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LAHONTAN CUTTHROAT TROUT (*ONCORHYNCHUS CLARKI HENSHAWI*) SPAWNING AND DOWNSTREAM MIGRATION OF JUVENILES INTO SUMMIT LAKE, NEVADA

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ABSTRACT.—The only remaining self-sustaining native population of lacustrine Lahontan cutthroat trout (*Oncorhynchus clarki henshawi*) not affected by nonnative salmonids is in Summit Lake, Humboldt County, Nevada. Annual spawning runs in 1993 and 1994 were monitored at a fish trap on Mahogany Creek, the only spawning tributary for Summit Lake. Number of spawners was similar in both years, with 1290 upstream migrants observed in 1993 and 1255 in 1994. In 1993, 137 postspawners (10.6% of upstream migrants) returned to the lake, and in 1994, 434 postspawners (34.6% of upstream migrants) returned downstream through the fish trap. Two distinct groups of subadult Lahontan cutthroat trout were observed moving downstream in 1994. The first group passed downstream between 27 April and 29 July and included 1188 fish (average fork length = 90 mm). Between 1 August and 31 October, 1160 fish (average fork length = 42 mm) moved downstream. Size differences of these 2 groups suggest that the 1st group comprised fish that had overwintered in Mahogany Creek, while the 2nd group were probably young-of-the-year.

Key words: Lahontan cutthroat trout, Oncorhynchus clarki henshawi, *Mahogany Creek, migration, Nevada, spawning, Summit Lake.*

Until relatively recent times, Lahontan cutthroat trout (*Oncorhynchus clarki henshawi*) was widespread and abundant in the northwestern American Great Basin of northern Nevada, northeastern California, and southeastern Oregon (Behnke 1992). The fish has been present in the area perhaps since mid-Pleistocene or Pliocene (Taylor and Smith 1981). Its range presumably expanded and contracted with regional climatic changes (Benson 1978, Benson and Thompson 1987, Grayson 1994), but when Europeans colonized the area it was found in most suitable waters (LaRivers 1962). Since the late 19th century, however, its range has declined substantially. Lahontan cutthroat trout has been nearly eliminated from former habitats in the western Great Basin and persists only in relatively small, isolated populations. It now occupies about 10% of former fluvial habitat and <1% of former lacustrine habitat (Coffin and Cowan 1995); it is federally listed as threatened (U.S. Office of the Federal Register 40[1975]:29864). The population of Lahontan cutthroat trout in Summit Lake, Humboldt County, Nevada, comprises the single secure lacustrine population remaining in native range (Coffin and Cowan 1995). Protection of this population is considered essential for recovery (Coffin and Cowan 1995), and this population has long been recognized as a valuable resource (LaRivers 1962). Behnke (1992) considers the native cutthroat trout from Humboldt Basin to comprise a separate subspecies from fish in other tributaries to pluvial Lake Lahontan (i.e., Truckee, Carson, and Walker rivers), but this determination has not been formally recognized.

Summit Lake formed in a relatively small, shallow basin (maximum depth ± 12 m) with no outlet (Fig. 1). The basin was formed 8000–19,000 yr ago (Mifflin and Wheat 1979, Curry and Melhorn 1990) by a landslide that blocked a channel south into Blackrock Basin. This effectively reversed the drainage pattern so that overflow from the lake should drain north into the Alvord Basin, although this has not been observed (LaRivers 1962, Curry and Melhorn 1990). All shoreline of Summit Lake except a small private inholding is contained within Summit Lake Paiute Reservation, established in 1913 (LaRivers 1962). Cutthroat trout comprises an important resource for Summit Lake Paiute Tribe, and preservation of the fish has been a primary concern of the tribal fisheries program (Cowan 1990).

