

FISHERIES SURVEY OF THE LOWER VIRGIN RIVER, BEAVER DAM WASH, ARIZONA TO LAKE MEAD, NEVADA

July 1993 - December 1997



BIO/WEST and Southern Nevada Water Authority fisheries biologists seining in the Virgin River.

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EXECUTIVE SUMMARY

In 1993 the Southern Nevada Water Authority and the Nevada Division of Wildlife initiated a cooperative study of the fish fauna of the Virgin River from Riverside, Nevada, to Lake Mead, Nevada. Emphasis was placed on woundfin (*Plagopterus argentissimus*), an endangered fish once common in this portion of the river. In 1996 the study was expanded to include all of the Virgin River below the Virgin Gorge in Arizona. The primary objectives of the study were to determine woundfin presence and abundance in the river and which reaches were most important to this species and other native fishes. Sampling with seines was initiated in July 1993 and concluded in October 1997. A total of 28 sampling trips (three to eight trips per year) were made during the 5 years of the study.

Flows during the 5 study years varied from very low to very high, with 1994 and 1996 being low flow years and 1993 and 1995 being high flow years. Portions of the lower Virgin River were dry in summer 1994 and 1996 (flow less than 5 cfs) due to irrigation diversions, whereas during the other years summer flows were generally greater than 50 cfs. Woundfin were found during the second trip in August 1993 and during every trip thereafter. The greatest numbers of woundfin were captured during low flow summers when they were concentrated in small pools and runs below riffles. Young-of-the-year were found in 1994 and 1995. The expansion of the study area in 1996 and 1997 resulted in woundfin captures near Mesquite, Nevada, but only very few were found near the mouth of Beaver Dam Wash, Arizona.

The data collected during the 5-year study indicate that a population of woundfin persisted in the lower Virgin River in spite of very low flows during some summers and large numbers of nonnative red shiner (*Cyprinella lutrensis*) which compete and/or prey on woundfin. Sufficient reproduction occurred in the woundfin population to make it self-sustaining, although some downstream movement of woundfin from upstream Utah populations may also have occurred. The population below Riverside was the largest in the lower Virgin River and was likely comprised of a few hundred adults. The population near Mesquite was smaller. No population appeared to occur near the mouth of Beaver Dam Wash, an area that contained thousands of woundfin up until the early 1980s. Substrate in this area had changed from a dominant sand type in the 1970s to a cobble type, favoring native speckled dace (*Rhinichthys osculus*), desert sucker (*Pantosteus clarki*), flannelmouth sucker (*Catostomus latipinnis*), and the endangered Virgin chub (*Gila seminuda*). Habitat use by woundfin during low, clear flow periods was different than during more normal flow periods. Sand substrate runs are typically used, but pools and runs below riffles were selected during low, clear flow periods.

Density of all species declined in late summer of low flow years in the lower Virgin River, which may have been due to high water temperatures (near 35°C). Woundfin have the highest Critical Thermal Maximum temperature (39.5°C) of the native Virgin River fishes and the nonnative red shiner. Reasons why woundfin favored the area below Riverside are not clear, although this area provided a mixture of riffle (cobble substrate) and run (sand substrate) habitat. Density patterns of woundfin in the three study areas sampled during 1996 and 1997 suggest that such a mixture of habitat is favored by woundfin; however, previous reports have suggested that sand substrate river reaches were favored by this species.

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BACKGROUND

The lower Virgin River in Nevada and Arizona has been highly altered by humankind for many years. Irrigation withdrawals were initiated in this portion of the river in the late 1800s and continue to the present time (USFWS 1995). The lower 35 miles (mi) of the river have been inundated by Lake Mead since the mid-1930s. These activities have had a negative effect on native fishes: two species that occupied this area, the woundfin (*Plagopterus argentissimus*) and the Virgin River chub (*Gila seminuda*), are now listed as endangered species. Woundfin, which inhabit main channel habitats, were likely once quite abundant in the lower Virgin River, but they have only been found seasonally in this portion of the river since the 1970s (Cross 1975). Virgin River chub were also likely common in deeper pool habitats in the lower Virgin River, and they were likely reduced in abundance by human activity (USFWS 1995). In the 1950s or 1960s a nonnative cyprinid, the red shiner (*Cyprinella lutrensis*), was introduced and became abundant in the lower Virgin River. Cross (1975) noted that this species may also have been a factor in declines of woundfin in the lower Virgin River.

During the mid-1970s, the Woundfin Recovery Team (now the Virgin River Fishes Recovery Team) (Recovery Team) initiated a woundfin monitoring program in the Virgin River. Monitoring stations in the lower Virgin River were located near the mouth of Halfway Wash (River Mile [RM] 41.00), just below the Riverside Bridge (RM 49.00), near the Bunkerville Diversion (RM 62.00), and near the mouth of Beaver Dam Wash (RM 72.00) (Figure 1). During the late 1970s, monitoring studies showed relatively high numbers of woundfin at the Beaver Dam Wash and Bunkerville Diversion stations, but only a few woundfin at the two lower stations. The general conclusion at that time was that woundfin were only found below the Bunkerville Diversion (Figure 1) during higher flow periods and that they disappeared later in the summer when flows were reduced by irrigation withdrawals. An abundant red shiner population at these two lower sites was also a likely factor in low woundfin numbers. At that time (late 1970s), red shiner was very abundant below the Bunkerville Diversion, but they were found in much smaller numbers above the Bunkerville Diversion. In the mid-1980s, woundfin numbers were reduced dramatically at Bunkerville Diversion and Beaver Dam Wash. At the same time, red shiner exploded in abundance above the Bunkerville Diversion and upstream into Utah to below the Washington Fields Diversion. The general conclusion of the Recovery Team has been that woundfin cannot sustain a population when faced with the potential competition and/or predation of an abundant red shiner population. Due to the abundance of red shiner and the results of earlier monitoring, the lower Virgin River was thought to not contain self-sustaining woundfin populations. Hence, monitoring at the Riverside Bridge and Halfway Wash stations was often not conducted during the 1980s and early 1990s.

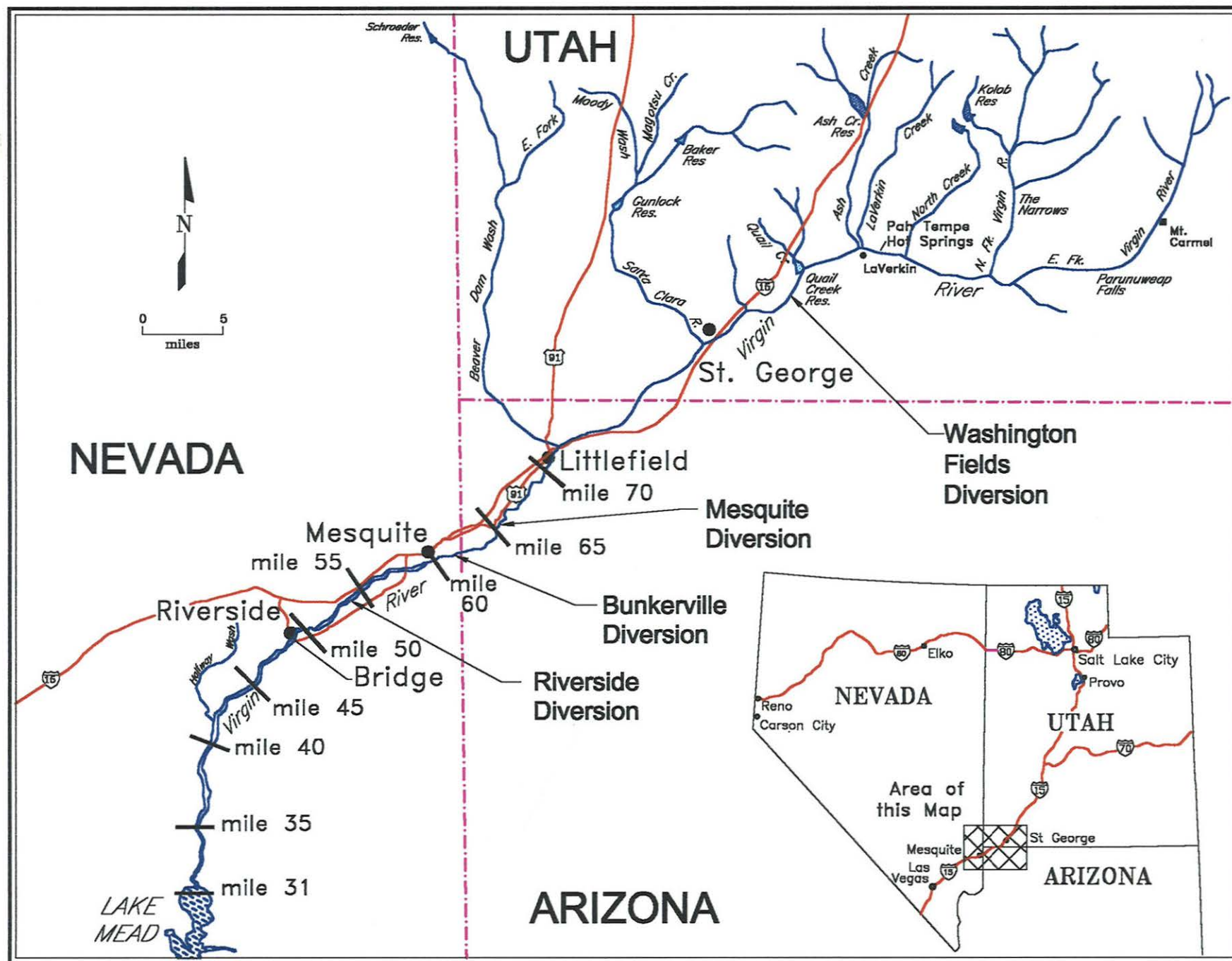


Figure 1. Map of the Virgin River study area.

STUDY OBJECTIVES

In 1993, the Southern Nevada Water Authority, through funding to BIO/WEST, Inc. (BIO/WEST) and the Nevada Division of Wildlife, initiated a cooperative study in the Virgin River below Riverside, Nevada. The initial objectives of the study were to:

- ▶ Determine if woundfin were still found in the lower Virgin River;
- ▶ Determine if woundfin reproduced in the lower Virgin River or originated from downstream drift; and
- ▶ Determine what habitats were used by woundfin in the lower Virgin River, and especially what habitats allowed them to survive low flow periods.

Studies during 1993 and 1995, both high flow years, and 1994, a low flow year, showed that woundfin were still found consistently in the Virgin River below Riverside, so in 1996 and 1997 the study area was expanded above the initial study area to also include the reach upstream to Beaver Dam Wash, Arizona. Objectives of this portion of the study were to:

- ▶ Determine the importance of various reaches in the lower Virgin River to woundfin;
- ▶ Determine if downstream drift significantly contributed to the Riverside woundfin population; and
- ▶ Determine what physical habitat factors appeared to be important in maintaining a woundfin population in the lower Virgin River.

This report details the results of the studies that were conducted from 1993 to 1997 to meet the objectives noted above.

STUDY AREA

The initial study area for the project was located in the lower Virgin River from Riverside Bridge to the termination of the Virgin River at Lake Mead, Nevada (Figure 1). River mile designations used in this study were taken from U.S. Geological Survey (USGS) quadrangle maps (1:24,000). River miles correspond to the distance upstream from the historical confluence of the Virgin and Colorado rivers. Data collection began at the Riverside Bridge (RM 49.25) during all sampling trips conducted in 1993, 1994, and 1995. During the initial sampling trip in July 1993, sampling was conducted to within 1.5 mi of the average inflow (approximate surface elevation of 1,200 feet [ft]) to Lake Mead (RM 34.50). Based on preliminary findings where few native fish were found below RM 40.00, the study area was abbreviated for subsequent sampling trips. Sampling during the August and October 1993 trips was terminated at RM 38.75 and RM 38.25, respectively. In 1994, the study area was terminated at about RM 41.00. Therefore, the primary study area in the Riverside reach from 1993 to 1995 was an 8-mi reach between RM 49.25 (Riverside Bridge) and RM 41.00 (Halfway Wash). This report includes only the data collected in this reach for 1993 to 1995.

The study area was expanded in 1996 and 1997 to encompass the section of river from Beaver Dam Wash to Lake Mead. Specifically, a 3.5-mi section of river downstream of Beaver Dam Wash (RM 72.00 to RM 68.50) and Mesquite Bridge (RM 58.00 to RM 54.50) was consistently sampled in 1996 and 1997, in addition to a 3.5-mi reach below Riverside Bridge (RM 49.25 to RM 45.50).

METHODS

Study Design

As discussed above, the study was conducted in two parts, corresponding to the areas sampled. From 1993 to 1995, only the Riverside reach was consistently sampled. From 1996 to 1997, three reaches were sampled: Beaver Dam Wash, Mesquite, and Riverside. Sampling techniques were the same for the two time periods (1993 to 1995 and 1996 to 1997) and between the three study reaches.

For purposes of analysis, the study design followed a stratified random sampling design. The three study reaches were stratified into 0.25 mi sections and habitats were randomly sampled within these reaches, generally based on availability. Habitat types were categorized as run, riffle, pool, backwater, eddy or other. The Virgin River in the study area was dominated by run and riffle habitat; these types were sampled in proportion to their availability. However, almost every individual, rare habitat type encountered, such as pools and backwaters, was sampled because it occurred so infrequently.

Data Collection

Sampling protocol involved walking downstream through each reach, selecting habitats based on availability, and likely sampling efficiency for seines, the primary sampling tool. During the first trips, each sample consisted of three seine hauls conducted in the same location. The three-pass sample was modified in subsequent trips to allow more of the available habitats to be sampled. The seining protocol was altered so that multiple passes were only conducted if the initial seine haul contained woundfin. Spatially, sampling was randomly applied within 0.25 mile sections. Some samples were taken in adjacent habitats, whereas in long, consistent sections of stream, samples may have been separated by as much as 100 yards (yd). Several types of seines were used for fish collection, including a 30 ft x 6 ft with a 0.25 inch (in.) mesh, a 10 ft x 4 ft with a 0.125 in. mesh, and a 4 ft x 15 ft seine with 0.125 in. mesh, although the 4 ft x 15 ft seine was the primary sampling tool.

The following information was recorded for each sample: sample number, river mile in quarter mile increments, reach, date and time of collection, habitat type, gear type, approximate length and width of the sampling unit, average and maximum depths, the two dominant substrate types (silt, sand, fine gravel [<1 in. diameter], course gravel [1 to 3 in. diameter], small cobble [3 to 6 in. diameter], large cobble [6 to 10 in. diameter], and boulder [>10 in. diameter]), and cover availability. A sketch and written description were recorded for unique habitats and for locations that contained uncommon fish species. Photographs were taken of various habitat types and atypical sections of the Virgin River.

The total number of each fish species captured in each seine haul was recorded. When more than 50 red shiner were captured in a single seine haul, their number was estimated. All native fish species and uncommon species (less than 25 captured) were measured for total length (TL).

Electrofishing, using a canoe to hold the generator and VVP unit, was attempted during the August 1993 trip to sample deep pools. This method proved to be labor intensive and relatively ineffective in the turbid river, and it was not attempted again. Electrofishing data are not included in this report.

Stream temperature was measured with a hand-held mercury thermometer approximately every hour during sampling trips. Flow information was obtained from the USGS for the Virgin River at Littlefield gage. Flows in the river were checked via telephone prior to field trips. Trips were not conducted when average daily flows were over 300 cubic feet per second (cfs), since this flow level made seining in the river difficult and inefficient. Five to seven sampling trips per year were generally scheduled to occur seasonally. In total, eighteen trips were conducted from July 1993 through December 1995.

The same methods used from 1993 to 1995 were continued during the 1996 to 1997 period when the study was enlarged to include the reaches above Riverside. The three study reaches that were established were based on the amount of river that could be sampled during 1 day on each reach (about 3.5 miles) and on reasonable river access.

Data Analysis

Due to changes in sampling protocol (from three seine hauls per sample to only one), data analyses only included information from the first seine haul at each location. Catch rate was calculated as the number of fish caught in the first seine haul per 10,000 square feet (ft²) area seined. In some analyses, woundfin numbers rather than catch rates were used because these data sometimes reflected a more real condition for rare catches. Catch rates used in analyses were log₁₀-transformed to reduce heteroscedasticity (Zar 1984). An *a priori* α value of 0.1 (10% chance of type I error) was set for all statistical tests due to the high level of natural variation in the dynamic Virgin River system and because of low sampling sizes for some treatments.

1993 to 1995 8-Mile Riverside Reach

Analyses were performed to determine the following: (1) if densities of woundfin varied among sampling trips; (2) if this variation could be explained by seasonal, annual, or flow factors; and (3) if woundfin occupied specific reaches or habitat types in greater densities. First, an analysis of covariance (ANCOVA) using sampling trips as the main factor and discharge as the covariate was conducted to determine if woundfin densities varied among sampling trips. Discharge was used as a covariate because it was suspected that discharge affected sampling in a predictable pattern where efficiency decreased with discharge. To determine if seasonal or annual factors explained variation in woundfin densities, a two-way analysis of variance (ANOVA) using year and season as treatments was conducted. For purposes of analyses, season was generally based on flow patterns related to flows. Seasons were defined as summer (July and August), fall (September, October, November) and winter/spring (December through June). Interaction between season and year was also included in this model.

Two-way Pearson chi-square tests were conducted using the percentage of sampled habitat as the expected value and the percentage of occupied habitat as the observed value to determine if woundfin and other native fish (flannelmouth sucker, desert sucker, and speckled dace) occupied specific habitat types in a different proportion than their availability. For purposes of analyses, habitat was categorized as run, riffle, and all others (eddy, backwater and pool). The two-way Pearson chi-square tests were also conducted for substrate and depth categories to determine if woundfin and other native species occupied specific substrate and depth conditions. Primary substrate type was grouped into sand/silt, fine gravel, coarse gravel, small cobble and large cobble/boulder categories, and depth was broken into 6 categories: 1" to 3", 4" to 6", 7" to 9", 10" to 12", 13" to 15", and >15".

1996 to 1997 Three 3.5-Mile Reaches

To determine if woundfin occupied specific reaches in greater densities, a two-way ANCOVA was conducted using reach and year as treatments and discharge as the covariate. Year was included in this model to determine if annual variation was significant regardless of discharge. The same ANCOVA was conducted for red shiner densities among the three reaches.

Marked Woundfin and Virgin River Chub

The Nevada Division of Wildlife initiated stocking of marked woundfin and Virgin River chub at various locations within the study area in October 1993. Several tagging methods were used to identify the stocked fish, including wire tags, dye, and clipped dorsal spines. All woundfin were checked for all types of marks upon capture. Coded wire tags were detected with a magnetic scanner. In most cases dye marks were readily apparent, and clipped dorsal spines were always recognizable.

Habitat Sampling Trip

Habitat sampling was conducted in December 1997 to gain information concerning reasons for the distributional differences between native and nonnative fishes for the three study reaches. Data were collected by first identifying channel type and habitat type for a portion of river and then measuring various aspects of the river within each habitat type. Channel types included main channel, large side channel (>one-third of flow but not more than one-half) and small side channel (<one-third of flow). Identified habitat types included backwaters, eddies, riffles, runs, pools, and pools below riffles. Area (in ft²) of each habitat was determined by pacing and measuring tape. Average and maximum depths were measured in inches with a yard stick, and dominant and subdominant substrate size was determined visually. Substrate types included silt, sand, fine gravel (<1 in. diameter), coarse gravel (1 to 3 in. diameter), small cobble (3 to 6 in. diameter), large cobble (6 to 10 in. diameter), and boulder (>10 in. diameter).

RESULTS

Flow and Temperature

Figure 2 shows the flow in the Virgin River at the Littlefield USGS gage (see Figure 1 for location) during the course of the study. Flows during 1993 and 1995 were generally high with large runoff floods and relatively high summer flows. Flows during 1994 and 1996 were low, with small runoff peaks and flows below 100 cfs at the gage by June. Flows during 1997 were moderate to low, with higher June and July flows than in 1994 and 1996, but summer flows were considerably lower than in 1993 and 1995.

