STATIC SEAWATER CHALLENGE TEST TO MEASURE RELATIVE STRESS LEVELS IN SPRING CHINOOK SALMON SMOLTS

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Abstract

A static seawater challenge test was successfully developed and used in 1982 to establish a profile of the relative stress levels of spring chinook salmon smolts *Oncorhynchus tschawytscha* within the smolt collection and transport system at Lower Granite Dam on the Snake River in Washington State. A major feature of the test was the development of water-to-water transfer techniques designed to assure minimal stress interference associated with sampling and transferring test fish from the freshwater sample sites to the seawater test chambers. We used the test to isolate stresses associated with movement of smolts through the system, with our handling and marking procedures, and with holding spring chinook salmon smolts in the presence of predominately hatchery steelhead *Salmo gairdneri* smolts.

The test results clearly indicated a pattern of increasing stress levels as smolts moved through the system. The bypass system, the fish and debris separator complex, and transport by truck were areas where stress levels increased. Dip netting smolts with a standard (netted) dip net was implicated as the major contributor to the overall stress increase associated with our handling and marking procedures. The stress level of spring chinook salmon smolts appeared to be influenced by the presence of predominately hatchery-reared steelhead smolts.

Procedures used in this test series provided reliable but somewhat variable results. Recommended changes for reducing this variability include reducing the test time and using a different method of replication.

Introduction

Multipurpose hydroelectric projects constructed on the Snake and Columbia Rivers in the Pacific Northwest have created environmental conditions which are detrimental to the smolt migrations of valuable stocks of chinook salmon *Oncorhynchus tschawytscha* and steelhead *Salmo gairdneri*. These conditions include long, relatively slow-moving reservoirs which delay downstream migrations (Raymond 1979), turbines which kill smolts outright (Long et al. 1968), and spillways which cause nitrogen supersaturation resulting in mortalities during periods of heavy spill (Ebel et al. 1975; Ebel and Raymond 1976). Presently, salmonid smolts emigrating from upriver tributaries of the Snake River must pass through eight of these projects (Fig. 1) to reach the sea. Even during years with relatively ideal environmental conditions, passage through this dam complex results in unacceptably high mortality levels (Raymond 1979).

In recent years, an intense research effort has been directed towards the development of collection and transportation systems whereby smolts are collected from turbine intakes at upriver dams and transported in trucks or barges to release sites below the lowermost dam. The collection and transport system at Lower Granite Dam on the Snake River is described in detail by Matthews et al. (1977). As shown in Fig. 2, smolts are diverted from near the ceilings of the turbine intakes into gatewells by submerged traveling screens located at the opening of the gatewells. They exit the gatewells via submerged orifices and pass into a bypass channel and pipe which carries them to the collection facility located downstream from the dam. Smolts emerge from the bypass pipe in an upwell area and pass over an inclined screen and porosity plate complex (designed to eliminate water) into the fish and debris separator. From here, they move into the collection raceways where they are held at various densities for about 10-12 hours. The fish are then loaded into trucks or barges for subsequent transport and release below Bonneville Dam.

These efforts have greatly benefitted upriver steelhead runs, but upriver summer and spring chinook salmon runs have continued to decline to dangerously low levels. Although the exact reasons for these declines are unknown, delayed mortality studies conducted by Park et al. (1976; 1979; 1980) and Smith et al. (1980) have shown that post-collection and transport mortality of spring chinook salmon smolts is consistently and significantly higher than for steelhead smolts. Further, mortalities within the collection and transport systems have been consistently higher for spring chinook salmon smolts (Basham et al. 1982; 1983). This information suggests the possibility that spring chinook salmon smolts may be less capable of survival than steelhead smolts during and after exposure to various inherent stressors encountered during passage through the present collection and transport systems.

As smolts pass through these systems, there are several areas of potential stress including contact with the traveling screens, delay in the gatewells and bypass galleries, high velocities and pressure differentials in the bypass pipe, passage through the fish and debris separator which may include some delay and crowding, holding and crowding in raceways, and loading and transport in trucks or barges. Stresses encountered in any or all of these areas could impact short and long term survival of spring chinook salmon smolts.

