquatic ecosystems in that they provide shelter for organisms, provide substratum for attachment by certain sessile organisms, oxygenate the water, act as sediment traps, and, upon death and decomposition, become an important detrital food source for many organisms. Macrophyte beds may not be prominent in early spring, and may consist only of the rooted parts and masses of last year's dead growth. Depending on the time of year, dewatering could potentially impact macrophytes by desiccation and possible scouring of the substrate if increased current velocities occur.

An important component of aquatic ecosystems, and one which was not studied in detail in this investigation, is the algal food base for grazing and filter-feeding invertebrates. Prolonged dewatering will obviously severely impact this community where it develops on solid substrata, such as the rip-rap. It can die by desiccation or be scoured from the substrate by increased water velocities. In either case, it is not lost to the energy base of the ecosystem because it can be used in either form by filter-feeding invertebrates or by benthic detrital feeders. Periphyton communities will recolonize rapidly (~3 weeks, Cushing 1967).

OBJECTIVES

There were two objectives to the benthic studies:

Objective 1. To quantify the impact of the experimental dewatering on the soft bottom benthic invertebrate community and determine the temporal sequence of recovery of the invertebrates following refilling, and to qualitatively assess the impact upon the hyporheic and rip-rap community.

Objective 2. To use the data gathered in Objective 1 to assess its usefulness for future evaluation and monitoring of dewatering operations.

There were two objectives to the macrophytes and mollusc beds studies:

Objective 1. To assess the impact of dewatering on aquatic macrophytes and mollusc beds.

Objective 2. To use the data gathered in Objective 1 to assess its usefulness for future evaluation and monitoring of dewatering operations.

Again, it must be emphasized that to adequately fulfill the objectives of these studies, baseline data in the form of adequate control and/or pre-disturbance data are needed, but were not available. If ecological assessments are going to be a part of further dewatering operations, it is essential to obtain a basic data set on the ecological resources in these reservoirs, including seasonal and spatial variations of the biota, and diversity of species.

STUDY LOCATIONS

The evaluation of the impact of the dewatering on the soft bottom benthic community was done in both Little Goose and Lower Granite reservoirs, with emphasis on the former (Figure 1). It was not possible to obtain pre-dewatering samples from Lower Granite Reservoir prior to drawdown, but a sampling regime was established that would provide pre-dewatering and post-filling benthic samples from Little Goose Reservoir. Post-filling samples from Lower Granite Reservoir were collected in case some of the earlier data on this site (Bennett et al. 1988; 1990; 1991) could be used to compare with our samples. Obviously, the main emphasis was on the Little Goose site where the full suite of data from the same sampling stations was available.

Lowering of Lower Granite Reservoir began on March 1, 1992, at a rate of 2 ft per day (steady throughout the 24-h period). A drawdown of 27 ft below normal minimum operating pool (MOP) was achieved on March 15. Nine spill tests were conducted between March 15 and March 27, during which Lower Granite Reservoir was drafted an additional 9 ft. Simultaneous with the Lower Granite spill tests, Little Goose Reservoir was lowered a total of 12.5 ft below normal minimum operating pool (also at a rate of 2 ft per day, but actual drafting was limited to daylight hours).

As a result of the drafting schedules and spill tests, the benthic substratum beneath the upper 27 ft of reservoir water in Lower Granite reservoir was exposed for a substantial period of time. The additional 9 ft (for a total of 36 ft) were exposed for a very minimal amount of time because of the spill tests, which consisted of rapid pool lowering and refill, and the relatively short total test duration (refill by April 1 was required). Discharge increases required for the spill tests resulted in water surface elevation increases in Little Goose Reservoir over substantial areas, but particularly at the upstream end (higher discharge equals higher tailwater elevation). Figure 2 shows Lower Granite and Little Goose reservoir elevations during March 1992. Pool fluctuations during the March 1992 test do

