Proximate Composition and Fatty Acid Differences in Hatchery-Reared and Wild Snake River Sockeye Salmon Overwintering in Nursery Lakes

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To cite this article: M. S. Powell, R. W. Hardy, T. A. Flagg & P. A. Kline (2010): Proximate Composition and Fatty Acid Differences in Hatchery-Reared and Wild Snake River Sockeye Salmon Overwintering in Nursery Lakes, North American Journal of Fisheries Management, 30:2, 530-537

To link to this article: http://dx.doi.org/10.1577/M09-002.1
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Proximate Composition and Fatty Acid Differences in Hatchery-Reared and Wild Snake River Sockeye Salmon Overwintering in Nursery Lakes

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Abstract.—In the artificial propagation program for endangered Snake River sockeye salmon Oncorhynchus nerka, a portion of the F1 progeny (produced from spawning captive parents) are retained in the hatchery through maturation and spawning; the remaining progeny are reintroduced to nursery lakes in central Idaho at several life history stages (egg, presmolt, and smolt). In this study, the proximate and fatty acid compositions of sockeye salmon from presmolt releases were analyzed both at planting and at out-migration to assess their feeding success after overwintering in nursery lakes relative to that of overwintering wild fish. Hatchery-origin presmolts did not grow significantly over the winter. However, size and length were similar between hatchery-origin fish and wild out-migrants. Average percent whole-body lipid declined significantly in hatchery-origin sockeye salmon overwinter. Hatchery-origin out-migrants also had significantly lower whole-body lipid than wild counterparts migrating from Redfish Lake, Idaho, over the 6 years examined. The lack of growth and significantly lower body fat content of hatchery-origin sockeye salmon suggest that the food resources available to both wild and hatchery-origin presmolts were not utilized equally. There were also significant differences in fatty acid composition between wild and hatchery-origin out-migrants. Wild out-migrants had fatty acid profiles indicative of the zooplankton diet typical of resident sockeye salmon in the lake. In contrast, hatchery-reared juveniles introduced as presmolts in the fall had fatty acid profiles resembling those associated with hatchery diets and showed no evidence of the fatty acids characteristically observed in zooplankton. After overwintering, hatchery-origin out-migrants had fatty acid profiles that were intermediate between those of fish at planting and those of wild fish, reflecting some zooplankton intake during this period. The compromise in lipid quantity and quality for hatchery-produced presmolts may, in part, explain the large observed reductions in smolt-to-adult survival relative to that of naturally produced sockeye salmon.

The last remaining population of anadromous sockeye salmon Oncorhynchus nerka within the Snake River watershed swims upstream 1,448 km from the Pacific Ocean to spawn in three central Idaho lakes. Redfish Lake is the largest of these sockeye salmon nursery lakes, along with Alturas and Pettit lakes (Figure 1). These lakes, located within the Stanley basin, are the southernmost lacustrine environments that support anadromous sockeye salmon and the highest lakes in terms of altitude (2,138 m) where sockeye salmon spawn. Redfish Lake is also the only known lake to support all three life history forms of sockeye salmon (Allendorf and Waples 1996). Typically, Snake River sockeye salmon return from the ocean after 2 to 3 years and spawn in October and November along shallow gravel beach areas of the shoreline (Brannon et al. 1992). Fry emerge in the spring, remain for 1 to 2 years feeding in limnetic areas, then migrate to the ocean in the spring as smolts.