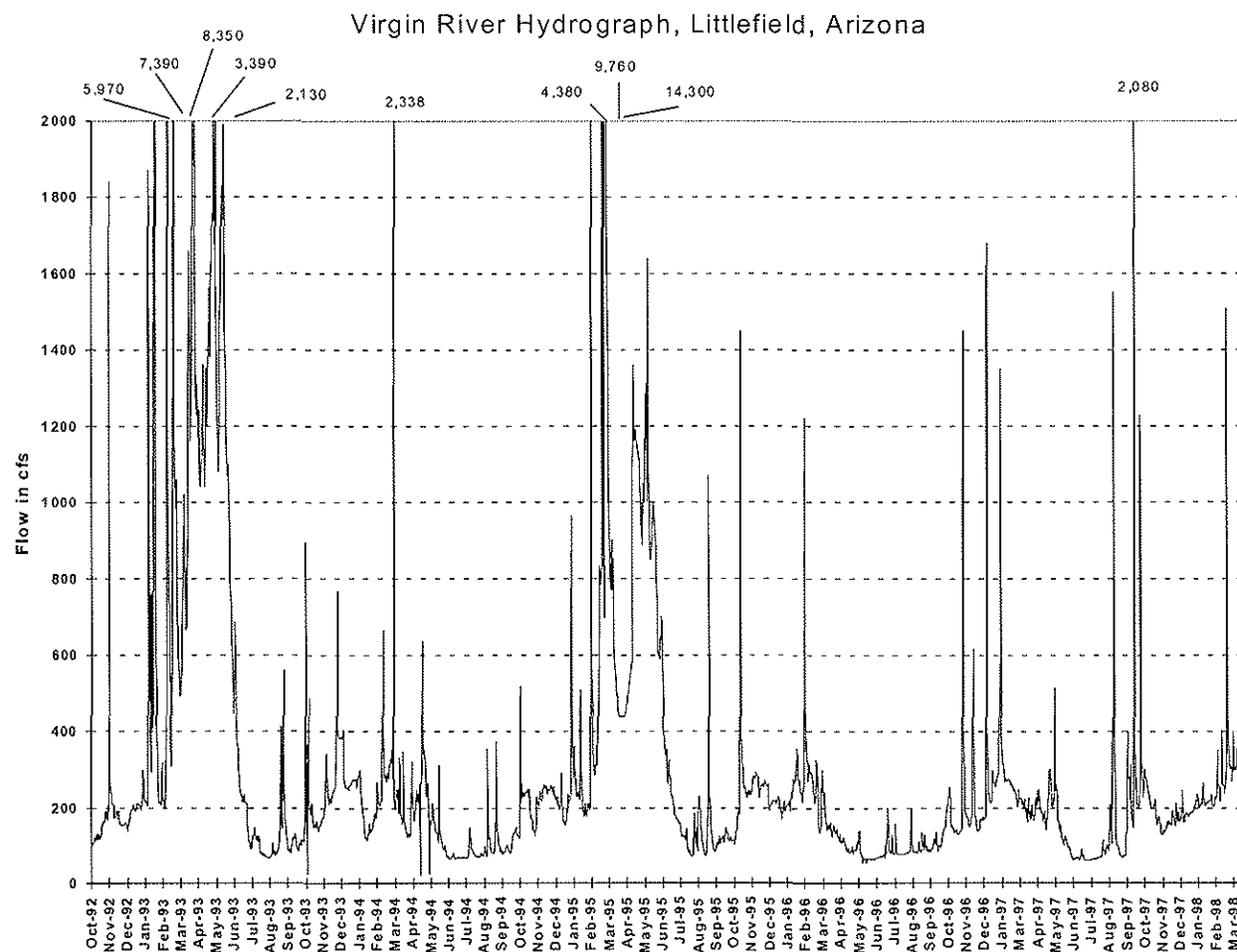


Figure 2. Daily mean flow of the Virgin River at the USGS gage near Littlefield, Arizona, 1992 to 1998.

Flows at the Riverside reach were generally lower than at the Littlefield gage during summer months due to the three irrigation diversions below the gage (Figure 1): the Mesquite, Bunkerville, and Riverside diversions. During July and August 1994 and 1996, flows at the Riverside Bridge were nonexistent due to all river flow being diverted at the Riverside Diversion, although channel seepage and irrigation return flows resulted in flows of up to 10 cfs about 0.5 mi below the bridge (Plate 1) Flows at the Mesquite reach were also lower than flows recorded at the gage, since the Mesquite and Bunkerville diversions are above the gage. During sampling trips, flows at the Mesquite reach never were as low as those at the Riverside reach, in part because of its location above the Riverside Diversion. Flows at the Beaver Dam Wash reach were the same as flows recorded at the Littlefield gage, since the gage was within that reach.



Plate 1. Virgin River at the Riverside Bridge, July 15, 1994, RM 49.25.

Figure 3 shows the lowest and highest daily stream temperatures that were recorded during the sampling trips at the Riverside reach. Temperatures ranged from 7° Celsius (C) in January 1994 to a high of 36°C in August 1996. The highest temperatures were generally recorded during the summer months of 1994 and 1996 (Figure 3) when flows were the lowest (Figure 1). Daily temperature swings varied from only a few degrees to a 15.5°C change in July 1994 at the Riverside reach when early morning temperature was 18°C and the mid-afternoon temperature was 33.5°C. Temperatures at the Mesquite reach in 1996 and 1997 were similar to those at the Riverside reach,

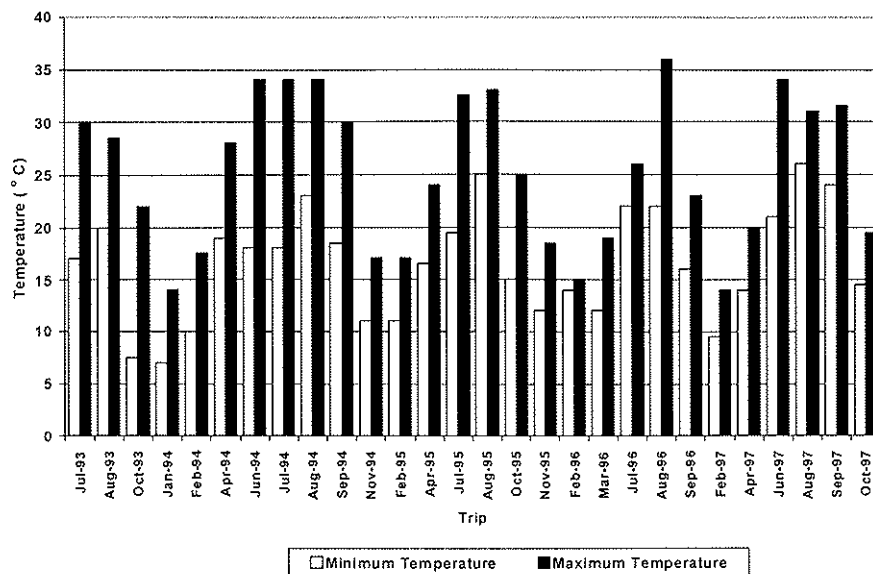


Figure 3. Maximum and minimum surface water temperature as measured during sampling trips in the Virgin River, 1993 to 1997.

although slightly lower on average with summer highs in the 30 to 33°C range. Summer temperatures at the Beaver Dam Wash reach were also slightly lower on average than temperatures at the Riverside reach, and fell in the 28 to 32°C range. Winter temperatures at the Beaver Dam Wash reach were slightly higher than at the Riverside reach, probably due to higher flow and the effect of warm spring inflows.

The Virgin River is typically fairly turbid, with high amounts of silt and a shifting sand bottom in many locations. Turbidity was not measured during the study, but it was high during most sampling trips. The exception was during low flow periods, such as the summers of 1994 and 1996, when clarity of the Virgin River improved dramatically, especially below the Riverside reach. No flow occurred between the Riverside Diversion and the Riverside Bridge during July and August 1994 or in 1996, so the small flow below the bridge, primarily from stream channel seepage, was exceptionally clear.

Riverside Site, 1993 to 1995

Woundfin Collections

The first sampling trip was conducted in July 1993, and no woundfin were collected, but they were found during the second trip (August 29 to September 2) and on all subsequent trips (Figure 4). The amount of sampling during each trip varied, from a low of about 75 sites seined during the first trip to over 200 sites seined during later trips (Figure 5). This near tripling of sampling sites was due to a change in methods as described in the Methods section. Reduced numbers of samples were also made in July and August 1994 during very low flow periods when the Virgin River above the Riverside reach was dry, and fewer habitats were available for sampling.

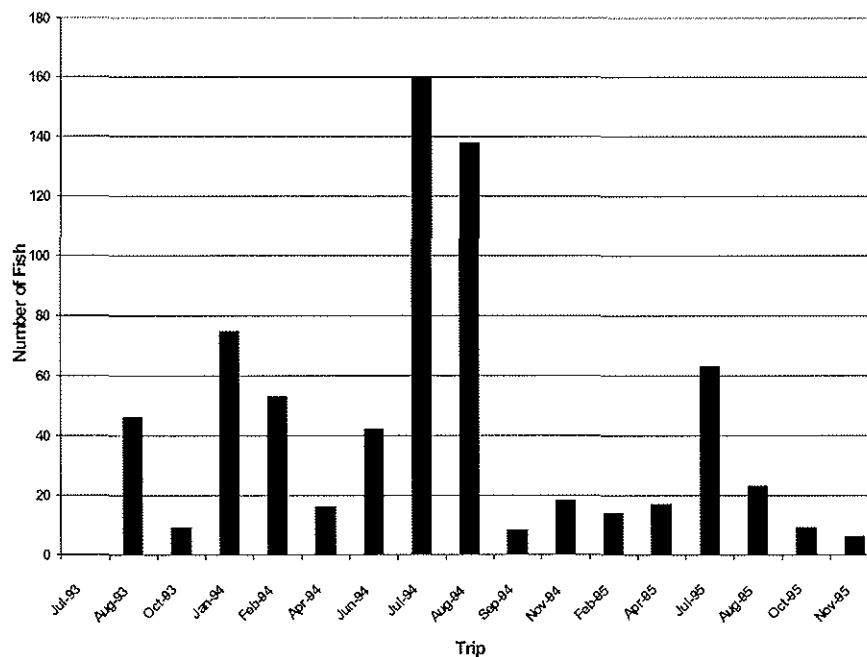


Figure 4. Number of woundfin collected by sampling trip in the Virgin River at the Riverside reach (RM 41.00-49.25), 1993 to 1995.

Numbers of woundfin collected varied between sampling trips, from a low of 0 in July 1993 to a high of 160 in July 1994. Numbers of woundfin collected were generally low (<20 per trip), except for July and August 1994 trips. Following a general yearly pattern, numbers of woundfin dropped during fall sampling, and increased during the next winter. In addition, numbers of woundfin appeared to drop after August 1994, and they remained low during the remainder of the study.

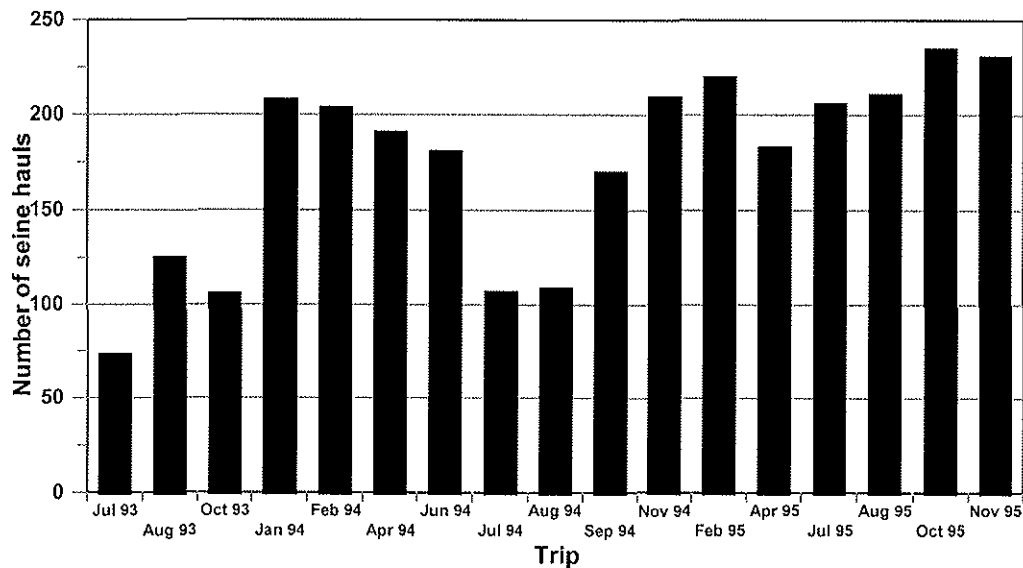


Figure 5. Number of seine hauls made per sampling trip in the Virgin River at the Riverside reach (RM 41.00-49.25), 1993 to 1995.

Catch rates tended to show less variability than the total numbers collected (Figure 6), except for July and August 1994, when catch rates rose dramatically. Because the July and August 1994 catch rates were obvious outliers, they were excluded from the statistical tests of these data. Based on the ANCOVA using discharge as a covariate, catch rates between trips were not significantly different except for the periods of August 1993, January 1994, and July 1995, which were significantly higher ($p < 0.001$). This analysis supported the conclusion that catch rates were generally low ($< 10/10,000 \text{ ft}^2$) and relatively consistent, except for summer 1994 samples.

Discharge was not a significant covariate ($p = 0.119$), which suggests that variation in catch rates was not related to flow magnitude. A comparison of catch rates with flow is shown in Figure 7. Catching more fish with seines during lower flows is possible because there are fewer usable habitats in the river, the fish should be more concentrated, and more of the available habitat can be sampled with a given number of seine hauls. But the relationship between flow rate and catch rate was not significant since the catch rate at most flows (trips) was fairly similar, except for the two very low flow periods in 1994.

Very high catch rates seen during July and August 1994 (which were not included in the ANCOVA) were likely due to a combination of reduced sampling effort and larger numbers of fish collected (Figure 4 and Figure 5) during a low flow period. Flows at the Littlefield gage during July and August 1994 were near 65 cfs, the lowest of the study period, and flows below Riverside Bridge were from 0 to about 5 cfs. In addition, the water below Riverside Bridge was also exceptionally clear since most of it was seepage from the river bed.

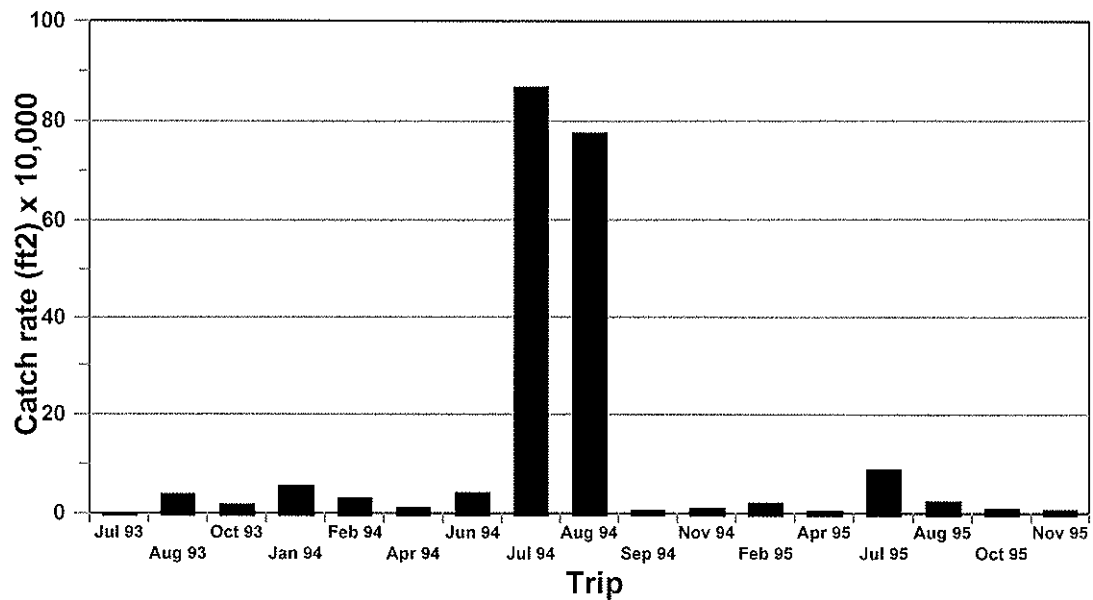


Figure 6. Catch rate (# per 10,000 ft² of seining) of woundfin by sampling trip in the Virgin River at the Riverside reach (RM 41.00-49.25), 1993 to 1995.

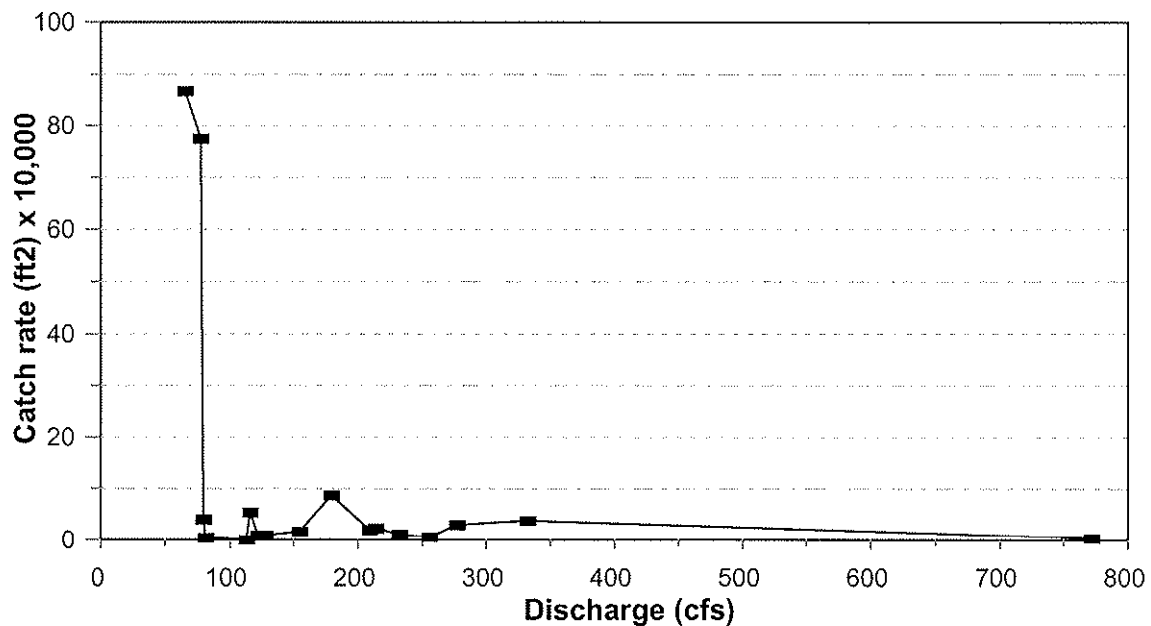


Figure 7. Catch rate (# per 10,000 ft² of seining) of woundfin in the Virgin River at the Riverside reach (RM 41.00-49.25) compared with the highest flow recorded at the Littlefield USGS gage during sampling trips, 1993 to 1995.

These data suggest that there is not a good relationship between flow and woundfin catch except at very low flows. This analysis suggests that woundfin were generally evenly distributed in portions of the study area during all flows, except the very low flow period of 1994. The great difference in both numbers caught and catch rate for the summer 1994 samples also suggests that woundfin were concentrated during this period.

The pattern of lower numbers in the fall was also evident in the catch rates, which declined in the fall compared with spring and summer catch rates. The drop in numbers noted after August 1994 was not as dramatic in the catch rate, suggesting that the reduction in numbers of woundfin collected was, at least in part, related to sampling effort, but a decline after August 1994 was still evident. Based on a two-way ANOVA on catch rates that included the July and August 1994 data, there were significant differences among seasons and years, as well as a significant interaction between season and year. Post-hoc pairwise tests showed that summer had highest densities, and fall had the lowest densities (all $p < 0.01$). In addition, density in 1994 was significantly higher than in 1995 ($p < 0.001$). This test supported the conclusion of lower numbers each fall and lower numbers in 1995 following the 1994 low flow period. The use of the summer 1994 data adds some bias to this analysis since they were obviously different, but the analysis did show that winter/spring and fall samples were also different.

Woundfin were found in all reaches of the Virgin River from RM 49.25 to RM 41.00 (Figure 8), although abundance peaked around RM 45.00 to 46.00 in 1993 and 1994. In 1995, woundfin were somewhat more scattered than they were during the previous 2 years. Abundance in 1995 peaked at near RM 48.00, just below the Riverside Bridge. One potential cause for the change in distribution in 1995 was the high spring flows of 1995 (Figure 2) that rearranged much of the river. Daily flows up to 14,300 cfs occurred that year, and the flood resulted in numerous channel changes, created new channels in some locations, and deposited numerous rootwad clusters in the stream channel.

Size classes of woundfin collected by trip and year are shown on Figures 9, 10, and 11. No young-of-the-year (YOY) were collected in 1993, but they were found in July and August 1994 and 1995 as evidenced by fish in the 20 to 30 millimeter (mm) TL size range (Figures 10 and 11). Growth of woundfin could be traced from sample to sample. For example, the primary cohort collected in August 1993 averaged 45 to 50 mm TL. By October, they were 55 to 60 mm TL. In January and February of 1994, they were 60 to 65 mm TL, and they increased to 75 to 80 mm TL by fall 1994. A second, smaller cohort of YOY also was collected in June 1994 and July 1994. By spring 1995, the original (1993) group of fish were 80 to 90 mm TL, but they were found in only small numbers and disappeared after spawning in the spring. This growth information suggests that the fish collected were the same group from year to year, entering the collections generally at 30 to 40 mm TL and disappearing at 80 to 90 mm TL. Generally, two distinct age cohorts can be seen during 1994 and 1995. The 1993 and 1994 cohorts in 1994, and then the 1994 and 1995 cohorts in summer 1995. This suggests that woundfin became sexually mature at the end of their first year in the river, spawned for two springs, and then disappeared following spawning the second year. Hence, they lived for only 24 months or slightly more, but spawned twice during that period.