The standardized seawater challenge test described in this paper was developed to provide a profile of the relative stress levels of chinook salmon smolts at different points within the collection and transportation system operated at Lower Granite Dam on the Snake River. The test is a secondary performance stress test which takes advantage of the stress induced osmoregulatory disturbances which upset water and ion balance in fish (Maetz 1974; Pic et al. 1974 and 1975; Mazeaud et al. 1977; Girard and Payan 1980). The effects of these disturbances on euryhaline fish are much more pronounced in full strength seawater than in fresh water primarily because the osmoregulatory demand is much greater, regardless of stress, in the seawater environment. For example, Potts et al. (1970) report that the ion exchange rate between a salmon smolt and its environment can be as much as ten times greater in seawater than in fresh water. Theoretically, the net result of this highly complicated phenomena is that the higher the stress level of a group of salmon smolts, the less capable individuals within the group are of osmoregulating in seawater. Since failure to osmoregulate in seawater results in death, measures of differences in mortality between groups of variably stressed smolts introduced to or challenged to seawater should provide the needed stress profiles. Ideally, the test should have sufficient sensitivity to detect relatively small differences in primary stress levels since smolts move rapidly through some areas and slowly through other areas of the collection and transport system.

During the collection and transport operations at Lower Granite Dam in the spring of 1982, samples of spring chinook salmon smolts were obtained from various areas of the system and challenged to artificial seawater in a standardized manner. In addition, the seawater challenge test was used to determine the relative stress effects of holding chinook smolts alone or with steelhead smolts and to determine the stress effects of handling and marking fish. This paper discusses the procedures and results of these tests.

Methods

Test Protocol

Testing began at Lower Granite Dam on 14 April 1982 and continued through 4 May 1982 encompassing the majority of the spring chinook smolt outmigration for that year. Test fish were naturally migrating smolts (mean length 120 mm) which were collected from each test area the same day to provide a reasonable assurance that subpopulation mixtures were equal among test groups. Each test series was completed before another test series was started.

To provide reliable test data, sampling of smolts from the various freshwater areas of the collection and transport system and their subsequent transfer instantly into artificial seawater had to be done carefully to minimize stresses that might result from handling. This was accomplished by continuously maintaining them in a water environment through water-to-water transfer techniques. To sample shallow or confined areas, we dipped fish with a hand dip net fitted with a watertight bag (sanctuary dip net). To sample deeper or less confined areas such as raceways and fish transport trucks and barges, we used a more elaborate net sampler (Fig. 3). This device consisted of an expandable upper frame, a middle area of netting in the shape of a fyke, and a lower watertight bag with a removable plug. The net sampler was lowered to the bottom of a sample area, allowed to remain there for approximately 2 minutes, then pulled up quickly thereby capturing any fish in the vertical column of water above the net frame. As the sampler was lifted out of the water, any fish that had been captured remained in the watertight bag below the netting. Once captured and maintained in water in either the sanctuary dip net or the net sampler device, the fish and water were placed into a 100-liter plastic container for transfer from the sample area to the seawater test chambers. A screened opening near the bottom of the transfer container allowed the water to drain to exactly 15.5 liters so that nearly the same amount of fresh water was added each time to the seawater test chambers. Duct tape covered the drain until we were ready to transfer the fish into seawater. This transfer generally required less than 10 minutes.

The seawater test containers were standard 38-liter glass aquariums set in a water bath of continuous flow river water to maintain ambient river temperatures within the aquariums. Water temperatures ranged from 7.4° to 10.6°C from the beginning to the end of the test period. The aquariums were covered to eliminate external interferences, and oxygen levels were maintained at or above 100% saturation by bubbling oxygen through air stones.

Artificial seawater (Marine Environment[1/]) was used as the test medium and was mixed as a stock solution at 54 ppt in a Living Stream Model 700-liter recirculating system. This system cycled the seawater stock solution approximately once every 7 minutes to provide continuous mixing and was equipped with a refrigeration unit for temperature control.

1/ Reference to trade name does not imply endorsement by National Marine Fisheries Service, NOAA.

To begin a test, 19 liters of the seawater stock solution was poured into a test aquarium and the duct tape was removed from the drain of the transfer container. Once the fresh water had drained to exactly 15.5 liters, the test fish were poured from the transfer container into the test aquarium containing the seawater stock solution. The combination of 15.5 liters of fresh water and 19 liters of 54 ppt seawater instantly brought the salinity in the aquarium to about 30 ppt. The actual salinity at this point was influenced by the volume of fish in the transfer container. Salinity measurements were made using a YSI Model 33 salinity/conductivity meter to determine if small adjustments in the final salinity were necessary. Minor adjustments were made by adding small amounts of the seawater stock solution or fresh water.

