BIOLOGY OF RAINBOW TROUT (SALMO GAIRDNERI), BROWN TROUT (S. TRUTTA) AND INTERIOR DOLLY VARDEN (SALVELINUS CONFLUENTUS) IN THE McCLOUD RIVER, CALIFORNIA, IN RELATION TO MANAGEMENT

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Abstract.

Movements, growth, age structure, and condition of rainbow trout, brown trout, and interior Dolly Varden in the lower McCloud River, California, were studied in the summer of 1974, in order to determine the best management strategy for a section of stream previously closed to the public, and containing trout populations unique to California. The population of native rainbow trout was found to be largely resident, while the non-native brown trout spent only the first 2 or 3 years of their life in the river before migrating downstream to Shasta Reservoir. Brown trout return to spawn at age IV and older. Growth in the river for both species is somewhat slow compared to other populations in the western United States, but growth in the reservoir for brown trout is rapid. Both species have condition factors typical for the species and both experience mid-summer depressions in condition, apparently related to reduced food availability. Dolly Varden were found to be extremely rare and only two fish were examined. It is likely that the Dolly Varden is non-migratory and slow-growing in the McCloud River. Following the study, special angling regulations were adopted to preserve the integrity of the native trout populations. Future management needs are discussed.

INTRODUCTION

The lower McCloud River, California, is of considerable interest to both biologists and anglers because it contains (1) the last virtually unexploited big-river trout populations in California, (2) the rainbow trout (Salmo gairdneri) strain which was the progenitor of many hatchery strains and introduced wild populations (Wales 1939, MaCrimmon 1971), and (3) the southernmost population of the interior Dolly Varden (Salvelinus confluentus), which is the only population in California (Moyle 1976, Cavender, in press). In 1974, The Nature Conservancy (TNC) acquired land adjoining about 10 km of the lower McCloud River as a nature preserve. The previous owners (McCloud River Club) had excluded the public since the early 1900's and had imposed strict angling regulations on its small membership that resulted in negligible harvest of the trout (unpublished records, McCloud River Club). In the summer of 1974, studies were undertaken to determine (1) the characteristics of a lightly exploited population of native rainbow trout, (2) the status of the Dolly Varden, (3) the role of the introduced brown trout (Salmo trutta) in the river, (4) the impact of the domestic trout that had been planted upstream from the study area, and (5) the most desirable angling regulations should the TNC preserve be opened to fishing. This paper reports the results of studies on movement, growth, age structure, and status of trout populations in the preserve, and the management recommendations made as a result of these studies. Investigations of feeding habits of the trout have been reported elsewhere (Tippets and Moyle, in press).

STUDY AREA

The study took place in the 10 km stretch of the lower McCloud River that flows through the McCloud River Preserve of The Nature Conservancy (TCN). The river immediately upstream from the Preserve has been open to public fishing since 1965, when McCloud Dam was constructed 6 km above the Preserve in 1965. The river empties into Shasta Reservoir, constructed in 1940, about 16 km downstream. Domestic trout from Mt. Shasta Hatchery have been planted in the 6 km upstream section since it was opened to the public. For the 16 km of the river below the Preserve, access and take of fish is severely restricted by two private fishing clubs.

The river, draining slightly over 1100 km^2, is characterized in the study area by large bedrock-lined pools (2 to 3 m deep, 20 to 100 m long) alternating with long boulder-strewn runs and deep riffles ($\frac{1}{2}$ to 1 m deep, 5 to 400 m long). The river flows through a steep canyon forested primarily by Douglas Fir (Pseudotsuga menziesii), black oak (Quercus kellogii), and maple (Acer sp.). Dense stands of alder (Alnus sp.) grow along the banks at the waterline. Seasonal flow patterns have been modified by diversion of over half the water in McCloud Reservoir to the Pit River, to generate electricity (U.S. Geological Survey 1973). Temperature regimes for the study section have not changed significantly since construction of McCloud Dam although the reduced flows apparently cause warmer temperatures farther downstream (California Department of Fish and Game, unpublished records). Observed summer flows averaged 6.36 m^3/sec while water temperatures ranged from 8 to 16 C from June through September 1974. Total dissolved solids in March 1971 were 53 mg/l, and in July 1971 were 74 mg/l (U.S. Geological Survey 1973).