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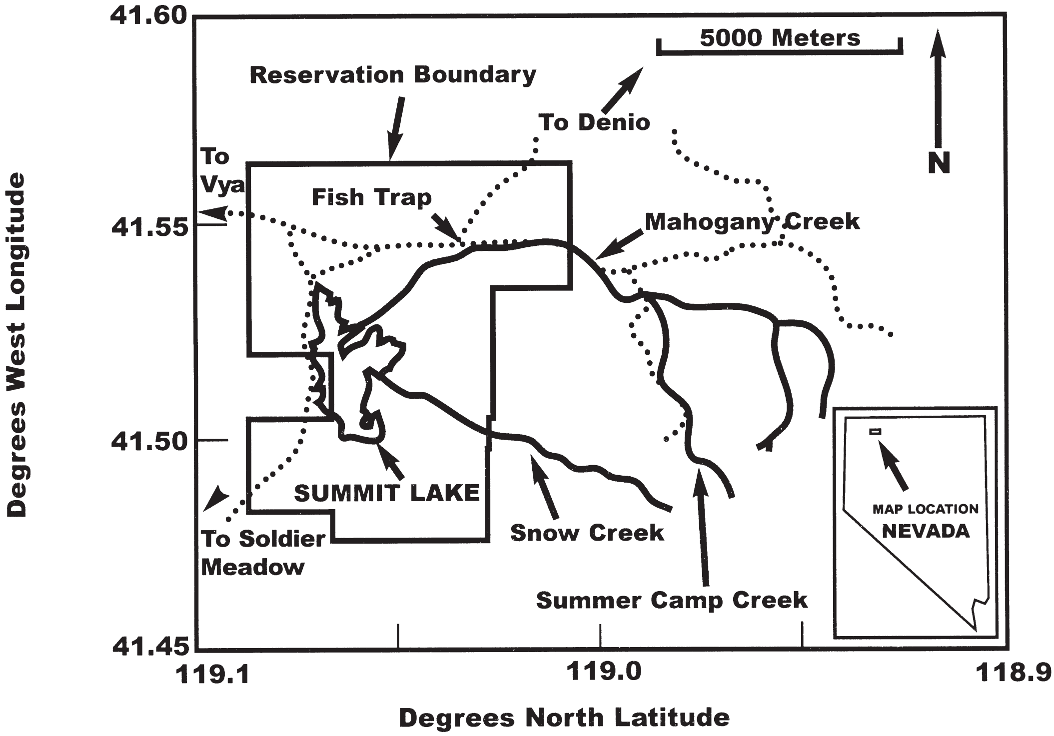

Fig. 1. Map of Summit Lake and Mahogany Creek, Nevada, the sole spawning tributary for *Oncorhynchus clarki henshawi* in the lake. Summit Lake Paiute Reservation encloses most of Summit Lake and the lower reaches of Mahogany Creek, Nevada. Site of the fish trap is approximately 2 km upstream from the lake within the reservation.

Mahogany Creek is the only tributary stream entering Summit Lake that supports reproduction by Lahontan cutthroat trout (LaRivers 1962). Mahogany Creek arises on public land administered by the U.S. Bureau of Land Management (BLM). It enters the reservation approximately 4.5 km upstream from the lake. Most gravel substrates suitable for trout spawning are on BLM land.

During the last 50 yr, range and riparian areas surrounding Mahogany Creek often have been intensively grazed. Destruction of much riparian habitat occurred before 1970 (Chaney et al. 1990). In 1974 a grazing exclosure was established on the BLM portion of Mahogany Creek, and the stream has recovered substantially (Chaney et al. 1990). Between 1968 and 1984 approximately 18 million eggs were taken from Summit Lake Lahontan cutthroat trout ascending Mahogany Creek for spawning, and approximately 968,000 fingerlings were stocked into the lake, comprising approximately 5% of the eggs taken (Cowan 1990). Additional concern was generated by the unauthorized introduction of nonnative minnnows (Lahontan redside, *Richardsonius egregius,* and speckled dace, *Rhinichthys osculus*) into the lake. Lahontan redside became abundant by the early 1980s, and it was unknown whether it might adversely affect spawning success of Lahontan cutthroat trout (Jack Piccolo personal communication). Cutthroat trout spawning runs declined, and by the mid-1980s there was considerable concern about its status and future prospects. Approximately 500 spawners were observed in Mahogany Creek in 1992 (Jack Piccolo unpublished data).