In response to severely declining returns, the unique population of sockeye remaining in Redfish Lake was designated as an evolutionarily significant unit (ESU; Waples et al. 1991) and was listed as a federally endangered species (Snake River sockeye salmon) in November 1991 (U.S. Office of the Federal Register 1992). At the time of listing, anadromous sockeye salmon in Alturas and Pettit lakes were considered to have been extirpated. Concomitantly, a large, multi-
Agency captive breeding program involving the Idaho Department of Fish and Game (IDFG), National Oceanic and Atmospheric Administration–Fisheries, Shoshone–Bannock tribes, and the University of Idaho was established (Flagg et al. 2004). The objective of the program is to propagate Redfish Lake sockeye salmon and to preserve remaining genetic diversity within the stock until factors causing population declines are resolved. Long-term strategies for the program also include increasing the number of adults returning to Redfish Lake to meet interim abundance guidelines to address sport and treaty harvest opportunities (NMFS 2002). The guidelines require the returns to be naturally produced (progeny from naturally spawning parents) and not simply the returns of hatchery-produced smolts and presmolt. Draft delisting criteria for the Snake River sockeye salmon ESU require, at minimum, a return of 1,000 adults to Redfish Lake, 500 adults to Alturas Lake, and 500 adults to Pettit Lake for two successive generations (NMFS 2002).

Currently, several year-classes of sockeye salmon have been established in captive culture, all of which originated from the capture of 16 anadromous adult returns, 26 residual adults, and 886 smolts between 1991 and 1998 (Willard 2004). The conservation program strategy follows a "spread-the-risk" philosophy by releasing $F_1$ offspring (e.g., progeny of captive adults) at various life stages (Hebdon et al. 2004). Prespawn adults are released in the fall, presmolt are released to Redfish Lake during late summer and fall, fertilized eggs are planted after captive spawning, and hatchery-reared smolts are released in the spring.

In general, many sockeye-salmon-containing lakes are known to be nutrient poor (Stockner 1987). Large-scale experimental efforts applying ammonium polyphosphate and ammonium nitrate to stimulate phytoplankton growth and indirectly enhance zooplankton abundance have made significant differences in sockeye salmon smolt size among nutrient-poor lakes in British Columbia (Stockner and MacIsaac 1996). Exceeding carrying capacity within the Stanley basin lakes by overplanting hatchery-origin presmolt has been an ongoing concern within the conservation program. To ensure zooplankton food resources within the lakes are not limiting, carrying capacity models were developed for Redfish, Alturas, and Pettit lakes (Teuscher and Taki 1995; Luecke et al. 1996) and have led to fertilization regimes similar to those employed by Stockner and MacIsaac (1996).

Additional concerns associated with the conservation program effort is the ability of hatchery-reared presmolt to make a transition from being fed pelleted feed in the hatchery to being able to forage successfully on live prey after release into Redfish Lake. Comparisons of feeding efficiency among hatchery-reared juvenile sockeye salmon fed different prey items
demonstrated in laboratory tests that familiar live prey were consumed more rapidly than novel prey but that naïve fish quickly learned to capture novel prey (Massee et al. 2007). In contrast, hatchery-reared brown trout *Salmo trutta* and Atlantic salmon *S. salar* require several weeks to months to learn to forage on live prey as effectively as wild counterparts after release into the wild (Soziak et al. 1979; Johnsen and Ugedal 2008). Environmental enrichment and prior experience with live prey improved foraging behavior in hatchery-reared Atlantic salmon (Brown et al. 2003). Differences between sockeye salmon and brown trout or Atlantic salmon in foraging behavior may be related to differences between stream-dwelling and lake-dwelling species: juvenile sockeye salmon are lake dwellers. Thus, although hatchery-reared sockeye salmon may quickly learn to forage successfully based on laboratory studies, in practice it remains unknown as to how successful presmolts will be in the more complex nursery lake environment. Given the lengthy downstream passage faced by emigrating Redfish Lake sockeye salmon smolts, fat storage deficits resulting from poor foraging ability as overwintering presmolts may be an important factor in the smolts successfully reaching estuarine and saltwater feeding habitats.

Accordingly, the objectives of this study were to compare weights, lengths, relative body composition, and fatty acid profiles of presmolts outplanted into Redfish, Alturas, and Pettit lakes with those of subsequent out-migrating smolts of the same year-class. Additionally, the relative body composition of wild out-migrants was compared with that of hatchery-origin out-migrants to assess this release strategy.

