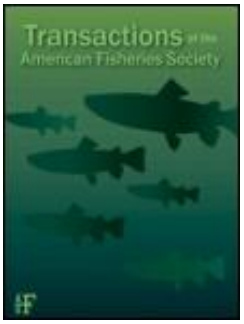

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Tolerance of Eggs, Embryos, and Alevins of Chinook Salmon to Temperature Changes and Reduced Humidity in Dewatered Redds

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Abstract

Changes in temperature and relative humidity can occur in gravel during dewatering of salmonid redds. Four intergravel development phases of chinook salmon *Oncorhynchus tshawytscha* were exposed to increased or decreased temperatures, and one phase was subjected to reduced relative humidity to define tolerance limits. Abrupt increases in temperature from 10°C to above 22°C for 1–8 h reduced survival of cleavage eggs. Embryos survived 8-h exposures to 25°C and 2-h exposures to 26.5°C. Eleutheroembryo and pre-emergent alevins tolerated 4-h exposures to 23.5°C and 1-h exposures to 25.0°C. Decreases in temperatures from 10.0°C to near freezing (about 0.0°C) did not reduce survival of eggs, embryos, or alevins. Reduced relative humidity adversely affected survival of embryos. Ninety-eight percent of dewatered embryos exposed to 100% relative humidity for up to 24 hours survived. Embryo survival at 90% relative humidity was 0%, 55%, and 100% for exposure periods of 24, 8, and 4 h, respectively. Control survival was greater than 97%.

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Altered flow regimes that result from management of surface waters for electric-power production, irrigation storage, or flood control alternately dewater and flood shoreline areas. Fluctuations in waters used by spawning salmonids can strand juvenile fish and dewater redds containing developing fish (Chapman et al. 1981; Perry and Graham 1981; Stober and Tyler 1982; Weitkamp et al. 1982; Reiser and White 1983). Losses of salmonid eggs and alevins from dewatering have been documented in both river and lake ecosystems (Martin 1955; Bayha and Koski 1974; Washington State Department of Fisheries 1976; McMullin and Graham 1981; Stober and Tyler 1982). To assess potential impacts of dewatering on intergravel development phases of chinook salmon, fisheries managers must understand the effects of environmental changes that occur during dewatering.

Our research objective was to determine what effects abrupt changes in water temperature and decreased relative humidity within the redd have on eggs, embryos, and alevins of chinook salmon *Oncorhynchus tshawytscha*. Our tests were designed to simulate these changes in the intergravel environment of a salmonid redd during dewatering. Temperature tests were conducted with four development phases: cleavage eggs, embryos, eleutheroembryos, and pre-emergent alevins. Relative humidity tests were conducted with embryos only.

The dewatering experiments discussed in this article were inspired by our tests with chinook salmon in 1979. At that time, we studied the effects of dewatering on intergravel development phases in artificial redds. The artificial redds could be manipulated to simulate dewatering under field conditions. We subsequently conducted tests with four early development phases of fall chinook salmon under two regimes: daily, sequential dewaterings and one-time, extended dewaterings (Becker et al. 1982, 1983). Observations of temperature changes in the intraredd environment throughout these tests were used to help design exposure conditions for the current studies.

Methods

Four heat shock, four cold shock, and three reduced humidity tests were completed during fall 1981 (Table 1). All test organisms were acclimated to 10°C. The heat shock tests involved exposure of four development phases of pre-emergent chinook salmon to five increased temperatures for up to 8 h. The cold shock tests involved exposure of four development phases to four reduced temperatures for up to 8 h. The humidity tests involved exposure of embryos to five reduced relative humidities for up to 24 h.

