
SUMMARY OF LOWER VIRGIN RIVER STUDIES 1996 - 2002, FINAL REPORT

PR-449-2

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Fish collected in the Virgin River
(clockwise from top left):
Flannelmouth sucker (*Catostomus*
latipinnis), elastomer-tagged woundfin
(*Plagopterus argentissimus*),
blue tilapia (*Oreochromis aurea*),
and Virgin River chub (*Gila seminuda*).

EXECUTIVE SUMMARY

BIO-WEST has been involved in a variety of research and management activities in the lower Virgin River for the past 10 years. In 1996, after 3 years of extensive sampling in the lower Virgin River, BIO-WEST created three long-term monitoring reaches. Since then, the three reaches have been monitored several times a year to establish trends in native fish populations. In 1999 BIO-WEST assumed the lead role in woundfin (*Plagopterus argentissimus*) stocking studies for the Lower Virgin River Recovery Implementation Team. The objective of the studies was to determine if mechanical removal of red shiner (*Cyprinella lutrensis*) and/or changes in stocking protocol could increase the survival of stocked woundfin in the lower Virgin River. Finally, after the July 2001 discovery of blue tilapia (*Oreochromis aurea*) in the lower Virgin River, BIO-WEST assumed primary responsibility for monitoring blue tilapia movement and distribution. BIO-WEST also assisted the Lower Virgin River Recovery Implementation Team in planning and implementing a pilot rotenone treatment in preparation for larger efforts designed to prevent the spread of blue tilapia, and eventually red shiner, to the upper Virgin River.

BIO-WEST found that all three long-term monitoring reaches had native fish populations. The Beaver Dam Wash Reach had the largest and most diverse native fish community. The Beaver Dam Wash Reach appears to be an important source of native flannelmouth sucker (*Catostomus latipinnis*), desert sucker (*Catostomus clarki*), and speckled dace (*Rhinichthys osculus*), as well as the endangered Virgin River chub (*Gila seminuda*). The Riverside Reach had a small but consistent woundfin population until summer 2000, when it began to decline. Native fish populations in all three reaches declined between 2000-2002. The Mesquite Bridge and Riverside Reaches were almost completely devoid of native fishes, including woundfin, by fall 2001. Multiple years of drought exacerbated by human water use have created conditions that are unsuitable for native fishes below the Bunkerville Diversion. The drought also appears to have impaired native fish recruitment upstream at Beaver Dam Wash.

BIO-WEST and the Lower Virgin River Recovery Implementation Team organized five large-scale red shiner removal efforts and three woundfin stocking efforts between May 1999 and May 2001. Woundfin were stocked immediately following large-scale mechanical removals of red shiner in May 1999, October 1999, and October 2000. Data collected during subsequent sampling indicated that mechanical removal of red shiner can only be successful at lowering red shiner numbers when the appropriate environmental conditions are present. Red shiner catch rates decline in winter in the absence of mechanical removal, so timing mechanical removal efforts to coincide with this critical period may assist in lowering red shiner numbers. Summer and fall drought conditions appear to promote the proliferation of red shiner and prohibit effective mechanical control.

Stocking young-of-year woundfin in the fall resulted in woundfin surviving substantially longer than when year-old woundfin were stocked in the spring. The young-of-year fish stocked in October 1999 and October 2000 also persisted longer than any previous stocking attempts. Fish from both fall stocking events survived, as evidenced by relatively consistent catch rates for 7-8 months, before major declines occurred. The fish stocked in October 1999 successfully spawned in spring 2000, producing fairly large numbers of young-of-year woundfin. Both the stocked adults and their progeny disappeared over the summer months. The October 2000 stocked fish disappeared in early summer 2001.

Red shiner numbers were highest in late summer and early fall when woundfin numbers were at their lowest. However, woundfin survived winter and spring 2000-2001 nearly as well as winter and spring 1999-2000, despite the fact that red shiner catch rates were almost two times higher in winter and spring 2000-2001. Drought conditions reduced summer flows well below the long-term average from 1999 through 2002. The high temperatures, low turbidity, and reduced habitat availability caused by the drought and exacerbated by human water use had a negative impact on summer survival of stocked woundfin. The proliferation of red shiner and other nonnative competitors and predators under the same low-flow conditions further reduced the chance for stocked woundfin survival.

Blue tilapia were first discovered in the lower Virgin River in July 2001. Monitoring from August to December 2001 found only young-of-year blue tilapia and showed that they disappeared as water levels increased and temperatures decreased. Before blue tilapia disappeared from our catch, one was found above the Bunkerville Diversion. Blue tilapia did not appear in the catch again until September 2002. The Virgin River was not connected to Lake Mead for most of that summer, until an early September storm event. Therefore, it appears that blue tilapia are migrating up the Virgin River from Lake Mead. Monitoring through December 2002 showed that blue tilapia once again disappeared from the catch when temperatures dropped. An experimental rotenone treatment was performed on a 1-mile section of river in October 2002. Blue tilapia were fairly tolerant to the effects of rotenone. Seining efforts prior to the treatment captured 13% of the number of blue tilapia removed during the treatment.

We conclude that the combined impacts of human water use and drought are responsible for the decline in native fishes, the inability of stocked woundfin to survive into the following fall, the high numbers of nonnative fishes, and potentially the blue tilapia invasion. We have provided a list of recommended studies and management actions to assist in recovery of native fishes in the lower Virgin River (see Chapter 4).

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GENERAL INTRODUCTION

In 1993 the Southern Nevada Water Authority (SNWA) contracted BIO-WEST, Inc. (BIO-WEST) to begin studies on the distribution and abundance of native fishes in the lower Virgin River. BIO-WEST sampled the Nevada portions of the river and found many species of native fishes, including the endangered woundfin (*Plagopterus argentissimus*). By 1996 BIO-WEST had sampled most of the Virgin River between Beaver Dam Wash, Arizona, and the confluence with Lake Mead. Long-term monitoring stations were delineated at Beaver Dam Wash (River Mile [RM] 72-68.5), Mesquite, Nevada (RM 58-54.5), and Riverside, Nevada (RM 49-45.5). Continued monitoring of these reaches has provided information about trends in the native fish populations of the lower Virgin River (Holden and Abate 1999, Holden and Golden 2000).

Between 1993 and 1997, BIO-WEST also assisted the Nevada Division of Wildlife (NDOW) with monitoring woundfin stocked in the lower Virgin River. In 1999 BIO-WEST assumed the lead role for the stocking studies in the lower Virgin River, with funding from both the SNWA and the U.S. Bureau of Reclamation (USBR). An "Experimental Reach" was delineated in the 4.75-mile reach of river between the Mesquite and Bunkerville Diversions. In the Experimental Reach BIO-WEST studied the age-related survival of stocked woundfin and the effects of red shiner (*Cyprinella lutrensis*) removal on woundfin stocking success in 1999 and 2000 (Holden and Golden 2000). Additional studies were conducted in 2000 and 2001. Monitoring of red shiner and stocked woundfin numbers continued through December 2002.

In July 2001 blue tilapia (*Oreochromis aurea*), a tropical cichlid, was discovered in the lower Virgin River. BIO-WEST was asked by the Lower Virgin River Recovery Implementation Team (LVRRIT) to monitor the survival and movement of this new nonnative species throughout the lower river. BIO-WEST was also asked to help plan and participate in a trial rotenone treatment of a portion of the river to determine the feasibility of keeping an area free of blue tilapia. The pilot treatment project also offered an opportunity to evaluate the effectiveness of seining as the primary monitoring method for blue tilapia. The SNWA and the Virgin River Resource Management and Recovery Program (VRRMRP) provided funding for these efforts.

Previous reports have documented the results of long-term monitoring and woundfin stocking experiments conducted through June 2000 (Holden and Abate 1999, Holden and Golden 2000). The following report presents data collected by BIO-WEST for both these projects since June 2000. Additionally, we analyze all data collected in the Experimental Reach since 1999 and examine trends at each long-term monitoring reach since 1996. Finally, we provide the results of blue tilapia monitoring and pilot rotenone treatment experiments. Each of the three studies, long-term monitoring, woundfin stocking, and blue tilapia monitoring and treatment, are covered in separate chapters. The final chapter provides an integrated discussion of all three projects and recommends management actions and areas for future study.

CHAPTER 1: LONG-TERM MONITORING SITES

Introduction

Similar to many southwestern desert rivers, the Virgin River has a unique native fish fauna that is imperiled by increased water development and the encroachment of nonnative fishes, particularly red shiner. Only six native fish species inhabit the Virgin River below Pah Tempe Hot Springs near LaVerkin, Utah. Two of these species, the Virgin River chub (*Gila seminuda*) and the Virgin spinedace (*Lepidomeda mollispinnis mollispinnis*), are definitely endemic to the Virgin/Muddy River system. The woundfin is probably endemic to the system as well, despite early survey records describing the species from other drainages (Holden et al. in press). The woundfin and Virgin River chub are both listed as federally endangered. The Virgin spinedace was proposed for listing, but was not listed in lieu of a conservation agreement. Certain stations along the Virgin River have been monitored regularly since the mid 1970s by the Virgin River Recovery Team (USFWS 1995, Holden et al. 2001, Virgin River Database 2001). This monitoring showed that by the early 1990s woundfin were virtually absent from the lower Virgin River. During monitoring low population numbers of all native fishes were found below Beaver Dam Wash. However, at that time, no surveys of large sections of the lower river had been completed since the 1970s (Cross 1975).

In 1993 BIO-WEST was contracted by the SNWA to survey the lower Virgin River for populations of native fishes. From 1993 through 1995 BIO-WEST surveyed the lower Virgin River and documented the presence of several native species between Riverside and Lake Mead, including a small but consistent population of woundfin below the Riverside Bridge (Holden and Abate 1999). Additional sampling from Beaver Dam Wash to the Riverside area documented the presence of Virgin River chub and Virgin spinedace, as well as relatively high numbers of native suckers and speckled dace (*Rhinichthys osculus*) in the Arizona portion of the river. In 1996 and 1997 BIO-WEST delineated three long-term monitoring reaches in the lower Virgin River: Beaver Dam Wash (RM 72-68.5), Mesquite Bridge (RM 58-54.5), and Riverside (RM 49-45.5). BIO-WEST has reported on the status of this long-term monitoring in previous reports (Holden and Abate 1999, Holden and Golden 2000). This chapter presents the results of long-term monitoring (June 2000 through October 2002) in these reaches and provides information on trends seen in the fish communities in the three monitoring reaches since 1996.

Methods

The long-term monitoring reaches remained the same as in past years (Figure 1-1). Methods for collecting fisheries and habitat information also remained the same as in previous years (Holden and Abate 1999, Holden and Golden 2000). The sampling protocol involved walking downstream through each reach and selecting habitats based on availability and probable sampling efficiency for seines, which were the primary sampling gear. 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 90 meters (m). Several types of seines were used for fish collection, but 1.2 m x 4.5 m x 3 millimeter (mm) seines were the primary sampling gear.

The following information was recorded for each sample: sample number, river mile (in 0.25-mile increments), reach, date and time of collection, habitat type, gear type, approximate length and width of the habitat sampled, average and maximum depths, the two dominant substrate types (i.e., silt, sand, fine gravel [< 25 mm diameter], coarse gravel [25-75 mm diameter], small cobble [75-150 mm diameter], large cobble [150-255 mm diameter], and boulder [> 255 mm diameter]), and cover availability. 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 numbers were estimated. All native fish species were measured for total length until 100 lengths for each species were obtained in each reach. Uncommon species (less than 25 captured) were also measured.

Flow information was obtained from the Littlefield, Arizona, gage (United State Geological Survey [USGS] gage #09415000). Temperature information was obtained in two ways. First, during sampling, temperature was taken with a hand-held thermometer approximately every hour. Second, beginning in summer 2000, thermographs (Optic Stowaway and Optic Stowaway XT1, Onset Computer Corporation) were deployed in all three reaches.

Data Analysis

The statistical program SYSTAT® was used to perform all statistical analyses. In order to more closely approximate a normal distribution, the natural log of fish numbers + 1 was used in all statistical analyses. Fish numbers are expressed as the natural log of fish numbers per seine haul + 1 in figures and as total numbers in tables. We used analysis of variance (ANOVA) with Tukey's Honestly Significant Difference multiple comparison follow-up procedure to compare the results of fish numbers between sampling trips and years. To compare fish utilization of different habitats, substrates, and cover, we used chi-square tests. We set an a priori value of 0.05 (5% chance of type I error) for all statistical tests.

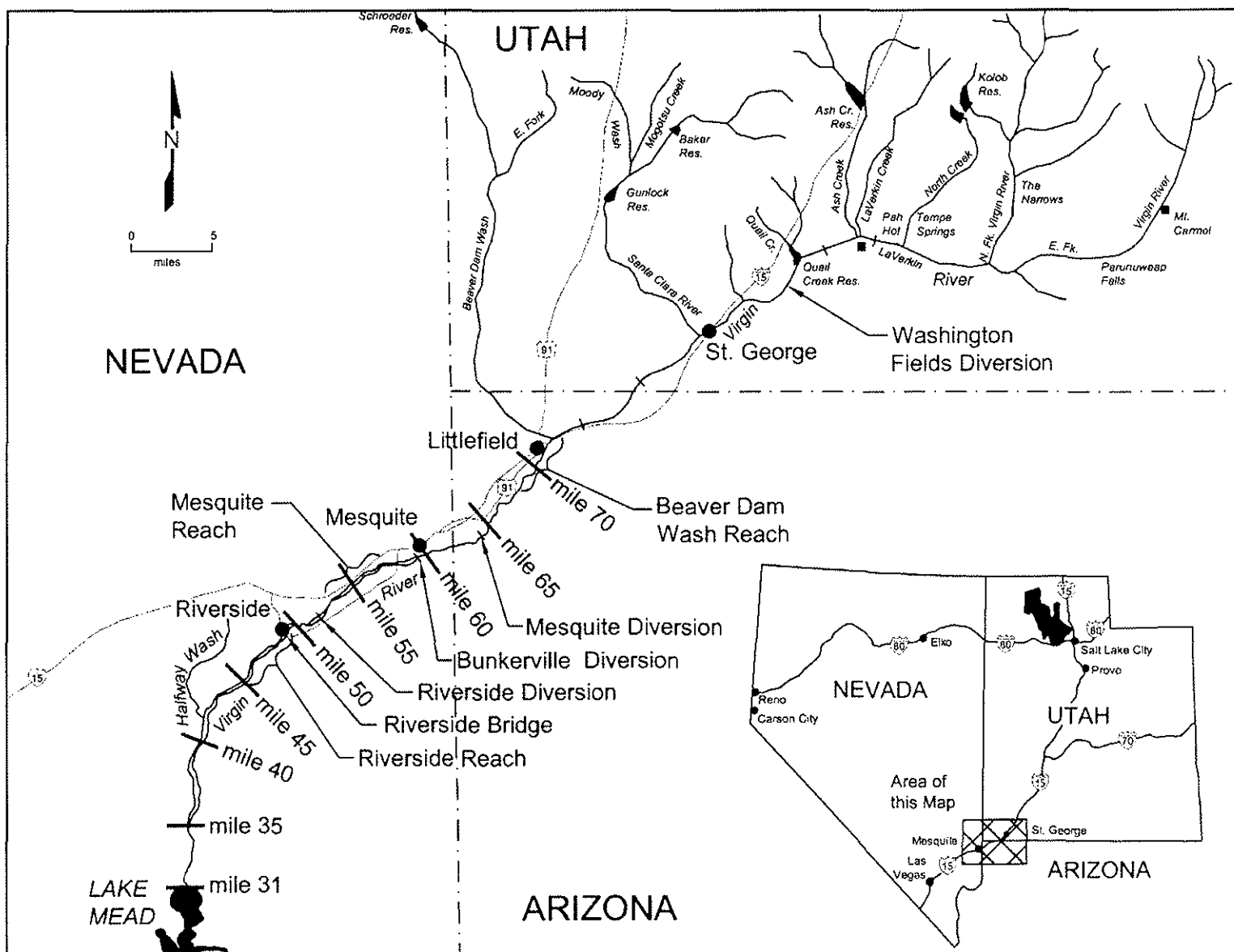


Figure 1-1. Locations of long-term monitoring reaches on the Virgin River.

Results

Figure 1-2 provides the results of the flow data collected at the USGS gage at Littlefield from 1996 to 2002. Viewing Figure 1-3 helps to put these years in the context of the past 32-years of flow information from that gage. During the study period, only 1998 approached the long-term average for spring runoff in the lower river. Conversely, 2000 through 2002 were very poor years for runoff, and 2002 had the lowest flows on record at the Littlefield USGS gage. While many of the study years were low-flow years, they still had different flow characteristics. For instance, in 1996, 1997, and 1999 high spring runoff did not occur, but there were several spate events throughout those years. During 2000 and 2001 we saw low spring runoff with few summer spate events, and in 2002 we saw no spring runoff and no summer spate events.

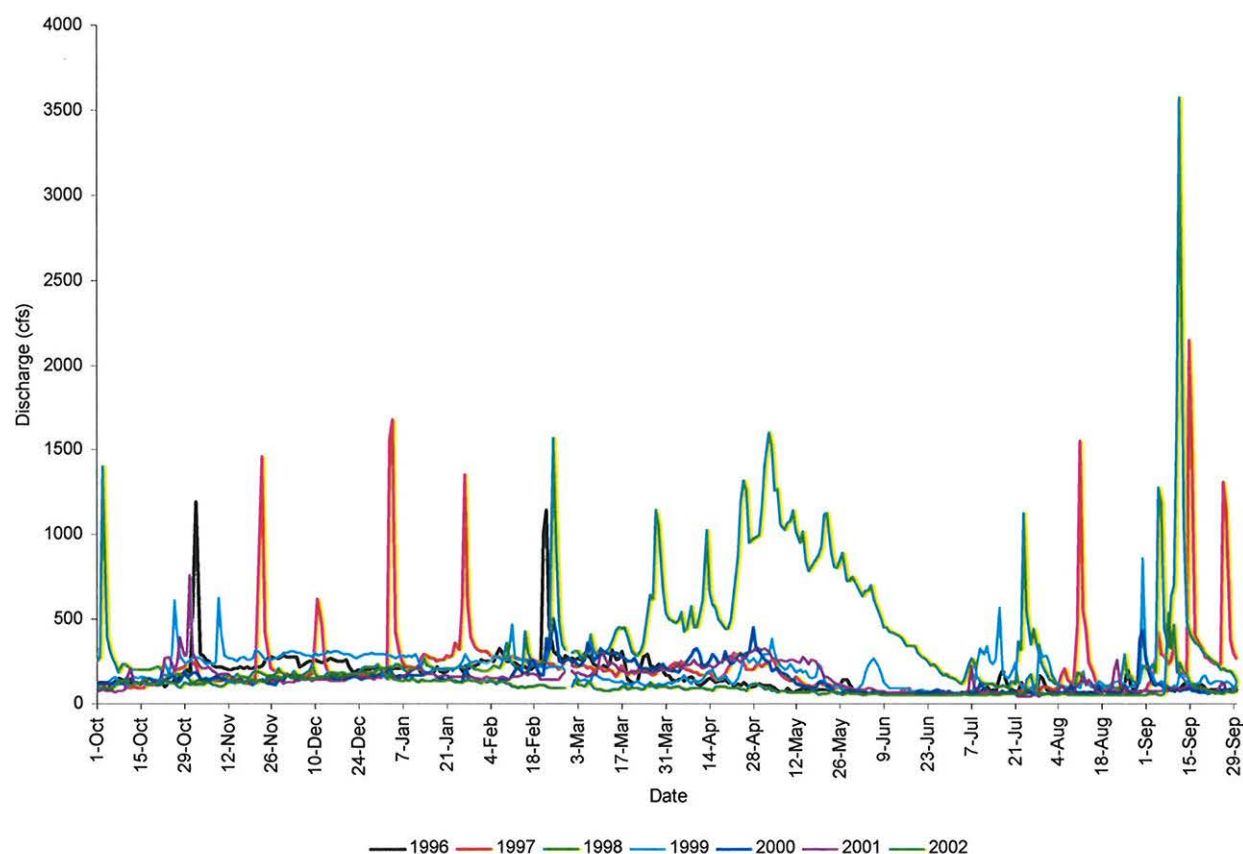


Figure 1-2. Average daily discharge of the Virgin River measured at the USGS gage at Littlefield from 1996 to 2002.

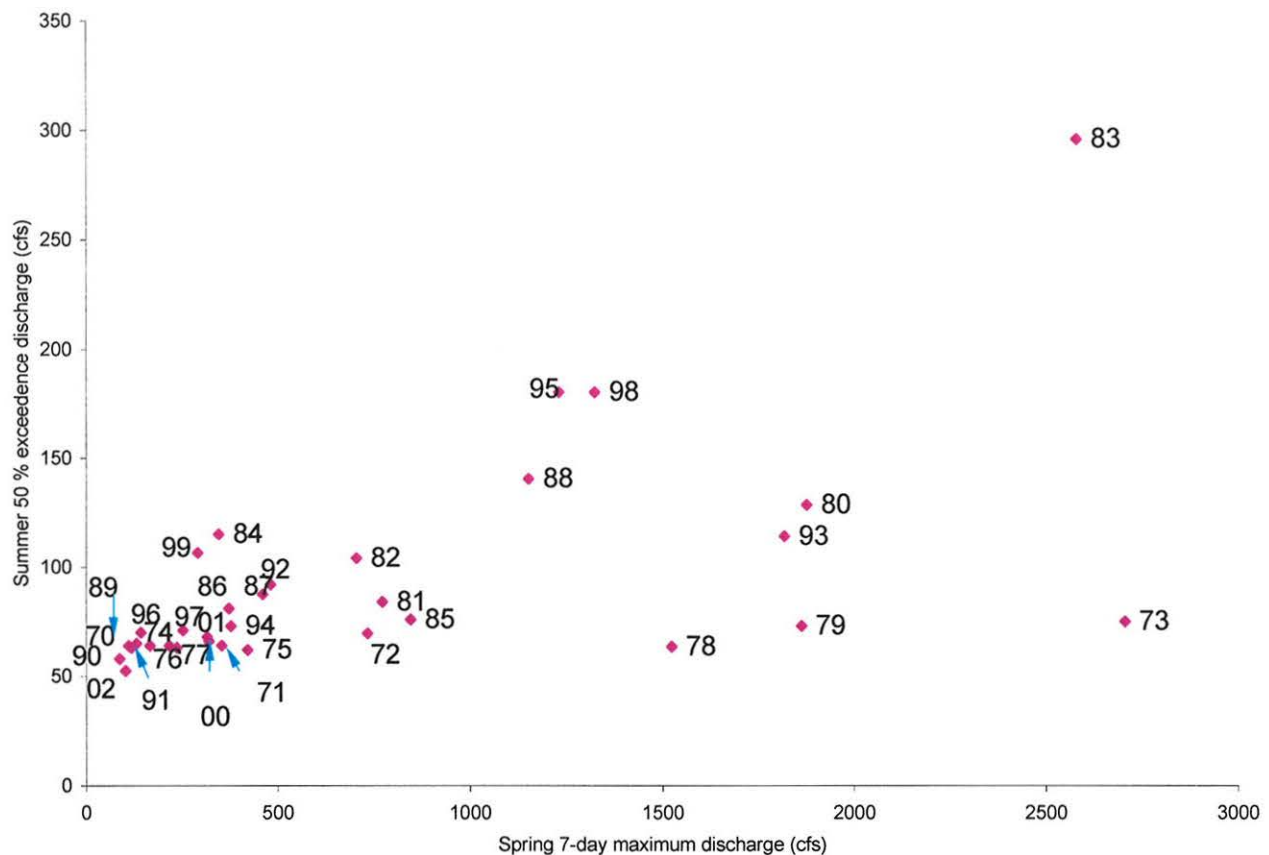


Figure 1-3. Cluster analysis of flow years from 1970 to 2002 at the Littlefield gage using 50% exceedence flow and 7-day spring maximum flow.

Temperature data for the Beaver Dam Wash and Riverside Reaches are shown in Figure 1-4. A thermograph deployed at the Mesquite Bridge Reach was blown out almost immediately by a spate. We were unable to find a suitable, easily accessible location to replace the Mesquite Bridge Reach thermograph in an area sheltered from high flow and depositional events. Additionally, we felt the presence of thermographs in the Experimental Reach and the Riverside Reach surrounding the Mesquite Bridge Reach would provide enough information on thermal variability. During their deployment the thermographs at the Riverside and Beaver Dam Wash Reaches each had to be moved at least once because they were covered with sediment during a spate or were dewatered during drought.

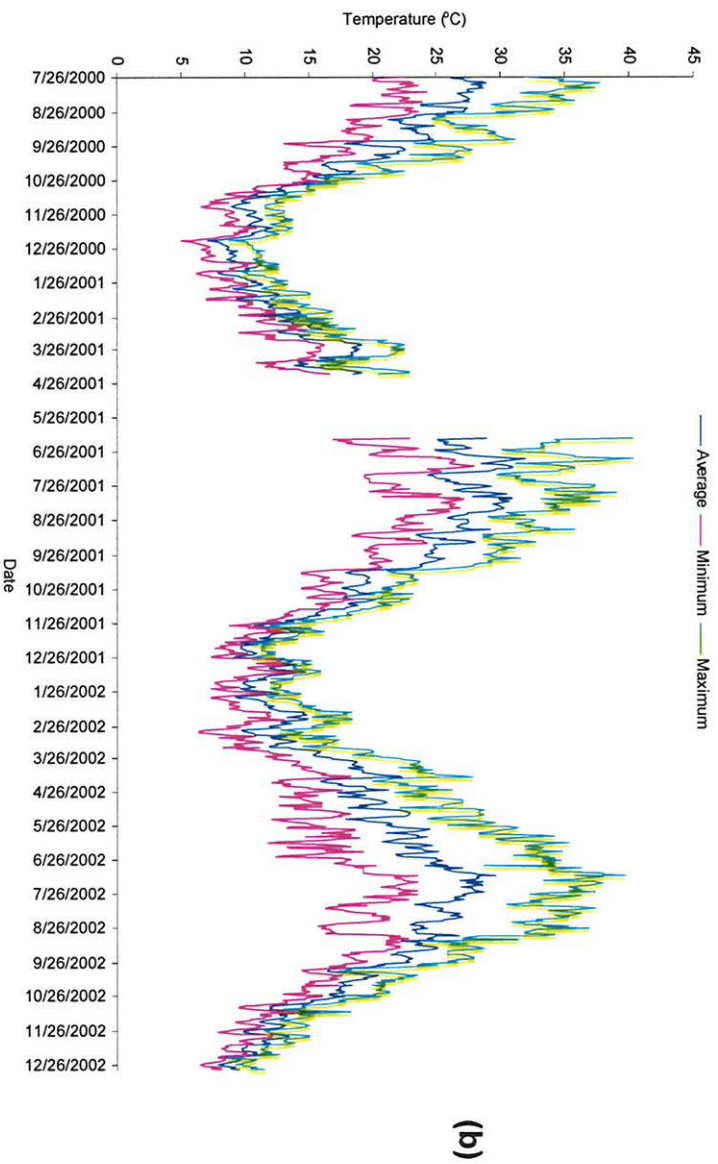
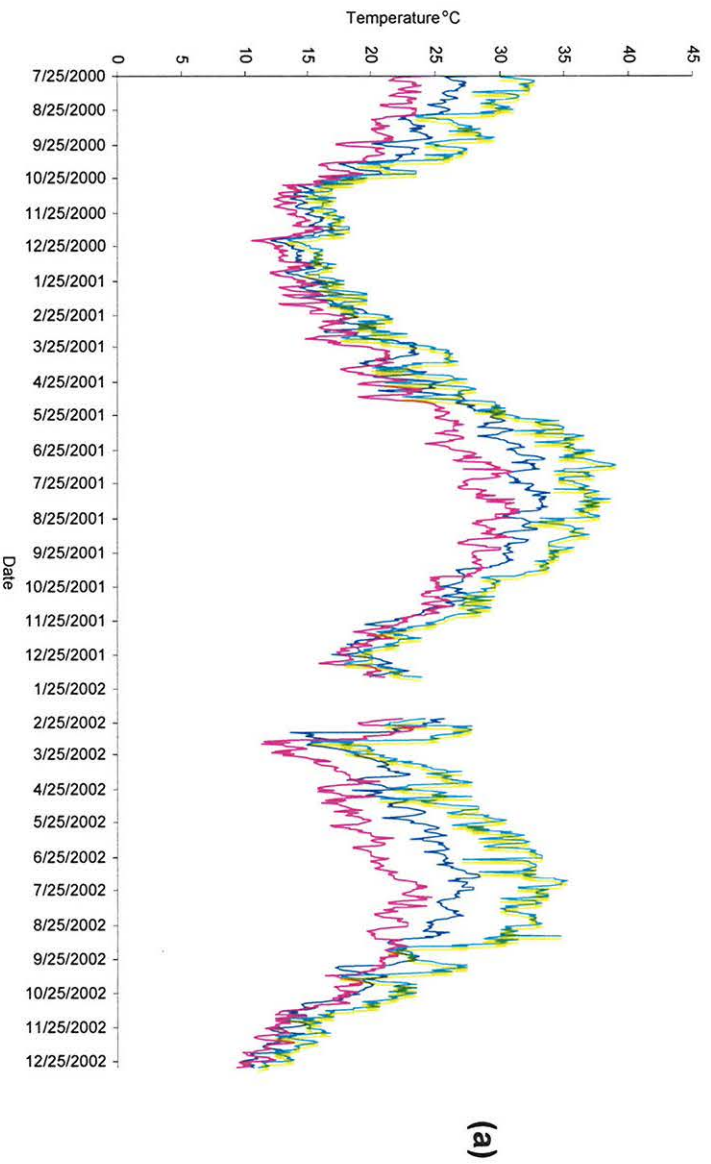


Figure 1-4. Average, minimum, and maximum temperature recorded from thermographs in the (a) Beaver Dam Wash Reach and (b) Riverside Reach.

