

Nonnative Fish Impacts and Control Options between Washington Fields Diversion and Pah Tempe Springs on the Virgin River

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Left: A portion of Berry Springs Pond, one of the off-channel sources of nonnative fish in the Study Area.

Below: Black bullhead removed from an off-channel beaver pond.



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EXECUTIVE SUMMARY

Nonnative fish species have negatively impacted many native fish species in the west through competition and predation. In the Virgin River, the proliferation of the exotic red shiner (*Cyprinella lutrensis*) is highly correlated with the decline of several native species, including the federally endangered woundfin (*Plagopterus argentissimus*). However, at least 13 other nonnative species have been documented in the Virgin River, including some highly piscivorous centrarchid and ictalurid species. Chemical treatments are in progress to control red shiner and other nonnative species below the Washington Fields Diversion. However, until now, little attention has been focused on reducing numbers of nonnative fishes present above the Washington Fields Diversion, where large numbers of native fishes reside. The Virgin River Fishes Recovery Plan (VRFRP) (USFWS 1995), the Virgin River Spinedace Conservation Agreement and Strategy (Lentsch et al. 1995), and the Virgin River Resource Management and Recovery Program (Program) Document (Utah Department of Natural Resources 1998) indicate that the reduction or elimination of all nonnative species may be necessary for the recovery of native species in the Virgin River. We designed a study to investigate the extent to which nonnative fishes, other than red shiner and western mosquitofish (*Gambusia affinis*), are a problem in the Virgin River between Washington Fields Diversion and Pah Tempe Springs (Study Area). Additionally, we evaluated potential controls for these nonnative species and provided recommendations for controlling these species in the Study Area.

We gathered historical data on nonnative fish captured in the Study Area and, in August 2001, we used seines and trammel nets to sample the river from the State Route 9 bridge below Pah Tempe Springs to the Johnson Diversion. During the August 2001 “baseline” sampling, we collected black bullhead (*Ameiurus melas*), green sunfish (*Lepomis cyanellus*), and largemouth bass (*Micropterus salmoides*) above the Washington Fields Diversion. We found high numbers of black bullhead and largemouth bass in the 2 miles surrounding Gould’s Wash. Moderate numbers of these species were found upstream from the Hurricane Bridge to about 1 mile below Gould’s Wash. Several potential off-channel sources of nonnative fishes were identified, and Berry Springs Pond was found to have high numbers of green sunfish and largemouth bass. We demonstrated that both black bullhead and largemouth bass fed on native fishes, including the endangered woundfin.

After deciding that nonnative fishes posed a potential threat to native fishes above the Washington Fields Diversion, we evaluated the potential for chemical, mechanical, biological, and physicochemical control of nonnative fishes in the Study Area. Poisoning at any level in the main stem of the Virgin River above Washington Fields would probably cause massive to complete mortality of the native fish populations. Since this area has the largest remaining populations of most of the native fish species, including the endangered woundfin, poisoning is not a viable option. However, chemical treatment may be a viable option for controlling nonnative fish populations in off-channel areas where the chemical can be contained. Introducing additional species or parasites to the system poses a threat to natives fishes, so we decided biological control

was an unattractive option. Since the Virgin River does not have any large reservoirs directly on the main stem, we felt physicochemical control was not an acceptable option. While mechanical removal is labor intensive and usually only results in a temporary reduction in the target species, we felt that experimenting with different methods of mechanical removal would be the best option at this time.

We attempted to lower numbers of nonnative fishes between Washington Fields Diversion and Johnson Diversion using seines and floating trammel nets in September 2001. We also used hoop nets and fyke nets to attempt to lower numbers of nonnative fishes in a network of off-channel beaver dam ponds. We evaluated our effectiveness against our prior sampling in August 2001 and numbers of nonnative fishes seen during a rotenone treatment of the reach by the Utah Division of Wildlife Resources (UDWR) for control of red shiner in October 2001. First pass catch-per-unit area was lower in September 2001 than in August 2001. We felt that this difference was probably caused by reduced sampling efficiency in September and not by our August sampling. Qualitative electrofishing of about 30 % of the Washington Fields Diversion to Johnson Diversion reach produced almost the same numbers of nonnative fishes as seining and trammel netting of the whole reach, which confirmed the inefficiency of mechanical removal with nets. The number of nonnative fishes we observed during the rotenone treatment was equivalent to almost seven times the density estimated by our mechanical removal efforts, indicating that our mechanical removal methods were ineffective at reducing numbers of nonnative fishes in the Virgin River. Numbers of nonnative fishes caught in the beaver dam complex did not show a depletion over 3 nights of sampling, and numbers seen during the rotenone treatment were five to ten times those seen in the September 2001 sampling.

We determined that our mechanical removal methods were ineffective at controlling numbers of black bullhead between Washington Fields and Johnson Diversion. Through the current study, we identified areas for future study from the data collected and current project limitations. Two directions for future work were identified. First, we could attempt to evaluate the extent of impact nonnative fishes are having on the native fish community in the Virgin River above Washington Fields Diversion. If the Program chooses to take this direction, we recommended conducting studies to examine seasonal use of the Virgin River by nonnative fishes and their seasonal food habits. Information provided from such studies would highlight the timing of the biggest impacts of nonnative fishes and the life stage of native fishes most vulnerable to predation. Second, we could assume that enough evidence was presented in the present study and other research to indicate that target nonnative species are impacting the native fish communities above Washington Fields Diversion. If the Program chooses this direction, we recommend that all off-channel sources of nonnative fishes be identified and either targeted for chemical reclamation or fitted with physical barriers to prevent introduction of these fishes into the Virgin River. Removing nonnative fishes from off-channel areas and preventing their reintroduction from recreational fisheries and private ponds in the area is probably the most effective way to control nonnative fishes in the Study Area.

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INTRODUCTION

Habitat degradation and impacts from introduced nonnative fish species are the two most prominent factors resulting in the extinction of fish in North America over the past century (Miller et al. 1989). The Colorado River system is a prime example of how severe habitat alteration, combined with a proliferation of nonnative species, can cause dramatic declines in, and even extirpate, native fish populations. Large dams and smaller irrigation diversions have combined with increased water demand to fuel development, caused by human population growth, to cause radical changes in the flow regime of the system. The alteration of flows and the associated habitat changes probably had a negative impact on native fish populations, which had adapted to function under the formerly unpredictable flow regime. Conversely, more than 40 species of nonnative fish, which may not have persisted in the unaltered river, now inhabit both the reservoirs and slower-flowing river sections of the system. Nonnative fishes have been shown to prey on and compete with native fishes (Meffe 1985, Osmundson 1987, Marsh and Minckley 1989, Hawkins and Nesler 1991, Lentsch et al. 1996, Tyus and Saunders 2000). As a result of these and other pressures, 22 of the Colorado River native fish species are federally listed as endangered, and two have been extirpated in the wild (Tyus and Saunders 2000).

The Virgin River is a Colorado River tributary that suffers from many of the same problems as the Colorado River itself. The main stem of the Virgin River is home to six native species. Three of these species are endemic to the Virgin River and/or Muddy River systems. Two of the three endemic species, the Virgin River chub (*Gila seminuda*) and the woundfin (*Plagopterus argentissimus*), are federally listed as endangered, and a conservation agreement is in place for the third, the Virgin spinedace (*Lepidomeda mollispinis mollispinis*) (Lentsch et al. 1995). Cross (1975) identified 13 nonnative species from the Virgin River and its tributaries. Cross considered only eight of these to be main stem species (Table 1). Data from the Virgin River Fishes Database (2001) indicates that yellow bullhead (*Ameiurus natalis*) have also been collected from the Virgin River main stem. Recent collections in Nevada have shown that blue tilapia (*Tilapia aurea*) is now found in the lower Virgin River main stem.

Several of the native fish species have undergone declines in both abundance and range in the last 25 years (Valdez et al. 1991, Addley and Hardy 1993, Holden et al. 2001). The endangered woundfin has perhaps seen the most dramatic declines (Holden et al. 2001). Negative interactions with the nonnative red shiner (*Cyprinella lutrensis*) are thought to be a major factor in the decline of native species, especially the woundfin (Cross 1975, Gregory and Deacon 1994, USFWS 1995, Holden and Abate 1999). Therefore, eradicating red shiner has been a priority for recovering woundfin since the mid-1980s (USFWS 1995, Lentsch et al. 1995). Advance of red shiner up the Virgin River from Lake Mead has been halted at the Washington Fields Diversion, largely because of rotenone applications by the Utah Division of Wildlife Resources (UDWR) and others involved with the Virgin River Fishes Recovery Program (USFWS 1995, Comella and Fridell 1998). However, both the Virgin River Fishes Recovery Plan (VRFRP) (USFWS 1995) and the Virgin

Table 1. Nonnative fishes identified as being in the main stem Virgin River.

COMMON NAME	SCIENTIFIC NAME
Black bullhead	<i>Ameiurus melas</i>
Bluegill sunfish	<i>Lepomis macrochirus</i>
Channel catfish	<i>Ictalurus punctatus</i>
Common carp	<i>Cyprinus carpio</i>
Green sunfish	<i>Lepomis cyanellus</i>
Largemouth bass	<i>Micropterus salmoides</i>
Red shiner	<i>Cyprinella lutrensis</i>
Western mosquitofish	<i>Gambusia affinis</i>

Source: Cross 1975.

River Spinedace Conservation Agreement and Strategy (Lentsch et al. 1995) list reduction or elimination of ALL nonnative fishes as a priority for maintenance and recovery of these rare and endangered species.

Black bullhead, largemouth bass, blue tilapia, green sunfish, western mosquitofish, common carp (*Cyprinus carpio*), and channel catfish (*Ictalurus punctatus*) have been identified as potential threats to native fish in other systems (Meffe 1985, Hawkins and Nesler 1991, Lentsch et al. 1996, Marsh and Douglas 1997, Brandenburg and Gido 1999, Tyus and Saunders 2000). The VRFRP priority of reducing and removing red shiner and other nonnative fishes from the Virgin River is being addressed below the Washington Fields Diversion by the aforementioned poisoning activities. However, the impact that nonnative species other than red shiner may be having on native and endangered fishes in the Pah Tempe Springs to Washington Fields Diversion section of the Virgin River Study Area (Study Area) has not been addressed. The Study Area holds the largest remaining woundfin population in the system and also has large numbers of other native fishes. Therefore, any negative impacts from nonnative fishes should be documented, and actions should be taken to reduce these impacts.

The Virgin River Recovery and Management Program (Program) contracted BIO-WEST, Inc. (BIO-WEST) to design a study that would address two main objectives. The first objective was to determine the extent to which nonnative fishes are a problem in the Study Area. The second objective was to evaluate potential controls for nonnative species and to develop a potential strategy for controlling these species in the Study Area.

METHODS

Identifying and Quantifying the Problem

To identify the target nonnative species, we spoke with agency representatives, searched the Virgin River Fishes Database, and sampled in the Study Area. We contacted Rick Fridell at the UDWR and received information about species that he said might inhabit the Study Area. We also queried the Virgin River Fishes Database (1976-1999) for information on all nonnative species from river miles VR82.27 (above Washington Fields Diversion) to VR99.64 (Old Diversion Seining site). This gave us a historical perspective on what nonnative species inhabited the Study Area. We also sampled the Study Area in an attempt to confirm that all nonnative species were identified and quantified.