Calibration of the challenge test to ensure adequate test sensitivity was conducted prior to testing by determining the highest seawater concentration up to 30 ppt which allowed 90% survival of fish designated as controls. This was accomplished by exposure of 15 fish each to seawater concentrations of 15, 20, 25, and 30 ppt for 48 hours. Survival in all of these groups exceeded 90%; therefore, 30 ppt was used as seawater concentration. Thereafter, survival of control fish in the previous replicate was used as an indicator for the appropriate seawater concentration in the following replicate. If survival was less than 90% during the previous replicate, control fish would again be challenged to the aforementioned concentrations before replication continued. In this manner, we determined that 30 ppt was the appropriate seawater concentration for all replicates during the study period.

Each test group of approximately 20-30 smolts was exposed to artificial seawater for 48 hours. Mortalities were removed at 24 hours and at the end of the test period.

Methods of discrete multivariate analyses were used to statistically compare among or between test and control treatments (Bishop et al. 1975). In this procedure, live and dead fish counts were structured as contingency tables and significance was determined by the G-statistic as described by Sokal and Rohlf (1981).

Experimental Groups

Collection and Transport System Test

To establish a stress profile for chinook salmon smolts moving through the collection and transport system, we sampled fish from the areas shown in Fig. 2 and described below.

Control Group.--The turbine intake gatewells are the first areas where smolts are available for sampling after they enter the collection system. These fish were sampled from C-Slot intake gatewells using a gatewell dip basket described by Swan et al. (1979). Fish were removed from the dip basket with a sanctuary dip net and placed into the transfer container as previously described.

Our rationale for selecting fish from these gatewells for controls was that they are generally less crowded and should be less stressed than fish in either of the other gatewells within the same turbine unit. This occurs because attraction velocities are lowest within these intakes, and fatigue or impingement against the traveling screens or barrier screens should be minimal.

Gatewell Group.--These fish were sampled from the A-Slot intake gatewells in the same manner as the previous group. Since the A-Slot intakes provide water to a turbine unit at the highest velocity, crowding is generally highest in these gatewells. Also, within these intakes, fish are more likely to be exposed to undesirable water velocities which may result in fatigue or swimming impairment. Differences in mortality in seawater between this group and the controls would isolate the stress incurred in gatewells.

Pre-Separator Group.--These fish were sampled just prior to entering the fish and debris separator. They had previously passed through submerged gatewell orifices, the bypass channel and pipe, the upwell area, and over the perforated porosity plate. The difference in mortality in seawater between this group and the Gatewell Groups would isolate the stress incurred in passing through this portion of the collection system.

Raceway + 45 Minutes Group.--These fish were sampled from a concrete holding raceway after an exposure to a raceway environment of no more than 45 minutes. The difference in mortality between this group and the Pre-Separator Group would isolate the amount of stress attributable to the separator complex.

Raceway + 10-12 Hours Group.--These fish were exposed to the raceway environment for 10-12 hours prior to sampling to coincide with the time smolts were usually held prior to loading them into a truck or barge during normal facility operations. The difference in mortality between this and the previous group would isolate stresses associated with holding fish in a raceway for this time period.

Truck During Loading Group.--These fish were sampled from a transport truck as they were loaded into the truck from the concrete raceways. The differences in mortality between this group and the previous group would isolate any stresses associated with loading smolts from the raceways into the transport truck.

Barge Post-Loading Group.--These fish were sampled from a transport barge immediately after they were loaded from a concrete raceway. The difference in mortality between this group and the Raceway + 10-12 hour Group would isolate stresses associated with loading smolts in the barge.

Truck Post-Transport Group.--These fish were sampled from a transport truck immediately upon arrival at Bonneville Dam after an 8- to 10-hour transport from Lower Granite Dam. The fish were transported at a maximum density of 60 g/liter of water. Differences in mortality between this and the Truck During Loading Group would isolate any stresses associated with trucking.

Truck Post-Transport + 24 Hours Group.--After truck transport from Lower Granite to Bonneville Dam these fish were held in fresh water for 24 hours prior to challenging with seawater. Differences in mortality between this group and the previous group would determine if stress could be reduced by holding them for a period prior to release.