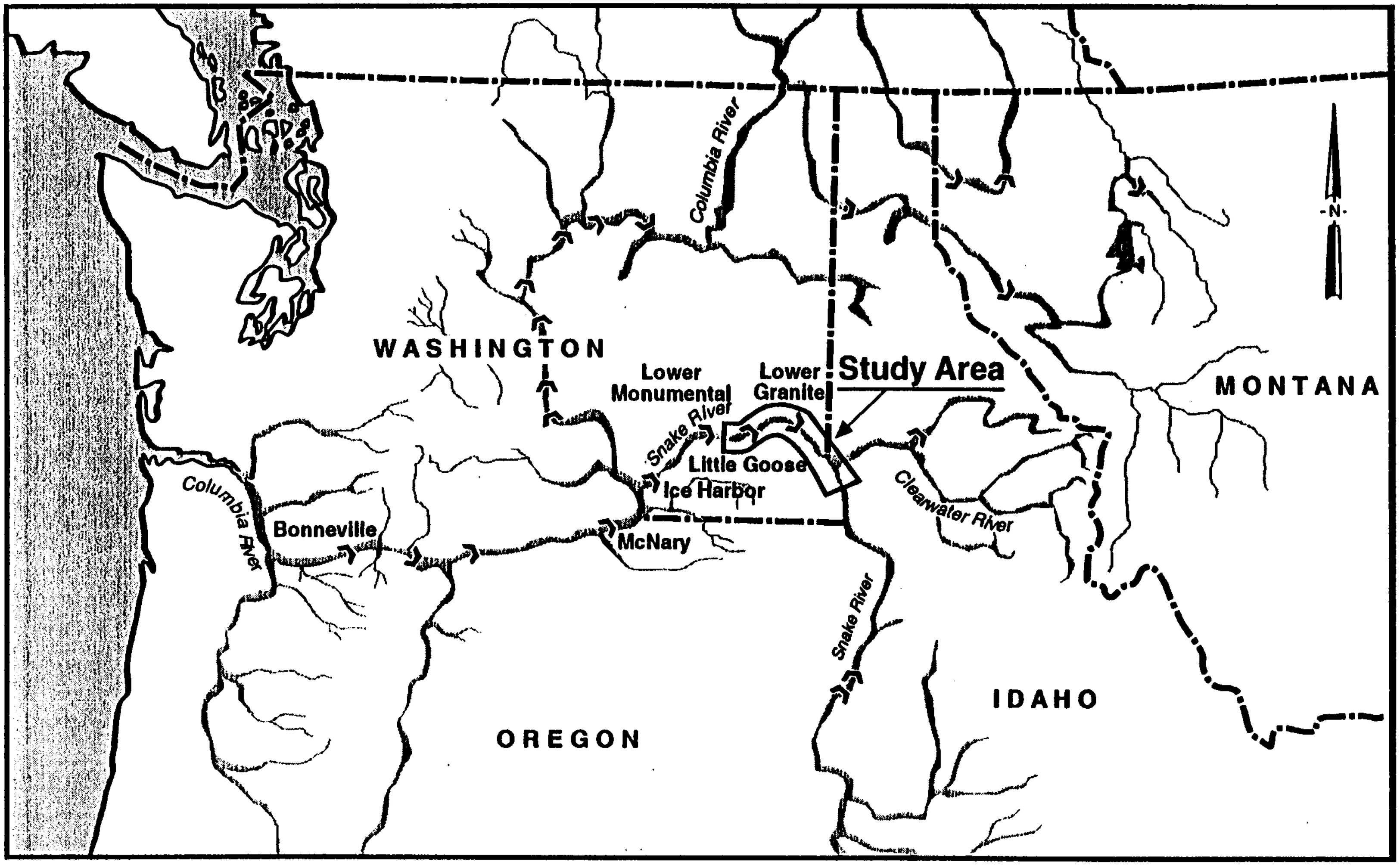

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FIGURE 1. Location of Study Area

not represent the conditions that would occur during a long-term drawdown operation; therefore, effects observed on benthic organisms do not necessarily represent those likely to occur.

Two sampling sites were established in Little Goose Reservoir for quantitative sampling (Figure 3). One was at Schultz Bar (RM 100), a site having a significant amount of sand in the substratum, and the other at Rice Bar (RM 93.5), a site where the bottom deposits contained significantly more silt and organic matter, and therefore where recolonization/recruitment would be expected to be more rapid. Dredge samples were collected in the 0 to 15 ft and 15 to 60 ft depth range at each site.

Two sampling sites were also established in Lower Granite Reservoir for quantitative sampling (Figure 4). One was just above Nisqually John Landing (RM 127.5) and the second at Chief Timothy State Park (RM 131). Samples were collected at the same depths as in Little Goose Reservoir.

Hyporheic and rip-rap samples were collected at various locations along the north shore of Lower Granite Reservoir. These qualitative evaluations included ground surveys and observations made at several sites between Wawawai Landing and Nisqually John Landing.