**Methods**

**Fish sampling.**—Juvenile sockeye salmon reared in captivity to presmolts at the Sawtooth National or Eagle Fish hatcheries in Idaho were sampled (*n* = 163) at release into Redfish Lake in October 1999–2001, Pettit Lake in July 2001, and Alturas Lake in July 2001. Out-migrating smolts were collected in May 1999–2004 in a smolt trap located at the outlet of Redfish Lake (*n* = 194). Additional wild and hatchery-origin out-migrants were collected in May from smolt traps at the outlet of Pettit Lake in 2001 (*n* = 39) and from Alturas Lake in 2000 and 2001 (*n* = 27). Samples of hatchery presmolts (*n* = 19) were also collected in a trawl of Pettit Lake in September 2001, 2 months after fish were released to the lake in July. Hatchery-origin presmolts were differentially marked with an adipose fin clip prior to release. The absence of an adipose fin was used to distinguish hatchery-origin smolts from wild smolts at out-migration. Smolts of the same age-class were used for hatchery–wild comparisons within years. Samples were placed on ice, transported to University of Idaho laboratory facilities, and stored at −80°C until analysis.

**Chemical analyses.**—Frozen whole-fish samples were partially thawed and individually weighed and measured. Fish were then pureed in an industrial food processor (Robot Coupe R2, Ridgeway, Mississippi). Samples used for proximate analysis were dried in a convection oven at 105°C for 8 h to determine moisture level according to the Association of Official Analytical Chemists (AOAC 2000). The dried samples were finely ground by mortar and pestle, and were analyzed for nitrogen (N) using a LECO FP-428 nitrogen analyzer (LECO Instruments, St. Joseph, Michigan). Crude protein (CP) was calculated from sample N content (total N × 6.25 = CP). Crude fat was analyzed using a Soxhlet extraction apparatus (Sextec System HT; Foss Tecator AB, Hoganas, Sweden) with methylene chloride as the extracting solvent, and ash was determined by incineration at 550°C in a muffle furnace. Lipids in wet fish samples were extracted for subsequent fatty acid analysis following Bligh and Dyer (1959). Extracted lipids were saponified using sodium methoxide in methanol (0.5 M) and esterified using 5% methanolic HCl. Fatty acid esters were injected into a Shimadzu GC 17A gas chromatograph containing a 30-m capillary column (ZB-wax; Phenomenex, Torrance, California). Analysis conditions were as follows: injection temperature, 250°C; detector temperature, 260°C; and oven temperature programmed to increase from 185°C to 240°C. Run time was 26 min. Fatty acids were identified by comparing retention times with those of standards (Supelco, Bellefonte, Pennsylvania) and expressed on a relative percentage basis.

**Statistical analyses.**—Individual lengths and weights of fish from different sample groups were compared using analysis of variance and *t*-tests assuming unequal variances (Statistica version 6.1; StatSoft, Tulsa, Oklahoma). Proximate composition and fatty acid percentages were compared using *t*-tests for proportions after *F*-tests were used to assess whether variances needed to be pooled. A significance criterion of *P* ≤ 0.05 was used for all tests.

**Results**

Lengths and wet weights of hatchery-reared, juvenile sockeye salmon at planting in the nursery lakes were not significantly different from out-migrating smolts over several years of sampling (Figure 2). Presmolts released to the lakes in October at an average size of 13.0 ± 3.2 g grew only slightly overwinter, reaching an average of 13.7 ± 3.1 g at out-migration (*P* = 0.269). Interestingly, wild out-migrants were remarkably similar in size, having an average weight of 13.1
However, hatchery-origin fish captured as out-migrants had significantly lower whole-body lipid than at planting, averaging only 1.4 \pm 0.8\% (P < 0.001; Figure 3). This represented a loss of 87.4\% from the 11.1 \pm 0.7\% whole-body lipid level in hatchery-reared presmolt sockeye salmon at planting and was less than half of wild out-migrant whole-body lipid levels at 3.9 \pm 0.8\%. Whole-body protein levels tended to increase over time in hatchery-origin sockeye salmon but were not significantly different from wild out-migrant whole-body protein levels at recapture 7 months later. Whole-body ash levels were not significantly different, and whole-body moisture varied inversely with lipid level (data not shown). In Redfish Lake, out-migrants of wild origin consistently had whole-body lipid percentages significantly higher than that of out-migrants of hatchery origin over a 6-year sampling period (Figure 4).

