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DIET OF JUVENILE FALL-RUN CHINOOK SALMON IN THE LOWER MOKELUMNE RIVER, CALIFORNIA

JOSEPH E. MERZ
East Bay Municipal Utility District
1 Winemasters Way, Suite K
Lodi, California 95240
e-mail: jmerz@ebmud.com

Gut contents of juvenile fall-run chinook salmon, *Oncorhynchus tshawytscha*, were collected on the lower Mokelumne River from January through June 1997 and 1998. Chinook salmon fed primarily on zooplankton and supplemented their diets with chironomid larvae and pupae and larval Sacramento suckers, *Catostomus occidentalis*, as they became available. The lower Mokelumne River experienced flood flows during the 1997 study period and elevated flows twice during the 1998 study period. These flows may have been responsible for the high percentage of zooplankton in the diets of these fish. Mean prey size was significantly related to fish length and sample year. However, the calculated index of fullness suggests that no significant difference in feeding activity occurred between the 2 water years.

INTRODUCTION

The Mokelumne River is a major tributary to the Sacramento-San Joaquin Delta. The regulated portion of the Mokelumne River below Camanche Dam is the subject of numerous proposed and implemented resource projects that affect fishes in this portion of the river. These projects include expansion of hatchery chinook salmon, *Oncorhynchus tshawytscha*, and steelhead, *O. mykiss*, production; improved fish passage at water diversions; salmonid spawning gravel enhancement projects; and possible water conveyance plans in the delta portion of the river. Several of these projects are specifically aimed at restoration of chinook salmon populations while impacts from other proposals are not clear. Changes in fish community structure, composition, and density resulting from such projects may have significant effects on the feeding ecology of fishes (Berg and Jorgensen 1991, Flecker 1992, Vetsler 1992, Baldwin et al. 2000). Furthermore, direct manipulation of habitat structure may affect habitat production, carrying capacity, and feeding rates of local fish populations (Shepherd et al. 1992, Mundie and Crabtree 1997, Maki-Petays et al. 2000). Understanding these processes is important in the evaluation of these projects. The main objectives of this study were to assess the relationships of fish size, river temperature, and flow, on prey size, feeding activity, and importance of zooplankton in the diets of lower Mokelumne River (LMR) juvenile chinook salmon in 1997 and 1998.

STUDY SITE

The LMR is an approximate 54-km reach of regulated river between Camanche Dam and its confluence with the Sacramento-San Joaquin Delta. The study area, between Camanche Dam and Lake Lodi, is characterized by alternating bar complex and flatwater habitats, with a gradient of approximately 0.17 m/km (Fig. 1). The drainage area below Camanche Dam consists of 87 km^2 of mostly agricultural and urbanized land (Anderson et al.[1] 1993). Several small streams and storm drains enter the lower river. Lake Lodi supplies a gravity-fed agricultural irrigation system and is annually filled from April through October. At least 34 fish species have been observed in the LMR since monitoring began in 1996 (Merz and Workman [2] 1998). Among the most abundant species, in addition to chinook salmon, are prickly sculpin, *Cottus asper*; Sacramento sucker, *Catostomus occidentalis*; and steelhead.