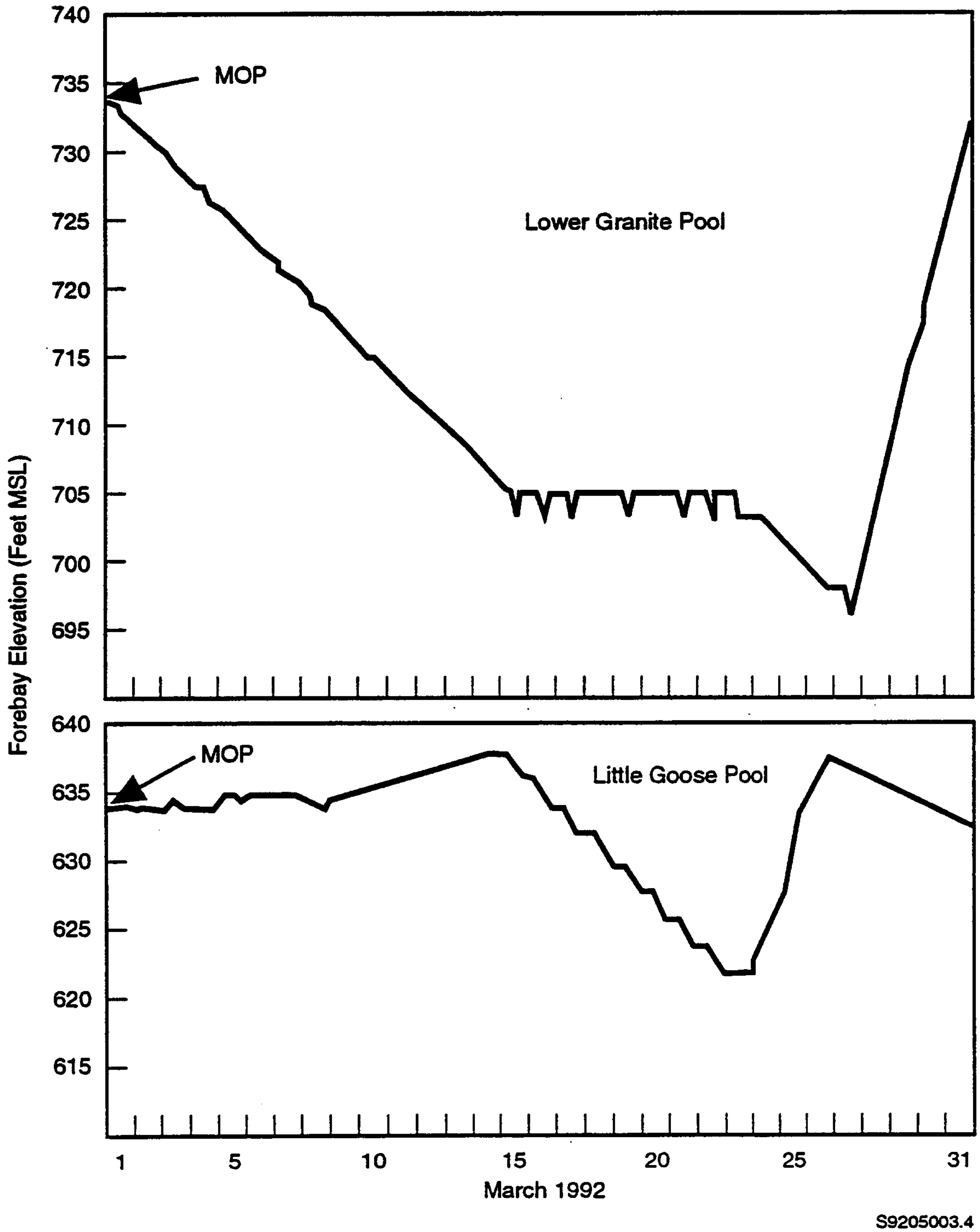

FIGURE 2. Pool Level Fluctuations in Lower Granite and Little Goose Reservoirs, March 1992

