A COMPARISON OF THE PERFORMANCE OF ACCLIMATED AND DIRECT STREAM
RELEASED, HATCHERY-REARED STEELHEAD SMOLTS IN NORTHEAST OREGON

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Abstract

We compared the performance of juvenile steelhead smolts that were acclimated in river water before release to those released directly into rivers. Beginning one to four hours after a stress challenge, acclimated fish typically exhibited lower plasma cortisol concentrations and higher plasma chloride levels than direct stream released fish. Acclimated and direct stream released groups did not exhibit consistent differences in gill Na\(^+\)K\(^+\) ATPase activities or levels of skin gillmine. Juvenile migration rates of acclimated releases were not consistently different than those of direct stream releases. However, juvenile survival indices of acclimated release groups were higher than those of direct stream release groups. Preliminary estimates also indicated that the smolt-to-adult survival of acclimated releases was greater than that of direct stream releases. The higher survival to adult that acclimated release smolts exhibited when compared to smolts released directly into a river may, in part, be attributable to differences in their ability to respond to a stressor.

Introduction

The sizes of many Pacific salmon populations appear to be declining and some may be nearing extinction (Nehlsen et al., 1991). Artificial propagation is used frequently to try to compensate for losses in natural populations, although the relative merits of artificial propagation have been challenged (Hilborn, 1992). It is evident that hatchery-reared salmonids generally do not survive in the natural environment as well as their wild counterparts (e.g. Miller, 1954).

Hatchery-reared salmonids are often transported from the hatchery to the site of release. Transportation appears to be stressful to fish (Barton and Peter, 1982) and may result in their mortality (Ayles et al., 1976). The stress which is experienced by fish during transportation seems to be associated with their initial crowding, handling and confinement (Maule et al., 1988). Stress from transportation may influence the performance capacity and survival of hatchery-reared salmonids (Pickering, 1992).

Hatchery-reared salmonids are often released when smolt development is thought to be nearly complete. However, hatchery-reared smolts which are stocked into streams may fail to migrate downstream (Wedemeyer et al., 1980). The timing of smolt development is influenced by a variety of natural environmental factors (Wedemeyer et al., 1980). In addition, a period of migration has been shown to be important for the completion of smolt development (Zaugg et al., 1985). Development in a hatchery environment may result in incomplete smolt development, which, in turn, may influence a fish's ability to perform and survive (Loyenko and Chernitsky, 1984).

The performance and survival of hatchery-reared salmonids may be improved by acclimating them to their release site. For example, hatchery reared coho salmon (Oncorhynchus kisutch) smolts that were acclimated to their release location survived to adults at a higher rate than
smolts released directly into the stream (Schreck et al., 1989). However, it is not clear if acclimation allows fish to recover from the stress associated with transportation or to smoltify more completely, nor is it clear whether acclimation provides benefits to other anadromous species with different life history requirements.

The objectives of this study were to examine whether the stress physiology and smolt development of acclimated fish were different than those of direct stream released fish. We also compared the performance and survival of acclimated steelhead (O. mykiss) smolts with steelhead smolts released directly into a stream. The steelhead used in this study begin their seaward migration 943 to 875 km from the ocean and their migration is influenced by a combination of 8 dams and the mitigative collection and transportation procedures associated with these dams.

Methods

This study was conducted in Northeast Oregon (USA). Juvenile steelhead were released into Deer Creek and Little Sheep Creek in the springs of 1991 and 1992. Thus, four experimental trials were conducted. The Big Canyon Acclimation Facility (BC) is located near the mouth of Deer Creek. Fish were released into Deer Creek approximately 943 km from the ocean and 248 km from Lower Granite Dam (LGD). The Little Sheep Creek Acclimation facility (LS) is located near river km 8 of Little Sheep Creek. Fish were released into Little Sheep Creek approximately 875 km from the ocean and 180 km from LGD. Lower Granite Dam is the first dam these fish encounter during their seaward migration.