Because of apparent reductions in Lahontan cutthroat trout in Summit Lake, and because there are no published studies of Lahontan cutthroat trout spawning runs, we initiated a study of the adult Lahontan cutthroat trout run in Mahogany Creek during 1993 and 1994. We monitored adult fish movement upstream and downstream during the spawning season in both years and movement of juvenile fish downstream after spawning in 1994. Our study had 3 primary foci: to (1) thoroughly document timing and magnitude of spawning migrations of Summit Lake Lahontan cutthroat trout, (2) monitor the return of postspawning fish into Summit Lake to assess spawner mortality, and (3) examine downstream migration of juvenile fish into Summit Lake to assess recruitment success from the stream. Current recovery efforts for Lahontan cutthroat trout (Coffin and Cowan 1995) point out a lack of adequate data to assess population conditions in most native populations of Lahontan cutthroat trout. They also identify the Summit Lake population as vulnerable to extirpation because of its small size. Our study contributes to understanding population characteristics of an important population of Lahontan cutthroat trout and may be useful in effecting its recovery (Coffin and Cowan 1995).

METHODS AND MATERIALS

Summit Lake Paiute Tribe's fish trap on Mahogany Creek (Fig. 1) blocks the entire flow and allows selective retention of fish of various sizes by inserting different mesh screens into the structure. Virtually all suitable gravel substrates for trout spawning are upstream from the trap. Consequently, the trap permits examination of both up- and downstream passage of spawning adults and downstream movements of juveniles. The fish trap was operated in 1993 from 2 April through 6 June and from 27 July through 4 November. Operation in 1994 was nearly continuous from 3 April through 31 October. The trap was checked 2 or more times daily during the spawning run and daily otherwise.

After adult fish were captured, we weighed (nearest g) and measured (fork length [FL], nearest mm) them and determined their sex. Upstream adult migrants in 1994 were tagged in the transparent tissues behind the eye using visible implant tags (Northwest Marine Technologies, Shaw Island, WA) for subsequent identification. Nonspawning subadult fish (FL <200 mm) moving downstream through the fish trap were counted, measured, tagged with binary coded wire tags, and most were weighed (in 1994). Procedures usually required less than 1 min per fish, and fish were promptly returned to the stream either above or below the trap, as appropriate.

Water temperature was recorded at the trap in both years. Measurements during 1993 were made twice daily with a thermometer, and in 1994 continuous recording dataloggers connected to thermistors (Onset Instruments, Pocasset, MA) were deployed. Discharge measurements were secured from the U.S. Geological Survey gauge on Mahogany Creek (USGS site #10353750) near the reservation boundary.

Data were analyzed using 1- and 2-sample Kolmogorov-Smirnov tests, analysis of variance (ANOVA), analysis of covariance (ANCOVA), linear regression, and *t* tests. To adjust for allometric growth, log transformations were performed on size data. Statistical analyses compared spawner populations between years, between spawners moving upstream and spent spawners moving downstream, and between various groups of juvenile fish moving downstream through the fish trap. Statistical tests were performed using SYSTAT (Wilkinson 1996) software.

RESULTS

Upstream Spawners

In 1993, from 2 April through 27 May, 1290 fish (653 female, 637 male) moved upstream. Average FL and weight (n = 385) of fish migrating upstream during 1993 were 460 mm (s = 80.4 mm) and 1.127 kg (s = 0.572 kg), respectively. Weight-length regression ($W = aL^b$, where W = weight in g and L = FL in cm) values for migrating spawners were a = 0.027 and b = 2.760 (n = 385). Two peaks in upstream spawner movement were observed, the 1st on 9 April (111 fish) and a 2nd on 4–5 May (437 fish; Fig. 2A). These 2 peaks accounted for $>42\%$ of the observed spawning run.