Barge Post-Transport Group.--These fish were sampled from a transport barge and challenged to seawater immediately upon arrival at Bonneville Dam, to measure stress associated with barge transport.

Handling and Marking Test

A variable percentage of the smolts which are collected each year for transport are randomly sampled from the system and used to provide information such as species composition, presence of previous marks, general condition, and weight. Many of these smolts are also marked and used for various test purposes.

It is widely accepted within the fisheries community that handling procedures induce severe stresses in fish (Mazeaud et al. 1977; Strange et al. 1977). In our procedures, smolts are dipped from the upwell box with a standard (netted) dip net into a sorting trough containing a 50 ppm recirculated solution of unbuffered MS-222. The fish are then manually examined for marks and either sent to a recovery tank or to a marking station where they receive an adipose fin clip, a freeze brand, and a micromagnetic wire tag in their snout. To isolate areas of stress within these procedures and determine possible methods for reducing stress from handling, we sampled and challenged to artificial seawater the groups of spring chinook salmon smolts described below:

Upwell Box Group (control).--These fish were sampled from the upwell box with a sanctuary dip net. The mortality of these fish in seawater would indicate the relative stress level of smolts prior to any handling or marking procedures.

Traditional Handling and Marking Group.--These fish were sampled after they had been dipnetted with a standard dip net and passed through our standard sorting and marking procedures as described previously. The mortality of these fish in seawater would indicate the maximum relative stress level of smolts after exposure to the entire procedure.

Isolate Standard Dip Net Group.--These fish were sampled and challenged to seawater after they had passed through the entire handling and marking procedures except that they were dipped from the upwell box with a sanctuary dip net rather than a standard dip net. The difference in the mortality in seawater between this group and the previous group would indicate the relative amount of stress incurred by dipping fish from the upwell box into the anesthetic trough using a standard dip net.

Unbuffered MS-222 Group.--These fish were challenged to seawater after they were dipped from the upwell box with a sanctuary dip net and exposed to a 50 ppm solution of unbuffered MS-222 only (no handling or marking). The difference in the mortality between this group and the control group would indicate if unbuffered MS-222 was stressful.

Benzocaine + Traditional Handling and Marking Group.--These fish were sampled and challenged to seawater after they had been dipped from the upwell box with a sanctuary dip net, placed in a bath of 25 ppm benzocaine, anesthetized, and dipnetted with a standard dip net into the sorting trough. The mortality of these fish in seawater would indicate if anesthetization prior to dipping with a standard dip net would reduce or eliminate the stress associated with this procedure.

Traditional Handling and Marking in 10 ppt Seawater Group.--These fish were challenged to seawater after they had passed through our traditional handling and marking procedures with 10 ppt artificial seawater added to the anesthetic solution. The difference in the mortality between this group and the Traditional Handling and Marking Group would indicate if 10 ppt seawater in the anesthetic would reduce or eliminate stress.

Chinook-steelhead Interaction Test

To determine if the relative stress levels of spring chinook salmon smolts were influenced by the presence of predominately hatchery-reared steelhead smolts, we randomly sampled fish from the sorting troughs and placed them in two net-pens. In one net-pen, chinook salmon smolts were held with conspecifics only (control), and in the other net-pen, chinook salmon smolts were held with steelhead smolts (test) at the same species ratio present in the facility the day of the test. Both groups were held at a density of 12 g/liter of water for 24 hours. After the holding period, chinook salmon smolts from both groups were subsampled and challenged to artificial seawater at 30 ppt for 48 hours.

Results

Collection and Transport System Tests

During normal facility operations, smolts are transported by truck early in the season when the number of fish collected are relatively few. As the season progresses and the numbers of smolts collected increase, barges replace trucks as the transport vehicles. Therefore, we have separated our test results into a truck phase consisting of the first three tests conducted from 14 to 19 April and a barge phase consisting of the last six tests conducted from 22 April to 5 May.

Overall, the process of collection and transportation was stressful to spring chinook salmon smolts (Fig. 4). In both the truck and barge phases of testing, stress levels generally showed increases as fish passed through the system. There were varying results from tests of significance conducted on differences among levels of stress of various component parts of the system.

Although not statistically significant, the stress level was slightly higher for chinook salmon smolts sampled from the A-Slot gatewells than from the C-Slot gatewells during either phase of testing (Fig. 4). Stress levels in the C-Slot remained constant in both phases, but levels increased in the A-Slot during the barge phase. This supports our decision to select smolts from the C-Slot gatewells as controls (least stressed) for the reasons discussed previously. Whether this difference, especially during the barge phase, is due to crowding or water velocities is not known. In any case, the difference is relatively minor and, in all likelihood, inconsequential to the overall stress effect of the system.