TABLE 1.—*Test designations and procedures for exposure of four development phases of chinook salmon acclimated to 10°C and exposed to increased temperatures, decreased temperatures, and decreased relative humidity.*

Test designation[a]	Development phase[b]	Temperature units[c]	Exposure procedure		
			Water temperatures (°C)	Relative humidity (%)	Exposure (h)
HE-1	Cleavage eggs	56	10.0, 22.0, 23.5, 25.0, 26.5, 28.0		1, 2, 4, 8
HE-2	Embryos	281	10.0, 22.0, 23.5, 25.0, 26.5, 28.0		1, 2, 4, 8
HE-3	Eleutheroembryos	566	10.0, 22.0, 23.5, 25.0, 26.5, 28.0		1, 2, 4, 8
HE-4	Pre-emergent alevins	837	10.0, 22.0, 23.5 25.0, 26.5, 28.0		1, 2, 4, 8
CO-1	Cleavage eggs	71	10, 5, 3, 1, 0		1, 2, 4, 8
CO-2	Embryos	304	10, 5, 3, 1, 0		1, 2, 4, 8
CO-3	Eleutheroembryos	579	10, 5, 3, 1, 0		1, 2, 4, 8
CO-4	Pre-emergent alevins	788	10, 5, 3, 1, 0		1, 2, 4, 8
RH-1	Embryos	247		100, 75, 50	4, 8, 24
RH-2	Embryos	411		100, 75, 50	4, 8, 24
RH-3	Embryos	440		100, 90, 80	4, 8, 24

[a] Progeny from three females were used in heat shock (HE) test. Progeny from two females were used in cold shock (CO) and relative humidity (RH) tests.

[b] Eggs from the Klickitat Hatchery were used for HE tests. Eggs from the Priest Rapids Hatchery were used for CO and RH tests.

[c] Temperature units, accumulated from egg fertilization to start of test, are in centigrade degree-days measured from 0°C. Most test organisms were reared at 10°C.

Exposures up to 8 h approximated periods of intergravel dewatering expected downstream of a hydroelectric dam during daily peaking-power operations; humidity tests were extended to more fully explore the influence of this variable.

Exposure Facilities

Heat shock tests were conducted in glass aquaria that were 68 cm long, 30 cm wide, and 30 cm deep (Fig. 1). Aquaria were filled with filtered Columbia River water approximately 12 h before tests to raise and stabilize temperatures. Water temperatures were controlled within 0.4°C with Cole-Parmer aquarium heaters.

Cold shock tests were conducted in glass aquaria (described above) for three of the five temperatures tested (10.0, 5.0, and 3.0°C). Water temperature was controlled with chilled Columbia River water. For the 1°C temperature exposures, we floated plastic trays in a 600-L fiberglass circular tank filled with river water that was cooled by three Frigid Unit chillers. The chilled water was also used to control water temperatures in the aquaria. Ice slurry exposures (about 0.0°C) were conducted in aquaria filled with crushed sanitary ice. A tray, filled with crushed frozen river water, was placed in each aquarium (Fig. 1). Exposures occurred in the river ice. The aquaria were filled with chilled water 12 to 16 h before exposures to reduce and stabilize temperatures.

Humidity tests were conducted in Sherer Model RFT and Lab-Line Model VIP56 environmental chambers (Fig. 1). Plastic trays were modified for remote dewatering after the chamber humidity reached equilibrium. The trays containing test organisms were filled with river water and placed in the environmental chambers. The relative humidity then was adjusted to the selected exposure level. Air temperature was adjusted to 10°C. Trays were dewatered after relative humidity reached equilibrium, about 24 h after the trays were placed in the environmental chamber.

Organisms were held in baskets during the exposures for all temperature and humidity tests. Baskets were constructed from 5.1-cm lengths of 7.6-cm-diameter polyvinyl chloride pipe. One opening of the pipe section was covered with 30-mm mesh plastic netting. The baskets were almost entirely submerged and fastened to the edge of the aquaria with clips. During tests with alevins, the baskets were covered with plastic dishes to prevent the alevins from jumping out. Baskets

