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CONDITION OF JUVENILE CHINOOK SALMON IN THE UPPER SACRAMENTO RIVER, CALIFORNIA

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The physical condition of juvenile chinook salmon, *Oncorhynchus tshawytscha*, rearing in the upper Sacramento River during 1995 and 1996 was compared to the condition of experimentally reared fish. The overall length-wet weight relation for field-caught juvenile salmon was allometric, resulting in a positive relation between condition factor (*K*) and fish size. Mean length, weight, and *K* increased, and mean percent body water decreased, over the study period. Though mean length and weight increased from upstream to downstream sites, there were no distinct spatial trends in *K* or percent body water. Analysis of covariance showed weight at a given length in Sacramento River chinook salmon increased progressively from February through June 1996 for salmon 50–90 mm fork length. Field-caught chinook salmon were generally in better condition, as measured by weight and percent body water at all lengths, than salmon from starved experimental treatment groups.

INTRODUCTION

Fall-run, late-fall-run, winter-run, and spring-run chinook salmon, *Oncorhynchus tshawytscha*, stocks use the upper Sacramento River and its tributaries for spawning. All 4 stocks have declined in an era of numerous anthropogenic changes to the river, such as construction of dams, flow regulation and diversion, stream channelization, conversion of floodplain to agriculture, and gravel extraction (Brown 1991, Fisher 1994). Winter-run chinook salmon are listed as endangered under the federal Endangered Species Act (NMFS[2] 1994), naturally spawned spring-run chinook salmon are classified as threatened (NMFS[3] 1999), and the fall and late-fall stocks are the focus of current protection efforts. Despite extensive research taking place on the Sacramento River to increase understanding of salmon life history and production, condition of juvenile chinook salmon rearing in the upper river has received little attention (Kjelson[4] 1993).

[1] Present address: 3059-E National Fish Hatchery Road, Hagerman, Idaho 83332.

[2] NMFS. (National Marine Fisheries Service) 1994. Endangered and threatened species; status of Sacramento River winter-run chinook salmon. Federal Register 59:440-450.

[3] NMFS. (National Marine Fisheries Service) 1999. Endangered and threatened species; threatened status for two chinook salmon evolutionarily significant units (ESUs) in California; final rule. Federal Register 64:50393-50415.

[4] Kjelson, M.A. 1993. Emigration. Pages 10-12 *in:* Notes and selected abstracts from the workshop on Central Valley chinook salmon, University of California at Davis, 4–5 January 1993. Department of Wildlife and Fishery Biology, University of California, Davis, California, USA.

Information on the condition of fish serves 2 important purposes. Condition indices such as percent body water or the condition factor (*K*) provide an assessment of how well fish are coping with their environment (Goede and Barton 1990). Condition indices, therefore, reflect how suitable the environment is for rearing. When viewed as a general measure of energy status or as an indicator of stress (Love 1970, Adams 1990), condition indices may additionally provide insight into the competency of the fish to meet future survival challenges such as food shortages and other similar stressors. For example, percent body water increases during fasting as fat and protein are depleted and, thus, provides an indirect measure of energy storage (Love 1970). Juvenile chinook salmon in the Sacramento River face a number of challenges as they emigrate from upper river habitats, including dams, water diversions, extreme temperature changes, and possible alteration of emigration path associated with anthropogenic changes in hydrology in the Sacramento-San Joaquin Delta. To the extent that measures of fish condition provide a view of both the rearing history and the possible future response of a fish to various stressors, baseline data on the condition of juvenile chinook salmon can be useful to fishery managers in the Sacramento River system.

The main objectives of this study were to 1) determine the physical condition of juvenile chinook salmon in upper river habitats, using condition factor, length-weight relation, and percent body water as indices of condition; 2) compare condition estimates of fish captured in the field with estimates obtained for experimentally reared salmon of known 2-week feeding history; and 3) determine spatial and temporal patterns in condition of field-caught juvenile salmon.

METHODS

Study Sites and Duration

The Sacramento River originates near Mt. Shasta in northern California, and travels approximately 595 river km (rkm) along the floor of the Central Valley to its mouth in the Sacramento-San Joaquin Delta. The northern Central Valley is bordered by the Sierra Nevada and Cascade ranges to the east and the Klamath and Coast ranges to the west. Most precipitation occurs in winter and spring and little or none in summer and fall.

Investigations of the condition of juvenile chinook salmon were conducted at 13 sites on the upper mainstem Sacramento River between the cities of Redding (rkm 481) and Chico (rkm 311) (Fig. 1) during July–August 1995 (brood year 1994) and February–June 1996 (brood year 1995). Samples collected at or downstream of rkm 438 may have included unmarked Coleman National Fish Hatchery (Anderson, California) juvenile chinook salmon. Because of the relatively low abundance of late-fall, winter, and spring-run salmon, fall-run young-of-the-year were used for percent body water estimates, which required sacrificing the fish. Juvenile fall-run chinook salmon were sacrificed for estimates of water content during April–June 1996 only.