Fatty acid profiles of hatchery-reared juvenile sockeye salmon sampled at release and at out-migration remained relatively similar in Redfish Lake except for a decline in total omega-3 fatty acids (P = 0.0247). Decosahexanoic acid (DHA; 22:6\(-\omega-3\)) declined significantly (P = 0.0368) in hatchery-reared fish from 8.1 \pm 1.4\% at release to 6.6 \pm 0.2\% at out-migration, which accounts for most of the loss in total omega-3 fatty acids (Table 1). However, fatty acid profiles of hatchery-reared out-migrant sockeye salmon differed significantly from the profiles of wild out-

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1 In this notation, the number to the left of the colon is the number of carbon atoms in the compound, the number immediately to the right of the colon is the number of double bonds, and the number after the hyphen indicates the position of the first double bond from the methyl end.
migrant sockeye salmon captured in Redfish Lake in May 2002. Hatchery fish contained 12.5 ± 0.3% total omega-3 fatty acids, whereas wild fish contained 17.7 ± 1.2% total omega-3 fatty acids (Table 1). Hatchery fish had significantly higher levels (P < 0.0001) of the omega-3 highly unsaturated fatty acid DHA, common in marine lipids used in salmon feeds, but significantly lower levels (P = 0.0032) of eicosapentaenoic acid (EPA; 20:5[ω-3]). Levels of arachidonic acid (ARA; 20:4[ω-6]) were similar, but the levels of stearidonic acid (18:4[ω-3]) and alpha-linolenic acid (ALA; 18:3[ω-3]) were five to six times higher in wild out-migrants than in hatchery-origin out-migrants. Hatchery fish sampled during a trawl of Pettit Lake in September, 2 months after their release to the lake in July 2001 (n = 19), had fatty acid profiles (Table 2) intermediate between presmolts of the same cohort held in the hatchery until planting in Redfish Lake in October and wild out-migrants from the Redfish Lake sampled in May 2002 (Table 1). In general, the fatty acid profiles of wild juvenile sockeye salmon were more complex in terms of the number of fatty acids than were those of hatchery-reared fish.

**Discussion**

The release of hatchery-reared sockeye presmolt into the Stanley basin lakes is part of a spread-the-risk philosophy of the Snake River sockeye salmon recovery program (Hebdon et al. 2004). Data from this study show differences in presmolt foraging success between Redfish and Pettit lakes as well as differences between hatchery- and wild-origin out-migrant fatty acid profiles. Moreover, proximate data from Redfish Lake show a dramatic loss of lipid in overwintering hatchery presmols by the time they out-migrate in May of the following year. These hatchery-reared fish consistently emerge with less whole-body lipid than wild cohorts out-migrating from the lake at the same time (Figure 4). No data are available for percent lipid in wild presmols in the fall to compare with hatchery-origin presmols at the time of release into the lake. However, based on fatty acid profiles of