Between 3 April and 5 June 1994, 1255 adult fish (784 female, 469 male) moved upstream through the fish trap (Fig. 2A). We tagged and released most (1223) of them upstream. Average FL and weight (n = 1245) were 462 mm (s = 78.5 mm) and 1.172 kg (s = 0.553 kg), respectively. Weight-length regression values were a = 0.024 and b = 2.797 (n = 1245). Maximum daily number of spawners entering the trap in 1994 (175 fish) was on 17 April. During the 10-d period beginning 14 April, 705 fish (56% of the total spawning run) moved upstream. This was followed by a decline in numbers, although there was a slight increase during the period 5–13 May when 217 fish (17% of the total spawning run) moved upstream. Number of fish moving upstream declined

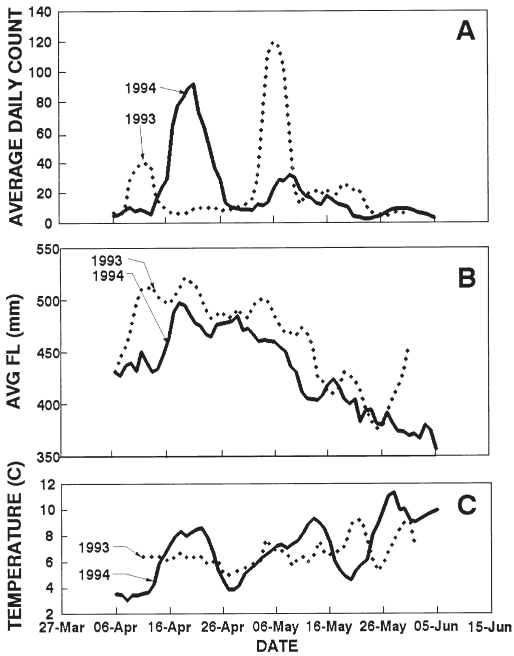

Fig. 2. Five-day running mean values of daily *Oncorhynchus clarki henshawi* count (A), fork length (B), and average daily temperature (C) at the Mahogany Creek, Nevada, trap during spawning runs in 1993 and 1994.

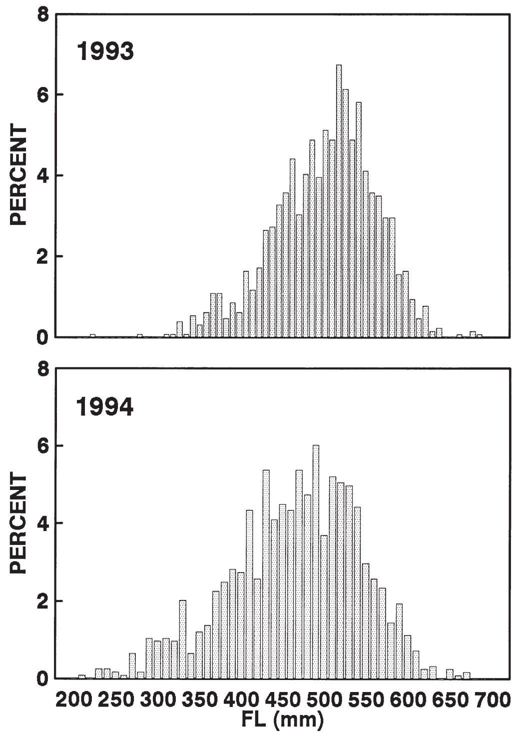

Fig. 3. Size frequency distribution (FL, mm) of adult *Oncorhynchus clarki henshawi* spawners at Mahogany Creek, Nevada, trap in 1993 and 1994. Total run in 1993 was 1290 fish, 1255 in 1994.

rapidly thereafter. We believe our observations spanned virtually all spawning fish in both years.

