CONTRIBUTIONS TO THE LIFE HISTORY OF SACRAMENTO PERCH, *ARCHOPLITES INTERRUPTUS*, IN PYRAMID LAKE, NEVADA

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Abstract.— During a two-year period (1976–1977), 180 Sacramento perch (*Archoplites interruptus*) were sampled from Pyramid Lake, Nevada, on a monthly basis using several capture methods in all lake areas. Age and growth determinations of these fish were inconsistent with previous research on this species. Sacramento perch are entirely carnivorous, adults feeding primarily on tui chub (*Gila bicolor*). Fish accounted for 6 percent of the diet (by volume) of Sacramento perch less than 300 mm fork length, and 98 percent for those exceeding 300 mm. Amphipods, Odonata, and Chironomidae composed 6.3, 5.7, and 1.8 percent, respectively, of the stomach contents by volume for all sizes combined. Females spawned from June to August when water temperatures approached 20 C, and their gonad weight was about 6 percent of the total body weight. A sample of 20 female perch had a mean fecundity of 84,203 eggs. The mean diameter of mature eggs was 0.88 mm. Sacramento perch almost exclusively inhabit the littoral zone of Pyramid Lake. Activity, as indicated by net catches, was greatest during the warm months of May to October. Monthly catches were significantly correlated with temperature ($r = 0.577$, $P < 0.01$). No short-term changes in population abundances were observed during 1976–1977.

The Sacramento perch is the only warm water gamefish in Pyramid Lake. Its preference for warm, shallow water makes it available to shore as well as boat fishermen during the hottest months of the year, when trout are relatively inaccessible. Although not abundant, the Sacramento perch supports a limited summer fishery and is an excellent food fish. An analysis of an aboriginal fishing site in central California indicated that Sacramento perch was the most abundantly utilized species (51 percent of the remains) by the prehistoric Native Americans (Schulz and Simons 1973). In 1931 Walford noted that the Sacramento perch was esteemed by anglers. In recent years interest has been renewed in this fish both as a game fish and as a candidate for the list of endangered species (Aceituno and Nicola 1976). It is currently classified as depleted (Miller 1972).

The Sacramento perch is the only member of the sunfish (Centrarchidae) family naturally distributed west of the Rocky Mountains (Murphy 1948). It is the only living member of the genus *Archoplites*, a relict of an ancient fauna that probably evolved before the formation of the Sierra Nevada and Rocky Mountain ranges (Miller 1946, 1958, 1959). The species is endemic to the S mento-San Joaquin drainage systems of fornia (Aceituno and Nicola 1976) (Fi Sacramento perch probably attained present distribution during the Mic epoch, some 25 million years ago (M 1959). The occurrence of fossil *Archopli* ancient Lake Idaho suggests a former h graphic connection between what are the Snake River and Sacramento River c ages (Miller and Smith 1967).

Lockington (1879) described the Sacramento perch population of the lower Sacramento and San Joaquin Rivers as being abundant in the late 1800s. Nevertheless, the species was noted to be declining in its native range before the turn of the century (Jordan and Evermann 1896). After the turn of the century it was considered uncommon (Rutter 1908), and by the end of the 1940s it was considered scarce, except in a few isolated localities (Murphy 1948, Curtis 1949). By 1955 the Sacramento perch was occupying only a fraction of its original range in California, being limited to 14 small and disjunct bodies of water (Aceituno and Nicola 1976). The decline of Sacramento perch in its native habitat has been attributed to predation, habitat

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Fig. 1. Original distribution of Sacramento perch (after Aceituno and Nicola 1976).

degradation, interspecific competition for food and space, and reduced abundance of native cyprinid prey (Jordan and Gilbert 1895, Neale 1931, Dill and Shapovalov 1939, Murphy 1948, 1951, Mathews 1962, Hopkirk 1973, Moyle et al. 1974). Aceituno and Nicola (1976) discuss these relationships in detail and suggest that competition from introduced exotic centrachids is a probable cause of the demise of Sacramento perch in California.

As Sacramento perch began declining in their native range, they were introduced into other waters. H. G. Parker (first fish commissioner of the State of Nevada) planted Sacramento perch from the Sacramento River into Washoe Lake in 1877 (LaRivers 1962). The species was subsequently distributed to other waters of Nevada, including Pyramid and Walker Lakes. By 1897 a relatively large population of Sacramento perch had apparently been established in Pyramid Lake, because Fish Commissioner G. T. Mills reported a commercial Indian fishery for the species (LaRivers 1962). Aceituno and Nicola (1976) summarized efforts to reestablish Sacramento perch in California waters. They noted that nearly all the waters where Sacramento perch now exist in California are artificial introductions, i.e., the species is virtually nonexistent in its original range.

Age and Growth

Age data, in conjunction with length and weight measurements, comprise an important aspect of fisheries biology because it provides information on stock composition, age at maturity, life span, mortality, growth, and production (Tesch 1971). This information is relevant to ecological relationships of a fish species living in various habitats. The most frequently used method of age determination in a temperate region is the measurement and interpretation of growth zones on the hard parts of fishes, particularly, scales. The classic aging techniques used in this study were not definitive for Sacramento perch.