Average and maximum temperatures during spring and fall 2000 to 2002 were similar to those seen in past years of sampling (Holden and Abate 1999). Average and maximum summer temperatures appeared to be higher than those previously reported, but this was the first time continuous temperature measurements were taken in the lower Virgin River. At the Beaver Dam Wash Reach, average temperature ranged from lows of 9 to 10°C in winter to highs between 29 and 34°C in the summer. The highest summer maximum temperatures exceeded 35°C in both 2001 and 2002. At the Riverside Reach average winter temperatures were between 7 and 9°C, and average summer temperatures were between 29 and 31°C. The highest maximum summer temperatures exceeded 37°C at the Riverside Reach in 2000, 2001, and 2002.

Riverside Reach

Long-term fish monitoring from June 2000 to October 2002 showed some interesting, but mostly negative, results. Sampling at the Riverside Reach showed relatively high numbers of woundfin in June and July 2000 (Table 1-1). However, we saw a precipitous decline in woundfin numbers in August 2000. Woundfin numbers remained low in June 2001, and woundfin disappeared from our catch by November 2001. No woundfin were collected in this reach in 2002. Flannemouth sucker (*Catostomus latipinnis*) showed trends similar to woundfin from 2000 to 2002.

Table 1-1. Number of seine hauls and fish captured during sampling of the Riverside Reach from 2000 to 2002.

DATE	SEINE HAULS	WF ^a	RS ^b	FM ^c	DS ^d	YS ^e	VRC ^f	SD ^g	BG ^h	CC ⁱ	CP ^j	GS ^k	LB ^l	MF ^m	TL ⁿ
5/25/00	113	4	2,761	420	7	96	0	1	0	1	1	0	2	15	0
6/28/00	99	50	4,226	784	7	0	0	6	0	10	5	0	4	33	0
7/27/00	42	27	2,307	16	0	0	0	0	0	1	5	0	1	46	0
8/28/00	93	1	6,838	30	0	0	0	3	0	3	7	0	5	159	0
6/13/01	114	3	17,877	320	11	0	0	3	0	7	537	0	11	242	0
11/5/01	0	0	21,774	1	0	0	0	0	4	0	6	2	0	1,813	1
6/3/02	119	0	10,879	2	0	0	0	0	0	0	6	1	5	417	0
9/24/02	109	0	2,893	1	0	0	0	0	0	0	1	0	0	3,294	2

^a WF = woundfin, ^b RS = red shiner, ^c FM = flannemouth sucker, ^d DS = desert sucker, ^e YS = young-of-year suckers, ^f VRC = Virgin River chub, ^g SD = speckled dace, ^h BG = bluegill, ⁱ CC = channel catfish, ^j CP = common carp, ^k GS = green sunfish, ^l LB = largemouth bass, ^m MF = western mosquitofish, ⁿ TL = blue tilapia.

We saw peaks in flannemouth sucker numbers in May and June 2000 and June 2001, after which they almost disappeared from our catch. The high catch rates in spring 2000 and 2001 were mostly young-of-year (YOY) fish. Low numbers of desert sucker (*Catostomus clarki*) and speckled dace were found in 2000 and spring 2001. However, these species also disappeared from our catch after spring 2001.

In contrast to native fish populations, red shiner and western mosquitofish (*Gambusia affinis*) numbers rose steadily in summer 2000 and were still extremely high in spring and fall 2001. Numbers of red shiner dropped substantially by fall 2002, but numbers of western mosquitofish remained high. Numbers of channel catfish (*Ictalurus punctatus*), largemouth bass (*Micropterus salmoides*), and common carp (*Cyprinus carpio*) were also elevated in 2000 and 2001. The number of YOY carp captured during spring 2001 sampling was extremely high.

Figure 1-5 illustrates how the catch rates from the last 2 years compare with catch rates over the 7 years of long-term monitoring at the Riverside Reach. Woundfin were found consistently in the catch at this station from 1996 through June 2001. About 20% (48 of 244) of the woundfin captured from 1996 to 1998 were tagged fish released by NDOW. An ANOVA revealed that the June 1997 trip had the highest catch rate of all trips and was significantly higher than all trips except those in August 1996, February and April 1997, and June and July 2000 ($p < 0.05$). The February 1997 trip also had a significantly higher catch rate for woundfin than most trips except for those noted above. When we compared differences between years, we found that 1997 had a significantly higher catch rate for woundfin than all other years except 1996 ($p < 0.05$). However, there was substantial contribution of stocked fish to the higher catch rates in 1996 and 1997. The 1997 collections with high catch rates had fairly large numbers of stocked woundfin, whereas only one tagged woundfin was captured in 1998, and no tagged woundfin were captured after that. The lowest catch rates for woundfin were seen in 2001 and 2002.

The Virgin River Fishes Recovery Team sampling targets spring and fall woundfin numbers to look at over-winter survival and new recruitment. Holden et al. (2001) used fall fish abundance information as a measure of recruitment strength for different years. When we compared fall catch rates for woundfin between years, we found that 1998 had a significantly greater catch rate than all other years ($p < 0.001$). Stocked fish seemed to have little influence on the fall 1998 catch rate. Only one stocked, tagged fish was captured at the Riverside Reach in 1998, and it was collected in the summer.

The catch rates of other native fishes in the Riverside Reach were sporadic throughout the course of the study. Only flannemouth sucker were consistently caught. The spring flannemouth sucker catch rates we saw in 2000 and 2001 were among the highest of the entire study period. We compared the combined catch rate of all native fishes between years and found that the native fish catch rate was significantly higher in 2000 than all other years ($p < 0.001$). We also found that the catch rates in 1997, 1998, and 2001 were significantly higher than catch rates in 1996, 1999, and 2002 ($p < 0.001$). As for woundfin, the fall native fish catch rate was significantly higher in 1998 than in all years except 1997 ($p < 0.001$). All years except 1996 had a significantly higher fall catch rate for native fishes than 2001 and 2002 ($p < 0.04$).

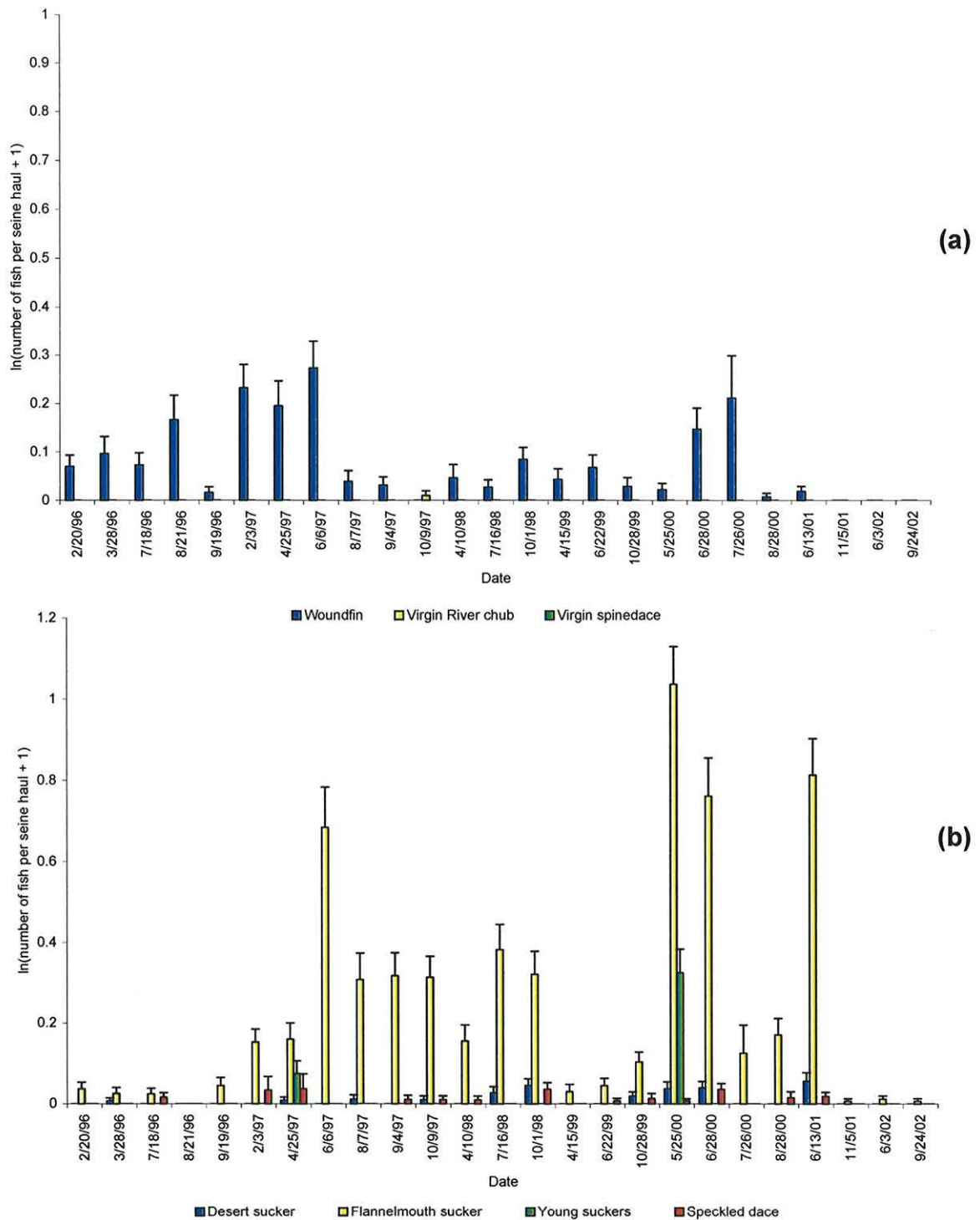


Figure 1-5. Catch rates (number of fish per seine haul + 1) in the Riverside Reach from 1996 to 2002 by trip for (a) endangered and endemic species, (b) other native fishes, (c) red shiner and western mosquitofish, and (d) other nonnative fishes.

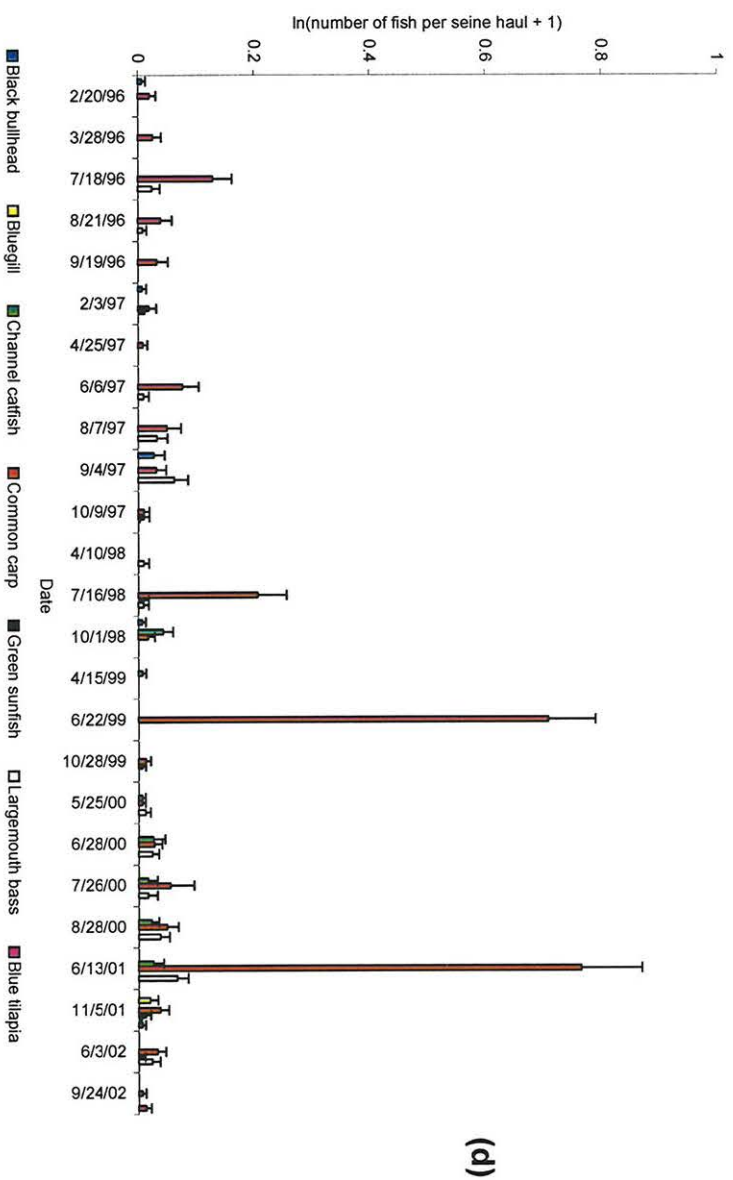
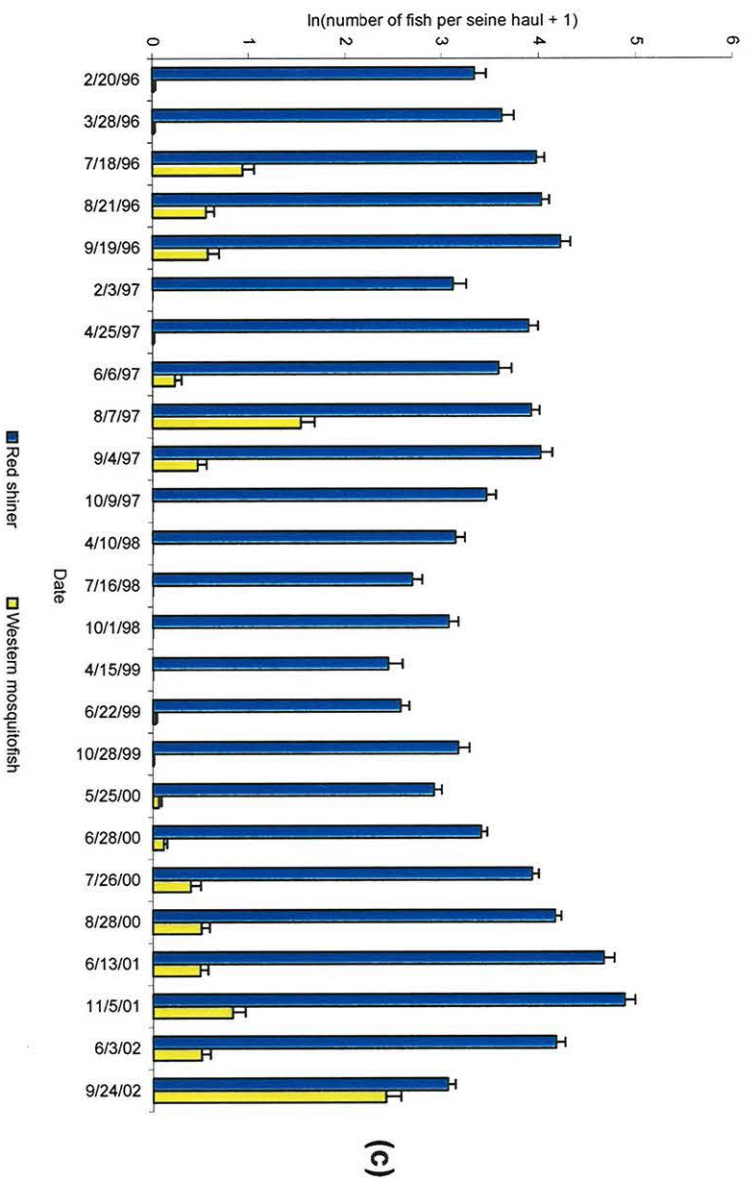


Figure 1-5. (cont.).

There was considerably more variation in red shiner catch rates between trips. However, the two collections in 2001 had significantly higher red shiner catch rates than all other collections except the September 1996 collection ($p < 0.05$). When we compared red shiner catch rates combined by year we found that 2001 had a significantly higher catch rate than all other years and that 1998 and 1999 had a significantly lower catch rate of red shiner than all other years ($p < 0.001$). When we compared fall red shiner catch rates between years, 2001 still had a higher catch rate than all other years ($p < 0.001$) but 2002 joined 1998 and 1999 with a lower catch rate than all other years ($p < 0.001$). The combined nonnative species catch rate followed the same patterns.

When we removed red shiner from the nonnative species catch rate we saw that 2001 and 2002 had the highest catch rates. The combined yearly catch rates of nonnative species other than red shiner were significantly higher in 2001 and 2002 than all other years ($p < 0.04$). When we looked at fall catch rates between years, we found that 2002 still had a higher catch rate than all other years ($p < 0.001$). The nonnative catch rate in fall 2001 was only significantly higher than those in 1997 through 1999 ($p < 0.05$). The increased catch rate of nonnative species other than red shiner in 2001 and 2002 was primarily the result of increased catch of western mosquitofish, but 2001 also had higher catch rates for common carp and largemouth bass.

Mesquite Bridge Reach

In the Mesquite Bridge Reach, we saw declines in numbers of native fishes similar to those in the Riverside Reach from 2000 to 2002 (Table 1-2). We captured woundfin at this site in October 2000, 2 weeks after stocking 9,500 woundfin less than 2 miles upstream. We continued to find woundfin of size classes similar to the stocked woundfin in June 2001. No woundfin have been collected in this section of river since then. We are fairly confident that most of the woundfin found in this reach from 2000 to 2002 were fish stocked upstream in the Experimental Reach. Native sucker numbers were fairly high in 2000 and 2001, only to suffer the same sharp decline we saw at the Riverside Reach by fall 2001. Red shiner and western mosquitofish numbers in the Mesquite Bridge Reach followed trends similar to the Riverside Reach. While common carp numbers showed a spike in spring 2001, it was not nearly as large as the spike we saw downstream at the Riverside Reach.

Additionally, we saw a spike in largemouth bass numbers in June 2001 in the Mesquite Bridge Reach, which was not as evident downstream.

Figure 1-6 shows the catch rates of fishes captured in the Mesquite Bridge Reach from 1996 to 2002. Numbers of woundfin captured in the Mesquite Bridge Reach have been more sporadic than at the Riverside Reach. We feel that the stocking programs of NDOW and the LVRRIT are the source of most of the woundfin captured by sampling in this reach. Woundfin were often stocked at the Mesquite Bridge (RM 58.0), which is at the top of the Mesquite Bridge Reach. Figure 1-6a indicates the dates of stocking and the number of woundfin stocked (Heinrich 1999, Holden and Golden 2000), as well as collections comprised predominantly of tagged fish. From 1996 to 1998 more than 50% (81 of 179) of the woundfin collected in the Mesquite Bridge Reach were tagged. Fish stocked

Table 1-2. Number of seine hauls and fish captured during sampling of the Mesquite Bridge Reach from 2000 to 2002.

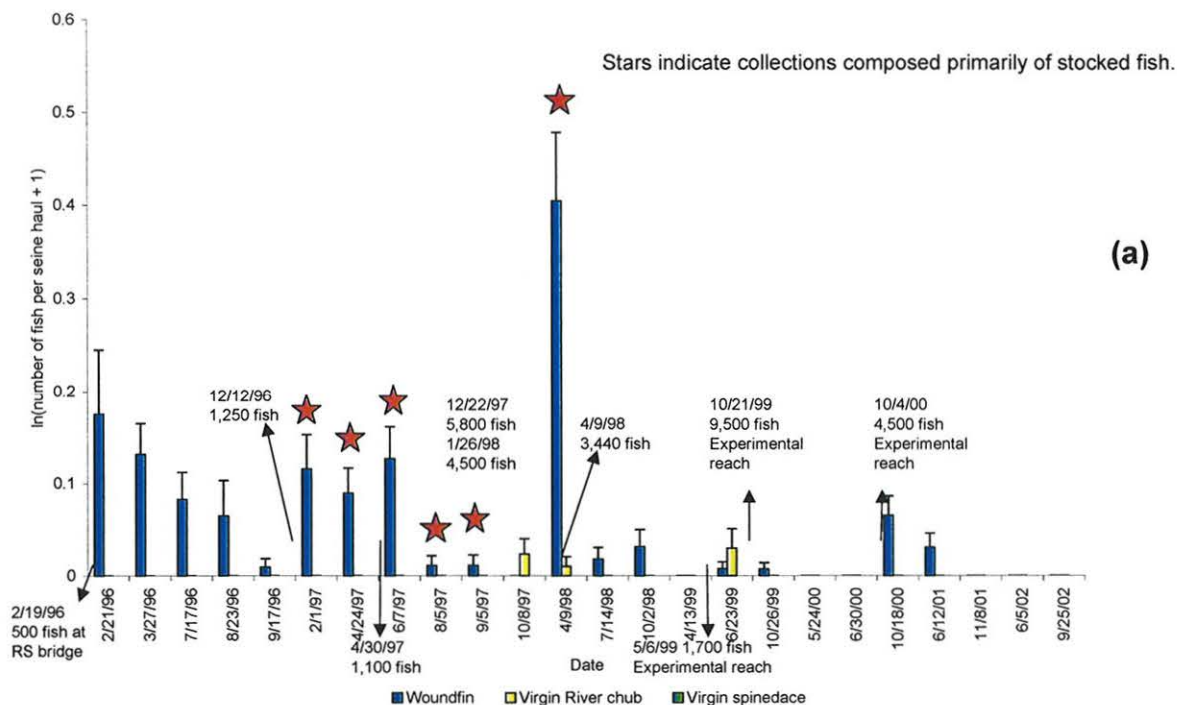
DATE	SEINE HAULS	WF ^a	RS ^b	FM ^c	DS ^d	YS ^e	VRC ^f	SD ^g	BG ^h	CC ⁱ	CP ^j	GS ^k	LB ^l	MF ^m	TL ⁿ
5/24/00	109	0	4,220	115	42	544	0	5	0	1	5	0	3	2	0
6/30/00	103	0	4,329	311	26	0	0	40	0	11	33	0	4	23	0
10/18/00	102	10	20,419	357	17	0	0	9	0	1	2	0	5	62	0
6/12/01	104	5	12,642	373	22	0	0	6	0	0	4	0	3	45	0
11/8/01	93	0	18,571	1	0	0	0	1	0	0	4	0	0	5	0
6/5/02	100	0	10,879	32	0	0	0	2	0	0	6	1	90	62	0
9/25/02	106	0	2,893	11	0	0	0	0	0	0	1	0	0	3,364	0

^a WF = woundfin, ^b RS = red shiner, ^c FM = flannelmouth sucker, ^d DS = desert sucker, ^e YS = young-of-year suckers, ^f VRC = Virgin River chub, ^g SD = speckled dace, ^h BG = bluegill, ⁱ CC = channel catfish, ^j CP = common carp, ^k GS = green sunfish, ^l LB = largemouth bass, ^m MF = western mosquitofish, ⁿ TL = blue tilapia.

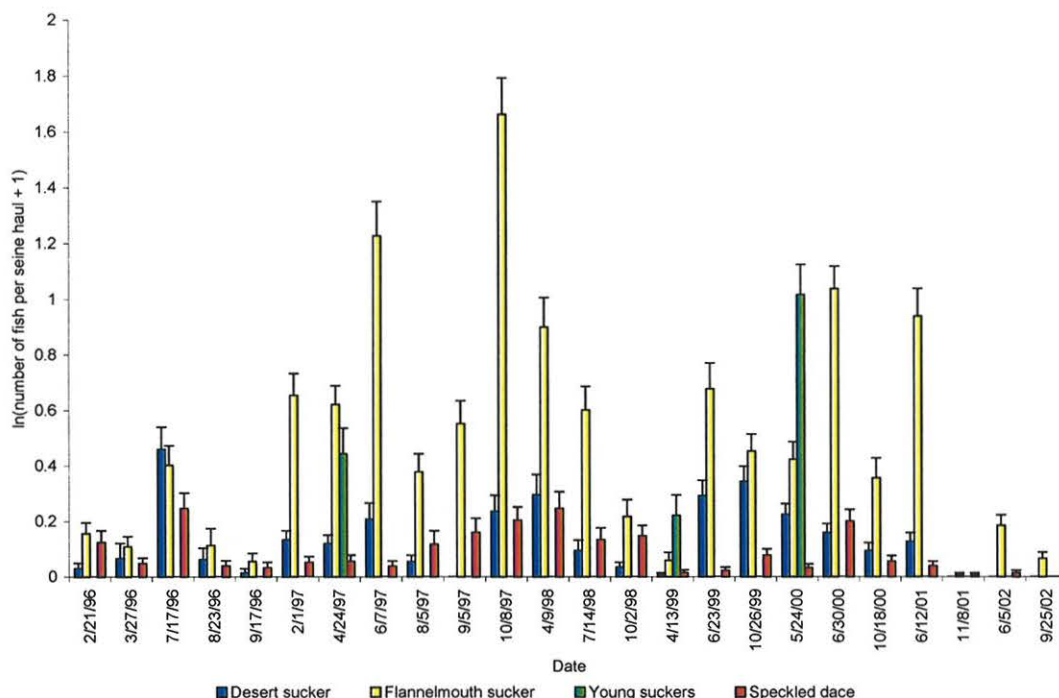
in October 1999 and 2000 were not implanted with coded wire tags, but the fish we captured in the Mesquite Bridge Reach from 1999 to 2001 were assumed to be displaced stocked fish.

