

TASK 12. FRY EMERGENCE (1991 AND 1992)

12.1 OBJECTIVE

Fry emergence was monitored from 28 chinook salmon redds in the Mokelumne River in 1991 to assess the effect of water temperature and substrate conditions on spawning success. Based on results from the 1991 study, the study design was modified in 1992 to include the use of incubation capsules in controlled laboratory and field experiments to quantify the effect of water temperature on spawning success. Twelve wild salmon redds were covered in 1992 to further evaluate the effect of substrate conditions on spawning success and quantify any effects emergent trapping may have on egg survival and subsequent production estimates. In both years, the abundance and size of fry emerging from wild salmon redds in the river were also determined.

12.2 METHODS

12.2.1 Monitoring of Wild Salmon Redds

12.2.1.1 1991 Study

Twenty-eight chinook salmon redds in 1991 were monitored to characterize the abundance and size of fry emerging from gravels in the Mokelumne River (Figure 12-1). Fry emergence was compared to substrate composition in the redds to describe any relationship that might exist.

To determine the potential impact on egg survival of warm temperatures in the Mokelumne River shortly after reservoir turnover (late October - early November), the emergent trapping data from the 28 redds was separated into four groups based on their exposure to different temperature conditions. It was assumed that if temperature was a factor, fry production should be significantly higher from redds constructed after river temperatures dropped below 14° C.

Redds were surveyed from 30 October to 21 December, 1990. During the surveys, EBMUD gathered information on the timing, location, and dimensions of redd construction as well as flow and temperature regimes (Hagar 1991). Based on this survey data, 28 redds were selected for study; these were further divided into four categories:

- Group A Redds (#4, 5, 14, 15, 16, 20, 34) exposed to a change in flow after completion and 15-28 days of water temperatures in excess of 14° C.

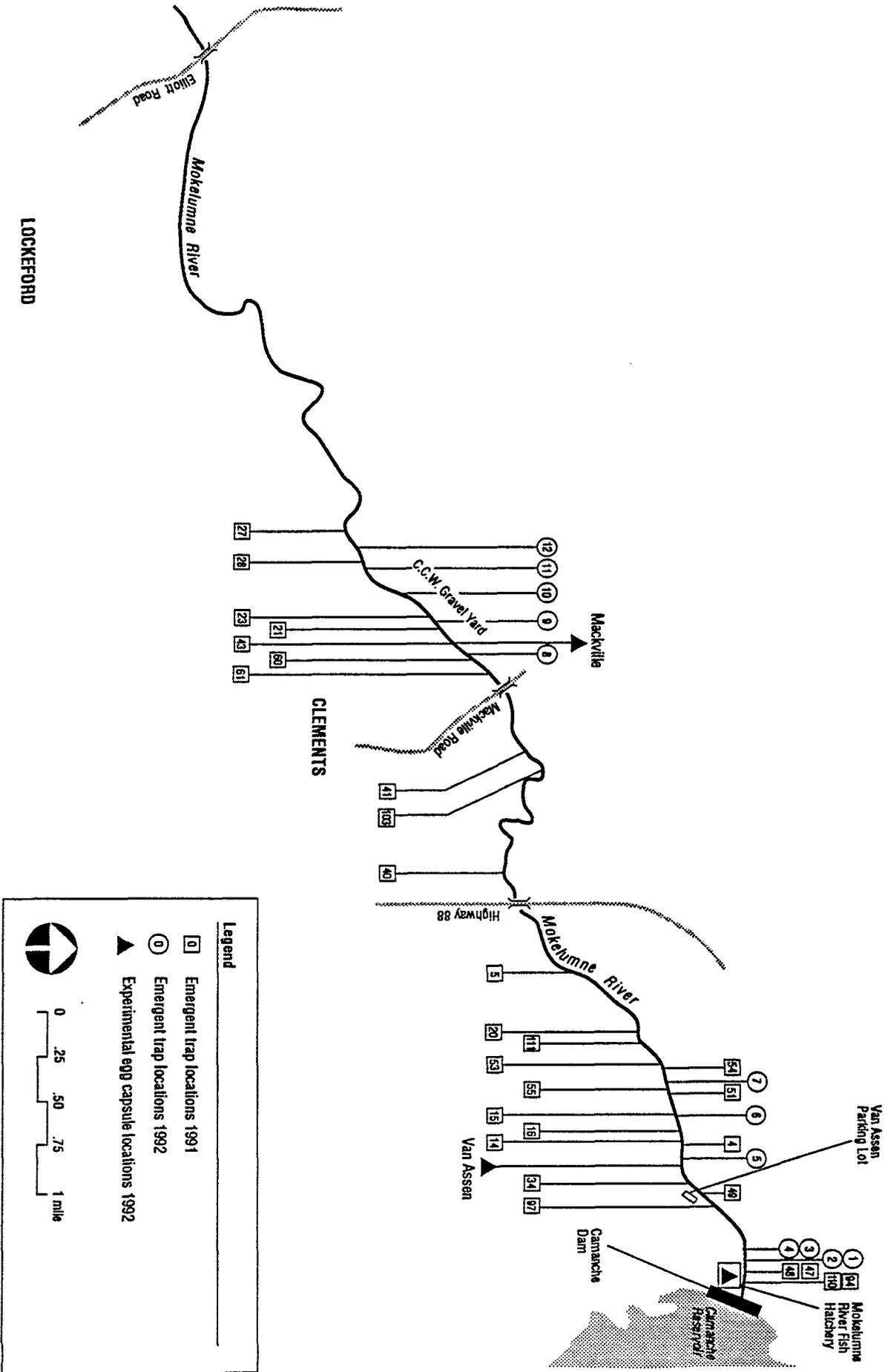


Figure 12-1. Location of chinook salmon redds covered with emergent traps in 1991 and 1992, and sites of 1992 experimental egg capsule studies.

- Group B Redds (# 21, 23, 27, 28, 40, 41, 43) exposed to a change in flow after completion and 7-13 days of water temperatures in excess of 14° C.
- Group C Redds (# 47, 48, 49, 51, 53, 54, 55) with constant flow after completion and exposure to 8 days of water temperatures in excess of 14° C.
- Group D Redds (# 60, 61, 94, 97, 103, 110, 111) with constant flow after completion and exposure to 0 days of water temperatures in excess of 14° C.

Emergent traps were installed on Group A redds between 3-8 January, on Group B redds between 7-9 January, on Group C redds on January 22, and on Group D redds on 5 February 1991. The emergent traps used in this study were rectangular shaped (2.1 m x 1.5 m) with 3.1 mm mesh and had a removable PVC trap cup (11.4 cm diameter; 30 cm length) at the base. The body of the trap had a 0.9 m zipper and the bag of the trap ahead of the cup had a 0.6 m long zipper. Grommets were located every 46 cm along the perimeter of the cap. The trap design was based on modified fry traps used by Phillips and Koski (1969).

Emergent traps were placed over the completed redds so that the egg pockets were covered (Chapman 1988). In some redds, the traps were not large enough to cover all potential egg pockets and in these cases the traps were placed to maximize coverage. The traps were secured by driving steel rebar into the substrate through the grommets on the trap rim and by placing burlap sacks filled with rock at all major stress points. Heavy rocks were placed on the remaining edges and gravels were used to seal smaller spaces where fry might escape. To assess whether a trap had been tampered with between checks, a black marble was placed into the collection cup. If marbles were missing during inspection periods, this was assumed to be a sign of tampering.

The emergent traps were cleaned by sweeping a push broom to force water over the netting to dislodge fines and algae from the trap surface. To minimize disturbance, care was taken to not touch the redd surface. After cleaning, each trap was inspected to ensure it fit properly.

All 28 emergent traps were checked and cleaned daily from 4 January - 11 February 1991. After 11 February, the non-producing traps were checked and cleaned every other day, since the time required to check all the traps was prohibitive. Emergent traps in which fry were hatching were checked on a daily basis until no fry emerged for two consecutive days. The redd was then checked every other day.

Each emergent trap was checked by raising and lowering the upstream portion of the cap mesh to move fry into the cup. The contents of the trap cup were examined, fry present were processed, and any dead fry were noted. The collection cup was then reattached and the front (upstream) portion of the cap netting was raised and lowered several times to flush remaining fry into the collection cup for processing.

If fewer than 15 fry were collected, all were measured to the nearest millimeter and weighed them using volumetric displacement. If more than 15 fry were collected, a subsample ($n \leq 30$) was hand measured and the remainder weighed by volume. Weight was later determined using the assumption 1 ml = 1 gm (Carlander 1977). All fry were released into the river after processing.

12.2.1.2 1992 Study

Twelve wild salmon redds were trapped in 1992 to further evaluate the effect of substrate conditions on spawning success and to quantify any effects emergent trapping may have on egg survival and subsequent production estimates. Comprehensive redd surveys were carried out to locate potential study redds at Van Assen Park and downstream of Mackville Road Bridge between 18 November and 30 November. During the daily surveys, salmon activity, redd size, and superimposition were noted. A total of 25 redds were located; 16 at Van Assen Park and 9 redds downstream of Mackville Road Bridge. Based on the preliminary data obtained from these 25 redds, 12 redds were selected for study which had been determined to be completed and not superimposed; 7 redds were at Van Assen Park and 5 redds were downstream of Mackville Road Bridge (Figure 12-1). When all activity on a suitable redd had ceased, the redd was covered with wire net (mesh size = 8 cm square) and re-bar stakes (40 cm) were placed around the perimeter of the redd to prevent superimposition.