METHODS

The 10 km study section was divided into 89 sampling areas, which were designated as either pool or riffle. These areas were numbered and marked with surveyor's flagging tape to allow determination of where fish were captured, and how far they had moved when recaptured. Angling proved the most efficient collection method for adult fish, although attempts were made using backpack electroshockers, gill nets, setlines, and fyke nets. Over 600 catchable sized fish were collected from May through November 1974. Additional fish were collected during occasional sampling trips in 1975 and 1976. Most fish were collected from the lower 4 km of the study area. Captured fish were anesthetized in MS 222, measured to the nearest mm for total (TL), fork (FL), and standard (SL) lengths, and weighed to the nearest 5 g. After removing scales for growth analysis, each fish was either given a numbered dorsal disc tag (non-reward) and released where captured, or preserved for food habits analysis and sex determination.

Growth rates were determined using acetate scale impressions formed with an hydraulic hot-press. Annuli were counted on scales at a magnification of 28.5 diameters. The distance from the focus to each annulus was measured along the anterior scale radius (ASR). Standard lengths (mm) at the time of annuli formation were back-calculated using a geometric mean functional regression (Ricker 1973) for anterior scale radius (ASR) and standard length (SL). The regression computed for rainbow trout was : $SL = 20.7 + 173.9\ ASR$ ($r = 0.93$), and for brown trout: $SL = 12.4 + 188.1\ ASR$ ($r = 0.96$). Mean lengths for all individuals fromeach year class at each age were computed from the back-calculated values for individual fish (Ricker 1975).

The back-calculated lengths for both rainbow and brown trout exhibited Lee's phenomenon for each cohort (Sturgess 1976). Consequently, the best estimate for growth was computed as follows (Ricker 1975): Expected l_t = (Observed l_t - Back-calculated l_{t-1}) + Observed l_{t-1} where:

l_t = Standard length at last annulus.

l_{t-1} = Standard length, penultimate annulus.

This slight adjustment compensates for size selective mortality that occurs during the year.

Condition (Fulton's K) for each fish was computed using the standard length and the expression:

$$K = \frac{wt\ (g)}{SL^3\ (mm)} \times 10^5 \text{ (Ricker 1975).}$$

The average weekly condition factor values (Sturgess 1976) were combined using a 3 week average to show changes in condition over the summer. To compare the McCloud River growth data with other trout populations, the conversion factors for SL, TL, and FL measurements (Table 1) were used (Sturgess 1976).

Table 1. Standard, fork, and total length conversion factors for rainbow trout and brown trout from the McCloud River.

Rainbow trout, n = 375	Brown trout, n = 92
SL = 0.8413TL - 1.742	SL = 0.8688TL - 7.695
FL = 0.9391TL + 0.155	FL = 0.9927TL - 10.501
SL = 0.8958FL - 1.888	SL = 0.8752 FL - 1.495

RESULTS

Movement

Of the 215 rainbow and 37 brown trout tagged in 1974, 25 rainbow and 4 brown trout were recaptured by the end of 1975. Twenty-three of the total recaptures were made by participants in the McCloud River study and 5 by anglers. The remaining tag return was from an angler who found a tag in feces of a river otter (Lutra canadensis). Time intervals from tagging to recapture varied from less than 5 minutes to 2 years. Most fish (59%) were recaptured in the same riffle or pool in which they were tagged, and over 72% were within one pool or riffle of the tagging site. Only 4 fish were recaptured outside the study area. Three tags were returned from Shasta Reservoir: a spent female rainbow trout (397 mm SL, 1360 gm), and two brown trout (520 mm SL, 2100 gm and 555 mm SL, 2500 gm); the rainbow and one of the brown trout were recaptured in 1974, the other brown trout in May 1976. Four tagged rainbow trout were captured 1-3 km upstream from the study area.

Hatchery rainbow trout of the Shasta strain (all marked with pelvic fin clips by the California Department of Fish and Game) were released in periodic plants in the river between McCloud Dam and Ah-di-nah Campground (1 km above the study area) during the summer of 1974. Of these 7194 fish, only 3 were observed in the study area: one was dead, one was missing the lower jaw and an eye and was dying, while the third appeared to be in good condition. All three hatchery fish were taken within 3 km of the plant site.