Annual growth increments of 104 Sacramento perch taken from Pyramid Lake during 1976–1977 exhibited a different pattern than had been previously reported for the species from Pyramid Lake and other waters (Table 1). The back-calculated length of Sacramento perch at time of first annulus formation during this study (137–244 mm) is comparable to the length reported at the second or third annulus of Sacramento perch sampled from Pyramid Lake by Johnson (1958) and Mathews (1962) and from Walker Lake by Allan (1958). The mean annual growth increments (in length) of Sacramento perch collected in 1959 by Mathews (1962) were, however, much greater than those calculated during this study. If, however, our 1976–1977 data are adjusted to make the length at first annulus (males) or first and second annuli (fe males) equal to that of Mathews (1962), then the subsequent annual growth increments are more comparable between the two time periods (Table 2). Such an adjustment, partitioning out the length at first annulus into the proportion determined by Mathews (1962), is arbitrary, but it suggests possible explanations of the ambiguous results: (1) the first annulus may be obscured or not laid down the first year, (2) a true annulus was interpreted as a check mark and disregarded, and (3) previous workers interpreted actual check marks as true annuli.

Annulus formation is probably a function of food availability and temperature in Pyramid Lake. Sacramento perch are spawned late in the year in Pyramid Lake due to the relatively slow warming of the water (Mathews 1962). Following scale formation

TABLE 1. Comparison of Sacramento perch growth from different California and Nevada waters.

	Calculated mean fork length (mm) at each annulus								
Locality	1	2	3	4	5	6	7	8	9
California									
Lake Greenhaven (Mathews 1962)	84	163	203	239	286	312			
Lake Almanor (Mathews 1962)	59	122	172	198	217	282			
Lake Anza (Mathews 1962)	86	120	131	138	147	154			
King Fish Lake (Mathews 1962)	115	—	—	—	—	—			
Clear Lake (Murphy 1948)	85	171	196	220					
Nevada									
Walker Lake (Allan 1958)	102–127	140–190	190–241	229–299	279–318	305–356			
Pyramid Lake (Johnson 1958)	76–127	127–190	178–254	229–305	279–343	305–356	324–368	381–398	314–400
Pyramid Lake (Mathews 1962)	99	158	221	261	299	325	346	371	382
Pyramid Lake (This study)	137–224	186–267	219–300	252–333	312–355				

Table 2. Annual growth increments of Sacramento perch sampled from Pyramid Lake during 1959 and 1976–1977.

	1959 (Mathews 1962)		1976–1977		1976–1977 adjusted[1]	
Age	Females	Males	Females	Males	Females	Males
I	105	91	213	160	105[2]	91[2]
II	58	60	42	58	58[2]	69
III	64	61	34	49	50	58
IV	44	30	30	37	42	49
V	39	24	20	–	34	37
VI	25	16	–	–	30	–
VII	18	22	–	–	20	–
VIII	24	34	–	–		
IX	23	11	–	–		

[1]Assuming 1976–1977 growth at first annuli (males) or first and second annuli (females) were equal to Mathews's (1962) determinations.
[2]Mathews's (1962) data.

(July–August), therefore, the growing season probably only encompasses 1–4 months. If the time of optimum growth extended for a month or less, the first annulus could be close enough to the focus to be obscured. During years of exceptionally late spawning and/or early winters, the young-of-year may overwinter before scale formation occurs, i.e., at a length of <54 mm. If the fish had actually completed two years of life before the first annulus was discernible, it would help explain why the age determined for the 1976–1977 collections was so much younger than had been previously reported for Sacramento perch from Pyramid Lake and other waters. No individuals aged at more than five years were sampled during 1976–1977. Mathews (1962) and Johnson (1958) both reported Sacramento perch through age IX from Pyramid Lake.

Growth zones regarded as false annuli or check marks were frequently encountered during this study. Scale circuli were determined to be true annuli by applying the criteria described by Aceituno and Vanicek (1976). Because we are unable to resolve apparent inconsistencies in the aging methodology, however, further interpretation of these data will not be presented.

The length-weight relationship for Sacramento perch is curvilinear (Fig. 2) and is best described by an exponential or logarithmic linear equation (Table 3). The slope of the logarithmic regression equation represents the rate of weight accrual for given lengths. In Pyramid Lake, our results indicated that female Sacramento perch (slope = 2.726) grow more rapidly than males (slope = 2.560) throughout life.

Coefficients of condition ($K = W \times 10^5/L^3$) were computed for 103 Sacramento perch. The condition factor of females averaged slightly higher than that of males (Table 4). This indicates that females were heavier than males per given length. With the exception of the young-of-the-year fish, the K-values generally decreased as length and age increased. K-values ranged from 1.165 and 2.759, with a mean of 1.965.

Food Habits

The diet of 42 Sacramento perch from Pyramid Lake was determined during 1976. The fish ranged between 203–376 mm in fork

Table 3. Regression equations of fork length (L) in centimeters versus weight (W) in grams, of 103 Sacramento perch taken from Pyramid Lake, Nevada, April 1976–November 1977.

Sex	Sample size (n)	Exponential	Logarithmic
Male	30	$W = .0840\ L^{2.5602}$ ($r^2 = .90$)	$\log_{10}W = -1.076 \times 2.560 \log_{10}L$ ($r^2 = .90$)
Female	59	$W = .0534\ L^{2.7257}$ ($r^2 = .92$)	$\log_{10}W = -1.272 \times 2.726 \log_{10}L$ ($r^2 = .92$)
Combined (including indeterminate)	103	$W = .0144\ L^{3.0935}$ ($r^2 = .96$)	$\log_{10}W = -1.841 \times 3.094 \log_{10}L$ ($r^2 = .96$)

length. The specimens were captured inshore, on the bottom at depths of 0–15 in various lake areas during all seasons. The 12 empty stomachs (28.6 percent) were seen from May through August, and may have been due to regurgitation.

