COMPARISON OF DIETS OF PRICKLY SCULPIN AND JUVENILE FALL-RUN CHINOOK SALMON IN THE LOWER MOKELUMNE RIVER, CALIFORNIA

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Abstract— I compared diets of prickly sculpin, *Cottus asper*, and juvenile fall-run chinook salmon, *Oncorhynchus tshawytscha*, in the lower Mokelumne River, California, from January through June during 1998 and 1999. Prickly sculpin fed primarily on chironomid (Diptera) larvae and hydroptilid and hydropsychid (Trichoptera) larvae. Juvenile chinook salmon fed on zooplankton, plus chironomid, hydroptilid, and hydropsychid pupae. Both supplemented their diets with several other prey items, including larval Sacramento suckers, *Catostomus occidentalis*. Their diets did not overlap significantly any time during the study. Each species fed more as time progressed in both years. A significant relationship between prey item and fish size was observed for juvenile chinook salmon in 1998 and for both species in 1999. The pattern of growth for chinook salmon and prickly sculpin suggests increased feeding might be more related to water temperature than increase in size. I observed no predation by prickly sculpin on juvenile chinook salmon during this study, although sculpin eggs and larvae were infrequently observed in salmon stomachs.

RESUMEN— Compare las dietas del sculpin espinoso, *Cottus asper*, y del salmon chinook, *Oncorhynchus tshawytscha*, juvenil, de corridas de otono en el bajo Rio Mokelumne esde enero a junio de 1998 y 1999. El sculpin espinoso se alimentaba principalmente de larvas de chironomid Diptera, hytroptilid y hydropsychid Tricoptera

mientras el salmon chinook juvenil se alimentaba de zooplancton y crisalidas de chironomid, hydroptilid y hydropsychid. Ambas especies suplementaban su dieta con otras presas incluyendo larva del Sacramento sucker, *Catostomus occidentalis,* cuando eran disponibles. Sus dietas no sobrepasaban significadamente durante el estudio. En los dos anos segun progresaba la temporada ambos peces se alimentaban mas. Una relacion significante entre el tamano del pez y la presa fue observada del salmon chinook juvenil en 1998 y de ambos peces en 1999. El patron de crecimiento del salmon chinook y del sculpin espinoso sugiere que el aumento de alimentacion puede tener mas relacion con la temperatura del agua que con el tamano del pez. No se observo predacion del sculpin espinoso al salmon chinook juvenil durante este estudio aunque infrecuentemente se observaba hueva y larva del sculpin en el estomago del salmon.

Freshwater sculpins, (*Cottus*), are small, bottom-dwelling fish that occupy a wide range of habitats along the Pacific Coast. The prickly sculpin, *C. asper*, is common in the Central Valley of California and is native to the Mokelumne River. It successfully spawns in freshwater lakes, cold, fast-moving streams, and intertidal zones of rivers, suggesting a life history well suited for its variable environment (Krejsa, 1967; Broadway and Moyle, 1978). Sculpins are of particular interest to fisheries managers because of their piscivorous nature and suspected competition with and predation on fish of higher economic value (Shapovalov and Taft, 1954; Patten, 1970; Mason and Machidori, 1976; Gregory and Levings, 1997; Gabler and Amundsen, 1999). Conversely, sculpins have been investigated as a potential control of pestiferous insects (Broadway and Moyle, 1978).

The fall-run chinook salmon, *Oncorhynchus tschawytscha*, also native to the lower Mokelumne River, is one of the most celebrated commercial and sport fish in California. Although substantial investment has been made by the State of California in managing the chinook salmon resource since the early years of the commercial fishery, chinook salmon have undergone substantial reduction in abundance. Several factors have been cited for the decline of this resource, including overfishing, blockage and degradation of streams by mining activities, and reduction of salmon habitat and streamflows by dams and water diversions (Yoshiyama et al. 1998). However, sculpins also have been implicated in reduction of salmonid production throughout North America and Europe (Reed, 1967; Dittman et al., 1998; Gabler and Amundsen, 1999).

I analyzed diets of prickly sculpin and juvenile fall-run chinook salmon in the Lower Mokelumne River over a 2-year period during January to June, when substantial numbers of both species were present.

Methods and Materials— Study Area— The Mokelumne River is a modified system that drains ca. 1,624 km^2 of the central Sierra Nevada. The Lower Mokelumne River is ca. 54 km of regulated river between Camanche Dam and its confluence with the Sacramento-San Joaquin Delta. The study area, between Camanche Dam and Lake Lodi (Fig.1), is characterized by alternating bar complex and flatwater habitats, and is above tidal influence, with a gradient of ca. 0.17 m/km. The drainage consists of 87 km^2 of mostly agricultural and urbanized land. Several small streams and storm drains enter the lower river. At least 35 fish species occur in the Lower Mokelumne River (Merz, 2002). The most abundant native species, in addition to prickly sculpin and fall-run chinook salmon, are Sacramento sucker, *Catostomus occidentalis*, steelhead trout, *Oncorhynchus mykiss,* and hitch, *Lavinia exilicauda.* Abundant nonnative fishes include western mosquitofish, *Gambusia affinis*, largemouth bass, *Micropterus salmoides*, spotted bass, *Micropterus punctulatus*, and golden shiner, *Notemigonus crysoleucas*. Chinook salmon and steelhead populations are supplemented by fish produced in the Mokelumne River, Feather River, and Nimbus (American River) fish hatcheries.