From August 17-24, 2001, we sampled the river between Pah Tempe Springs and the Johnson Diversion in six reaches (Figure 1, map insert). The reaches we sampled were Pah Tempe (from the State Route 9 bridge below Pah Tempe Springs to about 4 miles below the bridge), Gould's Wash (4 miles below State Route 9 bridge to the gravel pit area), Stratton Pond (from the gravel pit area to the Hurricane Bridge), Hurricane Bridge (from the Hurricane Bridge to the Washington Fields Diversion), Washington Fields Diversion (from the Washington Fields Diversion to the Washington Fields Road Bridge), and Johnson Diversion (from the Washington Fields Road Bridge to the Johnson Diversion). We also sampled the off-channel Berry Springs Pond/wetland (Berry Springs Pond).

The basic sampling methodology involved one crew (two people sampling and one person recording data) walking downstream through the reach, sampling with a 4x15-foot seine with 0.125-inch mesh and a 4x50-foot floating trammel net with 12-inch mesh outer panels and a 0.5-inch inside panel, depending on the habitat. The trammel net was strung between brails and used in a seine-like fashion. This method has been used by the Nevada Division of Wildlife and Arizona Game and Fish Department in their attempts to design a Virgin River chub monitoring protocol (Jim Heinrich, Nevada Division of Wildlife; Chuck Benedict, Arizona Game and Fish, personal communication). We performed a representative sampling of all habitat types, but special emphasis was placed on those habitats thought to contain nonnative fish, based on the life histories of species known to be present and other nonnative removal projects (Hawkins and Nesler 1991, Lentsch et al. 1996). Several of the species known to occur in this reach (particularly largemouth bass and green sunfish, but also channel catfish and black bullhead) are thought to have major sources in off-channel areas (Lentsch et al. 1996). In the lower Virgin River, BIO-WEST personnel have seen higher catch rates of certain nonnative species near the confluence of irrigation return flows and the main channel. Therefore, these areas were specifically targeted for sampling.

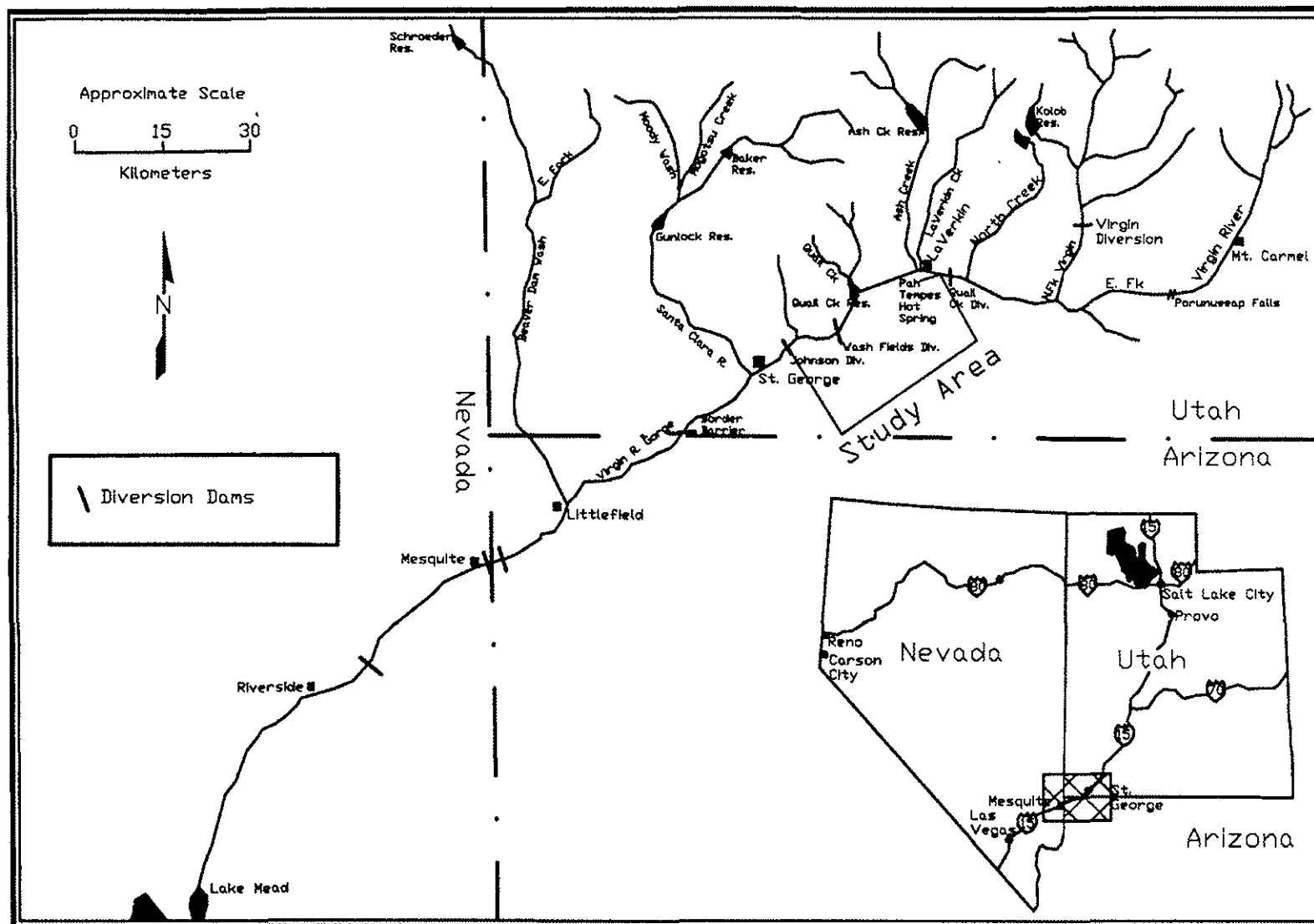


Figure 1. Map of the Virgin River and the Study Area.

Each seine or trammel haul taken during the baseline sampling followed a protocol similar to that used by BIO-WEST during monitoring of the lower Virgin River (Holden and Abate 1999). This protocol involved completing a data sheet for each sample. Data recorded included sampling gear, habitat type, date, time, habitat width, habitat length, substrate, available cover, water temperature (hourly), crew names, number of each species collected, and total length of all native and nonnative fishes (until a total of 100 fish per species were measured). Targeted nonnative species (species other than red shiner and mosquitofish) were measured, and all nonnative fishes were removed from the system. Native fishes were measured, and returned to the river as quickly as possible. In order to document concentrations of nonnative species, coordinates were taken with a Trimble Geo-Explorer Global Positioning Satellite Unit after every 10 samples at every location where large numbers of nonnative species were captured and wherever off-channel flows were seen entering the main channel. These data were entered into a Microsoft Access database. We sampled the Berry Springs Pond area using fyke nets and hoop nets.

When nonnative species were captured, the area was sampled until approximately 90 % depletion of nonnative fishes was achieved. We intended to calculate an abundance estimate for each nonnative species using the Zippin multi-step removal-depletion method (Zippin 1958, Platts et al. 1983). However, we often did not achieve depletion on the second and even third passes. Population estimates derived from multi-pass depletion sampling also depend on the assumption of a closed system (Addley and Hardy 1993). Using seines and floating trammel nets in a small section of the larger river channel did not ensure that fish were not moving into or out of the system during sampling, thus violating the closed system assumption. Since the assumptions of the model were violated, we chose to calculate the catch-per-unit area for the first pass instead. This allowed us to compare all samples, even those where only one pass was taken. If we had used the Zippin multi-step removal-depletion method, the estimates would have only been relative estimates of abundance, similar to the first pass catch-per-unit area.

In an attempt to determine if the nonnative species were having a direct impact on native species, we retained the first 40 “full” stomachs from each nonnative predator species (i.e., black bullhead, largemouth bass, green sunfish, and channel catfish) collected in the baseline sampling both above and below Washington Fields Diversion. We attempted to remove stomachs from as many age classes of fish as possible and to take stomachs from fish in channel and off-channel areas. Stomachs were removed and placed in a Whirl-Pak sampling bag with 15 % formalin and labeled with date, location, species, and length. In the laboratory, stomach contents were separated into general categories (e.g., insects, other invertebrates, detritus, and fish). We attempted to identify fish found in the stomachs to determine the percentage of native species in the diet of each nonnative predator.

Investigating and Implementing Actions

After determining what species were present and in what numbers, we evaluated potential methods for removing these fish from the Study Area, using the Washington Fields Diversion to Johnson

Diversion stretch as a surrogate. However, we imposed the same constraints that would likely be in effect above Washington Fields Diversion. The main constraint above Washington Fields would be to impact native species, especially the endangered species, as little as possible. We evaluated chemical, biological, mechanical, and physico-chemical removal methods.

We chose to experiment with mechanical removal methods below Washington Fields Diversion. Additionally, we chose to investigate the numbers of fish in off-channel areas more closely during the second sampling trip. From September 13-18, 2001, we sampled the reach between Washington Fields Diversion and Johnson Diversion more intensively, using a 4x15-foot seine and the 4x50-foot floating trammel net as previously described. We also qualitatively electrofished from the Washington Fields Road Bridge to the outlet of an off-channel wetland approximately 1.75 miles upstream ("burm" wetland outflow on Figure 1), using a Coffelt backpack electrofishing unit. We sampled the beaver dam complex above Johnson Diversion over 3 nights with an assortment of hoop nets and fyke nets, and set minnow traps for 1 night. We also sampled a marsh (Quail Creek seepage marsh) and a pond (Quail Creek seepage pond), created by seepage from Quail Creek Reservoir, with hoop nets and fyke nets. Finally, we resampled the Berry Springs Pond reach with hoop nets, fyke nets, and minnow traps. We also took additional stomachs from larger size classes of fish and from fish in off-channel areas.

Evaluating Effectiveness

We evaluated the effectiveness of our removal efforts by comparing our August baseline sampling data from Washington Fields Diversion in Johnson Diversion with our September removal period data from the same reach, by examining the UDWR sampling in the same reach for the 2000-2001 time period, and by assisting with the Program rotenone treatment of the Washington Fields to Johnson Diversion reach of the Virgin River on October 16, 2001. Prior to the treatment, the UDWR performed intensive sampling of the reach with assistance from BIO-WEST and others. Hundreds of seine hauls were made on October 12 and October 15, 2001, to salvage native fishes, and those data were obtained from the UDWR. We surveyed the pools below the Washington Fields Diversion immediately after drip stations were turned on at the diversion. Most nonnative fishes did not seem to be affected by the treatment until 3-4 hours had passed (Rick Fridell, UDWR, personal communication). As soon as we began to see nonnative fishes surfacing in the pool below Washington Fields Diversion, we made visual estimates of their numbers and moved down to the Johnson Diversion. We began walking the reach 3.5 hours after rotenone drips were set. We counted every fish (native and nonnative) that we observed. The UDWR assisted with estimates below the Washington Fields Diversion and in the beaver dam complex. We then compared numbers of nonnative fishes counted during the treatment to those removed during the sampling and removal periods. We also took additional stomachs from larger size classes of fish during the treatment using the methods described above.

RESULTS

Sampling Conditions

Conditions during our two sampling trips were variable. Flow was generally low, and the river was fairly clear during the sampling (Figure 2). However, a storm event elevated flow and turbidity for the latter part of our first sampling trip. Higher flow and turbidity levels were associated with the baseline (August 2001) sampling of the Hurricane Bridge reach and Johnson Diversion reach.