In the spring of 1991, one-year-old Wallowa stock steelhead were released into Deer Creek on 26 April. The acclimated fish had been transferred to BC on 20 March and thus, were acclimated for 37 d. The mean fork length of the acclimated fish (210 mm) was significantly longer than the mean fork length of the direct stream fish (195 mm). In the spring of 1992, one-year-old Wallowa stock steelhead were released into Deer Creek on 23 April. The acclimated fish had been transferred to BC on 27 March, and thus, were acclimated for 27 d. The mean fork length of the acclimated fish (206 mm) was similar to the mean fork length of the direct stream fish (200 mm). In the spring of 1991, one-year-old Imnaha stock steelhead were released into Little Sheep Creek on 23 April. The acclimated fish had been transferred to LS on 15 March and thus, were acclimated for 39 d. The mean fork length of the acclimated fish (208 mm) was significantly longer than the mean fork length of the direct stream fish (187 mm). In the spring of 1992, one-year-old Imnaha stock steelhead were released into Little Sheep Creek on 27 April. The acclimated fish had been transferred to LS on 24 March and thus, were acclimated for 34 d. The mean fork length of the acclimated fish (194 mm) was similar to the mean fork length of the direct stream fish (190 mm). Direct stream fish released into Deer Creek were transported nearly 200 km over a period of 4 h on the day of release. Direct stream fish released into Little Sheep Creek were transported nearly 300 km over a period of 5 to 6 h on the day of release.

Plasma levels of cortisol and chloride were evaluated as physiological indicators of stress. Baseline samples were collected from fish within 2 d prior to the release date. A stress challenge (confinement in a net held out of water for 30 s) was administered to fish at the release site on the day of release, after the direct stream fish had arrived. Acclimated fish were collected from the acclimation pond, whereas direct stream fish were collected from the transportation truck. After the stress challenge approximately 20 fish were placed into each of 10 (5 acclimated, 5 direct stream), 110 L plastic containers with mesh windows (to allow for water circulation) (1991) or in 0.61 x 0.61 x 0.92 m net pens (1992). Containers or pens were held in ponds adjacent to the acclimation area. Acclimated and direct stream fish were sampled immediately after (e.g. 0 h, not placed in containers or pens) as well as 1, 4, 12, 24 and 48 h after the stress challenge. Fish were anesthetized in tricaine methanesulfonate (150 mg/L) and blood collected from severed caudal vasculature. Plasma was separated and stored at -70°C until cortisol and chloride analysis. Since variances were heterogeneous, treatments were compared at each sample time using Mann-Whitney tests.

Gill Na⁺K⁺ ATPase activity and skin guanine concentration were evaluated as physiological indicators of smoltification. Approximately 20 acclimated and direct stream fish were sampled at each of four time periods relative to the acclimation period; prior to transfer of the acclimated fish to the acclimation facility (PT), approximately one-third (1/3) and two-thirds
(2/3) of the way through the acclimation period, and within 2 d prior to the release date (RE). Fish were anesthetized in tricaine methanesulphonate (150 mg/L), gill filaments collected into a standard buffer, and skin samples collected from standardized areas of frozen (placed in liquid nitrogen) fish. Samples were stored at -70°C until Na⁺K⁺ ATPase and guanine analysis. The data was transformed so that variances would be homogeneous and treatments were compared using analysis of variance and a Tukey post-hoc test.

Juvenile migration rate and survival were evaluated as indicators of juvenile performance. Approximately 40,000 branded fish were released each year from each experimental group. Branded fish were enumerated from collection facilities at LGD. The actual number of branded fish arriving at LGD was estimated using a standard expansion protocol (see Berggren and Filardo, 1993, for details about this process). Juvenile migration rate was calculated as the number of days after release a fish was estimated to have arrived at LGD. Treatments were compared using a chi-square distribution. Juvenile survival was calculated as the percentage of the branded releases that arrived at LGD over the entire migration. Treatments were compared using a binomial test.

Smolt-to-adult survival was estimated using coded-wire-tags. Approximately 50,000 coded-wire-tagged fish were released from each experimental group. Smolt-to-adult survival was calculated as the percentage of the CWT releases that were estimated to have been captured as adults (either in fisheries or at rearing or release facilities). Treatments were compared using a binomial test.

Results

Acclimated and direct stream fish had similar baseline levels of cortisol in three of the four experimental trials. After the stress challenge, acclimated fish exhibited lower cortisol levels than direct stream fish in 12 of the comparisons, exhibited similar cortisol levels as direct

![Graph of Plasma Cortisol and Plasma Chloride](image)

**Figure 1.** a) Levels of plasma cortisol from steelhead smolts scheduled for release into Deer Creek in 1991. b) Levels of plasma chloride from steelhead smolts scheduled for release into Little Sheep Creek in 1991. Baseline samples (B) were collected from fish within 2 d prior to the release date. Fish were also sampled 0, 1, 4, 12, 24 and 48 h after a stress challenge at the time of release. Values are expressed as median ± interquartile range. Stars represent differences (P < 0.05) between acclimated (■) and direct stream (□) fish at a given sample time.