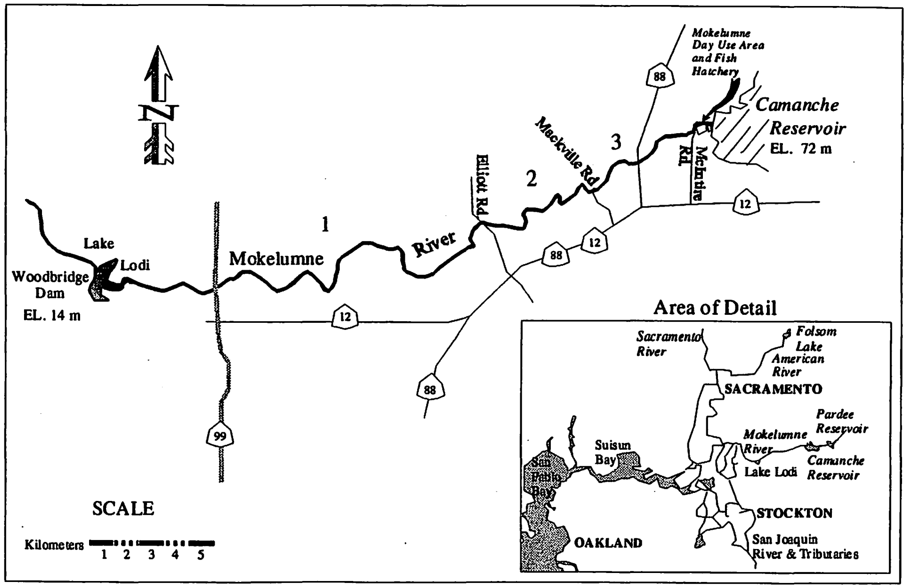

Figure 1. The lower Mokelumne River between Camanche Dam and Woodbridge Dam, San Joaquin County, California. The three reaches of river designated for this study are indicated.

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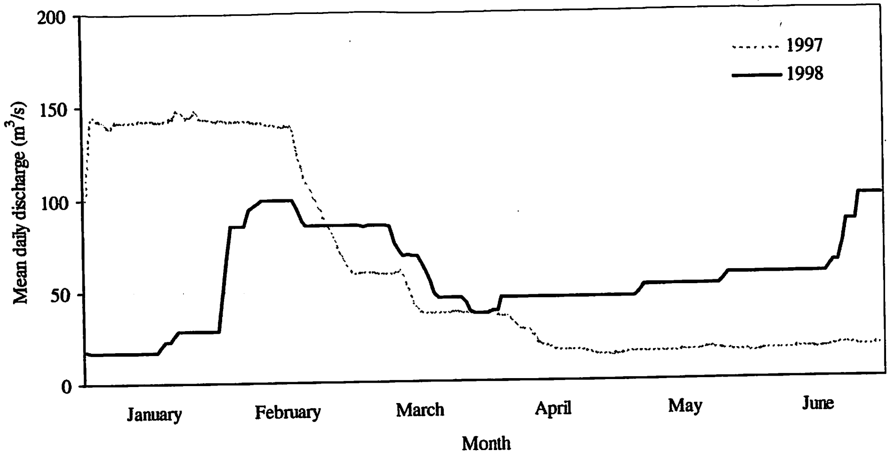
[1] Anderson, S.W., T.C. Hunter, E.B. Hoffman, and J.R. Mullen. 1993. Water resources data California water year 1992. Volume 3. Southern Central Valley Basins and the Great Basin from Walker River to Truckee River. U.S. Geological Survey Water-Data Report CA-92-3. U. S. Geological Survey, Sacramento, California, USA.

[2] Merz, J.E., and M. Workman. 1998. Lower Mokelumne River Fish Community Survey. East Bay Municipal Utility District, Lodi, California, USA

Daily discharge from Camanche Dam into the LMR ranged from 142 m^3/s (Camanche ill conditions) on 3 January 1997 to 13 m^3/s on 1 July 1997 (Fig. 2). Flows during 98 remained elevated from the beginning of February through June, peaking at 99.2 ^{3}/s in February and again in June.



igure 2. Mean daily discharge from Camanche Dam into the lower Mokelumne River from 1 anuary to 30 June 1997 and 1998.

Water temperatures in 1997 ranged from 9.4°C in January at Camanche Dam to 5.6°C in June in a small backwater at Highway 99. Water temperatures in 1998 anged from 10.0°C in February at Camanche Dam to 15.0°C in June at Highway 99.

METHODS

The Mokelumne River above Lake Lodi was separated into 3 reaches based on tream gradient and substrate characteristics (Fig. 1). Habitat types were identified nd assigned to 1 of 5 habitats (modified from Bisson et al. 1981): 1) channel pools unbroken surface, slow velocity, deep water), 2) glides (moderately shallow water ith an even flow that lacked pronounced turbulence), 3) runs (rippled surface, fast elocity, shallow water), 4) riffles (streambed substrate protruding through water urface), and 5) off-channel pools (slow, deep water adjacent but contiguous to the ain channel).

Juvenile chinook salmon were sampled between Lake Lodi and Camanche Dam uring monthly fish-community surveys. Sampling was performed for 3 days the 2nd eek of each month from January through July 1997 and 1998. Sampling occurred between 0900 and 1500 hr with a 15 x 2- m bag seine with 1.6 mm mesh in all habitat types within each reach in an effort to representatively sample the river. To reduce the take of chinook salmon, minimum monthly target sample size was at least 12 fish based on preliminary stomach analysis (see Hurtubia 1973).