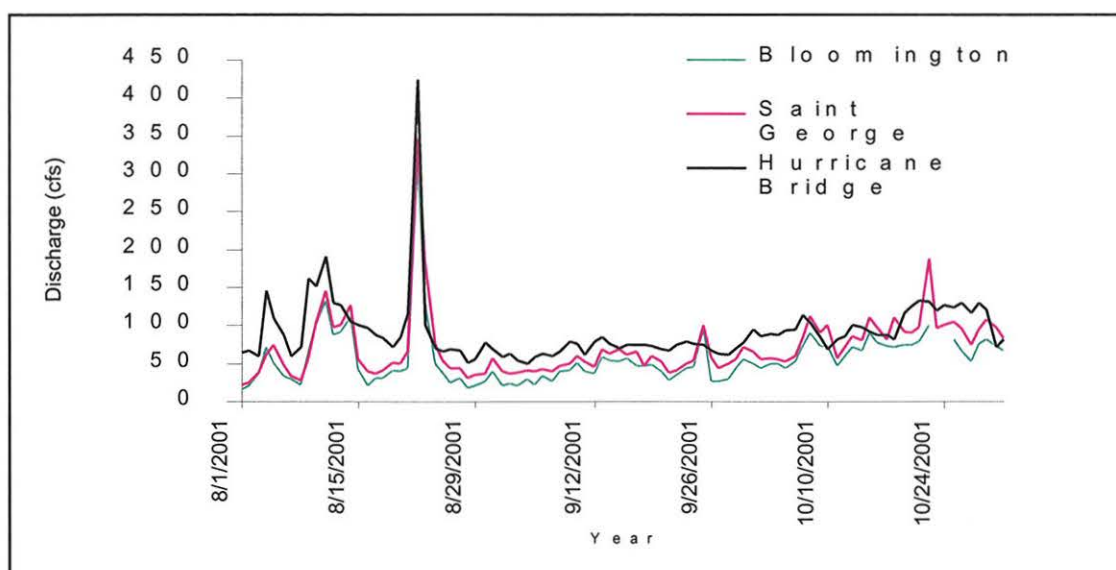


Figure 2. Flow at the Hurricane, Bloomington, and St. George U.S. Geological Survey gauge stations along the Virgin River, during the sampling period.

Identifying and Quantifying the Problem

Historical Data

Black bullhead was the species most frequently collected by the UDWR, but they also reported seeing bass and sunfish (Rick Fridell, UDWR, personal communication). Large numbers of black bullhead have been seen during UDWR poisoning efforts between Washington Fields Diversion and Johnson Diversion. Cross (1975) collected black bullhead from above the Johnson Diversion and above the confluence of Ash and LaVerkin creeks. The Virgin River Fishes Database showed sporadic numbers of black bullhead, largemouth bass, and green sunfish, along with lower numbers of channel catfish, between Pah Tempe Springs and the Johnson Diversion (Tables 2-5). Cross (1975) did not find largemouth bass, green sunfish, or channel catfish in the upper main stem, but he did collect them in the lower main stem of the Virgin River. He also collected largemouth bass

Table 2. Black bullhead found in the Virgin River database in collections from 1976-1999.

SITE	1976-1980	1981-1985	1986-1990	1991-1995	1996-1999
VR097.17-099.64 Pah Tempe to old diversion	0	0	0	3	66
VR095.32-095.96 Ash Creek to above LaVerkin Creek	0	0	0	0	3
VR094.75 1 mile below Ash Creek	0	0	0	0	0
VR089.18 above Quail Creek	0	0	0	1	2
VR086.23-087.85 above Hurricane Bridge to Cement Plant	0	0	0	0	0
VR084.19 below Hurricane Bridge	0	0	0	0	0
VR082.27 above Washington Fields Diversion	0	0	1	2	0

Table 3. Channel catfish found in the Virgin River database in collections from 1976-1999.

SITE	1976-1980	1981-1985	1986-1990	1991-1995	1996-1999
VR097.17-099.64 Pah Tempe to old diversion	0	0	0	0	0
VR095.32-095.96 Ash Creek to LaVerkin Creek	0	0	0	0	0
VR094.75 1 mile below Ash Creek	0	0	3	0	0
VR089.18 above Quail Creek	0	0	1	0	0
VR086.23-087.85 above Hurricane Bridge to Cement Plant	0	0	0	0	0
VR084.19 below Hurricane Bridge	0	0	0	0	0
VR082.27 above Washington Fields Diversion	0	0	1	0	0

Table 4. Green sunfish found in the Virgin River database in collections from 1976-1999.

SITE	1976-1980	1981-1985	1986-1990	1991-1995	1996-1999
VR097.17-099.64 Pah Tempe to old diversion	0	0	0	0	0
VR095.32-095.96 Ash Creek to LaVerkin Creek	2	1	0	1	1
VR094.75 1 mile below Ash Creek	0	3	3	0	0
VR089.18 above Quail Creek	0	0	2	1	1
VR086.23-087.85 above Hurricane Bridge to Cement Plant	1	0	97	0	0
VR084.19 below Hurricane Bridge	0	0	3	1	2
VR082.27 above Washington Fields Diversion	0	0	2	1	0

Table 5. Largemouth bass found in the Virgin River database in collections from 1976-1999.

SITE	1976-1980	1981-1985	1986-1990	1991-1995	1996-1999
VR097.17-099.64 Pah Tempe to old diversion	0	0	0	0	0
VR095.32-095.96 Ash Creek to LaVerkin Creek	1	0	2	0	13
VR094.75 1 mile below Ash Creek	0	49	42	0	0
VR089.18 above Quail Creek	0	5	9	0	0
VR086.23-087.85 above Hurricane Bridge to Cement Plant	0	0	0	1	0
VR084.19 below Hurricane Bridge	0	14	0	0	0
VR082.27 above Washington Fields Diversion	0	19	0	0	0

in the middle Santa Clara (Cross 1975). Cross hypothesized that all of these species moved into the Virgin River from Lake Mead, and possibly through introduction from farm ponds along the Virgin River.

Baseline Sampling

The numbers of nonnative fishes found in the Virgin River Fishes Database were sporadic and variable, which are partly a function of the habitats that these nonnative fishes use. Much of the historical data are from discrete monitoring stations set up by the Virgin River Fishes Recovery Team. However, more-extensive sampling in the lower Virgin River (Holden and Abate 1999, Holden and Golden 2000) and the upper Virgin River (Valdez et al. 1991, Addley and Hardy 1993) has shown that sampling longer sections of river can uncover information on species composition and abundance that may be missed by more site-selective sampling. Sandy-bottomed runs are the predominate habitat in the Virgin River. A large proportion of the data collected in the database was from sandy bottomed runs. Sampling was directed this type of habitat because of its abundance, ease of sampling, and the fact that woundfin are often found in these areas (Holden and Golden 2000, Holden et al. 2001). However, many of the target nonnative species utilize habitats different from those used by woundfin.

Black bullhead have been shown to use muddy, vegetated, backwater areas of warm water streams (Lentsch et al. 1996, Sigler and Sigler 1996). Green sunfish and largemouth bass also prefer slower-velocity habitats with some amount of cover in the form of vegetation and woody debris (Sigler and Sigler 1996). Conversely, channel catfish seem more adaptable to a variety of velocities and depths (Lentstch et al. 1996). We chose to sample all available habitats, while placing emphasis on the above habitats where we thought nonnative species would be most likely to occupy.

We found that black bullhead and largemouth bass were the nonnative species with the highest numbers above the Washington Fields Diversion (Table 6). We also captured green sunfish above Washington Fields Diversion. We caught one channel catfish, but it was below the Washington Fields Road Bridge. We considered black bullhead, green sunfish, and largemouth bass to be the target nonnative species above the Washington Fields Diversion.

The target nonnative species (largemouth bass, green sunfish, black bullhead, and channel catfish), were found in 51 of the 295 samples taken in the river (Table 7). Since red shiner and mosquitofish were not found above Washington Fields Diversion, they were not considered species of interest for this study. Native fishes were found in conjunction with nonnative fishes in 63 % of the samples. A two sample t-tests modified for unequal variances showed that target nonnative species were found at significantly shallower average depths ($p=0.013$, Figure 3). Nonnative species appeared to be found in samples with shallower maximum depths as well, but this was not significant. A chi-square goodness-of-fit test showed that the target nonnative species were found in slightly different habitats than we would have expected, based on the distribution of habitats sampled ($p=0.047$). However, black bullhead was the only target nonnative species using significantly different habitat than expected ($p<0.004$), showing preferences for pool and side

Table 6. Number of samples and fish of each species caught during sampling for nonnative fishes from the State Route 9 bridge below Pah Tempe Springs to Johnson Diversion in August 2001.

REACH	SAMPLES	BB	CC	DS	FM	GS	LB	MF	RC	RS	SD	VS	WF
PT	58	0	0	47	174	1	3	0	69	0	4	16	3
GW	59	33	0	7	96	9	46	0	25	0	2	4	4
SP	41	1	0	33	44	6	11	0	7	0	10	93	2
BSP	4	1	0	0	0	9	4	0	0	0	0	0	0
HB	53	0	0	34	78	0	0	0	13	0	23	114	27
WF-JD	83	22	1	14	1	5	12	17	21	547	13	68	61
Total	298	57	1	135	393	30	76	17	135	547	52	295	97

Species abbreviations: BB = black bullhead, CC = channel catfish, DS = desert sucker, FM = flannemouth sucker, GS = green sunfish, LB = largemouth bass, MF = mosquitofish, RC = Virgin River chub, RS = red shiner, SD = speckled dace, VS = Virgin spinedace, WF = woundfin.

Reach abbreviations: PT = Pah Tempe reach, GW = Gould's Wash reach, SP = Stratton Pond reach, BSP = Berry Springs Pond, HB = Hurricane Bridge reach, WF = Washington Fields Diversion reach, JD = Johnson Diversion reach.

Table 7. Habitats sampled versus habitats where native species and target nonnative species were captured in the Virgin River during the August 2001 sampling trip.

HABITAT	ALL SAMPLES	ALL TARGET NONNATIVE SPECIES	ALL NATIVES	BLACK BULLHEAD	LARGEMOUTH BASS	GREEN SUNFISH
Pool	23	8	11	5	5	3
Run	198	30	138	9	22	6
Eddy	29	5	21	0	4	1
Backwater	13	2	2	1	1	1
Side Channel	2	2	1	1	2	1
Side Run	4	1	1	1	0	0
Run/Riffle	6	3	6	2	0	0
Side Riffle/Run	1	0	1	0	0	0
Riffle/Run	9	0	6	0	0	0
Pool/Run	3	0	3	0	0	0
Riffle	3	0	2	0	0	0
Run/Eddy	4	0	2	0	0	0
Total	295	51	194	19	34	12

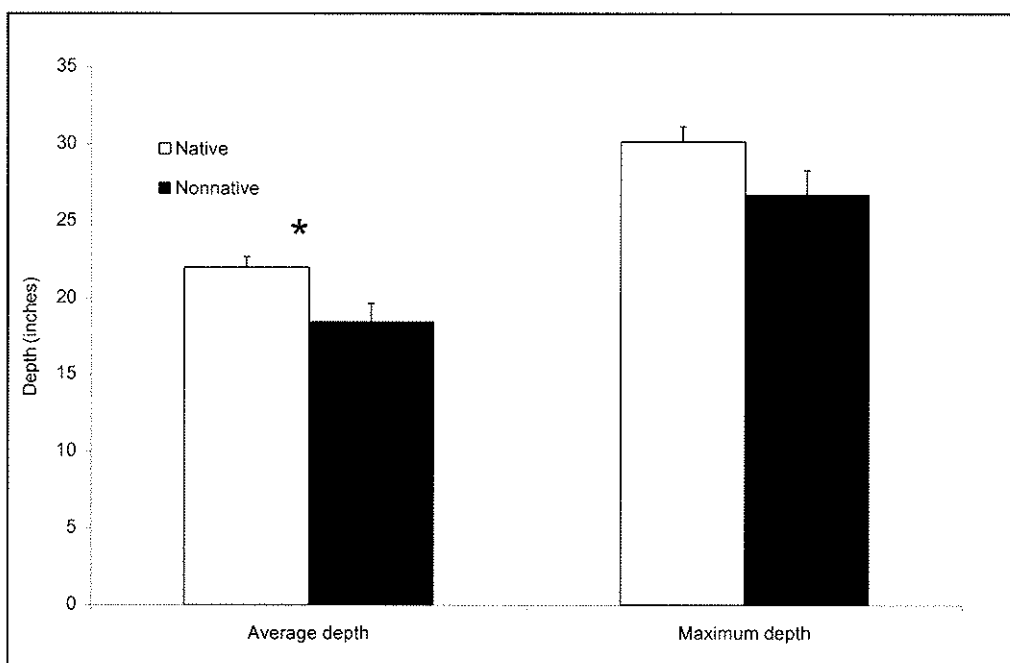


Figure 3. Average of mean and maximum depths measured for samples containing nonnative species and for samples containing native species. (*= Significant difference at ≤ 0.05 .)

channel habitats. All target nonnative species showed an affinity for slower-velocity habitats. Conversely, the overall distribution of habitats where native fish were sampled showed no difference from the distribution of habitats sampled.

