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# GROWTH OF AMERICAN RIVER FALL-RUN CHINOOK SALMON IN CALIFORNIA'S CENTRAL VALLEY: TEMPERATURE AND RATION EFFECTS

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## ABSTRACT

**Food consumption and growth rates of juvenile American River fall-run chinook salmon (*Oncorhynchus tshawytscha*) were measured at temperatures of 11, 15, and 19°C and ration levels of 100 and 25% satiation. Increasing temperature had a positive, significant effect on the growth and food consumption rates of salmon receiving the full ration. Salmon receiving the 25% ration had negative growth rates that were temperature independent. Growth rates of American River fall-run chinook are similar to those for more northern strains; a slight indication of greater adaptation to warmer water temperatures was noted for the thermal range tested.**

## INTRODUCTION

Chinook salmon, *Oncorhynchus tshawytscha*, that spawn in California's Central Valley (primarily in the mainstem Sacramento River and its tributaries) are members of the southernmost extant populations (Moyle 2002). Within this basin, there are at least four distinct salmon races or strains, including the Sacramento River winter, spring, fall, and late-fall runs (Moyle 2002). All Central Valley runs have been impacted to varying degrees by the effects of water development, habitat degradation, and over-harvest. The severity of these declines has led to the protection of the winter and spring runs under state and federal endangered species laws (Moyle 2002); recovery efforts, ranging from captive breeding programs to the development of management plans, have also been initiated.

The outcomes of the various recovery efforts hinge on a number of factors, including the availability of accurate data on the effects of biotic and abiotic factors on the survival of vulnerable life-stages, particularly larval and juvenile salmon (Kope and Botsford 1990). To date, however, few studies on the effects of factors, such as

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water temperature and ration level, have been published for Central Valley races. Castleberry et al. (1993)[2] evaluated the relationships between river conditions and growth rate, condition, and physiological performance of wild-caught juvenile chinook salmon and steelhead (*O. mykiss*) from the American River. The feeding and thermal history of these fish was not well known, but temperatures in the 15 to 17°C range appeared to be conducive to high growth rates. Marine (1997)[3] reared juvenile Sacramento River fall-run chinook salmon under low (13 to 16°C), moderate (17 to 20°C) and high (21 to 24°C) temperature regimes. Maximal growth rates of 3.3 percent weight per day (% weight/day) were observed in salmon reared at 17-20°C, with lower growth rates in salmon reared at 13-16°C and 21-24°C (Marine 1997)[2]. More extensive studies have been published for a number of chinook salmon races from more northern latitudes. Brett et al. (1982) reported that Big Qualicum River (BC, Canada) and Nechako River (BC, Canada) salmon fed maximal rations grew fastest at 20.5 and 18.9°C, respectively. Shelbourn et al. (1995) reported a reduction in growth rates as water temperatures declined for Nechako River salmon. Latitudinal differences in physiological performance (Kreiberg 1989)[4], behavior (Taylor and Foote 1991), and life-history strategies (Healey 1994) have been reported for other *Oncorhynchus* species. Because Central Valley salmon reside at the southernmost limit of their distribution, it is not unreasonable to expect appropriate responses to local environmental conditions, perhaps in terms of superior warm-water adaptation.

The purpose of this study was to evaluate the effects of temperature (11, 15, and 19°C) and ration level (100 and 25% of satiation) on the growth of American River fall-run chinook salmon. Our objectives were 1) to collect and publish baseline data on the growth of fall-run salmon for use in recovery efforts and; 2) to compare fall-run data with those published for salmon from northern races to see if significant differences in temperature responses exist. We predicted that American River fall-run chinook would show similar temperature responses to more northern strains (e.g., higher growth and food consumption as temperatures approached 19°C), but with comparatively higher growth rates than northern strains tested at similar temperatures because of a higher food conversion efficiency.

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Figure 1. Location of the Lower American River in California's Central Valley.