Growth and Age Structure

The mean back-calculated lengths for rainbow trout and brown trout are shown in Tables 2 and 3. The age structure of the catch shows differences between the rainbow and brown trout populations (Figure 1). Five age classes of rainbow trout were present, although the structure of the histogram strongly reflects the bias towards larger fish of the principal sampling method, angling. Despite this bias, the histogram for brown trout is bimodal. Surprisingly low numbers of age III and IV fish were captured, when compared to the number of age V and VI fish.

Condition

Average K for each age class and species (Table 4) yielded nonsignificant differences between sex, method of capture, or location in river using one-way analysis of variance. The rainbow and brown trout both showed a late August depression in condition followed by recovery in September and a decline through October (Figure 2). Summer growth for 1974 as indicated by post-annuli scale increments of rainbow trout followed closely the changes in condition factor for the same period, indicating that growth in both length and weight slows during mid-summer.

Dolly Varden

Only two Dolly Varden were observed during the study, both large adults (420 mm SL and 370 mm SL) captured in 1975. The scales from the two fish were hard to interpret but they appeared to be between four and six years old. The California Department of Fish and Game conducted a survey of the river in 1977 in order to determine the status of the Dolly Varden but none were captured (S. J. Nicola, pers. comm.).

Table 4. Average condition factors of McCloud River trout by age class.

Rainbow trout			Brown trout		
Age	K (SL)	n	Age	K (SL)	n
I	1.51	86	I	1.49	17
II	1.66	104	II	1.59	34
III	1.63	153	III	1.71	13
IV	1.58	54	IV	1.66	9
V	1.62	7	V	1.62	12
			VI	1.79	6

Table 2. Mean back-calculated standard lengths at annuli for rainbow trout (± one standard deviation) from the McCloud River.

	ANNULUS						
AGE	1	2	3	4	5	6	n
VI	73	125	159	222	273	302	1
V	74 ± 11	124 ± 31	184 ± 31	245 ± 33	292 ± 36		13
IV	81 ± 12	139 ± 23	207 ± 38	262 ± 39			61
III	79 ± 23	149 ± 25	214 ± 33				159
II	84 ± 14	146 ± 25					108
I	85 ± 16						42
BEST ESTIMATE	85.4	147.6	211.5	268.9	309.2	321.5	

Table 3. Mean back-calculated standard lengths at annuli for brown trout (± one standard deviation) from the McCloud River.

	ANNULUS							
AGE	1	2	3	4	5	6	7	n
VII	57	116	189	240	314	365	431	1
VI	86 ± 29	147 ± 56	227 ± 77	310 ± 80	391 ± 73	443 ± 61		9
V	85 ± 16	160 ± 41	246 ± 63	329 ± 64	392 ± 59			16
IV	84 ± 13	167 ± 29	254 ± 47	359 ± 47				10
III	81 ± 21	160 ± 47	258 ± 98					12
II	81 ± 15	145 ± 26						37
I	87 ± 20							18
BEST ESTIMATE	86.9	150.8	242.2	363.2	442.1	443.7	508.7	

DISCUSSION

Movement

Movements of individual wild rainbow trout in the study section were generally restricted to a particular pool-riffle combination since most recaptures of tagged fish were made close to the tagging site. Although the large female rainbow recaptured in Shasta Reservoir indicates that there is probably some movement between the reservoir and the study area, the large number of slow-growing adult trout (3-5 years old) found throughout the study period suggests the population is largely non-migratory. Since hatchery rainbow trout were found only in the uppermost portion of the study area, these fish also did not move much, and consequently, must not mix with the wild populations downstream. Newell (1957) also found little movement of hatchery rainbow trout. The lack of any records of Dolly Varden from Shasta Reservoir indicates that they are also probably non-migratory. In contrast, brown trout apparently move on a regular basis between the study area and Shasta Reservoir. This is suggested by: the paucity of age III fish in the catch as compared with ages I, II, IV, V, and VI, the two tag returns from Shasta Reservoir, increasing late summer and fall captures of age IV, V, and VI fish with little or no food in their stomachs (Tippets 1976), and the accelerated growth rates of older year classes, shown by wide, evenly-spaced circuli. These observations suggest that most juvenile brown trout remain in the study area only through their second year, then move down to Shasta Reservoir and return two or three years later. In areas with spawning migrations of brown trout, Allen (1938) found 76% moved downstream during their second year, and 12% each for first and third year fish. Similarly, Ball and Jones (1961) found 60% for second year fish, and 20% for first and third year fish.