Specimens were immediately preserved in an 80-85% ethyl-alcohol solution, packed in ice, and transported to the laboratory for analysis. The fork length (FL) of each fish was measured to the nearest mm and stomach contents were removed. Contents were hand-sorted in the lab under a dissecting microscope and magnifying illuminator. Food items were identified to family for aquatic organisms and order for terrestrial organisms; life stages (larva, pupa, or adult) were determined. Adult Ephemeroptera, Trichoptera, and Diptera were classified as terrestrial. Food items were also categorized into the following maximum length size classes: class 1 = <2mm; class 2 = 2-7 mm; class 3 = 8-13 mm; class 4 = 14-20 mm; class 5 = >20 mm (Baldridge et al.[3] 1987). Prey lengths were then estimated using the mean length for each size class.

Because most food items removed from fish stomachs were disarticulated or partly digested, representative samples of whole prey items from benthic and drift samples (Merz[4] 1997) were used to estimate dry biomass of stomach contents by oven drying selected samples of each taxon at 70°C for 24 hours to constant weight and then weighing the samples (Bowen 1983). As many of these organisms were extremely small (< 0.0001 g), groups of 20-50 organisms of a particular taxon from each size class were dried, depending on how many could be obtained. Mean weight was calculated for the taxon, life stage, and size class by dividing the dry weight of the group by the number of individuals. Mean weight was multiplied by number of the same taxon found in fish stomachs. Dry-weight sums were used to estimate monthly diet composition of juvenile chinook salmon following the methods of Johnson and Johnson (1981). Diet was pooled on a monthly basis and analyzed by frequency of occurrence, numeric, and gravimetric (dry weight) methods (Bowen 1983). To assess the relative importance of food items, an index of relative importance (IRI) (Hyslop 1980) was calculated for each food category:

$$IRI = (\%N + \%W) \times \%O,$$

where,

%N = a food item's percentage of the total number of organisms ingested,
%W = a food item's percentage of the total weight of food ingested, and
%O = a food item's percentage frequency of occurrence in all stomachs that contained food.

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[3] Baldridge, J.E., T.K. Studley, T.P. Keegan and R.F. Franklin. 1987. Response of fish populations to altered flows project. Study Plan. Entrix, Inc. Walnut Creek, California, USA.

[4] Merz, J.E. 1997. An evaluation of spawning gravel enhancement projects in the lower Mokelumne River, California. Mimeo Report, East Bay Municipal Utility District, Fisheries and Wildlife Division, Lodi, California, USA.

To make dietary comparisons, IRI values of each food item were converted to percentages based on total IRIs for each month (Merz and Vanicek 1996).

An overall index of fullness (IF) for each monthly sample was calculated by dividing the mean weight of stomach contents for that month by mean FL of all chinook salmon examined that contained food and multiplying this value by 100 (Merz and Vanicek 1996).

Statistical Methods

A paired t-test was used to compare mean daily river flow and water temperatures immediately below Camanche Reservoir between years (Zar 1996). A Wilcoxon paired signed-rank test was used to compare monthly mean indices of fullness between years (Sall et al. 2001). Estimated mean prey length was compared to chinook salmon FL and sample year using the JMP linear regression model function, which performs an analysis of variance (ANOVA) (Sall et al. 2001). ANOVA was also used to compare mean monthly IF to mean river flows and temperature from each sampling week and monthly zooplankton IRI to river flow. A significance level of 0.05 was used in statistical tests.

RESULTS

Mean daily releases from Camanche Dam were not significantly different between years ($t = 1.05$, df = 180, $P = 0.29$) (Fig. 2). However, mean daily water temperatures released from Camanche Dam were significantly cooler in 1997 than 1998 ($t = -13.7$, df = 180, $P < 0.001$) (Fig. 3). Stomachs from 158 juvenile chinook salmon in 1997 and 180 salmon in 1998 were examined. Juvenile chinook salmon first appeared in the Mokelumne River Day-Use Area (Fig. 1) in mid-December 1996 and 1997. Sufficient numbers of fish for diet analysis were not captured until February in 1997 and January in 1998 (Table 1). Greatest numbers of juveniles were captured during March in 1997 and during February in 1998 (Table 1). Almost all chinook salmon juveniles were gone from the Mokelumne River above Lake Lodi by the end of June in both years. Mean FL varied from 40 mm in February to 87 mm in May of 1997 and from 38 mm in January to 86 mm in June of 1998 (Table 2).