Table 8 shows the substrate affinity of native and nonnative species. Chi-square goodness-of-fit tests showed that the overall distribution for the target nonnative species, and for native species, did not vary significantly from underlying sampling distribution. The distribution of black bullhead did vary significantly from the underlying distribution ($p < 0.005$). Black bullhead were found over silt more often than expected. Table 9 shows the cover used by native species and the target nonnative species. More than one cover type was present in some samples, so a goodness-of-fit test was not conducted. A slightly higher percentage of nonnative species used some form of cover, but no major difference was seen between native species and nonnative species.

Catch-per-unit area for fish collected in the first pass showed that the highest nonnative fish densities were in the Gould's Wash and Washington Fields Diversion reaches of the Study Area (Figure 4). However, the high density in the Washington Fields Diversion reach was a result of the high densities of red shiner and mosquitofish. The Gould's Wash reach and Stratton Pond reach had the highest densities of the target nonnative species. The majority of fish captured in the Gould's Wash reach were within the 2-mile stretch surrounding Gould's Wash. The stagnant mouth of Gould's Wash and a large backwater about 1 mile downstream from Gould's Wash accounted for a large portion of the nonnative fishes.

Table 8. Dominant substrate type in samples where native species versus nonnative species were found during the August 2001 sampling trip.

SUBSTRATE	ALL SAMPLES	ALL TARGET NONNATIVE SPECIES	NATIVE SPECIES	BLACK BULLHEAD	LARGEMOUTH BASS	GREEN SUNFISH
Silt	49	14	22	9	9	6
Sand	235	35	168	9	25	6
Coarse gravel	4	0	1	0	0	0
Small cobble	3	2	2	1	1	0
Large cobble	1	0	1	0	0	0
Boulder	3	0	0	0	0	0
TOTAL	295	51	194	19	35	12

Table 9. Cover present in samples where target nonnative species were captured versus native species during the August 2001 sampling trip.

COVER	ALL SAMPLES	ALL TARGET NONNATIVE SPECIES	NATIVE SPECIES	BLACK BULLHEAD	LARGEMOUTH BASS	GREEN SUNFISH
Overhanging vegetation	37	7	18	4	4	0
Inundated vegetation	23	3	14	1	2	1
Roots	0	0	0	0	0	0
Small woody debris	18	3	9	3	0	0
Large woody debris	4	2	3	0	1	1
Boulders	0	0	0	0	0	0
Bedrock	0	0	0	0	0	0
No cover	225	38	155	13	28	10

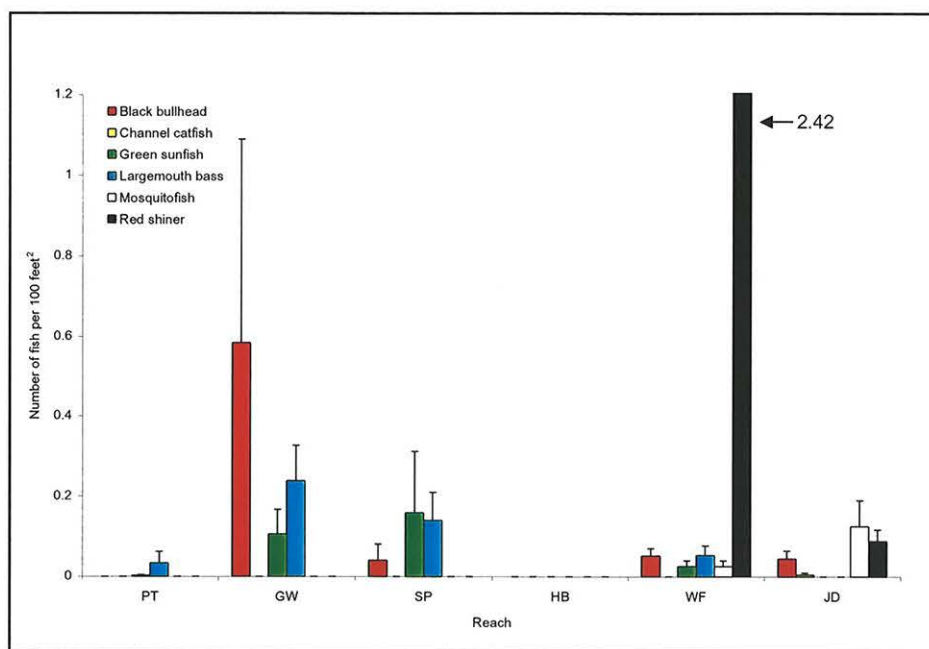


Figure 4. First pass catch-per-unit area of nonnative species during the August 2001 sampling trip.

Native fish densities were much higher above Washington Fields Diversion than below (Figure 5). The Pah Tempe and Gould's Wash reaches had higher Virgin River chub densities than the remaining sections. Virgin spinedace seemed to have higher densities in the Stratton Pond and Hurricane Bridge reaches, particularly after the Quail Creek return flow and the Stratton Pond inflow. Woundfin numbers were highest in the Hurricane Bridge reach and Washington Fields Diversion reach sections. The woundfin were concentrated from about 1 mile above the Washington Fields Diversion to about 2 miles below the diversion. In general, native fish densities appeared at least slightly higher than nonnative fish densities in all reaches above the Washington Diversion, except the Gould's Wash reach (Figure 6). Paired t-tests showed that native fish densities were significantly higher than nonnative fish densities in the Pah Tempe reach, and nonnative fish densities were significantly higher than native fish densities in the Washington Fields Diversion reach ($p < 0.001$).

The UDWR identified three potential off-channel sources of nonnative fishes for BIO-WEST to investigate: Berry Springs Pond, an off-channel wetland termed "the Burm," upstream from the Washington Fields Road Bridge, and a beaver dam complex upstream from the Johnson Diversion (Rick Fridell, UDWR, personal communication). During the baseline sampling trip, we were unable to locate the beaver dam complex and the Burm wetland was dry. However, we did find and sample Berry Springs Pond. All three nonnative species that were numerous in the river were present there (Figure 7). While we did not catch large numbers of fish, many adult and young-of-year largemouth bass and green sunfish were visually observed throughout the wetland area.

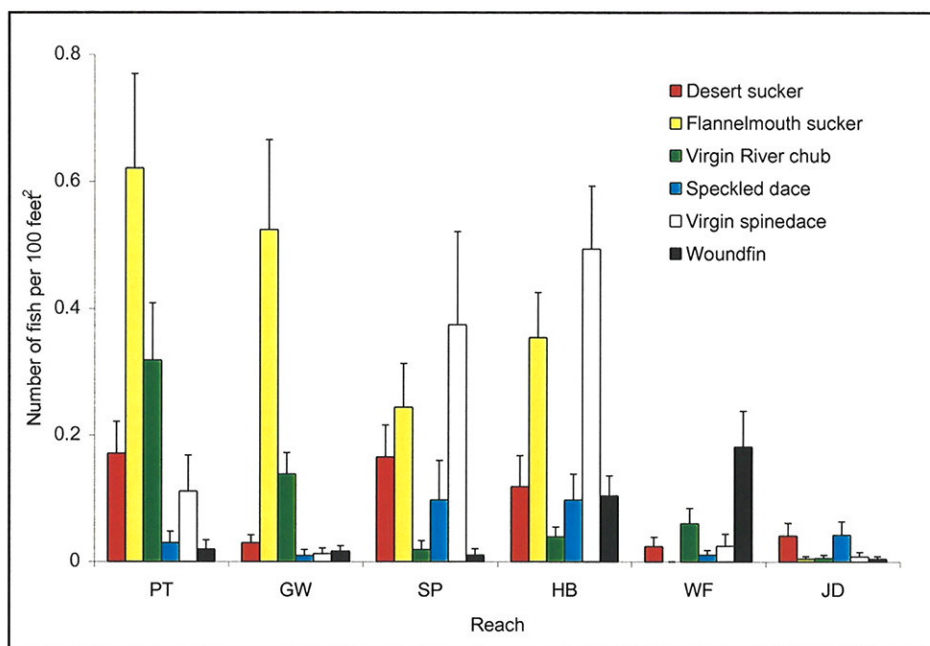


Figure 5. First pass catch-per-unit area of native species during the August 2001 sampling trip.

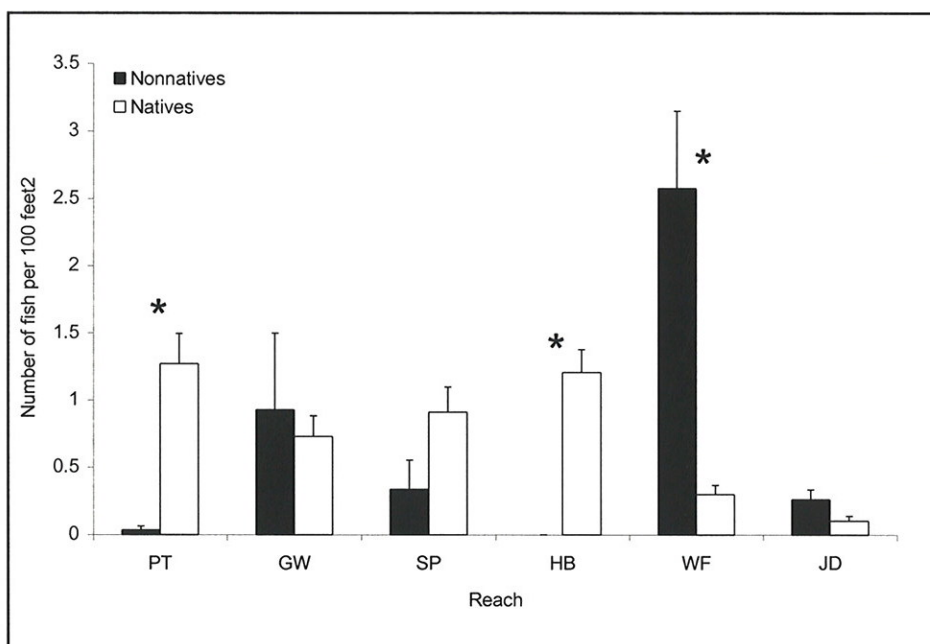


Figure 6. First pass catch-per-unit area of native species versus nonnative species during the August 2001 sampling trip. (*= Significant difference at ≤ 0.05 .)