TABLE 4. Average length (mm), weight (g), and condition factors of female and male Sacramento perch collected in Pyramid Lake, Nevada, from 1975 to 1977.

Length groups	Number of fish	Mean length (mm)	Mean weight (g)	Mean K
Female				
100–150	1	142	79	2.759
150–200	0	–	–	–
200–250	0	–	–	–
250–300	6	280	500	2.223
300–350	43	326	708	2.037
350–400	9	370	1061	2.078
Male				
100–150	2	143	72	2.478
150–200	0	–	–	–
200–250	2	236	250	1.902
250–300	14	276	432	2.099
300–350	12	326	627	1.810

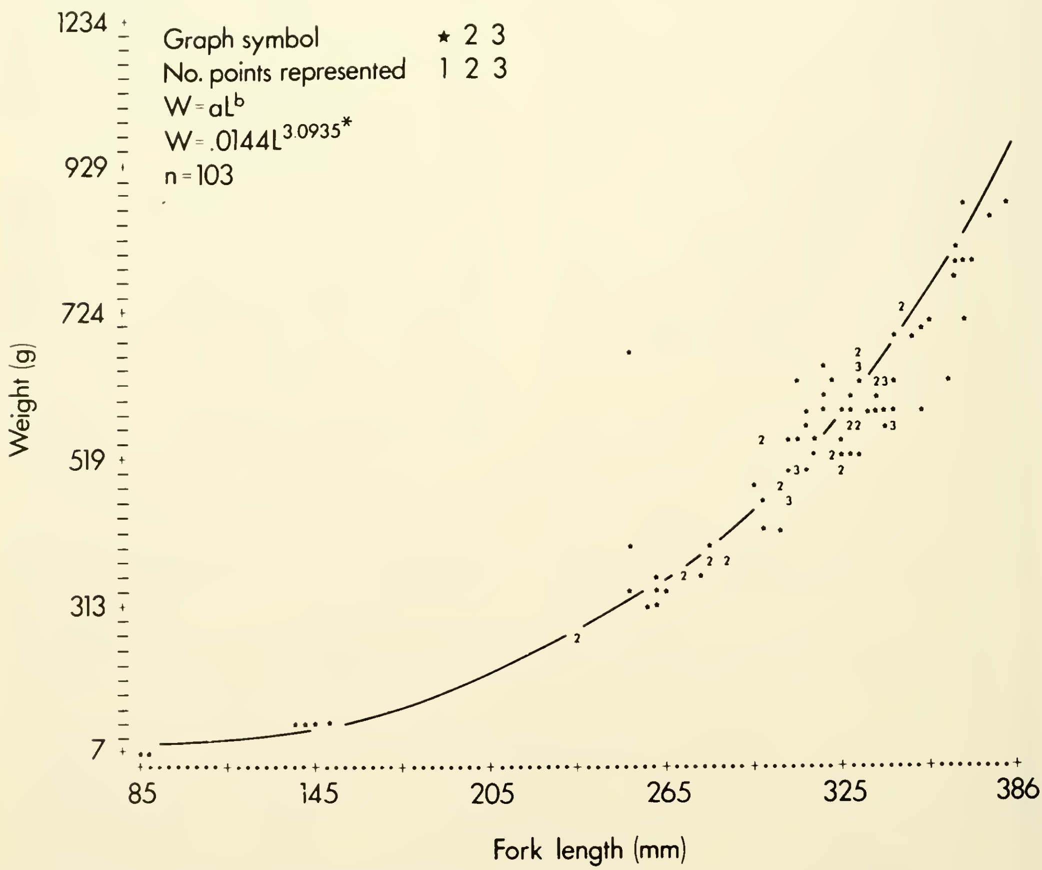

Fig. 2. Length-weight relationship of combined data for Sacramento Perch collected from April 1976 to November 1977, Pyramid Lake, Nevada. Mean length-weight values by age group are presented.

Food items in the Sacramento perch stomachs were separated into six categories: fish, Odonata, Chironomidae, Amphipoda, algae, and digested matter. Fish had been eaten by 65.6 percent of the Sacramento perch whose stomachs contained food and accounted for nearly 86 percent of the total volume of stomach contents (Table 5). Johnson (1958) reported that 49 of 54 (90 percent) of the Pyramid Lake Sacramento perch containing food in their stomachs had eaten fish. In Walker Lake, Allan (1958) determined that 110 of 164 (67 percent) of the Sacramento perch containing food in their stomachs had eaten fish. This piscivorous nature of Sacramento perch has been well documented (Neale 1931, Murphy 1948, Jonez 1955, LaRivers 1962, Mathews 1962, Sigler and Miller 1963).

During this study, all fish identified from stomachs of Sacramento perch were tui chubs. Johnson (1958) also found Sacramento perch from Pyramid Lake to predominantly contain tui chub minnows 25–127 mm in length, and Allan (1958) stated that all identifiable fish from stomachs of Sacramento perch in Walker Lake were tui chubs 38–178 mm in length. Moyle et al. (1974) and Mathews (1962) found tui chubs, Tahoe suckers, and other Sacramento perch in the stomachs of Sacramento perch from Pyramid Lake.