Average size of fish entering the trap showed similar patterns in both years (Fig. 2B). The first fish reaching the trap were relatively small but were quickly followed by the largest individuals within the first 20 d. Thereafter, average fish size generally declined over the remainder of the migration. Overall average fish length in 1994 (462 mm) was nearly identical to that observed in 1993 (463 mm). Length-frequency distributions were similar in both years (Fig. 3), and there was no significant difference (Kolmogorov-Smirnov, $P > 0.999$). Size distribution in both years differed significantly from a normal distribution (Kolmogorov-Smirnov, $P < 0.01$ in both cases). In 1993 both sexes were represented nearly equally in the upstream run (1.02 ♂:1.0 ♀), but the 1994 upstream migration was strongly female biased (0.58 ♂:1.0 ♀).

Ratio of male to female fish in adult Lahontan cutthroat trout moving upstream to spawn (♂:♀ ratio = 0.587) was higher than adults moving downstream (♂:♀ ratio = 0.426). This suggests that male fish experience higher mortality during spawning.

Downstream Movements of Spent Spawners

In 1993, 137 adult fish (10.6% of spawners) moved back to the lake through the trap. In 1994 more than 3 times as many spawners (434 fish, 34.6%) passed downstream from 26 April through 8 August (Fig. 4). Peak spawner return was in May. Spent fish passing through the trap included 129 males and 303 females (0.43 ♂:1.0 ♀). Average FL and weight were 441 mm (range = 227–610 mm) and 1.8 kg (range = 0.1–4.5 kg), respectively, both smaller than fish moving upstream. ANCOVA of log-transformed weight values using log-transformed length as a covariate revealed a significant reduction in weight in returning fish ($F = 7043$, df = 1, $P < 0.001$, $r^2 = 0.83$).

Tags were recorded from 344 (80%) returning spawners in 1994. Most tagged returning migrants had remained above the trap for

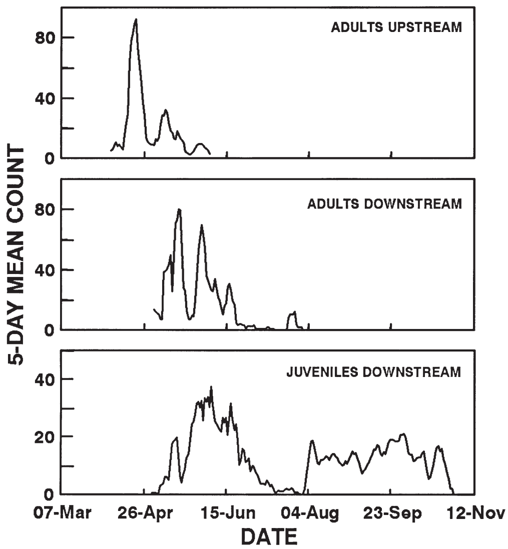

Fig. 4. Five-day running mean values of spawning adult *Oncorhynchus clarki henshawi* moving upstream, post-spawning adults moving downstream, and juveniles moving downstream through the Mahogany Creek, Nevada, trap in 1994. Two distinct groups of juvenile fish are evident moving downstream at different times.

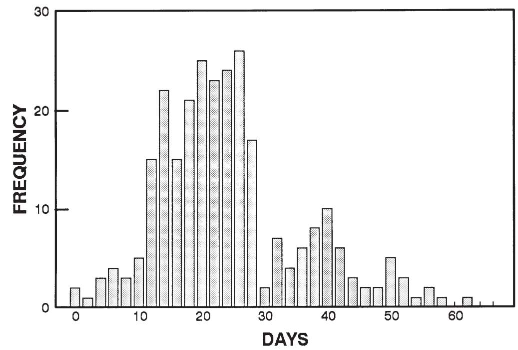

Fig. 5. Frequency distribution of days spent upstream of the trap by adult *Oncorhynchus clarki henshawi* spawners in Mahogany Creek, Nevada, in 1994. Data are derived from observations of adults tagged as they passed upstream through the trap and subsequently were recaptured as they moved downstream. No differences were detected between sexes (n = 280).