![Graph of Skin Guanine and Na⁺K⁺ ATPase](image)

**Figure 2.** a) Levels of skin guanine from steelhead smolts scheduled for release into Little Sheep Creek in 1992. b) Levels of gill Na⁺K⁺ ATPase activity from steelhead smolts scheduled for release into Deer Creek in 1992. Pretransfer (PT) samples were collected just prior to the beginning of acclimation. Fish were also sampled approximately one-third (1/3) and two-thirds (2/3) of the way through the acclimation period (27-34 d total) as well as just prior to release (PR). Values are expressed as the mean ± 95% confidence interval. No differences (P > 0.05) were observed between acclimated (■) and direct stream (□) fish at any given time.
stream fish in 11 of the comparisons, and only once exhibited higher cortisol levels than direct stream fish. Figure 1a illustrates the general pattern of cortisol levels observed in this study.

Acclimated fish had higher baseline levels of chloride than direct stream fish in three of the four experimental trials. After the stress challenge, acclimated fish exhibited higher chloride levels than direct stream fish in 19 of the comparisons, exhibited similar chloride levels as direct stream fish in four of the comparisons, and only once exhibited lower chloride levels than direct stream fish. Figure 1b illustrates the general pattern of chloride levels observed in this study.

Acclimated and direct stream fish had similar PT levels of skin guanine and gill Na\textsuperscript{+}K\textsuperscript{+} ATPase activity in all four trials. Of the 12 comparisons during the acclimation period, acclimated and direct stream fish had similar levels of skin guanine in 11 comparisons and similar levels of Na\textsuperscript{+}K\textsuperscript{+} ATPase activity in 9 comparisons. In one comparison acclimated fish had higher levels of skin guanine than direct stream fish (BC, 1991 releases, 1/3 sample time). Acclimated fish had higher gill Na\textsuperscript{+}K\textsuperscript{+} ATPase activities than direct stream fish in two comparisons (BC, 1991 releases, 1/3 and RE sample times). In one comparison (LS, 1992 releases, RE sample time) acclimated fish had lower Na\textsuperscript{+}K\textsuperscript{+} ATPase activities than direct stream fish. Within any sample group, only skin guanine levels from the 1991 samples increased consistently during the course of the experiment. Figure 2a and 2b illustrate the general pattern of guanine levels and Na\textsuperscript{+}K\textsuperscript{+} ATPase activities observed in this study.

Acclimated fish from the 1991 releases migrated to LGD more slowly than direct stream fish. Acclimated and direct stream fish from the 1992 releases migrated to LGD at similar rates. In both years, acclimated fish from both release locations survived to LGD at a higher rate than direct stream fish (Table 1). In 1993, three-year-old adults returned from the 1991 releases. Acclimated fish from both release sites returned at a higher rate than direct stream fish (Table 1).

Table 1. Estimated survival rates of acclimated and direct stream released steelhead smolts. Juvenile survival was estimated using brand recoveries at Lower Granite Dam. Adult survival was estimated using coded-wire-tag (CWT) recoveries in fisheries and at rearing and release locations. * indicates a significant difference (P < 0.05) between acclimated (ACC) and direct stream (DS) groups.

<table>
<thead>
<tr>
<th>Year</th>
<th>Location</th>
<th>Release strategy</th>
<th>Number of branded releases</th>
<th>% Juvenile survival rate</th>
<th>Number of CWT releases</th>
<th>% Adult survival rate</th>
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<tr>
<td>1991</td>
<td>Deer Cr.</td>
<td>ACC</td>
<td>41,600</td>
<td>53.2*</td>
<td>53,526</td>
<td>0.64(^a)</td>
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<td></td>
<td>DS</td>
<td>41,087</td>
<td>39.4</td>
<td>51,464</td>
<td>0.23(^a)</td>
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<td>Little Sheep Cr.</td>
<td>ACC</td>
<td>40,452</td>
<td>45.6</td>
<td>50,926</td>
<td>0.09(^a)</td>
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<td></td>
<td></td>
<td>DS</td>
<td>39,890</td>
<td>40.0</td>
<td>43,464</td>
<td>0.05(^a)</td>
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<tr>
<td>1992</td>
<td>Deer Creek</td>
<td>ACC</td>
<td>41,457</td>
<td>22.4*</td>
<td>52,713</td>
<td>--(^b)</td>
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<td>DS</td>
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<td>--(^b)</td>
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<td>DS</td>
<td>40,347</td>
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<td>52,023</td>
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</table>

\(^a\) Incomplete adult returns, \(^b\) no adult returns yet.