The proportion of fish in the diet increases as the size of the Sacramento perch increases (Table 6). Only 3 of 11 Sacramento perch 203–292 mm in length had eaten fish, whereas 17 of 19 perch measuring over 300 mm had fish in their stomachs. The percentage of fish in the total food volume of Sacramento perch from the two groups is even more striking. Fish amounted to only 6 percent of the volume for Sacramento perch less than 300 mm in length, but 98 percent for those exceeding 300 mm. Moyle et al. (1974) and Mathews (1962) noted a transition from invertebrates to fish in the diet of Sacramento perch at a much smaller size, i.e., Sacramento perch over 90 mm in fork length sampled during July 1961 from Pyramid Lake contained over 90 percent fish, by weight, in their stomach contents. This discrepancy may be partially explained by depth of habitat sampled. Fish in this study were captured in gill nets up to a depth of 15 m. Mathews (1962) primarily used minnow seines (also rotenone and angling), which restricted sampling to relatively shallow areas where small forage fish are more available for predation.

Odonata comprised nearly 42 percent of the benthic invertebrates in stomachs of Sacramento perch. They accounted for 5.7 percent of total Sacramento perch food and had been eaten by 13.3 percent of the specimens examined. Odonata are relatively abundant in the tufa and rock areas of Pyramid Lake inhabited by adult Sacramento perch. Chironomidae had been eaten by 9 of 30 Sacramento perch examined and composed 1.8 percent of the total volume. As Sigler and Miller (1963) observed, Sacramento perch of all sizes feed on Chironomodae. Chironomidae were consumed throughout the year but in the largest volumes during May, June, and July. Amphipoda had been eaten by 20 percent of the Sacramento perch (mostly small fish) and accounted for 6.3 percent of the total volume

Table 5. Stomach contents of 30 Sacramento perch (203–376 mm fork length) from Pyramid Lake, Nevada, during 1976.

Food item	Frequency	Percentage frequency of occurrence	Volume in cc	Percentage of total volume	Percentage of total volume excluding digested matter
Fish	20	66.67	96.5	85.93	81.16
Amphipoda	6	20.00	7.1	6.32	6.34
Odonata	4	13.33	6.4	5.70	5.71
Chironomidae	9	30.00	2.0	1.78	1.79
Algae	1	3.33	Trace*	Trace*	Trace*
Digested matter	2	6.67	0.3	0.27	–
Total	–	–	112.3	100.00	100.00

*Trace = less than 0.1.

of food. Mathews (1962) also observed that small (49–77 mm) Sacramento perch fed heavily on amphipods (71.7 percent of the diet), and larger Sacramento perch depended much less on benthic invertebrates (6.3 percent of the diet), of which odonata were the most important constituent.

The feeding behavior of Sacramento perch in Pyramid Lake is not known in detail. Moyle et al. (1974) concluded from stomach analyses that Sacramento perch fed primarily by picking invertebrates off the bottom substrate or by capturing organisms in midwater. LaRivers (1962) characterized Sacramento perch as "lurkers," hiding in rocky crevices, apparently in wait for passing prey. In Pyramid Lake, the convoluted habitat of tufa formations, combined with huge schools of tui chubs in shallow water, would make the lurking method of predation efficient for any piscivorous fish.

Sacramento perch can be categorized as a stenophagous species, i.e., they subsist on a limited variety of foods. Sacramento perch are entirely carnivorous, becoming almost totally piscivorous when they attain a large enough size. Their macroinvertebrate prey are restricted to benthic species that cohabit in shallow rocky areas. The great abundance and availability of all sizes of tui chubs inshore during the summer months make them the preferred food of Sacramento perch large enough to consume fish. The highest Sacramento perch predation on fish occurred during May–August when adult tui chubs were inshore spawning and young-of-the-year tui chubs were present in high numbers. Mathews (1962) examined 216 Sacramento perch from Lake Anza, California, and showed the highest occurrence of predation on fish to occur from May–September.

Reproduction

Sacramento perch ripen and spawn in various bodies of water at temperatures ranging from 20.0 to 23.9 C (Murphy 1948, Mathews 1962, 1965, McCarraher and Gregory 1970, Imler et al. 1975, Aceituno and Vanicek 1976). In Pyramid Lake, Sacramento perch spawn from June through August, beginning when water temperatures approach 20 C. Collection of young-of-the-year perch in late July and August 1976, when water temperatures were 21.1 to 22.2 C, further delineated Sacramento perch's spawning season in Pyramid Lake. The highest net catch rate of adult Sacramento perch in spawning condition was observed at the delta early in August; relatively large numbers of postlarval Sacramento perch were seined in this area by the end of the month. Female Sacramento perch

Table 6. Percentage of total volume and frequency of occurrence of food items consumed by Sacramento perch in relation to size. Perch were captured from January through December 1976 from Pyramid Lake, Nevada, with bottom-set horizontal gill nets.

Food item	Volume	Percent of total volume	Frequency by occurrence	Frequency of occurrence by percent
Size group 203-292 mm (n = 11)				
Fish	0.9	6.08	3	27.27
Amphipoda	5.8	39.19	4	36.36
Odonata	6.3	42.57	3	27.27
Chironomidae	1.5	10.14	6	54.55
Algae	Trace*	Trace*	1	9.09
Digested matter	0.3	2.03	2	18.18
Mean fork length = 255 mm		Mean weight = 390 g		
Range = 203–292 mm		Range = 177–830 g		
Size group 300-376 mm (n = 19)				
Fish	95.6	98.05	17	89.47
Amphipoda	1.4	1.44	2	10.53
Odonata	0.1	0.10	1	5.26
Chironomidae	0.4	0.41	3	15.79
Mean fork length = 326 mm		Mean weight = 735 g		
Range = 300–376 mm		Range = 544–1,148 g		

*Trace = less than 0.1.