## METHODS

American River fall-run chinook salmon were hatched and reared at the Nimbus Salmon and Steelhead Hatchery, which is owned by the U.S Bureau of Reclamation and operated by the California Department of Fish and Game. Fish (n = 720; mean weight: 1.7 g; mean total length: 60.4 mm) were transferred to the University of California, Davis, in late April 1998 and acclimated to air-equilibrated well water at 11, 15, and 19°C at 1°C/d. Salmon were stocked in 110-L round fiberglass tanks (four replicate tanks per temperature × ration treatment) at a density of 30 fish per tank. The indoor tanks received natural light through translucent roof panels and artificial lighting set to the natural photoperiod (latitude 38°55'N; May to July). Tanks received a constant flow (4 L/min) of 11, 15, or 19°C water. Water temperatures were monitored and maintained by a microprocessor-controlled mixing valve. Current velocities were adjusted using angled spray bars to one body length per second and flow direction was reversed every 5 days to uniformly exercise the fish. Mean well-water characteristics during the experiments were: total dissolved solids 390 mg/L, total suspended solids < 5.0 mg/L, total alkalinity 300 mg/L, pH 7.8, and hardness 320 mg/L. Dissolved oxygen concentrations in the flow-through experimental tanks, which also incorporated continuous aeration, were never below 90% air-saturation; weekly tests for dissolved ammonia detected none (0.1 mg/L detection limit).

Chinook salmon were fed Rangen 1.6 mm semi-moist salmon pellets. Fish were fed a full satiation ration (100% satiation) or a reduced ration (25% of satiation). The reduced rations were calculated using:

$$\text{Reduced ration} = \frac{\sum FC_{d-1}}{\sum W_f} \times W_r \times k \qquad (1)$$

where $\Sigma FC_{d-1}$ is the total amount of food consumed (g) by all the full-ration tanks at temperature $T$ the previous day, $W_f$ is the sum of the biomass (g) of the 4 full-ration tanks at temperature $T$ from the previous weighing, $W_r$ is the biomass (g) of the particular reduced-ration tank from the previous weighing, and $k$ is the reduction coefficient (0.25). The amount of food consumed was calculated by subtracting the number of pellets remaining in the tanks from the estimated number of pellets fed, based on a mean pellet weight of 0.005 ± 0.0003 g. The amount of food consumed was quantified after each feeding by subtracting the wet weight of the uneaten pellets from the wet weight of the food given. Feed dry weights were calculated by multiplying the wet weights by the percent dry matter determined from oven-dried feed samples (10% moisture). Mean consumption rate ($C$) in percent body weight of food consumed per day was calculated for each tank (Wurtsbaugh and Davis 1977) using:

$$C = \frac{C_i}{0.5 \times (W_1 + W_2) \times t} \times 100 \qquad (2)$$

where $W_1$ is the initial estimated dry weight of a group of fish, $W_2$ is the final dry weight of the group of fish, $t$ is the duration of the experiment in days (30 days), $C_i$ = estimated dry weight of food consumed. Fish dry weights were estimated by multiplying the total wet weight of the fish in each tank by the mean dry weights determined by oven-drying a subsample of 5 fish per treatment per sampling date at 60°C for 7 days.

Growth rates were determined on a per tank basis. All fish were weighed and measured on day 0, 10, 20, and 30. Fish were fasted for 24 h prior to weighing, anesthetized (50 ppm MS-222; 3 ‰NaCl; 0.1 ‰$NaHCO_3$), weighed to the nearest 0.1 g on a calibrated electronic balance and standard, fork, and total lengths measured to the nearest mm. Mean growth rates ($G$, in %weight/day) were calculated (Wurtsbaugh and Davis 1977) using:

$$G = \frac{W_2 - W_1}{0.5 \times (W_1 + W_2) \times t} \times 100 \qquad (3)$$

In order to facilitate comparison with literature values, we also calculated instantaneous or "specific" growth rates (SGR; Busacker et al. 1990), using:

$$SGR = \frac{\ln W'_2 - W'_1}{(t_2 - t_1)} \quad (4)$$

Gross food conversion efficiencies (*GCE*, %) were calculated for each tank using:

$$GCE = \frac{W'_2 - W'_1}{\sum_{30}^{1} C_1} \times 100 \quad (5)$$

where $W'_1$, $W'_2$ and $C_t$ were as above. Mean initial and final weights for each treatment were compared using Student t-tests. Differences among treatment mean *C* were tested using one-way ANOVA, with an $\alpha$ level of 0.05. The responses of *G* and *GCE* to the effects of temperature, ration level, and their interaction were evaluated using two-way ANOVA, with $\alpha$ levels of 0.05. Multiple pairwise comparisons were made using the Tukey HSD method (SAS 2000) at an $\alpha$ level of 0.05, but experiment-wise alpha levels were not used.