Diet Composition

Juvenile fall-run chinook salmon consumed a variety of prey types, but most of their diet was composed of only a few taxa of aquatic organisms. Major food items were zooplankton (daphniids and cyclopids), chironomid larvae and pupae, and Sacramento sucker larvae (Table 3). Trichoptera larvae and pupae (Hydropsychidae and Hydroptilidae) were important in May 1997 and January 1998 (Fig. 4). Juvenile chinook salmon relied heavily on zooplankton, primarily *Daphnia pulex* (Cladocera), and chironomid larvae and pupae throughout their rearing period in the LMR above Lake Lodi, but added Sacramento sucker larvae as an important diet component in

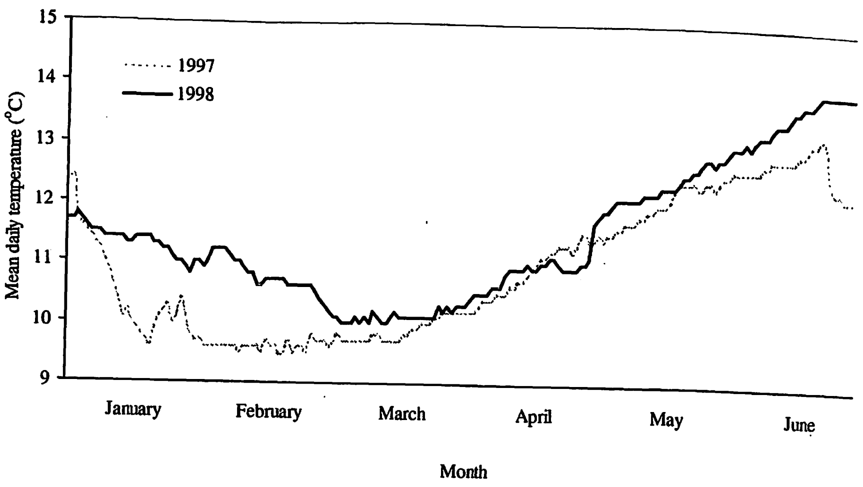

Figure 3. Lower Mokelumne River mean daily temperature measured directly below Camancl Dam from 1 January to 30 June 1997 and 1998.

Table 1. Number of juvenile chinook salmon captured by seine and the number sampled for stomach contents (in parenthesis) in the lower Mokelumne River by reach (see Fig. 1) and sampling period, 1997 and 1998.

Reach	January	February	March	April	May	June
1997						
1		14 (2)	160 (29)	138 (14)	10 (2)	6 (3)
2	6	186 (12)	24 (5)	82 (5)	41(10)	11(6)
3	3	17 (4)	160 (30)	104 (10)	165 (24)	5 (3)
Total	9	217 (18)	344 (64)	324 (29)	216 (36)	22 (12)
1998						
	January	February	March	April	May	June
1	468 (20)	211(20)	50 (10)	33 (10)	9 (9)	6 (6)
2	106 (12)	20 (5)	4 (1)	1 (0)	7 (7)	7 (7)
3	24 (5)	434 (30)	60 (14)	87 (15)	6 (6)	3 (3)
Total	598 (37)	665 (55)	114 (25)	121 (25)	22 (22)	16 (16)

Table 2. Monthly sample size, mean FL (mm) and percent sac-fry* of juvenile chinook salmon sampled for diets from the lower Mokleumne River, 1997 and 1998.

Year	January	February	March	April	May	June
1997						
Sample size		18	64	29	36	12
Mean FL (SD)		40(4.1)	43(1.3)	52(17.6)	87(16.8)	83(2.8)
% sac fry		11	6	3	0	0
1998						
Sample size	37	55	25	25	22	16
Mean FL (SD)	38(8.3)	40(4.7)	47(7.2)	58(14.3)	76(13.2)	86(6.1)
% sac fry	22	11	8	0	0	0

* newly hatched salmon before absorption of the yolk sac.