Two different sizes of emergent traps were used in 1992 including seven traps identical to those used in 1991 (2.1 m x 1.5 m) and five larger traps (3.0 m X 4.6 m). Apart from the size and number of zippers, both trap types were similar in design. The larger traps had three 1-m zippers in the cap area and a 1-m zipper in the bag portion.

The smaller emergence traps were installed using the methods outlined for the 1991 emergence studies. The larger traps were installed using 1991 methods with the exception that the perimeter of the trap was also buried 20 - 30 cm deep in the gravel around the redd. Three large emergence traps were placed at Van Assen Park (redd numbers 3, 5, 6) and two below Mackville Road Bridge (redd numbers 8 and 11). The remaining redds at both sites ($n=7$) were covered with the smaller traps (redd numbers 1, 2, 4, 7, 9, 10, 12).

The emergence traps were installed on 23 December and cleaned every other day from 23 December - 4 February, following 1991 methods. Daily monitoring for fry emergence started on 5 February and continued until the traps were removed on 28 March.

12.2.2 Substrate Sampling

12.2.2.1 1991 Study

To characterize substrates, 25 of the 28 redds monitored with emergent traps were sampled using a gravel sampler shortly after emergence was completed. Three redds disturbed by human activity after emergence was completed were not included in the substrate analysis. The gravel sampler, similar in design to a Surber sampler, consisted of a metal frame (45 cm x 45 cm) attached to the front of a screened collection box (45 cm x 45 cm x 60 cm, 200- μ mesh screen). The frame was placed in the back half of the pit area in the redd with the open end facing upstream so that flow could wash fines into the collection box. Sediments within the frame were taken from the redd and placed into a 5-gallon plastic bucket. Collection continued until sediments were no longer moveable by hand. Fines carried by the water current into the collection box were added to each sample. The samples were sent to Herzog Associates in Petaluma, California, for analysis.

12.2.2.2 1992 Study

After the emergent traps were removed on 28 March, a substrate sample was collected from each of the 12 study redds, using the same methods outlined in 1991. Two substrate samples were also collected from the two artificial redds (see Section 12.2.3.1) at the Van Assen Park and Mackville Road sites. A sample of pea-gravel, used in the incubation capsules, was also collected for analysis (see Section 12.2.3.4). As in 1991, all substrate samples were sent to Herzog Associates in Petaluma, California, for analysis.

12.2.3 Study Design for 1992 Emergence Experiments

The study design for the 1992 emergence studies is outlined in Figure 12-2. The study approach was to 1) monitor the effect of temperature on ova development and fry emergence from artificial redds in the river using egg incubation capsules containing a known number of eggs, 2) establish coldwater (<12.8° C) and ambient temperature controls at the MRFH to calibrate the in-river findings, and 3) monitor fry emergence/production in 12 salmon redds to quantify any effects of emergent trapping on egg survival and subsequent production estimates.

12.2.3.1 In-river Temperature Experiments

To determine the effect of temperature on egg survival under river conditions, groups of chinook salmon eggs were placed in the river on 24 and 31 October 1991 (Batch 1 and 2, respectively) when mean daily water temperatures were >15.2° C and on 16 December (Batch 3) when mean daily water temperatures were <12.8° C. Each batch of eggs was placed in one of the artificial redds constructed in the river at two locations, Van Assen Park and just downstream of the Mackville Road Bridge (Figure 12-1). These sites were chosen to represent the different conditions spawning chinook salmon encounter in the river

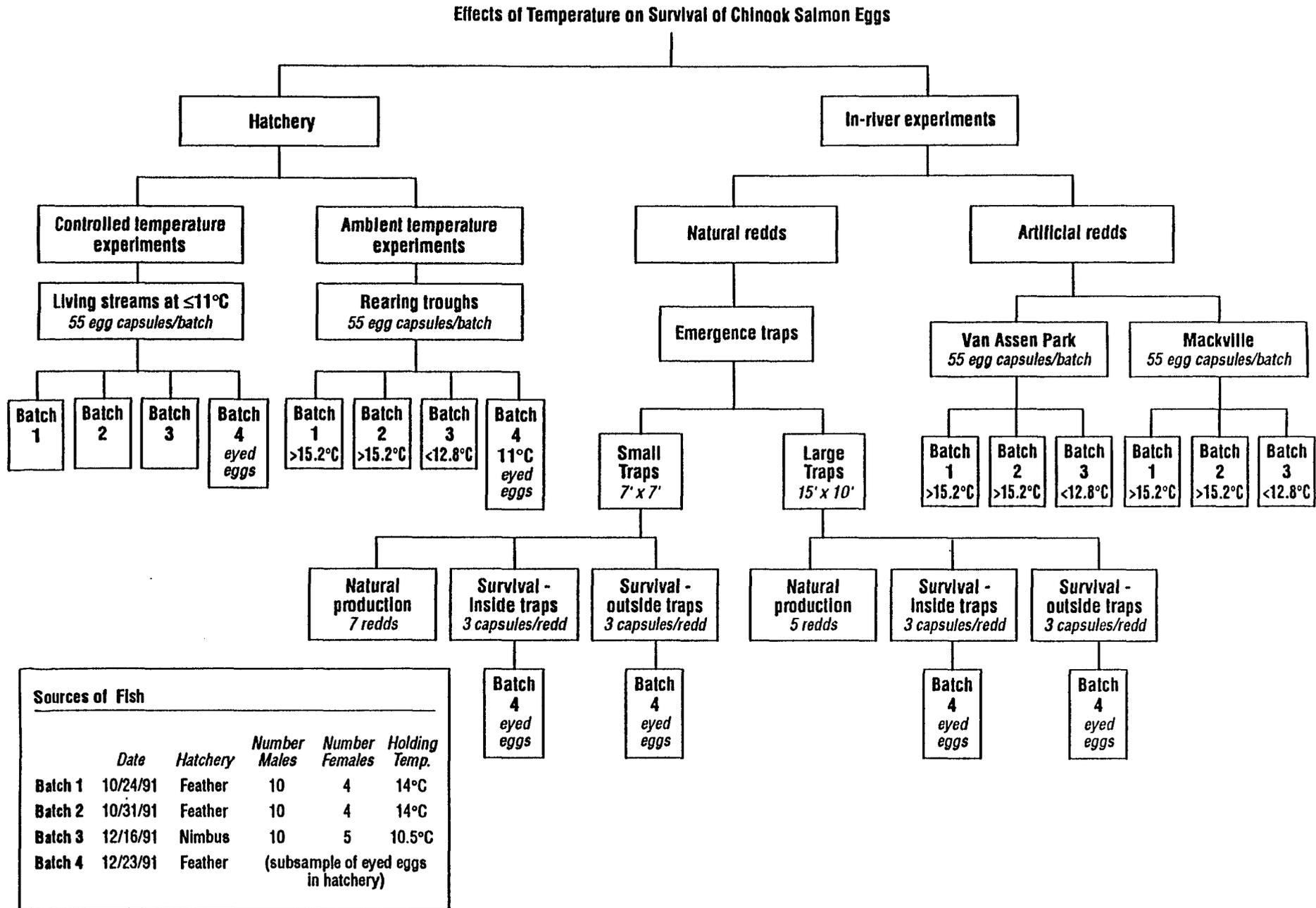


Figure 12-2. Study design for 1992 emergence studies in lower Mokelumne River.

(i.e., flow, temperature, substrate). The artificial redds were constructed in areas where salmon were observed spawning in 1990/1991 (Hagar 1991).

At each site, the substrate in a 4.5 m x 4.5 m area was turned over to a depth of 30 cm. This digging removed fines from the gravel and resulted in the construction of a artificial redd. To avoid disturbance by spawning salmon, the gravel areas were sectioned off by placing fencing posts around the perimeter and re-bar rods were scattered throughout the redd. Fish could swim through these artificial redds, but digging or spawning activity was prevented by the re-bar.

12.2.3.2 Hatchery Controls

The controls for the in-river experiments were conducted at the MRFH. Two controls were established, an ambient temperature control and a cold water control. For the ambient control experiment, a flow through system (18.9 l/min) in an aluminum rearing trough was used in the hatchery. The trough was 6 m long, 60 cm wide, and 20 cm deep. Black plastic covered the trough to reduce exposure of the eggs to changes in light conditions.

Two Frigid Unit Living Stream (Model LS700) tanks operating in series were used to establish the cold water control. Each tank (dimensions 2.1 m x 61 cm x 56 cm deep) had a capacity of 492 liters and was wrapped with fiberglass insulation to reduce heating of the water. Three Min-O-Cool cooling units (Model D1 - 33) were mounted on top of the first living stream; this tank acted as the initial cooling area or reservoir tank for the cold water experiments. A fourth cooling unit was placed in the second Living Stream tank to maintain water temperatures in the tank containing the developing eggs. The reservoir tank was situated higher than the experimental tank so that a gravity flow-through system could be achieved. The combined cooling units produced 15,800 BTU; this was sufficient to maintain water temperatures below 12° C while allowing a flow of 13.2 liters per minute through the system. Water was supplied to the ambient and cold water controls from the gallery line at Camanche Dam (Don Estey, CDFG, pers. comm).