## RESULTS

Salmon food consumption rates, growth rates, and gross conversion efficiencies were affected by temperature and ration level. Food consumption rates increased significantly with temperature (ANOVA; all $P < 0.01$; Table 1, 2). Both growth rates measures showed significant ($F = 348.76$; $df = 5$; $P < 0.01$ for *G*; and, $F = 359.94$; $df = 5$; $P < 0.01$ for *SGR*) temperature, ration, and interaction effects, whereas conversion efficiencies only showed a significant ration effect ($F = 120.12$; $df = 1$; $P < 0.01$; Table 1, 2). Salmon receiving the 25% ration did not show increased growth rates as temperature increased; the increase in consumption rates results from the dependence of the ration size on the corresponding 100% ration at that temperature. Gross conversion efficiencies for salmon receiving the 100% ration did not differ significantly with temperature, with an overall mean of 27%. Gross conversion efficiencies for reduced-ration salmon were all negative, with an overall mean of -10.2%.

## DISCUSSION

Our prediction that American River fall-run chinook food consumption and growth rates would increase as temperature increased over the 11 - 19°C range is supported by our findings. Food consumption and growth rates for salmon receiving 100% rations increased significantly with each increase in temperature from 11 to 15 to 19°C. Gross conversion efficiency showed a similar trend, but differences among temperatures were not statistically significant. Our results indicate that fall-run salmon can achieve high growth rates when favorable food and environmental conditions are present. If food

Table 1. Effects of temperature on the food consumption rates (*C*), growth rates (*G*), specific growth rates (*SGR*) and gross conversion efficiencies (*GCE*) of American River fall-run chinook salmon fed to 25% of satiation. Abbreviation for weight is "wt." and day is "d." Values are means ± SE. Significant differences ($P < 0.01$) are indicated by **.

| Temperature | n | *C* (% body wt./d) | *G* (% body wt./d) | *SGR* (% wt./d) | *GCE* (%) |
|---|---|---|---|---|---|
| 11° | 4 | 3.72 ± 0.04 | -0.28 ± 0.08 | -0.28 ± 0.08 | -7.3 ± 2.0 |
| 15° | 4 | 5.49 ± 0.06 | -0.75 ± 0.14 | -0.75 ± 0.14 | -13.6 ± 2.5 |
| 19° | 4 | 5.65 ± 0.13 ** | -0.53 ± 0.18 | -0.54 ± 0.18 | -9.6 ± 3.2 |

Table 2. Effects of temperature on the food consumption rates (*C*), growth rates (*G*), specific growth rates (*SGR*) and gross conversion efficiencies (*GCE*) of American River fall-run chinook salmon fed satiation rations. Abbreviation for weight is "wt" and day is "d". Values are means ± SE. Significant differences ($P < 0.01$) are indicated by **.

| Temperature | n | *C* (% body wt./d) | *G* (% body wt./d) | *SGR* (% wt./d) | *GCE* (%) |
|---|---|---|---|---|---|
| 11° | 4 | 11.20 ± 0.26 ** | 2.68 ± 0.16 ** | 2.84 ± 0.20** | 23.9 ± 1.4 |
| 15° | 4 | 13.49 ± 0.26 ** | 3.60 ± 0.06 ** | 4.02 ± 0.09** | 26.7 ± 0.4 |
| 19° | 4 | 15.02 ± 0.53 ** | 4.38 ± 0.05 ** | 5.25 ± 0.10** | 29.3 ± 1.2 |

resources are severely limited, as simulated by our 25% ration treatments, juvenile salmon are incapable of maintaining condition over the 11 - 19°C range.

American River fall-run and chinook salmon races further north respond similarly to increases in water temperature (Table 3). Fall-run fish used in this study performed similarly to both Sacramento River and British Columbia strains (Table 3). The observed differences are likely due to unequal fish size and experiment duration. Smaller fish tend to have higher growth rates than larger fish (Elliott 1976); short-term growth rates are typically higher than those measured over longer intervals. Growth rates for American River fall-run salmon tested at 19°C were the highest reported for any chinook race. The different results may be partially explained by the different initial weights and experiment duration, but the magnitude of the difference (1.3 – 2.0 % wt./d) suggests that the American River fall-run salmon are slightly better adapted to growth at 19°C. We observed maximal growth rates at 19°C, supporting earlier findings by Brett et al. (1982) and Marine (1997)[2]. It is important to note that these maximal growth rates only occurred when the fish were fed satiation rations under optimal environmental conditions. Should rations be reduced to some level below 100% satiation, as would be expected in the wild (Petrusso and Hayes 2001), then optimal growth temperatures would be somewhat lower, as has been shown in chinook salmon and other salmonids (Elliott 1975, Elliott 1976, Brett et al. 1982).