Minimum and maximum flows during the study period were 16.8 m^3/sec in January 1998, 103.9 m^3/sec in February 1998, 14.4 m^3/sec in January 1999, and 87.8 m^3/sec in February 1999. Water temperatures ranged from 10^o C in March 1998 to 13.9^o C in June 1998, and 9.1^o C in February 1999 to 12.9^o C in June 1999. Water temperatures were significantly warmer during the 1998 study period than the 1999 period ($F = 1.38$; $P < 0.01$).

Sampling—During 1998 and 1999, fish were collected monthly from January through June between Camanche Dam (river km 69) and Highway 99, the upper extent of Lake Lodi (river km 32). Fish were collected during the second week of each month between 0800 h and 1500 h, primarily with a 15 by 2 m beach seine with 3 mm^2 mesh. Some fish also were collected with a Smith-Root SR-18E electrofishing boat and Model 12 backpack electrofisher. Monthly target sample sizes were at least 13 prickly sculpin and 12 juvenile chinook salmon based on preliminary sampling used to calculate H'_p, as described by Hurtubia (1973):

$$H'_p = \frac{1}{(z - t + 1)} \sum_{k=t}^{z} h_k$$

where

H'_p = average number of stomachs at t

z = total stomachs sampled

t = stability of accumulated prey item diversity

h = successive increment of prey items per individual

k = number of pooled stomachs up to z stomachs

As stomach contents are randomly pooled, 1 at a time, the accumulated trophic diversity resulting from the greater number of prey individuals and species increases until it reaches stability at point *t*. Any number of stomachs greater than *t* is assumed sufficient to represent the trophic diversity of prey items for a population.

Standard length (SL) of each prickly sculpin and fork length (FL) of each chinook salmon were measured to the nearest millimeter. All fish were labeled and immediately preserved in an 80 to 85% ethanol solution, packed in ice in the field, and transported to the laboratory for storage and analysis.

Laboratory Analysis— Stomach contents were sorted in the laboratory 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) also were determined. Adult insects in the orders Ephemeroptera, Trichoptera, and Diptera were classified as terrestrial. Food items were categorized into the following size classes to the nearest mm: class 1 = <2 mm; class 2 = 2 to 7 mm; class 3 = 8 to 13 mm; class 4 = 14 to 20 mm; class 5 = >20 mm.

Because most food items removed from fish stomachs were disarticulated or partly digested, representative samples of whole prey items were used from benthic and drift samples to estimate dry biomass of stomach contents. Dry biomass of the organisms was determined by oven-drying selected samples of each taxon at 70^{o} C for 24 h to constant (dry) weight and then weighing the samples (Bowen, 1996) with a Scientech SA 120_{TM}

electronic scale. Because many of these organisms were extremely small (<0.0001 g), groups of 20 to 50 organisms of a particular taxon from each sample were dried. A mean weight was then calculated for that taxon, life stage, and size class. These weights were multiplied by numbers of the same taxon found in the fish stomachs. Dry weight sums were used to estimate monthly diet composition of juvenile chinook salmon following the methods of Johnson and Johnson (1981). Food habit data were pooled on a monthly basis and analyzed by frequency of occurrence, numeric, and gravimetric (dry weight) methods (Bowen, 1996). To assess the relative importance of food items, an index of relative importance (*IRI*) was calculated for each food category, as described by Hyslop (1980):

$$IRI = (FN + FW) \times FO,$$

where,

FN = a food item's percentage of the total number of organisms ingested,

FW = a food item's percent of the total weight of food ingested, and

FO = a food item's percentage frequency of occurrence in all stomachs examined that contained food.

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 SL of all prickly sculpins and FL of all fall-run chinook salmon juveniles examined that contained food and multiplying this value by 100 (Broadway and Moyle, 1978).

Statistical analysis— A 2-tailed Mann-Whitney *U* test (" = 0.05) was used to compare mean indices of fullness between years (Zar, 1996). Correlation analysis was used to measure the relationship between predator and prey sizes.

To analyze dietary similarity between the 2 species, I calculated Morisita's index of overlap, described by Horn (1966):

$$C_x = \frac{2\sum_{i=1}^{S} x_i y_i}{\sum_{i=1}^{S} x_i^2 + \sum_{i=1}^{S} y_i^2}$$

where

C_x = overlap coefficient,

X_i = proportion of the total diet of fish species x contributed by food category i, and

Y_i = proportion of the total diet of fish species y contributed by food category i.

A C_x value of 0 indicates no food categories in common and 1.0 indicates identical diets. I used the assumption made by Zaret and Rand (1971) that a value $\geq$0.6 indicates significant overlap.