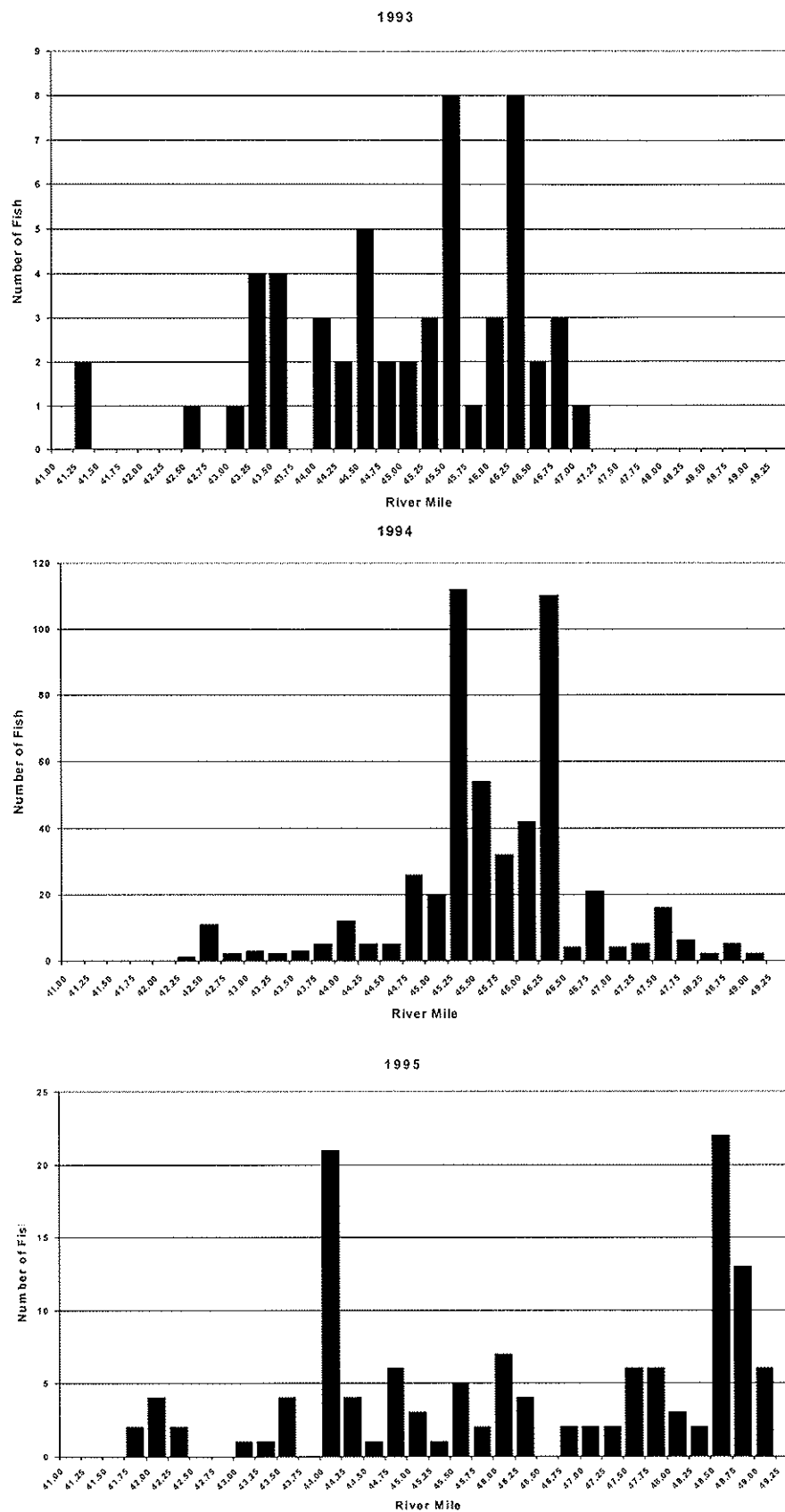


Figure 8. Number of woundfin collected by quarter river mile in the Virgin River at the Riverside reach (RM 41.00-49.25), 1993 to 1995.

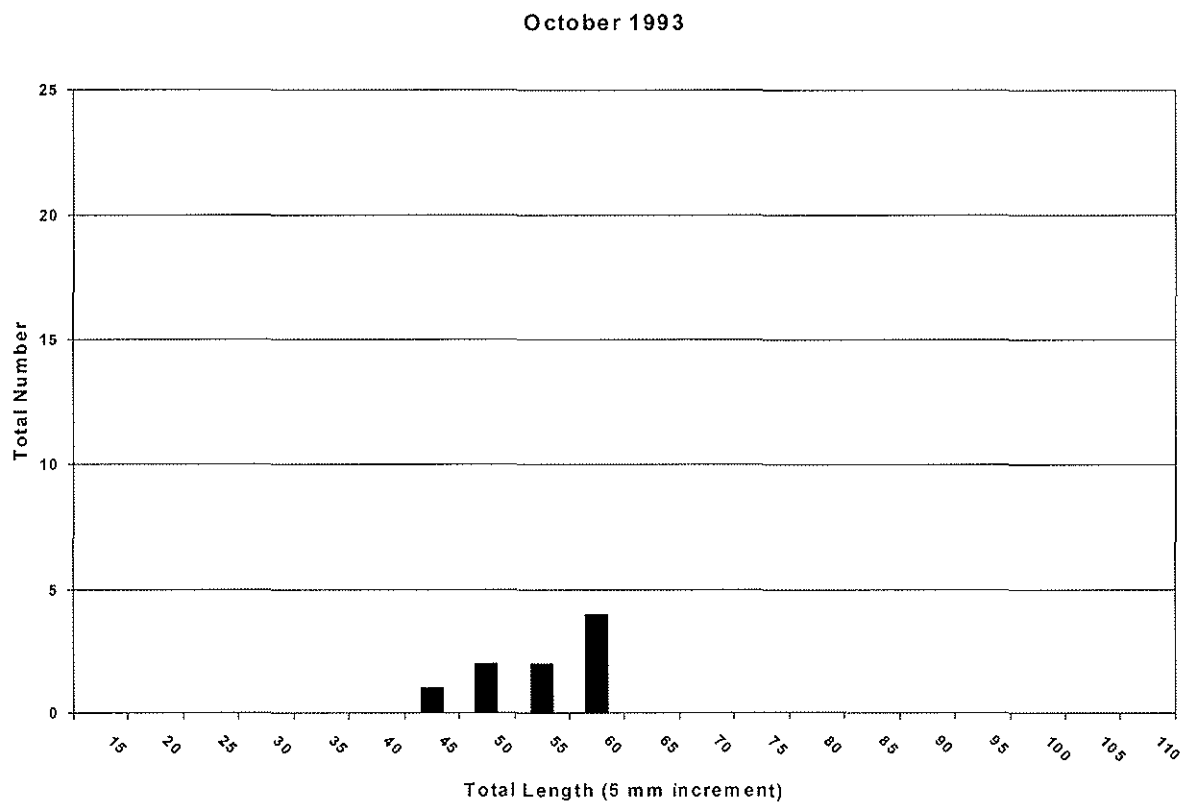
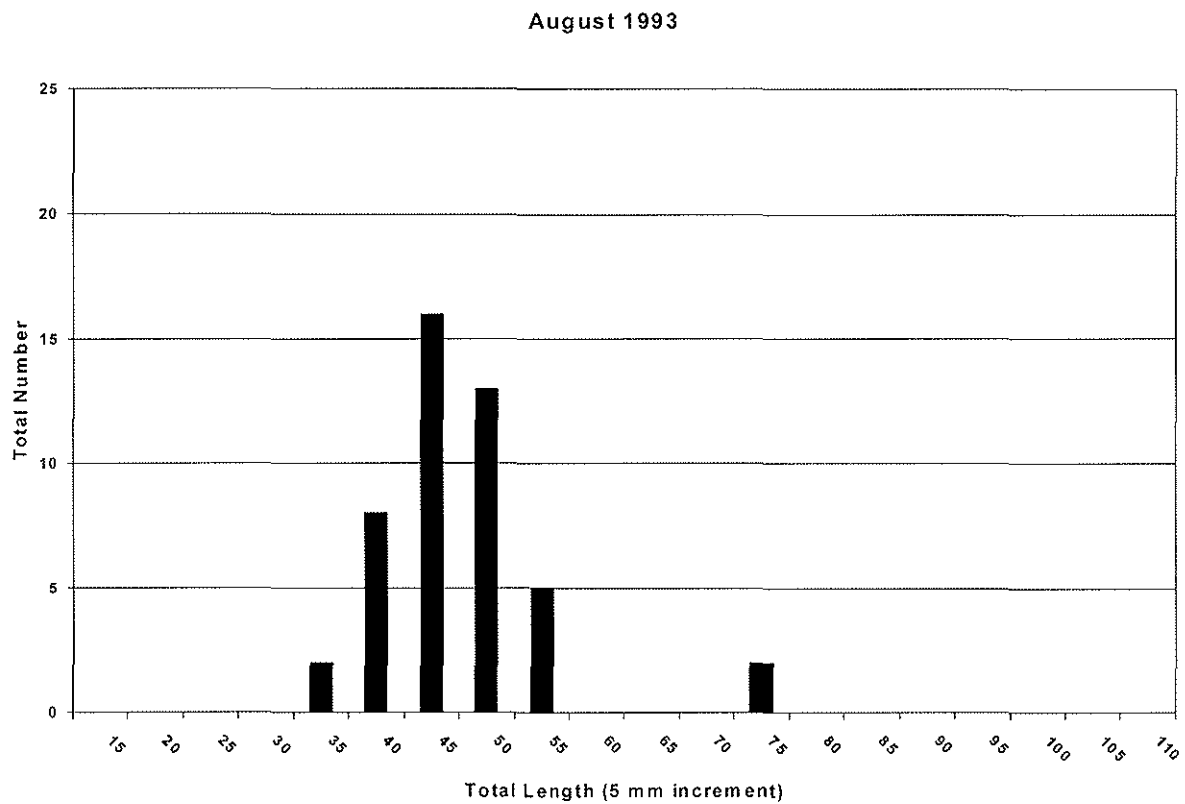


Figure 9. Length-frequency analysis for woundfin collected in the Virgin River at the Riverside reach (RM 41.00-49.25) by sampling trip in 1993.

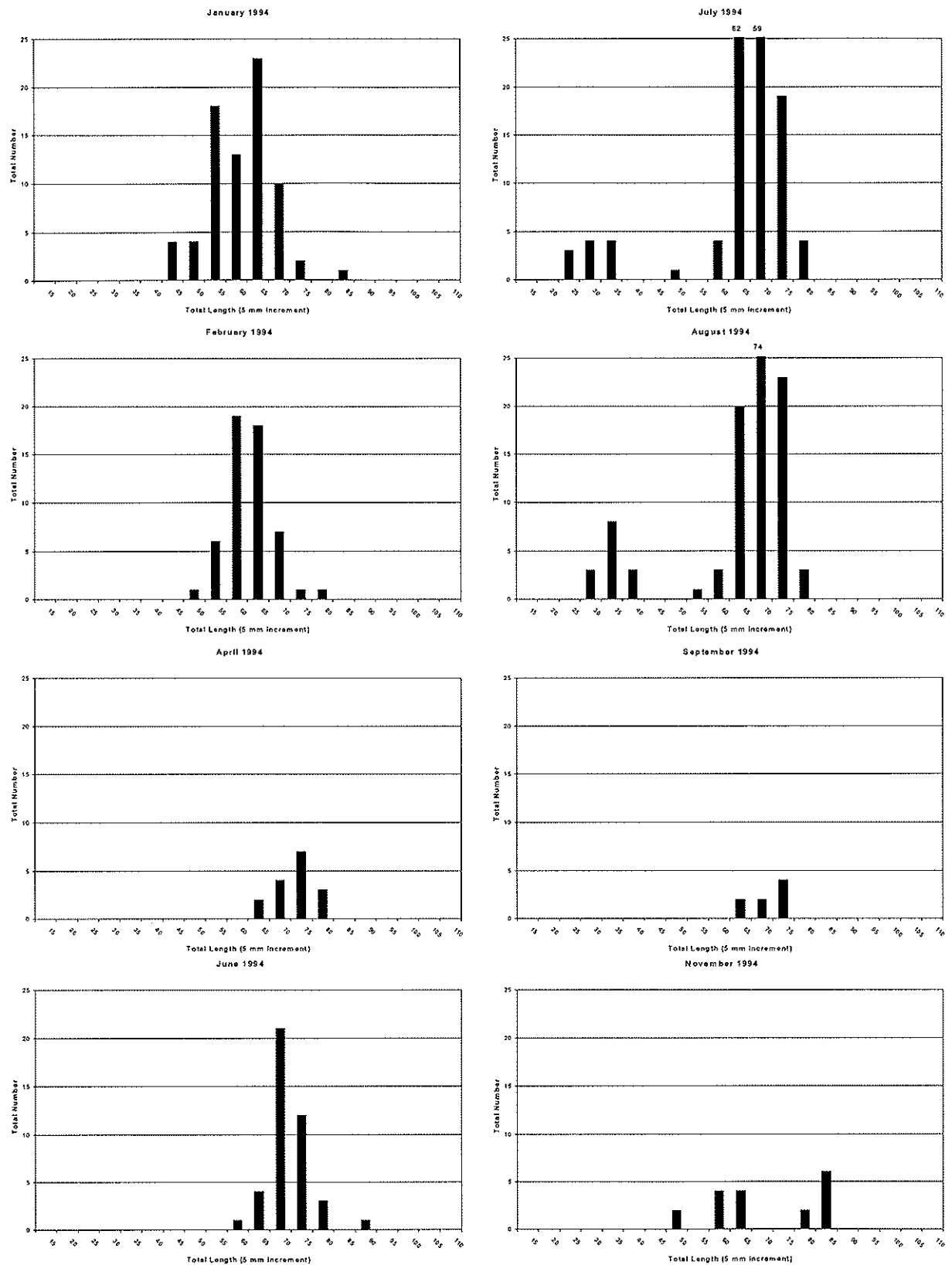


Figure 10. Length-frequency analysis for woundfin collected in the Virgin River at the Riverside reach (RM 41.00-49.25) by sampling trip in 1994.

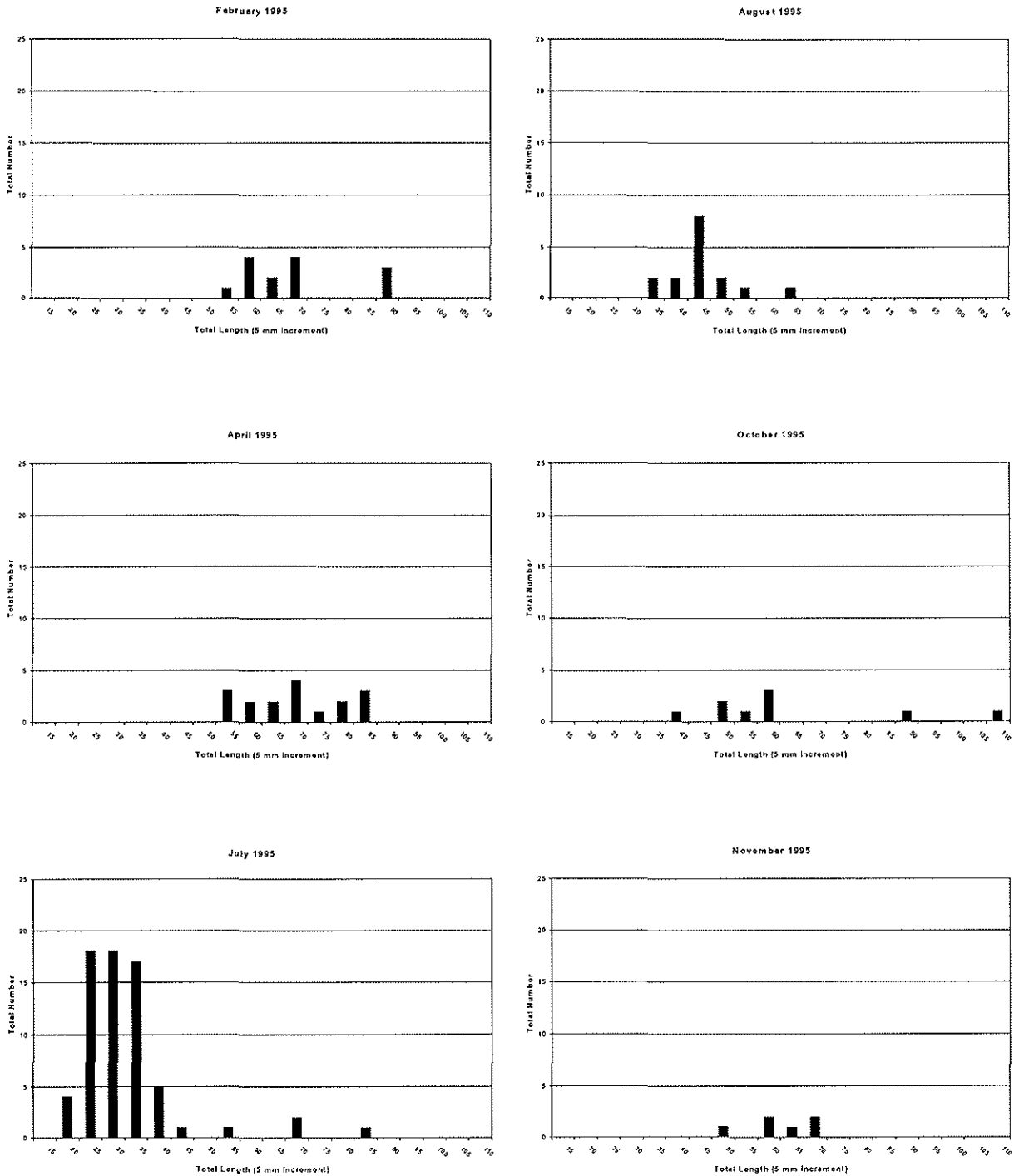


Figure 11. Length-frequency analysis for woundfin collected in the Virgin River at the Riverside reach by sampling trip in 1995.

YOY first appeared in collections at 20 to 30 mm in July, were 40 to 50 mm by August and September, and near 60 mm by November. They continued to grow during the winter and were ready to spawn the following spring at about 70 mm TL. Growth during the second year was much slower, and they spawned their second year at 80 to 90 mm, and then they disappeared from collections.

Figure 12 shows the habitats sampled and the habitats where woundfin were collected from 1993 through 1995. This analysis shows that runs with sand substrate and depths of 3 to 12 inches were the primary habitats sampled during all non-summer 1994 sampling trips. During those trips, woundfin were primarily collected in run habitats (83%), with some collections (13%) in riffles.

Habitat relationships were examined for two time periods, July and August 1994, and all other trips combined. July and August 1994 were examined separately because of extremely different flow circumstances and resultant catch rates. Because Pearson chi-square tests are sensitive for very large sample sizes, the tests suggested significant differences between habitat sampled and that used by woundfin for habitat type, substrate, and depth for the combined trips, excluding July and August 1994 (chi-square, $p < 0.0005$). However, these results are not considered biologically significant except where noted because most distributions of habitat use were similar to those sampled. For the July and August 1994 time period, smaller sample sizes allow chi-square tests to reveal more real differences in habitat used versus that sampled.

Woundfin were distributed within habitats according to availability. A Pearson chi-square test indicated that during the summer 1994 trips habitats in which woundfin were collected changed, and pools as well as runs showed high collection percentages (43% and 52%, respectively). Pools also were more sampled during this period than during higher flow periods, but the percent of captures in pools (43%) was considerably higher than the percent sampled for pools (18%), suggesting that pools were a very important habitat type during this time period (chi-square, $p < 0.0005$).

Sand substrate was the most sampled habitat, and captures of woundfin primarily occurred in sand habitats during non-summer 1994 periods (Figure 12). The percentages of captures and samples were fairly similar (84% versus 75%, respectively, chi-square, $p > 0.1$). Substrates where woundfin collections occurred changed somewhat during summer 1994. Captures in sand substrate habitats remained dominant, but a relatively high percentages of captures (22%) occurred in habitats with large gravel substrates, which only accounted for 11% of the samples. The difference in percentages suggests that large gravel also was an important habitat for woundfin during summer 1994 (chi-square, $p < 0.005$).

Depths where woundfin captures occurred for all samples except summer 1994 were generally in the shallow end of the range (1 to 9 inches) compared with what was sampled (Figure 12; chi-square, $p < 0.0005$). During the summer 1994 period, woundfin used slightly deeper habitats (12 to 15 in.) (chi-square, $p < 0.0005$) than what was sampled, and somewhat deeper habitats than those seen during the other period. Again, the depth used was related to the small pools where woundfin were concentrated during this period.