One interesting result noted in the 25% ration treatments was the change in relative size distribution over the course of the experiment. The distribution of initial weights in the 25% treatments was normal, but following the 30-d experiment, there were one

Table 3. Comparison of growth rates (*G*) of California Central Valley chinook salmon with salmon from more northern latitudes. Sources of data are as follows: 1. Brett et al. (1982); 2. This study; 3. Clarke and Shelbourn (1985); 4. Marine (1997)[2] and; 5. Shelbourn et al. (1995). Abbreviation for weight is "wt." and day is "d".

| Temp. (°C) | Strain | Initial weight (g) | Duration (days) | G (% wt./d) | Source |
|---|---|---|---|---|---|
| 10.3 | Nechako R. | 2.9 | N/A | 1.4 | 5 |
| 11 | American R. | 1.7 | 30 | 2.7 | 2 |
| 14 | Big Qualicum R. | 3.4 | 28 | 3 | 1 |
| 15 | American R. | 1.7 | 30 | 3.6 | 2 |
| 16 | Nechako R. | 2.3 | 28 | 3.1 | 1 |
| 16 | Big Qualicum R. | 3.3 | 28 | 2.9 | 1 |
| 16 | Big Qualicum R. | 0.6 | 90 | 3.7 | 3 |
| 19 | Nechako R. | 2.3 | 28 | 3.1 | 1 |
| 19 | Big Qualicum R. | 3.3 | 28 | 3 | 1 |
| 19 | American R. | 1.7 | 30 | 4.4 | 2 |
| 13 – 16 | Sacramento R. | 0.8 | 105 | 3.1 | 4 |
| 17 – 20 | Sacramento R. | 0.8 | 105 | 3.3 | 4 |
| 21 – 24 | Sacramento R. | 0.9 | 105 | 2.9 | 4 |

to two large fish in each tank, while the remainder formed a regular weight distribution (Fig. 2). A dominance hierarchy was evident. Hierarchies of this type have been widely documented in both laboratory and field studies (Wagner et al. 1996, McMichael and Pearsons 1998) and implies that if food resources in Central Valley rivers become limited, then increasing salmon density through hatchery releases could negatively impact the growth of most salmon present, though a small group of dominant individuals may experience high growth rates.

In the case of salmon receiving satiation rations, initial and final weight distributions are similar (Fig. 3). As we noted with the reduced-ration salmon, there were typically 1 or 2 salmon per tank that were substantially larger than the rest. Unlike the 25% ration fish, however, these fish did not have as severe an effect on the growth rates of other fish in their tank because rations were unlimited.

American River fall-run chinook salmon appear well-adapted to conditions in the American River. Our study demonstrated that temperatures up to 19°C pose no problem for these fish, provided that food is abundant and environmental conditions are optimal. American River salmon respond to temperature in a manner similar to other Central Valley and northern races; the American River fish appear to be slightly better adapted to warm temperatures. If current American River management practices with respect to water temperature are maintained, conditions should not preclude the continued rearing of juvenile chinook salmon.