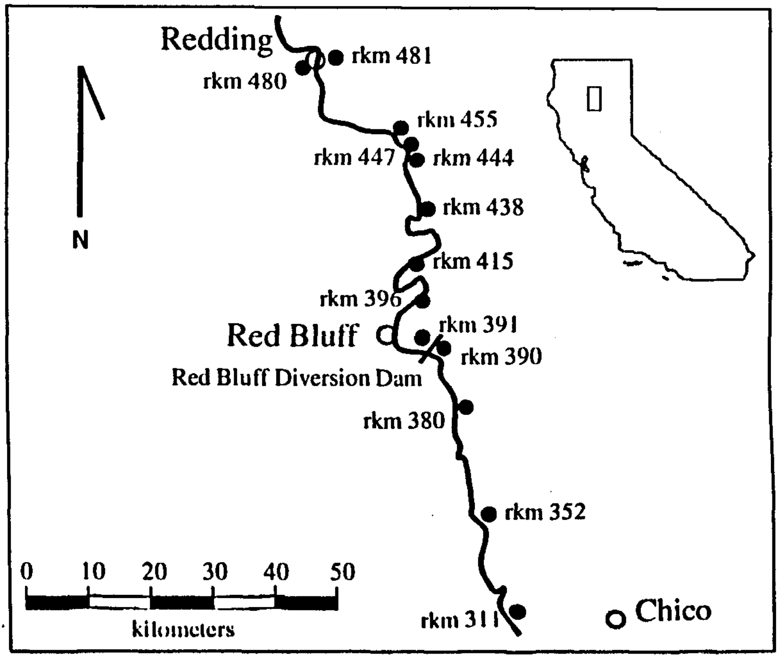

Figure 1. Map of sampling sites for juvenile chinook salmon in the upper Sacramento River, California, 1995–1996.

Fish Collection Methods

Beach Seining

Beach seines (1.21 m x 9.09–22.73 m, 3.2-mm mesh) were used to collect juvenile chinook salmon between 0800 and 1600 hours at each site every other week. Juvenile salmon were anesthetized with tricaine methanesulfonate (MS-222) mixed with river water. Fork length (FL, mm) and wet weight (nearest 0.1 g in 1995 or 0.01 g in 1996) were then measured for each fish. The salmon were blotted with a soft cloth prior to weighing on a portable electronic balance. Run (fall, late-fall, winter, or spring) was assigned based on fish length and date of capture (Fisher[5] 1992, as modified by Greene[6] 1992). On a given sampling date during April–June 1996, up to 20 fall-run salmon per site were euthanized by prolonged exposure to the anesthetic

[5] Fisher, F.W. 1992. Chinook salmon *Oncorhynchus tshawytscha* growth and occurrence in the Sacramento-San Joaquin river system. California Department of Fish and Game, Inland Fisheries Division, Red Bluff, California, USA.

[6] Greene, S. 1992. Estimated winter-run chinook salmon salvage at the State Water Project and Central Valley Project Delta pumping facilities. Memorandum to R. Brown, 5/8/92. California Department of Water Resources, Sacramento, California, USA.

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'or use in percent body water analyses. Sacrificed fish were placed in bags of water cept in an ice-filled cooler and later frozen in water.

Due to time constraints in the field, some of the sacrificed fish were measured for ength and weight just before transfer to frozen storage rather than at the time of :apture, resulting in a measurement delay of 4–11 hours postmortem. Two :xperimental trials were conducted to develop correction equations that could be ıpplied to delayed measurements. The experiments involved measuring the live weight of fish, storing the fish in bags of water in an ice-filled cooler to mimic :onditions in the field, and measuring postmortem weights periodically for up to 12 h. Regression equations developed from the combined results of the experiments (n = 80 fish) were used to convert delayed measurements from fish in the field to live length and weight estimates. The following correction equations were used:

Length: $y = 1.0237x - 0.7154$, $r^2 = 0.98$, and
Weight: $y = 0.9672x + 0.0188$, $r^2 = 0.99$,

where x is the postmortem (delayed) length or weight and y is the estimated live length or weight. Corrections were applied to the measurements of 445 out of 1,204 fish.

Other Methods of Fish Capture

Lengths and weights of juvenile salmon, and samples of fall-run juveniles, were also collected once per month during April–June 1996 at 2 rotary screw traps (rkm 447) operated by the California Department of Fish and Game.

Experimental Growth

Experiments with Hatchery Salmon

Two separate growth trials were conducted to compare fish of known feeding history with fish captured in the field. Each experimental trial included 1 fasted treatment group and 1 or 2 fed treatment groups (Table 1). Experiment I had 2 treatments in which the fish were fed, whereas Experiment II had only 1 fed treatment group. The experiments were conducted at different times of the year, and therefore, differed in the size range of fish used.

Coleman National Fish Hatchery brood year 1995 fall-run chinook salmon were held at the U.S. Bureau of Reclamation Fish Holding Facility, Red Bluff, California, in 780-liter fiberglass circular tanks supplied with aerated 16°C well water. Each treatment in growth experiments I and II began with approximately 300 fish per tank. BioMoist Grower pellets (Bio-Oregon, Inc.[7], Warrenton, Oregon, USA) were distributed to treatment groups on a 12-h belt feeder (1.0–2.4-mm pellets were used, depending on fish size). Initial rations were calculated based on the length-weight

[7] Use of trade names does not imply endorsement by the California Department of Fish and Game.

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Table 1. Summary of treatment information for growth experiments with brood year 1995 juvenile fall-run chinook salmon from the Coleman National Fish Hatchery. Starting date of Experiment I was 1/19/96, that of Experiment II was 4/30/96.

Treatment information	Experiment I	Experiment II
Number of treatments	3	2
Ration level (percent body weight fed per day)		
Treatment 0 (Zero ration)	0%	0%
Treatment 1 (Low ration)	2–5%	3–4%
Treatment 2 (High ration)	4–10%	Not applicable
Initial number of fish per tank	300	300
Mean initial FL of experimental fish (mm)	44	68
Initial FL range (mm)	40–47	58–75
Duration of treatment (days)	16	15

relations of initial subsamples of fish, and the rations were adjusted according to the number of fish remaining in each tank after subsamples were removed. The zero-ration treatments were halted after approximately 2 weeks, before fasting-induced mortality could occur.