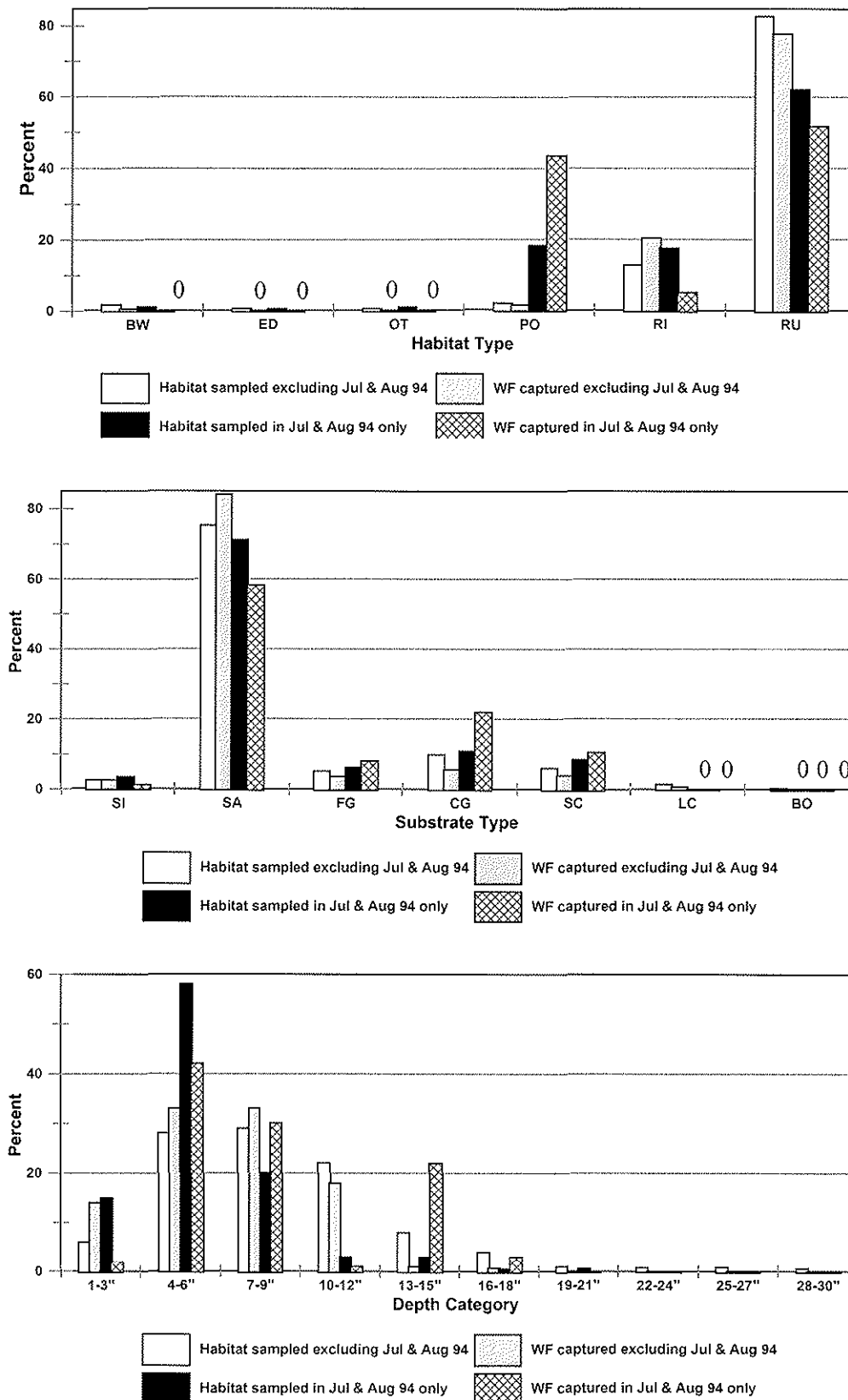


Figure 12. Comparison of habitat characteristics of woundfin collections between a low flow period (July and August 1994) and other sampling periods, 1993 to 1995.

These habitat data indicate that habitat important to woundfin changed during low flow periods. The other habitat characteristic not shown in Figure 12, but which may be important in the habitat selection, was water turbidity. The Virgin River was typically very turbid, but during the summer 1994 period the stream at the Riverside reach was extremely clear. This unusual condition was the result of stream bottom seepage, which accounted for all of the flow. Also, during the summer 1994 period, it soon became clear to the field crew that woundfin were selecting very distinct pools, primarily pools below riffles [Plate 2]. All of these habitats that could be efficiently sampled were sampled, accounting for the increase in sampling in pools in Figure 12. These small pools were the deepest portions of the stream, which typically was only a few inches deep. Habitat was considerably reduced in the river, with only shallow runs, shallow riffles, and these small pools below some riffles available to fish.

Virgin River Chub Collections

Only seven Virgin River chub were collected from 1993 to 1995 in the Riverside reach (Figure 13), less than one fish per trip, so relatively little definitively can be said about this species' use of the Riverside reach. No more than one Virgin River chub was collected in any one trip. Due to the scattered nature of Virgin River chub collections (Figure 14), it appeared that no population of this species existed in the Riverside reach. It was suspected that they came down the Virgin River during high flow periods. However, the collections do not verify such a pattern, since Virgin River chub were found in all seasons that were sampled, and they were not concentrated after high spring flow events. Therefore, Virgin River chub may have moved into the Riverside reach throughout the year rather than during one particular season or flow period. However, the numbers found were too small to draw any realistic conclusions.

Figure 15 shows the length frequency of the Virgin River chub collected during the 3-year period. Most of the fish collected were likely 1 or 2 years of age, and one adult was captured.

Other Native Fishes

Other native fish species collected during the 1993 to 1995 period included flannelmouth sucker (*Catostomus latipinnis*), desert sucker (*Pantosteus clarki*), speckled dace (*Rhinichthys osculus*), and Virgin spinedace (*Lepidomeda mollispinis*). Only 10 Virgin spinedace were collected, and all were collected on the July 1995 trip, so further analysis was not conducted on this species. This collection suggested the Virgin spinedace were washed downstream during the spring flood of 1995, possibly out of the Beaver Dam Wash reach. Figure 16 shows the number of flannelmouth sucker, desert sucker, and speckled dace collected by trip for the 3-year period. All three species tended to be most common in samples soon after runoff, with numbers declining in late summer and fall. This was especially apparent in 1994, the low flow year, when all three species disappeared from samples at the Riverside reach in fall and winter samples. Numbers of all three species reappeared in summer of 1995.



Plate 2. Above: Examples of small pools below riffles (RM 54.50) used by woundfin in July and August 1994 during low flows. Below: Flow in the Virgin River on July 12, 1995, at RM 45.50, showing typical habitat during a high flow summer.

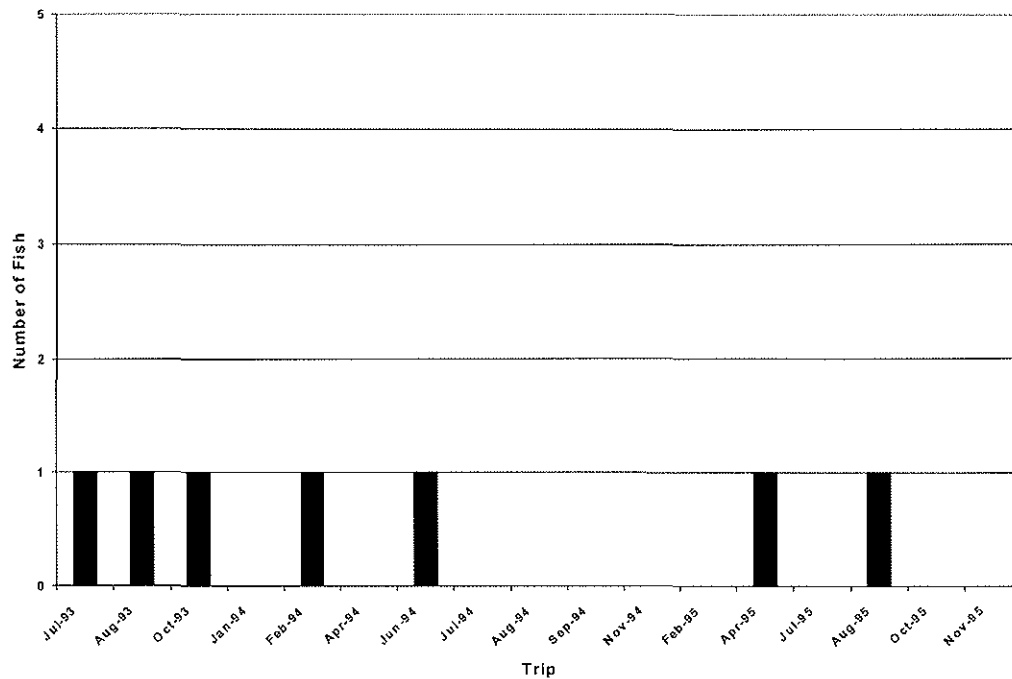


Figure 13. Number of Virgin River chub collected at the Riverside reach (RM 41.00-49.25) in the Virgin River by sampling trip, 1993 to 1995.

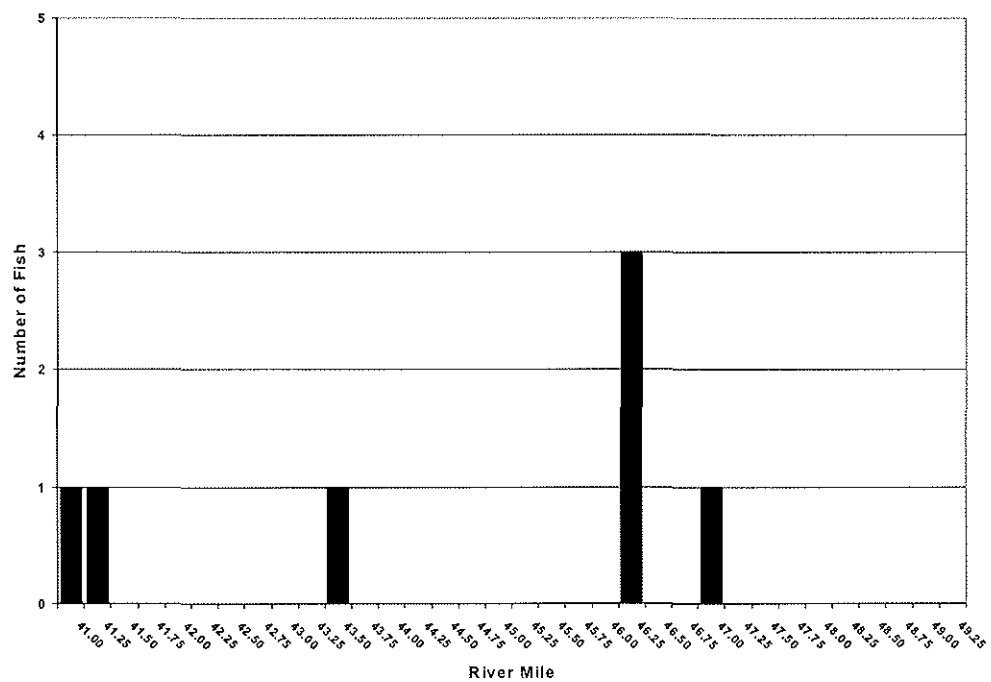


Figure 14. Number of Virgin River chub collected by quarter river mile at the Riverside reach (RM 41.00-49.25), 1993 to 1995.

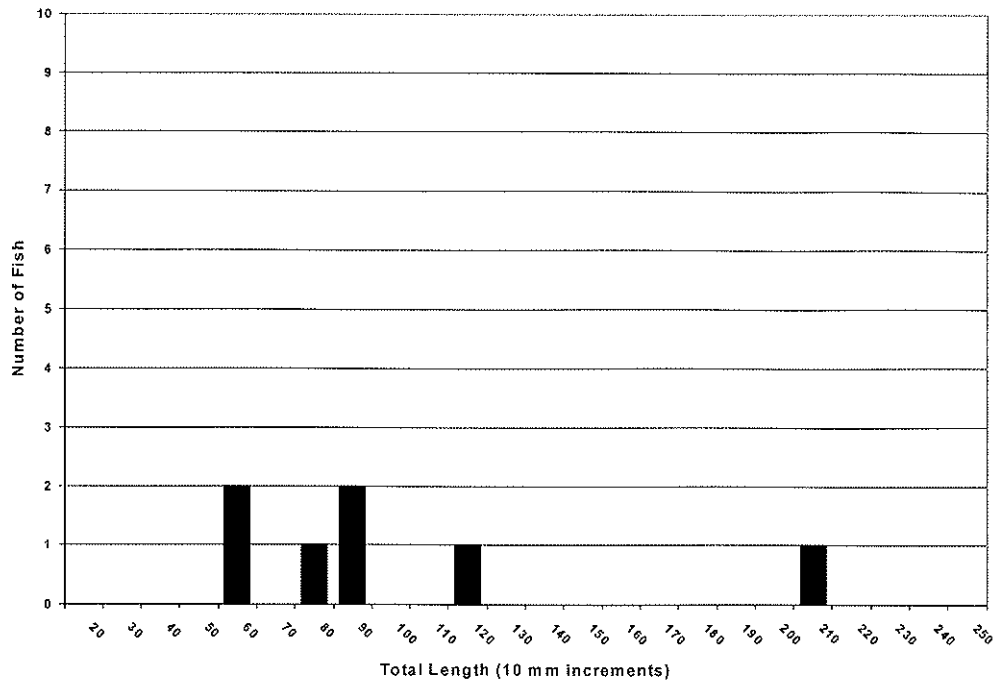


Figure 15. Length-frequency analysis for Virgin River chub collected in the Virgin River at the Riverside reach (RM 41.00-49.25), 1993 to 1995.

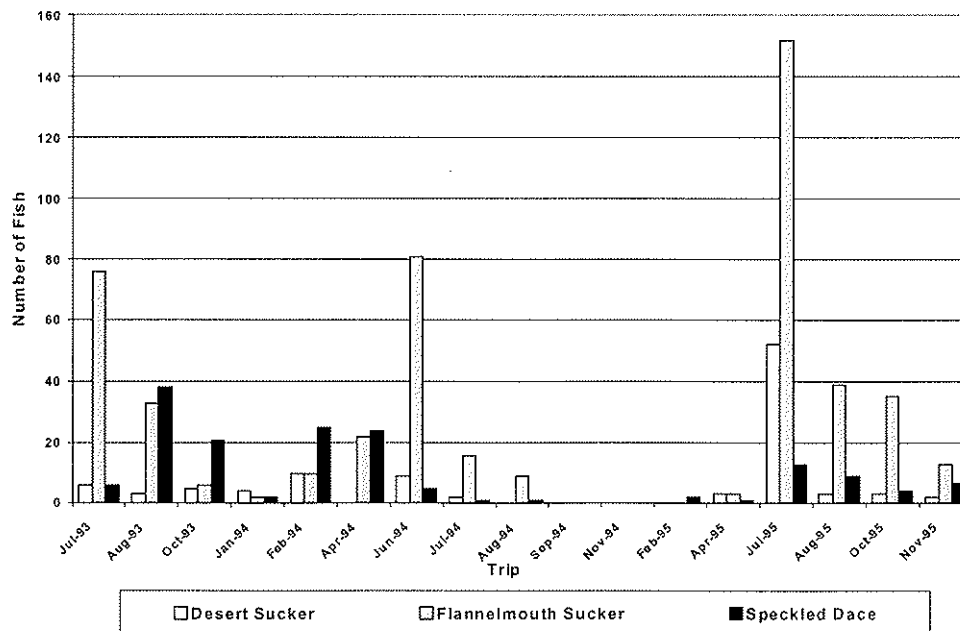


Figure 16. Number of desert sucker, flannemouth sucker, and speckled dace collected per sampling trip in the Virgin River at the Riverside reach (RM 41.00-49.25), 1993 to 1995.

Except for woundfin, flannelmouth sucker was the most common native species caught at the Riverside reach. Speckled dace were also caught relatively frequently and showed some consistency in numbers during late 1993 and early 1994, but then they disappeared along with the flannelmouth sucker and desert sucker following the low flow summer of 1994. Catch trends showed the same pattern (Figure 17) as number of fishes caught. Catch rates declined in the fall of all 3 years. All three native species were found in all 8 mi of the Riverside reach, but abundance was highest in the upper portion of the reach (Figure 18).

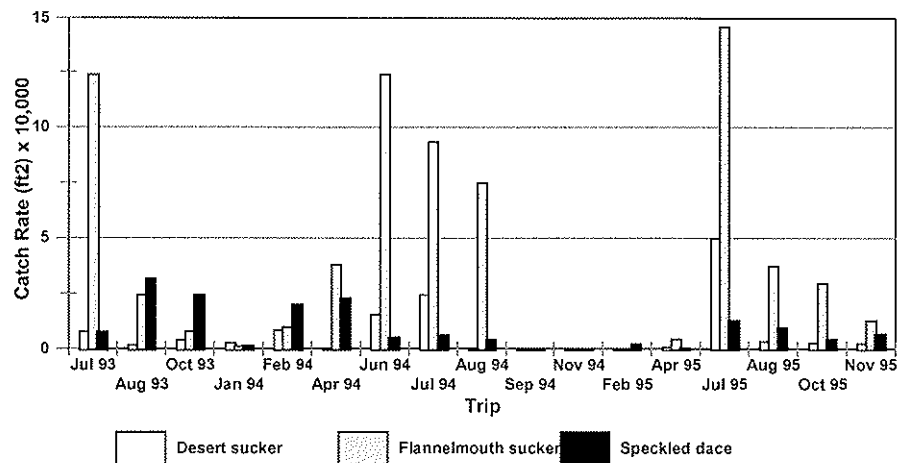


Figure 17. Catch rate (# per 10,000 ft² of seining) of desert sucker, flannelmouth sucker, and speckled dace by sampling trip in the Virgin River at the Riverside reach (RM 41.00-49.25), 1993 to 1995.

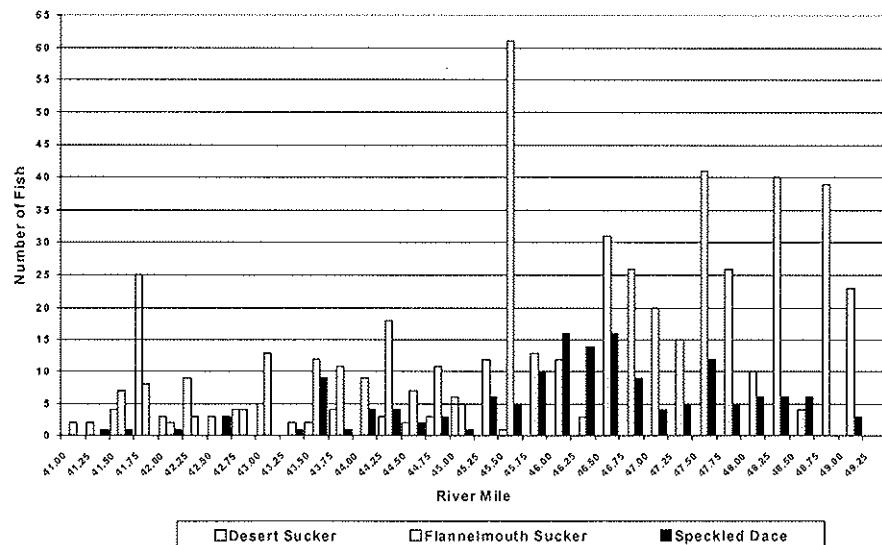


Figure 18. Number of desert sucker, flannelmouth sucker, and speckled dace collected by quarter river mile in the Virgin River at the Riverside reach (RM 41.00-49.25), 1993 to 1995.

Most of the flannelmouth sucker and desert sucker collected were YOY, although some 1-year-old flannelmouth sucker and a few adults were also captured (Figure 19). Speckled dace collections showed two size peaks, suggesting that both YOY and adults were found.

Flannelmouth sucker were found in a greater variety of habitats than either of the other two species, but pools appeared to be especially important (Figure 20). Chi-square tests showed that flannelmouth sucker were not as common in riffles, and they were more common in pools compared to percent habitats sampled for all trips excluding July and August 1994 ($p < 0.025$). However, during July and August 1994, flannelmouth sucker used pools more frequently than what was sampled ($p < 0.0005$). Flannelmouth sucker substrate use was also broader, although no one substrate type was used (chi-square $p > 0.10$). Flannelmouth sucker did not appear to occupy specific depths (chi-square $p > 0.10$), except during the summer 1994 period when they used deeper habitats than what was expected (chi-square $p < 0.0005$).

Desert sucker were generally found in riffles and runs during all trips, except July and August of 1994 where they occupied pools in a greater percent than what was sampled (Figure 21; chi-square $p < 0.0005$). Desert sucker were found in a variety of substrate types in proportion to what was sampled (chi-square $p > 0.25$), but they occupied deeper habitats than what was commonly sampled (chi-square $p < 0.0005$).