<table>
<thead>
<tr>
<th>Fatty acids</th>
<th>Fall release (n = 18)</th>
<th>Hatchery out-migrants (n = 20)</th>
<th>Wild out-migrants (n = 20)</th>
<th>Prey&lt;sup&gt;a&lt;/sup&gt;</th>
<th>P-value&lt;sup&gt;b&lt;/sup&gt; hatchery (versus wild)&lt;sup&gt;c&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>14:0&lt;sup&gt;e&lt;/sup&gt;</td>
<td>5.6 ± 0.7</td>
<td>5.7 ± 0.5</td>
<td>11.1 ± 2.1</td>
<td>4.6</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>16:0&lt;sup&gt;e&lt;/sup&gt;</td>
<td>21.9 ± 1.8</td>
<td>24.7 ± 2.0</td>
<td>21.7 ± 1.1</td>
<td>11.5</td>
<td>0.0006</td>
</tr>
<tr>
<td>18:0</td>
<td>9.2 ± 0.6</td>
<td>8.1 ± 0.3</td>
<td>11.4 ± 1.1</td>
<td>9.9</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>18:1[ω-9]</td>
<td>4.3 ± 0.2</td>
<td>6.1 ± 1.0</td>
<td>4.1 ± 0.3</td>
<td>4.4</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>18:1[ω-7]</td>
<td>28.5 ± 0.7</td>
<td>29.7 ± 2.5</td>
<td>14.9 ± 1.8</td>
<td>10.7</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>18:2[ω-6]</td>
<td>5.0 ± 0.6</td>
<td>4.1 ± 0.3</td>
<td>3.8 ± 0.4</td>
<td>-</td>
<td>0.0739</td>
</tr>
<tr>
<td>18:2[ω-3]</td>
<td>3.9 ± 0.4</td>
<td>3.8 ± 0.8</td>
<td>6.9 ± 0.9</td>
<td>6</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>18:3[ω-3]</td>
<td>0.5 ± 0.3</td>
<td>0.5 ± 0.1</td>
<td>3.0 ± 0.5</td>
<td>7.5</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>18:4[ω-3]</td>
<td>0.8 ± 0.1</td>
<td>0.8 ± 0.1</td>
<td>4.5 ± 1.4</td>
<td>4.3</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>20:4[ω-6]</td>
<td>4.0 ± 0.7</td>
<td>3.8 ± 0.5</td>
<td>5.2 ± 1.2</td>
<td>9.7</td>
<td>0.0032</td>
</tr>
<tr>
<td>22:5[ω-3]</td>
<td>0.9 ± 0.2</td>
<td>0.8 ± 0.1</td>
<td>1.2 ± 0.5</td>
<td>0.7</td>
<td>0.0232</td>
</tr>
<tr>
<td>22:6[ω-3]</td>
<td>1.1 ± 1.4</td>
<td>0.8 ± 0.1</td>
<td>3.8 ± 1.1</td>
<td>6.5</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Total saturated</td>
<td>31.8 ± 1.4</td>
<td>36.5 ± 1.8</td>
<td>36.9 ± 1.8</td>
<td>20.5</td>
<td>0.6253</td>
</tr>
<tr>
<td>Total ω-6</td>
<td>5.2 ± 0.6</td>
<td>5.1 ± 1.0</td>
<td>9.0 ± 2.2</td>
<td>9.6</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Total ω-3</td>
<td>14.3 ± 0.7</td>
<td>12.5 ± 0.3</td>
<td>17.7 ± 1.2</td>
<td>28.7</td>
<td>&lt;0.0001</td>
</tr>
</tbody>
</table>

<sup>a</sup> Average values for cladocerans, daphnia, and copepods from Higgs et al. (1995).

<sup>b</sup> Values in bold italics are significant at P ≤ 0.05.

<sup>c</sup> Saturated fatty acids.
hatchery-origin out-migrants, presmolts overwintering in Redfish Lake do not forage successfully. Their fatty acid profiles remain essentially unchanged from those at release in the fall and do not indicate an accumulation of fatty acids from zooplankton prey. Although the same size as wild smolts at out-migration, overwintering hatchery-origin presmolts in all Stanley basin lakes were essentially the same size as at release 7 months prior. With total lipid levels of hatchery-origin out-migrants approximately half of that of wild fish despite having been nearly three times higher at planting, the lack of overwinter growth and loss of lipid reserves in hatchery-reared presmolts may compromise their success during a lengthy out-migration.