Growth

Growth of rainbow trout in the McCloud River is considerably slower than average for trout streams in the western United States (Table 5). Age I and II rainbow trout were only 60% and 70%, respectively, of the average lengths at annulus formation of the populations reported in Carlander (1969), although lengths of older fish are closer (80 to 89%) to the average values. A somewhat different result is obtained from comparison of the McCloud River with other California streams. Data from Gerstung and Snider (Rubicon River Management Plan, California Fish and Game manuscript) shows the McCloud River rainbow trout growth rates to be at the upper 68 percentile of 18 rainbow trout streams in California. However, Hat Creek, which is also managed as a wild trout stream (Table 5), as well as two major tributaries to Shasta Reservoir (Pit River and Upper Sacramento River) have rainbow trout growth rates considerably faster than those observed in the McCloud River (Gerstung, personal communication).

Younger age classes of brown trout also show a slow growth rate compared to similar fish in other western streams, including Hat Creek (Table 5). Ages I and II are 69% and 77%, respectively, of average, but by year class III they are at 92% of average. After year III, growth accelerates, presumably because the trout are able to forage on abundant fish in Shasta Reservoir. Tippets (1976) found no evidence of piscivory in brown trout from the river to explain this accelerated growth. The moderately slow growth exhibited by both species may result from their reliance on epibenthic foraging rather than drift feeding (Tippets and Moyle, in press). In swift waters, epibenthic foraging is probably less efficient than drift feeding trout (Frost and Brown 1967, Waters 1972). Growth supression of younger age classes by dominant older fish may also contribute to the slow growth of the unharvested fish populations.

Growth data for all age classes of rainbow and brown trout were analyzed to project the impact of angling on the growth rates and age structure of the wild trout populations. One-way analysis of variance computations were performed to determine (1) if faster