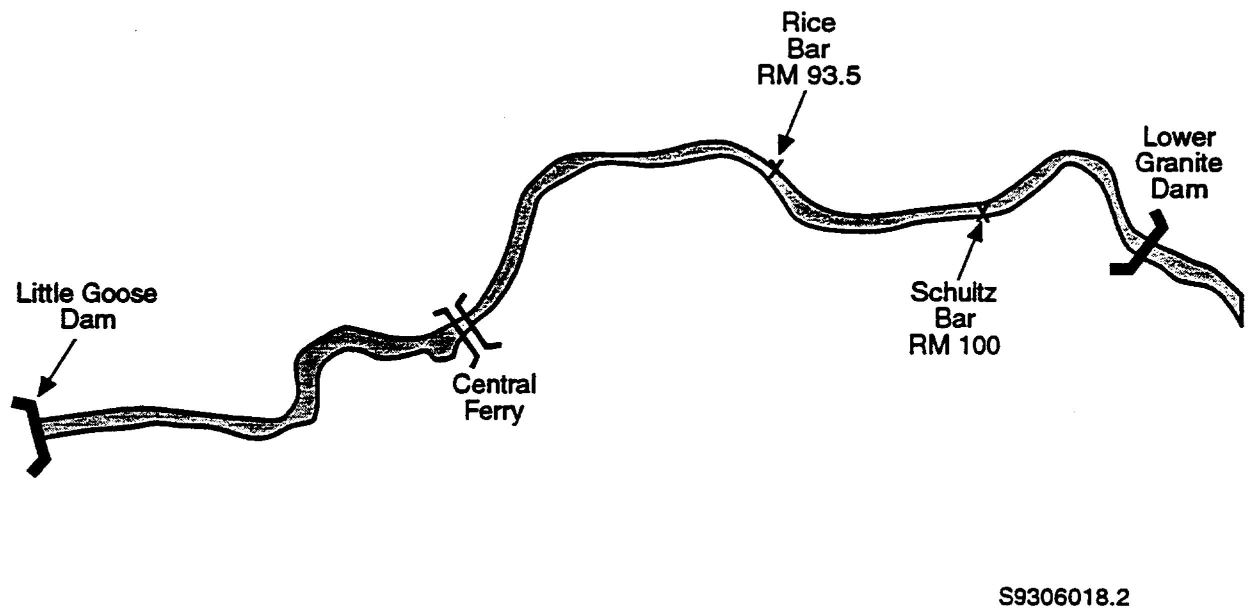

FIGURE 3. Sampling Locations in Little Goose Reservoir

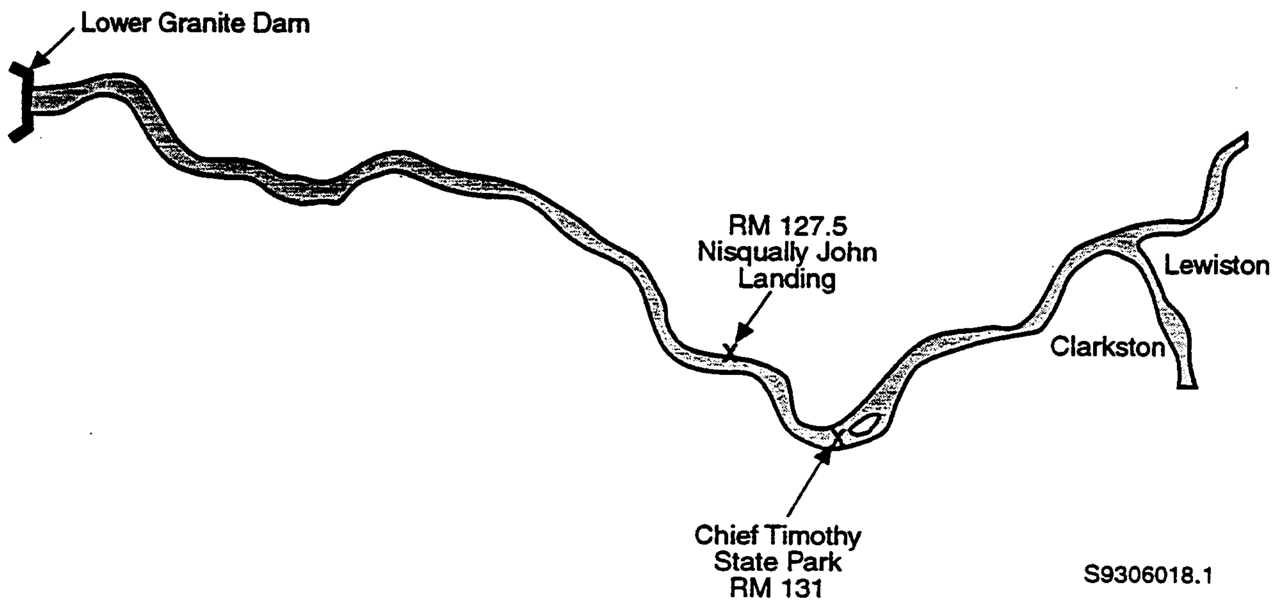

FIGURE 4. Sampling Locations in Lower Granite Reservoir

METHODS AND MATERIALS

SAMPLING METHODS

Soft-bottom benthos at two depth regimes in each reservoir were sampled: 0 to 15 ft and 15 to 60 ft. At each of the eight sampling sites [four in Little Goose (one deep, 15 to 60 ft; one shallow, <15 ft, at each of the two sites) and four in Lower Granite reservoirs (one deep, 15 to 60 ft; one shallow, <15 ft, at each of the two sites)], 15 Ponar dredge (235 cm^2 opening) samples were taken, sieved on-site (No. 30 mesh size; 0.0213 in.), and the samples preserved in 70% alcohol for laboratory analysis. The mean number of organisms for the 15 replicate samples taken at each depth regime represented an integrated evaluation of the fauna at these two depths. In the laboratory, samples were sorted (using staining and sugar flotation as aids), identified to the lowest practical taxon, counted, and weighed after drying at 90°C for 24 h.

A variety of methods were used to evaluate survival of invertebrates in the hyporheic and rip-rap areas. These included turning over stones by hand, digging by hand and by shovel, sieving samples taken at various distances from the water's edge, and general observations of such organisms as crayfish and molluscs.

STATISTICAL METHODS

All data on benthic numbers and weights (chironomids, oligochaetes, and amphipods) were subjected to a series of statistical analyses to determine if the population differences were statistically related to impacts of the drawdown. Initial questions were whether the same parameters differed between reservoirs, between shallow and deep sampling stations, or among sampling dates after drawdown. To normalize the data distributions and to allow the use of parametric statistical analysis (ANOVA), data on invertebrate counts were transformed using the formula $Y = \text{sqrt}(x+1)$, and weights were transformed using the formula $Y = \log(x+1)$. Interaction terms were included in the ANOVA to determine whether reservoirs behaved similarly at the same sampling depths and dates.

RESULTS AND DISCUSSION

Evaluation of the soft bottom benthic samples indicated that no adverse impacts occurred to this community as a result of the dewatering. However, there was a definite impact on the rip-rap community, where the dewatering resulted in extensive mortality to molluscs, insects, and amphipods, which suffered desiccation and death.

SOFT BOTTOM BENTHOS

Little Goose Reservoir

Results of benthic sampling at Schultz Bar are shown in Table 1. Chironomidae, oligochaetes, and amphipods appeared to increase in numbers by April 28, following refilling of the reservoir at the exposed shallow station, but not at the unexposed deeper station. These increases were unexpected because exposure of the substratum during dewatering should have reduced the number of benthic organisms, not increased their numbers. Gammarids are capable of both horizontal and vertical movements, which can be related to response to physical (light) or biological (predator) cues. Chironomids are capable of vertical migration within the sediments, and this source for the increase, although unlikely, cannot be discounted. Thus, it is likely that these higher numbers can be attributed to seasonal increases in the population or resulted from samples taken from areas with higher populations. In either case, it is unlikely that they were related to the drawdown. The higher numbers of chironomids and amphipods found at Schultz Bar on June 30, 3 months after the drawdown, were a result of sampling a different area, rather than an impact of dewatering. Attempts to sample at the same depths and at the same general location as in March and May proved ineffective; sand and rocks prevented closure of the Ponar grab, and the samples retrieved were depauperate in benthos. The June 30 samples were therefore collected about 30 m downstream from the regular station, in an area with more fine sediments and organic matter. Thus, high numbers of organisms were likely related to the characteristics of the bottom rather than to any effects of the drawdown.