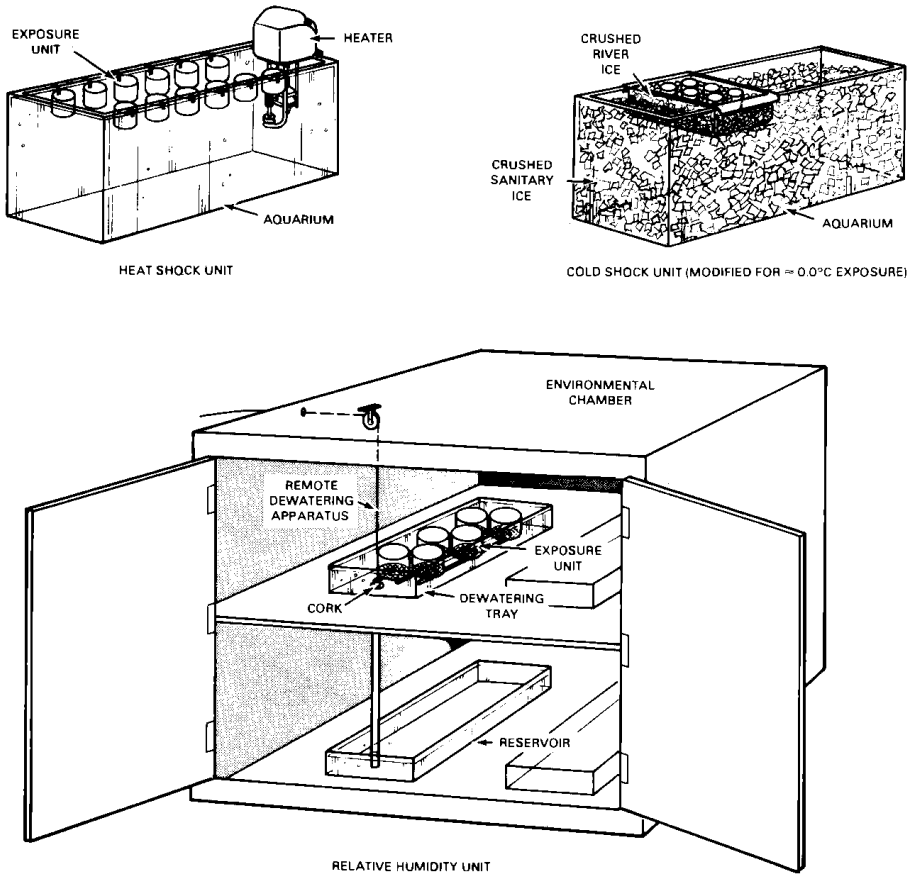

FIGURE 1.—*Exposure facilities for heat shock, cold shock, and relative humidity tests.*

placed in the humidity test trays were elevated from the tray bottom by glass tubing to ensure that the baskets drained completely.

Post-exposure Holding Facilities

Test organisms were held in Heath incubator trays after exposure to allow monitoring of hatching success, delayed mortality, and malformations. Trays were divided into 24 compartments (dimensions 5.1 × 7.6 cm) with perforated aluminum plating. Each aliquot of test organisms was held in a separate compartment. Development of the organisms was monitored until they obtained about 1,000 temperature units (TU), the end of the pre-emergent alevin phase. (One TU, or degree-day, equals one degree centigrade above 0°C for 24 h.)

Test Organisms

Intergravel development of salmonids encompasses four phases (Balon 1975): cleavage eggs and embryos (the prehatching phases); eleutheroembryos and pre-emergent alevins (the posthatching phases). Estimation of development phase was based on accumulated TUs; we assumed 1,000 TUs for development from fertilization to emergence of alevins from a redd, and 250 TUs for each intergravel development phase (Leitritz and Lewis 1976; Alderdice and Velsen 1978). The chinook salmon eggs for the heat shock tests were obtained from the Washington State Department of Fisheries hatchery at Klickitat, Washington. Eggs for the cold shock and humidity tests were obtained from the Public Utility District of Grant County hatchery at Priest Rapids Dam, Washington.

Eggs were removed from three fish at each hatchery by abdominal incision and placed separately in plastic bags. Milt from five fish was extruded into a glass jar. Eggs and milt were transported to our laboratory where the eggs were fertilized and placed in three separate Heath incubators in which water temperatures were maintained at 10°C.