A random subsample of 10–20 fish was selected from each tank at the beginning of the experiment and weekly thereafter. Fish were anesthetized with MS-222 until dead and were measured for fork length (mm) and wet weight (nearest 0.01 g) with the same equipment and methods used in the field. The carcasses were placed in bags of water and then frozen.

Condition Estimates

Condition Factor

The lengths and weights of field-caught and experimental juvenile chinook salmon were used to calculate the condition factor (K) for each fish, with the equation:

$K = 10^5 \times$ (wet weight / fork length^3).

Percent Body Water

Frozen salmon were thawed in the laboratory, and fork lengths (mm) and wet weights (mg) were recorded. Fish were dried to a constant weight in a drying oven at 70°C and the dry weight (mg) of each fish was recorded. Because fish were not tracked individually prior to thaw, their live length and weight measurements were estimated from thawed lengths and weights using regressions calculated from fish in the postmortem experiments (n = 80). The equations used to convert thawed to live measurements are as follows:

Length: $y = 1.0357x + 0.9421$, $r^2 = 0.99$, and
Weight: $y = 0.9337x + 0.0218$, $r^2 = 0.99$,

where x represents thawed measurements, and y represents estimated live measurements. Percent body water was estimated with the equation:

Percent body water = 100 x {[ELW – DW] / ELW},

where ELW = the estimated live wet weight (g) of fish and DW = dry weight (g).

Statistical Methods

Least squares regression was used to describe length-wet weight and length-percent body water relations. The length-weight data were $\log_e$ (*ln*) transformed to linearize relations and stabilize error variance. Length, weight, condition factor (*K*) and percent body water of fish captured in the field were analyzed in relation to month and river kilometer of capture using the SAS general linear model function (GLM), which performs a generalized analysis of variance appropriate for unbalanced data (SAS Institute 1989). Length-wet weight and length-percent body water relations of samples pooled by month and site of capture were compared using the slope heterogeneity test and analysis of covariance (ANCOVA) in SAS (Littell et al. 1991). Fish <50 mm FL and >90 mm FL were excluded from length-wet weight slope heterogeneity tests as they affected the linearity of the regressions. A significance level of 0.05 was used in statistical tests.

RESULTS

Length-Weight and Length-Condition Factor Relations

The overall regression of ln wet weight on ln length for juvenile salmon captured from the Sacramento River was described by the equation $y = 3.4852x - 6.6088$ ($F = 129{,}326$; df = 1, 1202; $P = <0.001$) (Fig. 2). The allometric length-weight relation, characterized by a regression slope b greater than 3.0, resulted in a curvilinear relation between length and condition factor (*K*) (Fig. 3), with values of *K* increasing with increased length until a decline at sizes >80 mm.

Field-caught salmon were generally heavier at any given length than fish experimentally fasted for 2 weeks, but slightly lighter at a given length than fish in fed treatment groups (Fig. 4). The crossing of the Experiment II low ration regression over the field regression (Fig. 4) indicated some overlap in weight-at-length. Among experimental groups, weight at a given length increased with ration level. Slopes of the ln length-ln weight regressions for fasted groups were high (3.5225 for Experiment I and 4.0178 for Experiment II), whereas slopes for fed groups were below 3.0.

Length-Percent Body Water Relation

The length-percent body water relation of juvenile chinook salmon collected in the field showed a decrease in percent body water with increasing length ($y = 0.144x + 90.516$) ($F = 533$; df = 1, 515; $P < 0.001$)) (Fig. 5). Length-percent body water relations for experimental fish showed that zero-ration treatments had

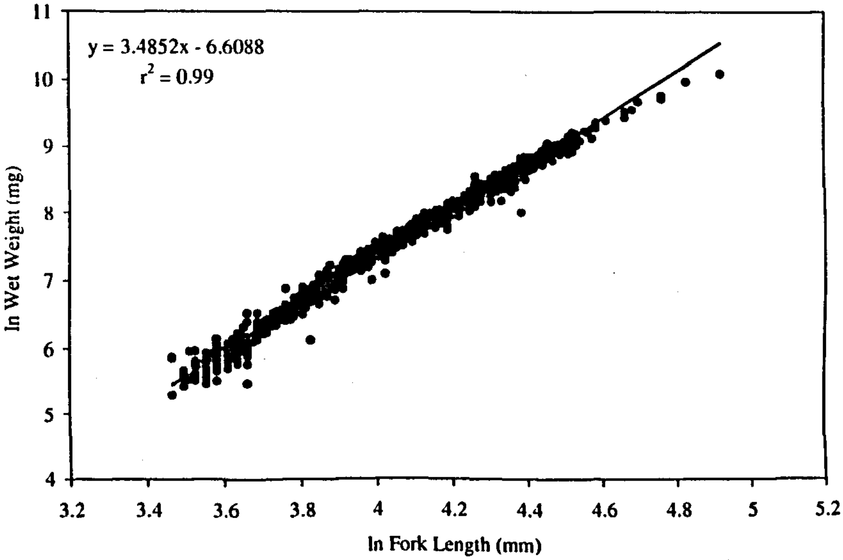

Figure 2. Regression of ln wet weight on ln fork length of juvenile chinook salmon captured from the upper Sacramento River, 1995–1996 (n = 1,204).