Discussion

Preliminary evidence suggests that more acclimated smolts survive to adulthood than direct stream fish. This claim is supported by the higher rate of return of acclimated fish to rearing and release facilities and tributary sport fisheries. This agrees with previous findings that acclimation improved survival in brown trout (Cresswell and Williams, 1983) and coho salmon (Schreck et al., 1989). It is possible that acclimated fish strayed from the area of release at a lower rate than direct stream fish. If this is the case, then the survival rates of each group may actually be similar. This alternative warrants further study.
The stress physiology of acclimated steelhead smolts was markedly different than that of direct stream steelhead smolts. The data suggest that chronic physiological stress may be experienced by fish in a hatchery but is somewhat alleviated by acclimation. This was evident when at the end of the acclimation period, but prior to transportation of the direct stream fish, acclimated fish generally had higher plasma chloride levels than direct stream fish. Furthermore, the physiological stress response associated with the release strategies used in this study appeared to be more moderate in acclimated fish when compared to direct stream fish. This was evidenced by generally lower, post-challenge cortisol levels and higher, post challenge chloride levels in acclimated fish when compared to direct stream fish. Although transportation is clearly stressful to fish (see Barton et al., 1980), the results of the present study confirm previous reports (Schreck et al., 1989; McDonald et al., 1993) which indicated that acclimation may circumvent some of the stress associated with transportation. In addition, the present study suggests that cumulative physiological stress responses (Barton et al., 1986), such as those which could be caused by transportation followed by direct release or other stressful events, may also be suppressed by acclimating fish prior to release.

Acclimated fish performed better than direct stream fish during their juvenile migration. The strongest indication of this was the consistently higher survival rate of acclimated fish to LGD when compared to direct stream fish. This result is similar to the observation of Cresswell and Williams (1983) that acclimation improved the survival of brown trout (Salmo trutta). In the present study, acclimated fish also migrated either more slowly than (1991) or at a similar rate to (1992) the direct stream fish. This is in apparent contrast to previous studies (Specker and Schreck, 1980; Maule et al., 1988) which suggested that the stress associated with transportation may reduce the swimming ability and rate of migration of direct stream fish. However, Specker and Schreck (1980) evaluated a 5.6 km migration distance, Maule et al. (1988) evaluated fish collected at dams and transported after their migration had begun, and neither study worked specifically with acclimated fish. The difference seen in 1991, and similarity seen in 1992, between the migration rates of acclimated and direct stream fish may be the result of relatively high flows in 1991 and low flows in 1992. Cresswell and Williams (1983) reported that acclimated and direct stream fish survived at a different rate during low flows but not during high flows. It is also possible that the differences in migration rates observed in 1991 resulted from the different sizes of acclimated and direct stream fish.

Acclimation did not appear to influence the smolt development of juvenile steelhead. This claim is supported by similar gill Na\(^+\)K\(^+\) ATPase activities and skin guanine levels between acclimated and direct stream fish. We expected gill Na\(^+\)K\(^+\) ATPase activities (Zaug and Wagner, 1973) and skin guanine levels (Vanstone and Markert, 1968) to increase in smolts during this investigation. However, we only observed slight increases in skin guanine levels from fish sampled in 1991. Thus, the general lack of difference that we observed in smolt characteristics between acclimated and direct stream fish may have been because neither group had begun final smolt development. Furthermore, absolute Na\(^+\)K\(^+\) ATPase activities and skin guanine levels were lower than typically associated with smolification (Vanstone and Markert, 1968; Zaug and Wagner, 1973).

In summary, acclimated fish survived to adults at a higher rate than direct stream fish. This improved survival may, in part, be attributable to differences in the abilities of acclimated and direct stream fish to respond to a stressor. Acclimating smolts is one tool available to help fisheries managers bridge the gap between the survival rates of hatchery-reared and wild fish.

Acknowledgement

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References


*gairdneri* at rest, and subjected to handling confinement, transport and stocking. Canadian Journal of Fisheries and Aquatic Sciences 37:805-811.


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