A highly significant increase ($P < 0.01$, $df = 1$) in stress was measured between the Gatewell Group and the Pre-Separator Group during the truck phase but not during the barge phase of the study. The latter resulted because stress levels in the gatewells increased from the truck to barge phase, whereas stress levels at the pre-separator area remained nearly the same during both phases. Thus, we do not know which test phase represents an accurate measure of the stress response between these areas. At best, these data reflect the need to conduct further detailed research designed to detect specific areas of stress within this portion of the bypass system before accurate conclusions can be expected.

A comparison of the results between the Pre-Separator Group and the Raceway + 45 Minutes Group isolates the fish and debris separator complex. Although the average percent mortality nearly doubled between these groups during both phases of testing, the differences were not statistically significant during either phase. However, we believe that further testing would implicate this area of the system as a contributor to the overall stress increase as smolts pass through the system. By design, the device provides a fairly large volume of relatively stagnant water and only one exit orifice, which together tend to promote delay and crowding.

Holding chinook salmon smolts in a raceway at relatively low densities for up to 12 hours actually resulted in a significant reduction ($P < 0.10$, $df = 1$) in stress during the truck phase but no reduction during the barge phase. This result is somewhat puzzling since raceway loading rates were low and fairly constant, and the species composition (about 48% steelhead) was nearly the same during both phases of testing. However, we did determine, from daily observations of marked hatchery-reared fish in the collection system, that there was a change in the composition of spring chinook salmon populations between the two test periods. It is possible that the mix of fish from hatcheries represented in the barge phase did not recover as readily from stress as the mix of fish present during the truck phase because of differences in overall fish condition.

There was a significant increase ($P < 0.05$, $df = 1$) in the stress level of spring chinook salmon smolts between the Raceway + 10-12 Hours Group and the Truck Post-Transport Group but not the Barge Post-Transport Group. However, spring chinook salmon smolts were at a higher stress level in the raceways prior to loading during the barge phase of testing. Nearly all of the increase measured during the truck phase was attributable to the transport operation.

Although not statistically significant, the stress levels of spring chinook smolts appeared to be declining 24 hours after truck transport. Further testing would be necessary to substantiate this finding.

Handling and Marking Tests

The stress profile for this test series is illustrated in Fig. 5. As expected, there was a highly significant increase in the stress level of spring chinook salmon smolts between the controls (upwell box) and the Traditional Handling and Marking Group ($P < 0.01$, df = 1). The stress level measured for the latter group was the highest level for any group during the study period. However, substantial, albeit not significant, reductions in stress levels were noted when spring chinook salmon smolts were dipped from the upwell box with a sanctuary dip net or anesthetized in a benzocaine solution prior to dipping with a standard dip net. We believe these results indicate that much of the handling and marking stress is incurred when smolts are dipped from the upwell box with a standard dip net and released into the shallow, well-illuminated anesthetic sorting trough. Once smolts are anesthetized, further sorting and marking procedures probably induce less stress than the dipping alone.

The addition of 10 ppt seawater to the MS-222 anesthetic bath did not significantly reduce stress levels during this operation. This result appears to be in conflict with the findings of others who have shown that handling and stressing fish in an isotonic salt solution results in mitigation of some of the physiological consequences of stress (Wedemeyer 1972; Redding and Schreck 1983) as well as a reduction in mortality during stress (Long et al. 1977; Strange and Schreck 1978). However, in our application, it is likely that the relatively short exposure time (approximately 10-15 minutes) is insufficient to provide any substantial benefits from handling fish in an isotonic medium.

Exposure of test fish to a solution of unbuffered MS-222 only did not result in an increase in stress levels above the control suggesting that the anesthetic itself was inconsequential to the overall stress effects of our handling and marking procedure. Again, the relatively short exposure time may not have been sufficient to elicit a measurable response.

Chinook-Steelhead Interaction Test

After the 24-hour holding period, the stress level of spring chinook salmon smolts was significantly lower ($P < 0.10$, $df = 1$) in the group held with conspecifics only than in the group held with steelhead smolts (Fig. 6). In the group held with steelhead smolts, the stress level was about what would be expected if they had been challenged immediately after the handling and sorting process. This suggests that the group held with conspecifics was recovering from stress during the holding period, whereas the group held with steelhead smolts was not.