Table 3. Major prey of juvenile chinook salmon in the lower Mokelumne River, 1997-1998. %O = percent frequency of occurance, %N = percent of the total number, %W = percent wieght, and %IRI = percent Index of Relative Importance.

Prey item	1997				1998			
	%O	%N	%W	%IRI	%O	%N	%W	%IRI
Daphniidae	62	42	0	49	58	66	2	76
Cyclopidae	26	8	0	4	1	0	0	0
Chironomidae larvae	21	3	0	1	26	5	3	1
Chironomidae pupae	54	41	2	38	67	21	14	16
Fish larvae	5	1	94	8	7	0	77	6
Other	13	6	3	1	13	8	5	1

late spring (Fig. 4). Less common prey included corixids; baetid, ephemerellid, and tricorythid mayflies; oligochaetes; perlodid stoneflies; and terrestrial Hymenoptera.

In 1997, 85% of zooplankton observed in stomachs was *D. pulex*; the rest were Copepoda, Hydracarina, and other species of Cladocera. *D. pulex* was even more prominent in the diet in 1998, when it made up 98% of zooplankton observed in chinook salmon stomachs.

Feeding Relative to Prey Size

The estimated mean prey length found in sampled juvenile chinook salmon was 1.5 mm (SD = 0.5) in 1997 and 2.3 mm (SD = 1.1) in 1998. Mean prey-length

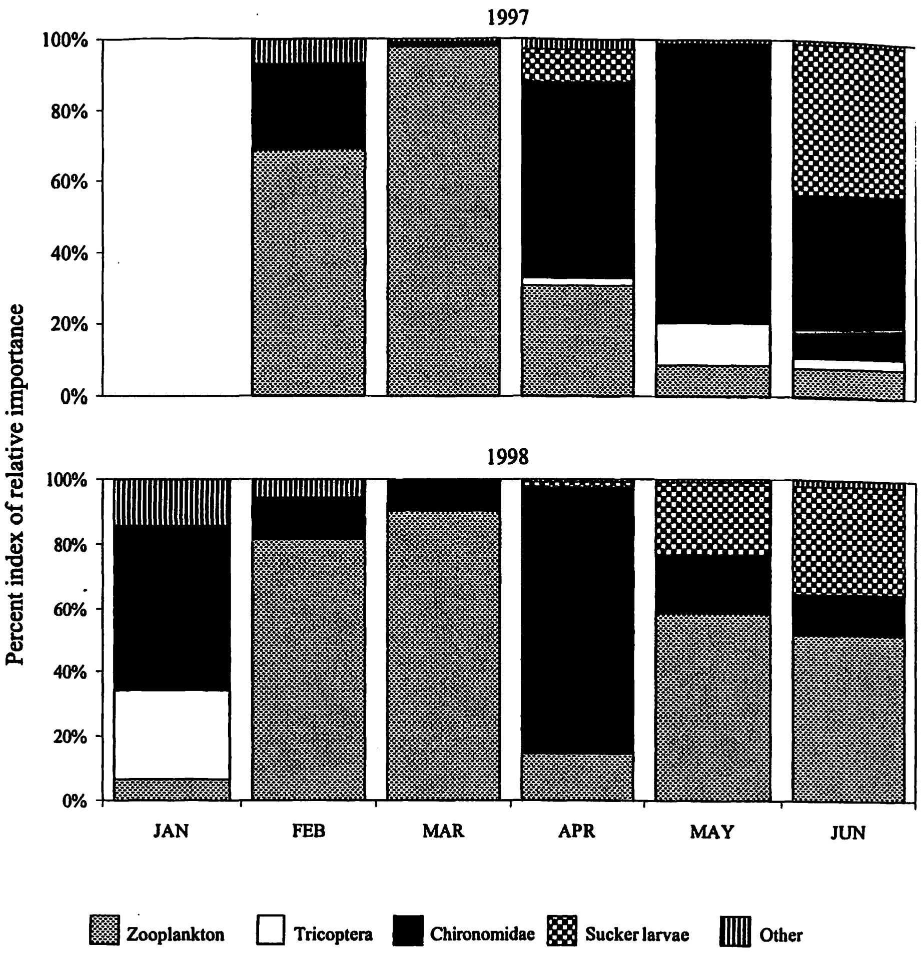

Figure 4. Percent index of relative importance (%IRI) for food of juvenile fall chinook salmon in the lower Mokelumne River by month, 1997 and 1998.

category was significantly related to chinook salmon FL and sample year (F = 46.5; df = 2, 115; P<0.0001) (Fig. 5). Prey size increased with fish length in both years and was larger in 1998 than 1997.