This loss of total body lipids could be due to a combination of factors: hatchery fish had high lipid reserves at planting as a result of (1) lack of exercise and (2) having been fed high-lipid commercial feeds (>16% lipid). Another explanation for the large loss of body lipid reserves in hatchery-reared fish during overwintering is that juvenile sockeye salmon prey in Redfish Lake are less abundant in winter compared with summer and that hatchery presmolts lacked adequate food resources. In summer and fall, daphnia are the preferred prey of juvenile sockeye salmon, but sockeye salmon diets shift to copepods in winter and chironomids in spring (Budy et al. 1995). Zooplankton abundance in Redfish Lake during the winter is approximately 25% of that in summer, although there are significant variations in year-to-year prey abundance during winter. In some years stomach contents of captured juvenile sockeye salmon from Redfish Lake exceed the amount of prey required for maintenance, but not in other years (Steinhart and Wurtsbaugh 2003). They also reported that few captured fish had empty stomachs, indicating that despite the low level of light under the ice, the low water temperature (≈4°C), and low zooplankton abundance, juvenile sockeye salmon in Redfish Lake actively forage during winter months. However, all juvenile sockeye salmon (both wild and hatchery origin) lose dry body mass during winter months in Redfish Lake, and whole-body lipid levels decline in some years to near-lethal levels. Based on the results of Masse et al. (2007), sockeye salmon presmolts adapt quickly to become effective zooplankton predators. This suggests that low prey abundance rather than poor foraging skill results in loss of lipid reserves in overwintering juvenile sockeye.

Lake fertilization has been used as a strategy by the Snake River sockeye salmon recovery program to enhance the survival of sockeye salmon in the Stanley basin lakes and increase carrying capacity for presmolt releases. Griswold et al. (2003) reported increases in zooplankton biomass after lake fertilization from 1995 to 1998. Increases in smolt survival were noted, but the authors also indicated that this may have been due to differences in hatchery practices between years. Hyatt et al. (2004) in a review of 24 sockeye salmon nursery lakes throughout British Columbia and Alaska as well as in Idaho showed that lake fertilization was associated with increased chlorophyll a concentrations and increased zooplankton biomass. Increased zooplankton biomass in nursery lakes was further associated with increased smolt size at out-migration and increased marine survival. Despite unintended consequences of lake fertilization within the Stanley basin lakes, such as the enhancement of the resident kokanee populations (Griswold et al. 2003), this strategy likely also enhances prey abundance for hatchery and wild presmolts alike.

Fatty acid profiles of juvenile sockeye salmon captured in a trawl of Pettit Lake 2 months after their release indicate presmolts releases to that lake in July had success capturing zooplankton prey. In contrast, cohorts released in Redfish Lake in October that same year had fatty acid profiles that remained relatively unchanged during the 7 months spent overwintering in that lake (Table 1). It is possible that a summer release of presmolts into Stanley basin lakes provide greater opportunities for hatchery-origin juvenile sockeye salmon to learn to forage effectively and also consume prey at higher densities than a fall presmolt release into the lakes. However, differences in fatty acid profiles which, in turn, reflect differences in diet may also indicate variability in foraging success among the Stanley basin lakes. Since Pettit, Alturas, and Redfish lakes are all part of the recovery strategy for Snake River sockeye salmon, further attention to presmolt foraging success and continued zooplankton productivity monitoring in each lake is fundamentally important.