Experimental Design

A randomized block design was used to assign aliquots of test organisms to the appropriate time–temperature or time–humidity exposure. Groups of 20 eggs from each female tested were randomly assigned to each combination of treatments. The randomized block design, in which each female constituted a block, isolated potential differences in egg viability associated with females. Aliquot sizes were reduced for some tests because stocks became depleted.

The combination of treatments varied with each type of test. Temperature and humidity levels chosen were based on observations of previous dewatering tests (Becker et al. 1982, 1983), range-finding test data, and field data (Weitkamp et al. 1982). For the heat shock tests, we used six temperatures and four durations of exposure. For the cold shock tests, we used five temperatures and four durations of exposure. For the humidity tests, we used three levels of humidity and three durations of exposure. For the heat tests and the cold tests, exposures at acclimation temperature (10°C) served as the controls. For the humidity tests, baskets of eggs placed in the environmental chambers but not dewatered served as the controls. The positions of the exposure baskets within each aquarium or chamber were randomized, as was the placement of the test organisms in the incubators for postexposure observation.

Numbers of live and dead test organisms were counted at the end of each exposure, 24 h after exposure, at hatching (egg phases only), and when about 1,000 TUs had accumulated. Mortality at 1,000 TUs was analyzed to determine exposure effects. Mortality estimates from the controls were used to adjust those from the treatment combinations in order to minimize effects of individual females, test aquaria, or test chambers.

The hypothesis that percent mortality of the treated organisms would be greater than the percent mortality of the controls was tested statistically to determine the effects of various combinations of increased and decreased temperature and decreased humidity. Data analyzed were arc sine transformations of percent mortality.

Analyses of variance were conducted to identify the effect of temperature, exposure duration, and the interactions of both on survival. If no significant interactive effect was detected, the effect of temperature or exposure duration was determined directly by counting the numbers of live and dead organisms. If significant interactive effects were detected, Tukey's multiple-comparison tests were conducted to identify sources of specific differences among levels of temperature and exposure duration.

TABLE 2.—*Percent mortality, through emergence, for chinook salmon exposed to increased water temperatures as cleavage eggs, embryos, eleutheroembryos, and pre-emergent alevins. Percentages are averages for 20 eggs from each of three females except for pre-emergent alevins, which are averages for 10–40 each from two females. Values along a row without a letter in common are significantly different ($P \leq 0.05$). No statistical comparison was made for pre-emergent alevins because of differences in aliquot sizes.*

Temperature (°C)	Exposure duration (h)			
	1	2	4	8
	Cleavage eggs			
10.0	5 a	3 a	2 a	2 a
22.0	3 a	8 a	10 a	10 a
23.5	22 a	18 a	25 a	40 a
25.0	22 a	28 a	35 a	88 b
26.5	15 a	57 b	100 c	100 c
28.0	100 a	100 a	100 a	100 a
	Embryos			
10.0	2 a	3 a	2 a	3 a
22.0	5 a	3 a	0 a	3 a
23.5	0 a	0 a	3 a	2 a
25.0	5 a	8 a	7 a	8 a
26.5	2 a	10 a	100 b	100 b
28.0	100 a	100 a	100 a	100 a
	Eleutheroembryos			
10.0	0 a	2 a	0 a	2 a
22.0	0 a	2 a	0 a	2 a
23.5	0 a	2 a	3 a	60 b
25.0	0 a	25 b	98 c	100 c
26.5	88 a	100 b	100 b	100 b
28.0	100 a	100 a	100 a	100 a
	Pre-emergent alevins			
10.0	0	0	0	0
22.0	0	0	0	0
23.5	0	0	3	60
25.0	10	78	[a]	100
26.5	84	100	100	100
28.0	100	100	[b]	[b]

[a] Test organisms lost to heater malfunction.
[b] No test group at this time–temperature exposure.

Results

Tolerance of chinook salmon to adverse changes in the intraredd environment varied with the magnitude and duration of the changes. Interactions of change and exposure duration were noted in heat shock and relative humidity tests.