Relatively large numbers of untagged woundfin were collected in 1996, when no fish were released at the Mesquite bridge. However, fish were stocked at the Riverside bridge in February 1996, and it is unclear whether fish were scanned for tags in the Mesquite Bridge Reach during this sampling trip (Holden and Abate 1999; P. Abate, BIO-WEST, Inc., personal communication). We saw rapid upstream migration of stocked fish in the Experimental Reach in 1999 and 2000 (Holden and Golden 2000) (see Chapter 2 of this report). Some of the fishes captured in the Mesquite Bridge Reach during the February 1996 collection effort could have moved upstream from the Riverside Reach and were not scanned for coded wire tags. Additionally, tag loss or reduced tag detectability was assumed to be a problem in May 1999 stocking efforts in the Experimental Reach (Holden and Golden 2000). The combination of these issues may mean that substantially more than 50% of woundfin caught in the Mesquite Bridge Reach between 1996 and 1998 were stocked fish. Therefore, trends in woundfin abundance in the Mesquite Bridge Reach were not statistically analyzed, because we felt we could not adequately differentiate yearly trends from stocked fish trends.

Because of the influence of stocked fish in the Mesquite Bridge Reach, we also removed woundfin from the combined native fish catch rate. When we compared the combined native fish catch rate between years, we found that 1997 and 2000 had significantly higher native fish catch rates than 1998, 1999, and 2001, which had significantly higher catch rates than 1996 and 2002 (Figure 1-6b; $p < 0.03$). Trends were not quite the same when we compared fall catch rates between years. The fall catch rate in 1997 was significantly higher than all other years ($p < 0.001$), and 2001 and 2002 had lower fall catch rates than all other years except 1996 ($p < 0.04$).



(a)



(b)

Figure 1-6. Catch rates (number of fish per seine haul + 1) in the Mesquite Bridge Reach from 1996 to 2002 by trip for (a) endangered and endemic species, (b) other native fishes, (c) red shiner and western mosquitofish, and (d) other nonnative fishes.

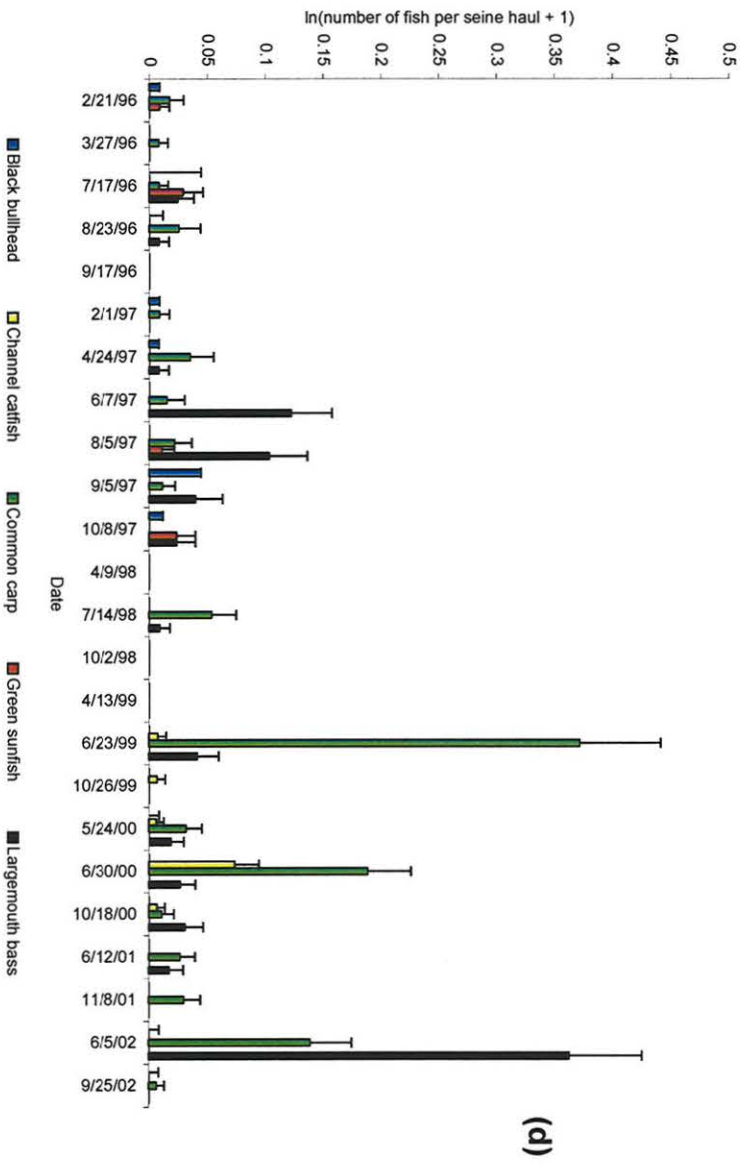
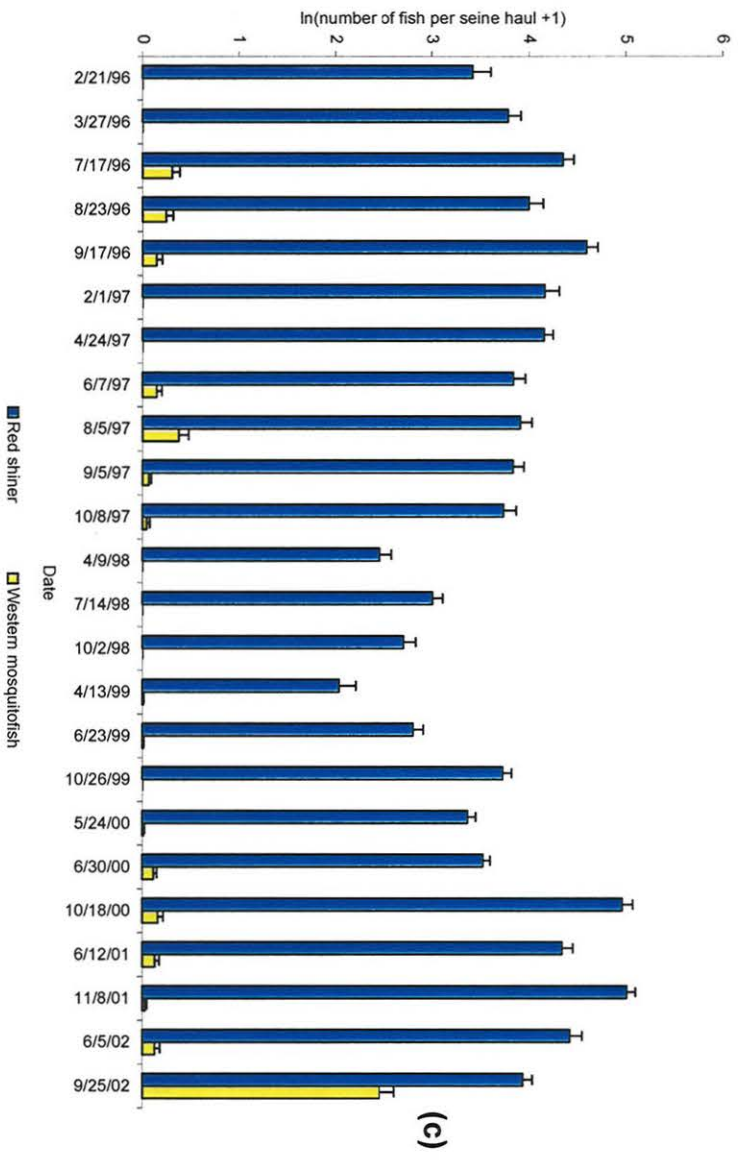


Figure 1-6. (cont.).

Red shiner numbers were highly variable between trips (Figure 1-6c), but the October 2000 and November 2001 collections had significantly higher catch rates than all but the September 1996 and June 2002 collections ($p < 0.05$). The April 1998 through June 1999 collections had significantly lower catch rates of red shiner than all other collections except for August 1996, May 2000, and June 2000. When we compared combined red shiner catch rates between years, we found that 2001 had a significantly higher catch rate than all other years and that 1996, 1997, 2000, and 2002 had significantly higher catch rates than 1998 and 1999 ($p < 0.001$). Comparing fall red shiner catch rates between years showed more differences. We found that fall red shiner catch rates in 2000 and 2001 were significantly greater than all other years ($p < 0.001$), and that 1998 had a significantly lower fall red shiner catch rate than all other years ($p < 0.001$). Additionally, 1996 had a higher fall red shiner catch rate than 1997 and 1999 ($p < 0.001$).

When we combined catch rates of all nonnative fishes, we saw trends similar to those seen in red shiner catch rates. However, when we looked at the combined catch rates of nonnative fishes without red shiner, we found that the catch rate of nonnative species in 2002, minus red shiner, was significantly higher than in all other years ($p < 0.001$). The fall catch rate of nonnative species in 2002, minus red shiner, was also significantly higher than all other years ($p < 0.001$). The higher catch rates in 2002 resulted mainly from increased catch of western mosquitofish, but they also resulted from increased catch of largemouth bass.

Beaver Dam Wash Reach

From 2000 to 2002 the Beaver Dam Wash Reach continued to support a large, more diverse native fish community than the lower reaches (Table 1-3). Reproduction of the native fishes was substantially higher in spring 2002 than in 2000 or 2001. Virgin River chub seemed to have an especially good reproductive year in 2002. The boom in Virgin River chub reproduction was evident throughout the Virgin River (Rick Fridell, Utah Division of Wildlife Resources, personal communication; Michael Golden, BIO-WEST, personal observation). However, the increased Virgin River chub reproduction did not translate into increased recruitment in 2002, as Virgin River chub numbers in fall 2002 were similar to those in 2000 and 2001.

Red shiner numbers were extremely high in fall 2001 at Beaver Dam Wash Reach and throughout the lower river. However, by fall 2002 red shiner numbers were very low. A spate event approximately 2 weeks before fall 2002 sampling seemed to cause a reduction in red shiner numbers throughout the lower river (Figure 1-2). Western mosquitofish numbers seem to have increased during 2000 to 2002. We also saw fairly high numbers of channel catfish in 2001.

Table 1-3. Number of seine hauls and fish captured during sampling of the Beaver Dam Wash Reach from 2000 to 2002.

DATE	SEINE HAULS	WF ^a	RS ^b	FM ^c	DS ^d	YS ^e	VRC ^f	SD ^g	BG ^h	CC ⁱ	CP ^j	GS ^k	LB ^l	MF ^m	TL ⁿ
5/22/00	103	0	830	165	138	723	2	26	0	0	0	0	0	4	0
6/29/00	99	0	2,880	341	791	0	24	373	0	5	0	0	0	451	0
6/11/01	104	0	2,052	218	368	7	15	43	0	0	0	2	2	421	0
11/6/01	94	0	19,773	91	47	0	14	419	0	17	0	0	3	139	0
6/4/02	96	0	3,825	2,011	563	22	358	1,124	0	1	0	0	3	531	0
9/23/02	112	0	391	405	40	0	18	241	0	1	0	0	0	888	0

^a WF = woundfin, ^b RS = red shiner, ^c FM = flannelmouth sucker, ^d DS = desert sucker, ^e YS = young-of-year suckers, ^f VRC = Virgin River chub, ^g SD = speckled dace, ^h BG = bluegill, ⁱ CC = channel catfish, ^j CP = common carp, ^k GS = green sunfish, ^l LB = largemouth bass, ^m MF = western mosquitofish, ⁿ TL = blue tilapia.

Figure 1-7 shows how the catch rates from 2000 to 2002 compared with catch rates over the 7 years of long-term monitoring at the Beaver Dam Wash Reach. While low numbers of woundfin were caught sporadically in 1996 and 1997, none have been collected since then. An occasional Virgin spinedace has also been captured in this reach. Virgin River chub are much more abundant in this reach than anywhere below the Mesquite Diversion. When we compared Virgin River chub catch rates by trip, we found that the catch rate from the June 2002 collection was significantly higher than all collections except the July 1996 collection ($p < 0.001$). Most of the other differences appeared to be related to yearly trends.

When we compared the combined Virgin River chub catch rates between years, we found that the catch rate was significantly higher in 2002 than all other years ($p < 0.02$). Additionally, 1996 had a higher catch rate than all remaining years, and 1997 had a significantly higher catch rate for Virgin River chub than 1998 or 1999 ($p < 0.03$). However, when we looked at fall catch rates between years, we found that only 1996 had a significantly higher catch rate than all other years ($p < 0.001$). When we compared the combined catch rates of native fishes between years, we found that 1997 had a significantly higher catch rate than all other years and 1998 and 2001 had significantly lower catch rates than all other years ($p < 0.02$). We also found that 1996, 1999, and 2002 had significantly higher catch rates of native fishes than 2000 ($p < 0.02$). When we compared the fall catch rate between years, we found that 1996 and 1997 had significantly higher fall catch rates of native fishes than all other years ($p < 0.02$).

We compared red shiner catch rates at the Beaver Dam Wash Reach between trips and found that there was considerable variability. However, the November 2001 collection had a significantly higher catch rate than all other sampling trips, except the August and September 1997 trips ($p < 0.005$). The July 1998, June 1999, and September 2002 collections had significantly lower red shiner catch rates than all other trips, except for the September 1998 and April 1999 trips ($p < 0.02$). When we compared combined red shiner catch rates between years we found that 1996, 1997, and 2001 had significantly higher catch rates than all other years, and 2000 and 2002 had significantly

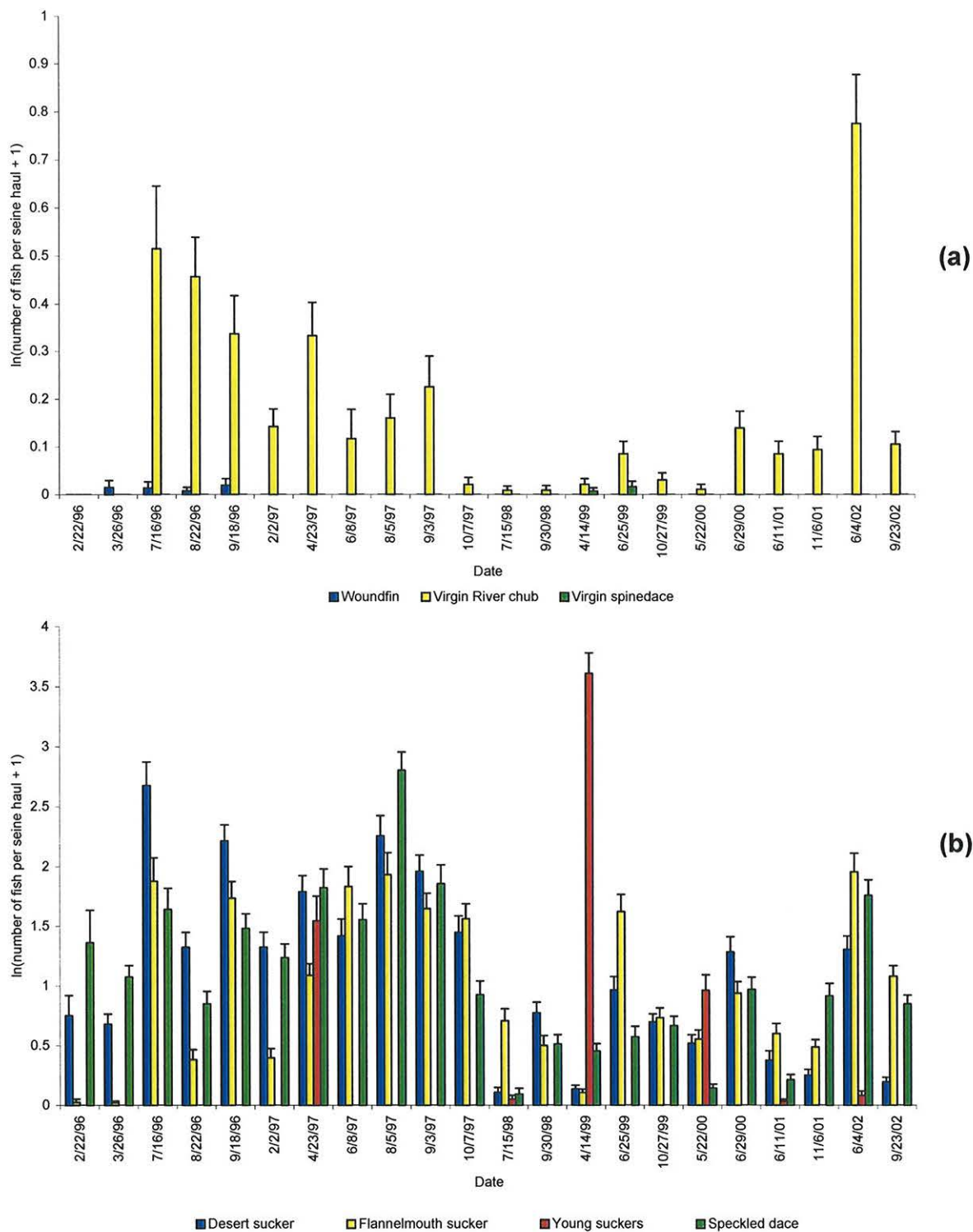


Figure 1-7. Catch rates (number of fish per seine haul + 1) in the Beaver Dam Wash Reach from 1996 to 2002 by trip for (a) endangered and endemic species, (b) other native fishes, (c) red shiner and western mosquitofish, and (d) other nonnative fishes.

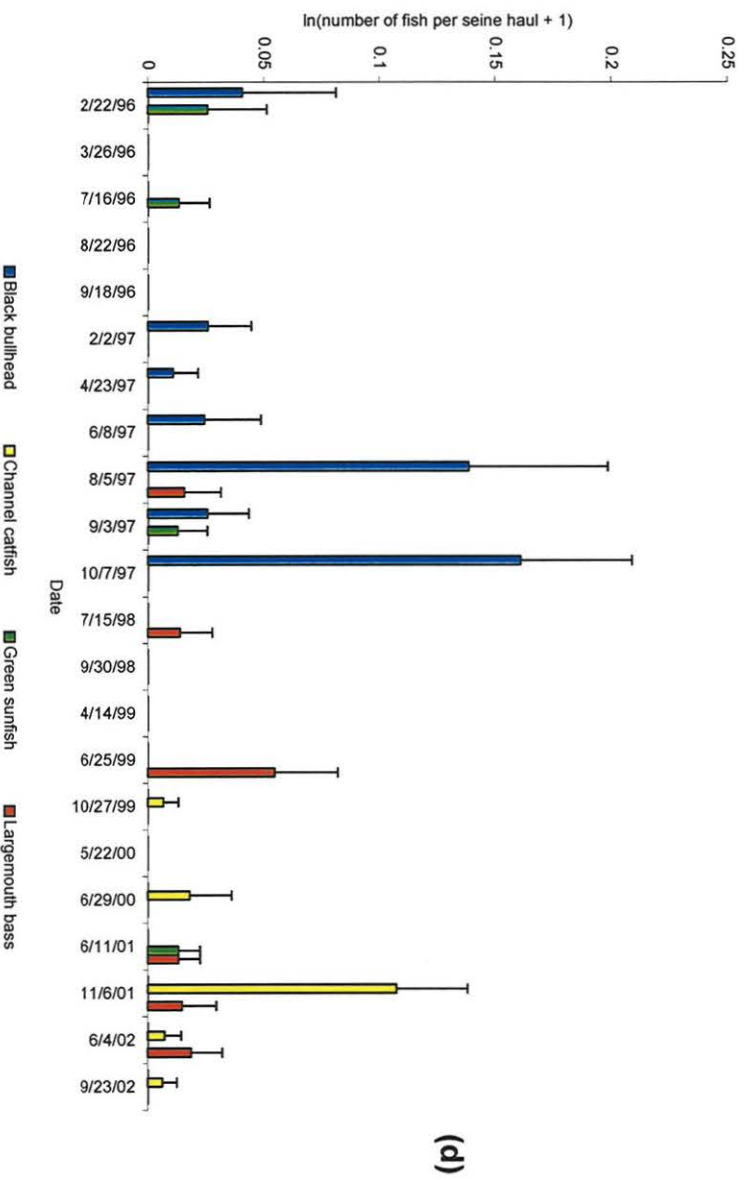
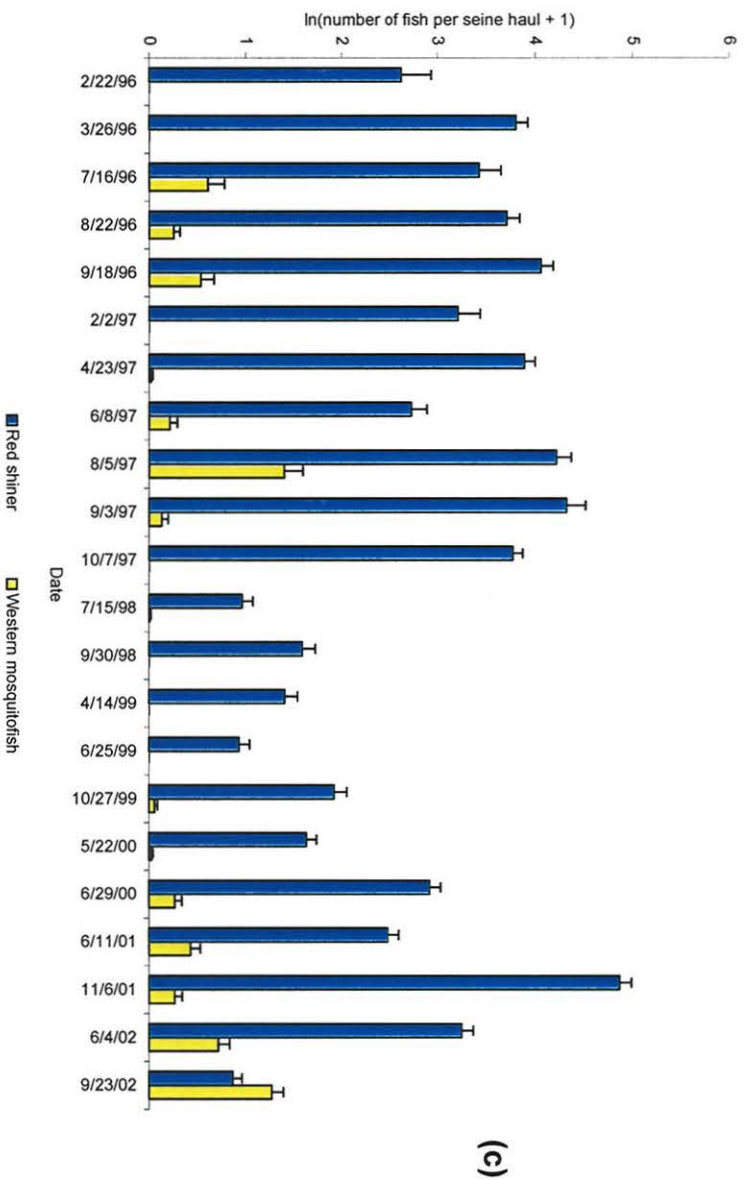


Figure 1-7. (cont.).

higher catch rates than 1998 and 1999 ($p < 0.001$). When we compared fall catch rates between years, we found that 2001 had a significantly higher catch rate than all other years, and 2002 had a significantly lower catch rate than all other years ($p < 0.001$). We also found that fall red shiner catch rates in 1996 and 1997 were significantly higher than in 1998 and 1999 ($p < 0.001$). No collection was made in fall 2000.

The combined catch rates of nonnative species mirrored trends in red shiner catch rates. However, when we compared combined and fall catch rates of nonnative fishes without red shiner between years, we found that 2002 had a significantly higher combined catch rate of nonnative species than all other years ($p < 0.001$). The higher catch rate was attributable to increased catch of western mosquitofish.

Reach Comparisons

Habitat Data

All three long-term monitoring reaches have been thought to differ in the types of aquatic habitat available, which could influence the fish communities in those areas (Holden and Abate 1999, Golden and Holden 2000). We found that a higher percentage of riffle- and pool-type habitats were sampled in the Beaver Dam Wash Reach than in the other two reaches (Figure 1-8). Conversely, we sampled a slightly higher percentage of run-type habitats in the Mesquite Bridge and Riverside Reaches. These data indicate that riffles and pools are more common in the Beaver Dam Wash Reach than in the other two reaches.

The substrate at Beaver Dam Wash Reach also appears to be coarser than that of the other two long-term monitoring reaches (Figure 1-9). We found that small cobble, large cobble, or boulders were the primary and secondary substrates in a higher percentage of samples from the Beaver Dam Wash Reach than from samples in the Mesquite Bridge and Riverside Reaches. The Beaver Dam Wash Reach also had sand as the primary substrate in a lower percentage of the samples than the other two reaches.

Perhaps most striking is the fact that Beaver Dam Wash Reach had significantly higher average, mean, and maximum depth than both other reaches for riffles, runs, and pools, as shown in Figure 1-10 ($p \leq 0.001$). The Mesquite Bridge Reach had significantly greater riffle depths ($p \leq 0.008$) than the Riverside Reach, and significantly higher mean and maximum depths in runs ($p < 0.001$).

Fish Data

Using combined data from all years, we found that the Riverside Reach had a significantly higher total woundfin catch rate than the Mesquite Bridge or Beaver Dam Wash Reaches ($p < 0.03$) and that the Mesquite Bridge Reach had a significantly higher catch rate than the Beaver Dam Wash Reach ($p < 0.001$). No differences in woundfin catch rate were seen between the three reaches in 1999, 2001, or 2002, because catch rates at all sites were low or nonexistent during this time period (Figure 1-11). In 2000 woundfin catch rates in the Riverside Reach were significantly higher than

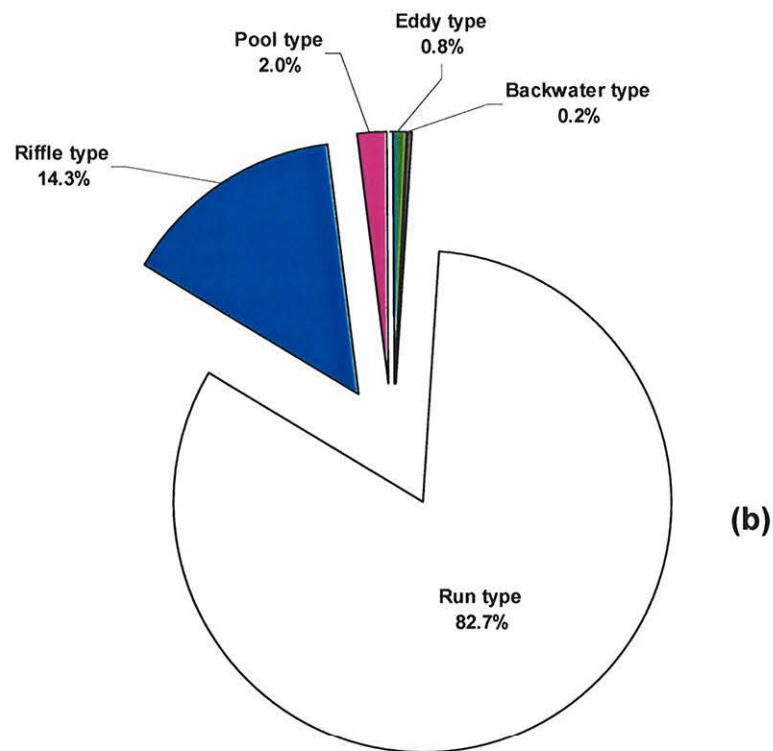
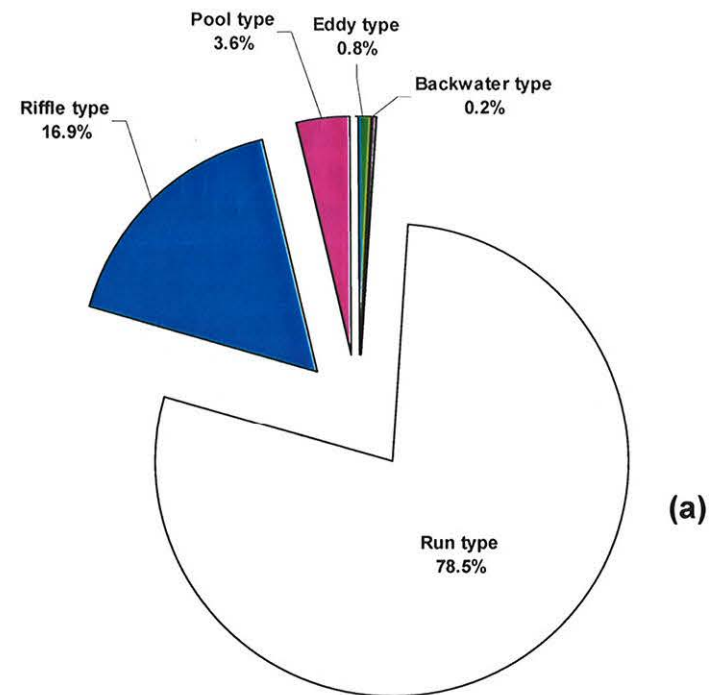


Figure 1-8. Percentage of samples taken in run, riffle, pool, backwater, and eddy habitats in (a) the Beaver Dam Wash Reach, (b) the Mesquite Bridge Reach, and (c) the Riverside Reach from 1996 to 2002.