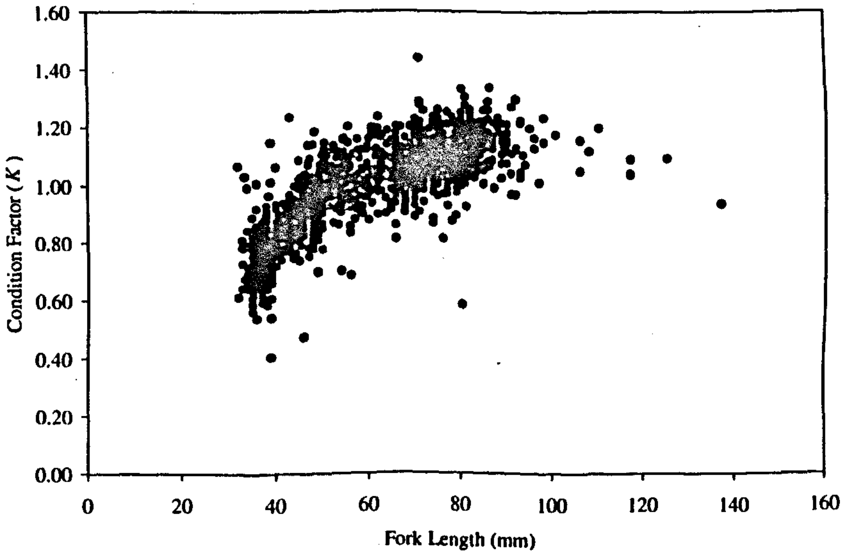

Figure 3. Relation between condition factor (K) and fork length of juvenile chinook salmon captured from the upper Sacramento River, 1995–1996 (n = 1,204).

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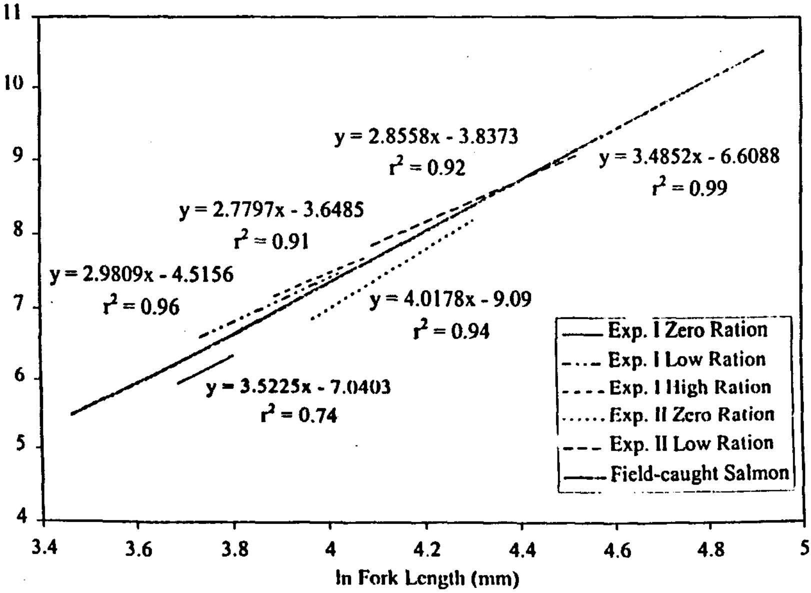

igure 4. Regressions of ln wet weight on ln fork length of juvenile chinook salmon from growth xperiments, compared with the regression for juvenile chinook salmon captured from the acramento River, 1995–1996 (field-caught salmon).

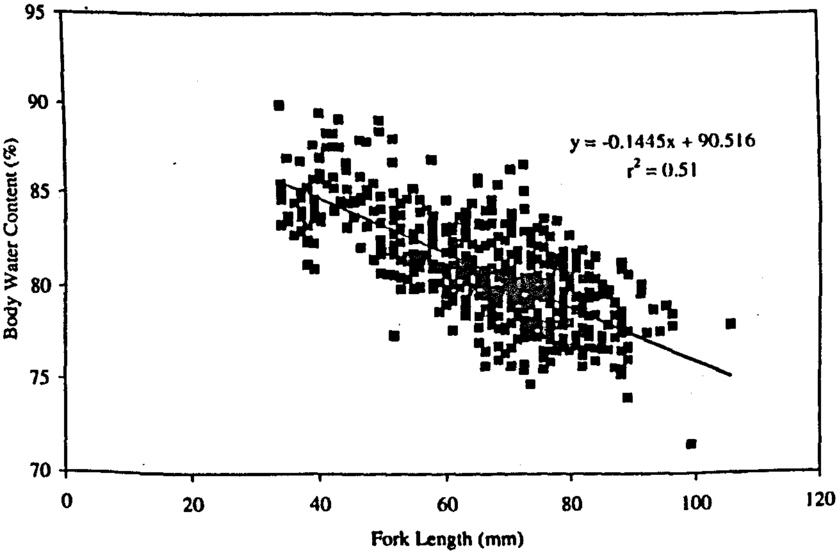

Figure 5. Regression of percent body water on fork length of juvenile chinook salmon captured from the Sacramento River, April–June 1996 (n = 517).

the highest percent body water for a given length and the fed treatments had the lowest (Fig. 6). As with the length-weight relation, percent water at a given length for field-caught salmon was intermediate between that of fasted and fed groups; however, the Experiment I low ration group overlapped the field regression at its initial lengths (Fig. 6).

General Linear Model Analysis of Spatial and Temporal Patterns

General linear model analysis indicated that the month and river kilometer effects on length, weight, condition factor *K* and percent body water were significant (P <0.0001 across all variables for both terms) with coefficients of determination (r^2) of 0.36, 0.30, 0.39, and 0.24 (Table 2). The month x river kilometer interaction effects, though significant, were excluded from the analyses, as the absence of some month-river kilometer combinations prevented meaningful interpretation. When included, interaction terms in the models accounted for little extra variation in the dependent variables (r^2 were 0.41, 0.34, 0.43, and 0.34 for length, weight, condition factor, and percent body water).