12.2.3.3 Egg Planting

For egg batches 1 and 2, approximately 6,000 fertilized eggs were obtained from the Feather River Hatchery on 24 and 31 October, respectively. These fertilized eggs were a subsample of eggs produced by 10 males and 4 females that had been held at the hatchery for two weeks at 14° C (Don Schlichting CDFG, pers. comm.). For the third egg batch, 6,000 fertile eggs were obtained from the Nimbus Hatchery on 16 December. These eggs were obtained from a subsample of 10 males and 5 females which were held at 10° C (Ron Ducey CDFG, pers. comm).

For each batch, the eggs were fertilized by CDFG personnel and water hardened for 1 hour prior to transportation to the Mokelumne River. During transport, the eggs were wrapped in cheesecloth and held in ice chests at 12° C. At the MRFH, the fertile eggs were counted

into 25-egg aliquots and placed into the incubation capsules. Small pea gravel (< 1.3 cm) was simultaneously added to the capsules with the eggs. The placement of eggs and gravel into incubation capsules was carried out underwater to avoid eggs being ruptured by handling or by the gravel. Incubation capsules were then placed into an ice cooler (12° C water) and taken to the river sites or the hatchery control tanks for planting.

The incubation capsules were constructed of ABS (acrylonitrile-butadiene-styrene) plastic cylinders with 3.2 mm holes drilled throughout the bottom, top, and sides. A capsule template produced a total of 165 holes in each capsule. The capsule body was 10 cm x 5 cm, with an inside diameter of 38 cm. Polyethylene caps were used for the bottom and top of the capsules. Colored electrical wire was attached to each capsule to mark the location of the incubation capsule in the gravel and to later remove the capsules.

In the hatchery controls, the incubation capsules were suspended in the water column while in the river the capsules were buried in the substrate. To bury the capsules in the river substrate a solid steel driving rod and a steel pipe (30 cm x 7 cm I.D) were used. The planting pipes were placed in the river gravel by driving the rod and planting pipe 20 cm into the river bed and then removing the rod, leaving the pipe in the gravel (Scrivener 1988). Usually, all planting pipes were placed in the gravel one day prior to placing the fertilized eggs in the incubation capsules. The incubation capsules were then placed into the planting pipes. The planting pipes were then removed, leaving the incubation capsules in the substrate at a depth of 20 cm.

For each of the three egg batches, 55 incubation capsules were planted at both the Van Assen Park and Mackville Road sites. Similarly, an additional 55 incubation capsules were placed in the cold water and ambient controls established at the MRFH. In all, 220 incubation capsules were planted for each egg group being studied (total 660).

12.2.3.4 Egg Survival Procedures

The survival of eggs exposed to different temperature conditions was determined at four times during their development period. Eggs were checked 36 hours after the incubation capsules were planted (phase 1), at the pigmented eye stage (phase 2) (350 - 450 degree days [DD]), at the hatch stage (phase 3) (750 - 850 DD) and at the pre-emergence or alevin stage (phase 4) (1,500 - 1,600 DD). Five capsules were removed from each site, including the hatchery controls, at phases 1-3. The remaining capsules from each site were removed at phase 4.

After the capsules were removed, the eggs were examined and placed into the following categories: live eggs/embryos (no yolk coagulation), dead eggs/no development (coagulated yolk), live pigmented eyes, dead pigmented eyes, hatchlings (free swimming and absorbing yolk sac), dead hatchlings, live alevins (button-up), and dead alevins. Egg survival in each capsule was then determined. After each check, all eggs or alevins were preserved in 5 percent formalin.

Water temperature was monitored throughout the study period by Omnidata thermal datapods which were set to record mean water temperatures every 2 hours. Datapods were installed in the ambient control, cold water reservoir, cold water control, at Van Assen Park, and at Mackville Road site. A certified thermometer was used to calibrate the datapods at each site.

12.2.3.5 Effects of Emergence Traps on Egg Survival

To determine the effects of the emergence traps on egg survival in wild salmon redds, three incubation capsules were placed underneath 11 emergence traps using methods described in section 12.2.3.3. Three additional egg capsules were placed in each salmon redd on the outside of the emergent traps to compare their survival with eggs placed under the traps. Eyed eggs were used instead of fertilized eggs because their development rate would be more closely associated with those already deposited in the redd by spawning salmon. The eyed eggs were obtained from the Nimbus Hatchery on 23 December from fish spawned on 26 November, and had acquired 480 degree days (R. Ducey CDFG, pers. comm). The egg capsules were removed from wild salmon redds at phase 4 on 7 and 11 February 1992.

12.3 RESULTS

12.3.1 Emergence Patterns (1991 -1992)

Twenty-eight redds were monitored with emergence traps in 1991 and, of these, 19 (67.9%) produced fry (Table 12.1). The number of emerging fry per redd averaged 128.2 and ranged from 0 to 1,519. The length frequency of emerging fry is illustrated in Figure 12-3. The distribution is bimodal; however, all the fish in the smaller size group were collected in one emergent trap only. The mean length of fry was 35.9 mm TL.

Of the twelve wild salmon redds monitored in 1992, 8 (67.7%) produced fry (Table 12.1). The number of fry produced per redd averaged 312.9 and ranged from 0 to 1,768. The length frequency distribution of emerging fry is illustrated in Figure 12-3. The mean length of emerging fry in 1992 (38.2 mm TL) was significantly larger than fry emerging in 1991 (t-value = 22.7, $p < 0.01$), although the difference between the means was only 2.3 mm.

12.3.2 Substrate Analysis (1991-1992)

The size distribution of substrate collected from salmon redds in 1991 and 1992 are presented in Table 12.2 and 12.3, respectively. Overall, gravel-size particles (6.3-7.5 mm) dominated the substrate in wild salmon redds in both years (Figure 12-4). Several researchers have found that egg survival is reduced by as much as 80 percent in redds containing 10-15 percent of 6-12 mm fines (Chapman 1988). Eighteen of the 25 (72%) redds sampled in 1991 contained fines at or above these levels (Table 12.1). Similarly in 1992, 75 percent of the redds sampled (9 of 12) contained high amounts of fines. Interestingly, the redd producing the highest number of fry in 1992 also contained the highest concentration of fines.

Table 12.1. Total number of emerging fry and percentage composition of fines (<9.5 mm) in chinook salmon redds monitored during 1991 and 1992 emergence studies.

REDD NO.	TOTAL NUMBER OF FRY	% FINES (<9.5 mm)
1991		
97	0	NA
28	94	NA
43	146	NA
27	135	0.1
15	390	3.4
16	1	5.1
53	0	6.3
40	197	6.6
14	387	8.2
41	1,519	8.7
47	4	10.3
54	17	10.3
4	249	12.5
103	34	13.6
111	124	14.0
61	31	15.2
55	0	15.5
97	162	15.7
21	0	15.8
34	0	17.0
51	0	17.8
20	37	17.8
60	36	18.0
5	0	23.8
23	25	24.3
48	0	26.4
110	0	27.6
49	1	28.3
Mean Number Fry = 128.2 SD = 289.4		
1992		
3	1	1.1
2	0	6.0
6	683	7.2
10	437	10.0
9	0	11.1
7	230	13.8
8	597	17.5
1	0	17.8
11	32	19.0
12	0	20.5
4	7	24.9
5	1,768	28.5
Mean Number Fry = 312.9 SD = 523.9		