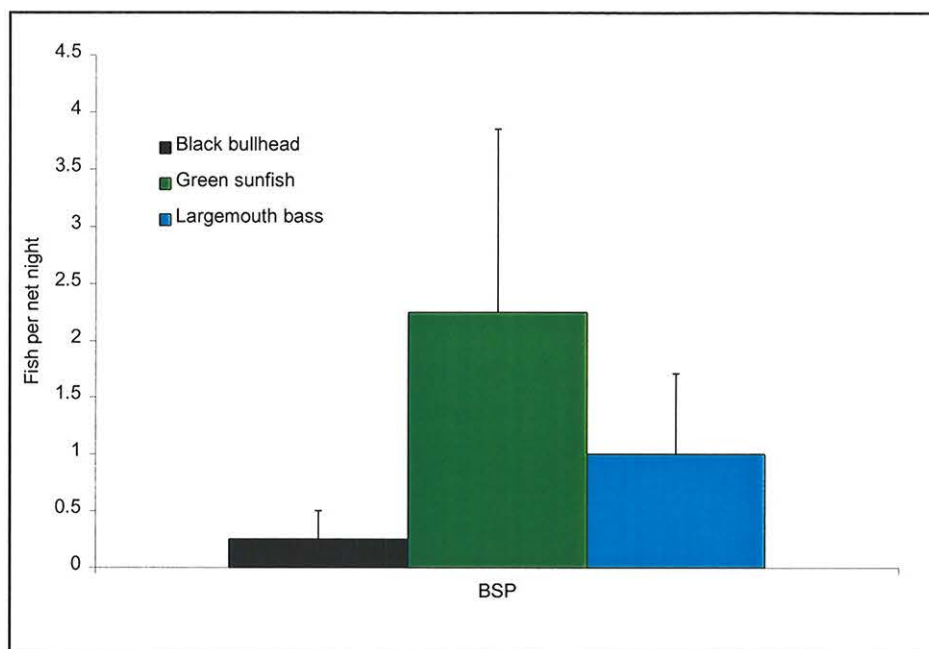


Figure 7. Number of fish-per-net night captured in Berry Springs Pond during the August 2001 sampling trip.

We also identified areas where dry or wetted channels were entering the river channel and a few other potential off-channel sources (see map insert). For instance, seepage from the south dyke of Quail Creek Reservoir created a pond (Quail Creek seepage pond) on both sides of State Route 9 northwest of the Hurricane Bridge and a marsh (Quail Creek seepage marsh) on the west side of the highway. Both of these areas drain into the river channel downstream of Hurricane Bridge. Quail Creek Reservoir also has a direct outflow to the river channel further upstream. Utah Outdoors Fishing Guide (2001) lists a sport fishery for rainbow trout, largemouth bass, bluegill, crappies (*Pomoxis* spp.), and black bullhead in Quail Creek Reservoir. Stratton Pond is also known to have black bullhead (Rick Fridell, UDWR, personal communication), and it also has an outflow to the river. Additionally, we identified a small neighborhood pond just upstream from the Washington Fields Road Bridge. This pond also has an outflow to the river, and if it is not already a source of nonnative fish, it is likely to become one. Finally, the impoundment above Quail Creek Diversion may contain nonnative fishes. While this impoundment is out of the Study Area, it has the potential to be a source of nonnative species to access the Pah Tempe reach and should be subject to future sampling.

Food Habits

We took 127 stomachs from three nonnative species – black bullhead, largemouth bass, and green sunfish – during the August and September 2001 sampling trips and during the October 2001 rotenone treatment. Stomachs were collected during all three phases of the study, in an attempt to maximize the variety of age classes and habitats sampled. However, this was not possible for all species. We collected over 40 full black bullhead and green sunfish stomachs during all phases of

the study, but only 33 full largemouth bass stomachs were collected. Of the 33 full largemouth bass stomachs collected, only 1 was greater than 150 millimeters (mm). We caught three largemouth bass larger than 200 mm in length, but they all had empty stomachs. We planned to collect more stomachs from larger-size classes of largemouth bass during the rotenone treatment, but we only observed one dead largemouth bass. Only one channel catfish was collected during the study, and its stomach was empty.

We found fish remains in 14 (11 %) of the stomachs (Table 10). We found identifiable native species in two of the stomachs. We found an approximately 50-mm-long woundfin in the stomach of a 111-mm-long largemouth bass during the August 2001 sampling and a 105-mm-long desert sucker (*Pantosteus clarki*) in the stomach of a 217-mm-long black bullhead in the river during the October 2001 rotenone treatment. Both native fish were found in stomachs of fish from the river (Table 11). The stomachs of green sunfish in off-channel areas contained the remains of green sunfish.

Two of the black bullhead stomachs from off-channel areas contained fish; one had a green sunfish, and the other unidentifiable fish remains. We did not capture any native species in off-channel areas, so we would not expect to find them as a major prey item. More piscivory was seen in fish captured in off-channel areas. Figures 8-10 show that nonnative species collected in off-channel areas for stomach samples tended to be bigger than fish collected for the same purpose in the Virgin River. We found that bigger fish collected in the river channel seemed to be more likely to have empty stomachs.

Table 10. Frequency and number of fish found in stomachs of nonnative species collected from the Pah Tempe Springs to Johnson Diversion section and from off-channel areas of the Virgin River. Number in parentheses is the total number of fish found, whereas the number out of parentheses is the number of stomachs in which fish were found.

SPECIES	NUMBER OF STOMACHS EXAMINED	WOUNDFIN	DESERT SUCKER	GREEN SUNFISH	UNIDENTIFIABLE	TOTAL
Green sunfish	44	0	0	6(10)	0	6(10)
Largemouth bass	33	1(1)	0	0	2(3)	3(4)
Black bullhead	50	0	1(1)	1(1)	3(3)	5(5)
TOTAL	127	1(1)	1(1)	7(11)	5(6)	14(19)

Table 11. Frequency and number of fish found in stomachs of nonnative species collected from the Pah Tempe Springs to Johnson Diversion section of the Virgin River. Number in parentheses is the total number of fish found, whereas the number out of parentheses is the number of stomachs in which fish were found.

SPECIES	NUMBER OF STOMACHS EXAMINED	WOUNDFIN	DESERT SUCKER	GREEN SUNFISH	UNIDENTIFIABLE	TOTAL
Green sunfish	20	0	0	0	0	0
Largemouth bass	30	1(1)	0	0	2(3)	3(4)
Black bullhead	33	0	1(1)	0	2(2)	3(3)
TOTAL	83	1(1)	1(1)	1(1)	4(5)	6(7)

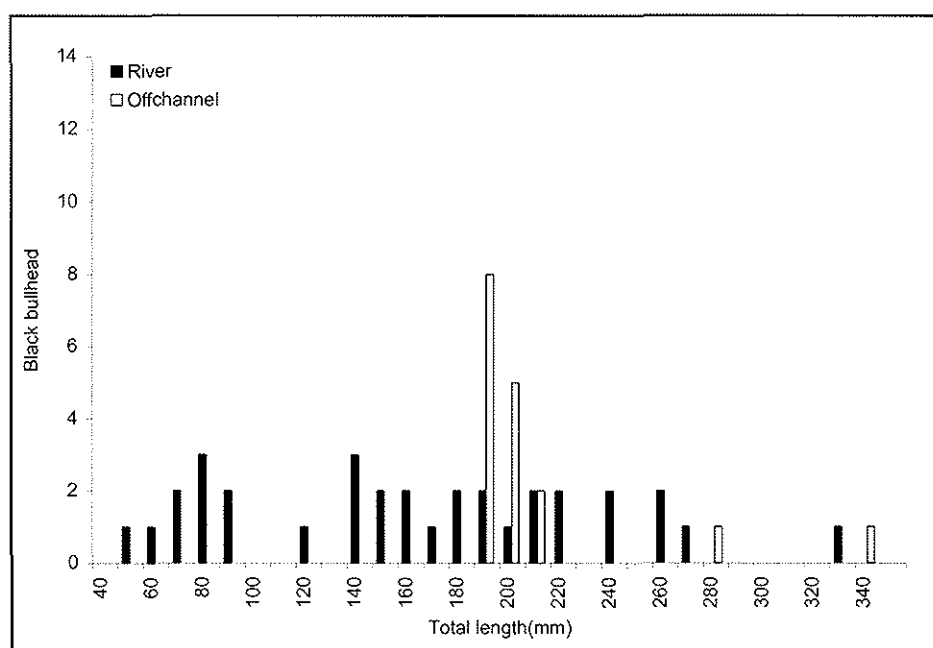


Figure 8. Length frequency distribution of black bullhead used in stomach sample analysis from the Virgin River and off-channel areas.

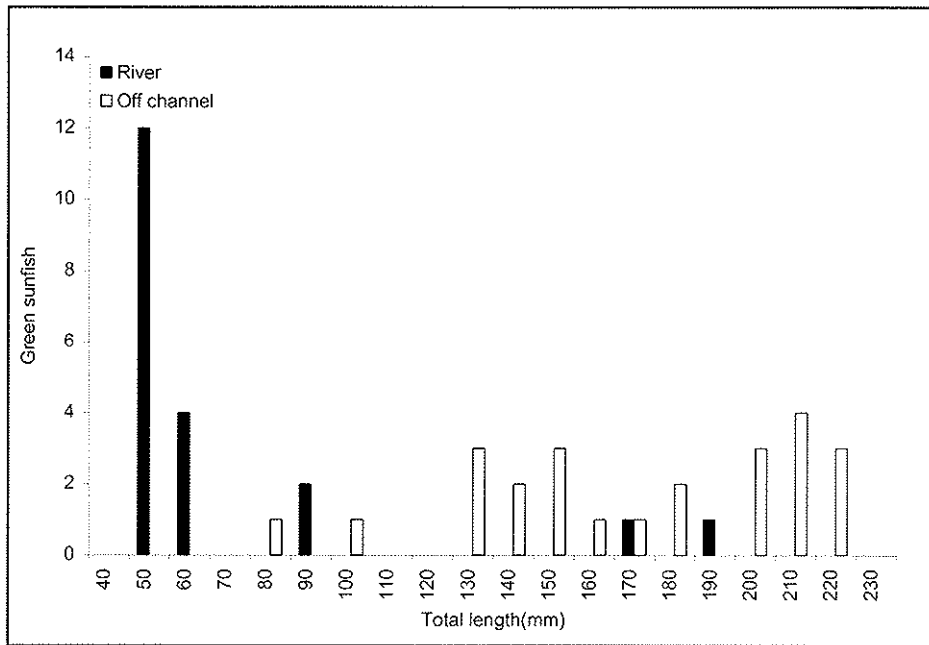


Figure 9. Length frequency distribution of green sunfish used in stomach sample analysis from the Virgin River and off-channel areas.