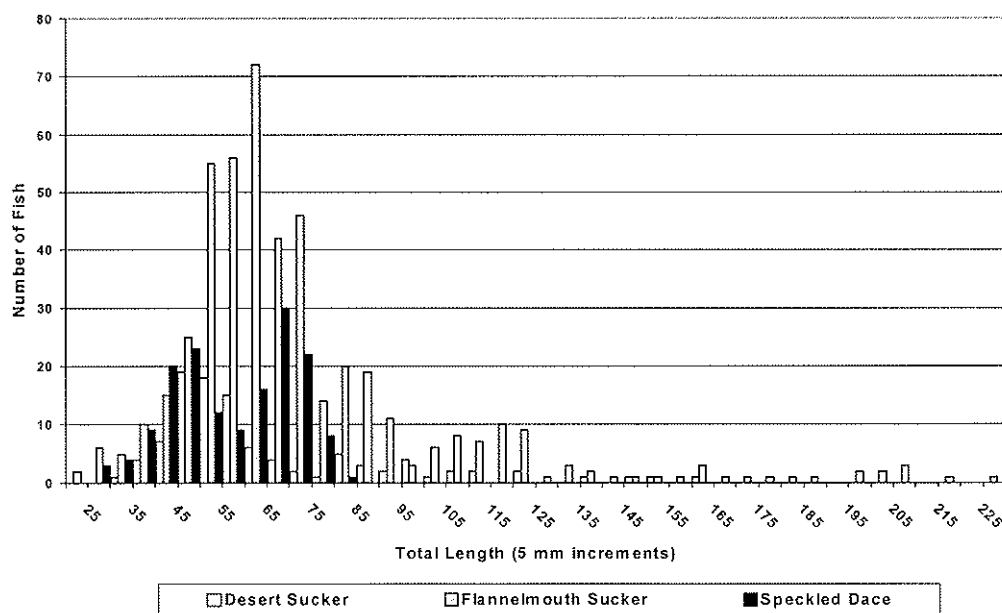


Figure 19. Length-frequency analysis for desert sucker, flannelmouth sucker, and speckled dace collected in the Virgin River at the Riverside reach (RM 41.00-49.25), 1993 to 1995.

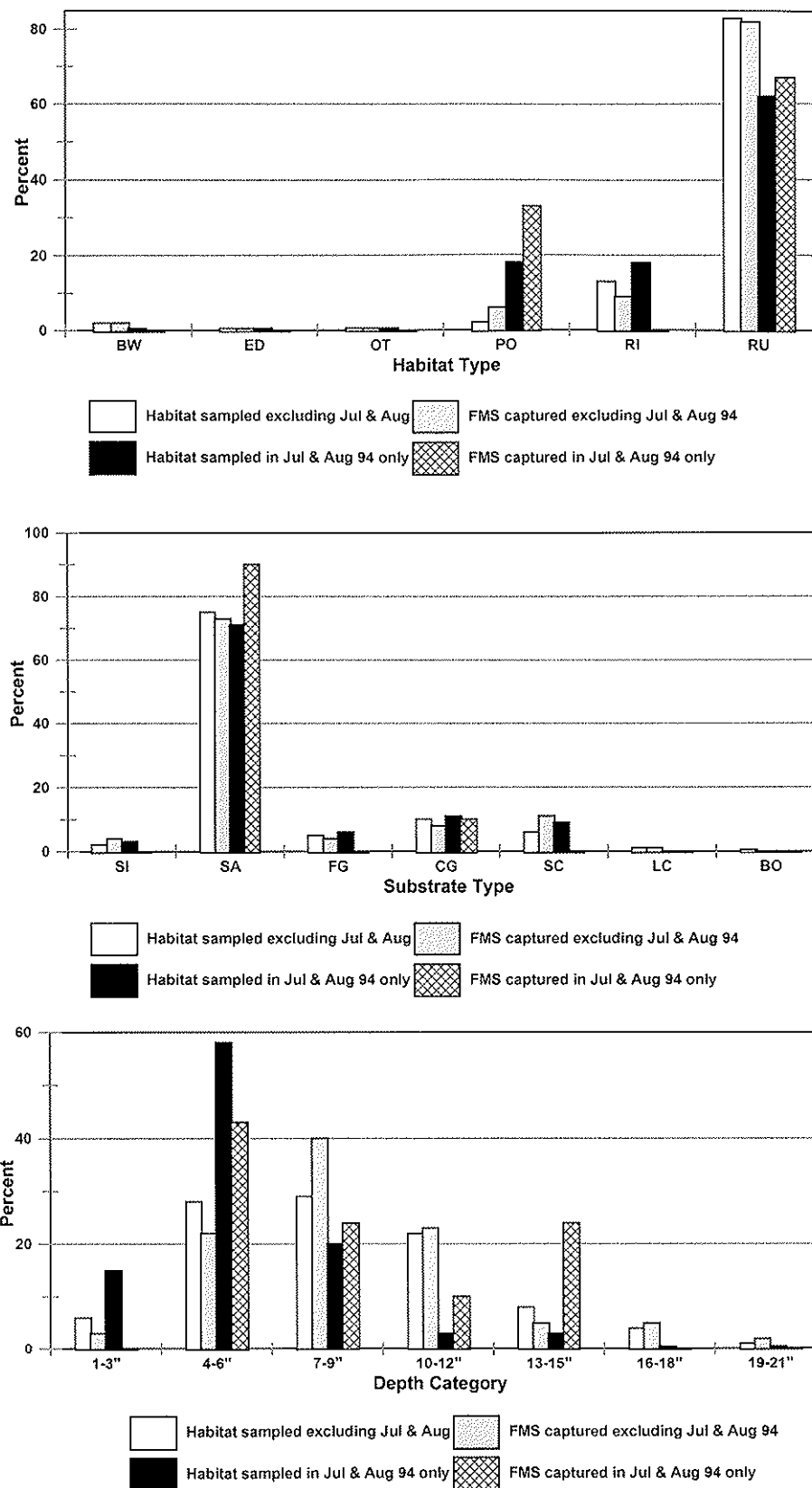


Figure 20. Comparison of habitat characteristics of flannelmouth sucker collections between a low flow period (July and August 1994) and other sampling periods, 1993 to 1995.

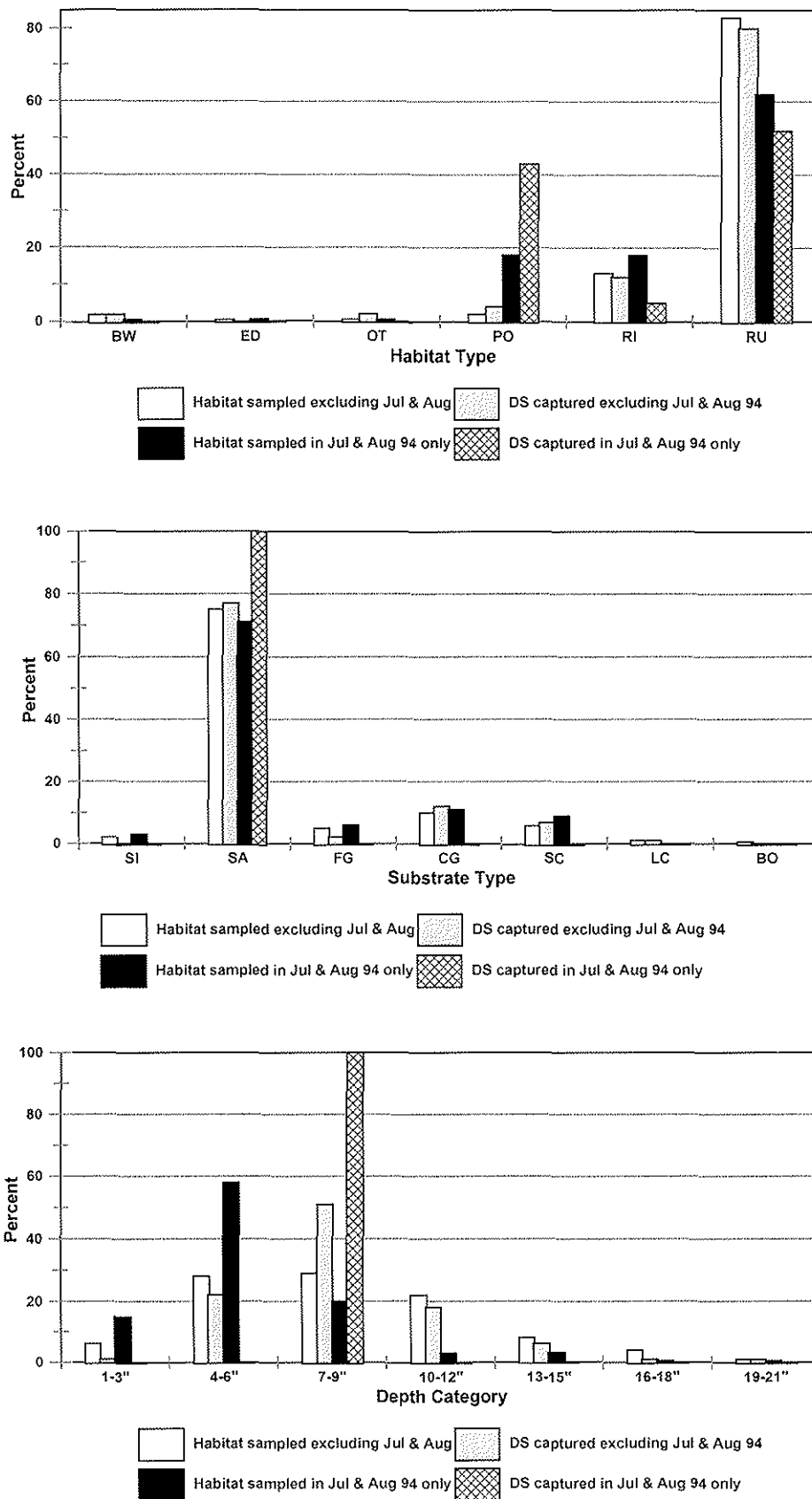


Figure 21. Comparison of habitat characteristics of desert sucker collections between a low flow period (July and August 1994) and other sampling periods, 1993 to 1995.

Habitat use information (Figure 22) showed that speckled dace were generally found in riffles and runs and at a much higher percent capture than percent sampled for riffles (chi-square $p < 0.0005$). In addition, speckled dace were captured more frequently in areas with large gravel to small cobble substrates compared with more-commonly sampled areas with sand and fine gravel (chi-square $p < 0.005$) and slightly shallower areas than what was commonly sampled (chi-square $p < 0.05$).

Red Shiner

The most abundant fish species in the Riverside reach during all sampling trips was the red shiner. Red shiner were caught in virtually every seine haul. Figure 23 shows the catch rate of red shiner by trip for the entire reach. Note that catch per 10,000 ft² was generally above 1,000 fish and frequently above 2,000 fish, compared with catch rates of 10 fish or less of native species. Based on an ANCOVA using discharge as a covariant, significant differences ($p < 0.001$) between trips were detected but there was no relationship between catch rate and discharge ($p = 0.597$). Red shiner density cycled seasonally, with lowest numbers occurring during the colder late fall and winter months and highest numbers occurring during summer and early fall. Overall, catch rates of red shiner were highest in 1994, a year of low flow, compared with the higher flow years 1993 and 1995. As noted for a similar occurrence with woundfin, the very low flows of summer 1994 allowed for sampling of a much greater percentage of the available habitat in the stream. Catch rate of red shiner also dropped noticeably in fall 1994 and did not rise again until summer 1995, similar to the pattern seen with woundfin and other native species.

Figure 24 shows the catch rate of red shiner by river mile for the 3-year study period. Red shiner abundance varied within the study area by both sampling trip and river mile but not consistently. No one portion of the study area tended to support more numbers of red shiner consistently, suggesting there was no preference for a specific portion of the Riverside reach.

Other Nonnative Species

Two other nonnative fish species were relatively common in the Riverside reach, western mosquitofish (*Gambusia affinis*) and common carp (*Cyprinus carpio*). Figure 25 shows the catch rates of these species by trip. Catch rates were similar to those for the native fish species rather than those for red shiner. Western mosquitofish density increased dramatically in the low flow year (1994) and was reduced in the higher flow years, especially 1993. This species was generally found in quiet backwaters and off-channel pools; but during the summer of 1994, the extremely low flows in the study area allowed them to occupy many mainstream habitats, including runs and riffles. In fact, velocity was so low along the shorelines of all habitats that western mosquitofish were collected in almost all seine hauls in July and August 1994, since they occupied the shoreline area almost continuously.

The pattern of common carp density was similar between years, with highest density in summer months and lowest density in winter months (Figure 25). Common carp density did not change much between years, suggesting there was little effect of spring flow magnitude on their density. Common carp were also fairly well distributed throughout the study area (Figure 26). Most common carp collected were YOY.

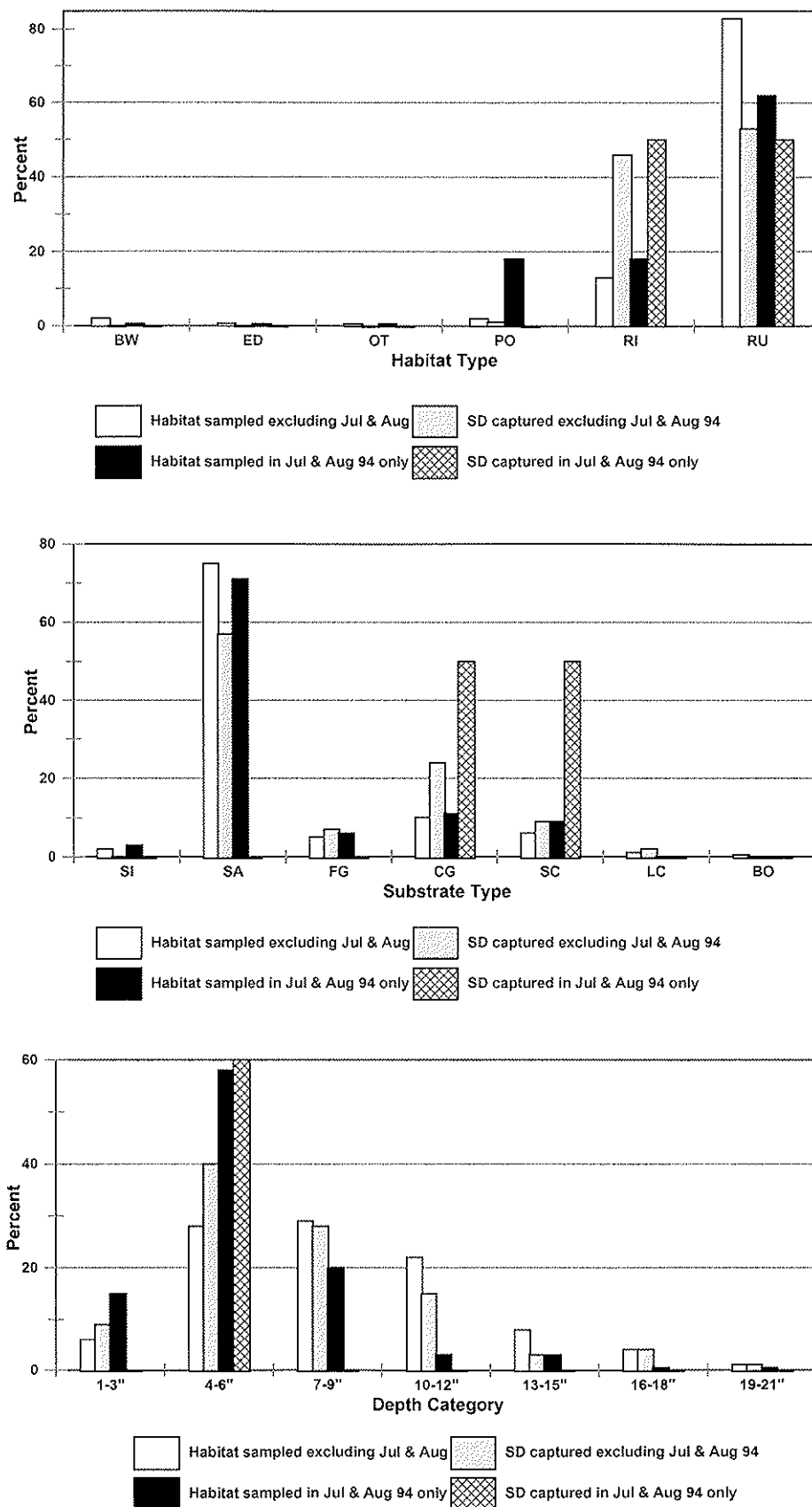


Figure 22. Comparison of habitat characteristics of speckled dace collections between a low flow period (July and August 1994) and other sampling periods, 1993 to 1995.

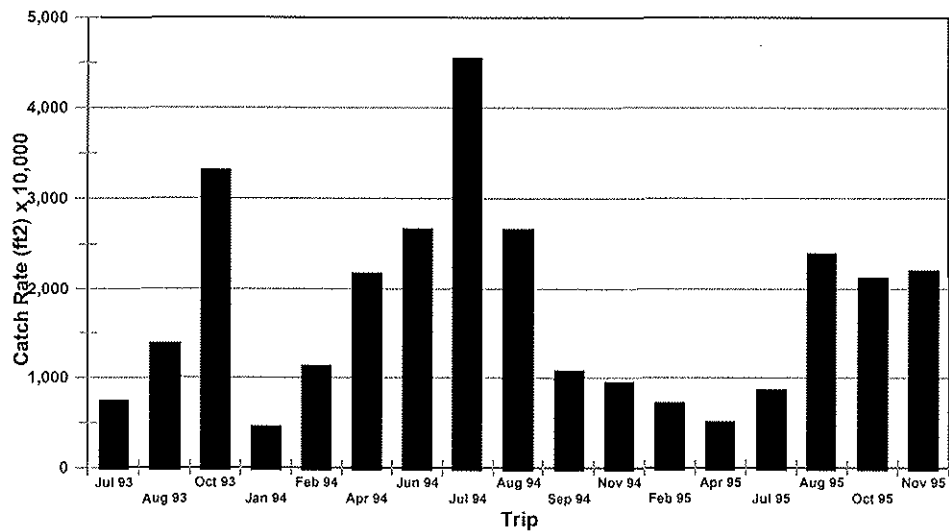


Figure 23. Catch rate (# per 10,000 ft² of seining) of red shiner by sampling trip in the Virgin River at the Riverside reach (RM 41.00-49.25), 1993 to 1995.

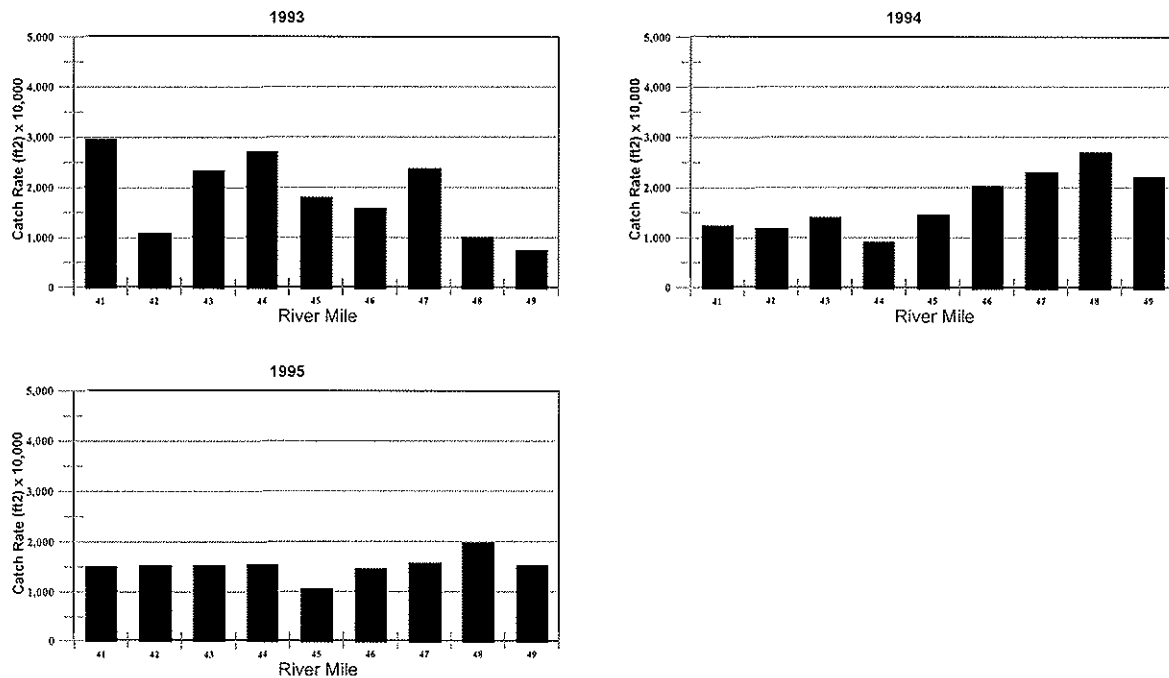


Figure 24. Catch rate (# per 10,000 ft² of seining) of red shiner by quarter river mile in the Virgin River at the Riverside reach (RM 41.00-49.25), 1993 to 1995.