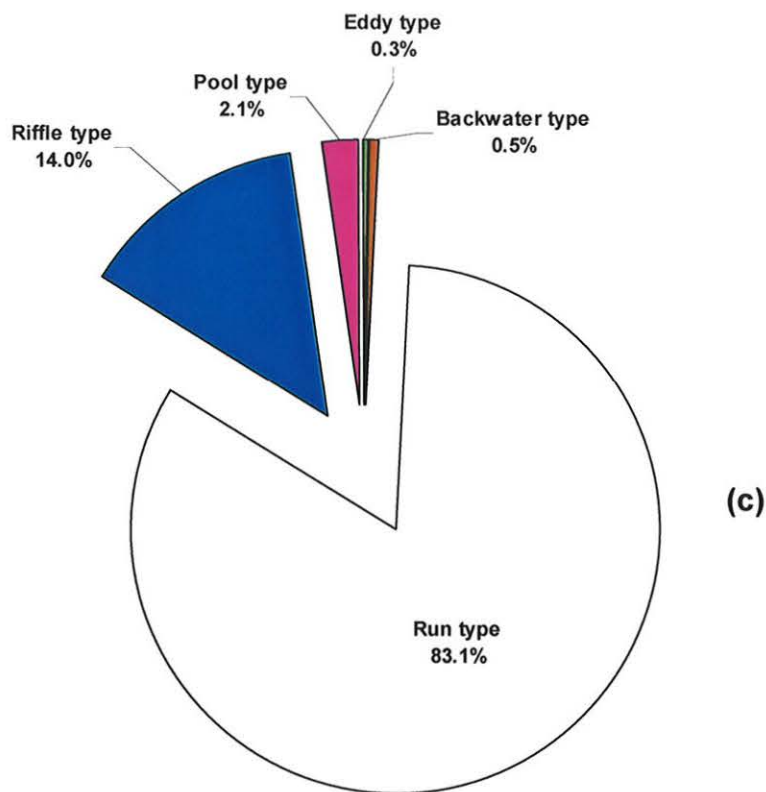


Figure 1-8. (cont.).

in the Beaver Dam Wash Reach ($p < 0.009$). In 1998 the Mesquite Bridge Reach had significantly higher woundfin catch rates than the Riverside or Beaver Dam Wash Reaches ($p < 0.01$). Finally, both the Riverside and Mesquite Bridge Reaches had significantly higher woundfin catch rates than the Beaver Dam Wash Reach in 1996 and 1997 ($p \leq 0.001$), and the Riverside Reach had significantly higher woundfin catch rates than the Mesquite Bridge Reach in 1997 ($p < 0.02$).

When we combined all data from each reach, we found that the Mesquite Bridge Reach had the highest catch rate of red shiner ($p < 0.001$) and that the Riverside Reach had a significantly higher red shiner catch rate than the Beaver Dam Wash Reach ($p < 0.001$). The Mesquite Bridge Reach had a significantly higher red shiner catch rate than Beaver Dam Wash Reach in all years, as shown in Figure 1-12. ($p < 0.03$). The Riverside Reach had a significantly higher red shiner catch rate than Beaver Dam Wash Reach from 1998 to 2002 ($p < 0.001$), and the Mesquite Bridge Reach had a significantly higher red shiner catch rate than the Riverside Reach in 2000 and 2002 ($p \leq 0.001$).

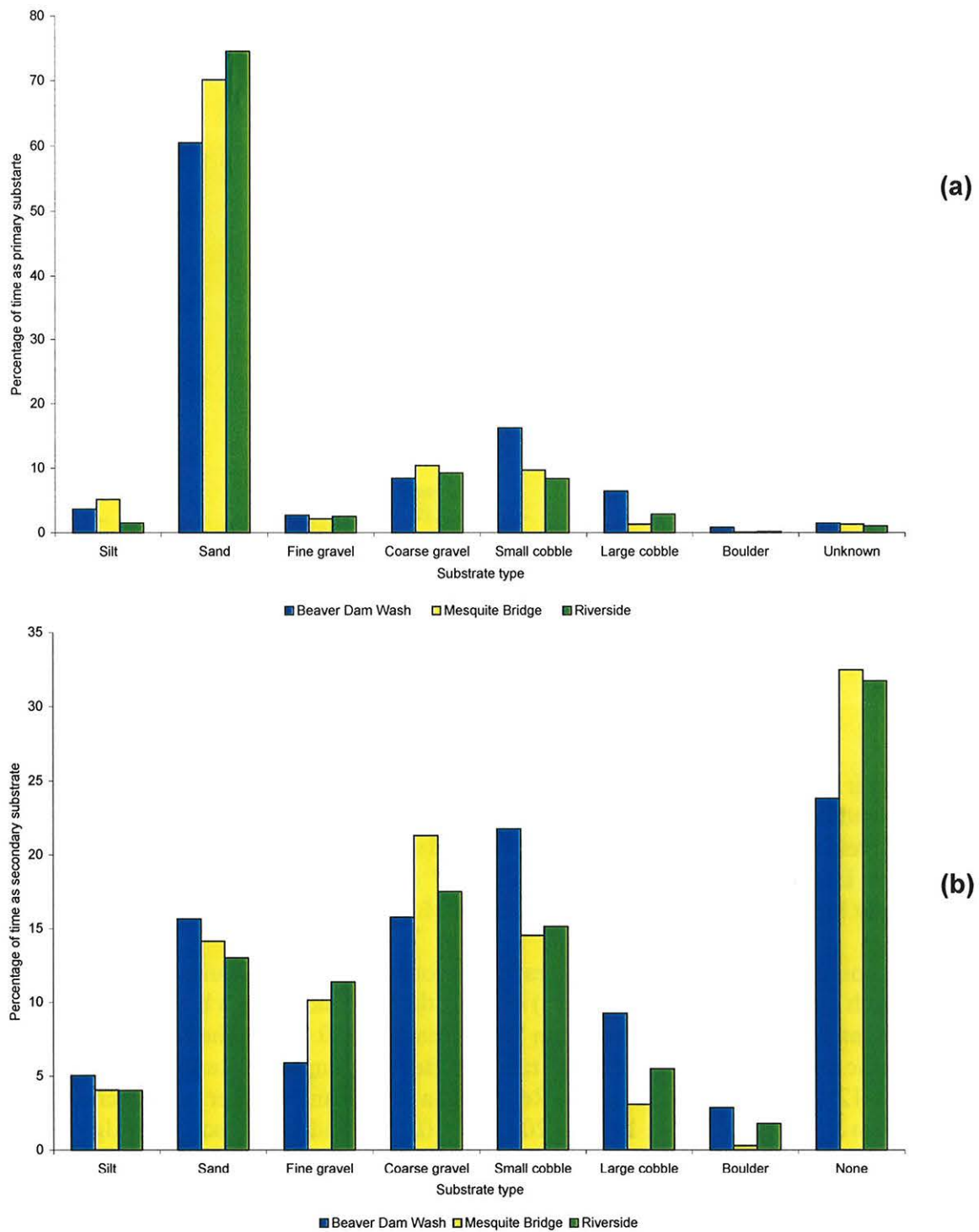


Figure 1-9. The percentage that each substrate category was found to be the (a) primary and (b) secondary substrate for a sample.

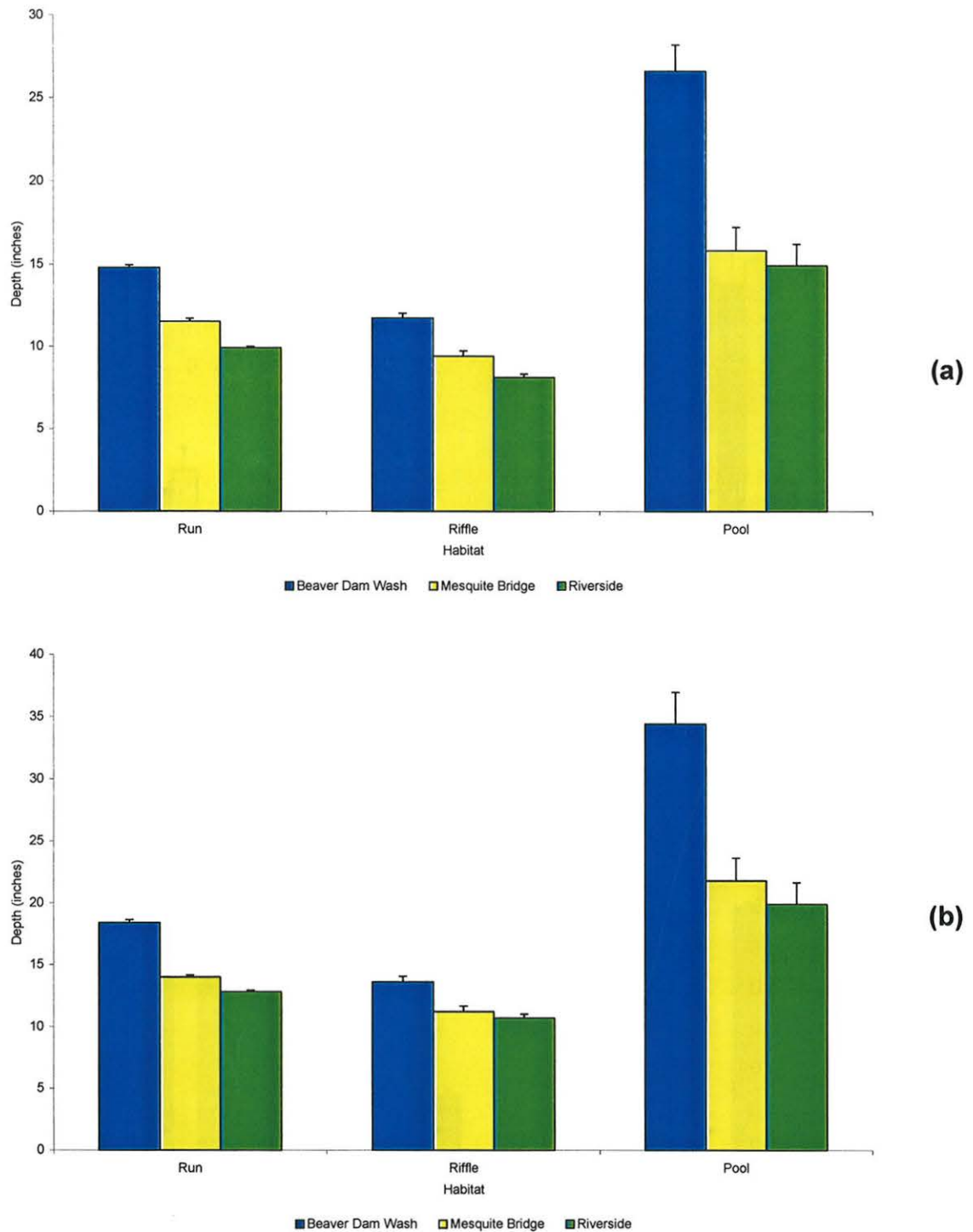


Figure 1-10. Average (a) mean and (b) maximum depths recorded from samples in riffles, runs, and pools in the three long-term monitoring reaches from 1996 to 2002.

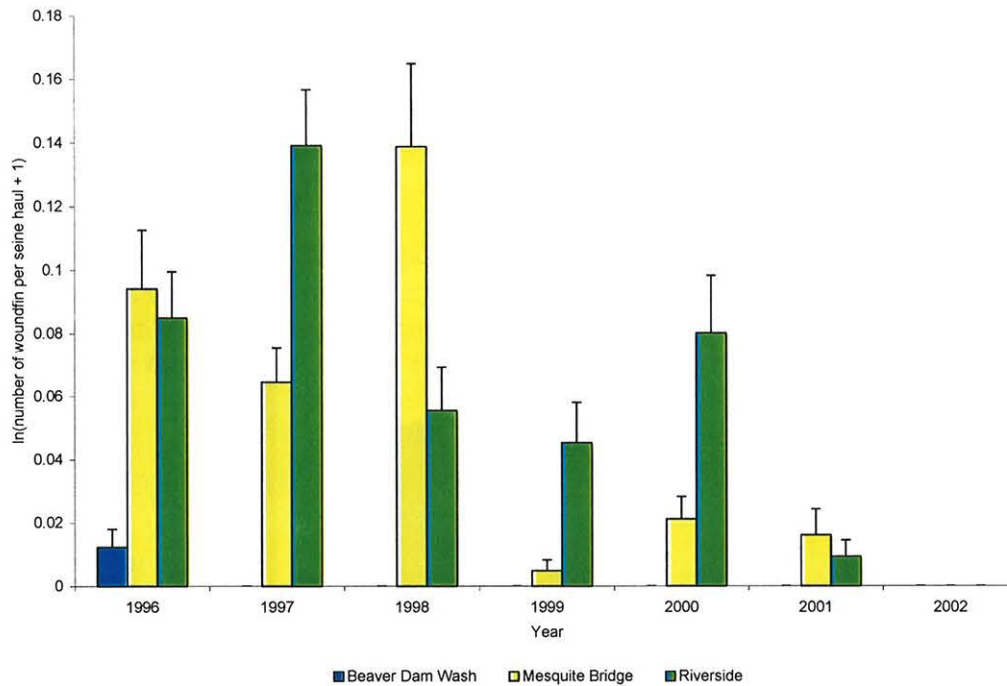


Figure 1-11. Average yearly catch rates of woundfin (number of fish per seine haul + 1) in the three long-term monitoring reaches from 1996 to 2002.

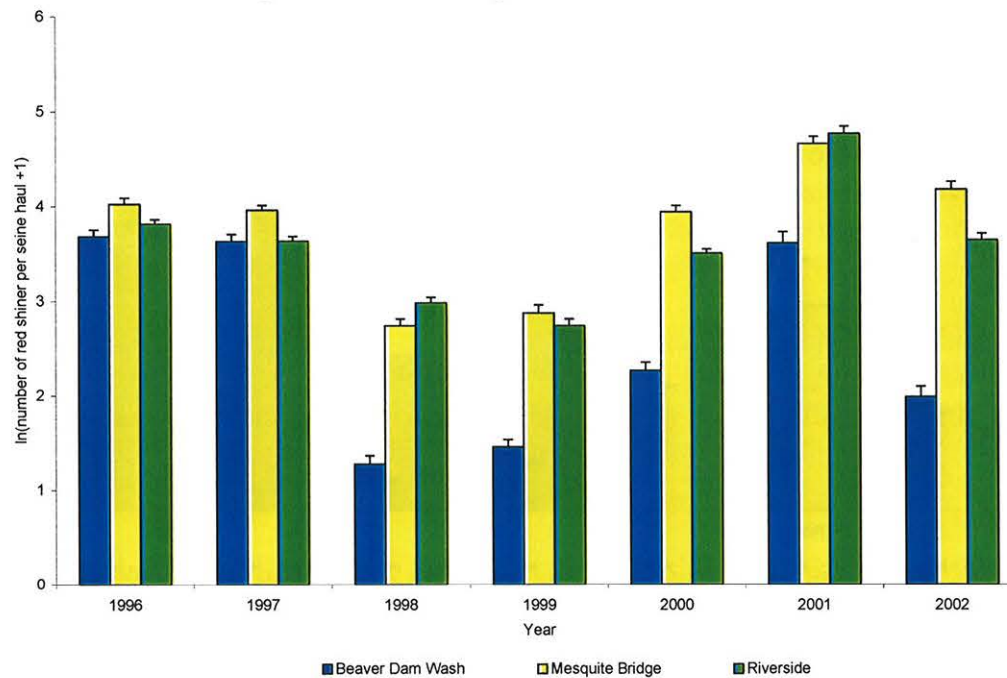


Figure 1-12. Average yearly catch rates of red shiner (number of fish per seine haul + 1) in the three long-term monitoring reaches from 1996 to 2002.

Unlike woundfin catch rates, catch rates of all other native fishes were significantly higher in the Beaver Dam Wash Reach than in the Mesquite Bridge or Riverside Reaches ($p < 0.001$). Additionally, catch rates for all native fishes, except Virgin River chub were significantly higher in the Mesquite Bridge Reach than in the Riverside Reach ($p < 0.001$). When we compared yearly differences between the three reaches using the catch rate for all native fishes we found that the Beaver Dam Wash Reach had a significantly higher native species catch rate than the other reaches in all years, as shown in Figure 1-13 ($p < 0.001$). Additionally, the Mesquite Bridge Reach had a higher catch rate of native fishes than the Riverside Reach from 1997 to 2000 ($p < 0.02$).

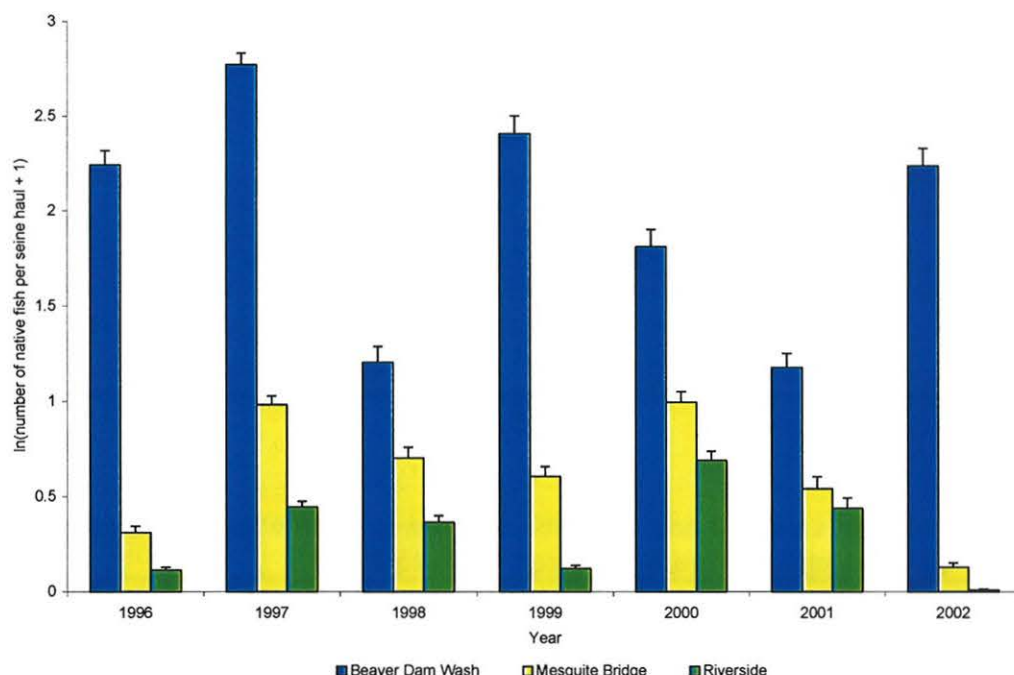


Figure 1-13. Average yearly catch rates of all native fishes (number of fish per seine haul + 1) in the three long-term monitoring reaches from 1996 to 2002.

Woundfin Habitat Use

Chi-square analyses showed that the habitats where woundfin were found did not differ significantly from the overlying sampling distribution of habitats in the Mesquite Bridge or Riverside Reaches (Table 1-4). We also compared habitat use in each season against the habitats sampled in each season. No differences were found in the distribution of habitats in which woundfin were found versus the distribution of habitats that were sampled during any season in the Riverside Reach. As shown in Table 1-5, the distribution of habitats where woundfin were captured in the fall differed significantly from the distribution of habitats that were sampled in the Mesquite Reach ($p < 0.02$). Woundfin were collected in the fall in the Mesquite Bridge Reach in riffle and riffle/run habitats more than expected. No differences were found in other seasons.

Table 1-4. Habitats sampled and habitats where woundfin were captured in the Riverside and Mesquite Bridge Reaches from 1996 to 2002.

HABITAT	MESQUITE BRIDGE HABITAT TOTAL	RIVERSIDE HABITAT TOTAL	MESQUITE BRIDGE WOUNDFIN CATCH	RIVERSIDE WOUNDFIN CATCH
Backwater	5	12	0	0
Eddy	17	7	2	0
Pool	34	38	3	3
Pool/run	0	3	0	0
Riffle	190	243	3	16
Riffle/eddy	0	2	0	0
Riffle/pool	6	7	0	1
Riffle/run	75	78	1	4
Run	1,700	1,897	106	141
Run/eddy	0	2	0	0
Run/pool	2	1	0	0
Run/riffle	20	20	1	0
Side channel run	2	4	0	0

Table 1-5. Habitats sampled and habitats where woundfin were captured during fall in the Mesquite Bridge Reach from 1996 to 2002.

HABITAT	MESQUITE BRIDGE HABITAT TOTAL	MESQUITE BRIDGE WOUNDFIN CATCH
Eddy	3	0
Pool	15	3
Riffle	53	0
Riffle/pool	3	0
Riffle/run	33	0
Run	631	15
Run/pool	1	0
Run/riffle	16	1
Side channel run	1	0

Average mean depth from samples where woundfin was collected was 26.0 cm in the Mesquite Bridge Reach and 22.3 cm in the Riverside Reach. The average maximum depths from samples containing woundfin was 34.8 cm in the Mesquite Bridge Reach and 29.0 cm in the Riverside Reach. Slightly higher average mean and maximum depths were observed during spring than in all other seasons in both reaches.

Discussion

Over the past 7 years, the native fish communities at all of the long-term monitoring reaches have been variable. However, since 2000, native fish communities in all reaches have declined. The areas below Bunkerville Diversion have been hardest hit during this time. Since we began the study in 1993, woundfin have been consistently found in the Riverside Reach. We saw a dramatic decline in woundfin numbers in summer 2000, and by fall 2001 no woundfin were collected. The other native fish populations have also seen major declines in areas below the Bunkerville Diversion.

Differences in available habitat types may account for some of the dissimilarity seen between reaches in the fish communities. The Beaver Dam Wash Reach appears to support a greater number of pools and riffles. Additionally, these pools and riffles are generally deeper than those found in the Riverside and Mesquite Bridge Reaches. Virgin River chub, Virgin spinedace, speckled dace, and desert sucker all could benefit from increased riffle and pool habitat, which might explain the increased native fish numbers at Beaver Dam Wash Reach. Conversely, woundfin are thought to use primarily hard-bottomed sand runs. The Mesquite Bridge and Riverside Reaches had a larger percentage of runs and had a larger percentage of samples with sand as the primary substrate. BIO-WEST personnel have observed that woundfin have an affinity for complex habitats. For example, woundfin may be collected in a hard-bottomed sand run, but this run will likely be alongside a riffle or part of an island complex. The Mesquite Bridge Reach seems to have less of these complex areas than the Riverside Reach, which may explain the persistence of woundfin in the Riverside Reach for so long.

While habitat differences probably explain some of the variation in fish numbers between the reaches, low flows, resultant high water temperatures, and increased water clarity are probably the reasons for the dramatic declines in native fishes seen throughout the lower Virgin River from 2000 to 2002. Drought has gripped the region since 1999, culminating in 2002, the lowest flow year on record. The drought-induced low flows result in about 50-70 cubic feet per second (cfs) in the river at the Littlefield USGS gage. Areas below the Bunkerville Diversion see little to no water under these flow conditions. The Mesquite Diversion takes 37-40 cfs at RM 63.25, and the Bunkerville Diversion takes 15-20 cfs at RM 59.25. Therefore, when the Littlefield USGS gage is showing 50-70 cfs, the flow in the Mesquite Bridge Reach is comprised of seepage through the Bunkerville Diversion, groundwater upwellings, and any agricultural and municipal return flows. The Riverside Diversion at RM 51.25 takes the bulk of this flow before the Riverside Reach. Flows in the Mesquite Bridge and Riverside Reaches during these low-flow periods were less than 20 cfs and were at times 0-5 cfs.

Holden et al. (2001) showed that fall woundfin abundance was significantly lower in drought years than in non-drought years. Golden and Holden (2002a) found that abundance of all Virgin River native fishes was significantly lower in drought years than in non-drought years. Additionally, fall woundfin abundance is significantly lower in years where summer 50% exceedence flows are below 75 cfs (Holden et al. 2001). Fall woundfin abundance declines even further at summer 50% exceedence flows below 50 cfs (Holden et al. 2001). Summer 50% exceedence flows were below 70 cfs in 2000, 2001, and 2002 at the Littlefield USGS gage. In 2002 the summer 50% exceedence flow was 52.5 cfs at the Littlefield USGS gage. Summer 50% exceedence flows were probably 10-30 cfs below the Mesquite Diversion and 0-20 cfs below the Bunkerville Diversion from 2000 to 2002. These extremely low flows resulted in the almost complete loss of the native fish community below the Bunkerville Diversion in 2001 and 2002.

The results of sampling in the Beaver Dam Wash Reach support our theory on the impact of low flows on the native fish community. The Beaver Dam Wash Reach is above the Mesquite Diversion and is less impacted by human water use that reduces flows. The Littlefield USGS gage is within this reach, so flows shown in Figure 1-2 should be similar to the flows throughout the Beaver Dam Wash Reach. Therefore, flows were considerably higher in this reach than in the Mesquite Bridge or Riverside Reaches. While native species catch rates in the Beaver Dam Wash Reach seemed lower in 2001 and 2002, catch rates in most other years were similar. However, the number of young fish captured in the fall collections was low in 2000, 2001, and 2002, indicating that recruitment was limited during this time. Poor recruitment success was seen for Virgin River chub in 2002. We captured the highest number of YOY Virgin River chub during the 7 years of the study in spring 2002, but by fall Virgin River chub numbers declined and were similar to all other years. Others have noted a lack of recruitment success for woundfin during low-flow summers (Deacon and Hardy 1984, Holden et al. 2001).