spawn when their gonad weight is about 6 percent of the total body weight. In 1976, this GSI was reached during July and August. Shallow littoral areas with substrates of gravel, boulders, algae, and/or rooted aquatic plants are characteristic spawning habitats of Sacramento perch (Murphy 1948, Mathews 1965, McCarraher and Gregory 1970). Spawners are generally paired, and they exhibit increasingly aggressive behavior that culminates in egg deposition in which both fish are often vertically positioned with the vents close together (Murphy 1948). The eggs are formed in long adhesive strings laid conspicuously over a discrete area of substrate about 0.5 m in diameter. Unlike other centrarchids, Sacramento perch exhibit little if any nest-building behavior (McCarraher and Gregory 1970). After completion of spawning, the male may (Mathews 1965) or may not (Miller 1948) display nest-guarding territoriality for several days. Presence or absence of this protective behavior would certainly affect reproductive success. Scuba diving observations indicate that Sacramento perch exhibit nest-guarding territoriality in Pyramid Lake.

Although actual spawning of Sacramento perch in Pyramid Lake was not observed during this study, tufa formations probably provide suitable spawning substrate. Net catches of young-of-the-year Sacramento perch in the vicinity of the pinnacles and the delta attest to successful reproduction in these areas. The abundant wind-blown tumbleweed in Pyramid Lake may also provide spawning substrate; this plant was utilized by Sacramento perch in White Lake, South Dakota (McCarraher and Gregory 1970).

Natural recruitment of Sacramento perch in Pramid Lake has apparently resulted in maintenance of a stable population since the fish was first introduced in the late 1800s. The delta area may be an important nursery area for Sacramento perch, because the largest catch of postlarval juveniles was taken in this area. Eggs and young probably have higher survival rates in the vicinity of Truckee River inflow due to reduced total dissolved solids (TDS) levels. Fry and fingerling Sacramento perch are less tolerant of high TDS than adults, and apparently a mortality threshold greatly reduces the survival of fry to maturity (McCarraher and Gregory 1970). Sacramento perch successfully reproduced in saline Colorado ponds ranging from 1,000–19,000 mg/l TDS, with total alkalinity less than 400 mg/l (Imler et al. 1975). It is generally conceded, however, the alkalinity (carbonates-bicarbonates) and not salt (NaCl) is the TDS constituent harmful to fish (Beatty 1959, Mitchum 1960).

Alkalinity may also directly affect the reproductive potential of adult Sacramento perch and is probably the mechanism that eliminated this species from Walker Lake. Walker Lake's now extinct Sacramento perch reached their limit of "alkalinity" tolerance when they could no longer reproduce in the early 1950s, when the total alkalinity was approximately 2,500 mg/l as HCO_3 (Cooper 1978). Natural reproduction did not occur in Nebraska hatchery ponds unless the total alkalinity was less than 2,000 mg/l over the summer months (McCarraher and Gregory 1970). Several of the adult females sampled during 1976–1977 in Pyramid Lake exhibited hardened ovaries; concurrent alkalinity levels were in excess of 1,400 mg/l. This condition certainly impairs reproductive success. If the proportion of sexually viable females in the population were decreased in Pyramid Lake by increasing concentrations of alkalinity, the Sacramento perch would eventually be eliminated from the lake.

Sacramento perch from Pyramid Lake usually mature sexually at a mean length of 227 mm. Sexually mature males range in mean length from 160–295 mm, and females at 213–327 mm. Decreasing numbers of male Sacramento perch at larger sizes have been noted by other workers. Mathews (1962) stated that creel census data from Pyramid Lake revealed that about six females per male were taken and that the ratio of older fish was imbalanced in favor of females. In research on Lake Anza, Mathews (1962) also found that all age group V and VI perch were females. Survival of females to older age groups maintains a higher reproductive potential while altering the sex ratios toward the female.

Sacramento perch exhibit high fecundities, as do most members of the family Centrarchidae. During 1976–1977, a sample of 20 female Sacramento perch from Pyramid Lake

TABLE 7. Comparison of mean fecundities of Sacramento perch from Pyramid Lake, 1959–1961 and 1976–1977.

Age[1] group	n	Mean fecundity 1959–1961 (Mathews 1962)	n	Mean length (mm)	1976–1977
II	2	20,825	–	–	–
III	5	62,792	8	295	62,800
IV	5	76,078	9	318	93,279
V	3	112,363	3	327	114,049
VI	–	–	–	–	–

[1]Ages from 1976–1977 data assigned by length frequency.

had a mean fecundity of 84,203 eggs. Mathews (1962) reported fecundities, by age group, of Sacramento perch from Pyramid Lake that closely match the 1976 data of corresponding age groups (Table 7). The mean fecundity of 67,672 eggs that Mathews (1962) observed can be attributed to his sample containing a larger proportion of young fish.

A slow-growing population of Sacramento perch from Lake Anza, California, averaged 11,439 eggs per female. Because fecundity is a direct function of fish size, the larger Pyramid Lake fish would be expected to have more eggs. The fecundity of Sacramento perch shows a significant linear relationship with both fork length (mm) and weight (g) ($P<0.05$) (Fig. 3).

The mature egg diameter for Pyramid Lake Sacramento perch during 1976 varied from 0.79 to 1.00 mm (mean = 0.88). In 1962 Mathews reported that egg diameters of Sacramento perch from both Lake Anza and Pyramid Lake averaged 0.67 mm.