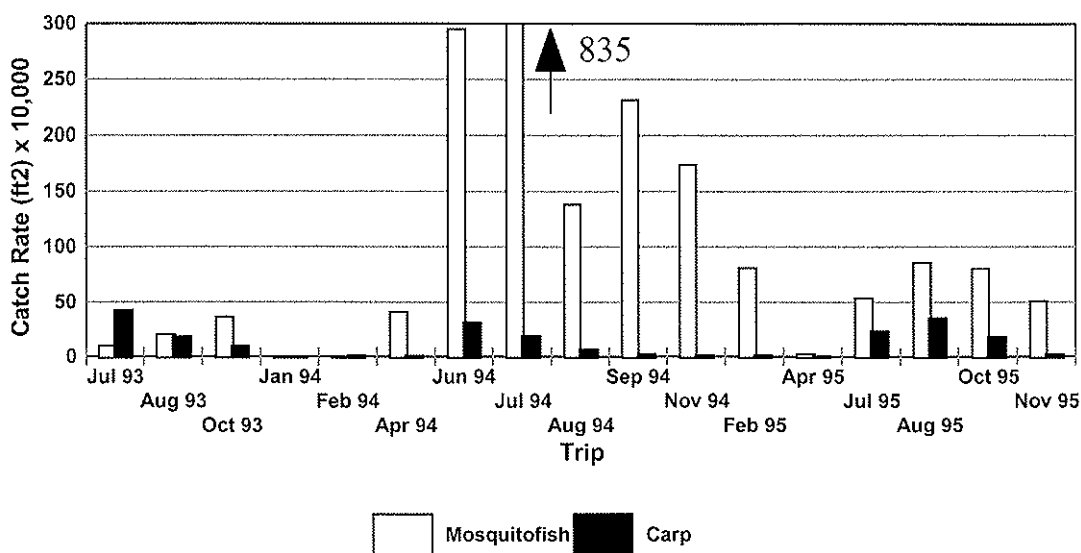


Figure 25. Catch rate (# per 10,000 ft² of seining) of western mosquitofish and common carp by sampling trip in the Virgin River at the Riverside reach, 1993 to 1995.

Other nonnative fishes that were captured more sporadically include channel catfish (*Ictalurus punctatus*), black bullhead (*Ameiurus melas*), largemouth bass (*Micripterus salmoides*), and green sunfish (*Lepomis cyanellus*).

Sampling, 1996 to 1997

Woundfin

In 1996 and 1997, three study reaches were seined during 11 trips to compare densities of fish and investigate the potential for downstream emigration of woundfin into the lower Virgin River. Figure 27 shows the catch rate of woundfin collected by trip during this period at the three reaches, Beaver Dam Wash, Mesquite, and Riverside. An ANCOVA comparing densities among the three reaches with a covariant of discharge showed that woundfin density was highest at the Riverside reach, and lowest at the Beaver Dam Wash reach ($p < 0.001$), and pairwise comparisons indicated Riverside and Mesquite catch rates were not significantly different ($p = 0.609$) but Beaver Dam Wash was significantly different than the other two reaches ($p < 0.01$). Discharge showed significant covariance with catch rate ($p = 0.004$) which can be explained by higher catch rates in the low flow year of 1996. Woundfin continued to be captured consistently at the Riverside reach until the last trip in October 1997. The general pattern seen in 1993 to 1995 continued, with higher numbers of woundfin occurring in spring and summer samples and decreasing in fall samples. Woundfin were also found at the Mesquite reach, but numbers declined in 1997, and none were found in the last three sampling trips (Figure 27). Very few woundfin were found at the Beaver Dam Wash reach;

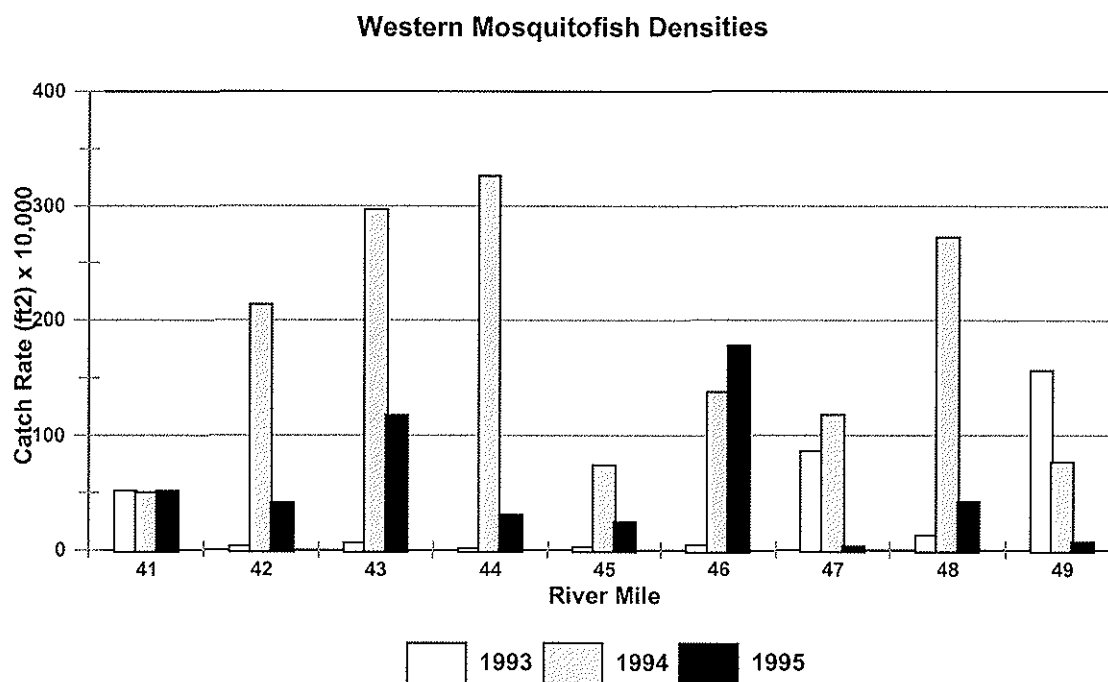
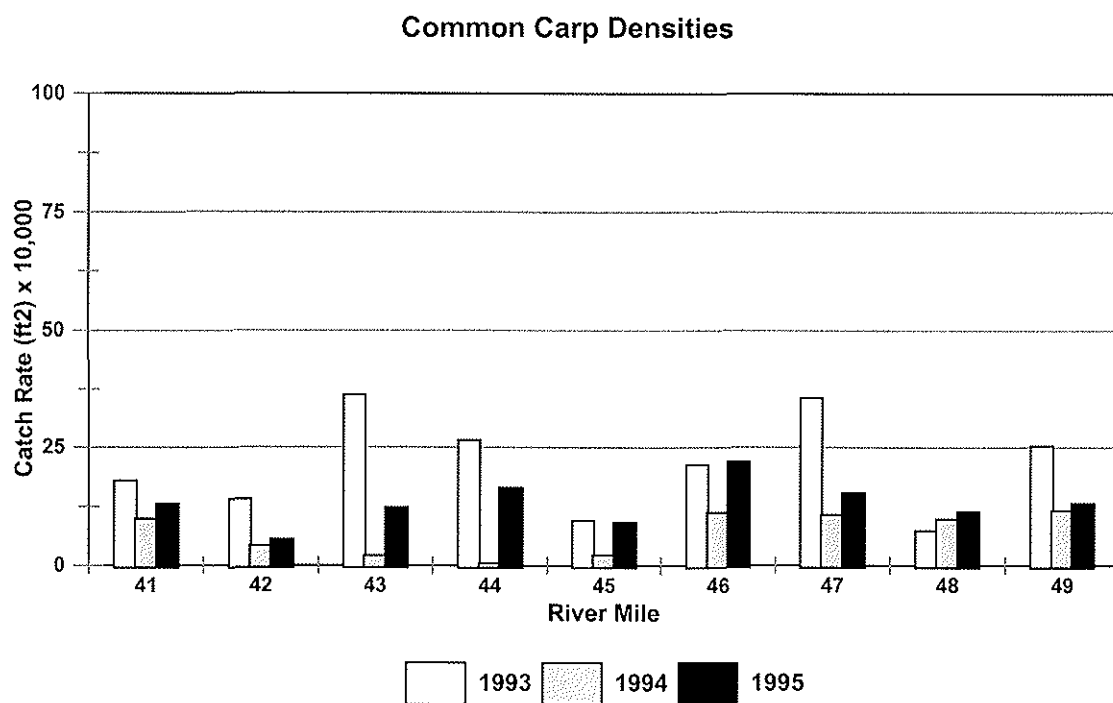


Figure 26. Catch rate (# per 10,000 ft² of seining) of western mosquitofish and common carp by quarter river mile in the Virgin River at the Riverside reach, 1993 to 1995.

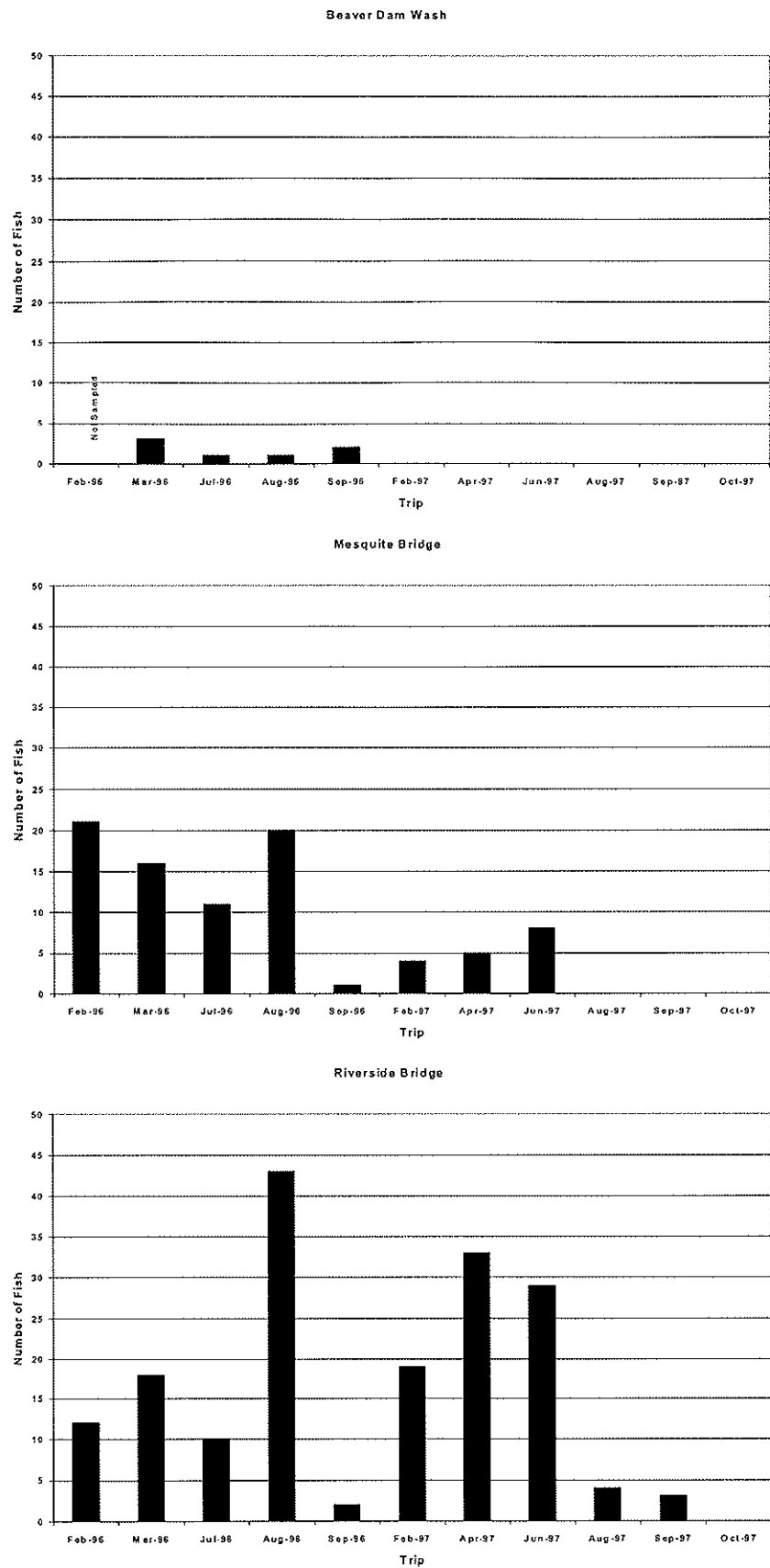


Figure 27. Number of woundfin collected at three reaches in the Virgin River by sampling trip, 1996 to 1997.

a total of seven were found over a 2-year period. All seven woundfin were collected in 1996, and no more than three were collected during any one sampling trip.

A total of 20 small YOY (<35 mm TL) woundfin were found at the Riverside reach, but only three were found at the Mesquite reach and none at the Beaver Dam Wash reach (Figure 28). These data suggest that reproduction at the Riverside reach occurs fairly regularly and is measurable, but reproduction at the Mesquite reach occurs irregularly, and at the Beaver Dam Wash reach it is hardly measurable or does not occur.

The distribution of woundfin at the Riverside reach varied somewhat from 1996 to 1997 (Figure 29), with a peak density at RM 46.00 in 1996 and at RM 47.50 to 48.00 in 1997. Distribution in 1996 was similar to that noted in 1993 and 1994, and distribution in 1997 was similar to that observed in 1995. Flow in 1996 was relatively low, and in 1997 it was high (Figure 2), suggesting that habitat may have changed between the 2 years due to the high spring flow in 1997. A similar shift to an upstream area was seen in 1995, an alteration also likely due to habitat changes caused by a high spring flow.

Virgin River Chub

Figure 30 shows the number of Virgin River chub collected by trip and reach in 1996 and 1997. The number found at the Beaver Dam Wash reach was generally relatively high, whereas collections at both the Mesquite and Riverside reaches were sporadic, where only two and one fish were captured, respectively. Occasionally, no Virgin River chub were caught at Beaver Dam Wash reach, as in March 1996. This phenomenon generally occurred during relatively high flows (>200 cfs) when deeper pools and runs were not able to be seined. Deeper pools and runs tended to be the habitat where most Virgin River chub were collected. Figure 31 shows the length frequency of the Virgin River chub collected, and it also shows that a variety of sizes were collected, from YOY to adults.

Other Native Fish

The densities of flannemouth sucker, desert sucker, and speckled dace were dramatically different between the three reaches (Figure 32). Numbers of all three species were much higher at Beaver Dam Wash reach than at either of the two lower reaches (note difference in number scale on figures). Numbers of these three native species increased at Riverside reach and Mesquite reach following spring runoff but then dropped during the fall and winter. This information showed that Beaver Dam Wash reach provides consistent year-round habitat for these common native species, whereas the other two reaches do not.

Red Shiner

Red shiner density was high at all three reaches, and an ANCOVA using discharge as a covariate showed no significant difference between the three reaches ($p=0.211$) (Figure 33). Also, discharge did not show a relationship with catch rate of red shiner ($p=0.392$). Late summer and fall catch rate was not as high in 1997 as in 1996, perhaps reflecting a higher flow year in 1997 with more high flow spikes (Figure 2).

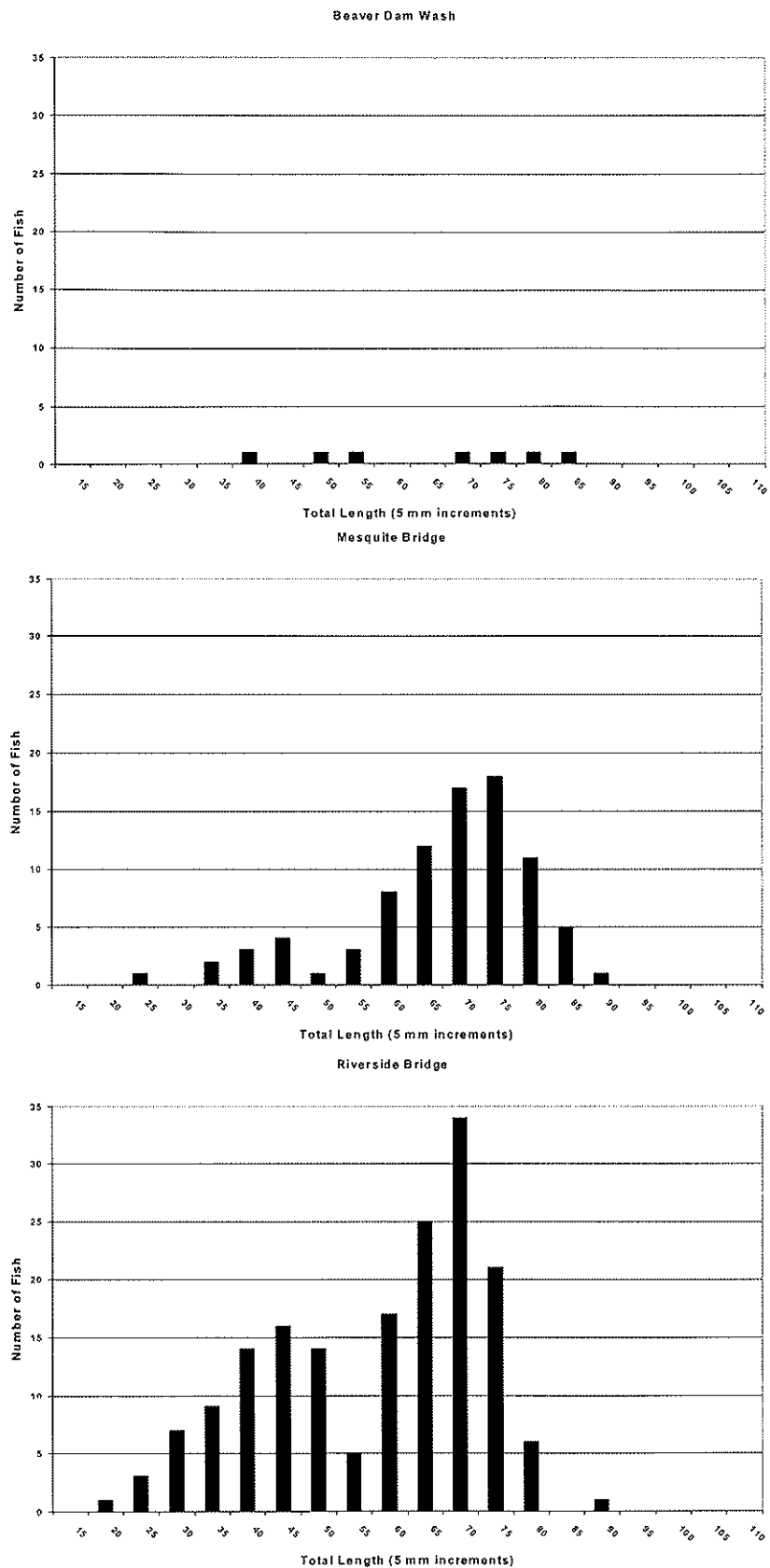
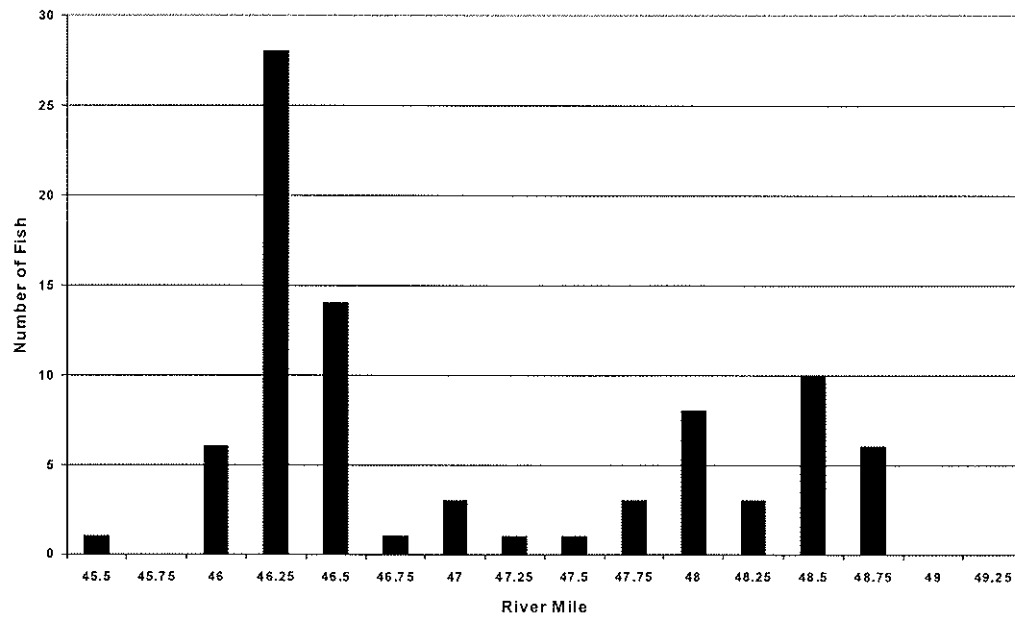


Figure 28. Length-frequency analysis for woundfin collected at three reaches in the Virgin River, 1993 to 1995.