Results— I examined stomach contents of 240 prickly sculpins and 469 juvenile fall-run chinook salmon (Table 1). Adequate numbers of prickly sculpin (13) were collected in all months except March 1998. Mean SL for prickly sculpin varied from 36 mm in April 1999 to 56 mm in January 1998. On the basis of length frequency groupings, most prickly sculpins sampled appeared to be in their second (1+) to fifth (4+) year. Adequate numbers of chinook salmon (12) were collected from January through June both years. Mean FL varied from 36 mm in January 1998 to 92 mm in June 1998. All chinook salmon were in their first (<1) year.

Diet Composition— Prickly sculpins fed mainly on aquatic insects in both years (Table 2). Chironomid (Diptera) larvae were important in the diets of prickly sculpins in all months of both sampling periods (Fig. 2). Hydropsychid larvae (Trichoptera) also were important, but less prevalent in June 1998 and January, May, and June of 1999. Fish larvae (primarily Sacramento sucker) were common in sculpin diets in May and June of both years. Zooplankton (primarily *Daphnia*) formed a substantial part of prickly sculpin diets only in March and May of 1999. Less common food items were gastropods, oligochaetes, tipulids, and plecopterans.

Juvenile fall-run chinook salmon used a wide variety of food items, including oligochaetes, ephemeropterans, plecopterans, and terrestrial arthropods (Table 2). Overall, the major portions of chinook salmon diets were zooplankton (primarily *Daphnia*) and chironomid pupae. This pattern occurred in all months of both years except January 1998, when hydroptilid (Trichoptera) pupae were more prevalent (Fig. 2). Fish eggs (primarily sculpin) and fish larvae (primarily Sacramento sucker) were common in chinook salmon diets in May and June of both years.

The diet of prickly sculpins and juvenile chinook salmon did not overlap significantly in either year. Dietary overlap ranged from 0.0 in February 1998 to 0.2 in June 1998 and

0.0 in February 1999 to 0.5 in March 1999. Increased feeding on zooplankton by both species caused the high March 1999 overlap. Slight increases also were observed in May and June of both years when fish eggs and larvae increased in the diets of sculpin and juvenile chinook salmon.

Feeding Activity— Patterns of feeding activity for prickly sculpin and chinook salmon, based on index of fullness, are reported in Fig. 3. The incidence of empty stomachs in prickly sculpin ranged from 0% in June 1998 to 21% in January 1998 and 0% in June 1999 to 10% in March 1999. Prickly sculpin IF values were not significantly related to mean monthly river flow (1998: $F = 0.27$, $df = 1$, $P = 0.64$; 1999: $F = 0.31$, $df = 1$; $P = 0.61$) but were significantly related to mean monthly water temperature for both years (1998: $F = 12.8$, $df = 1$, $P = 0.04$; 1999: $F = 15.4$, $df = 1$, $P = 0.02$). Conversely, empty stomachs in chinook salmon were observed only in January 1998 (7%) and January 1999 (3%). Chinook salmon IF values were not significantly related to mean monthly river flow (1998: $F = 0.41$, $df = 1$, $P = 0.56$; 1999: $F = 0.77$, $df = 1$, $P = 0.43$) but were significantly related to mean monthly water temperature for both years (1998: $F = 27.2$, $df = 1$, $P = 0.01$; 1999: $F = 28.7$, $df = 1$, $P = 0.006$).

Both species showed a general increase in feeding activity as the year progressed in 1998 and 1999. Feeding activity between years was significantly different for both prickly sculpins ($U = 14$, $P < 0.05$) and juvenile chinook salmon ($U = 28$, $P < 0.05$).

Calculated mean size of prey items ingested by prickly sculpins was 1.9 mm ($SD = 0.3$) in 1998 and 2.0 mm ($SD = 0.6$) in 1999. A significant relationship between prey item size and prickly sculpin SL was observed in 1999 only (Fig. 4).

Mean size of prey items ingested by juvenile chinook salmon was 1.7 mm (*SD* = 0.4) in 1998 and 1.5 mm (*SD* = 0.3) in 1999. A significant relationship between prey item size and juvenile chinook salmon FL was observed in 1998 and 1999 (Fig. 5).

No clear feeding pattern was observed for prickly sculpin in either year. However, zooplankton %IRI in the diets of juvenile chinook salmon was significantly related to mean monthly Camanche Reservoir releases in both years (1998: $F = 20.68$; $df = 1$; $P = 0.01$; 1999: $F = 15.67$; $df = 1$; $P = 0.01$), suggesting drift-feeding behavior.

Piscivory— Prickly sculpin stomachs contained larval fish in May and June of both years (Fig. 2). Larval Sacramento suckers were the most common prey fish of prickly sculpins in 1998 and comprised 69% of the cumulative IRI value in June of that year. Sculpin larvae were the most common prey fish in 1999. Prickly sculpins also fed on larval cyprinids, centrarchids, and Pacific lamprey, Lampetra tridentata**.** Larval fish were found in the stomachs of prickly sculpins 19 mm SL and larger. One juvenile sculpin (13 mm SL) was observed in the stomach of a 46 mm SL adult.

Larval fish (primarily Sacramento suckers and prickly sculpin) were present in the diets of juvenile chinook salmon from February through June in 1998, and May and June of 1999. Chinook salmon also fed infrequently on larval cyprinids and western mosquitofish. Larval fish were found in the stomachs of juvenile chinook salmon 54 mm FL and longer. A western mosquitofish (17 mm SL) was observed in the stomach of an 82 mm FL chinook salmon.