TABLE 3.—*Percent mortality at emergence for chinook salmon exposed to decreased water temperatures as cleavage eggs and embryos. Percentages are averages for 20 eggs from one female and 40 eggs from another female.*

Temperature (°C)	Exposure duration (h)			
	1	2	4	8
	Cleavage eggs			
10.0	0	8	10	18
5.0	3	5	8	10
3.0	13	18	8	5
1.0	3	3	3	10
0.0	3	5	15	8
	Embryos			
10.0	0	2	3	2
5.0	5	7	0	5
3.0	0	0	3	0
1.0	3	2	3	2
0.0	0	0	0	0

TABLE 4.—*Percent mortality at emergence for chinook salmon exposed at 10°C to decreased relative humidity as embryos. Percentages are for 20 embryos from one female and 40 embryos from another female. Values along a row without a letter in common are significantly different ($P \leq 0.05$).*

Relative humidity (%)	Exposure duration (h)			
	0[a]	4	8	24
		Test RH-1		
100	3 a	3 a	5 a	3 a
75	10 a	23 a	65 b	100 c
50	5 a	35 b	68 c	100 d
		Test RH-2		
100	0 a	0 a	0 a	5 a
75	3 a	5 a	63 b	100 c
50	0 a	3 a	65 b	100 c
		Test RH-3		
100	3 a	0 a	0 a	3 a
90	0 a	0 a	45 b	100 c
80	0 a	3 a	58 b	100 c

[a] Embryos were placed in the exposure chamber but were not dewatered.

Heat shock caused malformed individuals. Cold shock did not affect chinook salmon at the temperatures and exposure durations tested. Tolerances to the changes did not vary among progeny from different females.

Heat Shock

The ability to tolerate abrupt heat shock varies with the development phase of chinook salmon (Table 2). Few deaths in any development phase occurred at exposures of 22°C or below. Above this temperature, effects appeared to be a function of temperature, duration of exposure, and development phase. Cleavage eggs were the least tolerant, but this was due, in part, to their characteristically high sensitivity to handling. Embryos were the most tolerant, surviving 8-h exposures to 25°C and a 2-h exposure to 26.5°C. Eleutheroembryos and pre-emergent alevins tolerated 4-h exposures to 23.5°C and a 1-h exposure to 25.0°C.

Most mortality in our heat shock tests occurred during exposure or within 24 h after exposure. Postexposure mortalities, including those during hatching, were generally low. A few cleavage eggs and embryos had malformations, expressed primarily as spinal deformations and failure of one or both eyes to develop; these were counted as though dead.

Cold Shock

The intergravel development phases of chinook salmon tolerated cold shock (Table 3) but not freezing. Again, cleavage eggs showed some losses among all exposure regimes, including the control, because eggs are extremely sensitive to handling. Brief exposure to temperatures just above freezing did not cause lethal or sublethal effects in any of the four development phases.

Cleavage eggs were not affected by the temperatures or exposure durations tested (Table 3). For the embryos, analyses of variance indicated that temperature significantly influenced mortality. A Tukey's multiple-comparison test did not identify at what temperature the significance occurred, but a Newman–Keuls test indicated that mortalities at 5°C were significantly greater than mortalities at other test temperatures. There were no significant differences among mortalities at other temperatures. No eleutheroembryos and only four pre-emergent alevins died; the alevins died in one of the three 8-h exposures at 0.0°C.

Humidity Tests

A relationship clearly exists between chinook salmon embryo survival and saturation of air with moisture (Table 4). No mortality occurred among embryos dewatered for 24 h in 100% humidity. Exposure at lower humidities resulted in gradual extraction of liquid and eventually in emplosion of the embryo envelope.

We did not examine the effects of intergravel

moisture on survival of posthatching phases. Previous tests indicated that survival of posthatching development phases during dewatering is relatively brief (Becker et al. 1982, 1983; Reiser and White 1983). Chinook salmon require intergravel water after they hatch.