1996



1997

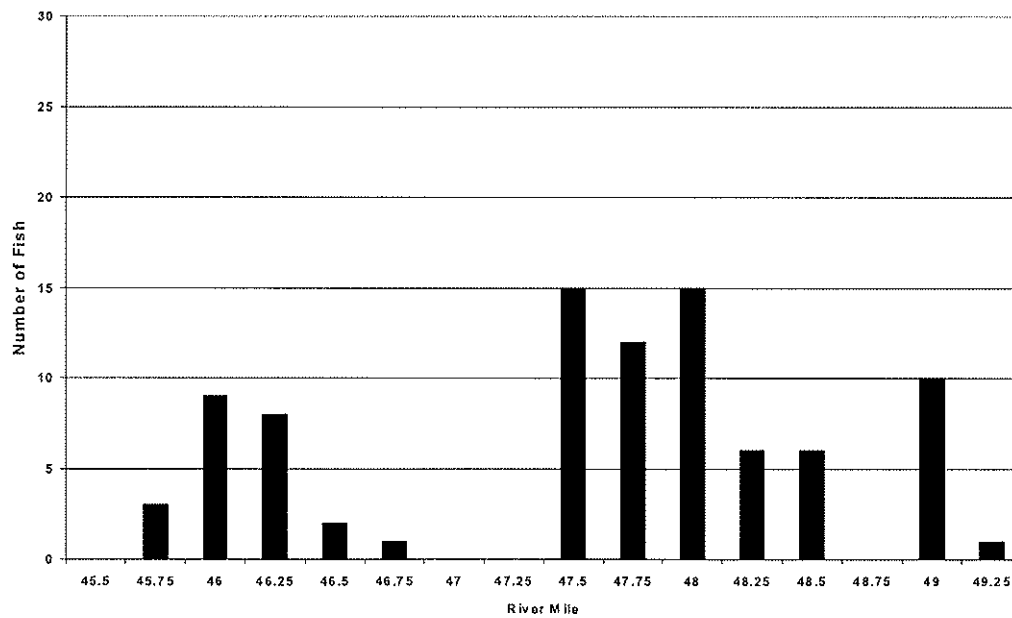


Figure 29. Number of woundfin collected at the Riverside reach in the Virgin River by quarter river mile, 1996 to 1997.

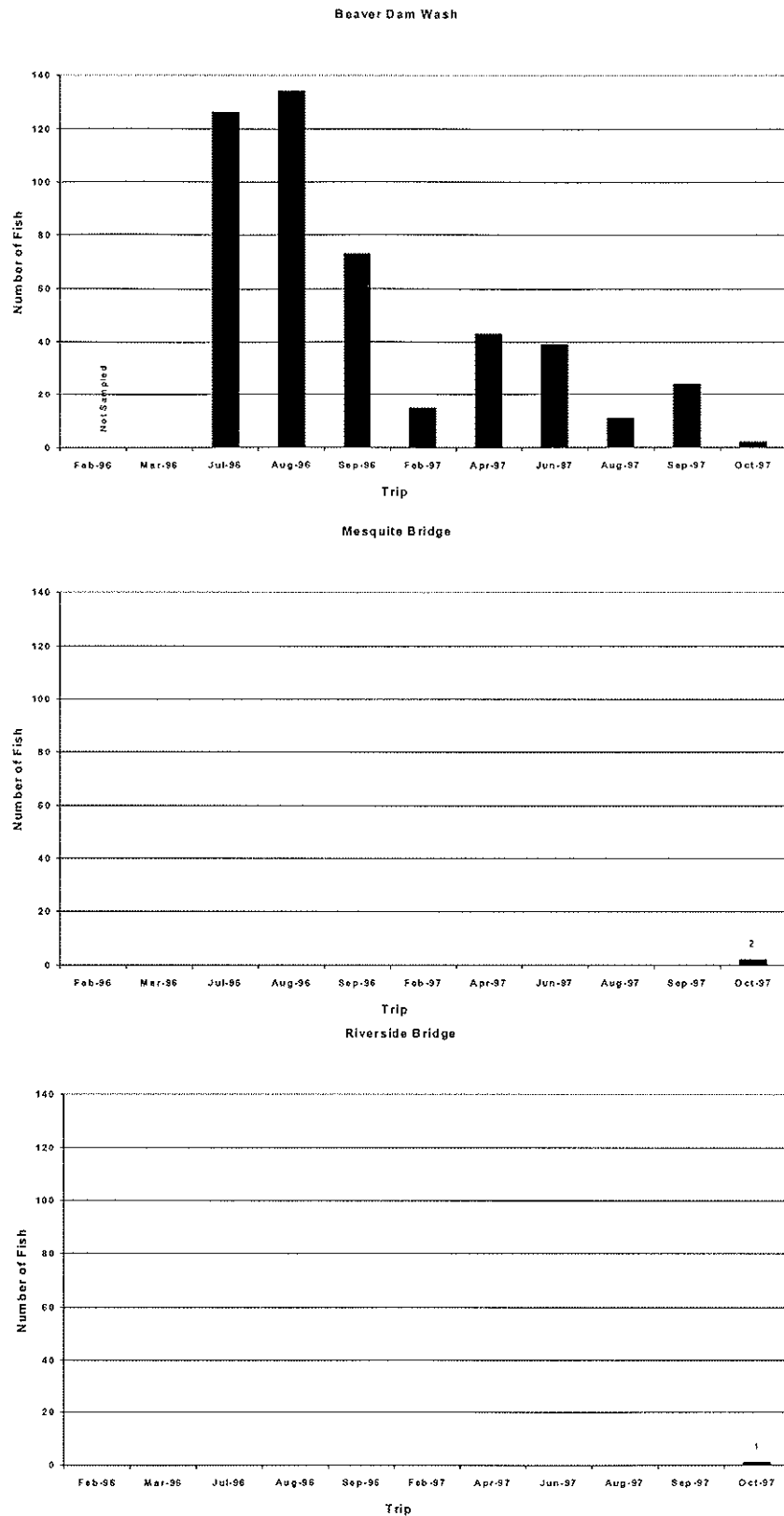


Figure 30. Number of Virgin River chub collected at three reaches in the Virgin River by sampling trip, 1996 to 1997.

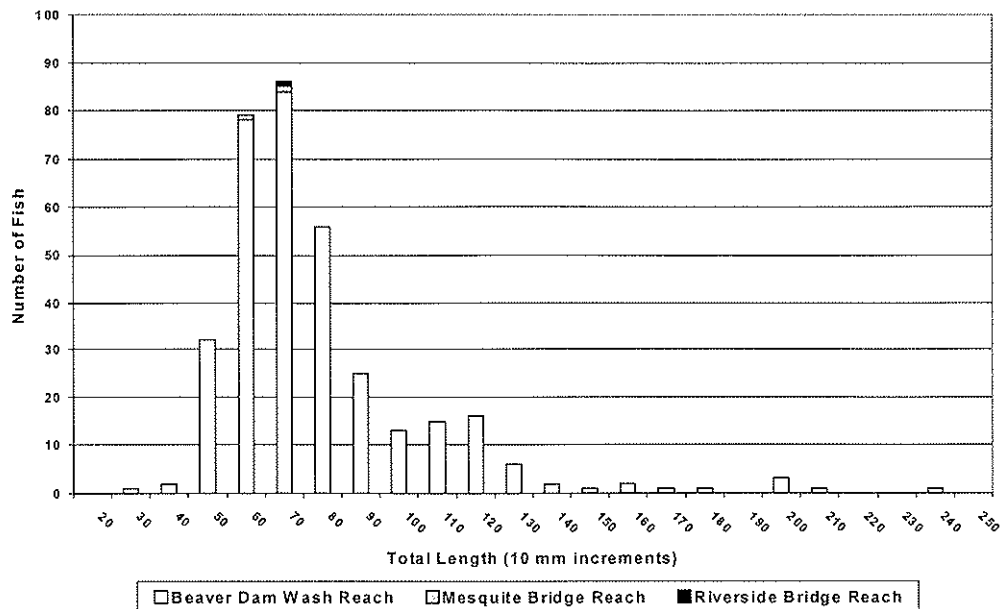


Figure 31. Length-frequency analysis for Virgin River chub collected at three reaches in the Virgin River, 1996 to 1997.

Marked Woundfin and Virgin River Chub Collections, 1994 to 1997

Between October 1993 and April 1997, the Nevada Division of Wildlife stocked about 23,500 woundfin and 1,100 Virgin River chub in the river. They were stocked at either the Riverside Bridge or the Mesquite Bridge, and numbers were split fairly equally between the two reaches. Figure 34 shows the captures of marked woundfin by trip from February 1994 to October 1997 at Riverside reach and Mesquite reach. Stocking dates and numbers are also shown on Figure 34. Stocking generally occurred during fall or winter (October to January) each year, starting in October 1993. Number of marked woundfin captured was generally fairly high within a few months after stocking, but it then declined in following months until only one or two marked woundfin were collected 6 months or more after a stocking. During spring months, marked woundfin were collected in spawning condition (breeding tubercles), so it is possible that marked woundfin contributed to the YOY collected at Riverside reach. Heinrich et al. (1994) noted that some shedding of tags occurred (in approximately 10% of the tagged woundfin), suggesting that a few of the untagged fish collected and considered “wild” in the analyses above may have actually been stocked fish. The number of untagged stocked fish collected would have been low, about 10% of the total number of marked fish collected (201) or about 20 fish. A total of nearly 1,000 wild woundfin were collected during the 5 years of the study, and 20 more or less fish would have had a negligible affect on the results.

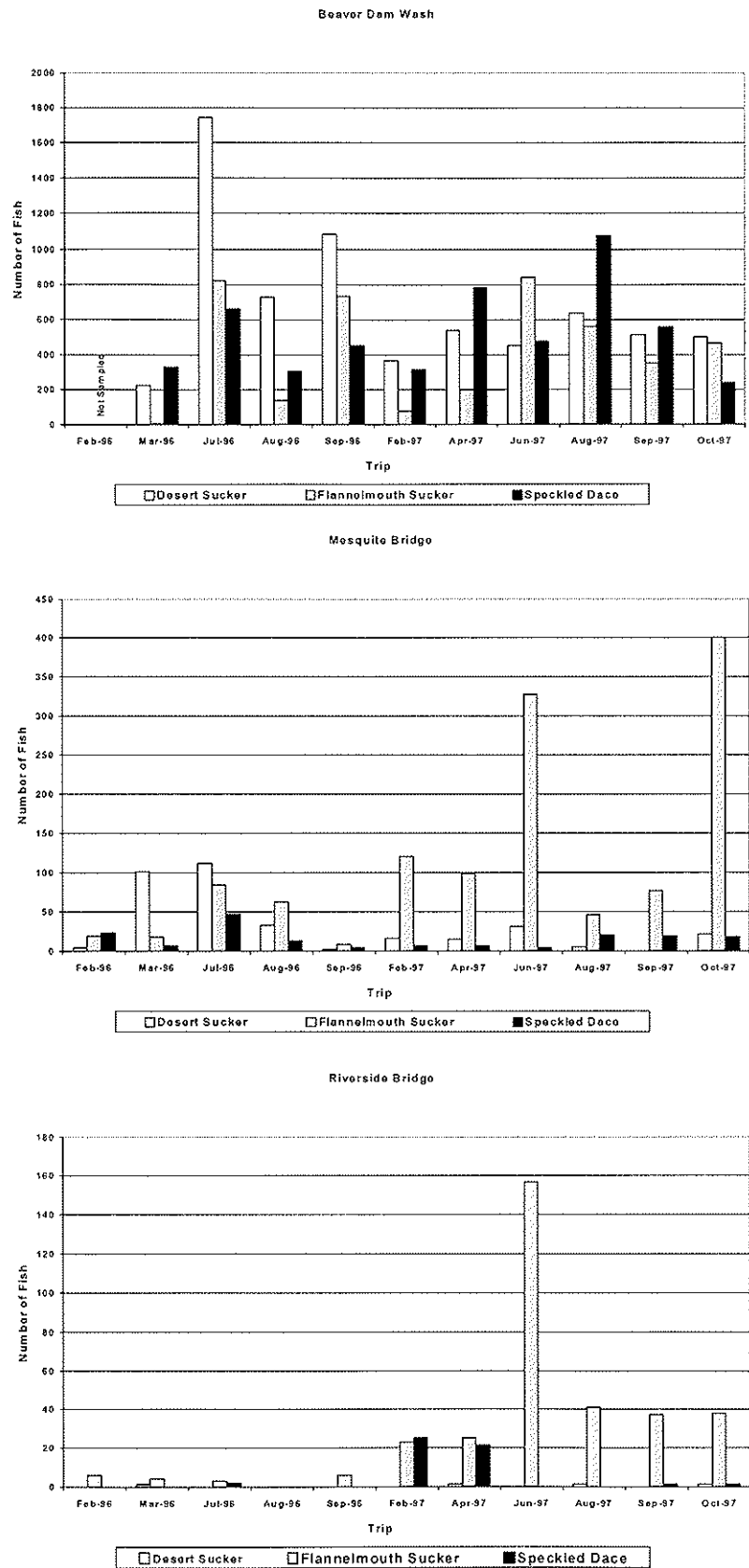


Figure 32. Number of desert sucker, flannelmouth sucker, and speckled dace collected at three reaches in the Virgin River by sampling trip, 1996 to 1997.

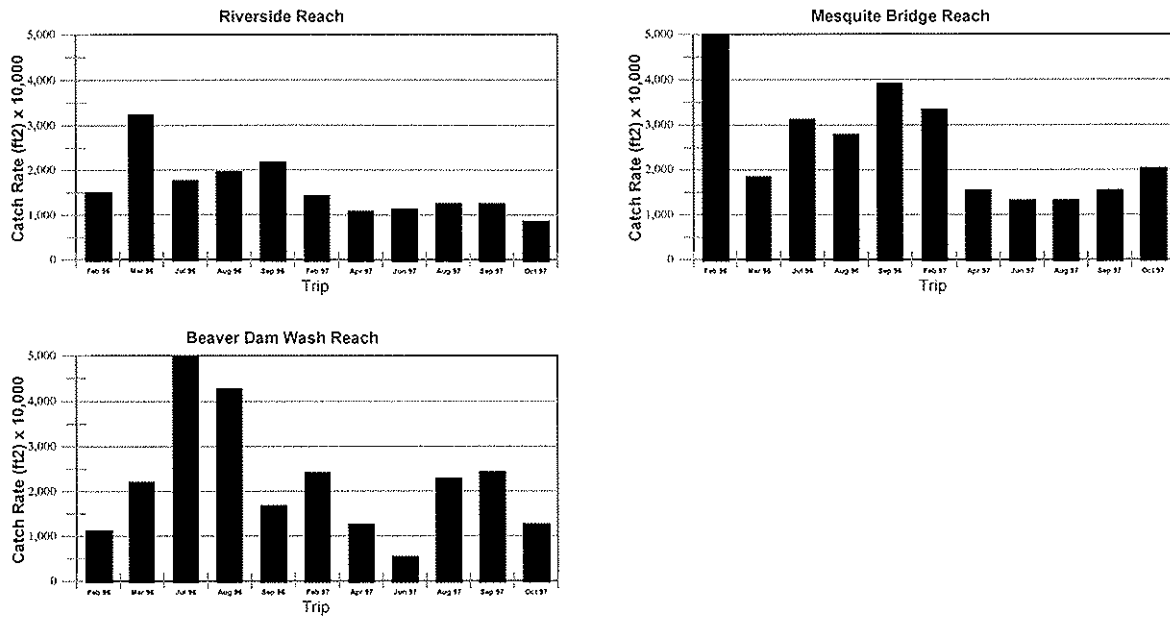


Figure 33. Catch rate (# per 10,000 ft² of seining) of red shiner collected at three reaches in the Virgin River by sampling trip, 1996 to 1997.

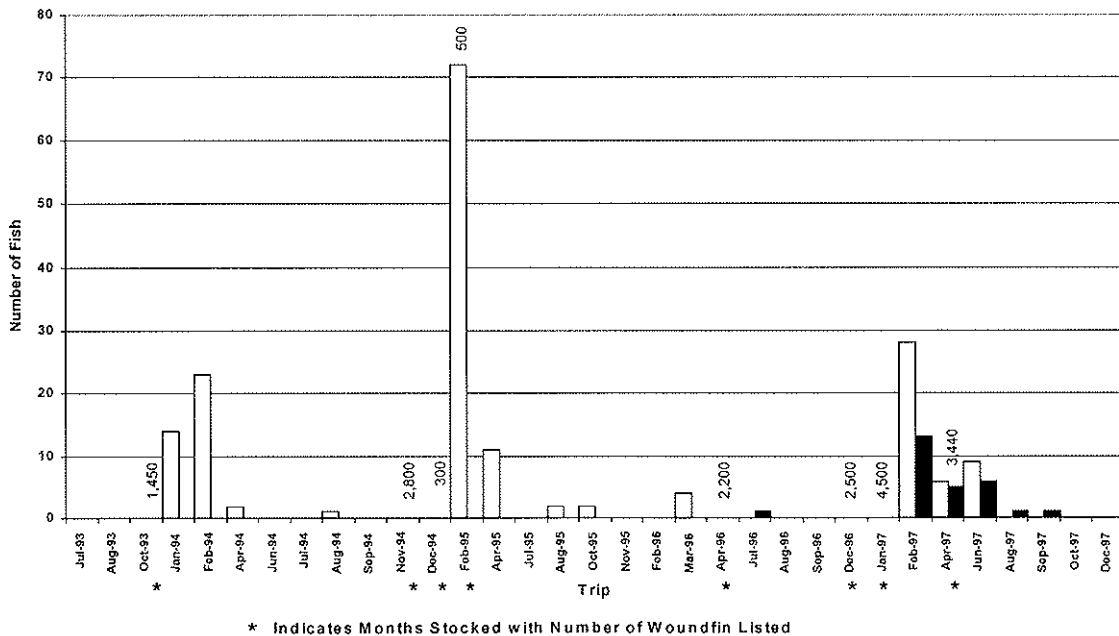


Figure 34. Number of marked woundfin collected at two reaches in the Virgin River by sampling trip, 1994 to 1997.

Virgin River chub were stocked in late 1994 at the Mesquite and Riverside bridges, and at the Mesquite bridge in January, April, and December of 1997. Five tagged Virgin River chub were recaptured in February 1995 at the Riverside reach, but no other tagged Virgin River chub were found.

Habitat Measurements, 1997

In December 1997 habitat measurements were made throughout the three study reaches in an attempt to quantify potential physical similarities and differences that may be important in determining differences in fish density and distribution. The physical data collected showed that the Beaver Dam Wash reach has the highest amounts of cobble-gravel substrates, whereas the other two reaches are dominated by sand substrates. The Riverside reach has more cobble-gravel substrates than the Mesquite reach, resulting in an increased number of riffles compared with Mesquite, but both reaches are dominated by sand runs.

Beaver Dam Wash Reach (RM 72.00 to 68.50)

Several factors have contributed to river channel morphology of the Beaver Dam Wash reach, including gradient, floodplain vegetation, substrate material, and geologic controls. The section of river sampled downstream of the Beaver Dam Wash reach was moderately sinuous (1.31) with a low gradient of 0.5%. This reach had the highest gradient of all three reaches and consequently had the largest amount of cobble and gravel substrate (Table 1). Entrenchment appeared highest here also and likely contributed to more effective sediment transport. This reach had cliffs running down the east and west sides of the Virgin River and dense, well-rooted vegetation on the floodplain in between these sections. These controls have caused the Virgin River to maintain the same relative channel without the meandering found in the other two reaches. Higher entrenchment and gradient are probably the causes for this reach having the lowest overall amounts of sand of the three study reaches.

Table 2 shows the results of habitat measurements made December 6, 1997. In total, 3.45 mi of the Virgin River were sampled for habitat with a total area measured of 1,058,659 ft². This section of river had the highest percentage of riffles and lowest percentage of runs. In addition, this section had the largest percentage of fine gravel, small cobble, large cobble, and boulder. Depth at the Beaver Dam Wash reach was the deepest of the three reaches, with depths over 24 in. covering nearly 38% of the reach.

Mesquite Reach (RM 58.00 to 54.50)

This section of river was dominated by a sand bottom and was moderately sinuous (1.32) with a 0.3% gradient. The Mesquite reach had the same sinuosity as the Beaver Dam Wash reach, although the gradient was 0.2% less. This difference was likely a result of individual river channel morphology and riparian vegetation characteristics at each of the study reaches. The Mesquite reach had much less bedrock cliff abutting the river channel and vegetation that was not as well established

Table 1. Dominant substrate and depth composition for three reaches on the lower Virgin River as surveyed December 1997.

TYPE OF HABITAT MEASURED						
Substrate Type	Beaver Dam Wash		Mesquite Bridge		Riverside Bridge	
	Area-ft ²	% of Total	Area-ft ²	% of Total	Area-ft ²	% of Total
Silt	1,000	0.09	600	0.05	4,436	0.33
Sand	605,985	57.24	922,555	80.11	1,026,734	76.82
Fine Gravel	5,338	0.50	260	0.02	2,120	0.16
Coarse Gravel	16,780	1.59	22,331	1.94	31,143	2.33
						November 9, 1998
Small Cobble	178,846	16.89	141,774	12.31	125,579	9.40
Large Cobble	217,447	20.54	61,872	5.37	129,632	9.70
Boulder	33,263	3.14	2,204	0.19	16,830	1.26
TOTAL	10,586	100.00	1,151,596	100.00	1,336,474	100.00
Depth (Inches)	Area-ft ²	% of Total	Area-ft ²	% of Total	Area-ft ²	% of Total
1-6	12,749	1.2	5,320	0.5	39,151	2.9
7-12	63,997	6.0	64,115	5.6	204,562	15.3
13-18	434,368	41.0	675,612	58.7	920,181	68.9
19-24	145,239	13.7	328,702	28.5	148,262	11.1
25-30	360,556	34.1	71,072	6.2	22,318	1.7
31-36	34,795	3.3	5,275	0.5	2,000	0.1
37-42	25	0.0	0	0.0	0	0.0
43-48	800	0.1	0	0.0	0	0.0
49-54	0	0.0	0	0.0	0	0.0
55-60	1,680	0.2	1,500	0.1	0	0.0
61-66	0	0.0	0	0.0	0	0.0
67-72	2,850	0.3	0	0.0	0	0.0
73-78	0	0.0	0	0.0	0	0.0
79-84	1,600	0.2	0	0.0	0	0.0
TOTAL	10,586	100.0	1,151,596	100.0	1,336,474	100

Table 2. Total coverages for individual habitat types as measured December 1997 at the three lower Virgin River reaches.