Discussion-Food habits of prickly sculpins and juvenile chinook salmon from the Lower Mokelumne River were similar to those reported in other studies of these species (Cook, 1964; Sasaki, 1966; Mason and Machidori, 1976; Moyle, 1976; Broadway and

Moyle, 1978; Busby and Barnhart, 1995; Merz and Vanicek, 1996). The relative importance of zooplankton, particularly *Daphnia*, in the diet of juvenile chinook salmon accounted for much of the low dietary overlap between prickly sculpins and juvenile chinook salmon in the Lower Mokelumne River. Furthermore, although these 2 species utilized some of the same prey taxa, notably chironomids, each fed on different life stages of the prey. Specifically, prickly sculpins fed on chironomid, hydroptilid and hydropsychid larvae. Chinook salmon fed on chironomid, hydroptilid, and hydropsychid pupae. Several reports suggest that aquatic invertebrates have a higher relative propensity to drift during the later and larger life cycle stages (Anderson, 1967; Elliott, 1967; Waters, 1972). This suggests that chironomid and trichopteran larvae might be more susceptible to the ambush feeding lifestyle of the bottom-dwelling prickly sculpin (Broadway and Moyle, 1978). Conversely, zooplankton and the pupae of chironomids, hydroptilids, and hydropsychids may be more easily acquired by the opportunistic drift-feeding behavior of juvenile chinook salmon (Sagar and Glova, 1988; Merz and Vanicek, 1996).

No measurable growth was observed for sampled prickly sculpin, although juvenile chinook salmon increased in size over each 6-month period. Even so, I observed increased IF values over each period for both species (Fig. 3). Furthermore, both species had significantly higher IF values in 1998, a warmer water year. Numerous studies indicate a relationship between fish metabolic rates and water temperature (Brett, 1971; Fry, 1971; Smith and Li, 1983). Therefore, increased feeding might be due more to seasonal increase and yearly differences in water temperature than fish growth. This relationship should be evaluated further.

January is when a high percentage of Lower Mokelumne River chinook salmon alevins use yolk reserves, which explains the presence of a few empty stomachs in the early samples. Many fry, even with yolk still present, were actively feeding during this and other studies (Merz, 2002). This, and the lack of empty salmon stomachs from February through June of both years, might be indicative of the caloric intake needed to obtain an appropriate size for ocean migration. In contrast, prickly sculpins appear to grow more slowly and do not require migration during their life (Krejsa, 1967). This might explain the sporadic occurrence of empty sculpin stomachs throughout the study period, and further suggests different feeding strategies for these 2 species.

Sculpins have been reported to feed on eggs and fry of salmon and trout from California to Alaska (Shapovalov and Taft, 1954; Hunter, 1959; McLarney, 1967; Mason and Machidori, 1976). During this study, salmon eggs and juveniles were absent from the diets of prickly sculpin. However, sculpin eggs and larvae were infrequently observed in the stomachs of juvenile chinook salmon in May and June of 1999 (7% total).

These data suggest that competition with and predation on juvenile chinook salmon by prickly sculpins is inconsequential in the Mokelumne River. This seems logical considering the long co-evolutionary history of these species (Moyle, 1976; McGinnis, 1984). Furthermore, prickly sculpins appear to provide forage for juvenile chinook salmon, although in a limited capacity. It is important to note that no night sampling was done for this survey nor were sculpin diets sampled during the major portion of the chinook salmon spawning period (October to December). Further study may be warranted, especially at sites of impoundment and diversion, where unnatural conditions exist.