Discussion

Cessation of intergravel flow and drainage of water from gravel are the most immediate and direct consequences of water-level reduction over a salmonid redd. However, several physical factors may influence the survival of eggs and alevins during dewatering: increased or decreased temperatures, drying, reduced dissolved oxygen concentrations, settling of the gravel, and increased concentration of biotic wastes.

We first observed the effects of increased intergravel temperatures resulting from insolation on dewatered artificial redds in 1979 (Becker et al. 1982). Intergravel temperatures rose from 10°C to 28°C during a 16-h dewatering, and survival of chinook salmon cleavage eggs was reduced.

The effects of decreased intergravel temperatures and freezing on survival of intergravel development phases of salmonids were observed downstream of Hungry Horse Dam in Montana (Perry and Graham 1981). Cold air temperatures killed kokanee (nonanadromous sockeye salmon *Oncorhynchus nerka*) when redds froze. Reiser and Wesche (1979) observed reduced survival for eggs of brown trout *Salmo trutta* subjected to freezing temperatures in the Laramie River, Wyoming. These observations indicate that temperature fluctuations in dewatered redds may have adverse effects on developing salmonid eggs and alevins.

Another environmental change in dewatered gravel is the drying and subsequent reduction of relative humidity in the intergravel air. As long as gravel within a redd is wet, the interstitial areas will remain at or near 100% relative humidity (Puri 1949). As gravel begins to dry, the relative humidity in the interstices quickly drops to ambient values. In earlier tests, we examined survival of chinook salmon eggs and alevins during extended periods of dewatering in which drying of gravel might occur (Becker et al. 1983). We discovered that cleavage eggs and embryos can survive extended dewaterings (up to 12 d) as long as the intergravel environment remained moist. Reiser and White (1981) also observed prolonged survival of salmonid eggs under experimental conditions where high moisture levels were maintained.

Changes in Intergravel Temperature

Intergravel temperatures in dewatered gravels can be expected to vary more widely than those in watered gravels due to diel changes in insolation and air temperature. In most situations, warming can be expected during the day and cooling at night. Extreme warming or freezing for periods less than 1 h can be lethal to developmental phases of salmonids. Salmonids exposed to freezing temperatures long enough to crystallize their cellular contents will die (DeVries 1971). Juvenile salmonids, after their emergence from the gravel, have limited tolerance of temperatures below 0.0°C, because blood and the aqueous humor freeze at −1.0°C and −1.5°C, respectively (Brett and Alderdice 1958).

Our data indicate that survival of egg phases depends on retention of moisture that provides nearly 100% relative humidity in the gravel. Reiser and White (1981) reported that eggs of chinook salmon and steelhead *Salmo gairdneri* can develop normally without being submerged in water if they remain moist. Dehydration of redds from direct insolation or wind on exposed gravel surfaces for brief periods of 4 to 8 h can kill eggs and embryos. This effect will be related to egg depth within the redd and extent of moisture loss.

Extrapolation of our data to field situations is complicated by site-specific conditions. Salmonid redds in streams are not likely to dry abruptly after dewatering, because the gravel retains pockets of still water and receives flowing water from bank storage. Snow and rain also prevent dehydration of gravel. Dehydration is apt to be less severe if dewatering occurs at night than during the day. Bank-stored flow may protect eggs, embryos, and alevins in redds from air temperature, wind, and insolation. Nevertheless, dewatering that results in increased or freezing intergravel temperatures can affect eggs, embryos, and alevins. Dewatering that reduces intergravel relative humidity can affect the survival of chinook salmon cleavage eggs or embryos. Field studies to quantify the physicochemical conditions of the intraredd environment will help fisheries and water managers coordinate their efforts to resolve conflicting needs related to water resources. Comprehensive field measurements should include gravel composition (permeability), inter-

gravel flow rates (watered and dewatered situations), persistence of intergravel flow after drawdown (ground water or bank-storage flows), dissolved oxygen concentrations (flowing or standing water), and intergravel temperatures in relation to atmospheric conditions during gravel exposure.