Type of Area Measured	Beaver Dam Wash		Mesquite		Riverside	
	Area-ft ²	% of Total	Area-ft ²	% of Total	Area-ft ²	% of Total
Backwater (ft ²)	1,000	0.09	0	0.00	620	0.05
Eddy (ft ²)	2,025	0.19	1,429	0.12	675	0.10
Pool (ft ²)	985	0.93	14,582	1.30	8,149	0.60
Riffle (ft ²)	320,374	30.30	163,845	14.20	271,201	20.30
Run (ft ²)	725,409	68.50	971,740	84.40	1,055,829	79.00
Total (ft ²)	1,058,659	100.00	1,151,596	100.00	1,336,474	100.00

compared with the Beaver Dam Wash reach. This resulted in a larger floodplain and more channel change following high flow events.

Total values for habitat measurements conducted December 7, 1997, indicated that the Mesquite reach had the highest percentage of pool and run habitat and the lowest amount of riffle habitat as compared with the other two reaches (Table 2). This is likely a function of the lower gradient and lower presence of geologic controls such as the conglomerate cliffs found at the Beaver Dam Wash reach. This reach had the largest amount of sand substrate (80%) of the three reaches, and lower amounts of gravel and cobble substrate (Table 1). Depths at Mesquite reach were deeper than at Riverside reach but considerably shallower than depths at Beaver Dam Wash reach. In the areas where there are adjacent cliffs, the river channel generally remained the same throughout the duration of the study. However, in areas where there were no stable geologic controls, the channel tended to wander more during the course of the study.

Riverside Reach (RM 49.25 to 45.30)

Extending from the Riverside Bridge 3.95 mi downstream, the Riverside reach was characterized by a mostly sand-bottomed section of river with moderate gradient (0.2%) and a sinuosity of 1.25. Substrate was generally similar to that at the Mesquite reach, except for slightly higher amounts of gravels, cobbles, and silt as measured December 8, 1997 (Table 1). Overall, depth at the Riverside reach was shallower than at the other two reaches, with only 2% of the area over 24 in. deep. Habitat types were also fairly similar to the Mesquite reach, except that riffles made up somewhat more of the stream at the Riverside reach. Geologic controls included loose conglomerate cliffs that abutted the Virgin River at approximately each mile and vegetated banks in between cliffs.

This larger portion of the Virgin River studied in 1993 to 1995, downstream of Riverside Bridge and extending to Halfway Wash (RM 41.00), had a similar channel configuration to that of the upper portion, with an overall gradient of 0.3% and a sinuosity of 1.17. The lower portion of this reach had the widest width-to-depth ratio, the least amount of entrenchment, and was predominantly sand bottomed.

Overall, the Virgin River decreased in gradient with proximity to Lake Mead. Consequently, the section of river below Halfway Wash exemplified a shift from faster runs and riffles to slower runs and backwaters with increasing distance downstream. At approximately RM 40.00, the Virgin River was characterized by an aggrading channel. Here water began leaving the main channel and flowed into the riparian corridor on both sides of the river. The volume of water in the channel progressively decreased until the main channel was completely dry at base flows at approximately RM 38.20. At that point, the entire Virgin River consisted of slow-flowing water in the riparian zone. The disruption of the main channel and flow of water through the riparian zone represented the backwater effect of Lake Mead and probably influenced fish distribution in the lower Virgin River. Below RM 40.00, there was little habitat that would have been suitable for native fish species. In contrast, much suitable habitat existed for nonnative species adapted to lentic conditions.

DISCUSSION

When this study was initiated in 1993, the major goal was to determine if a population of woundfin persisted in the Virgin River in the Riverside reach. The consistent collection of woundfin from 1993 through 1997, along with collection of young-of-the-year in 1994, 1995, and 1996, and the growth patterns of the fish collected in this area that showed the same cohorts of fish from year to year, all suggested that a woundfin population did, in fact, persist below Riverside reach. The data also showed that the population was centered around RM 45.00 in 1993 and 1994, and it became more scattered in 1995 following high flows. Relatively few woundfin were collected near the Riverside Bridge (RM 49.00) or near Halfway Wash (RM 38.00), the two monitoring stations used by the Recovery Team. Therefore, the perception that a population of woundfin did not persist in the lower Virgin River was due to monitoring outside the area where the population was most abundant.

The question then arose whether the young found at the Riverside reach were produced from reproduction in that area, or whether they moved downstream from some upstream population center. During the 1990s the only extensive population of woundfin remaining in the Virgin River occurred above the Washington Fields Diversion in Utah, a distance of nearly 50 mi above the Riverside reach. The collection of woundfin in a relatively small reach of river tended to support a reproducing population theory rather than a downstream movement theory. Young moving downstream would more likely be found spread out in the river reach rather than concentrated, whereas young produced by a population would more likely be found near the density center of that population. YOY in the lower Virgin River tended to be found near or just below the centers of population density. In addition, sampling in the Virgin Gorge, about half way between the upstream population center of woundfin and the Riverside reach (Figure 1), during this time did not find young woundfin (C. Addley, Utah State University, personal communication). If downstream movement was occurring, it would have made sense that some woundfin would have been found scattered in between the Riverside reach and the upstream population center.

Also, during the low flow year of 1994, YOY woundfin would have been unable to move downstream to the Riverside reach during the summer because dry sections of the river occurred both above the Riverside reach and in the Virgin Gorge. Movement around the lower, dry river section would have been possible in the Riverside irrigation canal, but this route of movement was probably not feasible since most of the canal water was applied to irrigated fields before returning to the Virgin River. Sampling in 1996 and 1997 was aimed at answering the question about downstream movement, and these data continued to show YOY woundfin in the Riverside reach, with a few in the Mesquite reach, and none at the Beaver Dam Wash reach. A similar pattern of density was shown for adult woundfin. It would be difficult to justify such a disjunct distribution pattern with downstream movement. These data further supported a conclusion that the population in the Riverside reach, and perhaps including the Mesquite reach, was self-sustaining rather than due to downstream movement.

In addition, population levels of woundfin above Washington Fields Diversion in Utah declined rather dramatically in 1996 and 1997 (unpublished Recovery Team data). This suggests that during the latter portion of the present study, relatively few young were available to move downstream as

far as the study area. Downstream movement of woundfin and other native fishes was noted immediately below Washington Fields Diversion following poisoning operations in 1996 and 1997 (R. Fridell, Utah Division of Wildlife Resources, personal communication), so it is known that the species does move downstream. However, the information collected during the present study suggests very strongly that the populations of woundfin in the Riverside reach, and probably in the Mesquite reach, are self-sustaining through natural reproduction. Some limited downstream movement may augment the population occasionally, but reproduction is the primary factor in sustaining the populations.

The primary data that support a theory of downstream movement as the factor maintaining woundfin populations in the lower river is the lack of small YOY. Although YOY were collected, they were generally found in July or August at a relatively large size (30 to 40 mm TL), rather than in May or June at a smaller size (15 to 30 mm TL) and in larger numbers. It is possible that sampling did not adequately cover the low velocity habitats that small woundfin inhabit and that the mesh size of the seines used was too large to catch such small fish. It is also possible that the timing of sampling was not correct to catch small woundfin, since June sampling occurred only 2 years out of the 5 years, and no sampling was conducted in May, and May and June are the two months when small YOY woundfin are likely available. Therefore, there appear to be a number of reasons why smaller and more abundant YOY woundfin were not found, and those reasons need to be investigated before the question of downstream movement will be completely answered.

Normal habitat use by woundfin is for medium-depth (0.5 to 1.5 ft) runs with a sand or sand-gravel substrate (Hardy et al. 1989), and habitat use information from this study substantiated that conclusion. But the change in woundfin habitat use during the low, clear flows was dramatic. Woundfin were found concentrated in small pools and runs immediately below riffles during July and August 1994, and again during low flow periods in summer 1996. This habitat type provided some of the deepest water in the stream at that time, as well as likely relatively high oxygen levels (oxygen was not measured) due to the turbulence of the riffle, and perhaps high levels of food (macroinvertebrates), also due to the riffle. Woundfin also became more grouped during this period. Individual seine hauls during summer 1994 included up to 38 woundfin, whereas during other times they were much more scattered and seldom were more than two found in any one seine haul. Woundfin grouping in habitats below riffles was recently documented in the Utah section of the Virgin River during low, clear flow periods (R. Fridell, Utah Division of Wildlife Resources, personal communication), and during sampling in Utah portions of the Virgin River from 1984 to 1987 (Hardy et al. 1989), supporting the habitat-use change noted during this study. The concentration of woundfin during low, clear flow periods suggests that the fish actively seek out these special habitats, whereas during other more-normal flow periods their habitat use is more random and scattered.

A study by Cross (1975), as well as monitoring by the Recovery Team in the 1970s and 1980s (Holden and Zucker 1996), suggested that woundfin were consistently spread over most of the Virgin River from their upstream limit at Pah Tempe Hot Springs to the Bunkerville Diversion. Virgin River reaches that had lower numbers of woundfin were those areas near St. George, Utah, and the reach below the Bunkerville Diversion, where summer flows were often very low and comprised only of irrigation return flows. Little sampling has been done that shows a distinct pattern of woundfin occupation, as was seen in the Riverside reach during this study, with apparent woundfin avoidance of some portions of the reach with similar flow characteristics.

The catch of woundfin, desert sucker, flannelmouth sucker, speckled dace, and red shiner all showed a drop following August 1994. This decline was more dramatic than declines in 1993 or 1995 and suggested that low flow, perhaps together with high temperatures, may have caused major declines in fish at the Riverside reach. Stream temperatures of near 35°C were measured in July and August 1994, and sampling was often stopped by mid afternoon before the highest temperatures of the day occurred. Deacon et al. (1987) determined Critical Thermal Maximum (CTM) temperatures for Virgin River fishes. CTM for flannelmouth sucker, bluehead sucker, and speckled dace was about 37°C, for red shiner it was about 39°C, and for woundfin it was about 39.5°C. It is possible that some fish may have died due to high temperatures in August or early September 1994, as CTM may have been reached on occasion in 1994. The field crews also noted numerous fish-eating birds (e.g., herons, egrets) along the stream at this time. The concentrated nature of woundfin, and other species, into fewer habitats may also have contributed to increased predation during this period. Hence, a number of mortality factors may have worked simultaneously on reducing native fish and red shiner numbers during late summer 1994, and all of these factors were related to low flow. However, the catch rate of all species recovered in summer 1995.

The decline in woundfin numbers and catch rates seen in fall samples at the Riverside and Mesquite reaches was atypical for this species. Hardy et al. (1989) reported on sampling in Utah portions of the Virgin River in the mid-1980s, and they did not show declines in woundfin numbers in the fall. In fact, during many years, numbers of woundfin actually increased due to the presence of large numbers of YOY. Low numbers of woundfin typically occurred in winter and spring samples in the Utah portion of the Virgin River. This information also suggests that habitat factors during late summer, such as temperature and predation, may be the primary limiting factors for woundfin in the lower Virgin River, whereas limiting factors in the upper Virgin River appear to occur at other times of the year. Hardy et al. (1989) suggested that overwinter mortality was a primary population-limiting factor in the upper Virgin River.

Based on the 1996 and 1997 fish and habitat sampling, river reaches with a pure sand substrate may not be the most important habitat for woundfin: if that were the case, then the Mesquite reach should have had greater woundfin numbers. A mixture of riffles with sand dominated runs appears to be important. This may be a reflection of the habitat preference switch during low, clear flow periods, when pools and runs below riffles become almost the only habitat type selected by woundfin. It is interesting that the Riverside reach appeared to be better for woundfin even though it had the lowest flows and was the section most impacted by irrigation diversions. At the same time, woundfin appeared to avoid the Beaver Dam Wash reach, which had relatively high and stable flows, but relatively little sand substrate. Depth was also greater overall at the Beaver Dam Wash reach. Based on these data, habitat availability appears to play an important role in determining which stream reaches woundfin will use.

During 1996, sampling was conducted to determine if other concentrations of woundfin were found outside the three intensive study reaches in the lower Virgin River. The area from RM 72.00 to RM 48.00 was sampled in its entirety during August. No other population centers were found, although woundfin were found scattered in areas outside the three study reaches. This information further supports the uniqueness of the Riverside reach in the lower Virgin River.

The age, growth, and reproductive cycle seen during this study, in which woundfin young appear to spawn at the end of their first and second years, and then disappear, was also seen in the Virgin

River by Deacon and Hardy (1980). They suggested that the second year adults contribute most of the spawning during any spring spawning period.

Although population estimation was not part of this study, the data do provide for at least an approximate population estimate at the Riverside reach. During July and August 1994, it appeared that most of the woundfin at the Riverside reach were caught. This was due to the very low flow level, the concentration of woundfin in discrete habitats, and the sampling efficiency these two conditions allowed. During all other trips, a much smaller percentage of woundfin were caught. This information suggests that the population of woundfin at the Riverside reach from 1993 to 1997 was likely 200 to 400 total individuals, depending on time of year and reproductive success.

Virgin River chub occur only sporadically below the Beaver Dam Wash reach. The Beaver Dam Wash reach has consistent flows during all seasons due to large springs and absence of irrigation diversions. The Beaver Dam Wash reach also has more rocky substrate and deeper pools. These factors are apparently important in allowing this area to maintain a relatively strong population of Virgin River chub. Populations of flannemouth sucker, desert sucker, and speckled dace also are strong at the Beaver Dam Wash reach. These populations likely provide the young that show up almost annually downstream near Riverside reach. The Riverside and Mesquite reaches apparently do not provide adequate habitat for these four native species, even with a relatively strong upstream population that allows for downstream movement of young.

In addition to physical habitat conditions, high late summer temperatures may also limit Virgin River chub, flannemouth sucker, desert sucker, and speckled dace below the Bunkerville Diversion. CTM values for Virgin River chub are about 36.5°C, the lowest of these four native species, and CTM values for the other three native species are 37°C (Deacon et al. 1987). High late summer temperatures may be a limiting factor for all four of these species below the Bunkerville Diversion.

Red shiner has been described as a major species of concern for native Virgin River fishes (USFWS 1995). The data from 1996 and 1997 showed that red shiner density was high at all three study reaches. The density of red shiner did not appear to be a factor in distribution or density of the native fish, since native fish density varied between the three reaches whereas red shiner density was relatively similar. This does not mean that elimination of red shiner from any reach would not result in an increase in native fish density, but it may mean that increases in density of native fishes would not be dramatic, since other habitat factors may control numbers of the native flannemouth sucker, desert sucker, Virgin River chub, and speckled dace more than red shiner interactions.

Woundfin, as well as the other native species, were abundant in the Beaver Dam Wash reach during the 1970s and early 1980s. Numbers of woundfin, in particular, declined in the mid-1980s, and the suspected cause for the decline was increased numbers of red shiner (Cross 1975, Deacon 1988, Holden and Zucker 1996). Holden and Zucker (1996) suggested that substrate composition in this reach was predominately sand in the 1970s and early 1980s, based on Recovery Team monitoring data, and that a change to more cobble and less sand substrate appeared to occur in the mid-1980s due to unknown reasons. Data from the present study confirms the high amount of cobble substrate and also tends to support a hypothesis that substrate change may have been an important factor in woundfin decline in this reach. If red shiner had been the only cause of the decline in woundfin density, the differences noted between the Beaver Dam Wash reach and the Mesquite and Riverside reaches during the present study should not have occurred.

Habitat usage by speckled dace, flannemouth sucker, and desert sucker at the Riverside reach is generally similar to the accepted norm for these species. Speckled dace, in particular, are thought of as a riffle-dwelling species, and flannemouth sucker and desert sucker also tend to favor rocky substrate. Habitat data from this study supported these general use patterns.

Red shiner dominate the fish community of the lower Virgin River. Hardy et al. (1989) documented the decline of woundfin as red shiner became abundant in the Utah section of the Virgin River. This makes the occurrence of a sustaining population of woundfin in the Riverside reach even more unique. As noted above, sampling location and intensity are important in locating small populations of woundfin. The sampling intensity in this study was generally greater than in most previous Virgin River studies. Without the intensive sampling of several miles of river at a given reach, the small populations of woundfin in particular, may not have been seen accurately. The information collected during this study suggests that woundfin are able to sustain some level of population, even under the influence of large numbers of red shiner and reduced flow.

The detailed habitat measurement of the three study reaches in 1997 did not show any obvious habitat-related reason why the Riverside reach seemed to be selected by woundfin, except perhaps for depth. The Riverside reach had fewer deeper portions of the stream than the other two reaches. The habitat analysis also did not show why woundfin may have favored different portions of the Riverside reach. It appears that the mixture of riffle (cobble/gravel substrate) and run (sand substrate) habitat is important to woundfin, especially during low flow years, but that these areas are selected even during higher flow periods. The exact mechanism for this habitat selection, or the variables influencing such a habitat selection, were not determined.

CONCLUSIONS

This study was initiated in 1993 with the primary objective of determining if woundfin maintained a population in the lower Virgin River. Woundfin were found in the lower Virgin River, especially below Riverside reach, and a reproducing population was found consistently for 5 years. Another objective was to determine habitats important to woundfin, especially during low flow periods. The study found that habitats important in maintaining woundfin through low, clear flow periods were small pools and runs below riffles. Woundfin appeared to be able to survive late summer flow periods when portions of the Virgin River were dry due to irrigation withdrawals, but woundfin did decline more than during higher flow summers. A fairly complex habitat mix of sand runs and riffles appears to be the habitat factor important for woundfin in selection of river reaches to inhabit. This is somewhat different than the traditional habitat conclusion that indicated that sand runs were the important habitat type (USFWS 1995, Hardy et al, 1989).

Sampling was extended upstream in 1996 and 1997 to try to determine if woundfin in the lower Virgin River were there due to downstream movement from upstream population centers, or due to self-sustaining reproduction. The study results suggest that reproduction in the lower river was the likely reason for the consistent population because upstream and intervening areas did not have woundfin. In addition, numbers of woundfin in the Utah population center declined dramatically during these years, affecting the number of young that were available to move downstream.

Sampling in 1996 and 1997 compared three reaches. Woundfin apparently did not prefer the Beaver Dam Wash reach because of too much riffle and cobble habitat. The other native fishes in the Virgin River system were much more common in the Beaver Dam Wash reach than in the other two reaches. Virgin River chub are generally found in deeper pool habitats, and the Beaver Dam Wash reach had the greatest depth of the three reaches studied. This reach also had the most cobble substrate, the most consistent flows, and the lowest summer temperatures. These characteristics apparently are important to flannelmouth sucker, desert sucker, speckled dace, and Virgin River chub.

In conclusion, this study has shown that several factors appear to be important to woundfin. Physical habitat, more than flow or red shiner density, was important to woundfin in the lower Virgin River. Woundfin preferred habitats below irrigation diversions with less summer flow (Riverside reach) but apparently better physical habitat characteristics rather than areas with higher flow but poorer habitat features (Mesquite and Beaver Dam Wash reaches). Areas with high and consistent flow do not necessarily equate to consistent woundfin numbers, as was seen at Beaver Dam Wash reach. A lower-gradient mixture of runs and riffles was selected by woundfin, even under very severe flow limitations. But flow augmentation to the Riverside reach may improve conditions for woundfin, since high temperatures may be a problem during low flow late summer periods. Red shiner density was similar between the three study reaches, yet woundfin numbers varied, suggesting that habitat was a deciding factor rather than red shiner density. Most of the other native fishes apparently require just the opposite flow and habitat compared to woundfin. Consistent higher flows and a dominant rocky substrate supported higher numbers of native flannelmouth sucker, desert sucker, speckled dace, and Virgin River chub.

RECOMMENDATIONS

As is so often the case, as more is learned about a situation, more questions arise. Although the objectives of this study were met, several questions still remain. How much movement occurs in the woundfin in the lower Virgin River? Why weren't YOY found at a smaller size and earlier each year? How large are the populations at the Riverside and Mesquite reaches? What would increased flow do for the small populations of woundfin? To answer these questions, it is recommended that studies be continued that are directed at the specific objectives below.

1. Continue to sample at least seasonally in the lower Virgin River at the Riverside and Mesquite reaches to monitor population changes.
2. Use the marking techniques developed by the Nevada Division of Wildlife to mark wild woundfin at the Mesquite and Riverside reaches. Use a reach-specific mark so that movement between the two reaches can be determined. In addition, a mark recapture population estimates should be used to determine population size and changes between years.
3. Measure habitat more intensively than it was measured in this study to attempt to determine what physical factors are important in woundfin distribution and density in the lower Virgin River.
4. Sample the Mesquite and Riverside reaches for YOY woundfin, concentrating on low velocity habitats rather than mainchannel runs and riffles. Sampling should be conducted in May or June, depending on flow levels, and seines with .0625 in mesh should be used.

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