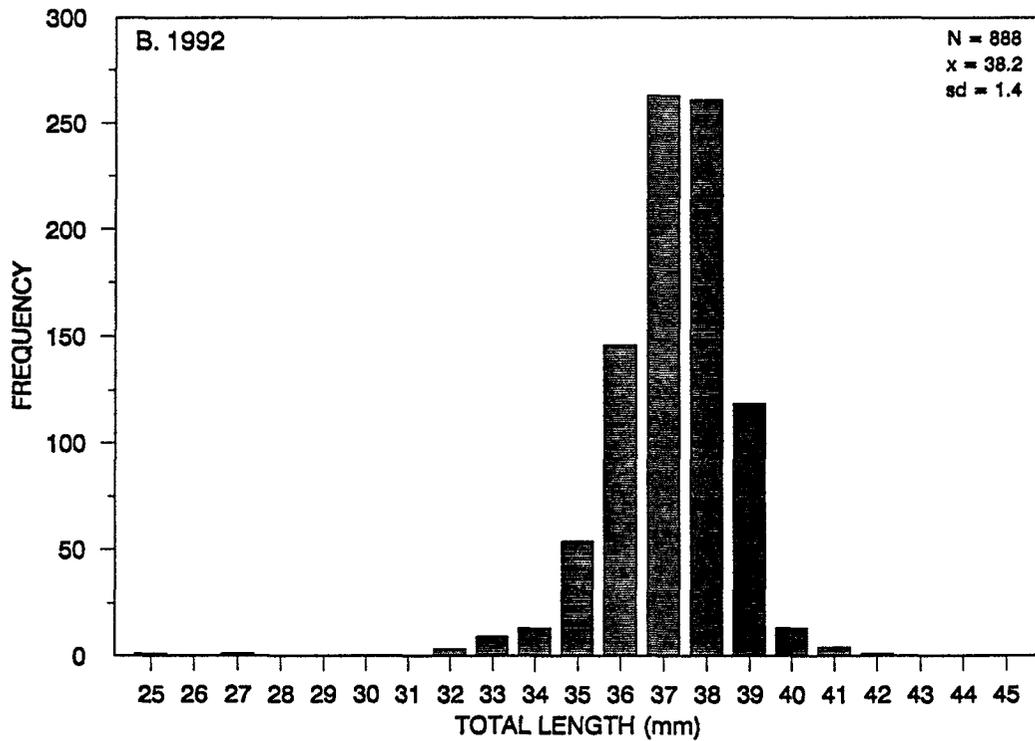
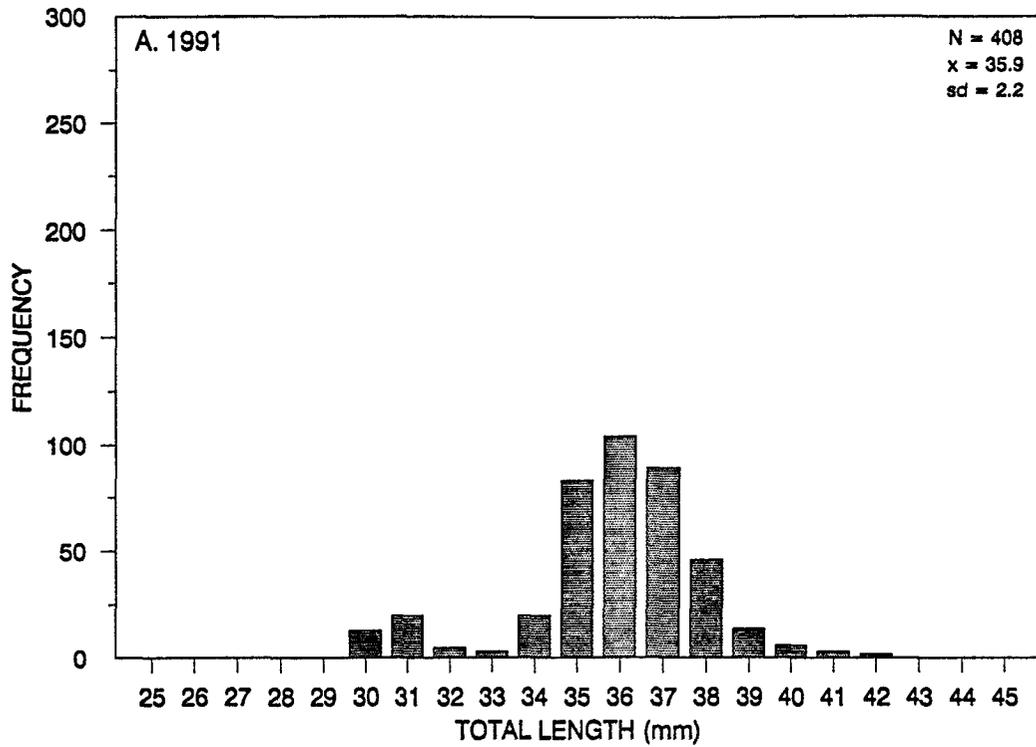


Figure 12-3. Length frequency distribution of salmon fry collected in emergent traps on the Mokelumne River in A) 1991 and B) 1992.

Table 12.3 Size distribution (by percent) of substrate samples collected in redds monitored during 1992 emergence studies on the Mokelumne River.

RANGE OF PARTICLE SIZE (mm)	BIOSYSTEMS TRAP NO.:	SIZE DISTRIBUTION AT INDIVIDUAL REDDS (%)																	
		1	2	3	4	5	6	7	8	9	10	11	12	ET	MV-1	MV-2	VA-1	VA-2	
>152.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
76.2 - 152.4	0.0	0.0	7.7	0.0	13.2	33.2	0.0	6.0	5.4	19.9	9.3	10.4	0.0	0.0	0.0	0.0	11.5	13.9	14.4
38.1 - 76.2	44.7	56.3	70.9	38.2	23.6	31.7	33.5	46.7	51.5	39.6	30.9	27.4	0.0	43.4	47.1	25.6	27.5	29.7	40.2
19.1 - 38.1	26.8	27.7	17.4	20.9	18.2	19.5	40.4	18.4	24.1	21.6	23.3	28.1	0.0	26.5	27.4	25.6	27.5	29.7	20.8
9.5 - 19.1	10.7	10.0	2.9	16.0	16.5	8.4	12.3	11.4	7.9	8.9	17.5	13.6	46.2	13.6	13.6	8.5	13.9	10.8	10.8
6.4 - 9.5	5.8	5.5	1.1	9.5	9.5	5.1	7.5	6.6	4.3	5.0	9.9	7.9	27.0	7.7	7.7	5.9	8.1	6.6	6.6
4.8 - 6.4	2.3	0.3	0.0	3.8	4.9	1.0	2.2	3.0	1.8	1.4	2.7	2.4	19.9	2.5	2.5	0.7	1.9	1.7	1.7
2.4 - 4.8	3.9	0.1	0.0	5.7	7.9	0.8	2.8	3.8	2.5	1.5	3.6	3.9	6.4	3.7	3.7	0.5	2.5	2.5	2.5
1.2 - 2.4	2.6	0.1	0.0	2.8	4.0	0.2	0.9	1.4	1.4	0.9	1.2	2.3	0.3	1.8	1.8	0.1	1.3	1.5	1.5
0.6 - 1.2	2.5	0.0	0.0	2.1	1.9	0.0	0.3	1.5	0.8	0.9	1.1	2.7	0.0	0.6	0.6	0.1	1.0	1.2	1.2
0.3 - 0.6	0.6	0.0	0.0	0.8	0.3	0.1	0.0	0.3	0.2	0.2	0.4	1.1	0.1	0.2	0.2	0.0	0.1	0.1	0.2
0.2 - 0.3	0.0	0.0	0.0	0.1	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.2	0.0	0.0	0.0	0.0	0.0	0.1	0.1
0.1 - 0.2	0.1	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
SAMPLE WEIGHT (kg):	11.1	14.7	17.9	12.8	16.9	20.7	13.1	12.1	18.6	12.9	9.7	17.9	1.1	14.0	15.6	15.3	13.8		

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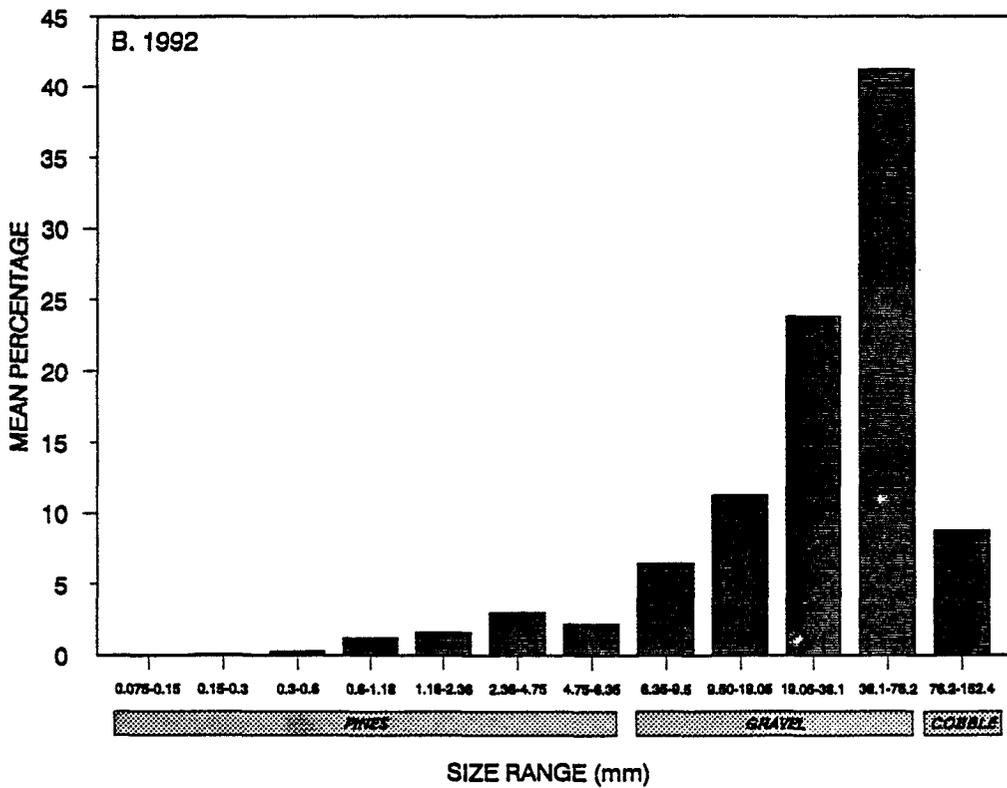
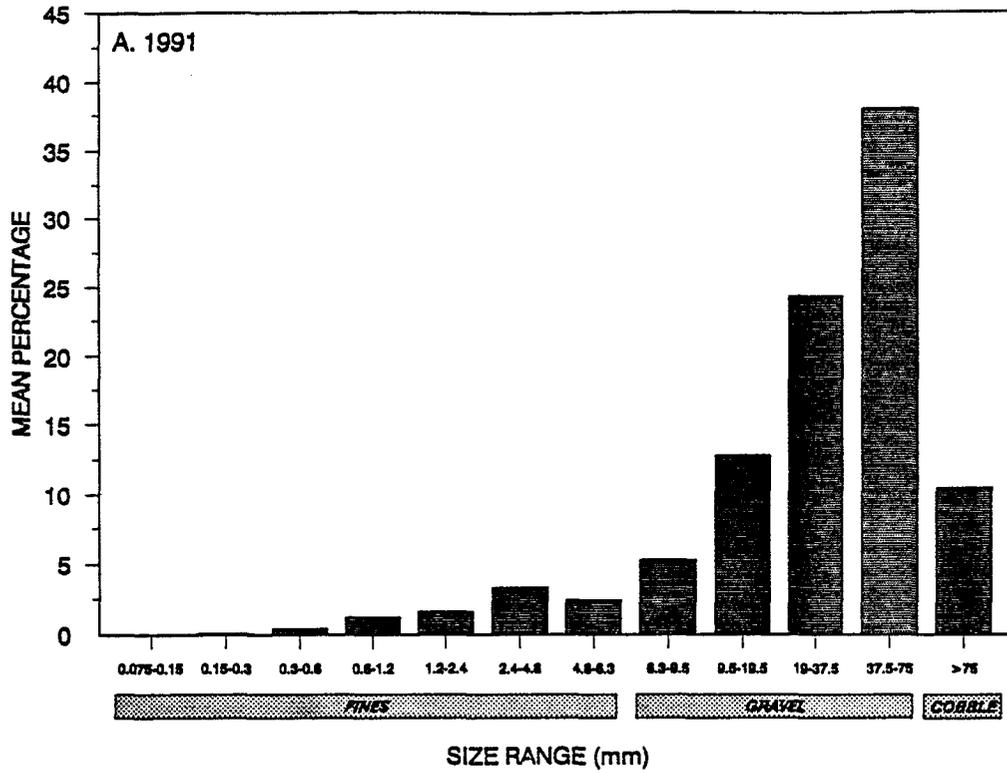