Food quality has been shown to be a significant factor in sockeye salmon growth. Ballantyne et al. (2003) hypothesized that food quality, specifically DHA intake, was a more important constraint to growth of sockeye salmon in Lake Washington (Seattle, Washington) than water temperature or food quantity. However, wild juvenile sockeye salmon in Redfish Lake contained higher levels of highly unsaturated omega-3 fatty acids than did hatchery fish at planting despite having lower levels of DHA. The high level of DHA in hatchery fish reflects the use of marine oils in hatchery feeds. Salmonids are able to interconvert DHA and EPA, plus elongate and desaturate linolenic and stearidonic acids to EPA and DHA (Tocher 2003). This makes it unlikely that DHA levels constrain growth of Redfish Lake sockeye salmon.
Differences in fatty acid profiles of wild and hatchery-origin out-migrants from Redfish Lake reflect differences in the fatty acids of their diets. Wild juvenile sockeye salmon mainly consume cladocerans, daphnia, and copepods during lake residence. These prey are rich sources of omega-3 fatty acids, particularly ALA and stearidonic acids (both 18-carbon fatty acids). Sockeye salmon prey are also excellent sources of ARA (Higgs et al. 1995). While ARA levels did not change in hatchery-origin sockeye salmon following fall release, ALA and stearidonic acid were found in significantly higher amounts in juvenile sockeye salmon of wild origin. Arachidonic acid is increasingly recognized to be an important dietary nutrient for juvenile salmonids in part because of its role as a precursor to eicosanoids, key elements of the immune system (Bell and Sargent 2003; Bransden et al. 2004). Hatchery-reared juvenile sockeye salmon at planting and out-migration had slightly lower levels of ARA than wild juveniles and higher levels of DHA, reflecting the dietary fatty acid content of fish oils used in commercial salmon feeds used in hatcheries (NRC 1993). However, juvenile hatchery fish planted in Pettit Lake began to consume natural prey, and their fatty acid profile reflected a shift in composition to a more wild-type fatty acid profile ostensibly as new fatty acids are deposited in fish tissues. Fatty acid deposition in salmonids follows a simple dilution model (Jobling 2003), meaning that newly consumed fatty acids dilute but do not replace fatty acids previously deposited. Fatty acid profiles may be a useful index of successful transition of hatchery-reared sockeye salmon to wild prey in the Redfish Lake system.

Differences in lipid quantity and quality for hatchery compared with naturally produced sockeye salmon documented in this study may help explain observed large-scale differences (greater than five times) in survivability between the groups. Hebdon et al. (2004) reported large differences in overall smolt-to-adult (SAR) survival rates for unmarked, naturally produced sockeye salmon smolts exiting Redfish Lake compared with adipose fin-clipped marked smolts produced from hatchery-reared presmolt releases. Differences in SARs ranged from 0.36% unmarked versus 0.04% marked for adult return year 2000, 0.21% unmarked versus 0.04% marked for adult return year 2001, and 0.66% unmarked versus 0.09% marked for adult return year 2002 (Hebdon et al. 2004). Despite record returns of 833 sockeye in 2009, only 32 of these returning adults (3.8%) were from fall presmolt releases to the Stanley basin lakes. Presmolt releases accounted for only 0.65 adult returns for every 1,000 out-migrants compared with 4.0 adults per 1,000 out-migrants from smolt releases (M. Peterson, IDFG, personal communication).

Sockeye salmon smolts exiting Redfish Lake make a 1,448-km downstream migration through the Columbia River system to the Pacific Ocean. Given the long downstream migration these fish undertake and the limited opportunities to feed during migration, this survival difference may be related to the amount and quality of lipid energy reserves at time of out-migration. Thus, producing hatchery fish with wildfish lipid reserves and fatty acid profiles may aid in recovery efforts for this endangered population. Future management of Snake River sockeye salmon conservation efforts should continue to monitor limnological parameters within the Stanley basin lakes and make adaptive changes in management, where necessary. Additional study of overwinter survival and general condition of fall-planted presmolts should be considered if this release strategy will continue to be used in the Snake River sockeye salmon recovery program as part of a spread-the-risk philosophy.

Acknowledgments

This study was supported by the Bonneville Power Administration, U.S. Department of Energy. We thank IDFG personnel for collecting samples used for analysis. Reference to trade names does not imply endorsement by the U.S. Government.

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