TABLE 1. Mean Number and Dry Weight (mg)/m² of Taxa Collected at Schultz Bar, Little Goose Reservoir, 1992; n = 15 for all Samples

	Sampling Date			
	3-9-92	4-1-92	4-28-92	6-30-92
Chironomidae				
0 to 15 ft depth				
Number	23	43	105	884
Weight	11.0	26.0	18.7	215.0
15 to 60 ft depth				
Number	0	3	3	9
Weight	0	2.0	0.1	2.0
Oligochaeta				
0 to 15 ft depth				
Number	23	17	99	31
Weight	6.0	12.0	39.1	8.0
15 to 60 ft depth				
Number	3	31	0	6
Weight	0.1	20.0	0	0.2
Amphipods				
0 to 15 ft depth				
Number	155	193	439	1292
Weight	199.0	111.0	135.1	366.0
15 to 60 ft depth				
Number	241	799	147	6970
Weight	174.0	64.0	72.0	1469.0
Others (3 taxa)				
0 to 15 ft depth				
Number	0	0	0	71
Weight	0	0	0	127.8
15 to 60 ft depth				
Number	0	14	0	3
Weight	0	57.0	0	0.4

Increased numbers of chironomids and amphipods were observed at the deepwater sites on June 30, whereas no increase occurred for oligochaetes. A possible explanation for this phenomenon could have been the deposition of organisms carried down from upstream, when the increased velocities may have scoured organisms from the bottom of Lower Granite Reservoir (Kroger 1973; Durkin et al. 1980). If this is the explanation, then oligochaetes should also have increased in numbers because they inhabit the same region of the sediments as do the chironomids. However, chironomids and amphipods are more mobile and opportunistic feeders than are oligochaetes, which may have contributed to their being picked up and transported preferentially. However, no data on increased drifting of these organisms during the experimental drawdown are available.

Results of benthic sampling at Rice Bar are given in Table 2. Chironomids and amphipods appeared to increase in numbers at both 1 and 3 months following dewatering, and oligochaetes were more numerous 3 months afterwards. Again, it would appear that the dewatering had a positive, rather than negative, effect on populations of these invertebrates. The lack of a suitable control sample (see below) severely restricts any definitive interpretation of these data.

At the deep water site, no obvious trends were found. Thus, if the increased numbers found at the deepwater site at Schultz Bar were truly the result of organisms flushed from Lower Granite Reservoir, it would mean that this effect was absent at Rice Bar, 6 mi downstream from Schultz Bar. It is hard to imagine that this drifting phenomena would spend itself in so short a distance. However, this effect could also be related to the physical location of the two sampling stations in that the morphometry of the river/reservoir basin could influence the deposition site of the drifting organisms - similar to the way sediments are deposited. The location of the sampling site at Rice Bar was on the inside of a channel curve, while that at Schultz Bar was located on the outside of a curve. This would tend to make the Rice Bar site more of a depositional zone, and this was confirmed by the greater amounts of organic detritus and fine sediments found in the dredge samples there.

TABLE 2. Mean Number and Dry Weight (mg)/m^2 of Taxa Collected at Rice Bar, Little Goose Reservoir, 1992; n = 15 for all Samples Except as Indicated

	Sampling Date			
Chironomidae	3-10-92	3-31-92	4-27-92	6-29-92
0 to 15 ft depth				
Number	94	122	363	399[a]
Weight	125.0	142.0	71.4	109.6
15 to 60 ft depth				
Number	23	65	45[b]	23
Weight	2.5	1.7	13.0	3.8
Oligochaeta				
0 to 15 ft depth				
Number	142	45	170	307[a]
Weight	164.0	24.0	34.0	85.0
15 to 60 ft depth				
Number	62	315	85[b]	31
Weight	19.5	98.6	24.2	8.9
Amphipods				
0 to 15 ft depth				
Number	402	96	1479	2275[a]
Weight	296.6	64.0	377.0	673.0
15 to 60 ft depth				
Number	1116	4501	3145[b]	5066
Weight	838.0	1183.0	1068.0	1215.0
Others (3 taxa)				
0 to 15 ft depth				
Number	3	3	3	10[a]
Weight	3.4	0.1	0.1	2.0
15 to 60 ft depth				
Number	53.6	29	21[b]	0
Weight	151	69.8	38.6	0

(a) n = 13.
(b) n = 14.

It should be kept in mind that data from a suitable control in Little Goose Reservoir were lacking. One set of pre-dewatering samples was collected at both depth regimes at Schultz Bar and Rice Bar to serve as controls. Although these obviously are of some value, they do not provide information on possible temporal changes in the populations that could have occurred during the 3 months of the study.

Lower Granite Reservoir

Data on benthic organisms collected at Chief Timothy State Park are shown in Table 3. Numbers of chironomids increased considerably 3 months following the dewatering at the shallow site, but the same pattern was not as obvious for the oligochaetes. Amphipods were absent from collections at this depth both before and after dewatering. Numbers of organisms collected at the deepwater sites did not reveal any trends, as expected. There appeared to be an increase in the numbers of oligochaetes collected at the deepwater site, but it is difficult to attribute this to any aspect of the experimental drawdown.

The results of the benthic sampling at the Nisqusally John Landing site are given in Table 4. Chironomids and oligochaetes were collected in higher numbers on July 1, 3 months postfill, but again, it is difficult to explain this, although seasonal increases may be occurring. Numbers collected at the deepwater sites did not reveal any trends. Again, it should be emphasized that the absence of pre-dewatering data severely limited the interpretation of these data.