Figure 12-4. Average percent composition of particle sizes in substrate samples collected from salmon redds on the Mokelumne River in A) 1991 and B) 1992.

The number of fry emerging from trapped salmon redds in the Mokelumne River in 1991 and 1992 was tested to see if there was a correlation with the percentage of fines in four size categories (diameter < 4.8 mm, < 6.3 mm, < 9.5 mm and < 19.5 mm). In 1991, it was found that fry emergence from wild redds was inversely related to the percentage of fines in each of the four size categories (Table 12.4). However, in 1992, there was no correlation between the percentage of fines and fry emergence from the wild redds. Apparently, some factor other than the percentage of fines in 1992 may have influenced fry emergence.

Table 12.4. Correlation coefficients between substrate composition and total fry emerging from each redd in 1991, 1992, and these two years combined. Redd 41 in 1991 and redds 1-4 in 1992 was considered as an outlier and was excluded from the analysis.

	% FINES			
	<4.8 mm	<6.3 mm	<9.5 mm	<19.5 mm
1991				
Fry	-0.46*	-0.51*	-0.51*	-0.49*
1992 (excluding redds 1-4)				
Fry	0.50	0.55	0.50	0.43
1991 + 1992				
Fry	0.06	0.07	0.09	0.05
*Significant at 0.05 level				

12.3.3 Effects of Temperature on Egg Survival

12.3.3.1 1991 Study

The effects of temperature and flow regimes were analyzed by grouping redds according to their exposure to temperature variation and/or changes in flow (Table 12.5). No correlations between the abundance of emerging fry and variations in temperature or flow were found (Student-Newman-Keuls multiple comparison test, $p > 0.1$).

Table 12.5. Number of fry produced per redd in relation to temperature and flow during spawning and incubation in 1991.

GROUP A: FLOW CHANGE/15-28 DAYS >14° C										
REDD NO.:	14	5	15	4	20	16	34	MEAN	STD. DEV.	TOTAL
TOTAL FRY PRODUCED PER REDD:	387	0	390	249	37	1	0	152.0	170.5	1,064
GROUP B: FLOW CHANGE/7-13 DAYS >14° C										
REDD NO.:	27	28	23	21	43	40	41	MEAN	STD. DEV.	TOTAL
TOTAL FRY PRODUCED PER REDD:	135	94	25	0	146	197	1,519	302.3	500.8	2,116
GROUP C: NO FLOW CHANGE/8 DAYS >14° C										
REDD NO.:	48	47	54	51	53	55	49	MEAN	STD. DEV.	TOTAL
TOTAL FRY PRODUCED PER REDD:	0	4	17	0	0	0	1	3.1	5.8	22
GROUP D: NO FLOW CHANGE/0 DAYS >14° C										
REDD NO.:	97	94	103	61	111	60	110	MEAN	STD. DEV.	TOTAL
TOTAL FRY PRODUCED PER REDD:	162	0	34	31	124	36	0	55.3	58.1	387

12.3.3.2 1992 Study

Temperature Conditions During Experiments - Water temperatures during the in-river and hatchery control experiments for egg batches 1-3 are outlined in Figure 12-5 and Table 12.6. In the hatchery cold water controls, bi-hourly water temperatures were below 12° C in all three cold water control batches the majority of the time. In the ambient hatchery controls, bi-hourly water temperatures in batches 1 and 2 were above 15° C early in the incubation period and reached as high as 18.0° C and 16.5° C, respectively. Bi-hourly water temperatures in batch 3 in the ambient hatchery control were always below 12.0° C.

At the river sites (Van Assen and Mackville), bi-hourly water temperatures often exceeded 15° C early in the incubation period of egg batches 1 and 2. In general, bi-hourly water

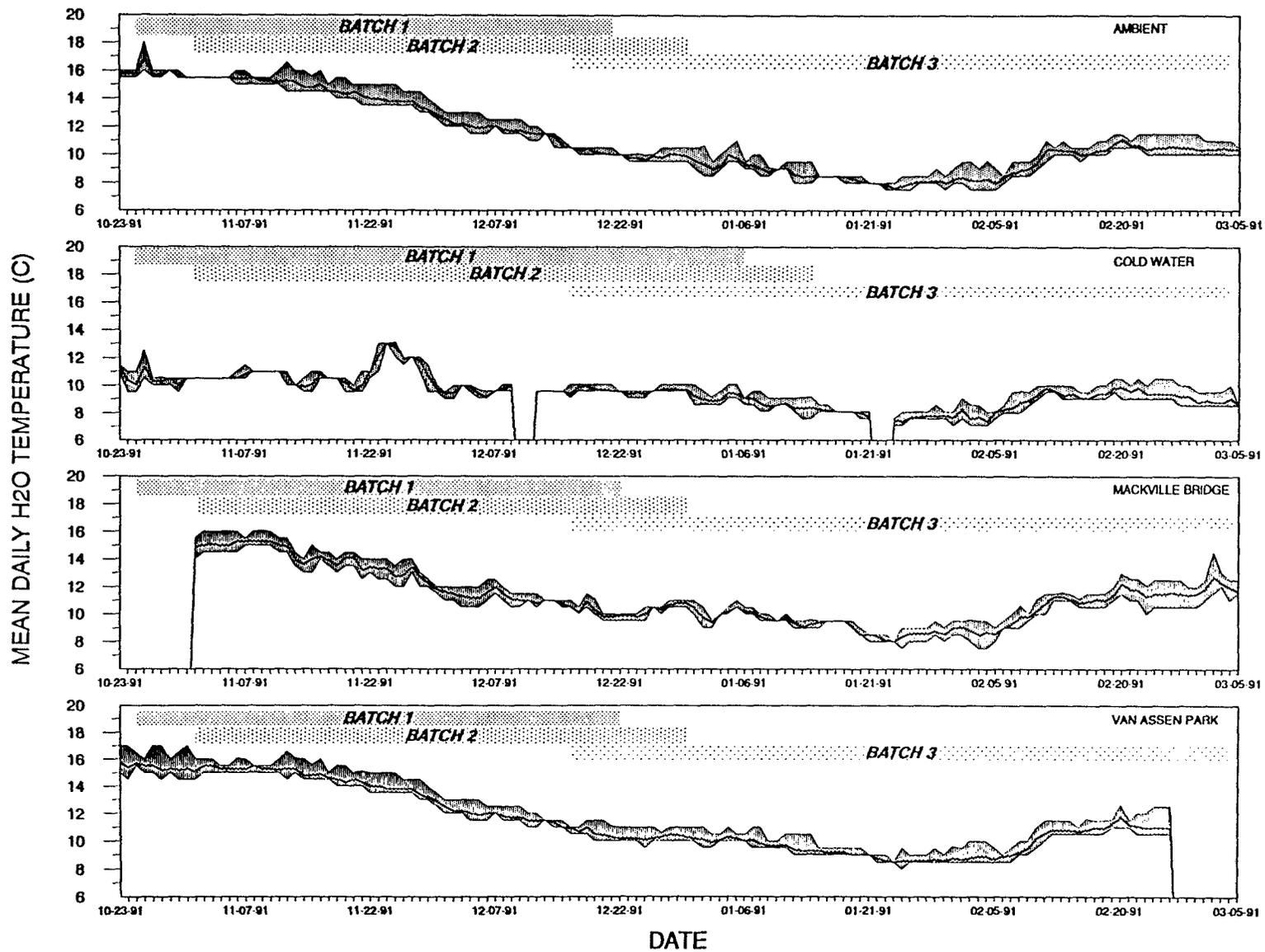


Figure 12-5. Mean and range of daily water temperatures recorded at the four egg experiment locations from 23 October 1991 to 5 March 1992.