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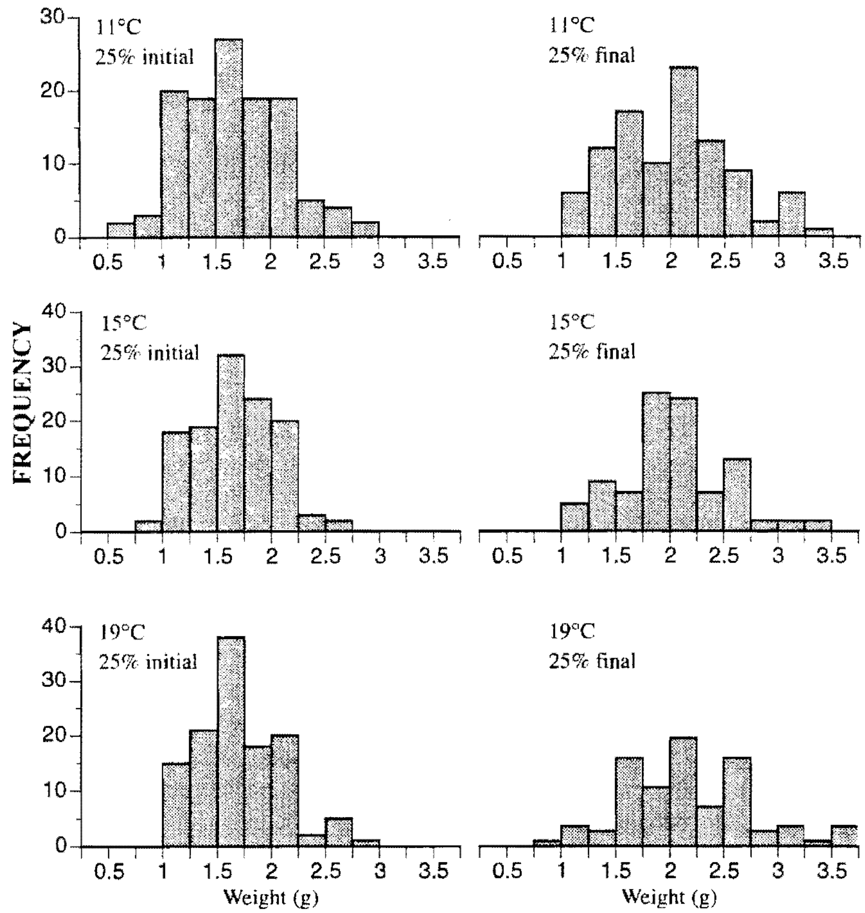


Figure 2. Distribution of initial and final weights (g) of American River fall-run chinook salmon fed 25% satiation rations.

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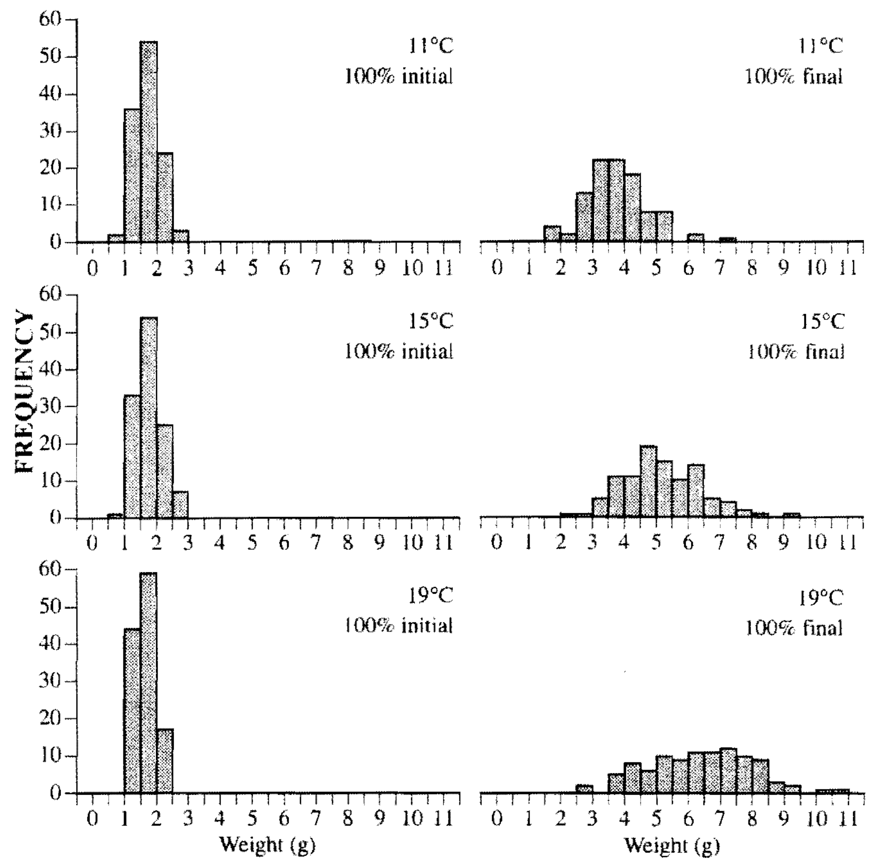


Figure 3. Distribution of initial and final weights (g) of American River fall-run chinook salmon fed satiation (100%) rations.

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