HABITAT AND ECOLOGY

Sacramento perch are currently the least abundant of the five major fish species in Pyramid Lake. A very limited habitat is one reason for the relatively low number of perch. This species is apparently restricted to shallow inshore areas, i.e., the littoral zone. During two years of sampling, almost all Sacramento perch were taken in shore sets.

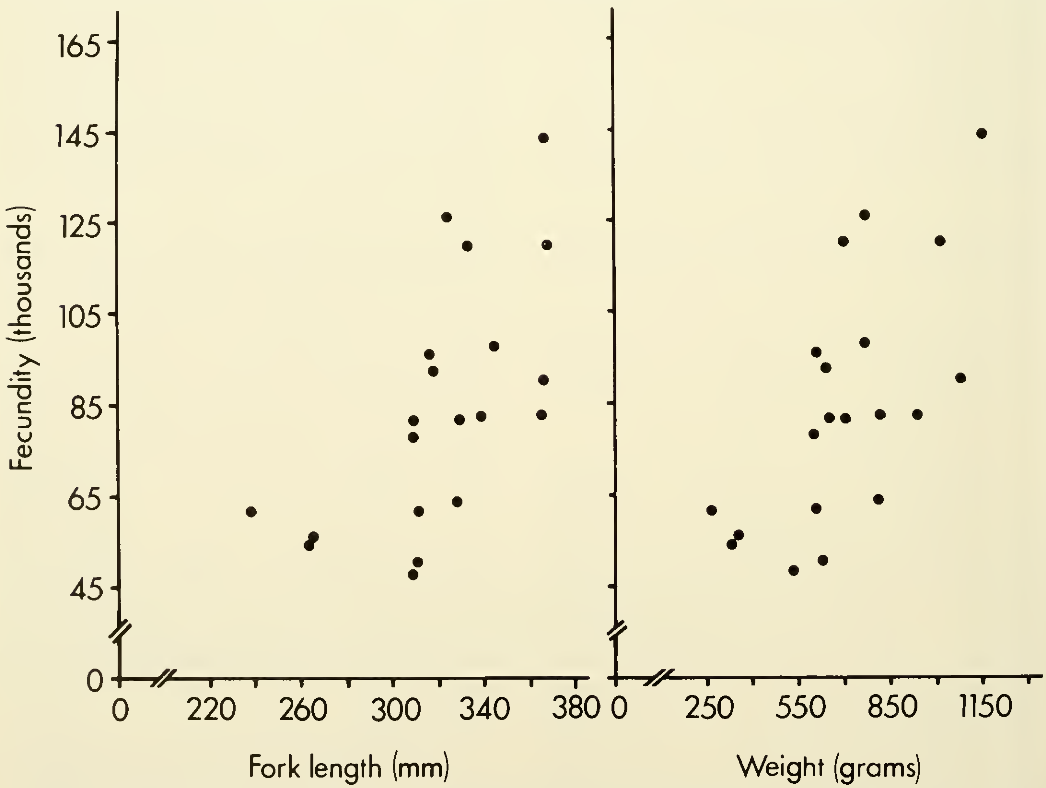

Fig. 3. Length-fecundity and weight-fecundity relationships for 20 Sacramento perch collected in Pyramid Lake, Nevada, during 1976 and 1977.

None were captured at depths greater than 23 m nor in offshore (limnetic) waters at any depth. The littoral zone (0–15 m) of Pyramid Lake provides only about 11 percent of its surface area and about 1.27 percent of the total volume.

LaRivers (1962) notes the sedentary nature of Sacramento perch and their association with rocky habitats and crevices. Recent observations by divers confirm the observation that these fish congregate around rocky points, breakwaters, and tufa caves. Our quantitative net samples indicate that the greatest numbers of Sacramento perch were taken in areas of tufa substrate. The favored habitat of this fish seems to be areas of extensive tufa development, e.g., the Pyramid and vicinity, Hells Kitchen, the Pinnacles, and Pelican Point.

There was no apparent short-term change in abundance of Sacramento perch during 1976 and 1977. The mean catch effort of 177 standardized (18 hr) gill net sets during 1976 (0.29 fish/net) was not significantly different from that of 172 comparable net sets during 1977 (0.33 fish/net) ($P = 0.77$, $F = 0.09$). Due to high within-season variation, no significant difference was detected in mean catch of Sacramento perch by season during 1976 ($P>0.05$). However, a significant seasonal difference was detected for 1977 ($P<0.001$). The population was relatively inactive from November through April. For both years, about 85 percent of the total annual catch was taken during May–October.

In Pyramid Lake, temperature has the most pronounced environmental effect on Sacramento perch. Monthly mean catch of Sacramento perch was significantly correlated with water temperature ($r = 0.577$, $P<0.01$). During both years, minimum gill net catches corresponded to temperature minima; catch rate subsequently increased during spring and peaked in July at a temperature of about 21.5 C (Fig. 4). We hypothesize that the temporal thermal regime of Pyramid Lake further tends to restrict the population potential of Sacramento perch because optimum temperatures for active feeding and growth are apparently available for such a short time.