Table 12.6. Summary of water temperature conditions during the incubation period of each of the three batches of experimental eggs.

	COLD WATER CONTROL						AMBIENT HATCHERY CONTROL					
	BATCH 1		BATCH 2		BATCH 3		BATCH 1		BATCH 2		BATCH 3	
Mean daily water temperature	10.2		10.0		8.9		13.7		12.8		9.4	
95% Confidence interval	0.2		0.2		0.2		0.5		0.5		0.2	
Minimum mean daily water temperature	8.8		8.3		7.4		10.1		9.7		7.6	
Maximum mean daily water temperature	13.0		13.0		10.0		16.8		15.5		11.1	
Minimum bi-hourly water temperature	8.6		7.6		7.1		10.0		9.5		7.5	
Maximum bi-hourly water temperature	13.0		13.0		10.5		18.0		16.5		11.5	
	HOURS	DAYS	HOURS	DAYS	HOURS	DAYS	HOURS	DAYS	HOURS	DAYS	HOURS	DAYS
> 18	0	0	0	0	0	0	0	0	0	0	0	0
17 - 18	0	0	0	0	0	0	8	1	0	0	0	0
16 - 17	0	0	0	0	0	0	10	1	2	1	0	0
15 - 16	0	0	0	0	0	0	420	24	268	18	0	0
14 - 15	0	0	0	0	0	0	246	10	246	10	0	0
13 - 14	0	0	0	0	0	0	174	2	174	2	0	0
12 - 13	126	7	118	6	0	0	226	12	226	12	0	0
< 12	1,626	66	1,658	68	1,842	78	306	8	546	18	1,918	80

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Table 12.6. Summary of water temperature conditions during the incubation period of each of the three batches of experimental eggs. (cont.).

	VAN ASSEN PARK						MACKVILLE BRIDGE					
	BATCH 1		BATCH 2		BATCH 3		BATCH 1		BATCH 2		BATCH 3	
Mean daily water temperature	13.5		12.9		9.9		12.7		12.4		10.1	
95% Confidence interval	0.5		0.5		0.2		0.5		0.5		0.3	
Minimum mean daily water temperature	10.2		10.1		8.5		9.8		9.8		8.0	
Maximum mean daily water temperature	15.7		15.5		11.8		15.3		15.3		12.7	
Minimum bi-hourly water temperature	10.0		9.5		8.0		9.5		9.5		7.5	
Maximum bi-hourly water temperature	17.0		17.0		12.5		16.0		16.0		14.5	

	HOURS	DAYS										
> 18	0	0	0	0	0	0	0	0	0	0	0	0
17 - 18	0	0	0	0	0	0	0	0	0	0	0	0
16 - 17	24	7	8	2	0	0	0	0	0	0	0	0
15 - 16	278	19	200	17	0	0	108	11	108	11	0	0
14 - 15	382	10	308	10	0	0	210	6	210	6	2	1
13 - 14	174	2	174	2	0	0	220	9	220	9	0	0
12 - 13	226	12	226	12	36	6	228	11	228	11	204	16
< 12	354	10	546	18	1,716	67	470	15	662	23	1,738	64

temperatures were higher at the Van Assen site than the Mackville site, peaking at 17.0° C and 16.0° C, respectively. For batch 3, bi-hourly water temperatures were almost always below 13° C at the two sites.

Batch and Location Effects - The experimental design to test whether chinook salmon egg survival is adversely affected by exposure to warm temperatures in the Mokelumne River during the early spawning period (late October - mid-November) required that different batches of eggs (batch 1-3) be exposed to varying water temperatures in the river (Figure 12-6). Before simply comparing the mean survival of different batches of eggs exposed to varying temperature conditions (Table 12.7), the batches of eggs (batches 1-3) were tested to see if they had different viabilities unrelated to their temperature history (batch effect). Testing for a batch effect was conducted by placing egg capsules from each experimental group in a control tank in the hatchery where incubation conditions were optimal.

Table 12.7. Mean survival and associated standard deviation of batches of chinook salmon eggs placed at different locations over time (phases).

LOCATION	BATCH		
	1	2	3
PHASE 1 (36 hours)			
Ambient	0.78±0.12	0.84±0.04	0.99±0.02
Control	0.77±0.07	0.86±0.05	0.99±0.02
Mackville	0.63±0.06	0.85±0.05	0.99±0.02
Van Assen Park	0.72±0.24	0.86±0.03	1.00±0.00
PHASE 2 (Eyed)			
Ambient	0.83±0.05	0.25±0.09	0.92±0.12
Control	0.74±0.17	0.52±0.13	0.93±0.10
Mackville	0.39±0.28	0.17±0.15	0.92±0.07
Van Assen Park	0.43±0.23	0.47±0.08	0.94±0.08
PHASE 3 (Hatched)			
Ambient	0.39±0.27	0.07±0.06	0.90±0.11
Control	0.78±0.11	0.29±0.17	0.94±0.10
Mackville	0.21±0.15	0.07±0.10	0.94±0.13
Van Assen Park	0.12±0.11	0.11±0.12	0.74±0.12
PHASE 4 (Emergence)			
Ambient	0.16±0.13	0.005±0.01	0.47±0.19
Control	0.39±0.20	0.07±0.12	0.67±0.19
Mackville	0.05±0.08	0.06±0.09	0.28±0.23
Van Assen Park	0.02±0.05	0.02±0.03	0.27±0.28

A significant difference in egg survival between batches was observed in the hatchery control group at all phases (F-test, $p < 0.05$), indicating that the egg batches had different viabilities unrelated to their temperature exposure in the Mokelumne River. To remove the batch effect

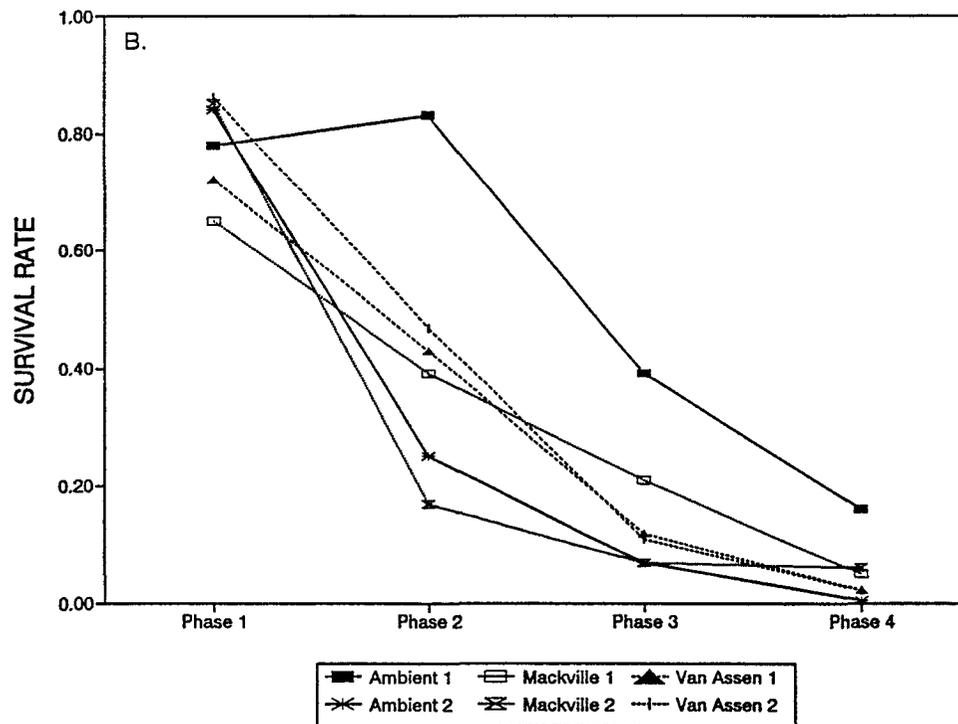
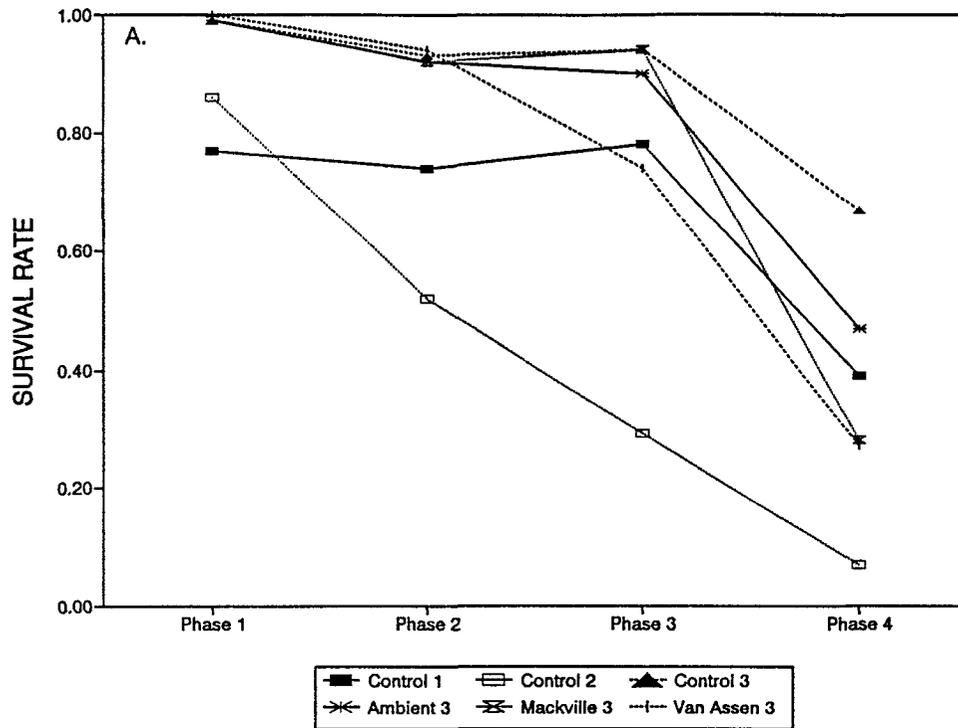


Figure 12-6. Mean survival of different batches of chinook salmon eggs exposed to A) cold water (<14° C) and B) warm water (>15.5° C) over the incubation period.