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References

ALDERDICE, D. F., AND F. P. J. VELSEN. 1978. Relation between temperature and incubation time for eggs of chinook salmon (*Oncorhynchus tshawytscha*). Journal of the Fisheries Research Board of Canada 35:69–75.

BALON, E. K. 1975. Terminology of intervals in fish development. Journal of the Fisheries Research Board of Canada 32:1663–1670.

BAYHA, K., AND C. KOSKI. 1974. Anatomy of a river. An evaluation of water requirements for the Hell's Canyon reach of the Snake River conducted March 1973. Pacific Northwest River Basin Commission, Vancouver, WA, USA.

BECKER, C. D., D. A. NEITZEL, AND C. S. ABERNETHY. 1983. Effects of dewatering on chinook salmon redds: tolerance of four developmental phases to one-time dewatering. North American Journal of Fisheries Management 3:373–382.

BECKER, C. D., D. A. NEITZEL, AND D. H. FICKEISEN. 1982. Effects of dewatering on chinook salmon redds: tolerance of four developmental phases to daily dewaterings. Transactions of the American Fisheries Society 111:624–637.

BRETT, J. R., AND D. F. ALDERDICE. 1958. The resistance of cultured young chum and sockeye salmon to temperatures below 0 C. Journal of the Fisheries Research Board of Canada 15:805–813.

CHAPMAN, D., D. WEITKAMP, T. WELSH, AND E. GULLEKSON. 1981. Vernita Bar spawning survey 1979–1980. Report to Public Utility District 2 of Grant County, Document 81-0115-004F, Ephrata, WA, USA.

DEVRIES, A. L. 1971. Freezing resistance in fishes. Pages 157–190 *in* W. S. Hoar and D. J. Randall, editors. Fish physiology, volume 6. Academic Press, New York, NY, USA.

LEITRITZ, E., AND R. C. LEWIS. 1976. Trout and salmon culture. California Department of Fish and Game, Fish Bulletin 164.

MARTIN, N. V. 1955. The effect of drawdowns on lake trout reproduction and the use of artificial spawning beds. Transactions of the North American Wildlife Conference 20:263–271.

MCMULLIN, S. L., AND P. J. GRAHAM. 1981. The impact of Hungry Horse Dam on the kokanee fishery of the Flathead River. Montana Department of Fish, Wildlife, and Parks, Kalispell, MT, USA.

PERRY, S., AND P. J. GRAHAM. 1981. The impact of Hungry Horse Dam on the aquatic invertebrates of the Flathead River. Prepared by the Montana Department of Fish, Wildlife and Parks for the Water and Power Resources Service, Boise, ID, USA.

PURI, A. N. 1949. Soils their physics and chemistry. Reinhold, New York, NY, USA.

REISER, D. W., AND T. A. WESCHE. 1979. In situ freezing as a cause of mortality in brown trout eggs. Progressive Fish-Culturist 41:58–60.

REISER, D. W., AND R. G. WHITE. 1981. Incubation of steelhead trout and spring chinook salmon eggs in a moist environment. Progressive Fish-Culturist 43:131–134.

REISER, D. W., AND R. G. WHITE. 1983. Effects of complete redd dewatering on salmonid egg hatching success and development of juveniles. Transactions of the American Fisheries Society 112:532–540.

STOBER, O. J., AND R. W. TYLER. 1982. Rule curves for irrigation drawdown and kokanee salmon (*Oncorhynchus nerka*) egg to fry survival. Fisheries Research (Amsterdam) 1:195–218.

WASHINGTON STATE DEPARTMENT OF FISHERIES. 1976. Reduction of flow at Priest Rapids Dam to 36,000 cfs during the period April 10–11, 1976. Washington State Department of Fisheries, Olympia, WA, USA.

WEITKAMP, D., D. CHAPMAN, T. WELSH, AND T. SCHADT. 1982. 1980 Vernita Bar spawning survey. Final report to Public Utility District 2 of Grant County, Document 82-0910-019F, Ephrata, WA, USA.