Feeding Activity

Temporal patterns of chinook salmon feeding, as indicated by occurrence of empty stomachs and quantity of food in stomachs, varied little between years. Only 1 of 61 sac-fry observed over both years had an empty stomach, suggesting that fry began exogenous feeding before completely absorbing the yolk sac. No fish with empty stomachs were collected in 1997 and only 4 of 180 (2%) in 1998 (Table 4). Feeding activity, as indicated by the IF, was not significantly different between the 2 years

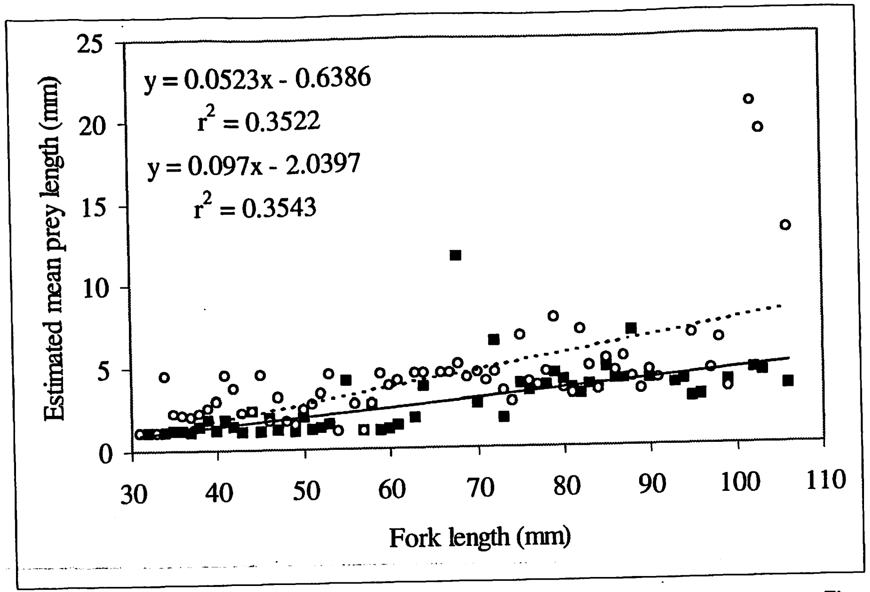

Figure 5. The relationship between lower Mokelumne River juvenile chinook salmon FL and estimated mean prey length in 1997 and 1998. Regression equations for simple linear regression are indicated for 1997 and 1998.

Table 4. Frequency of empty stomachs and index of fullness (IF) by month for juvenile chinook salmon in the lower Mokelumne River, 1997 and 1998. Number in parenthesis indicates the number of individuals with stomachs containing food.

	1997		1998	
Month	%Empty stomachs	IF	%Empty stomachs	IF
January			8(37)	0.005
February	0(18)	0.001	0(55)	0.002
March	0(64)	0.003	4(25)	0.001
April	0(29)	0.070	0(25)	0.069
May	0(36)	0.102	0(22)	0.824
June	0(12)	1.436	0(16)	0.965
Mean (SD)		0.32(0.56)		0.32(0.42)

(W= -0.05; df = 4; $P = 0.56$). Mean IF for each week sampled was not significantly related to mean weekly flow ($r^2 = 0.10$; F = 1.05; df = 1, 9; $P = 0.33$). In contrast, mean IF for each week sampled was related to mean water temperature below Camanche Dam in 1997 ($r^2 = 0.67$; F = 18.35; df = 1, 9; $P = 0.002$) and 1998 ($r^2 = 0.81$; F = 27.20; df = 1, 4; $P = 0.01$). The high IF in June of both years resulted from increased consumption of Sacramento sucker larvae. Zooplankton IRI values for each week sampled were significantly positively related to flow ($r^2 = 0.56$; F = 11.24; df = 1, 9; $P = 0.009$).