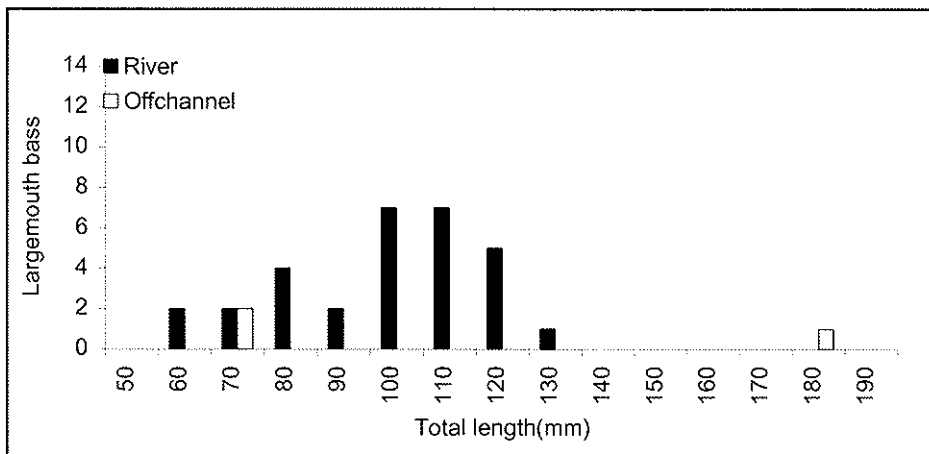


Figure 10. Length frequency distribution of largemouth bass used in stomach sample analysis from the Virgin River and off-channel areas.

Table 12 shows the food habits of nonnative fishes collected in both the river channel and in off-channel areas. Black bullhead seemed to be the most omnivorous, especially in the river channel. Green sunfish, while primarily feeding on invertebrates in the river, fed more on fish and detritus in the off-channel areas. Largemouth bass appeared to be the most specialized, concentrating on a few invertebrate taxa and on fish. Unfortunately, our sample size was lacking for different size classes of largemouth bass and for largemouth bass in off-channel areas.

Summary

Historical data on nonnative fishes captured in the Study Area and baseline data collected using seines and trammel nets during sampling efforts on the Virgin River from the State Route 9 bridge below Pah Tempe Springs to the Johnson Diversion in August 2001, showed that the target nonnative species above the Washington Fields Diversion were black bullhead, green sunfish, and largemouth bass. We found moderate numbers of black bullhead and largemouth bass in the 2 miles surrounding Gould's Wash, with high concentrations of nonnative fishes at the stagnant mouth of Gould's Wash and a connected backwater side channel. We also found moderate numbers of these species upstream from the Hurricane Bridge to about 1 mile below Gould's Wash. Several potential off-channel sources of nonnative fishes were identified, and Berry Springs Pond was found to have high numbers of green sunfish and largemouth bass. We demonstrated that largemouth bass and black bullhead fed on native fishes, including the endangered woundfin.

Investigating and Implementing Actions

Options for Nonnative Species Control

Our catch data from the August 2001 sampling showed that target nonnative species were present above the Washington Fields Diversion. In certain areas, they seemed to be present in densities higher than those found below Washington Fields Diversion (Figure 4). A review of pertinent literature showed that these species are known and/or suspected to have negative effects on other native species in the Colorado River system. Additionally, we found native species and unidentified fish remains in the stomachs of nonnative species taken from the river channel. For these reasons, we felt that species of nonnative fish collected above Washington Fields Diversion posed a potential threat to native fish species in this area. Therefore, we evaluated potential methods for removing and/or reducing of these nonnative species in the Study Area.

Hawkins and Nesler (1991) and Lentsch et al. (1996) discussed options for nonnative fish control in the Upper Colorado River Basin. Black bullhead, green sunfish, and largemouth bass are all found in the Upper Colorado River and have been implicated in the decline of imperiled native fishes, including the Colorado pikeminnow (*Ptychocheilus lucius*) and the razorback sucker (*Xyrauchen texanus*). We drew heavily from these existing works to determine the best options for removing nonnative species.

Table 12. Prey items found in stomachs of target nonnative species.

TAXA	VIRGIN RIVER			OFF-CHANNEL AREAS		
	BLACK BULLHEAD	GREEN SUNFISH	LARGE-MOUTH BASS	BLACK BULLHEAD	GREEN SUNFISH	LARGE-MOUTH BASS
INSECTA						
Diptera						
Ceratopogonidae	P ^a	P		P		
Chironomidae	P	P	P	P	P	P
Empididae	P	P				
Tipuliidae	P					
Simuliidae	P	P	P			
Unknown	P		P	P		
Terrestrial			P			
Ephemeroptera	P	P	P	P		P
Odonata	P	P	P	P	P	P
Trichoptera	P	P	P			
Hemiptera	P	P	P	P	P	P
Coleoptera	P	P	P		P	
Lepidoptera	P					
Megaloptera	P					
Homoptera (Terr.)	P					
Hymenoptera (Terr.)	P	P			P	
ARACHNIDA		P				
Hydrachnidia		P				
CRUSTACEA						
Decapoda	P			P	P	
Isopoda	P	P				
Ostracoda	P	P		P	P	
Cladocera				P		
Copepoda	P	P	P			
OLIGOCHAETA	P	P			P	
GASTROPODA	P	P			P	P
Fish	P		P	P	P	
Detritus	P	P	P	P	P	
Algae	P			P		
Mammal	P					

^a P = Present.

Chemical

Chemical treatment is probably the most common method of fish control (Lentsch et al. 1996, Meronek et al. 1996). Chemical treatment of waterways has most often been used to remove undesirable “trash” and “rough” fish (sometimes native species) to improve the production of a sport fishery (Holden 1991, Rinne and Turner 1991). More recently, chemical treatment has been used as a tool for eliminating threats to native and endangered fishes (Rinne et al. 1981, Rinne and Turner 1991, Stefferud et al. 1992, Lentsch et al. 1996, Comella and Fridell 1998, Blasius 2001). Ponds, lakes, and reservoirs have been common targets for chemical reclamation. Use of chemical reclamation in lotic situations is usually restricted to smaller streams. However, Lentsch et al. (1996) noted that Strawberry Reservoir (4.85 hectares) was successfully treated, along with 161 miles of its tributary streams.

Red shiner is thought to have a negative impact on native fishes, particularly the woundfin, and is present in large numbers below the Johnson Diversion. Therefore, the UDWR has used rotenone to control red shiner below the Washington Fields Diversion several times since 1988 (USFWS 1995, Comella and Fridell 1998). However, these treatments have not been completely effective; this reach has been recolonized by nonnative species, including red shiner, and the target nonnative species for this study. Above the Washington Fields Diversion, large numbers of native fishes and lower numbers of target nonnative fishes are present. A large-scale poisoning of the Virgin River with a general fish toxicant does not appear to be a prudent alternative. While some species-specific chemicals, such as squoxin for squawfish (*Ptychocheilus* sp.) and 3-trifluoromethyl 1-4 nitrophenol (TFM) for lampreys (*Petromyzon* sp.) (Wiley and Wydowski 1993), do exist, we found no evidence of chemicals that were designed specifically for the target nonnative species in this study.

Piscicides have been found to have variable toxicities to different fishes. BooGaard et al. (1996) found that TFM was more toxic to ruffe (*Gymnocephalus cernuus*) than to yellow perch (*Perca flavescens*) and black bullhead. They were able to reduce ruffe densities in two river estuaries, with little impact to the native fish fauna. Similarly, others have found rotenone and antimycin A can reduce numbers of target species with minimal loss to game fish (Peters 1961, Berger 1965). Unfortunately, many of the game species that are unaffected by these toxins are the target nonnative species in the Virgin River. Berger (1965) found that common carp and other species were impacted by an application of 10 micrograms per liter ($\mu\text{g/l}$) antimycin A per 1.9 hectares, but black bullhead and channel catfish were not. BooGaard et al. (1996) found that an application of TFM at 3.2 $\mu\text{g/l}$ impacted ruffe but not black bullhead or yellow perch. Native fishes in the Virgin River are affected more quickly by and probably at lower concentrations of rotenone than are the target nonnative species, especially black bullhead (Rick Fridell, UDWR, personal communication). Therefore, poisoning at a level that would remove the target nonnative species in the main stem of the Virgin River above Washington Fields would probably cause massive to complete mortality of the native fish populations. Since this area has the largest remaining populations for most of the native fishes, including the endangered woundfin, this is not a viable option.

Smaller areas with high concentrations of target species can potentially be treated. Beyerle and Williams (1967) were unsuccessful in targeting bluegill nests for control with copper sulfate. McHugh (1990) poisoned the littoral zones of two reservoirs to reduce numbers of largemouth bass. Hawkins and Nesler (1991) noted that some researchers felt well-timed chemical or mechanical removal of nonnative fishes in backwaters along the Upper Colorado River could help increase recruitment of native fishes. We have been investigating selectively poisoning larval aggregations of red shiner as a way to help supplement mechanical removals on the lower Virgin River. Similarly, Lentsch et al. (1996) listed chemical treatment of spawning congregations of green sunfish, largemouth bass, and channel catfish as a potential option for reduction of these fishes in the Upper Colorado River. In off-channel areas with high densities of nonnative fishes, where the chemical can be contained, chemical treatment may be a viable option for controlling nonnative fish populations in the Virgin River above Washington Fields.

Biological

With the negative impacts that species introductions have already had in the Virgin River Basin, and without a native top level predator capable of reducing the species thought to be a problem above the Washington Fields Diversion, biomanipulation does not appear to be an alternative. Supposed species-specific pathogens for channel catfish and largemouth bass have been developed: Channel Catfish Virus Disease and the bass tapeworm, respectively (Plumb et al. 1989, Maine Department of Inland Fisheries and Wildlife 2001). Channel catfish do not appear to be a problem above the Washington Fields Diversion. While largemouth bass are a problem, the bass tapeworm seems to impact other species, so introducing this parasite could potentially impact native and endangered species.

Prevention of further introduction and stocking of the nonnative species might be considered a biological control (Lentsch et al. 1996). Off-channel areas seem to be supplying large numbers of nonnative species to the Virgin River main stem. Data collected during the baseline sampling and by the UDWR confirm this (Rick Fridell, UDWR, personal communication). Cross (1975) concluded that off-channel areas were probably sources for nonnative species introductions in the Virgin River. We felt that further investigation of off-channel areas was warranted during the removal period. Documentation of nonnative species present in off-channel areas, and investigating the connections of these off-channel areas to the river, are important to understanding the dynamics of nonnative fish populations in the Virgin River. Holden et al. (1997) documented stocking of largemouth bass and bluegill sunfish into the Virgin River system by the state of Utah between 1980 and 1995. They recommended that stocking warm water predators where native fishes are already imperiled be discontinued. Therefore, limiting or eliminating future stocking in Quail Creek Reservoir, Sand Hollow Reservoir, and other off-channel areas along the Virgin River may help prevent accidental and angler-related introductions of nonnative species into the Virgin River. Stocking sterile fish might be considered.

Mechanical

Mechanical removal techniques are labor intensive and usually involve a combination of fisheries sampling techniques (e.g., seining, floating trammel netting, hoop netting, electrofishing, box

trapping). The major benefit of mechanical removal is having the ability to determine the number and type of fish that are removed. As with chemical removal techniques, historical removal attempts centered on improving sport fisheries. Hanson et al. (1983) successfully lowered the number of black bullhead by almost 80 % in a small Wisconsin Lake with 352 fyke net days of effort. Moyle and Clothier (1959) saw a 50-fold decrease in common carp weight per seine haul after 13 years of commercial fishing with hoop nets and seines. Meronek et al. (1996) found that seine, trap, net, and electrofishing removal had success rates ranging from 33-57 %. Mechanical removals targeting game fishes saw the lowest success. Lentsch et al. (1996), however, noted the difficulty of successful mechanical removal projects, because partial or temporary control is achieved.