Least squares (adjusted) mean length and weight determined by the GLM analyses (Littell et al. 1991) generally increased from upstream to downstream sites, and from winter to summer months (Tables 3 and 4). Least squares mean condition factor increased over time, from 0.82 in February 1996 to 1.15 in June 1996 (Table 3). Spatial trends in mean condition factor were not as apparent, with only slight differences among sites; however, mean condition factors below 1.0 were associated

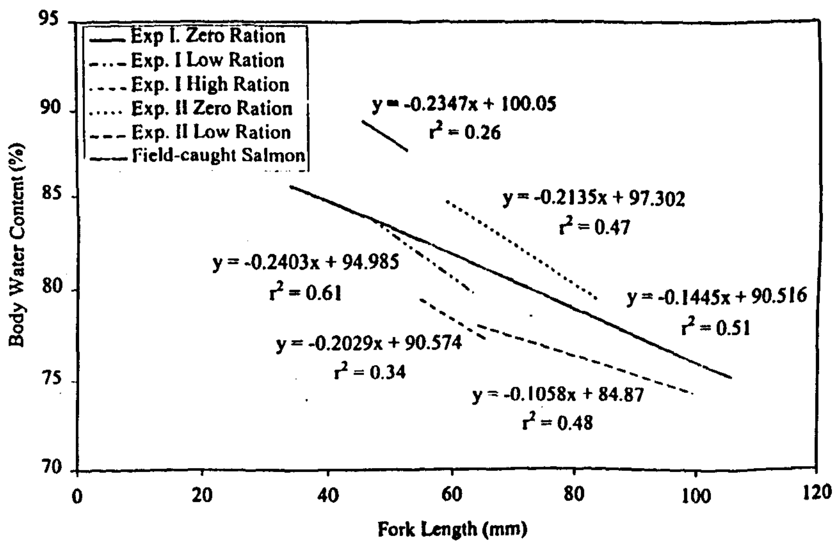

Figure 6. Regressions of percent body water on fork length of juvenile chinook salmon from growth experiments, compared with the regression for juvenile chinook salmon captured from the Sacramento River, April–June 1996 (field-caught salmon).

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able 2. Results of general linear model analyses, describing the effect of month and river lometer (rkm) of capture on length, wet weight, condition factor (*K*) and percent body water 'juvenile chinook salmon captured from the Sacramento River, 1995-1996 (n = 1,204 for ngth, weight, and *K*; n = 517 for percent water). CV is the coefficient of variation.

Variable	Factor/source	df	F-ratio	*P*	r^2	CV%
Length	Model	16	41.20	0.0001	0.36	24.80
	Main effects					
	Month	5	83.06	0.0001		
	Rkm	11	6.26	0.0001		
Weight	Model	16	31.17	0.0001	0.30	80.10
	Main effects					
	Month	5	68.91	0.0001		
	Rkm	11	4.45	0.0001		
Condition (*K*)	Model	16	47.83	0.0001	0.39	13.63
	Main effects					
	Month	5	93.48	0.0001		
	Rkm	11	9.05	0.0001		
Percent body water	Model	9	17.58	0.0001	0.24	3.15
	Main effects					
	Month	2	51.87	0.0001		
	Rkm	7	10.53	0.0001		

Table 3. Least squares mean length, weight, condition factor (*K*), and percent body water (with standard errors in parentheses) of Sacramento River juvenile chinook salmon by month of capture, averaged across all sites. The estimates were produced by general linear model analyses (n = 1,204 for length, weight, and *K*; n = 517 for percent body water). Delayed length and weight data were converted to live estimates by regression.

Brood Year	Capture date	Fork length (mm)	Weight(g)	Condition factor (*K*)	Percent body water
1994	July 1995	75 (2)	5.28 (0.31)	1.06 (0.02)	No data
1995	Feb 1996	44 (1)	1.33 (0.18)	0.82 (0.01)	No data
1995	Mar 1996	47 (2)	0.99 (0.30)	0.92 (0.02)	No data
1995	Apr 1996	58 (1)	2.31 (0.16)	0.96 (0.01)	82.04 (0.18)
1995	May 1996	65 (1)	3.26 (0.21)	1.06 (0.01)	79.96 (0.25)
1995	June 1996	76 (2)	5.61 (0.26)	1.15 (0.02)	78.75 (0.40)

with sites upstream of rkm 391, whereas fish sampled at sites below that point had mean condition factors above 1.0 (Table 4). Least squares mean percent body water decreased over time (Table 3) but exhibited no clear pattern with respect to river kilometer (Table 4).

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Table 4. Least squares mean length, weight, condition factor (K), and percent body water (with standard errors in parentheses) of Sacramento River juvenile chinook salmon by site (river kilometer [rkm]), averaged across months of capture. Estimates were produced by general linear model analyses (n = 1,204 for length, weight, and K; n = 517 for percent water). Delayed length and weight data were converted to live estimates by regression. Percent body water was calculated based on data from juveniles captured April–June 1996.

Site (rkm)	Fork length (mm)	Weight (g)	Condition factor (K)	Percent body water
480	54 (3)	2.04 (0.42)	0.95 (0.02)	No data
455	54 (3)	2.22 (0.42)	0.95 (0.02)	No data
447[a]	59 (1)	3.23 (0.17)	0.95 (0.01)	79.20 (0.22)
444	58 (6)	2.99 (0.96)	0.98 (0.06)	No data
438	58 (3)	2.66 (0.43)	1.02 (0.03)	82.46 (0.51)
415	58 (2)	2.93 (0.32)	0.97 (0.02)	80.92 (0.76)
396	62 (2)	3.07 (0.30)	0.98 (0.02)	79.41 (0.43)
391	68 (2)	4.43 (0.30)	1.05 (0.02)	No data
390	65 (2)	3.36 (0.32)	1.02 (0.02)	77.99 (0.68)
380	62 (1)	3.12 (0.16)	1.02 (0.01)	80.44 (0.28)
352	65 (1)	3.64 (0.20)	1.02 (0.01)	81.20 (0.32)
311	66 (1)	3.87 (0.20)	1.05 (0.01)	80.38 (0.29)

[a] Rotary screw trap site; all other data collected by beach seine.