DISCUSSION

Other researchers have found that riverine juvenile chinook salmon mainly consume immature stages of aquatic insects (Shapovalov and Taft 1954, Moyle 1976, Sagar and Glova 1988, Power 1992, Merz and Vanicek 1996). According to Sasaki (1966), only 16% of insects consumed by emigrating chinook salmon in the lower Sacramento-San Joaquin system were chironomids. In contrast, over 90% of the insects consumed by chinook salmon in LMR were chironomids.

Several reports also discuss the importance of zooplankton in the diets of juvenile chinook salmon, but this is most common in estuaries, lagoons, and reservoirs (Allen and Hassler[5] 1986, Rondorf et al. 1990, Busby and Barnhart 1995). However, in February and March of 1997 and 1998, zooplankton provided over 70% of the IRI for diets of LMR juvenile chinook salmon (Fig. 4), in an area approximately 20 km upstream of tidal influence and 50 km above saltwater intrusion. The predominance of *D. pulex* in the diet is most likely due to the large number of fry captured in January and February of 1998 (Table 1). After reduction in zooplankton in the diets of juvenile chinook salmon, chironomids, primarily pupae, and Sacramento sucker larvae predominated stomach contents (Fig. 4). Chironomids and larval Sacramento suckers are often found in high numbers in the drift (Waters 1972, Merz[6] 1993). This suggests that juvenile chinook salmon in the lower Mokelumne River during 1997 and 1998 fed primarily on drift organisms.

Fish diet is greatly affected by the relative size of the fish to its prey (Zaret and Rand 1971, Johnson and Ringler 1980, Bowen 1983). In both years, a positive relationship between juvenile salmon FL and mean prey size was observed (Fig. 5).

River flow and time of year may also influence the diet of juvenile chinook salmon by altering prey availability. High water levels and low temperatures probably were responsible for the relatively simple chinook salmon diets observed early in February

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[5] Allen, M.A. and T.J. Hassler. 1986. Species profiles: Life histories and environmental requirements of coastal fishes and invertebrates (Pacific southwest), chinook salmon. USDI Fish and Wildlife Service, Biological Report 82(11.49).

[6] Merz, J. E. 1993. A survey of drift and benthic communities and their use in the diet of the more abundant fish species in the lower American River, February - July, 1992. California State University, Sacramento, Foundation Contract Report FG1353.

and March of 1997 and most of 1998. Dramatic changes and fluctuations in stream velocities affect benthic and drift organisms (Franklin and Pearson 1968, Fisher and LaVoy 1972, Ward 1976, Petts 1984) and alter their availability to predators. Camanche Dam reached flood-stage release (142 m^3/s) well before the majority of juvenile chinook emerged in 1997 (Fig. 2). Plankton tows in Camanche Reservoir along the dam face in spring 1996 showed dense populations of daphniids and cyclopids in the water column (Merz[7] 1997). These organisms may have been dispersed throughout the LMR during high flow conditions in both 1997 and 1998. The relationship between zooplankton IRI values and river flow was strong in both years, but statistically significant only in 1998. This suggests flow magnitude influenced zooplankton consumption by juvenile chinook salmon in the LMR (Fig. 2 and 4). Thus, juvenile chinook salmon relied heavily on zooplankton early in the 1997 season and began consuming chironomids and larval suckers as the salmon grew and these prey items increased in availability later in the season. Conversely, lower flows during January of 1998 may have provided juvenile chinook salmon greater opportunity to forage on chironomid larvae and pupae, Trichoptera and other aquatic and terrestrial organisms (Fig. 2 and 4).

In summary, it appears that 3 factors affected juvenile chinook salmon feeding habits in the LMR in 1997 and 1998. First, high flows probably influenced the availability of prey, so that, at high flows, zooplankton (probably from Camanche Reservoir) predominated the diet. As flows decreased, other prey items in the drift became available and were more important in the diet. Second, prey size increased as the juvenile salmon grew. Finally, feeding rate, as indicated by the IF, increased as water temperature increased. The importance of each of these factors is confounded by temporal trends and the fact that they frequently co-vary. As both 1997 and 1998 were years of higher-than-normal precipitation and flow, future dietary investigations should be conducted during more varied flow regimes and in conjunction with drift and benthic sampling. This may better explain the mechanisms influencing juvenile chinook salmon feeding behavior in the LMR.

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