It is noteworthy that during the portion of the outmigration that these tests were conducted, the majority of the steelhead smolts in the system were hatchery-reared fish. Hatchery-reared steelhead smolts are generally much larger than their wild counterparts. Also, recent studies indicate that hatchery-reared salmonids appear to be more aggressive than wild fish at higher population densities such as those encountered in holding raceways (Moyle 1969; Fenderson and Carpenter 1971; Bieber 1977).

We have no direct evidence that this combination of increased size and aggression contributes to increased interspecific stress. Occasionally, however, we have observed individual hatchery-reared steelhead initiating seemingly aggressive behavior towards other steelhead smolts as well as spring chinook salmon smolts as they interact in the raceway environment.

Discussion

Secondary performance or challenge tests of various types are used to aid in assessing the ability of fish populations to endure various environmental alterations. In these tests, the fishes' ability to tolerate severe secondary stressors is used as an indicator of relative primary stress levels. Wedemeyer and McLeay (1981) summarized the various challenge tests and emphasized the need to develop more types of standardized tests. Among other possibilities, they mentioned the potential use of a seawater challenge test in this regard but offered no further details.

Results obtained from the standardized seawater challenge testing described in this paper indicate that such tests provide a reliable method for measuring relative differences between stress levels in spring chinook salmon smolts. A useful feature of the test is that adjustments in test sensitivity can be accomplished by simply increasing or decreasing the seawater concentration. This procedure also allows us to adapt the test to smolts of other salmonid species which may be more or less tolerant of salinity levels than spring chinook salmon smolts. We can also adjust for differences in tolerance to seawater by the various races of spring chinook salmon being collected over a typical 45-day migration period. We are unaware of any reasons why salinities in excess of 30 ppt could not be used if increased test sensitivity is desired. In addition, since more than 85% of the recorded mortalities occurred in the first 24 hours, we believe that a 24-hour test would be sufficient to produce reliable results. A 24-hour test would reduce by one-half the time required to complete a test series. This should reduce the variance in our data caused by fluctuations in the populations of smolts passing through the system over time. To further reduce data variance, we believe three test series with three randomized replicates per test would be superior to conducting nine separate tests with only one replicate per test as was the case in these studies.

Since these tests were completed in 1982, we have conducted further tests incorporating the changes in the test procedures that we have recommended here (manuscript in progress). Increased test sensitivity and much less variation in the data were accomplished in these subsequent tests.

We have used this basic test concept successfully to measure relative differences in stress levels between or among different test groups of spring chinook salmon smolts over a 3-year period. In this time, we have recognized other favorable features of the test including the advantage of knowing test results immediately, the relative low cost of testing after the initial equipment is purchased or built, and the simplicity of the test itself which allows us to utilize non-technical field personnel in the conduct of these studies.

We must re-emphasize, however, that to conduct the test properly, extreme care must be taken when sampling and transferring test fish to avoid adding extraneous stresses. Water-to-water transfer techniques are an absolute requirement. Also, when interpreting results of these tests, mortality following the secondary challenge in artificial seawater has no known relationship to long-term survival. The information is useful only for determining where primary stresses occur so that action can be taken to reduce stresses to smolts and provide for maximum long-term survival.

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Figure 1.--Map of area showing the locations of dams on the lower Columbia and Snake Rivers.

Figure 2.--Diagram of the fish collection and transport system at Lower Granite Dam showing the sample areas.

Figure 3.--Diagram of vertical net sampler device and sanctuary dip net used to capture and transfer test fish while continually maintaining them in water.

Figure 4.--The average percent mortality of spring chinook salmon smolts sampled from the designated areas of the collection and transport system at Lower Granite Dam and challenged to artificial seawater at 30°/oo for 48 hours (vertical lines indicate SE).

Figure 5.--The average percent mortality of spring chinook salmon smolts sampled during the handling and marking procedures at Lower Granite Dam and challenged to artificial seawater at 30°/oo for 48 hours (vertical lines indicate SE).

Figure 6.--The average percent mortality of spring chinook salmon smolts held alone or with steelhead smolts for 24 hours at Lower Granite Dam and challenged to artificial seawater at 30°/oo for 48 hours (vertical lines indicate SE).