Analysis of Covariance of Spatial and Temporal Patterns

Because condition factor and percent body water GLM results were strongly dependent on mean length of fish sampled, the question remained whether weight or percent body water for a given length differed between months or sites. Slope heterogeneity tests indicated that slopes of the ln length-ln weight regressions by month and river kilometer were not significantly different for the 50–90-mm size range when fish from July 1995 were excluded; therefore, ANCOVA was used to compare intercepts of fish of this size range captured in 1996 (n = 623 for months; n = 621 for sites). Intercepts were significantly different among months (P <0.0001) and sites (P <0.0001). Slopes of the length-percent body water relations were homogeneous between months, but heterogeneous between sites (P = 0.003; n = 517). Tables 5 and 6 summarize the length-weight and length-percent body water regression parameters by month and river kilometer. In cases where slopes were homogeneous and intercepts were significantly different, higher intercepts indicated more weight ("better" condition) or a greater proportion of water ("worse" condition) for a given length. For length-weight relations by month in 1996, the pooled slope (3.1796) was accompanied by intercept values that increased incrementally each month from February (–5.4149) to June (–5.2342) (Table 5). Length-percent body water relations showed a different result: fish captured in May had the best water content (lowest intercept, a = 89.3318), followed by June and then April (pooled slope b = –0.1362) (Table 5). For the analysis by site (rkm), no clear progression in length-weight intercept value from upstream to downstream, given a pooled slope of 3.2389, was

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apparent (Table 6). Note that the ranges of y-intercept values in Tables 5 and 6 represent small absolute differences in weight or percent body water.

Table 5. Slopes and intercepts for ln length-ln weight regressions for fish 50–90 mm FL and length-percent body water regressions by month for juvenile chinook salmon captured from the Sacramento River, 1995–1996 (n = 623 for length-weight; n = 517 for length-water). Pooled slopes were estimated by slope heterogeneity tests. Intercepts, determined by analysis of covariance (ANCOVA), are ranked from highest to lowest for weight, and from lowest to highest for percent body water. Data from July 1995 were excluded from the ANCOVA due to difference in slope, but regression parameters are presented for comparison. Ln L = Ln length and Ln W = Ln weight. Numbers in parentheses are ANCOVA ranks.

Brood year	Capture date	Ln L-Ln W slope or pooled slope (b)	Ln L-Ln W intercept (a)	Length-percent body water pooled slope (b)	Length-percent body water intercept (a)
1994	Jul 1995	3.5362	–6.8393	No data	No data
1995	Feb 1996	3.1796	–5.4149 (5)	No data	No data
1995	Mar 1996	3.1796	–5.3497 (4)	No data	No data
1995	Apr 1996	3.1796	–5.3166 (3)	–0.1362	90.3157 (3)
1995	May 1996	3.1796	–5.2924 (2)	–0.1362	89.3318 (1)
1995	Jun 1996	3.1796	–5.2342 (1)	–0.1362	89.5674 (2)

Table 6. Slopes and intercepts for ln length-ln weight regressions for fish 50–90 mm FL and length-percent body water regressions by river kilometer (rkm) for juvenile chinook salmon captured in the Sacramento River in 1996 (n = 621 for length-weight; n = 517 for length-water). The length-weight pooled slope (3.2389) was estimated by a slope heterogeneity test. Length-weight intercepts, determined by analysis of covariance (ANCOVA), are ranked from highest to lowest. Both slopes and intercepts are reported for the length-percent body water regressions due to heterogeneity of slopes. Ln L = Ln length and Ln W = Ln weight. Numbers in parentheses are ANCOVA rank.

Site (rkm)	Ln L-Ln W intercept (a)	Length-percent body water slope (b)	Length-percent body water intercept (a)
447[a]	–5.5565 (6)	–0.1388	89.4373
438	–5.5416 (4)	–0.1177	90.4213
415	–5.6003 (8)	–0.1493	91.3032
396	–5.6063 (9)	–0.1391	89.3011
391	–5.5344 (2)	No data	No data
390	–5.5939 (7)	–0.0983	87.9603
380	–5.5311 (1)	–0.1633	91.4561
352	–5.5489 (5)	–0.0987	88.6904
311	–5.5396 (3)	–0.2020	94.8743

[a] Rotary screw trap site; all other data collected by beach seine.

DISCUSSION

Condition of Field-Caught Juvenile Chinook Salmon

Length-Weight and Length-Condition Factor Relations

The length-weight relation for juvenile chinook salmon captured in the Sacramento River was characterized by a slope greater than 3.0. Length-weight relations have been used to compare condition of fish samples or populations (Cone 1989) and to represent changes in body form over ontogeny (Safran 1992). Some authors assume that the length-weight regression line is unidirectional, with growth in weight proceeding from the smallest length, and with breaks in the regression delineating growth stanzas (LeCren 1951, Wootton 1992). Using the regression slope to designate instantaneous samples as representing "isometric" ($b = 3.0$) or "allometric" ($b \neq 3.0$) growth (e.g., see Cone's response in Springer et al. 1990) may be incorrect. Godinho (1997) recognized that variations in the slope of the length-weight relation for the hatchetfish, *Triportheus guentheri*, could occur if individuals of different lengths experienced weight changes of differing rates or directions. Fasted experimental groups in our study exhibited the highest length-weight slopes (Fig. 4), providing evidence that the slope does not always indicate growth form for a population. Condition of populations should be compared by the entire length-weight relation given the limitations of using only the slope or intercept (Bolger and Connolly 1989, Cone 1989).