12–28 d (Fig. 5). Some individuals returned in fewer than 10 d, but more remained upstream in excess of 30 d (Fig. 5). Females remained upstream longer if they moved upstream early in the run (linear regression, b = –0.40, F = 29.68, r^2 = 0.09, P < 0.001; Fig. 6). However, the relatively small amount of explained variation suggests that other factors also affect results. A similar relationship was not evident for male fish. Number of days spent upstream by both males and females was significantly related to fish length (linear regression, b = 0.06, F = 14.31, r^2 = 0.05, P < 0.001; Fig. 7).

Multiple linear regression of day of the year (January 1 = 1) and 5-d running mean values for temperature against 5-d running mean values for fish entering the trap during 1994 indicated that both day and temperature were significantly correlated with number of upstream migrants (Table 1).

Juvenile Movements Downstream

In 1994 from 27 April through 31 October, 2348 juvenile fish entered the trap from upstream. Two periods were observed (Fig. 4). The 1st began in late April while spawning adults were still moving upstream and continued through late June. Maximum daily total counts of juveniles in this period were observed about mid-June. Average size declined over this period, from >110 mm FL at the beginning to <90 mm FL at the end (Fig. 8). Water temperature was highest during the period when downstream movement stopped.

The 2nd period began in early August and extended through October (Fig. 8). There was no trend evident in daily numbers of fish comprising this group. Fish in the 2 periods of downstream movement differed significantly in length (t test, T = 18.89, df = 91.6, P < 0.001). During the early migration, average FL and weight of 1188 juveniles were 90 mm (range = 24–199 mm) and 8.5 g (range = 0.1–71.8 g), respectively, and average size declined significantly over the period (linear regression, n = 69, a = 109.3, b = –0.411, F = 23.4, P < 0.001).

In contrast, 1160 fish in the later period (Fig. 8) were significantly smaller (average FL = 42 mm, range = 22–161 mm). Linear regression of fish size over time showed a significant increase over the later period (linear regression, n = 72, a = –0.68, b = 0.31, F = 119.1, P < 0.001).

DISCUSSION

Similar numbers of fish entered the spawning migrations from Summit Lake into Mahogany Creek each year. Timing varied

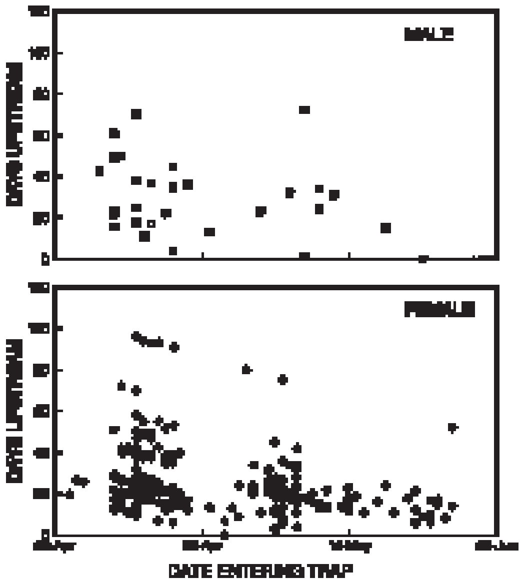

Fig. 6. Number of days *Oncorhynchus clarki henshawi* spent upstream of the trap in Mahogany Creek, Nevada, in relation to date of passing the trap in 1994. Earlier fish tended to spend slightly more time upstream before returning to the fish trap. There were no detectable differences between sexes.

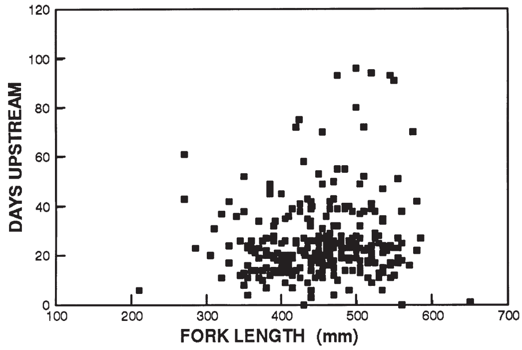

Fig. 7. Number of days *Oncorhynchus clarki henshawi* spawners spent upstream of the Mahogany Creek, Nevada, trap in relation to fish size (FL, mm) in 1994. Larger fish tended to spend slightly more time upstream before returning downstream. There were no detectable differences between sexes.

between years, but a relatively large proportion of each run occurred in fewer than 10 d.