Table 12.8. Relative mean survival and associated standard deviation of chinook salmon eggs (adjusted, based on survival of control) at different locations over time (phases).

LOCATION	BATCH		
	1	2	3
PHASE 1 (36 hours)			
Ambient	1.00±0.15	0.98±0.05	1.00±0.02
Control	1.00±0.09	1.00±0.06	1.00±0.02
Mackville	0.85±0.08	0.99±0.06	1.00±0.02
Van Assen Park	0.94±0.32	1.00±0.04	1.01±0.00
PHASE 2 (Eyed)			
Ambient	1.12±0.07	0.48±0.18	0.99±0.13
Control	1.00±0.23	1.00±0.25	1.00±0.10
Mackville	0.52±0.38	0.32±0.30	0.98±0.07
Van Assen Park	0.59±0.31	0.91±0.15	1.02±0.09
PHASE 3 (Hatched)			
Ambient	0.50±0.34	0.25±0.20	0.95±0.11
Control	1.00±0.14	1.00±0.57	1.00±0.11
Mackville	0.27±0.19	0.25±0.34	1.04±0.13
Van Assen Park	0.15±0.14	0.39±0.40	0.79±0.13
PHASE 4 (Emergence)			
Ambient	0.41±0.34	0.07±0.19	0.71±0.29
Control	1.00±0.52	1.00±1.75	1.00±0.28
Mackville	0.13±0.20	0.86±1.35	0.41±0.35
Van Assen Park	0.06±0.14	0.28±0.46	0.40±0.41

from the analysis and therefore assess whether temperature differences alone during incubation significantly alter egg survival, the mean egg survival of the different batches at each location and phase (Table 12.7) to relative mean egg survival (Table 12.8) was adjusted based on survival in the hatchery control. This conversion involved increasing the mean survival of each hatchery control group at the different phases to 1.00 to characterize optimal incubation conditions and proportionately increasing egg survival at the other experimental locations (hatchery ambient, Mackville, and Van Assen Park) corresponding to that hatchery control batch and phase.

Temperature Effects - To focus the analysis on the effect of temperature on relative mean egg survival, egg survival was compared only between batches within a location. This analytical procedure eliminated any differences in egg survival that may have occurred between locations as the result of environmental conditions other than temperature (i.e., substrate). If warm temperatures in the Mokelumne River early in the incubation period adversely affects chinook salmon egg survival than the relative mean survival of eggs in batch 3 (cold water batch) should be significantly higher than in batch 1 or 2 (warm water batches) at all locations.

Significant differences (Newman-Keuls multiple range test, $p < 0.05$) in the relative mean survival of eggs between batches were found at all locations except for during phase 1 (Table 12.9). In general, the results from the hatchery ambient location (phases 2,3,4) and from the Mackville and Van Assen Park sites (phases 2,3) are consistent with the hypothesis that warm temperatures in the river early in the incubation period reduces egg survival. However, results from the two former sites during phase 4 (i.e., batch 2 had the highest survival) suggest that differences in egg survival during the experiment cannot be solely attributed to temperature.

Table 12.9. Experimental findings of egg survival study (based on Newman-Keuls multiple range test [$p < 0.05$]) comparing mean egg survival from batches 1, 2, and 3.

Ambient	Phase 1	Batch 1 = 2 = 3
	Phase 2	Batch 1&3 > 2
	Phase 3	Batch 3 > 1&2
	Phase 4	Batch 3 > 1 > 2
Mackville	Phase 1	Batch 2&3 > 1
	Phase 2	Batch 3 > 1&2
	Phase 3	Batch 3 > 1&2
	Phase 4	Batch 2 > 1&3
Van Assen Park	Phase 1	Batch 1 = 2 = 3
	Phase 2	Batch 2&3 > 1
	Phase 3	Batch 3 > 1&2

To further investigate the differences in survival rates between egg batches exposed to different temperature conditions, the data were separated into two experimental groups based on temperature exposure (cold water and warm water) and the actual mean survival rates of each egg batch were plotted through the four developmental phases at each location (Figure 12-6). Differences in the height of the curves are a result of batch and location effects and are relatively unimportant compared to the overall shape of the survival curves which is an indicator of a temperature effect.

The survival curve for all the cold water experimental groups except one (control group - batch 2) exhibit a similar shape in which survival is relative high through hatching but drops sharply from hatching to emergence. Conversely, the survival curves of the warm water groups generally drop markedly between phase 1 (36 hour after fertilization) and phase 2 (eyed eggs) after which it continues to decline at a slower rate through emergence. The curve for the cold water control group (batch 2) more closely resembles the curves of the warm water groups than the cold water groups; this suggests some factor other than temperature reduced egg survival in this control experiment. Turbidity increased substantially in the hatchery for a brief period of time during the early incubation period of this control group which may explain the atypical survival curve for this control group.

Since the mean survival of the control group of batch 2 was adjusted to 1.00 and used to determine a correction factor to adjust the survival rates of the other experimental groups in batch 2, a potential bias may have been introduced into the analysis. If the control group in the hatchery was differentially affected by the turbidity event compared to the in-river groups, the relative mean survival of the in-river groups was incorrectly increased. This error would substantially effect the interpretation of the temperature experiments for batch 2. The unadjusted survival data for the two warm water batches (1 and 2) reveal that in-river survival of these groups was quite similar, despite considerable differences in survival at the two hatchery locations (Table 12.7). This supports the hypothesis that there may have been a problem in the hatchery during the batch 2 experiment.

If batch 2 is excluded from the analysis, significant differences (Newman-Keuls multiple range test, $p < 0.05$) in the relative mean survival of eggs between batches 1 and 3 were observed at all locations after phase 1 (Table 12.10), except for the ambient group at phase 2 and the Mackville group at phase 4. In general, the results from the hatchery ambient location (phases 3 and 4), Mackville (phases 2 and 3), and Van Assen Park sites (phases 2,3, and 4) support the hypothesis that warm temperatures in the river early in the incubation period reduce egg survival.

Table 12.10. Experimental findings of egg survival study based on Newman Keuls multiple range test ($p < 0.05$) comparing mean egg survival from batches 1, 2, and 3.

Ambient	Phase 1	Batch 1 = 3
	Phase 2	Batch 1 = 3
	Phase 3	Batch 3 > 1
	Phase 4	Batch 3 > 1
Mackville	Phase 1	Batch 3 > 1
	Phase 2	Batch 3 > 1
	Phase 3	Batch 3 > 1
	Phase 4	Batch 3 = 1
Van Assen Park	Phase 1	Batch 1 = 3
	Phase 2	Batch 3 > 1
	Phase 3	Batch 3 > 1
	Phase 4	Batch 3 > 1

12.3.4 Effects of Emergent Trapping on Fry Production Estimates

12.3.4.1 Size of Emergent Traps

In 1991, emergence traps (2.1 m X 1.5 m) were placed over wild chinook salmon redds to quantify fry emergence. The mean number of fry emerging from the redds was relatively low and quite variable (mean = 128.2, SD = 289.4). To test whether the emergence traps used in 1991 may have been too small and therefore underestimating the number of fry, 12

wild chinook salmon redds were trapped in 1992 using two different size traps (2.1 m x 1.5 m and 3.0 m x 4.6 m). Although a higher mean number of fry were collected from the larger emergence traps (616.20 ± 716.11) as compared to the smaller trap (96.29 ± 172.73), this difference was not significant ($F\text{-value}=3.54, p>0.05$) because of the high variability observed between redds.

The 1992 emergent data were further separated into three groups based on their location in the river (near MRFH, Van Assen Park, and Mackville) to try to reduce variability. Although large differences in the mean number of fry collected from the wild redds were observed (Table 12.11), none of these differences were significant either between locations ($F=2.66, p>0.05$) or within a location between traps ($F=2.53, p>0.05$). The interaction between the location and trap size was also not significant ($F=1.40, p>0.05$). Clearly, neither the location nor size of the emergent trap explained the high variability in the trapping data.

Table 12.11. Comparison of fry emergence from wild chinook salmon redds at three locations.