Because the slope of the length-weight relation exceeded 3.0, the observed range of condition factors for Sacramento River salmon differed between length classes (Fig. 3). However, as just discussed, a slope >3.0 in the length-weight relation of a sample does not prove that the assumption of isometric growth, considered necessary for proper use of *K* (LeCren 1951, Cone 1989), has been violated. The greater limitation of the condition factor is that it does not allow visualization of true differences in weight-at-length between samples or populations. Our estimates of condition factor for juvenile chinook salmon in the mainstem Sacramento River were similar to estimates reported for juvenile chinook salmon in other systems (Carl 1984, Hard 1986, Field-Dodgson 1988), in intermittent tributaries of the Sacramento River (Moore[8] 1997), and in the lower American River (Snider and Titus[9,10] 1995,

[8] Moore, T.L. 1997. Condition and feeding of juvenile chinook salmon in selected intermittent tributaries of the upper Sacramento River. M.S. Thesis, California State University, Chico, California, USA.

[9] Snider, B. and R.G. Titus. 1995. Lower American River emigration survey, November 1993–July 1994. Stream Flow and Habitat Evaluation Program Report, California Department of Fish and Game, Environmental Services Division, Sacramento, California, USA.

[10] Snider, B. and R.G. Titus. 1996. Fish community survey, lower American River, January through June 1995. Stream Flow and Habitat Evaluation Program Report, California Department of Fish and Game, Environmental Services Division, Sacramento, California, USA.

1996; Snider et al.[11] 1997).

Condition factors are often used to estimate the energy status of fish, and attempts have been made to relate condition factor to percent fat, energy density, and other components of proximate analysis, with varying results (Caulton and Bursell 1977, Weatherley and Gill 1983, Herbinger and Friars 1991, Salam and Davies 1994, Jonas et al. 1996). Condition factors in juvenile fishes may be related to proximate components because all factors vary with fish size. However, an extremely low (size-specific) condition factor does reflect ecologically relevant differences in energy status. In our study, experimental juveniles that were starved for 2 weeks had low condition factors, were lethargic, and appeared to be swimming more slowly than fish in fed treatment groups. The ability of the starved fish to escape predation and to locate and capture prey may have been very limited upon release into the demanding river environment. However, with increased food availability and in the absence of high energy demand, starved juvenile salmonids can recover and compensate with rapid growth and increased condition (Weatherley and Gill 1981, Petrusso[12] 1998).

Length-Percent Body Water Relation

The length-percent body water relation is useful for representing true energy differences among sizes. Percent body water, or percent dry weight, can be used to estimate seasonal changes in energy density of fish with reasonable confidence (Hartman and Brandt 1995, Jonas et al. 1996), due to the fact that changes in dry weight primarily reflect changes in fat, the most important energy store in fishes (Hayes and Taylor 1994). Given the relation between percent body water and energy, the decrease in percent body water over the range of lengths (Fig. 5) indicates that larger juvenile salmon had greater proportions of energy and lower proportions of body water, and hence greater energy densities, than smaller fish. Similar patterns were seen for condition factor, with larger fish displaying higher condition factors than smaller fish.

What is the adaptive significance of length-related differences in body composition? One possible explanation has to do with predation risk or competitive interactions (Gardiner and Geddes 1980). Salmon fry are more vulnerable to predation due to small size and undeveloped swimming ability. However, a relatively high proportion of body weight in water may function to increase overall bulk when food is limited, making the difference between survival and predation by gape-limited piscivores. Bulkier fish may also be more likely to "win" in competitive interactions.

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[11] Snider, B., R.G. Titus, and B.A. Payne. 1997. Lower American River emigration survey, November 1994–September 1995. Stream Flow and Habitat Evaluation Program Report, California Department of Fish and Game, Environmental Services Division, Sacramento, California, USA.

[12] Petrusso, P.A. 1998. Feeding habits and condition of juvenile chinook salmon in the upper Sacramento River, California. M.S. Thesis, Michigan State University, East Lansing, Michigan, USA.

As the salmon grow to smolt sizes, swimming ability develops, and avoidance of predation by avian and other non-gape-limited predators depends more upon a quick escape than upon bulk. Therefore, a streamlined body (without the water bulk) associated with smolting and preparation for ocean existence has its advantages in freshwater rearing. Differences in body composition among sizes may be associated with the different risks of being large versus small.

Comparison of Field-Caught and Experimental Salmon

Because length-weight regression parameters for juvenile chinook salmon are not commonly reported in the literature, juvenile salmon of known rearing history from growth experiments provided a useful standard of comparison. Field-caught salmon were heavier at all lengths than juvenile salmon that were fasted for 2 weeks, but generally lighter than juveniles fed a pelleted diet. The fact that wild juvenile chinook salmon were heavier and therefore in better condition than fasted fish of similar length indicates that environmental conditions were conducive to feeding and growth. Such a result corroborates findings on stomach fullness in Sacramento River chinook salmon (Petrusso[12] 1998), which suggest that juveniles, while not feeding at maximum rates, were maintaining an adequate level of energy intake. Juvenile chinook salmon captured in the field had lower percent body water (more stored energy) for a given length than experimental fish from fasted treatments and higher percent body water than experimental fish from fed treatments (Fig. 6), which accords with results from the length-weight relation. Experimental salmon fed low and high rations were in better condition than juvenile chinook salmon captured from the Sacramento River; however, this may be partly explained by differences both in quality of food and in energy demands between experimental and field-caught fish. At a constant 16°C, water temperature in the experiments was higher than water temperatures measured in the study area during February and March, but similar to temperatures at sites downstream of Red Bluff Diversion Dam from April through July. Upstream sites between Bend Bridge (rkm 415) and Keswick Dam (rkm 486) are maintained below 13.3°C from April 15 to August 31 to benefit winter-run chinook salmon spawning habitat (NMFS[2] 1994).