Upstream spawner movement was most prominent when water temperature at the fish trap exceeded 6°C (Figs. 2A–C), and our results suggest upstream migrations were associated with relatively rapid water temperature increase. The correlation with water temperature is supported further by observation in both years that declining water temperature in late April coincided with reduced upstream movement. In a radiotelemetry study of spawning movements of Yellowstone cutthroat trout (*O. clarki bouveri*), Brown and Mackay (1995) also noted increased activity with increases in temperature. Other workers reported spawning by cutthroat trout at temperatures of 5.0–15.5°C (Varley and Gresswell 1988). Additional factors, such as discharge, density-dependent behavioral interactions, and other environmental conditions also probably affect migration timing.

A similar regression performed on 1993 data did not produce a statistically significant result. The discrepancy may be accounted for by observation in 1993 that 2 distinct peaks in upstream movement occurred, and that the 2nd migration in May included more individuals. The 1994 pattern was of a single dominant migration in early spring (April) with no comparable periods later in the summer. Significant results from 1994 thus should be viewed with caution; additional data are required to assess whether number of migrants is related to day or temperature. These results suggest that factors triggering fish movement upstream may vary in complex ways from year to year. Timing of gonad development and reproductive behavior, for example, are likely to be affected by multiple intrinsic and extrinsic factors. Our observations are consistent with suggestions that cutthroat trout exhibit a wide range of spawning behavior and life history strategies (Gresswell et al. 1994) as adaptations to different habitats (Brown and Mackay 1995) or to temporal variations in habitat quality (Nelson et al. 1987).

Spawning mortality was high in Mahogany Creek, and observed values (89% and 65% in 1993 and 1994, respectively) were outside the 13–60% range for spawning mortality rates reported for various populations of other subspecies of cutthroat trout (Platts 1959, Bjornn and Reiser 1991, Brown and Mackay 1995). It is not clear why the mortality rate was so much higher in 1993. High mortality may be related to somewhat later timing of the peak episode of upstream migration (Fig. 2A) or residual impacts of the previous year's drought. Mean fish size was slightly larger in 1993 (Fig. 3). This

TABLE 1. Results of multiple linear regression analysis of 5-day running mean *Oncorhynchus clarki henshawi* spawner catches in 1994 at the Mahogany Creek, Nevada, fish trap against Julian day and 5-day mean temperature in 1994.

Variable	Coefficient	$s_{\bar{x}}$	T	*P*		
Constant	111.87	15.54	7.20	<0.001		
Julian day	–1.17	0.16	–7.46	<0.001		
5-day temp	8.07	1.25	6.47	<0.001		
Source	SS	df	MS	*F*	*P*	r^2
Regression	14876	2	7438	30.05	<0.001	0.509
Residual	15348	58	264			

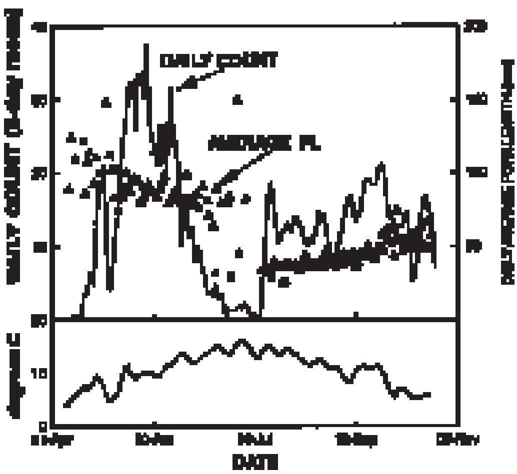

Fig. 8. Daily count of juvenile *Oncorhynchus clarki henshawi* moving downstream through the Mahogany Creek, Nevada, trap, and daily mean fork length (mm) of juvenile fish during the 1994 spawning run. The distinct size difference of the 2 different groups of moving juveniles is evident, as is the mean size decrease during the earlier movement and size increase in the later.