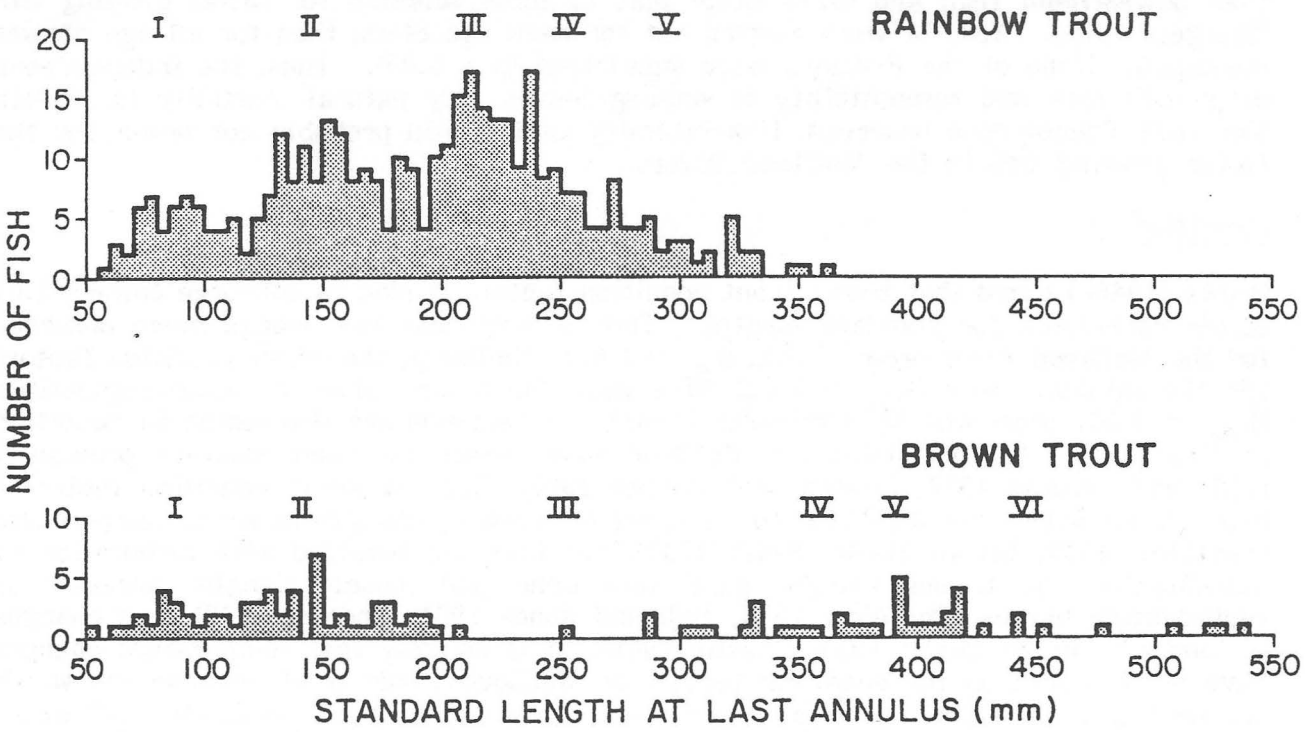

FIGURE 1. Length frequency histograms of rainbow trout and brown trout taken from the McCloud River in 1974, based on back-calculated lengths at time of last annulus formation.

Table 5. Comparison of the mean fork lengths (FL) at annulus formation of different age classes of rainbow and brown trout from the McCloud River with means from other streams in the Western United States and Hat Creek, Shasta County.

Age Class	Rainbow trout				Brown trout			
	McCloud River	Western Streams[1]		Hat Creek[2]	McCloud River	Western Streams[1]		Hat Creek[3]
	FL (mm)	Ave. FL (mm)	Central 50%	FL (mm)	FL (mm)	Ave. FL (mm)	Central 50%	FL (mm)
I	104	173	142-224	169	109	157	132-165	157
II	178	231	211-269	271	182	234	190-279	251
III	254	287	254-353	355	288	312	300-348	350
IV	322	361	315-445	387	427	368	348-406	428
V	370	460	368-508[4]	---	494	429	419-486	---
VI	385	---	---	---	519	465	340-622	---
VII	---	---	---	---	594	549	346-800	---

[1]From Carlander 1969.

[2]From Demas 1973.

[3]From Teleki 1972; best estimate from 1971 data, adjusted from TL to FL.

[4]Total range of means (central 50% not available).

growing fish were the first to be captured in an area; (2) if upstream fish grew faster than downstream fish; and (3) whether bait or lures selected for faster growing fish (Sturgess 1976). ANOVA were carried out for each age class, then for all age classes combined. None of the F-values were significant ($p = 0.05$). Thus, the independence of growth rate and susceptibility to angling leaves only natural mortality to explain the Lee's Phenomenon observed. Low-intensity angling will probably not select for the faster growing fish in the McCloud River.

Condition

Brown (1946b) found that brown trout condition factors tended to converge toward 1.61 (after conversion for standard length). This is very near the overall mean observed for the McCloud River brown trout, $\bar{K}_{SL} = 1.62$. Similarly, the mean condition factors for the rainbow trout ($\bar{K}_{SL} = 1.62$) were near the mean value for other populations ($\bar{K}_{SL} = 1.58$) presented by Carlander (1969). A mid-summer depression in condition factors similar to that noted for McCloud River trout has been observed previously (Ellis and Gowing 1957, Beyerle and Cooper 1960). Depressions in condition factor in brown trout have been attributed to a number of factors: changes in water temperature (Pentelow 1939, Brown 1946a, Swift 1955), the time lag involved with elaboration of accumulated fat tissues (weight gain) into bone and muscle (length increase) or reproductive organs (Pentelow 1939, Ball and Jones 1961, Thomas 1963), and changes in food availability (Swift 1955, Chastin 1969). It is unlikely that temperature changes have much effect on the condition factors of McCloud River trout because the water released from McCloud Dam is drawn from the bottom of the reservoir and water temperatures remain well within the optimal limits for trout throughout the summer. The time lag phenomenon also seems to be unlikely, since both rainbow and brown trout show the same chronology for the depression in condition factor, yet rainbow trout spawn in the spring while brown trout spawn in the fall. Tippets (1976) noted that the average fullness of trout stomachs was lowest in late August, as was the average number of invertebrates taken in bottom samples. These trends were coincident with the decline in condition factors. Thus, the mid-summer depression in condition factors may be at least partially the result of decreased food availability.