Spatial and Temporal Trends in Condition

The patterns of salmon length, weight, condition factor and percent body water estimated by the least squares means (GLM analysis) suggest that environmental conditions were conducive to fish growth and increased condition over time and as the fish migrated downstream. However, condition in the GLM analysis was partially confounded with length due to the unequal representation of size classes in samples from different months or sites. Though it provided a reasonable representation of spatial and temporal condition patterns in this study, the GLM may work best in situations uncomplicated by the protracted, overlapping emergence times of several stocks.

Use of ANCOVA to compare salmon weight or percent body water at a given length between months and sites confirmed some patterns from the GLM analysis and suggested differences in others. Weight-at-length (for fish 50–90 mm) increased from February through June 1996 (Table 5), which may reflect a progressive increase in temperature, photoperiod, and food availability during that period. However, trends in percent body water at a given length were not consistent across the 3 months for which data were available, April–June 1996. The highest intercept estimate of percent body water (which would indicate lowest energy density, or poorest condition) was for April, and the lowest was for May. Though ANCOVA indicated statistically significant differences, the ranges in monthly intercepts were small, translating into a 4-mg difference in weight-at-length and 0.98% difference in percent body water-at-length. The biological significance of such differences in condition has yet to be demonstrated in performance measures. Weight for a given length indicated no clear spatial trends in condition, although higher ranks were generally associated with downstream sites (Table 6). The range of length-weight intercepts for sites (0.3 mg) was even narrower than that of monthly intercepts. Whereas the mainstem Sacramento River is generally cooler at upstream sites nearer Keswick Dam water releases, the availability of warmer tributaries and backwaters for rearing along the entire length of the study area may explain the variable estimates in weight-at-length from upstream to downstream.

Results of the GLM and covariance analyses were possibly complicated by the presence of large numbers of newly released hatchery fish in areas of the system below Coleman Hatchery release points. About 7.5 million unmarked fall-run fry and 12.3 million smolts (8% marked) were released during the study period in 1996, either into Battle Creek (confluence at rkm 438) or at rkm 390 below Red Bluff Diversion Dam (S. Croci, U.S. Fish and Wildlife Service, personal communication). Hatchery fish released as fry, that rear in the upper river for an extended period, can still provide useful information on habitat suitability, assuming these fish are able to develop similar behaviors as salmon spawned in the river. Unmarked smolts that pass through the upper river quickly and whose condition is solely representative of the hatchery rearing environment would cause the most difficulty in data interpretation. Discontinuity in spatial condition patterns indicative of hatchery influence was not apparent in our results (Table 4).

CONCLUSIONS

The length-weight relations, condition factors, and estimates of percent body water of juvenile chinook salmon in the upper Sacramento River indicate that environmental conditions should be generally favorable for growth and robustness during wet years similar to 1995 and 1996. Wet years are characterized by an increase in habitat and greater lateral habitat complexity in the form of backwaters and intermittently flowing tributaries, as compared with dry years (Schlosser 1991). Though it was not possible to separate fish in this study based on the primary habitat(s) responsible for growth (hatchery, tributary, mainstem, or a combination of these), field-caught salmon in general were in better condition (heavier at all lengths) than salmon starved for 2 weeks

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under experimental conditions. The growth experiments also revealed that the smallest salmon may be the most affected by food limitation. Still, in a separate study of juvenile chinook salmon rearing in tributaries of the Sacramento River in 1996 (Moore[8] 1997), fish reportedly grew at rates near the published maximum for juvenile chinook salmon in the wild. An interesting question, unanswerable with our data, concerns the condition of juvenile salmon during dry and critically dry years. Dry years would presumably be characterized by lower habitat quantity and quality. Future studies could focus on comparing the growth and condition of fish in different water years in different parts of the Sacramento River (upper, middle, lower) and the delta.

Based on our results, juvenile chinook salmon reared in the upper river were relatively competent, in an energetic sense, to withstand some of the natural stressors encountered during emigration. Energy status only partially determines a fish's ability to survive, however, particularly when water development in the river is considered. Mortality risk may be higher for smaller salmon, even those in relatively good condition for their size, due to greater vulnerability to piscivorous fish waiting below dams (Garcia[13] 1989) and lower screening efficiency at water diversions (Clark and Strong 1991). Other factors, such as elevated water temperatures in the lower river, delta water diversions, and entrainment in delta pumps may reduce salmon survival regardless of condition (Kjelson and Brandes 1989).

Our study suggests a more critical approach to the use of condition factors for comparing samples or populations, one that involves analysis of length-weight and length-percent body water relations where possible, as well as the reporting of both regression parameters. If salmon stocks in the Sacramento River continue to decline, the availability of baseline data on condition will become increasingly important, and should be made available in a variety of forms beyond the standard reporting of mean condition factor.

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[13] Garcia, A. 1989. The impacts of squawfish predation on juvenile chinook salmon at Red Bluff Diversion Dam and other locations in the Sacramento River. USFWS Report No. AFF/FAO-89-05. U.S. Fish and Wildlife Service Fisheries Assistance Office, Red Bluff, California, USA.

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