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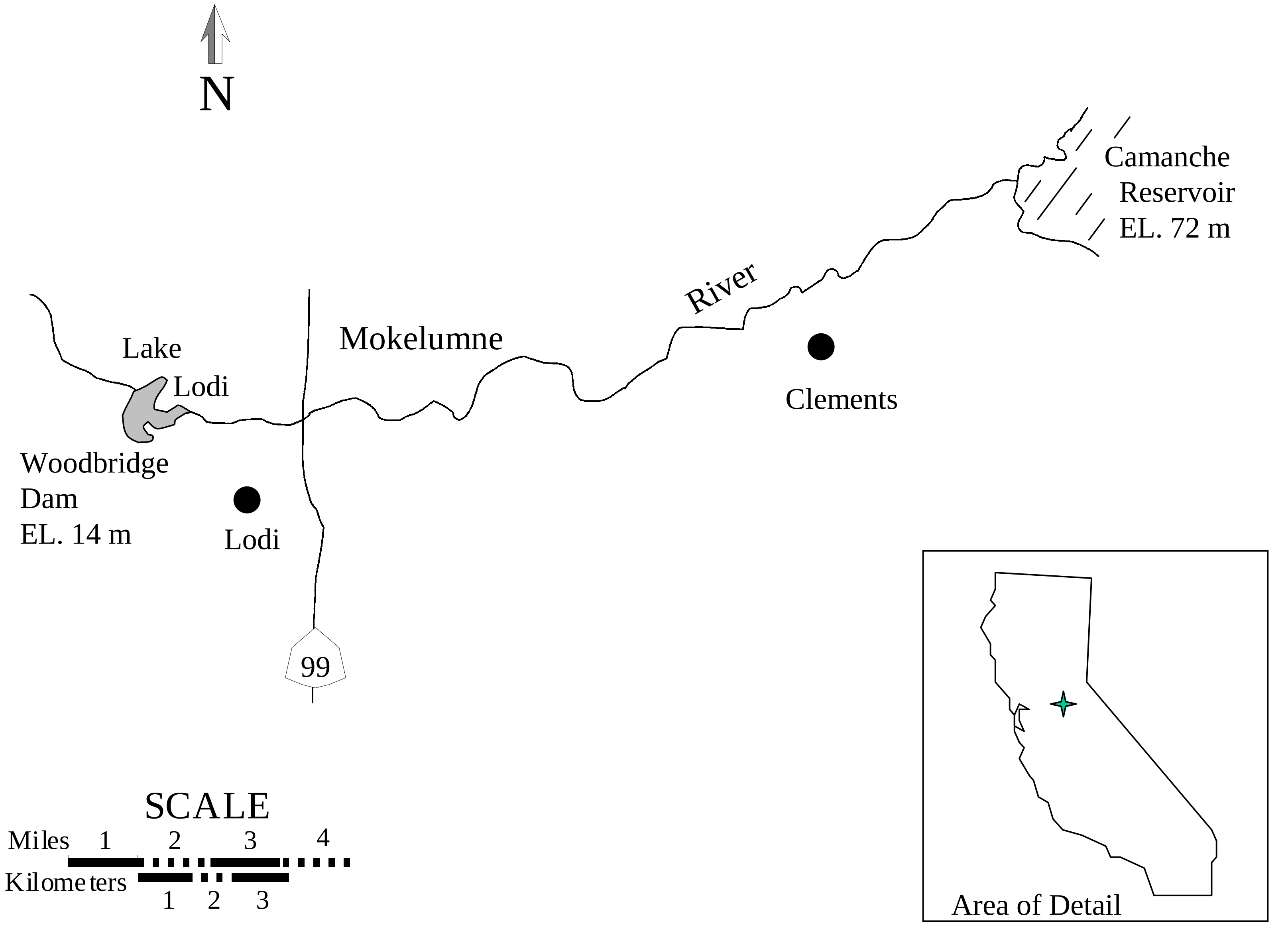
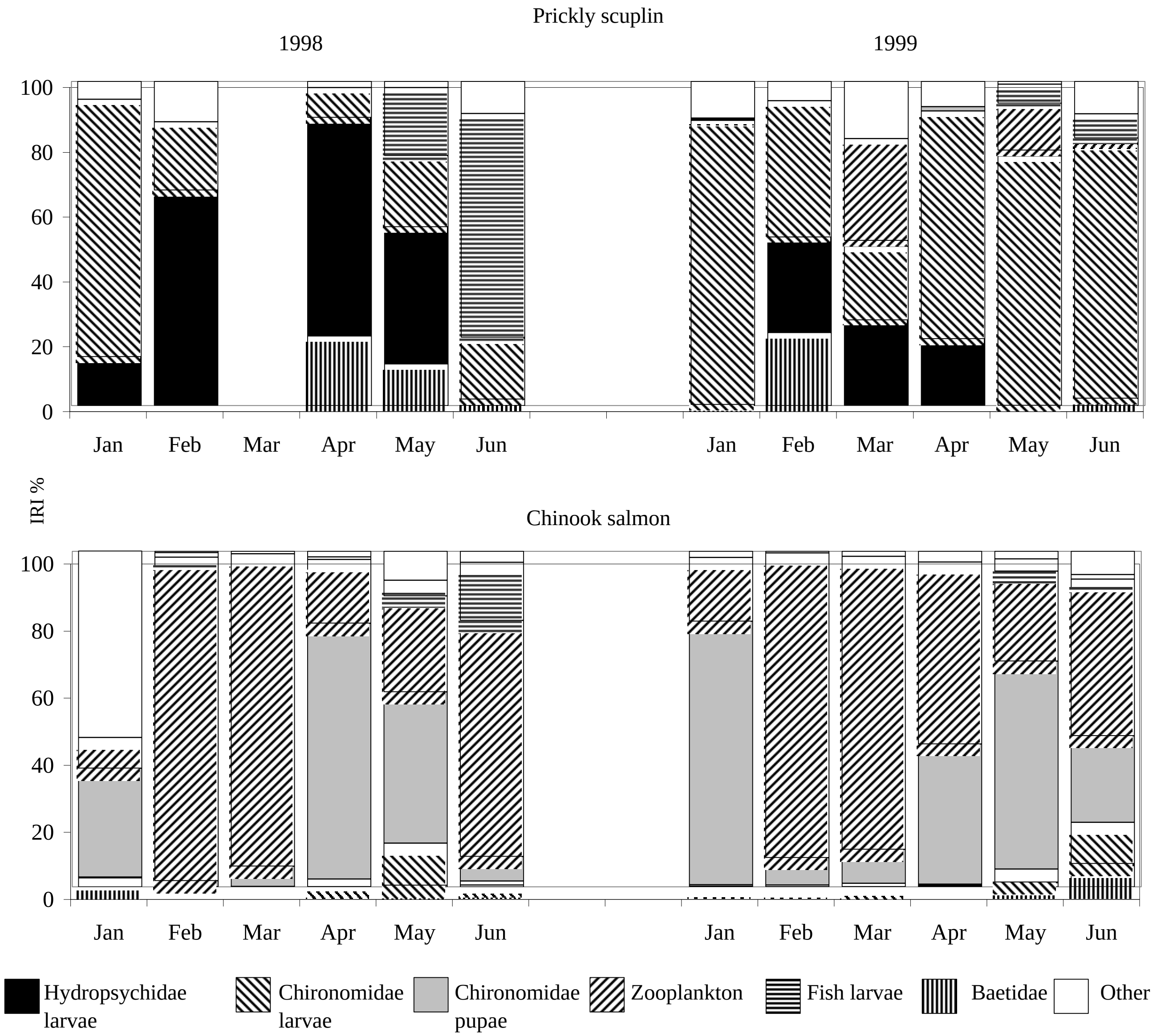