Low flows not only physically reduce the amount of wetted habitat but also reduce the utility of the remaining habitat because temperatures are high and water clarity is low. Deacon et al. (1987) showed the critical thermal maximum (CTM) for woundfin to be 39.5 °C. The CTMs for all other native species were between 36.4 and 37.2 °C. Temperatures recorded on the Riverside Reach thermograph suggest that the CTM for woundfin is exceeded several times during low-flow years in this area of the river. The CTMs for other native fishes were routinely approached and exceeded in the Riverside Reach. Temperatures recorded at the Beaver Dam Wash Reach show that the CTMs for most of the native species are often approached and sometimes exceeded in this section of river, too. However, the Beaver Dam Wash Reach has significant flows (50 cfs and up), so more thermal refugia are probably available. Riffle and pool depths were significantly higher in samples from the Beaver Dam Wash Reach, which supports the hypothesis that this reach may have more thermal refugia. Virtually all of the few pools that remained below the Mesquite Diversion were stagnant and very warm during summers 2001 and 2002.

Water clarity has also been identified as a limiting factor for woundfin in the Virgin River (Virgin River Researchers Meeting, January 2002). Turbidity has been shown to be a source of cover for some species of fish (Stanley et al. 1978, Gregory 1993). Johnson and Hines (1999) found that larval razorback sucker (*Xyrauchen texanus*) had increased survival in tanks with higher turbidity when predators were present. When water clarity is high and flows are low, woundfin and other native fishes tend to use habitats with more cover (Holden and Abate 1999). Native suckers, speckled dace, and woundfin move out of riffles and runs into areas of deeper water with debris for cover. Few of these areas exist when flows are 5 cfs and below.

Crowding native fishes into these limited refugia probably increases their competition with one another for resources, but it also increases the risk of negative interactions with nonnative fishes (Golden and Holden 2002b). While we saw declines in native fish numbers during the drought, we saw an increase in the number of red shiner, western mosquitofish, common carp, channel catfish, and largemouth bass during this time period. The low flows increase the amount of lentic habitat available for these species to thrive (Golden and Holden 2002a).

Holden et al. (2001) and Golden and Holden (2002a) found that fall red shiner abundance was higher in drought years than non-drought years. Fall red shiner catch rates were significantly higher in 2001 at the Riverside and Beaver Dam Wash Reaches and in 2000 and 2001 in the Mesquite Bridge Reach. No collections were made in fall 2000 at the Riverside and Beaver Dam Wash Reaches. However, based on catch rates in the Mesquite Bridge Reach and the Experimental Reach (see Chapter 2), red shiner catch rates were probably elevated at the Riverside and Beaver Dam Wash Reaches in fall 2000. Red shiner catch rates were high in other sections of the river during summer 2002, but a flow spike in early fall 2002 reduced catch rates drastically throughout the lower river. If not for the well-timed flow spike, red shiner numbers in all three reaches would probably have been nearly as high in fall 2002 as they were in 2000 and 2001.

Low flows caused by drought and human water use resulted in habitat reductions, high temperatures, and increased water clarity during summers 2000-2002. This combination of factors appears to have resulted in poor recruitment success for all native species while increasing the ability of nonnative predators and competitors to survive and proliferate in the river. Any native fishes that can survive the direct mortality from high temperatures and dewatering below the Mesquite Diversion have to contend with increased predation and competition. Therefore, few native fishes have survived the low flows seen in this section of the river from 2000-2002. While native fishes seem to persist at Beaver Dam Wash Reach, the sublethal effects of high temperatures and competition, along with the increased threat of predation, appear to have reduced recruitment success in this area, too. As long as the drought continues, continued declines in the native fish populations of the lower Virgin River are expected.

CHAPTER 2: EVALUATING RED SHINER REMOVAL AND WOUNDFIN STOCKING SUCCESS

Introduction

As BIO-WEST was beginning surveys of the lower Virgin River, NDOW began to experiment with stocking woundfin from Dexter National Fish Hatchery in similar areas (Heinrich 1999, Holden and Golden 2000). Multiple stocking efforts from 1993-1998 showed poor retention and survival of stocked woundfin in the lower Virgin River. However, these stocking efforts occurred below the Bunkerville Diversion, where red shiner are abundant and summer flow conditions can be very low. Red shiner have been implicated in the decline of native fishes throughout the southwest, including the woundfin on the Virgin River (Cross 1975, Gregory and Deacon 1994, Holden et al. 2001, Deacon and Williams 2002). Low flows from drought and human water use have also been implicated in the decline of native fishes in the Virgin River (Gregory and Deacon 1994, Holden et al. 2001, Deacon and Williams 2002). Therefore, woundfin stocking success may be greater in areas with more constant water supply and lower numbers of red shiner (Heinrich 1999).

In 1999 BIO-WEST assumed primary responsibility for the woundfin stocking studies in the lower Virgin River, under the direction of the LVRRT. The SNWA and USBR provided funding for these studies. The LVRRT wanted to investigate the impact of different stocking techniques and the mechanical removal of red shiner on the survival of stocked woundfin. In order to alleviate some of the low-flow issues, fish were stocked in an area between the Mesquite and Bunkerville diversions because it had a more constant water supply. The diversions also offered some restrictions to fish movement into and out of the reach. Two stocking efforts were orchestrated in 1999; one with year-old fish in May and one with YOY fish in October. Both of these stocking efforts were preceded by 3 days of mechanical removal of red shiner (Holden and Golden 2000).

By late August 1999 the woundfin stocked in May had largely disappeared, and red shiner numbers had risen significantly above their May starting density. Conversely, red shiner numbers were significantly reduced prior to the October 1999 stocking and remained low until June 2000. Woundfin catch rates were consistent throughout the winter, and an estimated 625 stocked woundfin remained in the reach by June. Additionally, more than 200 YOY woundfin, presumably the offspring of the October 2000 stocked fish, were captured in early June 2000 (Holden and Golden 2000). The initial success of this study led to additional monitoring and experiments involving red shiner removal and woundfin stocking efforts. The results of the red shiner removal and woundfin stocking experiments from 1999 to 2002 are summarized below.

Methods

Study Site

The general study area was the lower Virgin River in Arizona and Nevada (Figure 2-1). A 4.5-mile reach of the Virgin River in Arizona and Nevada between two diversion structures was selected as the “Experimental Reach” for the study. The most-upstream structure, the Mesquite Diversion, is located approximately 3.0 miles upstream from the Arizona-Nevada state line, and the Bunkerville Diversion is approximately 1.5 miles downstream from the state line. We hoped that the Bunkerville Diversion would present a barrier to upstream red shiner immigration and that the Mesquite Diversion would present a barrier to upstream emigration of the stocked woundfin.

Removal and Stocking Efforts

Three-day red shiner reduction efforts were conducted using 1.2 m x 4.5 m x 3 mm seines. Seining focused on quantity of habitats sampled and on habitats that were expected to yield high numbers of red shiner, rather than habitats thought to be more suitable for woundfin or a stratified random design. Fish numbers by species for each seine haul were recorded in field notebooks, and endangered fish were measured. Native fishes were returned to the river, and nonnative fishes were discarded. Personnel from BIO-WEST, USBR, SNWA, NDOW, Arizona Game and Fish Department (AZGFD), University of Nevada-Las Vegas, United States National Park Service, and United States Fish and Wildlife Service (USFWS) participated in one or more of the red shiner removal efforts. Eight to ten personnel were typically available, and they were split between the upper and lower portions of the Experimental Reach. The entire Experimental Reach was sampled daily during the first 2 days. On the third day the crews were combined to sample the upper portion of the reach, where red shiner were more common.

Immediately following red shiner removal efforts in May 1999, October 1999, and October 2000, woundfin from Dexter National Fish Hatchery were stocked at two sites in the Experimental Reach just downstream from the Arizona-Nevada border. The fish were removed from a holding tank in a delivery truck and taken to the river in 5-gallon buckets. They were acclimated to river temperature for several minutes in the buckets and then stocked. During the May 1999 stocking, woundfin were held for several months by NDOW and marked with coded wire tags (Northwest Marine Technology). In October 1999 and October 2000, woundfin were transported by truck directly from Dexter National Fish Hatchery and were not implanted with tags prior to stocking.

A total of five red shiner removal efforts and three woundfin stocking efforts were conducted from May 1999 through December 2002. The three woundfin stocking efforts in May 1999, October 1999, and October 2000 were preceded by red shiner removal efforts. Additional red shiner removal efforts were conducted in June 2000 and May 2001 to reduce red shiner numbers to promote YOY woundfin survival. Removal and stocking efforts were discontinued after May 2001 because of an inability to obtain woundfin from Dexter National Fish Hatchery.

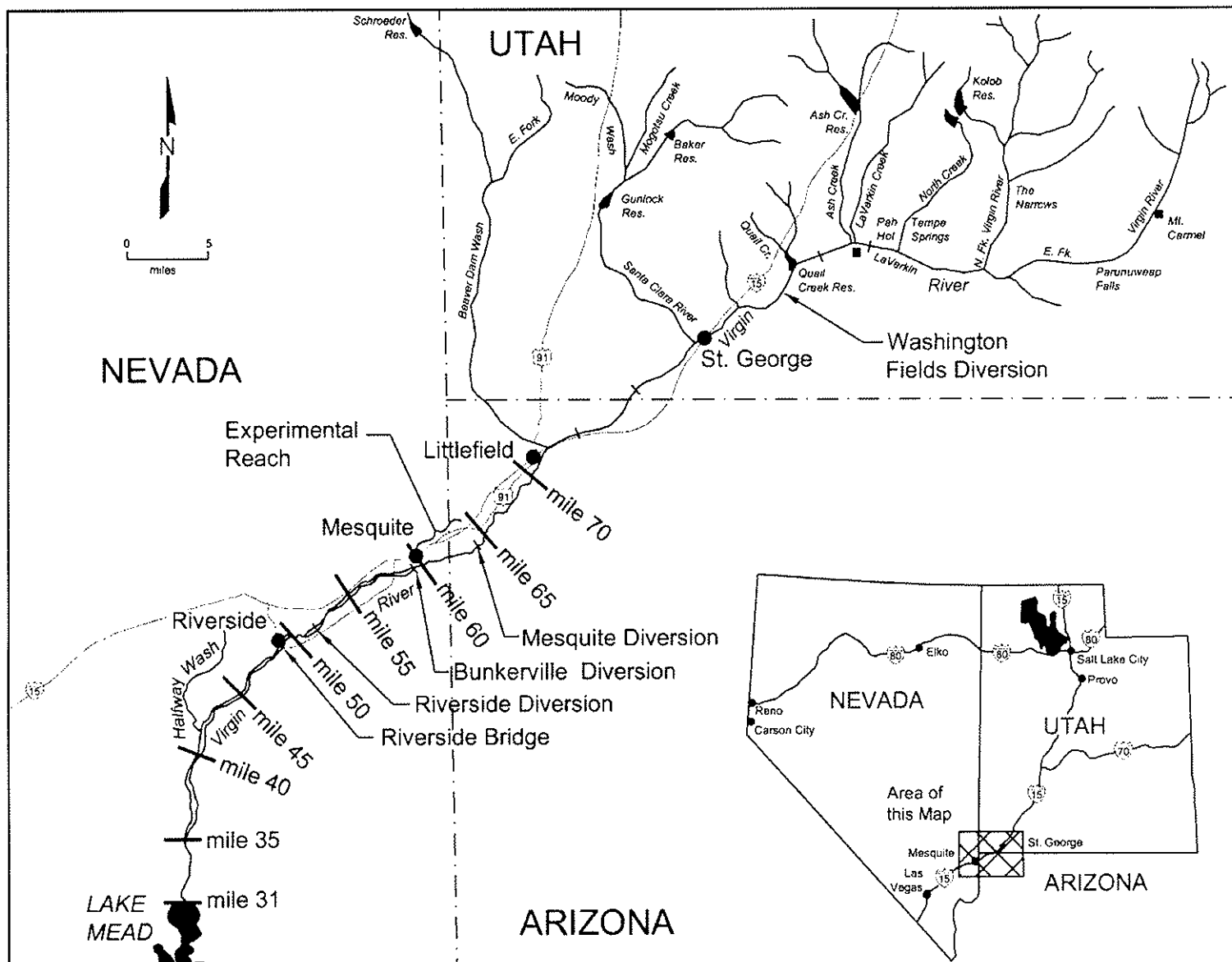


Figure 2-1. Location of the Experimental Reach in relationship to the rest of the Virgin River.

Fish Monitoring

Monitoring of stocked fish occurred twice monthly for 2 or 3 months after stocking and monthly thereafter. Problems at Dexter National Fish Hatchery resulted in no woundfin being available for stocking in 2001 and 2002. Even though no fish were stocked in October 2001, we continued monthly sampling of the reach through December 2002 to follow any remaining stocked woundfin and to investigate red shiner population dynamics in the absence of mechanical removal. The basic sampling methodology involved one three-person crew (two people seining and one person recording data) walking downstream through the entire Experimental Reach, sampling with a 2 m x 4.5 m x 3 mm seine. Similar sampling was conducted within each river mile and among habitat types, but we also gave special emphasis to habitats that woundfin prefer (e.g., hard-bottomed runs, shoals, and riffle eddies, as well as low-velocity, coarse gravel riffles during the spawning season). As much habitat as possible was sampled. During low-flow conditions, a higher percentage of available habitat was seinable than during high-flow conditions. Initially, 1 full day of seining was used for the entire reach, but this was expanded to 2 days after October 1999. Data recorded for each seine haul included habitat type, river mile, date, time-of-day, habitat area, habitat length, water temperature (hourly), crew names, number of each species collected, and total length of all native fishes (until a total of 100 fish per species was collected). Native fishes were returned to the river unharmed, and nonnative fishes were discarded on the river bank.

Flow information was obtained from the Littlefield USGS gage. Temperature information was obtained in two ways. First, during sampling, temperature was taken with a hand-held thermometer approximately every hour. Second, beginning in summer 2000, thermographs (Optic Stowaway and Optic Stowaway XT1, Onset Computer Corporation) were deployed in the Experimental, Beaver Dam Wash, and Riverside Reaches.

Data Analyses

The statistical program SYSTAT® was used to perform all statistical analyses. In order to more closely approximate a normal distribution, the natural log of the fish numbers + 1 was used in all statistical analyses. We used ANOVA with Turkey's Honestly Significant Difference multiple comparison follow-up procedure to compare the results of fish numbers between sampling trips and years. To compare fish utilization of different habitats, substrates, and cover, we used chi-square tests. We set an a priori value of 0.05 (5% chance of type I error) for all statistical tests.

Results

Flows from the USGS gage at Littlefield for 1999 through 2002 are shown below (Figure 2-2). Temperatures recorded with thermographs in the Experimental Reach and the Beaver Dam Wash Reach are shown in Figure 2-3. As mentioned in Chapter 1, 1999 through 2002 were all low-flow years. The highest flow year of the 4 years was 1999, and 2002 was the lowest flow year on record for the Virgin River.

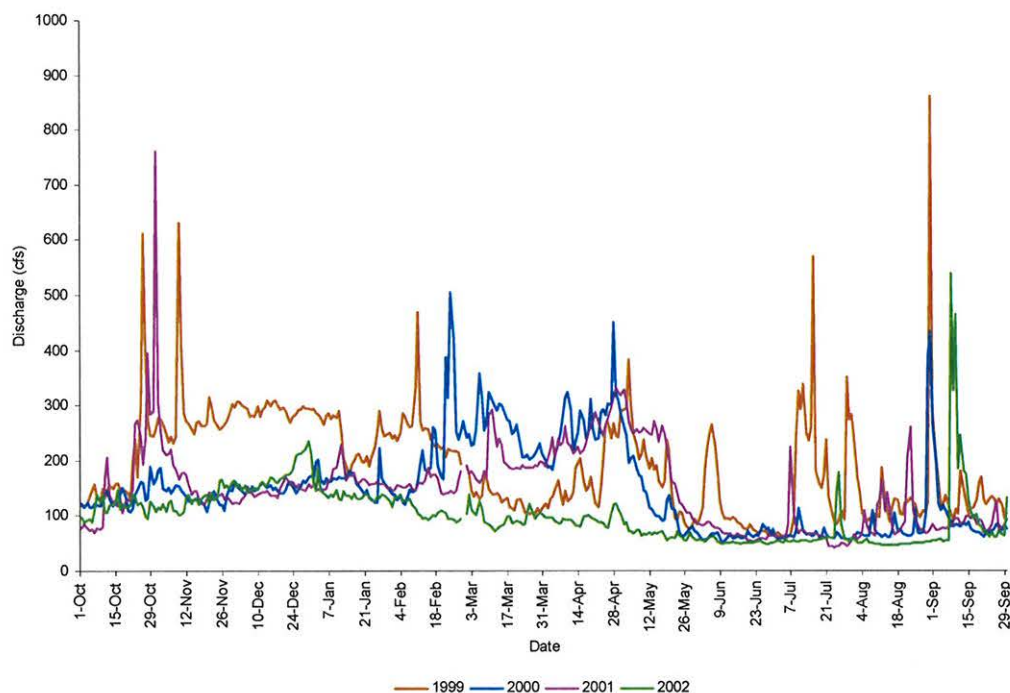


Figure 2-2. Discharge at the Littlefield, Arizona, USGS gage from 1999 to 2002.

The thermograph in the Experimental Reach gave the most inconsistent temperature records. It was first attached to the Mesquite Diversion, but we soon noticed that temperatures in the pools below the Mesquite Diversion seemed to be lower than the main river. Figure 2-3 shows that temperatures recorded from the Beaver Dam Wash thermograph were generally 3-5°C higher than the Experimental Reach thermograph throughout most of 2000 and 2001. After we moved the thermograph from the Mesquite Diversion, there were problems with sedimentation burying the thermograph and spates removing the thermograph. However, the thermograph did gather enough information to show that maximum temperatures in the 34-36°C range were not uncommon during summers 2000 through 2002.

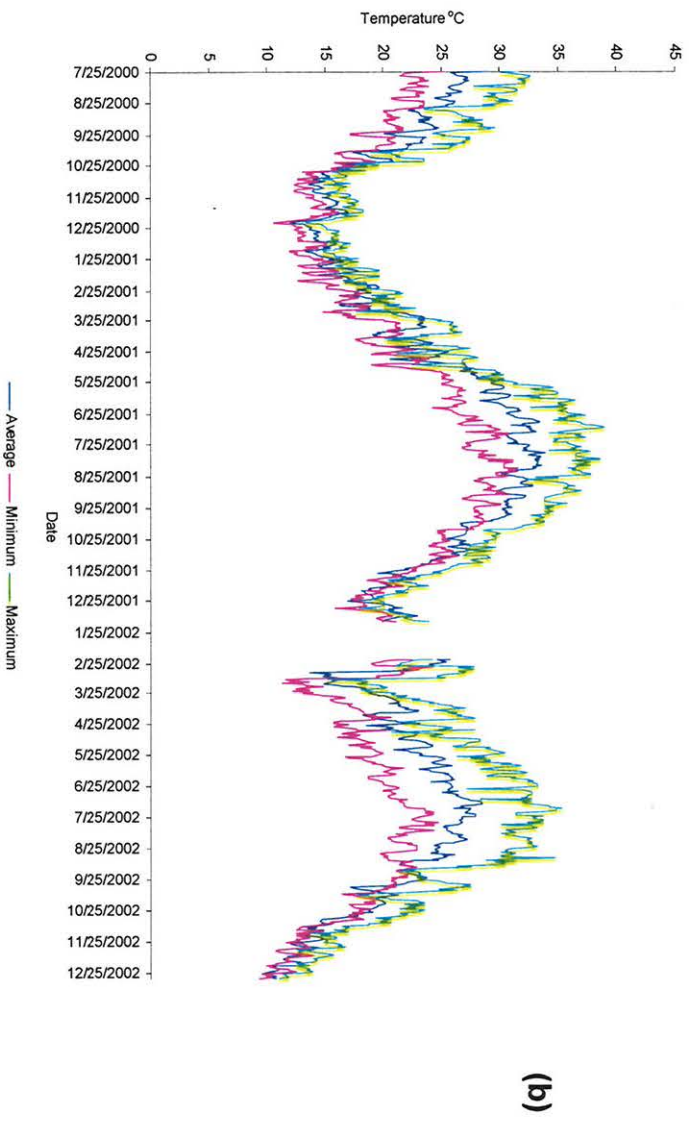
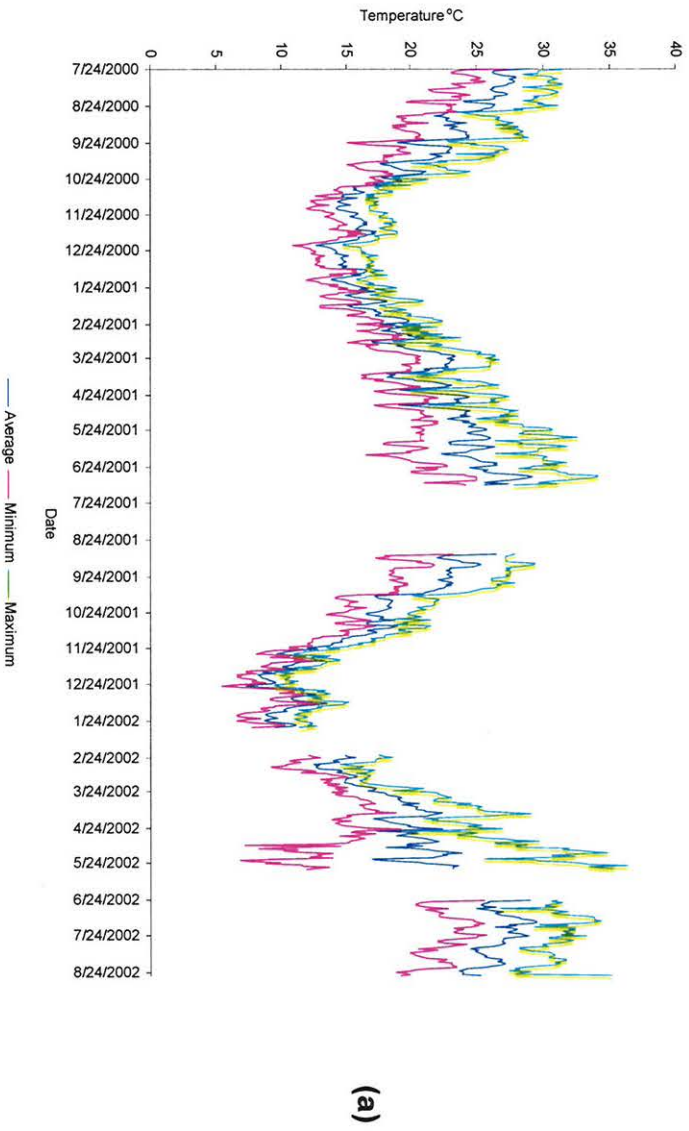


Figure 2-3. Temperature recorded at thermographs in the (a) Experimental Reach and (b) the Beaver Dam Wash Reach from July 2000 to December 2002.

May 1999 and October 1999 Stocking Efforts

Table 2-1 shows the results of the removal efforts and the number of fish stocked. The success of the first three red shiner removal efforts and two woundfin stocking efforts through June 2000 were detailed in Holden and Golden (2000). Below, we briefly summarize those findings and place them in the context of the full experiment. For a more detailed examination of the May 1999 through June 2000 data see Holden and Golden (2000). Figure 2-4 shows the catch rate of red shiner and woundfin from May 1999 to October 2000. When we compared red shiner catch rates between sampling days from May 1999 through September 2000, we found a significant decrease over the 3 days of the May 1999 red shiner removal effort ($p < 0.002$). However, by late July 1999, the red shiner catch rate was not significantly different from the first day of the May 1999 removal effort. Therefore, the May 1999 mechanical removal of red shiner suppressed red shiner numbers for less than 2 months.

Table 2-1. Number of seine hauls pulled, fish captured, and woundfin stocked during each of the five red shiner removal efforts.

DATES	WF ^a STOCKED	SEINE HAULS	RS ^b	WF ^a	YW ^c	VRC ^d	FM ^e	DS ^f	YS ^g	SD ^h	BB ⁱ	CC ^j	CP ^k	LB ^l	GS ^m	MF ⁿ
5/4-6/ 1999	1,700	636	7,805	9	0	6	215	60	23,562	601	6	4	0	2	0	0
10/19-21/ 1999	9,500	1,052	20,140	5	0	46	578	192	0	70	0	2	2	0	1	549
6/5-8/ 2000	0	1,117	7,170	400	242	8	5,388	310	7,488	341	0	1	50	63	0	321
10/2-4/ 2000	4,500	1,207	89,263	5	27	22	711	267	0	170	0	0	2	4	0	2,986
5/29-31/ 2001	0	993	25,672	87	0	16	308	140	296	119	0	1	15	2	0	126

^a WF = woundfin, ^b RS = red shiner, ^c YW = young woundfin, ^d VRC = Virgin River chub, ^e FM = flannelmouth sucker, ^f DS = desert sucker, ^g YS = young-of-year suckers, ^h SD = speckled dace, ⁱ BB = black bullhead, ^j CC = channel catfish, ^k CP = common carp, ^l LB = largemouth bass, ^m GS = green sunfish, ⁿ MF = western mosquitofish.

While red shiner catch rates were not significantly reduced by the 3-day October 1999 red shiner removal effort, they were significantly lower than the first day of the October 1999 removal effort for all but three collections: during monitoring trips from late October 1999 and the June 2000 red shiner removal effort ($p < 0.05$). Therefore, red shiner numbers appeared to be suppressed between winter and spring 1999-2000.

Red shiner catch rates were also not significantly reduced by the 3-day removal effort in June 2000, but catch rates remained significantly lower than the October 1999 removal effort ($p < 0.001$). By the June 21, 2000, collection, red shiner catch rates were significantly higher than those seen during the October 1999 removal effort. Red shiner catch rates from July 2000 through September 2000 were significantly higher than during all sampling trips up to that time ($p < 0.001$).