More recently, mechanical fish control projects have started to play a role in endangered species recovery. Hawkins and Nesler (1991) noted the idea of potentially removing nonnative species from backwater areas to increase recruitment of native species. Holden and Golden (2000) documented some success with partial, sustained mechanical removal projects in the Virgin River. Badame et al. (1999) had little success at reducing numbers of channel catfish in the Green River through mechanical removal. Lentsch et al. (1996) listed mechanical removal as a potential control option for channel catfish, green sunfish, and largemouth bass on the Upper Colorado River. Only a few areas in the Virgin River above Washington Fields Diversion had high densities of the target nonnative species. Several off-channel areas seem to have densities of nonnative species that are much higher than the Virgin River. We thought that experimenting with mechanical removal methods in the Washington Fields to Johnson Diversion reach and an off-channel area were the most acceptable options for nonnative fish control experiments on the Virgin River at the present time.

Physicochemical

Nonnative species are thought to proliferate rapidly in western rivers because many of these systems have been altered with respect to their historic flow regime, water quality measures, and habitat (Hawkins and Nesler 1991, Lentsch et al. 1996, Tyus and Saunders 2000). Information on the life histories of the target nonnative species can be used to identify limiting habitat requirements (Lentsch et al. 1996). Returning western rivers to their natural flow regime could help return degraded habitats to those more favorable to native fishes, and could create abiotic conditions unsuitable for nonnative species (Poff et al. 1997). Meffe (1984) noted declines in nonnative mosquitofish populations after flash floods and that mosquitofish and the Sonoran topminnow (*Poeciliopsis occidentalis*) only coexist in areas with frequent flooding. In areas with little flooding, the Sonoran topminnow is quickly extirpated after mosquitofish invasion (Meffe 1984). Moyle and Light (1996) concluded that abiotic factors, including the hydrologic regime, were the most important factors in determining the success of invasive species in California streams. Marchetti and Moyle (2001) saw increases in nonnative fishes during low-flow years but declines in these same nonnative species during high-flow years in a regulated stream in California. The nonnative species included all four species found during our sampling of the Virgin River. Holden et al. (2001) found that fall numbers of red shiner were higher during drought years versus non-drought years on the Virgin River.

The most common management action recommended for controlling nonnative fishes in the Upper Colorado River Basin was a return to a more natural flow regime, with increased frequency and magnitude of floods (Hawkins and Nesler 1991). Lentsch et al. (1996) recommended physicochemical controls as a potential control method for channel catfish and largemouth bass. While they did not recommend this type of control for green sunfish and black bullhead, both these species prefer more lentic habitats and are adversely impacted during high-flow events (Gido et al. 1997, Marchetti and Moyle 2001). Conversely, Tyus and Saunders (2000) felt increasing the frequency of high-flow events would only temporarily control nonnative fishes, and cause some negative impact to native fishes. The large number of dams and storage reservoirs on the Colorado River provides the potential for flow manipulations. Such engineered controls are not available on the Virgin River. While we believe that an increased frequency and magnitude of high-flow events would help decrease negative interactions between native and nonnative fishes, we see little potential for sufficiently manipulating river conditions on the Virgin River at this time.

Given the numbers and types of species known to occur in the Study Area and the fact that no negative impacts should occur to native fishes, we felt different methods of removing fish mechanically and preventing nonnative fish from entering the channel from off channel areas would be the most feasible and effective reduction methods. We sent an e-mail trip report to the Program Director and other Program participants, and we requested their input on the mechanical removal option. We also suggested further investigation of known off-channel areas that were potential sources for nonnative fishes, and experimenting with mechanical removal in some of these areas. We received no negative feedback and proceeded with the removal effort.

Mechanical Removal and Further Off-channel Investigations

The following results are from the September 2001 sampling of Washington Fields Diversion to Johnson Diversion, as well as further off-channel area investigations during that time. The numbers of fish caught during the mechanical removals in the beaver dam complex and between the Washington Fields and Johnson Diversions are shown in Table 13. Also shown are the results of sampling in Quail Creek seepage pond and marsh (created by the seepage from Quail Creek Reservoir) and additional sampling at Berry Springs Pond. We did not encounter as many of the target nonnative species in the river as we did during the baseline sampling (Table 6). Qualitative electrofishing for approximately 5,000 seconds over less than 30 % of the Washington Fields Diversion-Johnson Diversion reach (about 1.75 miles) showed almost the same number of black bullhead and half of the largemouth bass caught during more intense sampling of the entire Washington Fields Diversion-Johnson Diversion reach with the seine and trammel net. Flows seemed to be lower during this trip than during the August trip, and the deeper areas were around debris, which made sampling with nets difficult. Unfortunately, the low-flow conditions also created high conductivity in the water, and reducing our electric field to about 12 inches in diameter and 100 volts. This was enough to chase some fish from their cover, but it only incapacitated a few. The flow data from surrounding gauges did not support our observation of lower flows (Figure 2), but flows are highly variable through the Washington Fields reach because of fluctuating water demand.

Table 13. Number of samples and fish of each species caught during sampling for nonnative fish from the Washington Fields to Johnson Diversion and some off-channel areas in September 2001. Numbers in parentheses refer to the number of fishes observed but not captured during qualitative electrofishing.

AREA	SAMPLES	BB	CC	DS	FM	GS	LB	MF	RC	RS	SD	VS	WF
WF-JD	124	20	0	11	13	0	2	173	10	485	11	1	77
EFISH	Qual	7(12)	0	0	1	0	0(1)	1	3	3	0	0	0
BDC	35	1,310	0	0	0	2	1	0	0	0	0	0	0
QCM	3	0	0	0	0	0	0	0	0	0	0	0	0
QCP	4	0	0	0	0	48	0	0	0	0	0	0	0
BSP	21	0	0	0	0	54	24	0	0	0	0	0	0
TOTAL	187	1,330	0	11	0	104	27	173	10	485	11	1	77

Fish abbreviations: BB = black bullhead, CC = channel catfish, DS = desert sucker, FM = flannelmouth sucker, GS = green sunfish, LB = largemouth bass, MF = mosquitofish, RC = Virgin River chub, RS = red shiner, SD = speckled dace, VS = Virgin spinedace, WF = woundfin. Numbers in parentheses are fish observed, but not caught.

Reach abbreviations: WF = Washington Fields Diversion reach, JD = Johnson Diversion reach, EFISH = area qualitatively electrofished, BDC = beaver dam complex, QCM = Quail Creek seepage marsh, QCP = Quail Creek seepage pond, BSP = Berry Springs Pond.

First pass catch-per-unit area supported the observations that our catch was down from the August trip for all nonnative species except mosquitofish (Figure 11). Native species numbers were similar except for lower number of desert suckers and higher numbers of woundfin (Figure 12). Figure 13 shows that nonnative fishes seemed to use deeper areas during this sampling, but paired t-tests modified for unequal variances showed that these differences were not significant. The lack of significance may have been related to the small number of samples with nonnative fishes (N=5). Table 14 shows the habitats where the nonnative species were found in comparison to native fishes. Tables 14 and 15 show the habitat and substrates where target nonnative species were found versus where native fish species were found. Chi-square goodness-of-fit tests showed that the habitat distribution of the target nonnative species (essentially black bullhead) included backwaters more than expected and runs less than expected ($p < 0.03$). Table 16 shows the use of cover by the target nonnative species. Little can be drawn from this information because only five of the samples contained nonnative species. Qualitative electrofishing showed black bullhead were found almost exclusively in association with cover (undercut banks and woody debris).

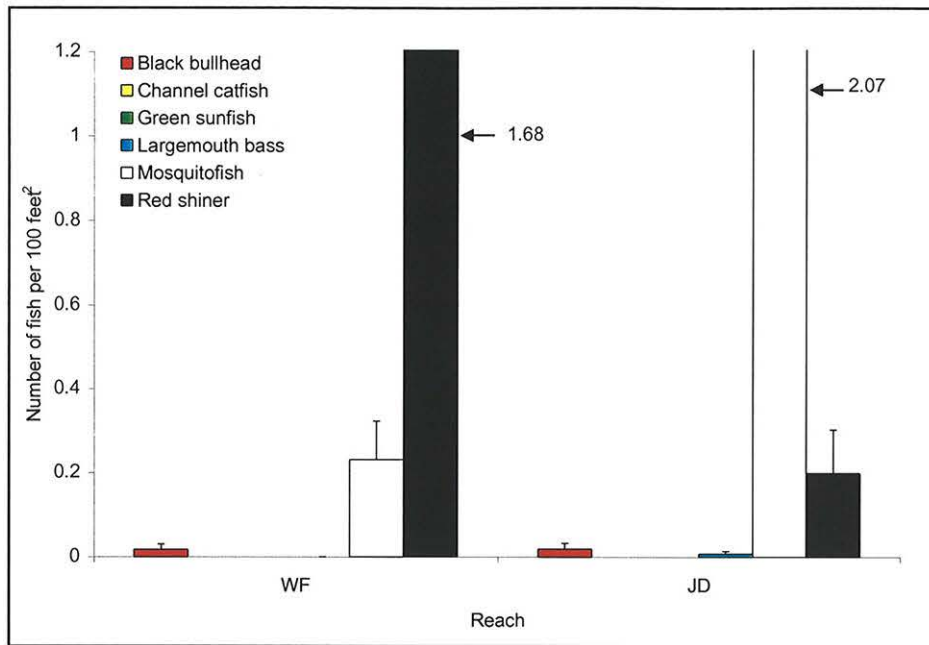


Figure 11. First pass catch-per-unit area for nonnative fishes in the Washington Fields Diversion reach and Johnson Diversion reach during the removal period.

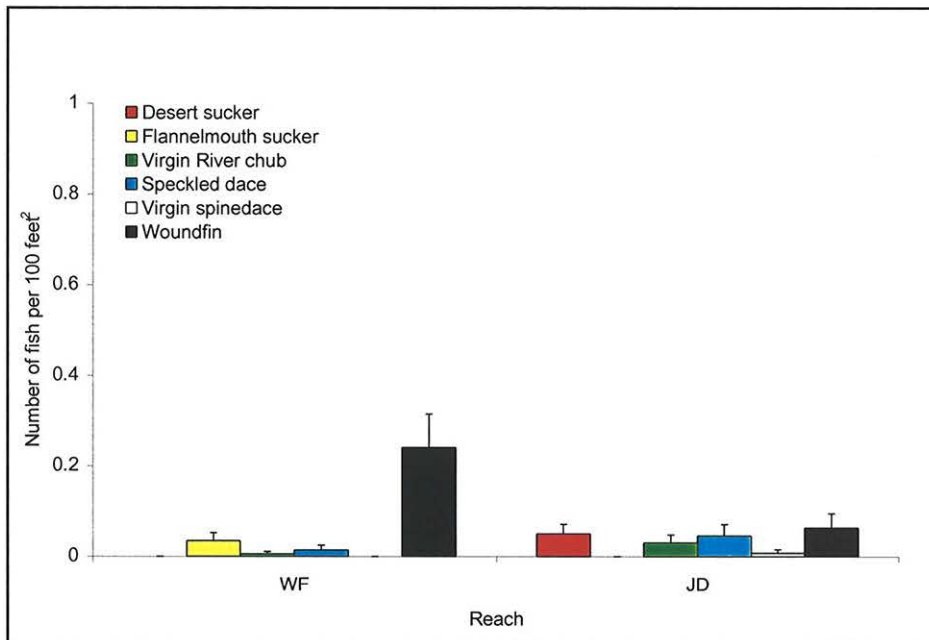


Figure 12. First pass catch-per-unit area for native fishes in the Washington Diversion reach and Johnson Diversion reach during the removal period.