N
Camanche
Reservoir
EL. 72 m
River
Mokelumne
Lake
Lodi
Clements
Woodbridge
Dam
EL. 14 m
Lodi
99
SCALE
Miles 1 2 3 4
Kilometers 1 2 3
Area of Detail

Table 1-- Monthly sample size and mean lengths of chinook salmon (FL) and prickly sculpin (SL), lower Mokelumne River, California, 1998 and 1999.

Species	Year		January	February	March	April	May	June
Prickly	1998	Sample size	16	13	0	21	14	14
sculpin		Mean SL (mm)	56	40	-	44	49	40
		SD	9	15	-	14	15	13
	1999	Sample size	34	14	20	14	45	35
		Mean SL (mm)	38	41	49	36	42	46
		SD	7	8	14	9	13	11
Chinook	1998	Sample size	43	73	18	28	67	13
salmon		Mean FL (mm)	36	41	49	59	77	92
		SD	2	5	5	16	9	7
	1999	Sample size	30	41	31	64	36	25
		Mean FL (mm)	37	41	41	59	62	88
		SD	3	4	4	14	11	10

Table 2-- Major food items of prickly sculpin and chinook salmon in the lower Mokelumne River, California 1998 and 1999, presented as percent Index of Relative Importance (IRI%) for each year.

		Prickly sculpin		Chinook salmon	
Prey Item	Life Stage	1998	1999	1998	1999
Aquatic Invertebrates					
Ephemeroptera					
Baetidae	nymphs	4.7%	0.4%	0.1%	0.7%
Other	nymphs	0.4%	0.3%	0.0%	0.0%
Diptera					
Chironomidae	larvae	58.7%	80.6%	2.2%	2.0%
	pupae	0.1%	1.1%	27.0%	29.3%
Other	larvae	1.2%	0.0%	0.0%	0.0%
	pupae	0.0%	0.0%	0.0%	0.1%
Trichoptera					
Hydropsychidae	larvae	10.8%	0.8%	0.0%	0.1%
	pupae	0.0%	0.0%	0.1%	0.4%
Hydroptilidae	larvae	1.3%	2.6%	0.0%	0.0%
	pupae	0.0%	0.0%	0.4%	0.1%
Oligocheata		0.0%	0.2%	0.2%	0.2%
Zooplankton		0.1%	8.3%	67.8%	66.2%
Gastropoda		0.4%	2.7%	0.0%	0.0%
Aquatic Invertebrate Sub-total		77.9%	97.0%	98.0%	99.2%
Fish	eggs	0.0%	0.0%	0.2%	0.1%
	juveniles	21.9%	2.9%	0.9%	0.3%
	Fish Sub-total	21.9%	2.9%	1.1%	0.3%
Terrestrial Arthropods		0.0%	0.0%	0.9%	0.3%
All Others		0.2%	0.1%	0.0%	0.1%
	Grand Total	100.0%	100.0%	100.0%	100.0%


Prickly scuplin
1998
1999
100
80
60
40
20
0
Jan
Feb
Mar
Apr
May
Jun
Jan
Feb
Mar
Apr
May
Jun
IRI %
Chinook salmon
100
80
60
40
20
0
Jan
Feb
Mar
Apr
May
Jun
Jan
Feb
Mar
Apr
May
Jun
Hydropsychidae larvae
Chironomidae larvae
Chironomidae pupae
Zooplankton
Fish larvae
Baetidae
Other