Sacramento perch introduced to Nebraska have been most successful in lakes where other fish populations have been artificially

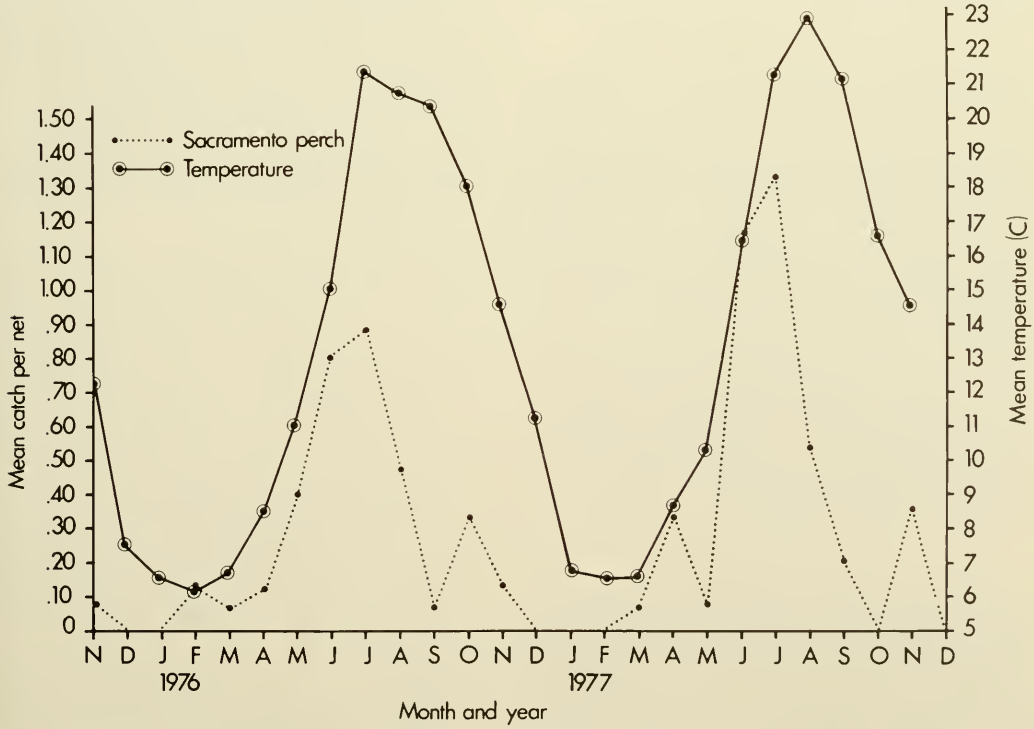

Fig. 4. Mean monthly Pyramid Lake Sacramento perch catches (15 gill net sets per month) from November 1975 through December 1977 in relation to mean surface water temperature.

removed or in highly alkaline lakes that support only a naturally reproducing minnow species (McCarraher and Gregory 1970). Of all waters inhabited by Sacramento perch, Pyramid Lake's environment is most conducive to longevity and maximum growth (Aceituno and Vanicek 1976). The alkaline waters of Pyramid Lake result in a low species diversity. Mathews (1962) attributed the large size attained by Sacramento perch in Pyramid Lake to their highly piscivorous diet. The huge forage base of tui chubs in Pyramid Lake is crucial. Because the alkalinity of Pyramid Lake limits the diversity of its fish species, and the Sacramento perch is the lake's only warm-water piscivore, it holds a stable niche with little interspecific competition.

The fact that the Sacramento perch population apparently did not greatly increase and become a dominant predator when the Pyramid Lake Lahontan cutthroat trout became extinct in the late 1930s indicates that the population does not have a great capacity to increase in numbers and biomass, and that these two game species do not severely compete in Pyramid Lake.

Summary and Conclusions

At present, Sacramento perch and Lahontan cutthroat trout are the only species providing a sport fishery in Pyramid Lake. When the Sacramento perch was introduced into Pyramid Lake in the late 1800s, it filled an ecological niche that was previously void. Due to differential spatial and temporal distribution patterns, and the huge production potential of their common food source (tui chubs), the Sacramento perch population does not constitute dangerous competition for Lahontan cutthroat trout in terms of space and energy. Sacramento perch is a unique, relict fish that enjoys the precarious status of a depleted species.

Acknowledgments

The Pyramid Lake Paiute Indian Tribe was instrumental in initiating the ecological research effort on Pyramid Lake. The Pyramid Lake Ecological study was conducted by W. F. Sigler & Associates, Inc. under contract (#H50C14209487) to the United States Department of Interior, Bureau of Indian Affairs. Mr. Roy Whaley was responsible for the collection and analysis of the food habits research and Denise Robertson was responsible for age and growth. Dr. William F. Sigler was the directive influence behind the fish life history research on Pyramid Lake.

Literature Cited

Aceituno, M. E., and S. Nicola. 1976. Distribution and status of the Sacramento perch, *Archoplites interruptus* (Girard), in California. California Fish and Game 62(4):246–254.

Aceituno, M. E., and C. D. Vanicek. 1976. Life history of the Sacramento perch, *Archoplites interruptus* (Girard), in California. California Fish and Game 62(1):5–20.

Allan, R. C. 1958. Fisheries management report—Walker Lake. Lakes Pyramid, Walker, and Tahoe investigations. July 1, 1954, to June 30, 1958. Dingle-Johnson Project FAF-4-R. Nevada Fish and Game Dept. 30 pp. + appendices.

Ayres, W. O. 1854. Descriptions on *Sebastes ruber*, *Sebastes ruber* var. *parvus*, *Sebastes variabilis*, and *Centrarchus maculosus*. Pacific 3(46):182.

Beatty, D. B. 1959. An experimental study of the toxicity of sodium bicarbonate, sodium chloride, and sodium sulfate to rainbow trout. Unpublished thesis. Univ. of Wyoming. 69 pp.

Cooper, J. J. 1978. Contributions to the life history of the Lahanton tui chub, *Gila bicolor obesa* (Girard), in Walker Lake Nevada. Unpublished thesis, Univ. of Nevada, Reno. 89 pp.