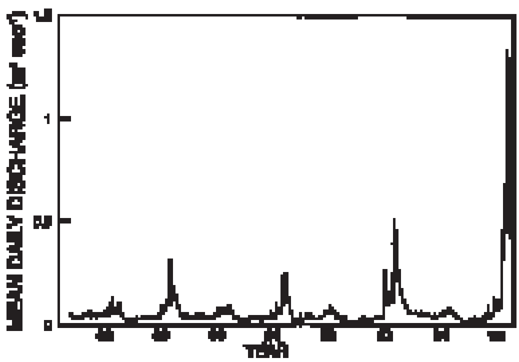

Fig. 9. Mean daily discharge of Mahogany Creek, Nevada, from 1987 through spring 1995. Data reported here include runoff in 1993 and 1994. These 2 yr differed substantially in total discharge and were the concluding years of an 8-yr drought in the area.

could be a result of fish delaying spawning from previous drier years (Fig. 9), making returning spawners potentially older than those in 1994.

Downstream movement of juveniles occurred during 2 distinct periods (Fig. 8). An early group passed through the trap at the conclusion of the spawning run in May and June. It was composed of approximately 1100 fish with an average FL of 90 mm. The 2nd group of juveniles comprised smaller-sized individuals (avg FL = 42 mm) that passed through the trap from August through October. Size and timing differences indicate the 1st group was probably produced in 1993 and had overwintered in Mahogany Creek. The decrease in average size of juvenile fish moving downstream during the spring and early summer (April–July) was unexpected, and we have no explanation for this pattern. The 2nd group of fish moving downstream (July–October) was young-of-year produced in 1994. Although not noted at the time, 2 size classes of juvenile fish were evident in data collected in 1990 (Cowan 1991).

Examination of cumulative rate of juvenile fish passage (Figs. 4, 8) indicates a significant pulse of fish moving downstream during spring and early summer from late April through July. This pulse built quickly to a peak in late May and then subsided; average fish size declined over the pulse. In early August, after this episode had concluded, another period of juvenile fish movement began. However, in this case the number of fish moving into the fish trap each day was relatively stable. A pattern of early summer movement suggests a response to different environmental factors in spring than in autumn. If we assume such downstream migrations are typical of this population, it is possible to estimate number of juvenile fish entering the lake on an annual basis. During the 3-month period from August through October, approximately 13.5 fish per day passed downstream through the fish trap. If fish continued to move downstream for 6–8 months at the rate observed in autumn, this could add approximately 2400–3300 juvenile fish into the lake. The actual number of fish moving into the lake is probably closer to the smaller figure because low temperatures and ice in Mahogany Creek are likely to reduce movements of juvenile fish during the heart of winter. If the pulse observed in late spring is typical, this might provide another 1000–2000 juveniles. This yields an estimated 3000–5000 juvenile fish entering Summit Lake annually.

In the 2 yr of our study the spawner population averaged approximately 1270 fish. Average number of females from both years was 723. Fecundity of fish 460 mm long would be approximately 2700 eggs (Sigler and Kennedy 1978). This would yield approximately 1.9 million eggs.

Future work at Summit Lake should retain operation of the Mahogany Creek fish trap to identify movements of large and small fish in both directions and should continue for as much of the year as the site is accessible. Intensive monitoring is consistent with recovery goals for Lahontan cutthroat trout (Coffin and Cowan 1995). There are many aspects of population demography of lacustrine and fluvial populations of Lahontan cutthroat trout that are poorly documented. Long-term studies of spawning behavior and reproductive success should assist in understanding cutthroat trout ecology and in developing models of population dynamics.

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