Status of Dolly Varden

In the late 19th Century, fishing for Dolly Varden was one of the main reasons anglers made the arduous trip to the lower McCloud River. At that time, Dolly Varden were abundant and attained large sizes in the river (Wales 1939). Following the acquisition of all land along the lower McCloud by fishing clubs in the early 1900's, records of Dolly Varden became infrequent. This was presumably because the members of the clubs were devotees of dry fly fishing and caught mainly rainbow trout. It is likely that the deline of the Dolly Varden to its present rare status post-dates the construction of Shasta Dam in 1940, which stopped large runs of chinook salmon (Oncorhynchus tshawytscha) from spawning in the McCloud River. The salmon may have served as a major source of food for the Dolly Varden, as eggs, fry, and carrion (Moyle 1976). The construction of McCloud Dam in 1965 may also have had a detrimental impact on the Dolly Varden, by stopping spawning migrations or other movements and by changing the flow regime of the river. A third factor perhaps contributing to the decline was the establishment of brown trout in the river, which are ecologically quite similar to the Dolly Varden in terms of food, occupation of deep pools, and spawning grounds (Moyle 1976).

Management

The three distinctive populations of wild trout (Dolly Varden, brown trout, rainbow trout) in the lower McCloud River each has its own management problems. Priority should be given to finding ways to increase the numbers of Dolly Varden, since they

are apparently still declining. An attempt by the California Department of Fish and Game to find Dolly Varden in the McCloud River in 1977 was unsuccessful (S.J. Nicola, personal communication). Largely as a result of the 1974 investigations, the California Fish and Game Commission has made it illegal to keep any Dolly Varden caught in California, and The Nature Conservancy now maintains the lower 4 km of the McCloud River in its Preserve as a Dolly Varden sanctuary, with no fishing allowed. Both measures should be continued until it can be domonstrated that the Dolly Varden population can sustain angling mortality or is extinct.

While rainbow trout, in contrast to Dolly Varden, are abundant in the study area, a consumptive fishery for them would not seem to be desirable. Such a fishery would be incompatible with the concept of the TNC Nature Preserve and natural study area, would probably increase fishing mortality of Dolly Varden, and would sacrifice a rather unusual angling opportunity, that of being able to fish a virtually unexploited population of trout. Although the growth rates of young trout of all species might increase following the removal of larger fish, the feeding conditions present in the river make it unlikely that the increased growth would compensate for the loss of the older fish (Tippets 1976). It is also possible that removal of large rainbow trout would increase the resident population of brown trout, which are less vulnerable to angling. The low number of brown trout in the river between 20 and 30 cm SL may be partially a response to the large numbers of rainbow trout in this size range (Figure 2). In recognition of the unique nature of the rainbow trout fishery in the lower McCloud River, the California Fish and Game Commission designated in 1976 the 11 km of river between McCloud Dam and the Dolly Varden sanctuary as a Wild Trout Stream. This section of the river is now closed to fishing with bait. The upper 6 km has a two fish limit and the lower 5 km a zero fish limit. In addition, The Nature Conservancy allows only 10 anglers at a time to fish the waters of the Preserve.