STATISTICAL ANALYSES

Statistical analyses included examination of the effects of time, depth, reservoir, and interactive effects. For instance, the invertebrate abundance and biomass were found to differ significantly according to the date and depth at which the samples were taken. Both variables also differed significantly between reservoirs. But three factors make it impossible to attribute these observed conditions to impacts of the drawdown: 1) the absence of true pre-drawdown control samples in Lower Granite Reservoir, 2) the lack of seasonal data on population changes under normal conditions, and 3) the presence of

TABLE 3. Mean Number and Dry Weight (mg)/m^2 of Taxa Collected at Chief Timothy State Park, Lower Granite Reservoir, 1992; n = 15 for All Samples Except as Indicated

	Sampling Date		
Chironomidae	**4-1-92**	**4-29-92**	**6-30-92**
0 to 15 ft depth			
Number	108	170	853[a]
Weight	214.6	145.7	384.0
15 to 60 ft depth			
Number	94	130[b]	112[b]
Weight	61.2	39.5	79.5
Oligochaeta			
0 to 15 ft depth			
Number	105	23	196
Weight	17.8	49.3	48.0
15 to 60 ft depth			
Number	43	227[b]	553[b]
Weight	10.2	72.2	164.0
Amphipods			
0 to 15 ft depth			
Number	0	0	0
Weight	0	0	0
15 to 60 ft depth			
Number	3	0	3[b]
Weight	0.1	0	0.4
Others (1 taxon)			
0 to 15 ft depth			
Number	0	3[b]	54
Weight	0	1.7	83.0
15 to 60 ft depth			
Number	0	3	6[b]
Weight	0	0.4	2.4

(a) n = 16.
(b) n = 14.

TABLE 4. Mean Number and Dry Weight (mg)/m^2 of Taxa Collected at Nisqually John Landing, Lower Granite Reservoir, 1992; n = 15 for All Samples Except as Indicated

	Sampling Date		
Chironomidae	4-2-92	4-28-92	7-1-92
0 to 15 ft depth			
Number	334[a]	167	1257
Weight	215.0	176.0	677.8
15 to 60 ft depth			
Number	485	317	96
Weight	376.0	298.0	40.3
Oligochaeta			
0 to 15 ft depth			
Number	79[a]	94	331[a]
Weight	108.3	212.0	67.2
15 to 60 ft depth			
Number	385	224	374
Weight	136.0	128.0	100.7
Amphipods			
0 to 15 ft depth			
Number	0	0	0
Weight	0	0	0
15 to 60 ft depth			
Number	3	0	0
Weight	2.1	0	0
Others (3 taxa)			
0 to 15 ft depth			
Number	0	17	73[a]
Weight	0	5.4	42.5
15 to 60 ft depth			
Number	0	6	0
Weight	0	4.2	0

(a) n = 14.

physical differences at "shallow" and "deep" stations. For instance, the increase in chironomid numbers at the shallow station at Schultz Bar in Little Goose Reservoir (Table 1) is statistically significant. However, it is not known if this is attributable to the drawdown or the result of a natural increase in the population during this time of year. No data are available for seasonal changes in these organisms in either Little Goose or Lower Granite reservoirs. In the almost 4-month period between the March 9 sampling and the June 30 sampling, it is possible that a cohort of chironomid larvae could have increased in size to the point where they were retained in June by the sieve mesh, but passed through the mesh in March. An indication of this possibility is the fact that the fluctuations in the numbers of chironomids do not track with the fluctuations in the weights of the chironomids.

Other observations in the statistical treatment indicated significant interactions among the physical variables mentioned above, but in no case were the proper pre-drawdown data available to permit positive interpretations relative to drawdown. Thus, it is necessary to refrain from presenting a series of unsupportable speculations based on these statistical analyses. These could be taken out of context and perpetuated without proper qualification. Rather, it should be emphasized that the results of these analyses indicate that a more comprehensive sampling program is necessary to assess impacts between benthic productivity and reservoir operation. Unfortunately, no adequate data were available which met the necessary criteria for control (pre-drawdown) samples from the same reservoir at the same depths and dates before and after drawdown. Consequently, there is no statistical method of evaluating the effects of drawdown on macroinvertebrates based on the present data.

HYPORHEIC BENTHOS

Qualitative information on survival of benthic organisms in the hyporheos is presented as a series of observations, with tentative conclusions given when feasible. Water level elevations on these days were: March 10 - 717 to 715 ft MSL, March 11 - 715 to 713 ft MSL, March 25 - 702.5 to 701.5 ft MSL. These represent drawdowns of approximately 17, 19, and 31 ft, respectively, below the predrawdown water level of 733 ft MSL.

Wawawai Landing, March 10, 1992: Several surface mud samples were collected just above and below the water's edge and screened. However, we found no living organisms in the samples.

Blyton Landing, March 10, 1992: Several surface mud samples were screened and living chironomids, *Corophium*, and gammarid amphipods were found in samples collected about 6 in. above the water's edge and also about 8 ft above the water's edge where it was still quite moist. Similar samples were taken about 6 in. below the water line and the same organisms were found, but in greater numbers. This may be an indication that once the silt is exposed, the organisms are burrowing deeper, being taken by birds, or desiccating. U.S. Army Corps of Engineer (COE) biologists reported finding dried-up amphipods (gammarids and *Corophium*) by digging in exposed shoreline substratum at several sites.[a]

Nisqually John Landing, March 11, 1992: Some semi-quantitative (equal volumes of substratum) samples were collected to determine if organisms were receding from the surface layers of the sediments into deeper sediments when the water levels dropped. "Shovel" samples were taken from 1) the surface (0 to -6 in.) at water's edge, 2) the surface (0 to -6 in.) about 10 ft above water's edge, and 3) the sub-surface (6 to 12 in. below #2). Results are shown in Table 5.