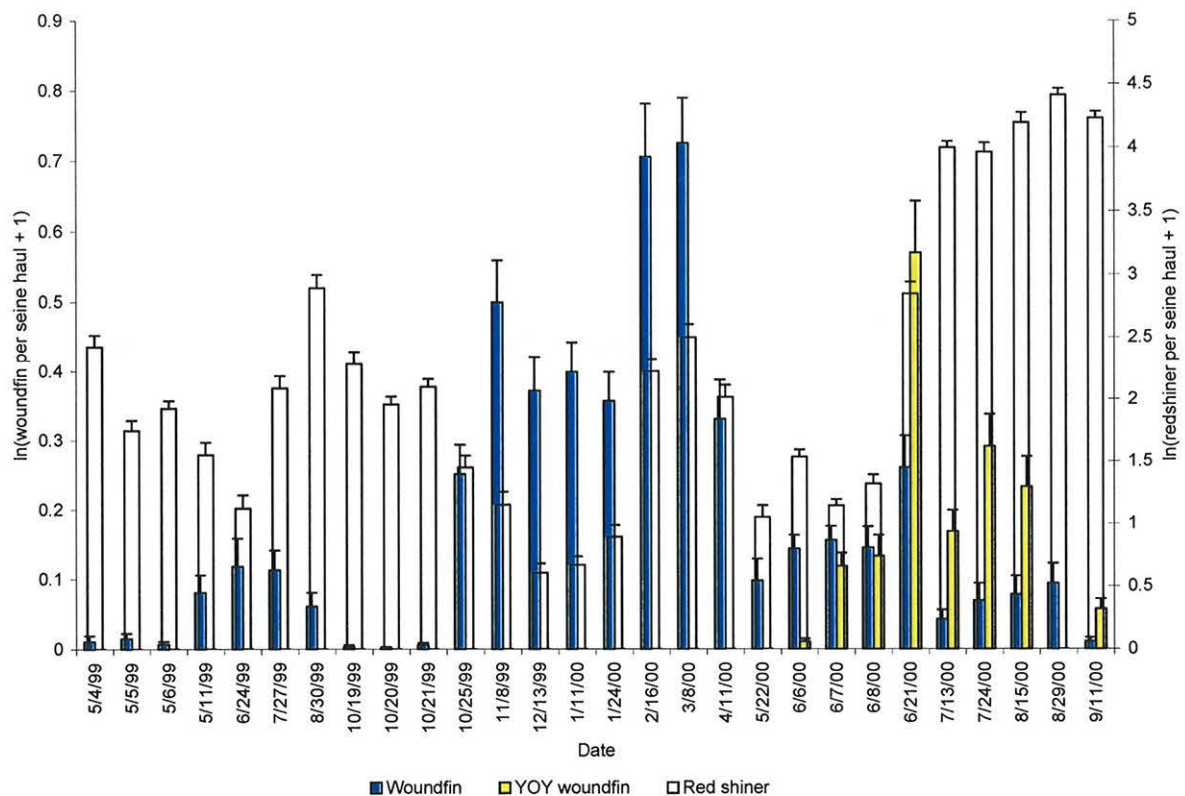


Figure 2-4. Catch rates of woundfin and red shiner during sampling from May 1999 to September 2000.

After the May 1999 stocking, woundfin catch rates did not show a significant increase over the May 1999 removal period catch rates. The fact that fairly low numbers (1,700) of woundfin were stocked may account for our inability to detect a statistical difference in catch rate. We did see an increase in woundfin catch rate after stocking, but the catch rate started to decline by late July 1999 and was similar to the May 1999 removal period catch rate by October 1999.

Conversely, woundfin catch rate increased significantly following the October 1999 stocking effort. Woundfin catch rate remained significantly higher than during the October 1999 red shiner removal effort catch rates through the June 21, 2000, collection ($p < 0.02$). The May 22, 2000, collection was the only exception. Woundfin catch rates were probably underestimated during that trip, because woundfin had shifted habitats, presumably to spawn (Holden and Golden 2000). A population estimate during the June 2000 removal period showed that approximately 625 of the 9,500 woundfin stocked remained in the reach (Holden and Golden 2000). After the June 21, 2000, collection, catch rates for adult woundfin declined significantly and were close to pre-stocking levels by September 2000.

We found that the stocked woundfin successfully reproduced in late April or early May 2000. During the June 2000 removal period, we captured close to 200 YOY woundfin (Holden and Golden 2000). The catch rate for YOY woundfin peaked during the June 21, 2000, collection, when almost 400 YOY woundfin were captured. Catch rates for YOY woundfin began to decline after this collection, and by September 2000 reached their lowest levels since the YOY woundfin were discovered.

Native fish numbers fluctuated throughout the May 1999 monitoring and October 1999 stocking efforts (Figure 2-5). Large numbers of YOY suckers (*Catostomus* spp.) were present in May 1999. In the fall the catch rates of native suckers and speckled dace both declined from those seen in spring 1999 collections. Native fish catch rates rose again in the spring of 2000 as reproduction introduced another cohort of YOY native fish into the river, but by the fall native fish catch rates had declined again. Virgin River chub catch rates were low throughout the study period. Native fish catch rates are statistically analyzed below in the “Yearly and Seasonal Comparisons” section.

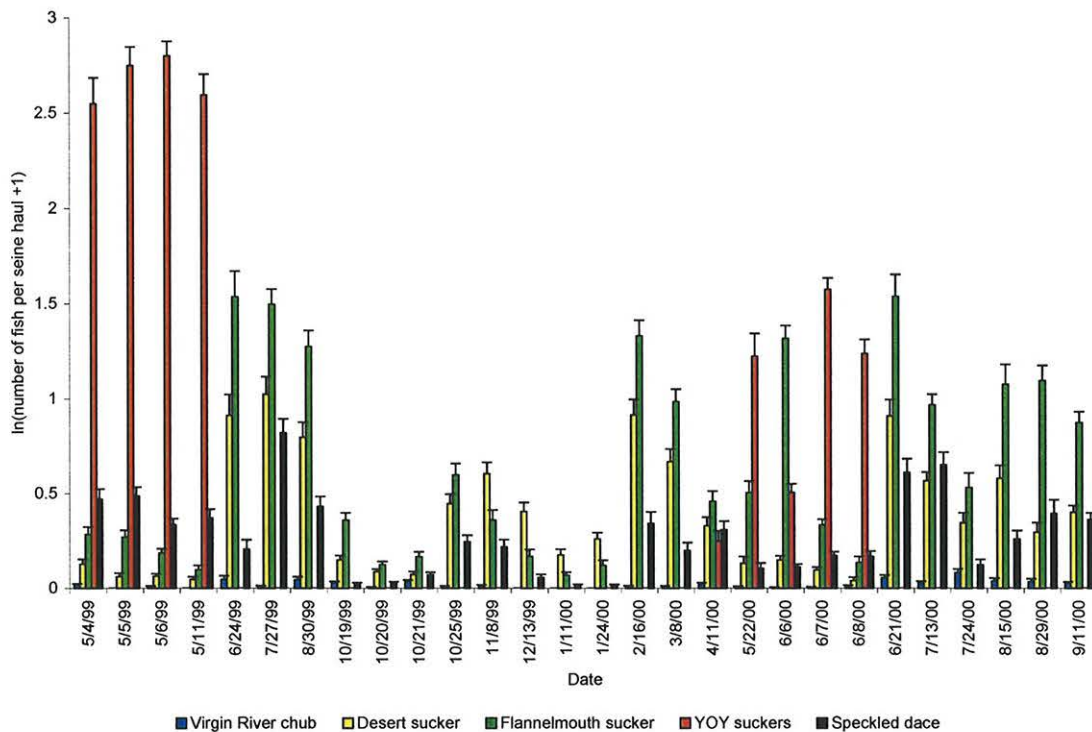


Figure 2-5. Catch rates of other native fishes during sampling from May 1999 to September 2000.

October 2000 Stocking

In October 2000 another red shiner removal and woundfin stocking effort was organized (Table 2-1). Figure 2-6 follows the catch rates of red shiner and woundfin from the October 2000 removal period through December 2002. After the September 2000 collections, we combined the YOY woundfin that were the progeny of the October 1999 stocked fish back into the general population of woundfin. Despite the addition of YOY woundfin back into the total numbers of woundfin, we found that woundfin catch rates during the October 2000 removal effort were similar to those found during the May 1999 and October 1999 removal efforts. This indicated that the two prior stocking efforts had not succeeded in increasing woundfin numbers in the Experimental Reach.

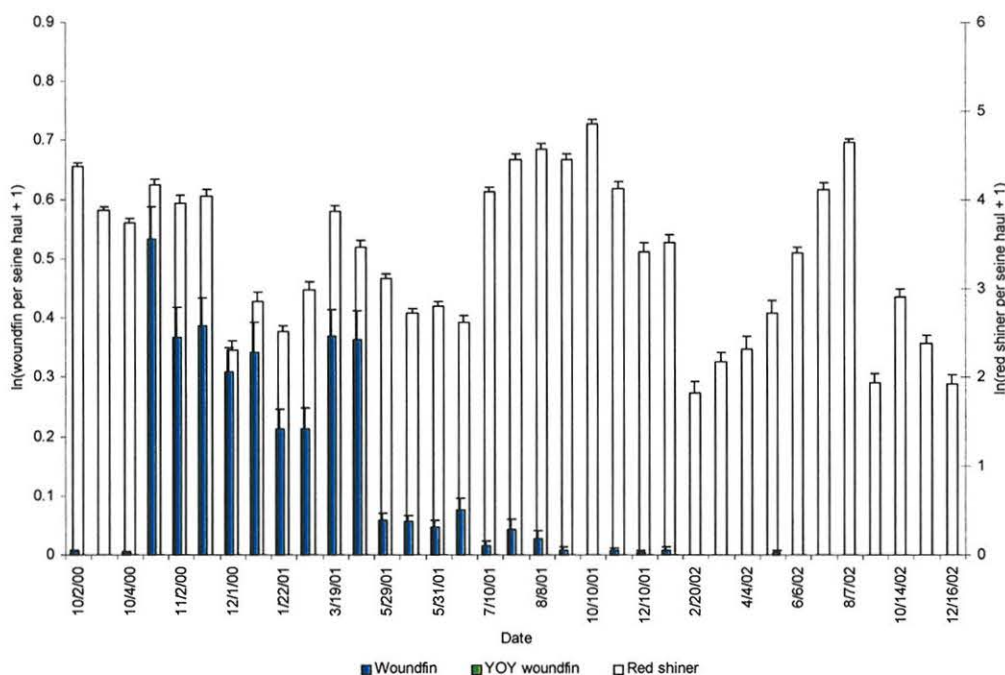


Figure 2-6. Catch rates of woundfin and red shiner during sampling from October 2000 through December 2002.

Red shiner numbers were significantly higher during the October 2000 removal effort than they were during any of the other removal efforts ($p < 0.001$). While we significantly reduced the red shiner catch rate red shiner over the 3-day removal effort ($p < 0.001$), by the last day the red shiner catch rate was still significantly higher than during any of the other removal efforts ($p < 0.001$). Within 2 weeks the red shiner catch rate had risen back to levels similar to the first day of the removal effort. Red shiner catch rate stayed high until early December, when catch rates dropped significantly ($p < 0.001$). Red shiner catch rates remained significantly lower than October catch rates until March and April, when they were similar. Red shiner catch rates fell again in May 2001 and were significantly lower than those in the October removal effort during this time ($p < 0.05$).

The red shiner catch rate was significantly reduced over the 3 days of the May 2001 removal effort ($p < 0.05$). Afterwards, the red shiner catch rate began to increase, and by July 2001 it was similar to the first day of the October 2000 removal effort. From July 2001 through September 2001, red shiner catch rates remained as high or higher than during the October 2000 removal effort.

Woundfin catch rates followed a trend similar to that observed during the October 1999 stocking effort. Immediately following stocking on October 19, 2000, woundfin catch rates were significantly higher than those during the October 2000 removal effort. Woundfin catch rates remained significantly higher through the April 2001 collection ($p < 0.001$). However, by the May 2001 removal effort, woundfin catch rates had declined to levels similar to those of the October 2000 removal effort. In collections following May 2001 woundfin catch rates continued to decline, and by late fall 2001 essentially none of the stocked fish remained. Additionally, little evidence of successful spawning was observed.

We continued to monitor the Experimental Reach monthly from September 2001 through December 2002. Woundfin essentially disappeared from the reach by February 2002. The red shiner catch rate reached its highest level in October 2001 ($p < 0.001$). In November 2001 catch rate of red shiner dropped significantly from this level ($p < 0.001$). From December 2001 to June 2002, red shiner catch rates remained significantly lower than they had been during the October 2000 red shiner removal effort ($p < 0.001$). However, by July 2002 they had risen to levels similar to those seen during summer 2001. The red shiner catch rate remained elevated until September 2002, when a significant drop was seen ($p < 0.001$). The decrease in red shiner catch rate was closely associated with a spate that occurred in early September 2002. From September 2002 through December 2002, red shiner catch rate remained low and was similar to catch rates seen during the winters of 1999-2000 and 2000-2001.

Numbers of other native fishes were distinctly lower from October 2000 through April 2002 than they were from May 1999 through September 2000 (Figure 2-7). Reproduction and subsequent recruitment appeared to be very poor in 2001 for all species. The catch rate of flannemouth sucker slightly rebounded in spring and summer 2002. Native fish catch rates are statistically analyzed below in the "Yearly and Seasonal Comparisons" section.

Yearly and Seasonal Comparisons

Physical conditions in the lower Virgin River changed throughout the 1999 to 2002 period. These changes probably influenced the success of mechanically controlling red shiner and stocking woundfin and are reflected in variations seen in the fish community during that time. We separated the study into four time periods coinciding with different aspects of the stocking study. The 1999 period encompassed the May 1999 stocking and monitoring efforts, from May through September 1999. The 2000 period included the October 1999 stocking and follow-up monitoring efforts from October 1999 through September 2000. The 2001 period included the October 2000 stocking and follow-up monitoring efforts, from October 2000 through September 2001. Finally, the 2002 period included the additional year of monitoring from October 2001 through December 2002.

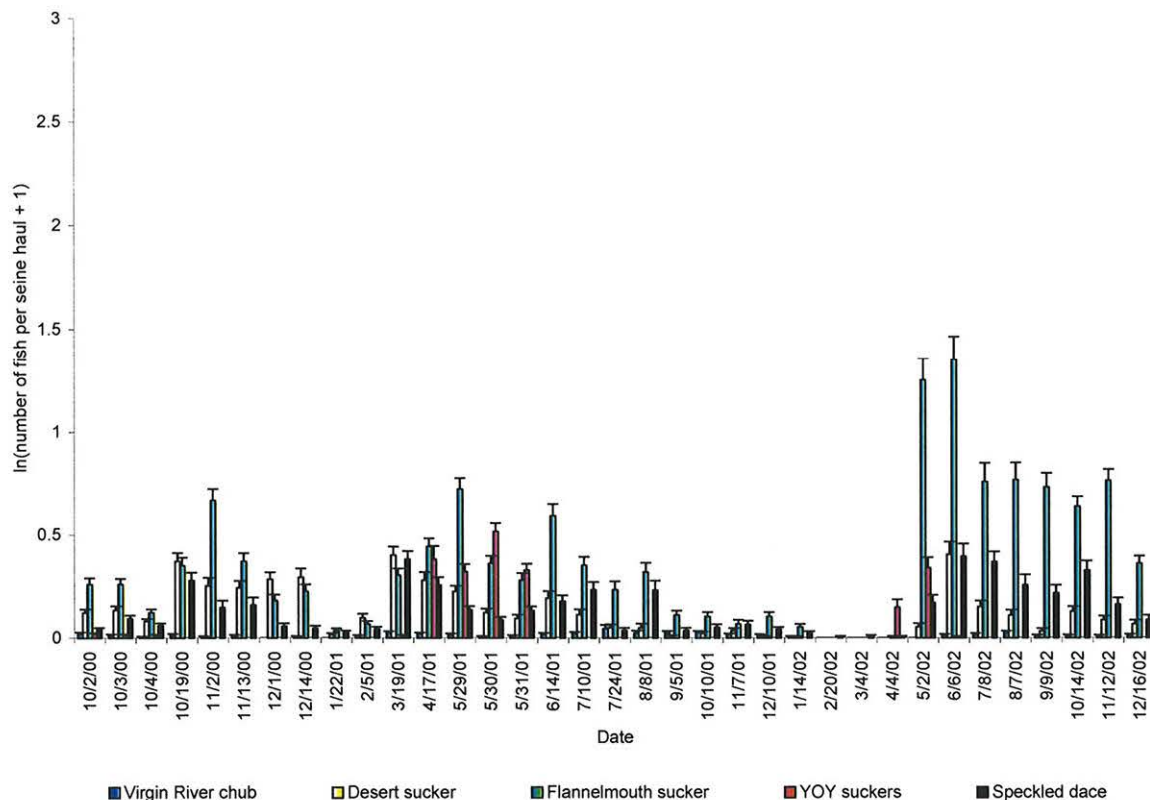


Figure 2-7. Catch rates of other native fishes during sampling from October 2000 to December 2002.

We found that 1999 had a significantly lower catch rate of red shiner than all other periods ($p < 0.02$), and 2000 had a significantly lower red shiner catch rate than 2001 and 2002 ($p < 0.001$). The red shiner catch rate in 2001 was significantly higher than the catch rate in all other periods ($p < 0.001$). We also saw seasonal differences in red shiner catch rate. When we combined data from all periods, we found that fall had the highest catch rates for red shiner, followed by summer, then spring and, finally, winter. The differences in red shiner catch rates between seasons were significant ($p < 0.007$).

We also compared red shiner catch rates within seasons between time periods. We found that the winter red shiner catch rate was significantly higher in 2002 than in 2000 or 2001 and that the winter red shiner catch rate in 2001 was significantly higher than in 2000 ($p < 0.001$). No winter collections were made in the 1999 period. We found that the spring red shiner catch rate was significantly higher in 2001 than all other time periods, and 1999 had a significantly lower spring red shiner catch rate than all other time periods ($p < 0.001$). The summer red shiner catch rate in 2002 was significantly higher than all other periods ($p < 0.001$). The summer red shiner catch rate was significantly higher in 2001 than 1999 or 2000 ($p < 0.001$). Finally, we found that fall 2001 had the highest red shiner catch rate followed by fall 2002 and fall 2000 ($p < 0.001$). No fall collections were made during the 1999 period.

We also compared woundfin catch rates between the four time periods and between seasons. We did not include the YOY progeny of the woundfin stocked in 1999 in these analyses. The three time periods when woundfin were stocked had a higher catch rate for woundfin than the 2002 period, when woundfin were not stocked ($p < 0.008$). When we compared woundfin catch rates between seasons, we found that spring and winter had significantly higher catch rates than summer and fall, and that winter had the highest catch rate ($p < 0.001$). This analysis reflects the fact that the stocked fish survived the months immediately after stocking but did not survive the summer. Since fall and summer woundfin catch rates were very low, we combined the winter and spring woundfin catch rate and compared it between time periods. The combined winter/spring woundfin catch rate was significantly higher in 2000 and 2001 than 1999 and 2002 ($p < 0.001$). While winter/spring catch rates appeared similar between 2000 and 2001, the analysis showed that 2000 had a significantly higher catch rate than 2001 ($p < 0.001$).

As mentioned previously, we also saw distinct changes in the native fish community through the study period. We found that catch rates for Virgin River chub were lower than for other native species throughout the entire study. However, the Virgin River chub catch rate was highest in 2000, significantly higher than 2002 ($p < 0.03$). The flannelmouth sucker catch rate was significantly higher in 1999 and 2000 than in 2001 or 2002 ($p < 0.01$). The flannelmouth sucker catch rate was significantly lower in 2001 than 2002 ($p < 0.001$). The speckled dace catch rate was also significantly lower in 2001 than in all other time periods ($p < 0.05$). The speckled dace catch rate in 1999 was significantly higher than in all other time periods, and the catch rate in 2000 was significantly higher than in 2001 or 2002 ($p < 0.01$). The desert sucker catch rate was significantly higher in 1999 and 2000 than in 2001 and 2002 ($p < 0.001$). As with desert sucker and flannelmouth sucker, the catch rate of unidentifiable YOY suckers was significantly higher in 1999 and 2000 than in 2001 or 2002 ($p < 0.001$). However, 1999 had a significantly higher catch rate of YOY suckers than 2000, and 2001 had a significantly higher catch rate than 2002 ($p < 0.001$).

We also examined seasonal differences in catch rate for each species. Virgin River chub had significantly higher catch rates in summer and fall than in winter and spring ($p < 0.03$). The summer had the highest catch rate for both flannelmouth sucker and desert sucker ($p < 0.001$). Catch rate of flannelmouth sucker was significantly lower in the winter than in all other seasons ($p < 0.001$). The speckled dace catch rate was also significantly lower in winter than in all other seasons ($p < 0.001$). The speckled dace catch rate was significantly higher in spring and summer than in fall ($p < 0.001$).

Woundfin Habitat Use

Having stocked woundfin present in the lower Virgin River provided an excellent opportunity to look at woundfin habitat use in the system. We examined overall and seasonal habitat use for all woundfin and YOY woundfin. The chi-square test for overall habitat use for combined adult and YOY woundfin showed that the distribution of habitats in which woundfin were found differed from

the distribution in which habitats were sampled, as shown in Table 2-2 ($p < 0.001$). Backwater, pool, and eddy habitats appeared to be used less than was expected, while run/riffle habitat, side channels, and side channel runs were used more than was expected. Riffles and runs were used the most, but they were not used disproportionately from what was expected from the sampling distribution. Average mean depth from samples containing woundfin was 29.2 cm, and average maximum depth was 39.9 cm.

Table 2-2. Habitats sampled and habitats where woundfin and young-of-year (YOY) woundfin were captured during sampling of the Experimental Reach from 1999-2002.

HABITAT	TOTAL	WOUNDFIN	YOY WOUNDFIN
Unknown	715	9	0
Backwater	51	1	1
Backwater/pool	4	0	0
Backwater/riffle	2	0	0
Backwater/run	21	1	0
Eddy	16	2	0
Eddy/riffle	1	0	0
Eddy/run	5	0	0
Irrigation return	9	1	0
Pool	212	13	4
Pool/run	44	1	0
Riffle	1,225	160	49
Riffle/eddy	8	0	0
Riffle/pool	13	1	1
Riffle/run	1,015	124	28
Run	8,992	1,135	153
Run/riffle	295	86	11
Side channel	30	7	2

When we broke the sampling data into seasons, we found that the only difference in the distribution of habitats containing woundfin from the distribution of overall habitats sampled was during the summer (Table 2-3, $p < 0.001$). During the summer, pools and runs were used less than was expected from the sampling distribution, and riffles, riffle/runs, run/riffles, and side channels were used in disproportionate numbers than was expected by the sampling distribution. In fall, winter, and spring, habitat use was dominated by runs, but this is also the habitat most often sampled. Winter had slightly higher average and maximum depths than other seasons.

Table 2-3. Habitats sampled and habitats where woundfin and young-of-year (YOY) woundfin were captured during sampling of the Experimental Reach in summer from 1999 to 2002.

HABITAT	TOTAL	WOUNDFIN	YOY WOUNDFIN
Unknown	1	0	1
Backwater	16	1	0
Backwater/pool	4	0	0
Backwater/riffle	1	0	0
Backwater/run	9	1	0
Eddy	9	2	0
Eddy/riffle	3	0	0
Eddy/run	1	0	0
Irrigation return	2	1	0
Pool	143	8	4
Pool/run	28	3	0
Riffle	613	112	49
Riffle/pool	5	1	1
Riffle/run	421	57	26
Run	3,029	331	139
Run/riffle	99	17	11
Side channel	2	2	2

Since we found many YOY woundfin in summer 2000, we had a unique chance to assess habitat use of recently spawned fish throughout their first summer, until they disappeared or recruited into the adult population. Using a chi-square analysis, we found that the distribution of habitats where YOY woundfin were captured differed significantly from the overall sampling distribution ($p < 0.001$). The YOY woundfin were found in riffles, riffle/runs, run/riffles, and side channels more often than expected and in runs less often than expected.

We classified YOY woundfin into the adult year class starting in October of each year. Additionally, except for one YOY woundfin captured in April 2002, the earliest we captured YOY woundfin was early June. Therefore, summer and fall were the only seasons that could be examined individually. However, we only captured YOY woundfin in 16 samples in the fall, so we only present the chi-square results for summer. Again, we found that the distribution of habitats where we found YOY woundfin in the summer was significantly different from the distribution of habitats sampled in the summer ($p < 0.001$). The results of this analysis mirrored those for all YOY woundfin.

Discussion

We found that mechanical removal efforts did not result in long-term depression of red shiner numbers and that our woundfin stocking efforts did not re-establish a viable population of woundfin in the Experimental Reach. However, this set of experiments still provided a wealth of information. Red shiner removal can result in short-term depression of red shiner numbers when environmental conditions are favorable. The May 1999 mechanical removal efforts depressed red shiner numbers for 2-3 months, and red shiner numbers remained depressed for 7-8 months after mechanical removal efforts in October 1999. Conversely, the October 2000 removal efforts did not curtail red shiner numbers for even 2 weeks. Despite the failure of mechanical removal to reduce the red shiner catch rate, we saw a significant drop in the catch rate in December 2000 with no further mechanical removal.

We saw a similar reduction in red shiner catch rate during winter 2001-2002 without using mechanical removal. From the results of the May and October 1999 woundfin stocking efforts, we concluded that mechanical removal efforts in late fall reduced red shiner numbers and that they remained low all winter (Holden and Golden 2000). The results of our continued experimentation and sampling from October 2001 through December 2002 indicate that red shiner catch rates were lower in the winter regardless of whether mechanical removal was performed in the fall. Red shiner appeared to suffer winter mortality or switch habitat during winter, making them less susceptible to capture by seining. Matthews et al. (2001) found that red shiner had density-dependent mortality over the winter. We may have seen a similar phenomenon in this study.

Mechanical removal of red shiner in late spring seemed to be ineffective at lowering red shiner catch rate for any length of time. The May 1999 removal reduced catch rates for about 2 months. The May 2000 and May 2001 mechanical removal efforts may have extended already-low spring red shiner catch rates for less than 1 month. Red shiner catch rates increased dramatically in early to mid summer in 2000, 2001, and 2002. In 1999 large increases in catch rates were not seen until August, and even then catch rates did not approach summer rates in 2000 through 2002. The difference is probably attributable to the flow characteristics of those years. The only year of the study with any appreciable spring runoff was 1999. Additionally, several spates occurred in summer 1999. Conversely, the summers of 2000 through 2002 had little to no spring runoff and almost no spate events. These summers were all considered drought years in a cluster analysis of summer 50% exceedence discharge with the 7-day spring maximum discharge (Golden and Holden 2002a).

Holden et al. (2001) noted an increase in red shiner abundance in drought years on the Virgin River. Many researchers have also noted the potential for flow spikes to reduce the abundance of nonnative fishes in western streams (Meffe 1984, Hawkins and Nesler 1991, Lentsch et al. 1996, Gido et al. 1997, Poff et al. 1997, Marchetti and Moyle 2000, Tyus and Saunders 2000). We believe that the low, consistent flows during the summers of 2000 through 2002 allowed red shiner catch rates to reach the extremely high levels we saw throughout those years of the study. The drop in red shiner catch rate in September 2002 shows the impact that a well-timed spate can have on red shiner populations. Catch rates dropped more than 50% from August 2002 to September 2002. The first

large spate in more than a year occurred on September 8-10, 2002. A drop in red shiner catch rates was seen river-wide after this spate (Rick Fridell, Utah Division of Wildlife Resources, personal communication) (see Chapter 3). Red shiner catch rates were at their lowest during the first year of the study before the severe drought period gripped the region. Therefore, it appears that flow and temperature conditions in the river have the greatest control on red shiner catch rates and that our mechanical removal efforts were only successful in conjunction with favorable environmental conditions.

Unlike red shiner catch rates, catch rates of stocked woundfin stayed relatively constant over the winter months after the October 1999 and October 2000 stocking efforts. After each of these stocking efforts woundfin catch rates remained significantly elevated for 7-8 months. Catch rates diminished much more quickly following the May 1999 stocking effort and previous stocking attempts by NDOW (Heinrich 1999, Holden and Golden 2000). Heinrich (1999) stocked woundfin at many different times of year with very little success. Since the October 1999 stocking effort was initially more successful than the May 1999 stocking effort, we concluded that stocking YOY woundfin in the fall was better than stocking year-old fish in the spring (Holden and Golden 2000).