The brown trout population also provides an unusual management challenge although one quite different from those presented by the other two species. The brown trout that move up from Shasta Reservoir to spawn in the river are large and numerous and provide considerable sport for anglers. However, they are also exotic fish that may be displacing native Dolly Varden. Reduction of brown trout populations in the river could benefit the Dolly Varden populations if in fact the two species are competing for limited resources. However, a selective fishery for brown trout would require that fishermen be able to distinguish them from Dolly Varden and rainbow trout, which would require a special education program for McCloud River anglers. Despite this difficulty, special regulations permitting the take of brown trout in the area should be considered

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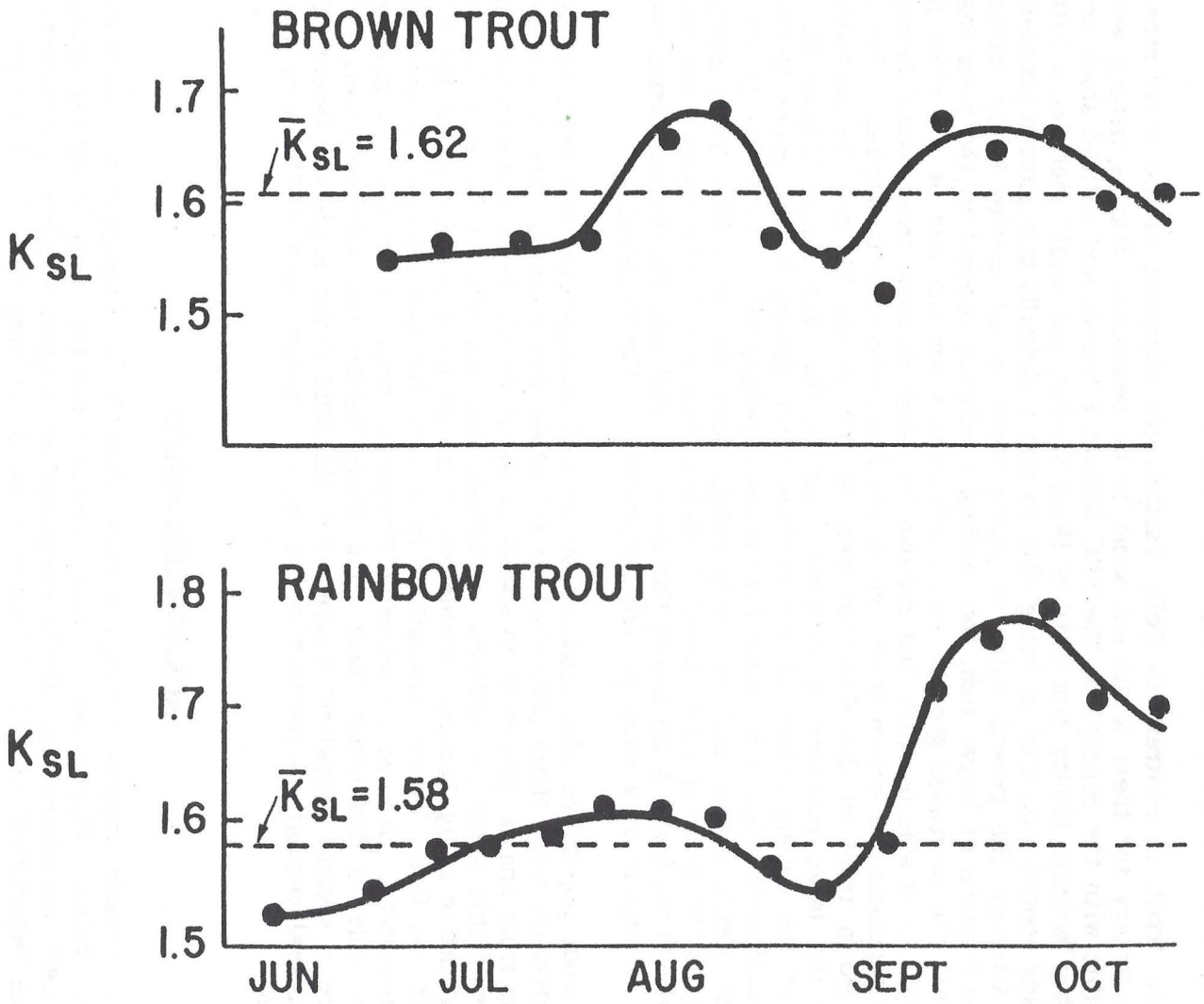

FIGURE 2. Condition factors (K_{SL}) of brown trout and rainbow trout from the McCloud River, CA, June through October 1974, based on 3-week moving averages. The dashed lines represent means for all fish.

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