Curtis, B. 1949. The warm-water game fishes of California. California Fish and Game 35(4):255–274.

Dill, W. A., and L. Shapovalov. 1939. california freshwater fishes and their possible use for aquarium purposes. California Fish and Game 25(4): 313–324.

Girard, C. 1854. Description of new fishes collected by Dr. A. L. Heermann, naturalist attached to the survey of the Pacific Railroad Route, under Lieut. R. S. Williamson, USA. Proc. Acad. Nat. Sci. Phila. 7:129–140.

Hile, R. 1941. Age and growth or rock bass (*Ambloplites repestris* Rafinesque) in Nebesh Lake, Wisconsin. Trans. Wisconsin Acad. Sci. Arts Lett. 33:189–337.

Hopkirk, J. D. 1973. Endemism in fishes of the Clear Lake region of central California. Univ. of California Press, Berkeley. 135 pp.

Imler, R. L., D. T. Weber, and O. L. Fyock. 1975. Survival, reproduction, age growth, and food habits of Sacramento perch, *Archoplites interruptus* (Girard), in Colorado. Trans. Am. Fish. Soc. 104(2):232–236.

Johnson, V. K. 1958. Fisheries management report—Pyramid Lake. Lakes Pyramid, Walker, and Tahoe investigations. July 1, 1954, to June 30, 1958. Dingle-Johnson Project FAF-4-R. Nevada Fish and Game Dept. 47 pp. + appendices.

Jonez, A. 1955. Life history of Sacramento perch. Annual completion report. Proj. FAF-4-R. Nevada Fish and Game Comm. 2 pp.

Jordan, D. S., and B. W. Evermann. 1896. Fishes of North and Middle America. Bull. U.S. Natl. Mus. 47(1):1–1240.

Jordan, D. S., and C. H. Gilbert. 1895. List of fishes inhabiting Clear Lake, California. Bull. U.S. Fish Comm. 14:139–140.

Kimsey, J. B., and L. O. Fisk. 1960. Keys to the freshwater and anadromous fishes of California. California Fish and Game. 46(4):453–479.

LaRivers, I. 1962. Fishes and fisheries of Nevada. Nevada State Fish and Game Comm. 782 pp.

LeCren, E. D. 1958. Observations on the growth of perch (*Perca fluviatilis L.*) over twenty-two years with special reference to the effects of temperature and changes in population density. J. Anim. Ecol. 27:287–334.

Lockington, W. N. 1879. Report upon the food fishes of San Francisco. California Dept. Fish and Game Biennial Rep., 1878–1879. 63 pp.

Mathews, S. B. 1962. The ecology of the Sacramento perch, *Archoplites interruptus*, from selected areas of California and Nevada. Unpublished thesis, Univ. of California, Berkeley. 93 pp.

______. 1965. Reproductive behavior of the Sacramento perch, *Archoplites interruptus*. Copeia (2):224–228.

McCarraher, D. B., and R. W. Gregory. 1970. Adaptability and current status of introductions of Sacramento perch, *Archoplites interruptus*, in North America. Trans. Am. Fish. Soc. 99(4):700–707.

Miller, R. R. 1946. The need for ichthyological surveys of the major rivers of western North America. Sci. 104(2710):517–519.

______. 1959. Origin and affinities of the freshwater fish fauna of western North America. Zoogeography 9:187–222.

______. 1961. Man and the changing fish fauna of the American Southwest. Michigan Acad. Sci., Arts, Letters 46:388.

______. 1972. Threatened freshwater fishes of the United States. Trans. Am. Fish. Soc. 101(2):239–252.

Miller, R. R., and G. R. Smith. 1967. New fossil fishes from Plio-Pleistocene Lake, Idaho. Occ. Papers Museum Zool., Univ. of Michigan 654:1–23.

Mitchum, D. L. 1960. An experimental study of the toxicity of calcium carbonate, calcium sulphate, magnesium carbonate, and magnesium sulphate to rainbow trout. Unpublished thesis. Univ. of Wyoming. 59 pp.

Moyle, P. B., S. B. Mathews, and N. Bonderson. 1974. Feeding habits of the Sacramento perch, *Archoplites interruptus*. Trans. Am. Fish. Soc. 103(2):399–402.

Murphy, G. I. 1948. A contribution to the life history of the Sacramento perch, *Archoplites interruptus*, in Clear Lake, Lake County, California. California Fish and Game 34(3):93–100.

______. 1951. The fishery of Clear Lake, Lake County, California. California Fish and Game 37(4):439–484.

Neale, G. 1931. Sacramento perch. California Fish and Game 17(4):409–411.

Rutter, C. 1908. The fishes of the Sacramento-San Joaquin basin, with a study of their distribution and variation. U.S. Bur. Fish Bull. 27:103–152.

Schulz, P. D., and D. D. Simons. 1973. Fish species diversity in a prehistoric central California Indian midden. California Fish and Game. 59(2): 107–113.

Tesch, F. W. 1971. Age and growth. Pages 98–130 *in* W. E. Ricker, ed. Methods for assessment of fish production in fresh waters. IBP Handbook No. 3. Blackwell Scientific Publications, Oxford and Edinburgh.

VanOosten, J. 1944. Factors affecting the growth of fish. Trans. Ninth N. Am. Wildl. Conf. 9:177–183.

Walford, L. A. 1931. Handbook of common commercial and game fishes of California. California Dept. Fish and Game, Fish. Bull. (28):1–183.