We believe the results of the October 2000 study and past studies support this assertion. The October 2000 stocking effort was successful similar to the October 1999 stocking effort, despite the fact that about half the number of woundfin were stocked in 2000. While essentially none of the stocked fish survived into the following fall in either study, they survived much longer than in any previous stocking experiments (Heinrich 1999) and provided the first evidence that stocked fish will reproduce in the river. Trammel and Archer (2000) saw higher success stocking YOY versus adult Colorado pikeminnow (*Ptychocheilus lucius*) in the San Juan River. Therefore, we maintain that stocking YOY fish in the fall appears to be a viable way for maintaining woundfin in the river through the winter.

While we saw fairly consistent winter and spring survival for the stocked fish in 1999-2000 and 2000-2001, essentially none of our stocked fish survived into the following fall. Additionally, the relatively large numbers of YOY woundfin that we collected in June 2000 did not recruit into fall 2000. Over the summer red shiner catch rates steadily increased; at the same time woundfin catch rates rapidly declined. It is unclear whether the increase in red shiner numbers is the reason for the decline in woundfin catch rates. We found that the catch rate of woundfin in winter and spring 1999-2000 was significantly higher than the catch rate in winter and spring 2000-2001. Fifty percent fewer woundfin were stocked in October 2000 than in October 1999, but the catch rate for woundfin in winter and spring 2000-2001 was only 35% less than the woundfin catch rate in winter and spring 1999-2000. Therefore, survival of stocked woundfin appears to have been similar between those two time periods.

Despite the fact woundfin survival appears to have been similar, red shiner catch rates were significantly (more than two times) higher in winter and spring 2000-2001. Woundfin survival was also poor during summer 1999, when red shiner catch rates were similar to those found in the winter and spring 1999-2000 and significantly lower than winter and spring 2000-2001. Therefore, we did

not always see a pattern of reduced woundfin survival with an increase in the red shiner catch rate. Woundfin numbers also declined in Utah areas free of red shiner during this same time period (Golden and Holden 2002a). Therefore, we feel that other factors, working independently or in conjunction with pressure from nonnative fishes, influenced woundfin survival.

We saw that native fish catch rates generally declined from May 1999 to April 2002. Flannelmouth sucker and speckled dace catch rates slightly rebounded in summer and fall 2002, but desert sucker and Virgin River chub catch rates remained low throughout 2002. All native fish appeared to respond negatively to conditions prevalent in the river in 2000 through 2002. We feel that the same river conditions that resulted in native fish declines are at least partially responsible for the failure of stocked woundfin to survive the full year in the Experimental Reach.

As discussed in Chapter 1, Holden et al. (2001) showed that fall woundfin abundance was significantly lower in drought years than in non-drought years, and Golden and Holden (2002a) showed similar trends for native fishes in general. Holden et al. (2001) also showed that fall woundfin abundance was significantly lower in years where summer 50% exceedence flows were below 75 cfs. Summer 50% exceedence flows in the Experimental Reach were below 75 cfs every year of the study; in the summers from 2000 to 2002, summer 50% exceedence flows probably ranged between 15-30 cfs in the Experimental Reach.

Flows below 50 cfs have been shown to result in extremely low fall woundfin abundance (Holden et al. 2001). We discussed many of the reasons for this in Chapter 1, including reduced habitat availability, high temperatures, and increased water clarity. While woundfin and other native fishes respond negatively to these low-flow conditions, red shiner seem to flourish under these conditions. The combined stress of the abiotic factors associated with low flows and increased competition for space and/or resources from higher numbers of nonnative fishes, such as the red shiner, appear to be the reason that stocked woundfin were unable to survive the summer in the Experimental Reach. The same factors are probably responsible for overall declines in native fish in the Experimental Reach from 2000 to 2002.

CHAPTER 3: BLUE TILAPIA MONITORING AND REMOVAL EFFORTS

Introduction

The native fishes of the lower Virgin River have undergone dramatic declines in the past 25 years. Changes in habitat and water quality and quantity, resulting from increased water development and drought, have combined with the negative impacts from a variety of nonnative fishes to severely impair native fish communities throughout the Virgin River (Deacon 1988, Gregory and Deacon 1994, Holden et al. 2001, Deacon and Williams 2002, Golden and Holden 2002a). In late July 2001 NDOW personnel discovered blue tilapia in the Virgin River below the Bunkerville Diversion. The invasion of blue tilapia was another potential stressor on a system barely maintaining its native fish fauna.

Blue tilapia is a tropical cichlid that was first discovered in the vicinity of the Virgin River in 1993, when it was found in the Muddy River. Subsequently, blue tilapia invaded Lake Mead from the Muddy River and have continued to persist and even thrive in some areas. In the Muddy River, the appearance and proliferation of blue tilapia was closely associated with the decline of several native fish species, including the endangered Moapa dace (*Moapa coriacea*), the endemic Moapa White River springfish (*Crenichthys baileyi moapae*), and the Virgin River chub (Scopetonne 1993, Scopetonne et al. 1998).

The LVRRIT decided that preventing the establishment of blue tilapia in the Virgin River should be a top priority. The SNWA authorized use of existing funds to have BIO-WEST monitor the survival, movement, and distribution of blue tilapia in the lower Virgin River for the LVRRIT. The VRRMRP provided additional funding for BIO-WEST to continue monitoring blue tilapia in 2002. The re-invasion of the lower Virgin River by blue tilapia in fall 2002 prompted a pilot treatment effort below the Bunkerville Diversion.

The pilot treatment effort had several goals. The first was to lower blue tilapia numbers immediately below the Bunkerville Diversion to reduce the risk of blue tilapia finding a way to breach the Bunkerville Diversion. The second was to examine the effectiveness of rotenone for removing blue tilapia from sections of the Virgin River. The USFWS and NDOW have used rotenone to control blue tilapia in sections of the Muddy River with some success (Jim Heinrich, NDOW, personal communication). Finally, the LVRRIT wanted to use the treatment to determine the effectiveness of seining as a method to detect the presence of blue tilapia.

BIO-WEST used funds from the SNWA and the VRRMRP to assist the LVRRIT in planning and implementing a pilot rotenone treatment in fall 2002. BIO-WEST examined the effectiveness of the rotenone treatment and seining by sampling the 1-mile treatment reach below the Bunkerville Diversion before, during, and after a trial rotenone application. This chapter provides the results of the blue tilapia monitoring and pilot treatment.

Methods

Nevada Division of Wildlife personnel first observed blue tilapia in July 2001, near the NDOW "Burn" Site (RM 51.25-51.0) and below the Bunkerville Diversion (RM 59.25). Nevada Division of Wildlife, USFWS, and BIO-WEST personnel set up small sites to monitor blue tilapia numbers and advancement in early August 2001. These sites included Halfway Wash (RM 41.5), the area below the Riverside Bridge (RM 49.25-49.00), the NDOW Burn Site (RM 51.25-51.00), and the area below the Bunkerville Diversion (RM 59.25-59.00). Most of these areas were sampled monthly until December 2001. In 2002 we extended the sites to encompass more river area. The NDOW Burn Site and the Riverside Bridge site were combined into a longer reach we called the Above Riverside Reach that extended from RM 51.25 to RM 49.00. Additionally, the site Below Bunkerville Diversion was extended to just above the Mesquite Bridge, and we called it the Below Bunkerville Diversion Reach (RM 59.25-58.00). More of the Halfway Wash area (RM 41.75-40.5) was sampled on several occasions, and we refer to that as the Halfway Wash Reach. The Below Bunkerville Diversion Reach was sampled monthly from January 2002 to December 2002. The other reaches were sampled more sporadically beginning in June 2002. Additionally, an area above the Mesquite Diversion (RM 68.5-63.25) was sampled in January 2002.

Blue tilapia monitoring efforts were focused on deep and low-velocity habitats that blue tilapia were thought to use. We used a 2 m x 4.5 m x 3 mm seine. Additionally, hoop nets and a backpack electroshocker were used at one or more sites over summer 2002 to more effectively sample stagnant pools with debris piles. Protocols for data collection and fish handling were similar to those outlined in Chapters 1 and 2.

To examine the effectiveness of a trial rotenone application, BIO-WEST used 2 m x 4.5 m x 3 mm seines to sample the Below Bunkerville Diversion Reach before, during, and after a trial rotenone treatment. Surveys were conducted the day before and the day after treatment using the same techniques used for monitoring surveys. Native fish captured on the day prior to treatment were salvaged and placed upstream or used for toxicity testing near the detoxification station. During the rotenone application, two people repeatedly walked the 1-mile reach using dip nets to collect all fish except red shiner and western mosquitofish. Another person stayed at the detoxification station, just above the Mesquite Bridge, and dip-netted fish at that point. Native fish were salvaged when possible, and nonnative fish were removed to avoid double counts.

Flow data were obtained from the USGS gage at Littlefield. Temperature information was obtained from a thermograph placed in the long-term monitoring Riverside Reach (see Chapter 1).

Results

Tables 3-1 and 3-2 summarize all the fish captured during blue tilapia monitoring in 2001-2002. The fish communities in all areas were dominated by nonnative fishes (particularly red shiner and western mosquitofish). Figure 3-1 provides catch rates for blue tilapia. Catch rates from the NDOW Burn Site and Riverside Bridge Site in 2001 were combined into the Above Riverside Reach.

Table 3-1. Number of seine hauls and fish collected during 2001 blue tilapia monitoring efforts.

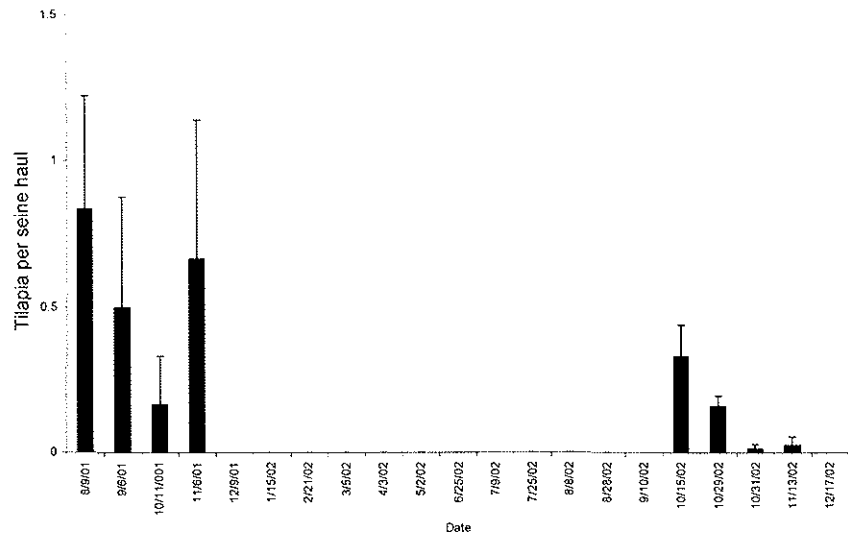
REACH	DATE	SEINE HAULS	WF ^a	RS ^b	FM ^c	DS ^d	YS ^e	VRC ^f	SD ^g	BG ^h	CC ⁱ	CP ^j	GS ^k	LB ^l	MF ^m	TL ⁿ
Below Bunkerville	8/9/01	12	0	6,710	40	4	0	0	1	0	1	3	0	1	383	10
Burn Site	8/9/01	10	0	1,230	0	0	0	0	0	0	0	0	0	0	210	17
Above Riverside	8/9/01	15	0	4,541	9	2	0	0	1	2	0	8	0	2	63	18
Halfway Wash	8/9/01	15	0	146	0	0	0	0	0	0	0	5	0	0	19	1
Below Bunkerville	9/6/01	8	0	7,025	0	0	0	0	0	0	0	0	0	1	291	4
Burn Site	9/6/01	12	0	2,370	0	0	0	0	0	0	0	0	1	1	320	15
Above Riverside	9/6/01	12	0	1,816	0	0	0	0	0	0	0	1	0	0	73	7
Halfway Wash	9/6/01	12	0	755	0	0	0	0	0	0	0	0	0	0	181	3
Below Bunkerville	10/10/01	12	0	5,255	0	0	0	1	0	0	1	1	0	0	672	2
Burn Site	10/10/01	13	0	2,223	0	0	0	0	0	0	0	0	0	0	213	5
Above Riverside	10/10/01	12	0	2,670	1	0	0	0	0	0	0	0	0	0	392	3
Halfway Wash	10/10/01	12	0	742	0	0	0	0	0	0	0	2	0	0	148	0
Below Bunkerville	11/6/01	9	0	2,601	0	0	0	0	0	0	1	3	0	5	2,930	6
Burn Site	11/6/01	13	0	2,185	0	0	0	0	0	0	0	0	0	0	351	0
Below Bunkerville	12/9/01	11	0	7,743	0	0	0	0	0	0	0	0	0	0	440	0
Above Riverside	12/9/01	9	0	1,358	0	0	0	0	0	1	1	5	0	0	1	0

^a WF = woundfin, ^b RS = red shiner, ^c FM = flannelmouth sucker, ^d DS = desert sucker, ^e YS = young of year suckers, ^f VRC = Virgin River chub, ^g SD = speckled dace, ^h BG = bluegill sunfish, ⁱ CC = channel catfish, ^j CP = common carp, ^k GS = green sunfish, ^l LB = largemouth bass, ^m MF = western mosquitofish, ⁿ TL = blue tilapia.

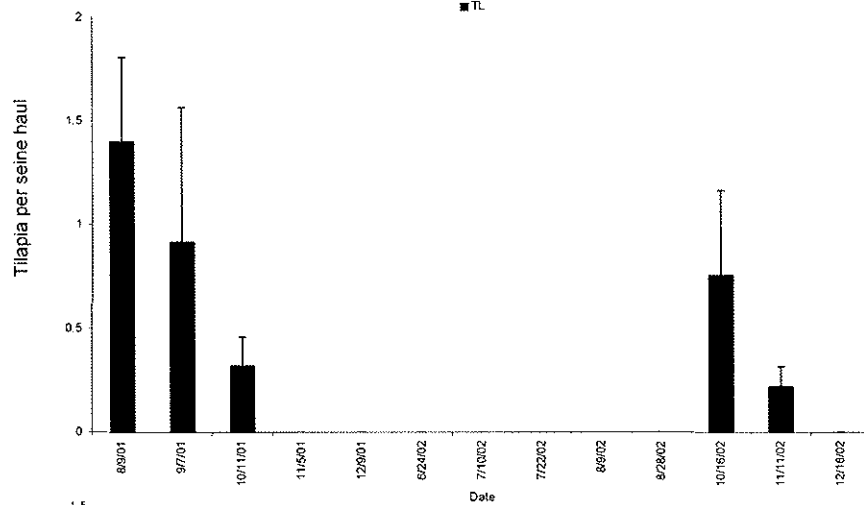
Table 3-2. Number of seine hauls and fish collected during the 2002 blue tilapia monitoring efforts.

REACH	DATE	SEINE HAULS	WF ^a	RS ^b	FM ^c	DS ^d	YS ^e	VRC ^f	SD ^g	BB ^h	CC ⁱ	CP ^j	GS ^k	LB ^l	MF ^m	TL ⁿ
Above Mesquite	1/16- 17/02	84	0	8,407	9	1	0	3	0	0	0	0	0	0	51	0
Below Bunkerville	1/15/02	24	0	2,334	0	0	0	0	0	0	0	9	0	0	38	0
Below Bunkerville	2/21/02	28	0	3,506	0	0	0	0	0	0	0	0	0	0	24	0
Below Bunkerville	3/5/02	26	0	621	0	0	0	0	0	0	0	0	0	0	56	0
Below Bunkerville	4/3/02	21	0	3,365	0	0	0	0	0	0	0	0	0	0	65	0
Below Bunkerville	5/2/02	14	0	3,503	4	0	0	0	0	0	0	0	0	0	67	0
Below Bunkerville	6/25/02	52	0	14,778	39	0	0	0	1	0	0	11	0	205	126	0
Above Riverside	6/24/02	48	0	1,207	5	0	0	0	0	0	0	29	0	9	179	0
Halfway Wash	6/24/02	33	0	2,916	0	0	0	0	0	0	0	5	0	0	412	0
Below Bunkerville	7/9/02	23	0	5,464	27	0	0	0	0	0	0	1	0	17	431	0
Above Riverside	7/10/02	37	0	10,598	41	0	0	0	0	0	1	76	0	5	601	0
Halfway Wash	7/10/02	21	0	626	0	0	0	0	0	0	0	0	0	0	186	0
Below Bunkerville	7/22/02	37	0	6,969	3	0	0	0	0	0	0	0	1	17	1,268	0
Above Riverside	7/22/02	38	0	7,664	2	0	0	0	0	0	0	43	0	19	1,241	0
Halfway Wash	7/22/02	DRY	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Below Bunkerville	8/8/02	22	0	4,319	0	0	0	0	0	0	0	1	0	26	2,230	0
Above Riverside	8/9/02	32	0	13,083	0	0	0	0	0	0	0	9	0	0	2,325	0
Halfway Wash	8/9/02	DRY	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Below Bunkerville	8/28/02	22	0	5,122	0	0	0	0	0	0	0	0	0	6	5,506	0
Above Riverside	8/28/02	25	0	9,419	0	0	0	0	0	0	0	7	0	9	3,147	0
Halfway Wash	8/28/02	DRY	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Below Bunkerville	9/10/02	27	0	535	12	0	0	0	1	2	0	0	0	0	254	0
Below Bunkerville	10/15/ 02	57	0	10,052	35	0	0	0	1	0	3	6	0	1	6,552	19
Above Riverside	10/16/ 02	41	0	1,081	0	0	0	0	0	0	0	0	0	0	884	31
Halfway Wash	10/11/ 02	50	0	859	0	0	0	0	0	0	0	0	1	0	415	2
Below Bunkerville	11/13/ 02	37	0	190	0	0	0	0	0	1	0	0	0	0	249	2
Above Riverside	11/11/ 02	32	0	635	0	0	0	0	0	0	0	0	0	0	657	7
Below Bunkerville	12/17/ 02	27	0	343	3	0	0	0	0	0	0	1	0	0	322	0
Above Riverside	12/18/ 02	20	0	165	0	0	0	0	0	0	0	0	0	0	158	0

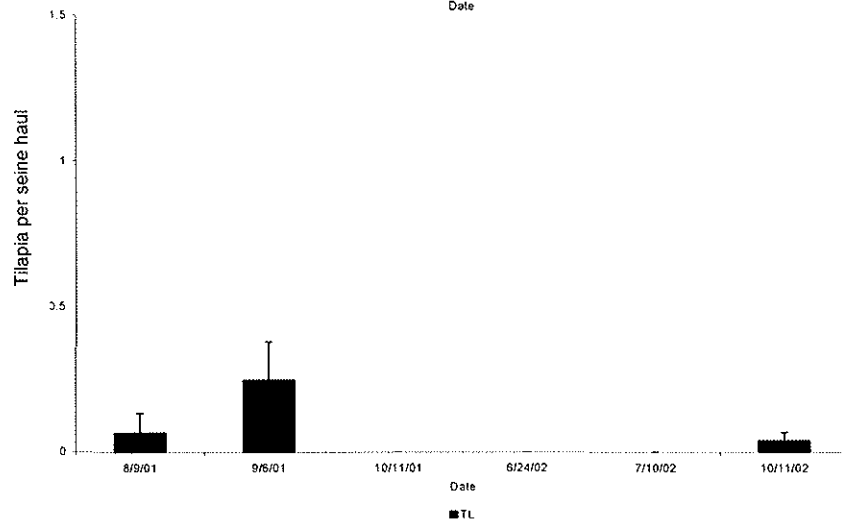
^a WF = woundfin, ^b RS = red shiner, ^c FM = flannelmouth sucker, ^d DS = desert sucker, ^e YS = young of year suckers, ^f VRC = Virgin River chub, ^g SD = speckled dace, ^h BB = black bullhead, ⁱ CC = channel catfish, ^j CP = common carp, ^k GS = green sunfish, ^l LB = largemouth bass, ^m MF = western mosquitofish, ⁿ TL = blue tilapia.



(a)



(b)



(c)

Figure 3-1. Blue tilapia catch rates in 2001 and 2002 at the (a) Below Bunkerville Diversion, (b) Above Riverside, and (c) and Halfway Wash Reaches.

Collections in August 2001, approximately 2 weeks after the discovery of blue tilapia, produced the highest catch rates of blue tilapia at the below Bunkerville Diversion and Above Riverside Reaches. Blue tilapia catch rates at the Above Riverside Reach declined after this until they reached zero in November 2001. The blue tilapia catch rate at the below Bunkerville Diversion Reach declined from August through October and then rose sharply in November, before falling to zero in December 2001. During November 2001 when blue tilapia numbers increased in the Below Bunkerville Diversion Reach, a single blue tilapia was captured near RM 59.5 in the Experimental Reach above the Bunkerville Diversion (see Table 2-2 in Chapter 2). Blue tilapia catch rate peaked at the Halfway Wash Reach in September 2001 but then fell to zero.

From December 2001 through August 2002 no blue tilapia were found in any sampled reaches, including the Experimental Reach and long-term monitoring reaches. However, in mid September 2002, NDOW and AZGFD personnel found five blue tilapia at Halfway Wash during their biannual Virgin River Recovery Team sampling (J. Heinrich, NDOW, personal communication). Concurrently, BIO-WEST found two blue tilapia while sampling the long-term monitoring Riverside Reach (see Table 1-1, Chapter 1). Blue tilapia were found at the Below Bunkerville Diversion, Above Riverside, and Halfway Wash Reaches in October 2002.

In late October 2002 the LVRRIT organized a pilot rotenone treatment of the Below Bunkerville Diversion Reach. Table 3-3 provides the total numbers of fish captured before, during, and after the treatment. Numbers of red shiner and western mosquitofish during the treatment are estimates. All other numbers are based on direct counts and are probably underestimates of the number of fish removed. The trial treatment did reduce numbers of fish in the "Treatment Reach." Catch rates of all species were significantly reduced during the post-treatment sampling ($p < 0.001$). However, blue tilapia, red shiner, and western mosquitofish were all present in the reach the day following treatment.

Table 3-3. Fish captured before, during, and after the rotenone treatment from the Bunkerville Diversion to just above the Mesquite Bridge Reach.

TIME	DATE	SEINE HAULS	RS ^a	MF ^b	TL ^c	WF ^d	FM ^e	SD ^f	CC ^g	CP ^h	GS ⁱ	BB ^j	LB ^k
PRE	10/29/ 2002	120	15439	6311	19	1	51	2	3	10	0	5	2
DURING	10/30/ 2002	--	~100,000	~50,000	140	0	~43	0	106	145	3	111	3
POST	10/31/ 2002	72	246	131	1	0	1	0	0	0	0	0	0

^a RS = red shiner, ^b MF = western mosquitofish, ^c TL = blue tilapia, ^d WF = woundfin, ^e FM = flannelmouth sucker, ^f SD = speckled dace, ^g CC = channel catfish, ^h CP = carp, ⁱ GS = green sunfish, ^j BB = black bullhead, ^k LB = largemouth bass.

Nineteen blue tilapia were captured in intensive seining the day before the treatment. During the treatment 140 blue tilapia were dip-netted from the Treatment Reach. If all blue tilapia stressed or killed by the rotenone were accounted for, seining efficiency for blue tilapia was 13.6%. However, the number of blue tilapia counted during the treatment is probably an underestimate. Fish that died quickly and sank to the bottom were probably missed, and other fish were probably missed because of turbidity and vegetation. Therefore, seining efficiency for YOY blue tilapia is probably lower than 13%.

Monitoring continued after the treatment, and blue tilapia were found through November 2002. No blue tilapia were found in the below Bunkerville Diversion and Above Riverside Reaches during BIO-WEST collection efforts in mid December 2002. However, NDOW personnel found one blue tilapia in the Below Bunkerville Diversion Reach and one blue tilapia in the Above Riverside Reach in early December 2002 (J. Heinrich, NDOW, personal communication).

All blue tilapia captured by sampling efforts during both years appeared to be YOY (Figure 3-2). The average size of blue tilapia captured in August and September 2001 (80 and 73 mm) was similar to the average size of fish captured in September and October 2002 (72 and 79 mm). However, the average size of blue tilapia in November and December 2002 (96 and 97 mm) was substantially smaller than the size of blue tilapia captured in October and November 2001 (112 and 146 mm).

River temperature and flow conditions could have impacted colonization times and growth rates of blue tilapia. Figures 3-3 and 3-4 show the discharge and temperature data for calendar years 2001 and 2002. The figures also indicate when blue tilapia first appeared in and subsequently disappeared from collections in the lower Virgin River. Little difference was seen between the 2 years in terms of discharge, except that July and August 2001 had slightly higher discharge than July and August 2002. However, Figure 3-3 is somewhat misleading in that regard. Flows below the Bunkerville and Riverside Diversions are substantially lower than the flows recorded at the Littlefield USGS gage (see discussion in Chapters 1 and 2). Flows were generally under 10 cfs below Bunkerville Diversion throughout most of July and August of both years.

The river channel was completely dry for a short distance below the Riverside Diversion and for extended distances around and below the Halfway Wash area during most of summer 2002, as shown in Figure 3-5 (M. Golden, BIO-WEST, personal observation). We noted that the river was dry around RM 40.5-40.75 during our Halfway Wash Reach collection in June 2002, and the entire Halfway Wash Reach was dry in July and August 2002. A flow spike in early September 2002 provided the first connection of the Virgin River to Lake Mead since sometime before June 2002.