These cursory data indicate that chironomids and oligochaetes are remaining in the surface sediments, at least while they remain moist, and are not moving into the deeper sediments to escape desiccation.

Wawawai Landing, March 25, 1992: A surface sample collected from sediments about halfway between the shoreline and water's edge was sieved; no organisms were found. A surface sample collected at the water's edge and sieved revealed living chironomids and oligochaetes.

Nisqually John Landing, March 25, 1992: This site had been previously examined on March 11, but the water edge was now some distance (~100 m) out over exposed mud flats. These mud flats were cracking and very deep. Some of

(a) Personal communication from Sarah Wik, U.S. Army Corps of Engineers.

TABLE 5. Numbers of Organisms Found at Different Locations Relative to Water Edge and Depth of Sample

	Surface		Subsurface
	Water's Edge	Above Edge	
Chironomids	75	45	0
Oligochaetes	42	88	6

the packed sediments were examined and revealed live chironomids in the moist sediments, indicating that the organisms can survive for some time as long as they remain moist. These were red bloodworms (chironomids), and they are known to contain body fluids rich in dissolved heamoglobins which enable them to survive low dissolved oxygen conditions (Pennak 1978). Near the water's edge beyond about 150 ft of sediment flats, piles of washed-up *Brachycentrus* (Trichoptera) cases were found in windrows where they had settled out. It is difficult to explain the presence of these cases so far from the solid substrata where they live. If they were washed from rip-rap surfaces, they should have been found farther up the shore. We found many of their cases desiccated but still attached to the rip-rap along the shoreline. The likely sources of these cases are the Snake and Clearwater rivers. Significant populations of *Brachycentrus* occur in these streams (Edwards et al. 1974; Brusven and Trihey 1978). However, cases from which the insects have emerged are found only above the water line still attached to rocks; whereas, rocks picked from underwater have living larvae and cases, but no dead cases. This suggests that empty cases below the water are dislodged and transported downstream. Otherwise, the rocks would eventually be covered with old, empty cases, and this does not occur. It is also possible that these cases are a natural phenomenon not related to the drawdown.

RIP-RAP BENTHOS

Wawawai Landing, March 10, 1992: Rocks at the water's edge were examined. Desiccated chironomids (Diptera), hydropsychids (Trichoptera), and amphipods (Crustacea) were found on rocks, indicating that these organisms in all likelihood were being lost as the water receded. None of these organisms have much capability to move rapidly as the water recedes (gammarid amphipods have a greater ability to move than do *Corophium*, a tube-dweller), and it is probable that the entire population which was exposed was lost. Some individuals may find a moist refuge which could sustain them. For example, the crayfish might find a moist refuge in macrophyte beds, but this would be related to the duration of the dewatering. Several crayfish were observed in the water's edge, and it appeared that they successfully migrated with the receding water, at least those observed along steep rip-rap. Crayfish in shallower areas would probably find it harder to migrate and are much more likely to be trapped and stranded; they apparently sought refuge in moisture cracks in the substratum, which would dry up in the next day or so. However, several crayfish stranded in the rocks above the water's edge were found. They, too, must find a moist refuge that persists until the water returns or they will perish.

Two miles downstream of Wawawai Landing, March 10, 1992: Amphipods, *Corophium*, were found drying out on the exposed rocks. There was a distinct band of dead periphyton coating the rocks at about 2 ft below the high water line. However, this community had developed when the MOP was higher than when the drawdown started. Thus, periphyton demise was likely not a result of the drawdown test. Whenever water levels are lowered, this community will be severely impacted. However, it will also recover rapidly; in the Columbia River it takes about 2 to 3 weeks to reach maturity (Cushing 1967).

Blyton Landing, March 10, 1992: Oligochaetes were found drying up on exposed rocks. *Brachycentrus* (Trichoptera) cases drying out on the exposed rocks were also found. These organisms cannot migrate rapidly enough to follow the receding water; some may survive short periods of exposure if they can remain moist. There was a huge mollusc loss in this area, but it is unknown how many survived by remaining in the mud. It was beyond the scope of this study to quantitatively determine the magnitude of the mollusc loss. This would have required adequate pre-dewatering studies, the establishment and sampling of transects, and subsequent sampling of the same areas.

Wawawai Landing, March 25, 1992: Rip-rap was examined, and many dead and dying *Corbicula* were found, but also many live ones in moist mud belowrocks. COE biologists made similar observations (COE 1992). Several dead crayfish were found among the rocks along with live ones at water's edge.

Vicinity River Mile 120, March 25, 1992: Many *Corophium* still alive in tubes under rocks where moisture was present were found at the water's edge, but many more dead and desiccated ones were present on the rocks. Living and dead *Anodonta* were present along the shoreline.