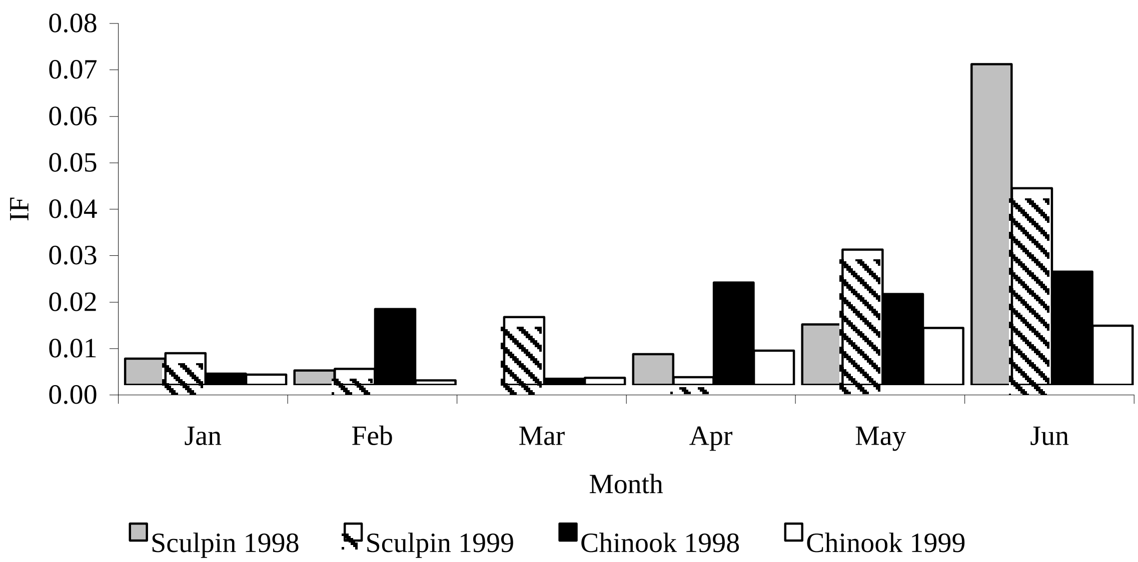
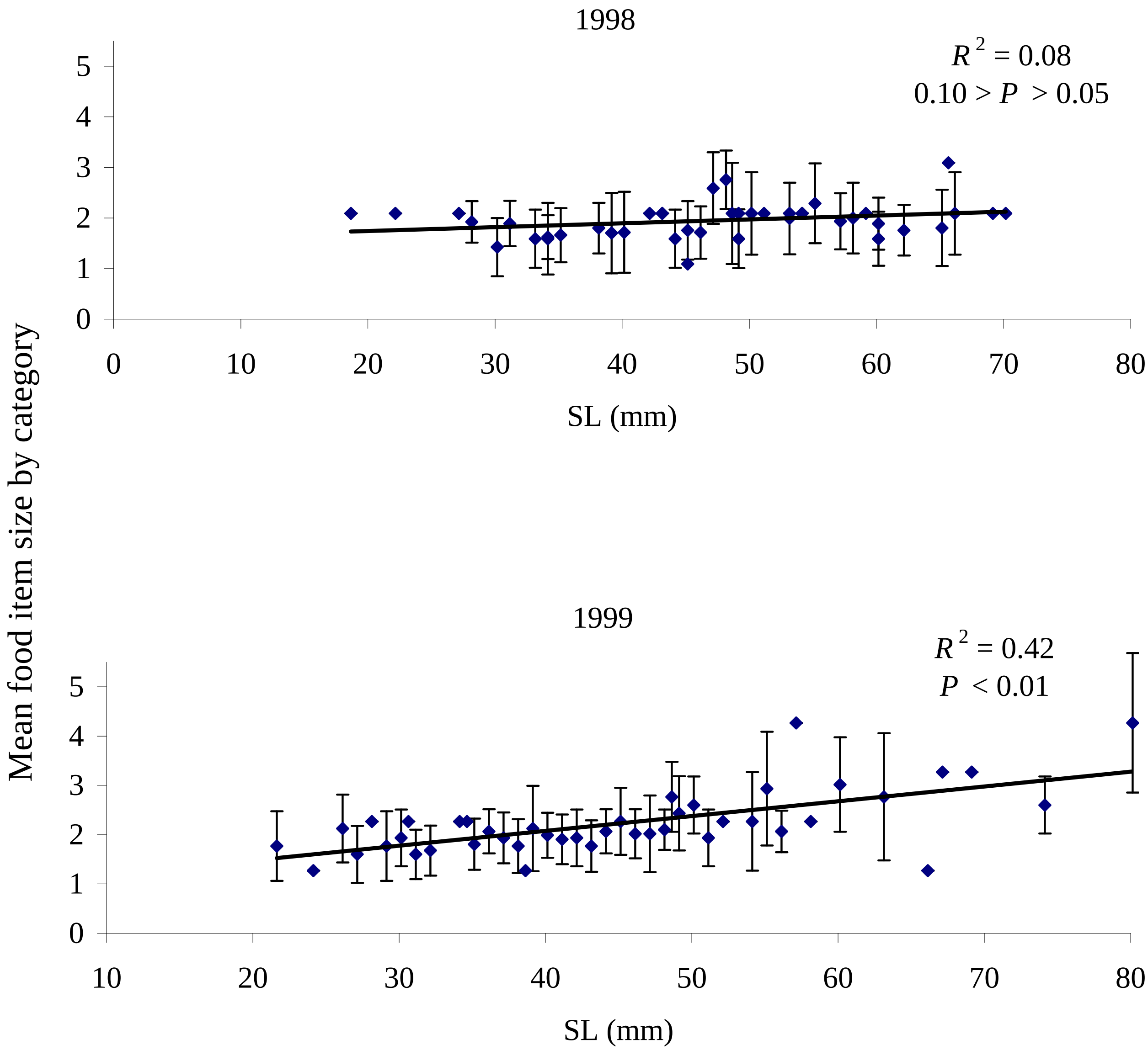
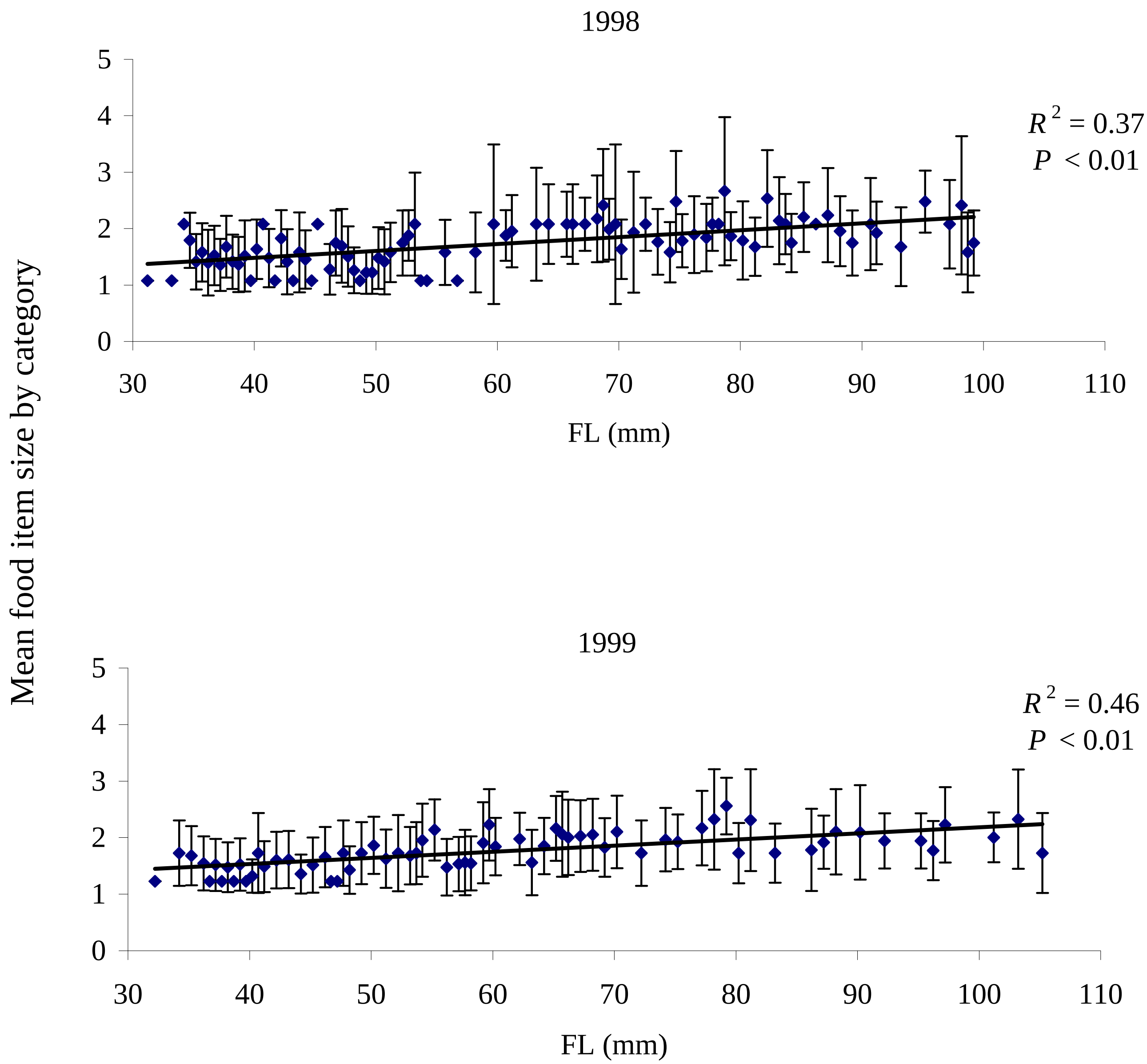


Figure 3. Monthly feeding patterns of prickly sculpin and juvenile chinook salmon from the lower Mokelumne River, California, 1998 and 1999, as indicated by Index of Fullness (IF).


1998
R^2 = 0.08
0.10 > P > 0.05
0
1
2
3
4
5
0
10
20
30
40
50
60
70
80
SL (mm)
Mean food item size by category
1999
R^2 = 0.42
P < 0.01
0
1
2
3
4
5
10
20
30
40
50
60
70
80
SL (mm)


1998
$R^2 = 0.37$
$P < 0.01$
0
1
2
3
4
5
30
40
50
60
70
80
90
100
110
FL (mm)
Mean food item size by category
1999
$R^2 = 0.46$
$P < 0.01$
0
1
2
3
4
5
30
40
50
60
70
80
90
100
110
FL (mm)