Flows in the lower Virgin River were slightly higher when blue tilapia appeared in 2002 than they were when blue tilapia first appeared in 2001. Additionally, temperatures were substantially lower when blue tilapia were found in the lower Virgin River in 2002. As shown in Figure 3-6, average monthly temperatures were significantly lower from July through December 2002 than July through December 2001. Additionally, temperatures in late September 2002 averaged between 20 and 23°C at the Riverside thermograph. In late July 2001 temperatures averaged between 25 and 29°C. In

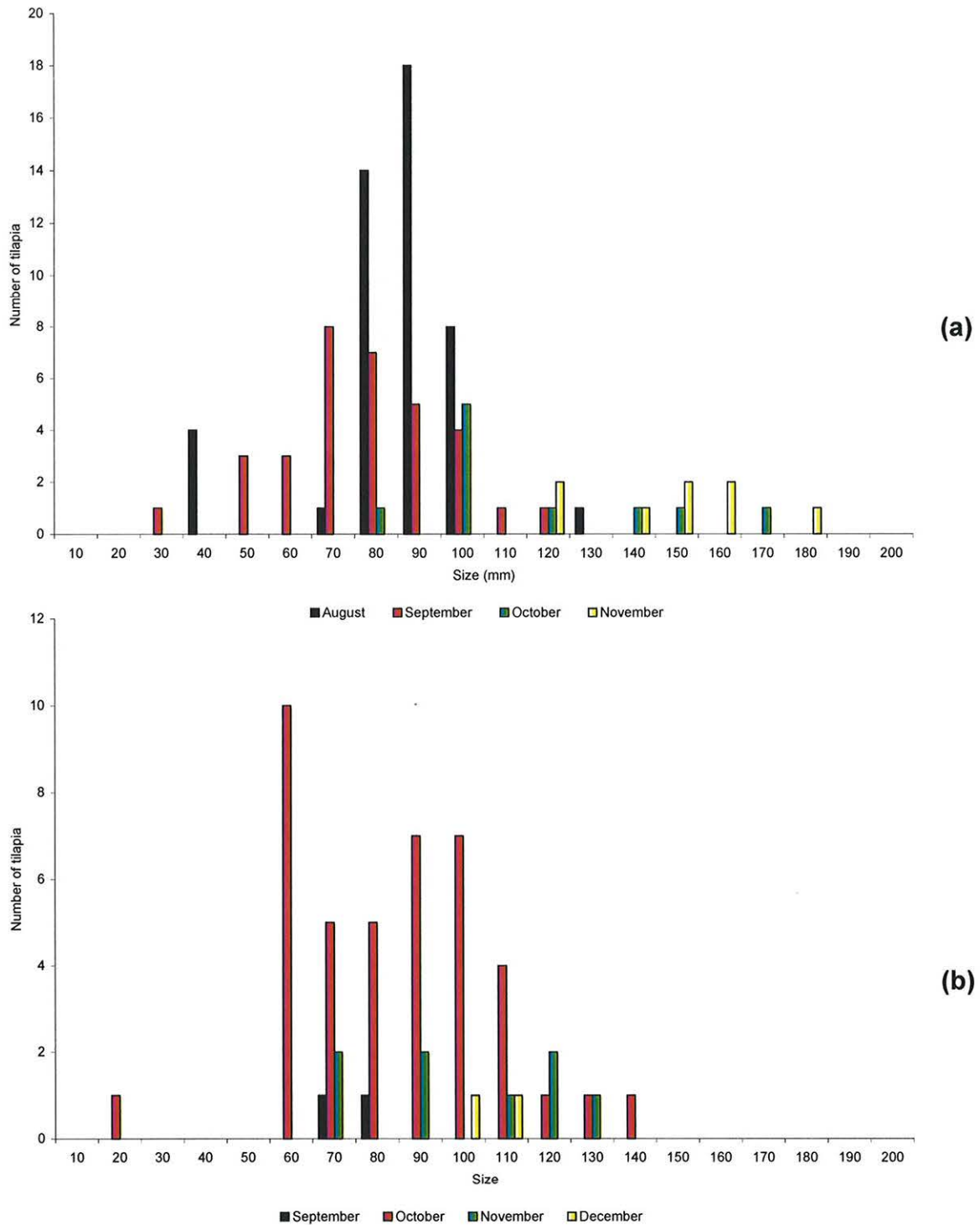


Figure 3-2. Length-frequency distribution of blue tilapia captured by month in (a) 2001 and (b) 2002.

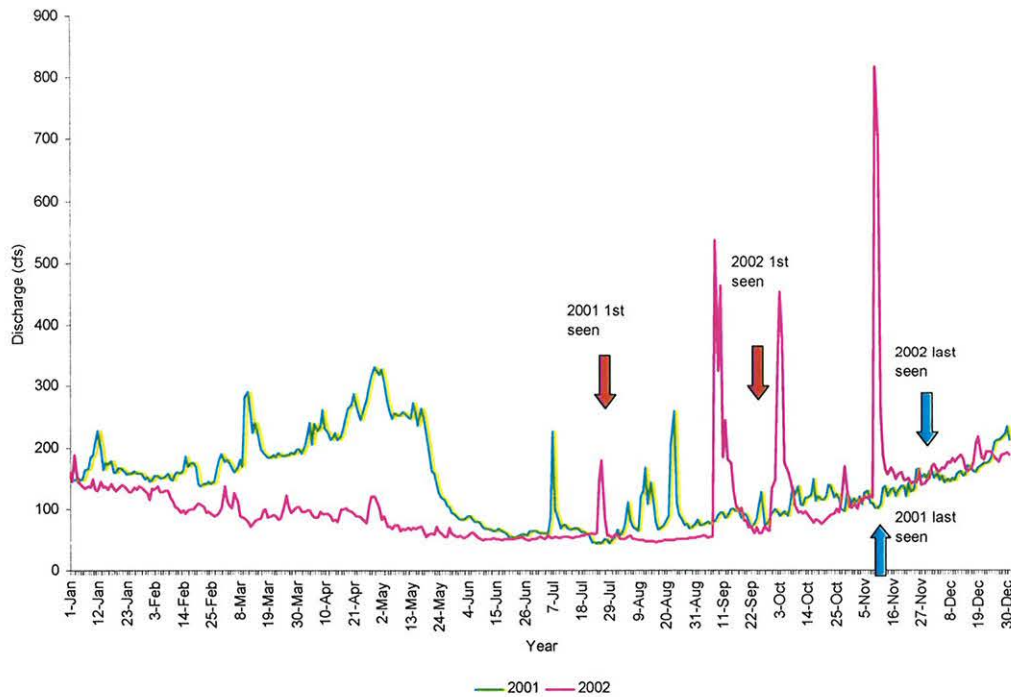


Figure 3-3. Discharge at the Littlefield, Arizona, USGS gage and the timing of blue tilapia invasion and disappearance in 2001 and 2002.

early December 2001 average temperatures ranged from 12 to 14°C, while in early December 2002 average temperatures ranged from 11 to 13°C.

Discussion

Our monitoring showed that in 2002 blue tilapia colonized the Virgin River much later in the year, and in lower numbers, than they had in 2001. Conversely, blue tilapia disappeared from our collections at roughly the same time during both years. Only YOY blue tilapia were captured during all monitoring efforts, including the pilot rotenone treatment. Blue tilapia are known to be present in the Virgin Bowl area of Lake Mead. At this time it appears probable that YOY blue tilapia are migrating up the Virgin River. If adult blue tilapia had overwintered in or around the Virgin River above Halfway Wash, we would have expected to see YOY blue tilapia appear sometime in July or early August, since flow and temperatures in the river were relatively similar between years during these months. Instead, we only saw an invasion of YOY blue tilapia after the Virgin River was reconnected to Lake Mead by a spate event in early September 2002. We saw no evidence of blue tilapia in the river from June 2002 through early September 2002, when the river was not reaching the lake. We found no evidence of adult blue tilapia in the system during our monitoring efforts or the pilot rotenone treatment.

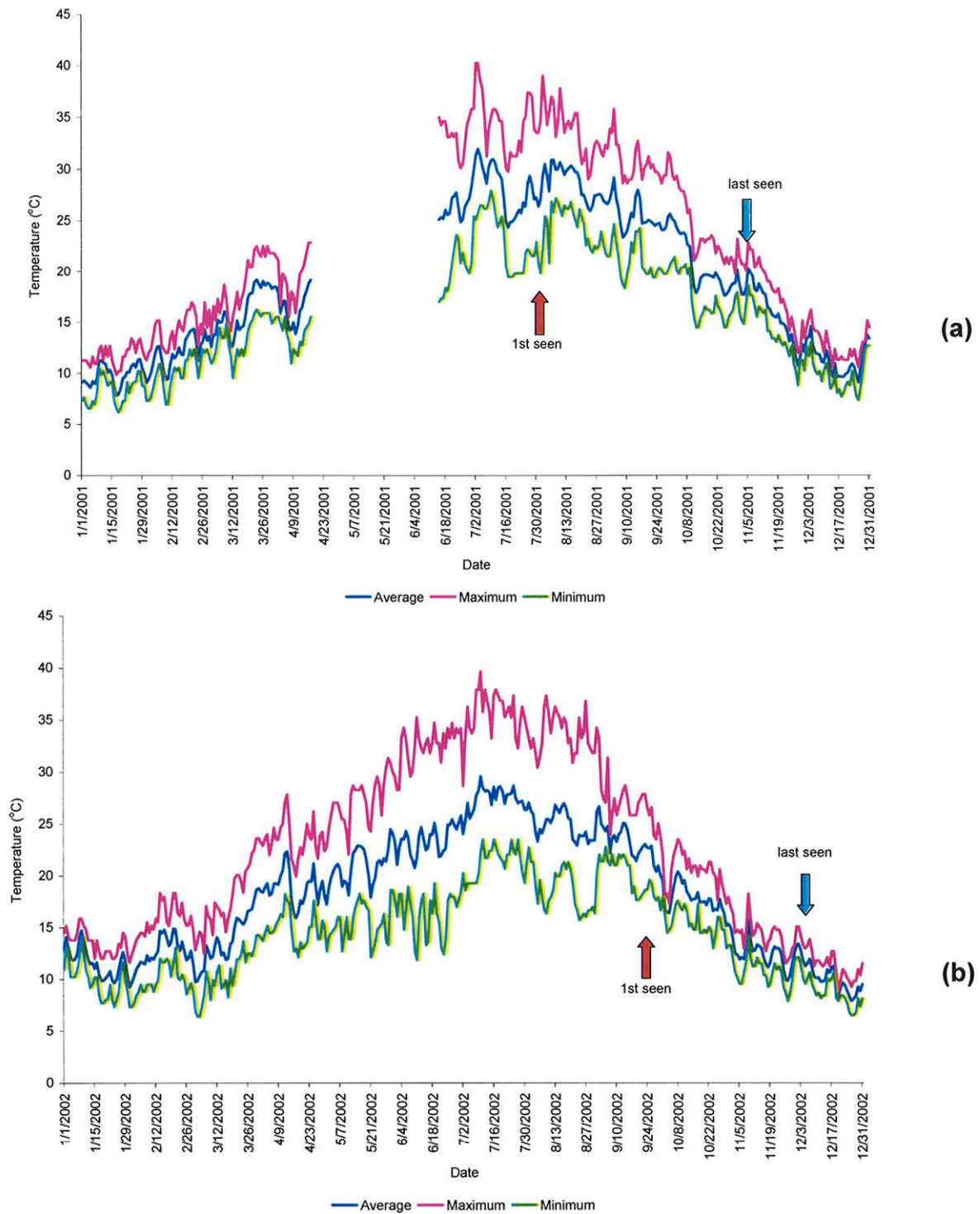


Figure 3-4. Average, maximum, and minimum temperatures during, and the timing of, blue tilapia invasion and disappearance in (a) 2001 and (b) 2002.



(a)
(b)



Figure 3-5. Photos taken (a) below the Riverside Diversion and (b) at the Halfway Wash Virgin River Recovery Team Monitoring station in August 2002.

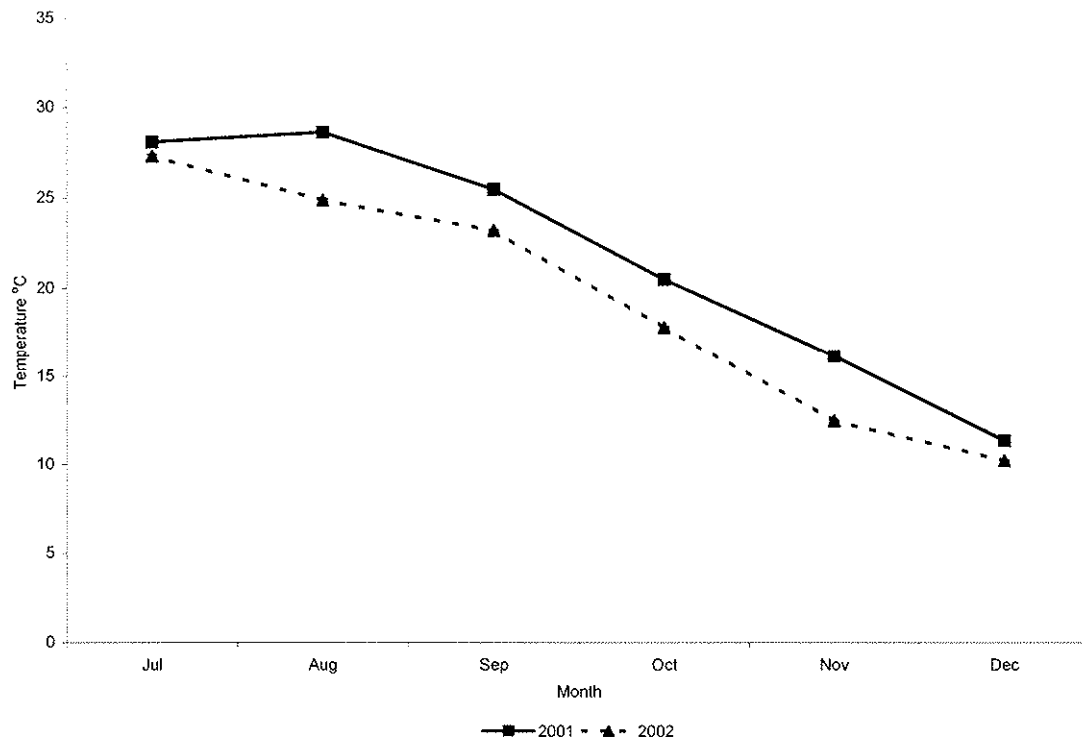


Figure 3-6. Average monthly temperatures from July to December 2001 and 2002.

Blue tilapia disappeared in early December in both years. Two explanations exist for this. One explanation is that blue tilapia had reached a size necessitating a habitat switch, or they had begun to actively avoid our seines, causing our sampling efficiency to be reduced to the point where we could not detect their presence. An alternative explanation is that the increased flows, elevated turbidity, decreased temperatures, or a combination of these factors that accompany the winter season caused mortality or downstream emigration of YOY blue tilapia. Additionally, the fact that we did not see any YOY blue tilapia in the system until the river and lake were reconnected in 2002 suggests that no adults were present in the system. Therefore, we feel that some combination of environmental variables that accompany winter probably lead to the mortality of YOY blue tilapia, or cause them to emigrate from the river back into the lake.

The major factor thought to limit the latitudinal distribution of blue tilapia is their intolerance to lower temperatures (Shaffland and Pestrak 1982). However, blue tilapia seem to be the most cold tolerant of the mouth brooding blue tilapia (Zale and Gregory 1989). Considerable variability exists in the data describing the lethal temperatures for blue tilapia. The lowest temperatures in which blue tilapia can survive for long periods appears to be around 12°C (Zale 1984, Kindle and Whitmore 1986, Zale and Gregory 1989, Starling et al. 1995). Temperatures of 5-7°C appear to cause quick stress and death (Zale and Gregory 1989, Stauffer et al. 1988). Temperatures in the lower Virgin River rapidly declined over the latter part of November 2001 and 2002. By early December of both years average daily water temperatures were between 11-14°C, and daily

minimums reached as low as 8°C. The sub-optimal temperature regime in the river by early December of both years could have caused mortality or emigration of blue tilapia, effectively eliminating the possibility of collecting them.

Zale (1987) found that blue tilapia immigrated into a stenothermal run from a Florida lake during early winter when the temperature in the run exceeded that of the lake. He also found that blue tilapia emigrated back to the lake when lake temperatures became higher than those in the run in spring. Other researchers have noted the tendency of blue tilapia to congregate to thermal refugia when surrounding water temperatures are low (Buntz and Manooch 1969, Noble et al. 1976, Shafland and Pestrak 1982). Blue tilapia may have migrated up the Virgin River in the summers of the past two low-flow years, because water temperatures were warmer in the river than in Lake Mead. Thirty degrees Celsius is the optimal temperature for blue tilapia (Beamish 1970). Temperatures in the Virgin River during July 2001 and 2002 averaged close to 28°C, with maximum temperatures in the mid 30s. Zale (1987) found blue tilapia utilizing lake and spring run habitat at different times of year, based solely on the temperatures of the habitats at the time. We may be seeing a similar phenomenon in the Virgin River. However, temperature data collected in late July 2001, during bimonthly water quality monitoring by the USBR, showed temperatures in the Virgin Bowl area of Lake Mead were similar to our average river temperatures (Chris Holdren, USBR, personal communication).

Evidence collected in other systems suggests that water clarity may also be a factor in blue tilapia migrations. In their native range spawning blue tilapia seek clear water to reproduce (Lowe-McConnel 1959). Blue tilapia in other life stages may also have a preference for clear water. The Virgin River is usually very turbid, even through the summer. However, in 2000 through 2002, the river underwent long periods of extreme clarity. Neither temperature nor clarity explains why we have only found YOY blue tilapia in the river. With all our sampling and the rotenone treatment efforts failing to turn up any adult blue tilapia, we suspect that only YOY are using the system. The habitat in the Virgin River may not be suitable for larger blue tilapia.

Blue tilapia is another in a long list of nonnative fish species that have invaded the Virgin River. More than a dozen nonnative species have already been documented in the Virgin River (Cross 1975, Golden and Holden 2002b). Many of these species are thought to have a negative impact on the native fish community (Cross 1975, USFWS 1995, Deacon and Williams 2002, Golden and Holden 2002b). Control and removal of nonnative fishes that adversely impact native fishes are thought to be imperative to the recovery of federally listed fishes, particularly the woundfin, in the Virgin River (USFWS 1995). Scopetone et al. (1998) noted the drastic decline in native fish numbers in the Muddy River following introduction of blue tilapia. Virgin River chub counts in the Warm Springs area of the Muddy River declined from over 8,000 fish in 1994 to 2 in 1997. Blue tilapia are thought to be primarily herbivorous, but Scopetone (1993) noted blue tilapia depredation on native fish in the Muddy River. He also saw that blue tilapia are omnivorous feeders and probably caused substantial declines in the aquatic vegetation and associated macroinvertebrates in parts of the Muddy River.

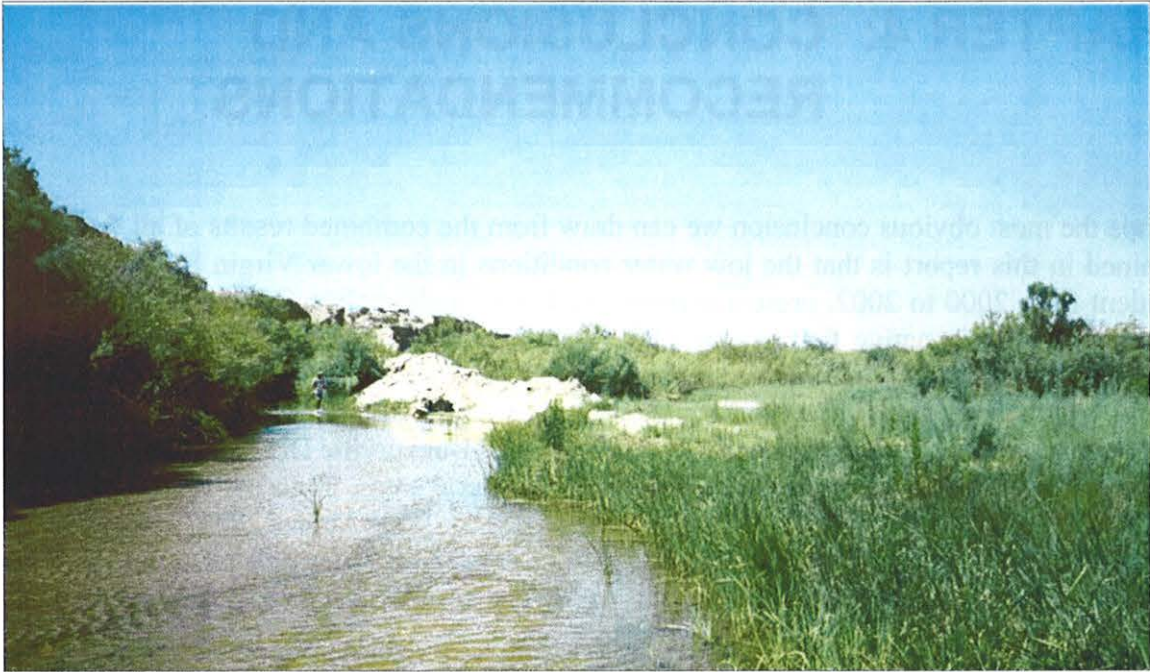
While blue tilapia may be unable to inhabit the Virgin River year round at this point, they can survive the summer and fall in the river. As noted in the previous chapters, the summer already appears to be a critical period for many of the native fish in the lower Virgin River. An additional nonnative species with the potential to cause substantial negative impacts on native fishes would only further deteriorate an already depleted fishery. Additionally, if blue tilapia managed to breach the Mesquite Diversion and find a thermal refuge in the warm springs near Littlefield, they may survive and proliferate year round in the Virgin River. Blue tilapia would then have the potential to seriously impact the sensitive native fish communities around Beaver Dam Wash and upstream into Utah.

CHAPTER 4: CONCLUSIONS AND RECOMMENDATIONS

Perhaps the most obvious conclusion we can draw from the combined results of all three studies examined in this report is that the low water conditions in the lower Virgin River, which were prevalent from 2000 to 2002, present serious problems for the native fish community. We saw dramatic declines in native fish numbers below the Mesquite Diversion during the 2000-2002 period. We also saw evidence of failed recruitment for all native species present in the lower Virgin River in 2001 and 2002. Throughout the lower Virgin River, discharge levels were below those shown to impair native fish recruitment. Flows below the Bunkerville Diversion were low enough to completely eliminate the native fish community in several areas. Figure 4-1 shows what flows looked like above and below the Riverside Diversion (RM 51.25) in August 2002. Very little habitat for fish was available with flows at this level. However, red shiner, western mosquitofish, channel catfish, largemouth bass, and green sunfish (*Lepomis cyanellus*) seemed to congregate in areas where water remained.

Water temperatures at all of the thermographs we placed in the lower river met and exceeded critical thermal maxima for most species of native fish. The warm temperatures probably resulted in acute and chronic mortality of some fish. The low flows and high temperatures resulted in fish being crowded together in the few remaining habitats that offered some refuge from high temperatures and extremely shallow, featureless habitat. The low flows also resulted in extremely clear water during the 2000-2002 time period. The clear water probably also encouraged fish to congregate in deeper areas with some cover. Unfortunately, the areas left for fish to seek shelter in were the prime habitats for predatory centrachids (largemouth bass, green sunfish) and ictalurids (channel catfish, black bullhead [*Ameiurus natalis*]). Nonnative red shiner, which are implicated in the decline of native fishes in the Virgin River, also flocked to these refuge areas. The clear, warm-water conditions created by low flows in 2001-2002 may also be the major reason blue tilapia migrated up the Virgin River. Therefore, in addition to the direct impacts of the high temperatures and low flows, those conditions also subjected the fish to increased interaction with predatory and competitive nonnative fishes.

Native fishes in the upper Virgin River have not fared much better during the drought period of 2000-2002 (Virgin River Recovery Team data for fall 2002 and spring 2003). Various researcher meetings and a Scope of Work on limiting factors submitted to the VRRMRP have identified low flows, and the resulting high temperatures and low turbidity, as the primary factors limiting native fish populations in the Pah Tempe Springs to Washington Fields Diversion section of the river. The results of our long-term monitoring and woundfin stocking studies support these assertions. Golden and Holden (2002b) determined that nonnative fishes other than red shiner probably have a detrimental impact on native fishes in the Virgin River, particularly during low-flow years. If blue tilapia become established they have the potential to inflict more damage to the native fish



(a)



(b)

Figure 4-1. Photos taken (a) above and (b) below the Riverside Diversion.

community than the centrachids and ictalurids that have already established themselves. In light of the present situation throughout the Virgin River, BIO-WEST recommends the following actions.

(1) Continue to monitor the Beaver Dam Wash, Mesquite Bridge, and Riverside Reaches.

In this report we show how continued monitoring of the same sites over a number of years can provide valuable insights on trends in the native fish community. Holden and Abate (1999) and Holden and Golden (2000) discussed the benefits of monitoring these longer stretches of river versus fairly small sections that are sampled for the Virgin River Recovery Team monitoring. Continued monitoring will provide updated information on the native fish populations in the lower Virgin River, as well as insight into what causes fluctuations in the populations. Additionally, continued monitoring can alert the LVRRIT to the presence of new threats, such as blue tilapia.

(2) Initiate more woundfin stocking studies in the lower Virgin River.

The three woundfin stocking experiments, along with the associated red shiner removal and monitoring efforts, provided considerable insight about many of the hurdles that need to be surmounted before woundfin reintroduction can be successful. It appeared that environmental conditions in the study reaches during summers 2000 and 2001 may have been responsible for the inability of stocked woundfin to persist. Continuing such studies, so that they encompass multiple flows years with different characteristics, should clarify which factors limit the success of reintroductions. Recent monitoring efforts in Utah sections of the Virgin River have shown that woundfin numbers are critically low throughout the Virgin River, highlighting the need for information on what factors are responsible for the demise of woundfin and the development of viable stocking protocols.

(3) Investigate options for increasing flows within critical habitat for woundfin and Virgin River chub in the Lower Virgin River.

The abiotic factors limiting woundfin in the Virgin River all revolve around flow. The combined influence of human water use and drought has left too little water in the Virgin River to maintain habitat, provide turbidity, and keep temperatures within a range tolerable to many native fishes. The LVRRIT should designate a subcommittee to investigate water rights on the Virgin River. The entire river was diverted at the Bunkerville and Riverside Diversions in 2002, but the water rights of users in this area are still unclear. Additionally, the feasibility of acquiring water rights for the fishes should be investigated. With further development in the Mesquite area a foregone conclusion, acquiring water for fish could be used to mitigate for development projects off the river.

(4) Ensure that the Bunkerville Diversion is a barrier to fish moving upstream.

Blue tilapia is not the first species from Lake Mead to invade the Virgin River, and it will probably not be the last. Having a barrier to the movement of these nonnative fishes well below the Beaver Dam Wash area, which is the last haven for native suckers, dace, and Virgin River chub in the lower river, is extremely important. Additionally, the Virgin River Fishes Recovery Plan calls for step-wise removal of nonnative fishes in a downstream manner from the Washington Fields Diversion (USFWS 1995). Treatment projects in the Utah portions of the Virgin River have shown that fish barriers are necessary for effective renovation of river reaches.

(5) Determine the feasibility of placing a fish barrier downstream from the Bunkerville Diversion.

The Utah Division of Wildlife Resources has found that they can not declare a river reach free of a target nonnative species until the reach below it is free of that species. If we want to create effective buffer zone protecting the Beaver Dam Wash area from blue tilapia and other nonnative fishes, a barrier must be placed further down the system than the Bunkerville Diversion.

(6) Continue planning for a treatment between the Mesquite and Bunkerville Diversions.

Once the Bunkerville Diversion is confirmed as a barrier to upstream fish movement, plans to treat the river between the Mesquite and Bunkerville Diversions should proceed. Ensuring that blue tilapia have not found an area above the Bunkerville Diversion where they can persist is critical in preventing continued upstream migration. The area below the Mesquite Diversion has also been dominated by nonnative fishes since late 2000, so this is an opportune time to treat this area and lose few native fishes. The treatment will also provide an excellent opportunity to continue the woundfin stocking studies with radically lower numbers of nonnative fishes. Red shiner recolonization patterns could also be studied.

(7) Continue monitoring the Virgin River and associated off-channel areas for the presence of blue tilapia.

While all indications are that blue tilapia are making a yearly migration up the Virgin River, this has not been confirmed. We recommend continued monitoring in the river during summers 2003 and 2004, with special emphasis placed on the areas below Halfway Wash. We need to document blue tilapia migrating up the river from Lake Mead to rule out other sources of blue tilapia in the lower Virgin River. Off-channel areas below the Mesquite Diversion that are connected to the river should also be investigated. Ponds and wetlands connected to the river may provide habitat hospitable enough in which for blue tilapia to over winter. These areas must be investigated, and plans to isolate habitats with direct connection to the river need to be initiated.

(8) Revive and finish the Lower Virgin River Recovery Plan.

A Recovery Plan for the lower Virgin River would provide a platform from which to continue ongoing projects and initiate new projects. Additionally, completing a plan may open the door to new funding sources to help with recovery actions.

In summary, data collected by BIO-WEST for various projects in the lower Virgin River have shown that the small populations of native fishes are in ever-growing danger of extirpation. We feel that the recommendations in this report would assist in reviving and recovering the native fish community in the lower Virgin River.

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