MACROPHYTES

No extensive macrophyte beds were found during our shoreline examination; Frest and Johannes (1992) also found no beds during their search for molluscs, and D. Bennett[a] verified the absence of macrophyte beds during and immediately after drawdown. A few strands of dried *Potamogeton* sp. were found alongside the boat dock at Wawawai Landing. It is probable that it was too early in the growing season for these communities to have yet developed. Underground parts probably existed in the sediments. It is unknown if the brief dewatered period will have any long-term impact on the development of these plants in the coming growing season. Kadlec (1962) reported on the response of macrophytes to alternate flooding and dewatering and found no noticeable effect on the common perennials, but noted that the submerged and floating-leaf species were reduced in abundance. He also reported that one species of pondweed *(Potamogeton)* exhibited luxuriant growth after the drawdown, apparently in response to the nutrient increases that occurred following dewatering and subsequent filling.

OTHER HABITATS

There was an obvious and extensive negative effect on the molluscs inhabiting the dewatered areas along the shoreline of Lower Granite Reservoir. The major impact appeared to be on the molluscs *Corbicula fluminia*. *Corbicula fluminia* is an introduced species and was first identified in North America

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(a) Personal communication from D. Bennett, Univ. of Idaho.

near the mouth of the Columbia River in 1938 (Britton and Morton 1982). Dead and dying organisms were found essentially everywhere – in the rip-rap and on exposed sandy reaches. Digging under the rip-rap, we found some live clams that had burrowed into the silt. Survival in this mode, however, is predicated on moisture retention, and this is obviously related to the length of the dewatering period. Specimens of *Anodonta californiensis* (a candidate Threatened and Endangered species) and *A. nutalliana* were also found dead and dying, but not nearly in as high numbers as *C. fluminia*. The loss of fewer *A. californiensis*, because of its candidate T&E status, would be of more concern than the loss of greater numbers of *C. fluminia*. Frest and Johannes (1992) also reported essentially the same findings, but also found very small numbers of *Gonidea angulata* in Lower Granite Reservoir. It is probable that these organisms could escape desiccation in muddy areas by burrowing into moist areas, but, again, survival here depends on the length of the dewatering period. Exposed molluscs are also more available to predators such as birds and raccoons.

USEFULNESS OF DATA FOR FUTURE EVALUATION AND MONITORING OF DEWATERING OPERATIONS

Certainly, the observations made to date are useful in an overall evaluation of the impact of the dewatering. The greatest shortcoming of the data collected on the soft bottom benthos was the fact that time was not available to obtain adequate pre-dewatering samples from Lower Granite Reservoir to establish a baseline for comparison with the post-filling samples. Further, the relatively short duration of the drawdown in relation to organism life histories would limit any analysis of apparent effects. It is suggested that if further perturbations are anticipated in the Lower Snake River system, either experimental or "permanent," then a thorough study of the soft bottom benthos be undertaken to adequately document the fauna both spatially and temporally. The benthic community appears to be crucial to the functioning of the food web supporting the fish species of interest (salmonids), and it is not adequate to have to infer impacts from comparative data collected for other purposes, such as dredge disposal studies. The reference samples which we used for comparison were collected for different objectives and at a different time, and thus were not as suitable as a well-planned study of this community, with temporal and spatial components, throughout the system.

CONCLUSIONS

SOFT BOTTOM BENTHOS

These results indicate no significant adverse impacts from the dewatering on the soft bottom benthos in Little Goose Reservoir. In fact, higher numbers of some taxa indicate that there may have been a washout of these organisms from Lower Granite Reservoir with subsequent deposition in the upper reaches of Little Goose Reservoir. This washout should have been accompanied by a concomitant decrease in these organisms from the benthos of Lower Granite Reservoir. However, we do not have pre-dewatering samples from Lower Granite Reservoir to either substantiate or refute this possibility, nor do we have data to confirm that an increase in drifting organisms occurred as a result of the dewatering. Very little drawdown occurred in Little Goose Reservoir, and we had no pre-drawdown data to use as a baseline for impact analysis.

HYPORHEIC AND RIP-RAP BENTHOS

Data suggest that dewatering resulted in significant losses of species that have low mobility, such as molluscs, amphipods, Trichoptera, and tube-dwelling chironomids on rocks. Mobile species such as crayfish were able to follow the receding water to some degree, although many succumbed in the rocks and pools. It also appears that many of the sediment-dwelling benthos were also lost as the surficial sediments dried out. It is probably safe to assume that a large percentage of the invertebrates inhabiting the dewatered areas were lost, but these populations probably were replenished after the area was resubmerged. This, of course, is related to how much of the soft bottom habitat is dewatered and how much remains covered with water and thus available as a source of recruitment. Reported values concerning the time required to reach equilibrium densities of invertebrates range from 14 to 21 days (Khalaf and Tachet 1977; Sheldon 1977) to 32 to 64 days (Shaw and Minshall 1980) or more (Williams and Hynes 1977; Gore 1982). However, we have found that experimental substrata in the Hanford Reach of the Columbia are repopulated by benthic organisms within 2 to 3 weeks of placing them in the water (Cushing 1993). Repopulation by survivors is obviously related to the length of the dewatering, the extent of the impact, and the presence of a source of recolonizing organisms. It would be of interest to determine, if possible, the overall impact on the *Corbicula* population, but this would necessitate having adequate pre-dewatering data on the population.

MACROPHYTES

The absence of significant macrophyte beds precluded a definitive analysis of the impacts of dewatering on these communities. Dewatering during the period of extensive growth could adversely impact these communities, resulting in loss of habitat following refilling.

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