TRAP SIZE	LOCATION		
	NEAR MRFH	VAN ASSEN PARK	MACKVILLE
Large	1.00 ± 0.00	1,225.50 ± 767.21	314.50 ± 399.52
Small	2.33 ± 4.04	230.00 ± 0.00	145.66 ± 252.30
	F-VALUE		P-VALUE
Location	2.66		0.15
Trap Size	2.53		0.16
Location * Size	1.40		0.31

12.3.4.2 Sampling Effects

The emergent traps themselves were investigated to see if they may be smothering eggs in the wild redds leading to overall low emergence. If the emergent trap differentially affected egg survival at individual redds because of differences in microhabitat conditions (i.e., flow, substrate), then the high variability in fry emergence from wild redds may be explained. These effects were tested by placing incubation capsules with a known number of eggs in the wild salmon redds both underneath and along side of the emergent traps and comparing survival to emergence.

Overall, no significant difference was found using F-test ($p>0.05$) in mean survival of eggs placed in capsules underneath or outside of the emergent traps (Table 12.12). The only

significant difference in egg survival based on its position was observed at redd 8 ($F=64.8$, $p<0.05$). It was concluded that the emergent traps are not smothering eggs and do not appear to differentially effect egg survival in selected redds.

Table 12.12. Mean survival and associated standard deviation of chinook salmon eggs in capsules placed inside and outside of emergence traps at 11 redds (batch 4).

LOCATION	REDD #	OUTSIDE	INSIDE	BOTH LOCATIONS
Mackville	8	0.40 ± 0.04	0.16 ± 0.00	0.30 ± 0.13
	9	0.43 ± 0.12	0.39 ± 0.31	0.42 ± 0.21
	10	0.47 ± 0.28	0.70 ± 0.08	0.56 ± 0.24
	11	0.57 ± 0.33	0.39 ± 0.32	0.48 ± 0.31
	12	0.23 ± 0.33	0.13 ± 0.23	0.18 ± 0.26
Van Assen Park	1	0.08 ± 0.14	0.01 ± 0.02	0.05 ± 0.10
	2	0 ± 0	0 ± 0	0 ± 0
	3	0 ± 0	0 ± 0	0 ± 0
	4	—	—	—
	5	0.36 ± 0.25	0.35 ± 0.31	0.35 ± 0.25
	6	0.41 ± 0.23	0.51 ± 0.22	0.46 ± 0.21
	7	0.49 ± 0.18	0.60 ± 0.17	0.54 ± 0.16

12.3.5 Egg Survival Within Wild Redds

Since only minor differences were observed in the mean survival of eggs placed in wild salmon redds, regardless of their position (either underneath or along side emergent traps), the data at individual redds were combined (Table 12.12) and overall egg survival between redds was compared. Using this combined data, a significant difference in egg survival between redds was detected (Student Newman Keuls Test, $p < 0.05$). In these 12 wild redds, mean egg survival to emergence in the egg capsule experiments ranged from 0.0 to 0.56. Using the Student Newman-Keuls multiple comparison test, the redds were placed into three groups, based on significant differences in mean egg survival (Table 12.13).

Table 12.13. Multiple comparison using Student-Newman-Keuls test of egg survival in wild chinook salmon redds.

GROUPING	MEAN EGG SURVIVAL	REDD	
		LOCATION	#
A	0.560	Mackville	10
A	0.536	Van Assen Park	7
A B	0.480	Mackville	11
A B	0.460	Van Assen Park	6
A B	0.420	Mackville	9
A B	0.353	Van Assen Park	5
A B C	0.304	Mackville	8
B C	0.180	Mackville	12
C	0.047	Van Assen Park	1
C	0.000	Van Assen Park	2
C	0.000	Van Assen Park	3

Key findings: Mean survival for Group A > Group B > Group C.

Although no significant correlation was found between the percentage of fines in redds and the number of fry collected in emergence traps in 1992 (Section 12.3.2), several factors may have obscured this relationship including differences in number or viability of eggs deposited in the different redds. Using the incubation capsule data in 1992 where the number and viability of the eggs in each redd are equal, a significant inverse relationship was found between mean survival of eggs in wild salmon redds and the percentage of fines in three of the size categories (Table 12.14).

Table 12.14. Correlation coefficient between survival rate and substrate composition at 8 redds (redds 1, 2, and 3 were excluded) in 1992.

	% FINES			
	<4.8 mm	<6.3 mm	<9.5 mm	<19.5 mm
Survival rate	-0.81**	-0.67*	-0.63*	-0.55

*Significant at 0.1 level
 ** Significant at 0.05 level

If emergent trapping data are a good index of habitat quality (i.e., substrate, inter-gravel flow, temperature), then a correlation should exist between the number of salmon fry emerging from wild redds and the mean survival of eggs placed in capsules within a redd. The data does not support the contention that emergent trapping results are a good index of habitat quality (Figure 12-7). Rather, some of the redds that had relatively high egg survival in capsule experiments produced almost no fry. These results suggest that factors other than habitat quality are influencing fry production in wild salmon redds. These factors may include differences in egg viability of the female salmon, fertilization rates, and number of eggs deposited in the redds.

The data suggest that many factors unrelated to habitat quality may influence the number of fry collected in emergent traps; therefore, emergent trapping results require very careful interpretation. The fact that no significant temperature effect was observed in the 1991 study is not surprising since emergent trapping data alone was relied upon and the quality or quantity of eggs deposited in wild redds could not be measured. Results from the 1992 emergent study, which controlled these factors, indicate a significant temperature effect on egg survival.

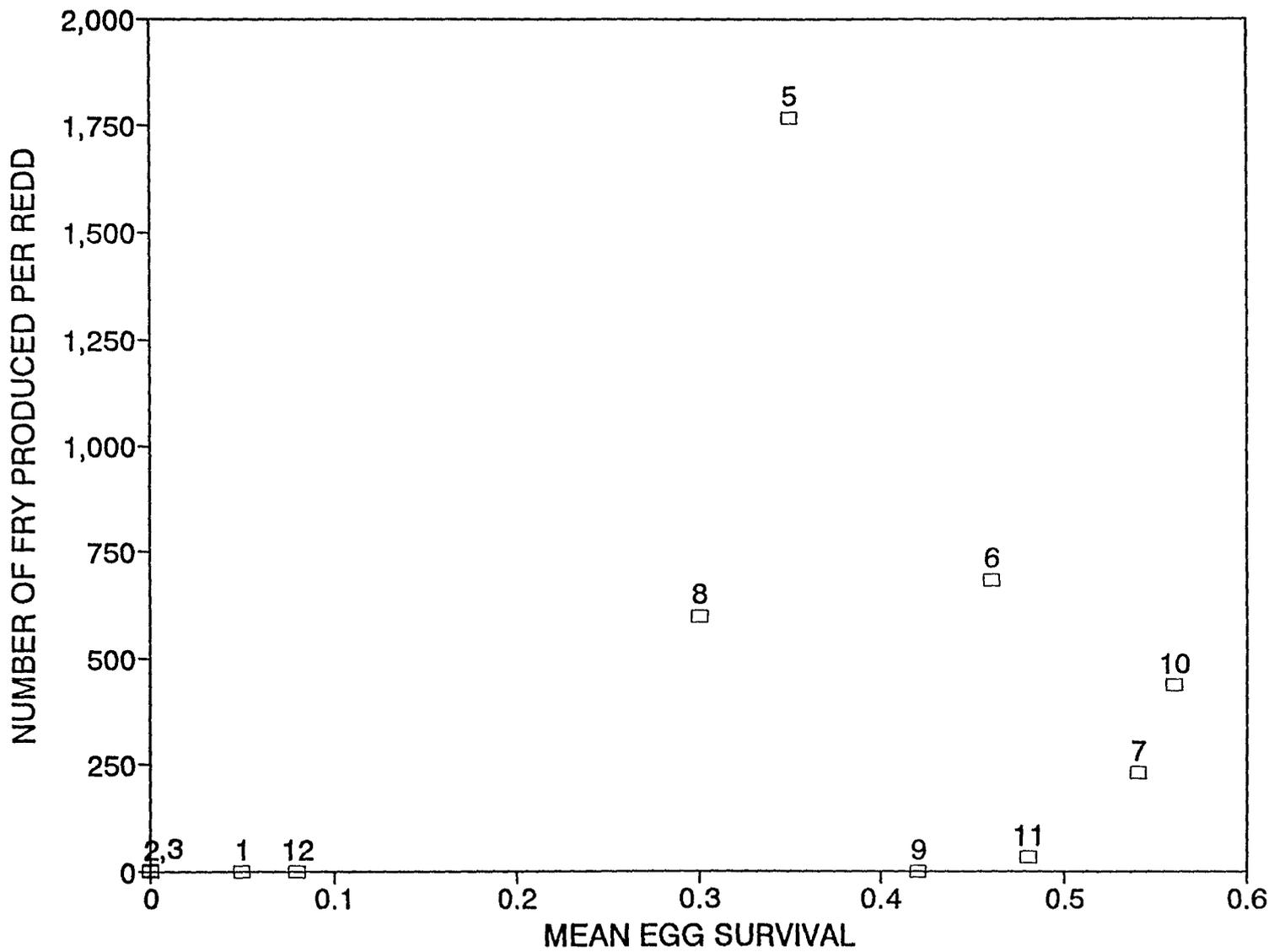


Figure 12-7. Relationship between mean egg survival in incubation capsules and number of fry collected in emergent traps in 11 wild redds.