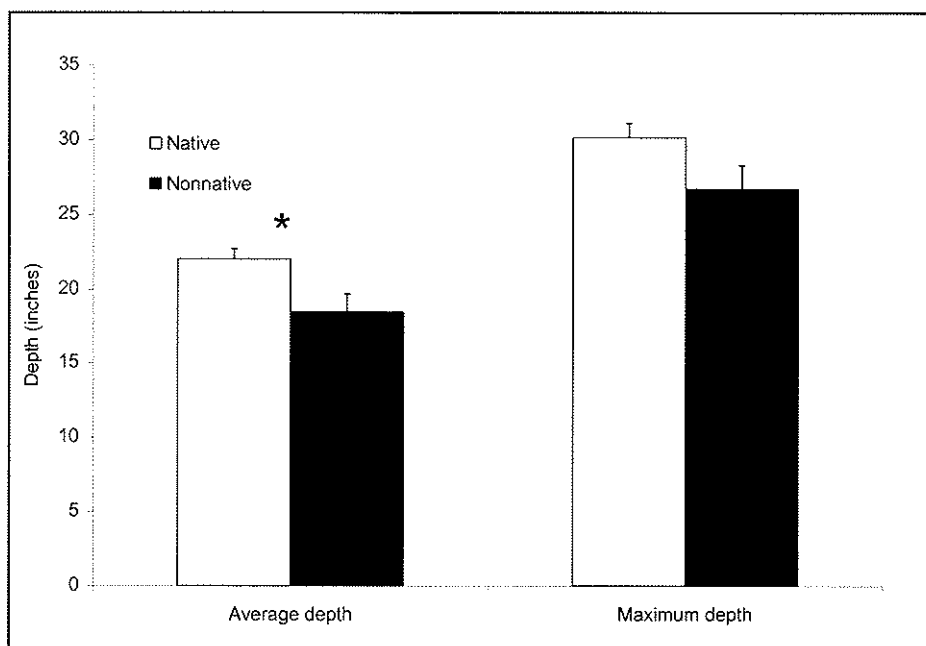


Figure 13. Average of mean and maximum depths measured for samples containing target nonnative species and for samples containing native species. (*= Significant difference at ≤ 0.05 .)

Table 14. Habitats sampled versus habitats where native species and target nonnative species were captured in the Virgin River during the September 2001 sampling trip.

HABITAT	ALL SAMPLES	ALL TARGET NONNATIVE SPECIES	ALL NATIVES	BLACK BULLHEAD	LARGEMOUTH BASS
Pool	4	1	2	1	0
Run	94	1	31	1	0
Eddy	6	1	2	1	0
Backwater	11	2	0	2	1
Side channel	0	0	0	0	0
Side run	2	0	0	0	0
Run/riffle	0	0	0	0	0
Side riffle/run	0	0	0	0	0
Riffle/run	2	0	0	0	0
Pool/run	5	0	1	0	0
Riffle	0	0	0	0	0
Run/eddy	0	0	0	0	0
TOTAL	124	5	36	5	1

Table 15. Dominant substrate type in samples where native species and target nonnative species were captured during the September 2001 sampling trip.

SUBSTRATE	ALL SAMPLES	ALL TARGET NONNATIVE SPECIES	NATIVES	BLACK BULLHEAD	LARGEMOUTH BASS
Silt	31	2	6	2	0
Sand	91	3	30	3	1
Fine gravel	1	0	0	0	0
Coarse gravel	1	0	0	0	0
Small cobble	0	0	0	0	0
Large cobble	0	0	0	0	0
Boulder	0	0	0	0	0
TOTAL	124	5	36	5	1

Table 16. Cover present in samples where target nonnative species and native species were captured during the September 2001 sampling trip.

COVER	ALL SAMPLES	ALL TARGET NONNATIVE SPECIES	NATIVES	BLACK BULLHEAD	LARGEMOUTH BASS
Overhanging vegetation	48	2	19	2	0
Inundated vegetation	23	0	4	0	0
Roots	0	0	0	0	0
Small woody debris	22	0	5	0	0
Large woody debris	2	0	1	0	0
Boulders	1	0	0	0	0
Bedrock	0	0	0	0	0
No cover	45	3	13	3	1

We saw a high catch-per-net night for black bullhead in the beaver dam complex (Figure 14). Unfortunately, while we saw some depletion over the first 2 nights, we caught double the first night's catch on the third night. The increase indicated that large numbers of black bullhead were present in the pond and that we had little impact on the population. Fyke nets seemed to be the most effective gear. Over 90 % of the fish caught in the beaver dam complex were found in fyke nets. Only three black bullhead were captured in 12 minnow traps set in the beaver dam complex on September 17, 2001.

Investigations of Quail Creek seepage pond, Quail Creek seepage marsh, and Berry Springs Pond showed that these areas had populations of centrarchids but few, if any, black bullhead (Figure 15). Fyke nets and hoop nets still did not seem to adequately sample the large numbers of largemouth bass and green sunfish we observed in Berry Springs Pond. Minnow traps seemed to do a slightly better job at capturing young-of-year centrarchids (Figure 16), but based on observation, we did little to impact the population of centrarchids in Berry Springs Pond.

Summary

After deciding that nonnative fishes posed a potential threat to native fishes above the Washington Fields Diversion, we evaluated the potential for chemical, mechanical, biological, and physicochemical control of nonnative fishes in the Study Area. Poisoning at any level in the main stem of the Virgin River above Washington Fields would probably cause massive to complete mortality of the native fish populations. Since this area contains the largest remaining populations of most of the native fishes, including the endangered woundfin, this is not a viable option. However, in off-channel areas where the chemical can be contained, chemical treatment may be a viable option for controlling nonnative fish populations. Introduction of additional species or parasites to the system poses too great a threat to natives fishes, so we decided biological control was an unattractive option. Since the Virgin River does not have any large reservoirs directly on the main stem, we felt physicochemical control was not an option. Mechanical removal is labor intensive and usually only results in a temporary reduction in the target species. However, given the limitations of other removal methods, we felt that experimenting with different methods of mechanical removal would be the best option at this time.

We attempted to lower numbers of nonnative fishes between Washington Fields Diversion and Johnson Diversion using seines and a floating trammel net during September 2001. We also used hoop nets and fyke nets to attempt to lower numbers of nonnative species in the off-channel beaver dam complex. First pass catch-per-unit area was lower in September 2001 than in August 2001. We felt that this difference was probably caused by reduced sampling efficiency in September and not by our August sampling effectively reducing numbers of nonnative fishes. Qualitative electrofishing over 30 % of the 6 miles between the two diversions produced almost the same numbers of nonnative fishes as seining and trammel netting the whole reach. Three nights of sampling in the beaver dam complex removed over 1,000 black bullhead but failed to show depletion in numbers over the 3 nights. Other off-channel areas above the Washington Fields Diversion had high numbers of green sunfish and largemouth bass.

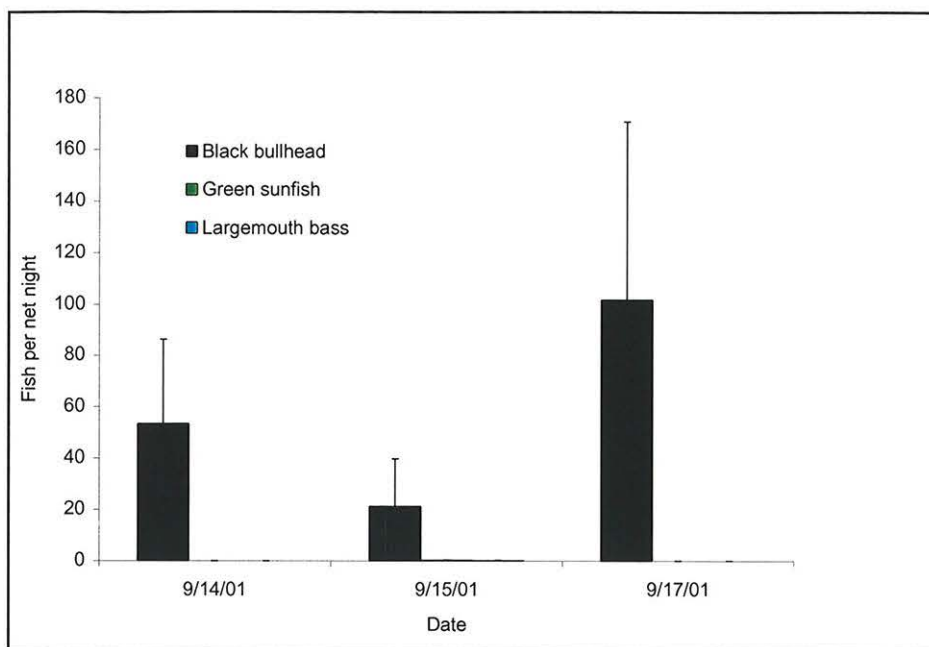


Figure 14. Catch-per-net night for nonnative fishes in the beaver dam complex over the 3-night period.

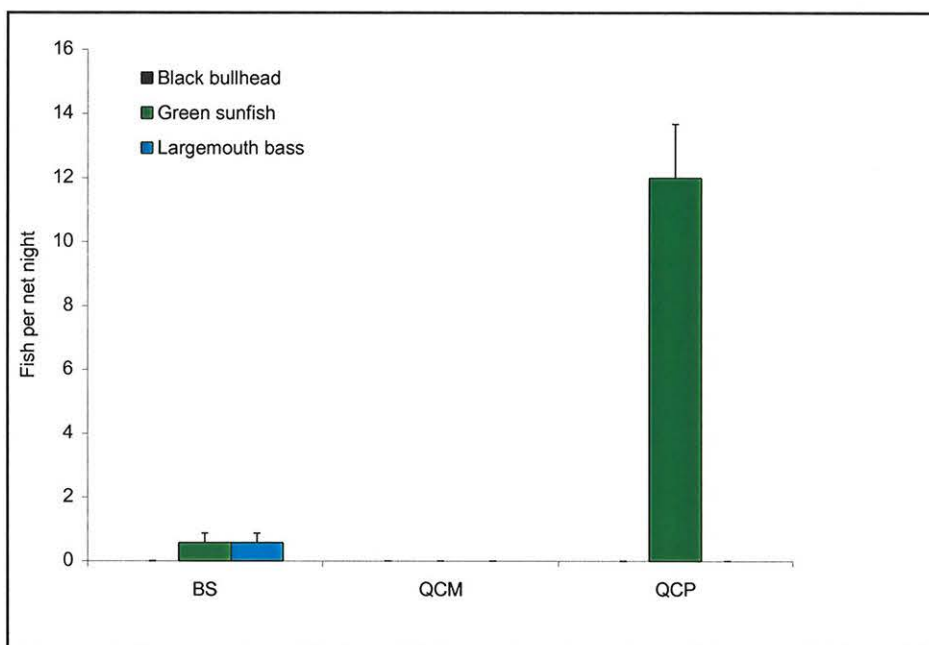


Figure 15. Catch-per-net night for nonnative fishes captured with fyke and hoop nets in Berry Springs Pond (BS), Quail Creek seepage pond (QCP), and Quail Creek seepage marsh (QCM).

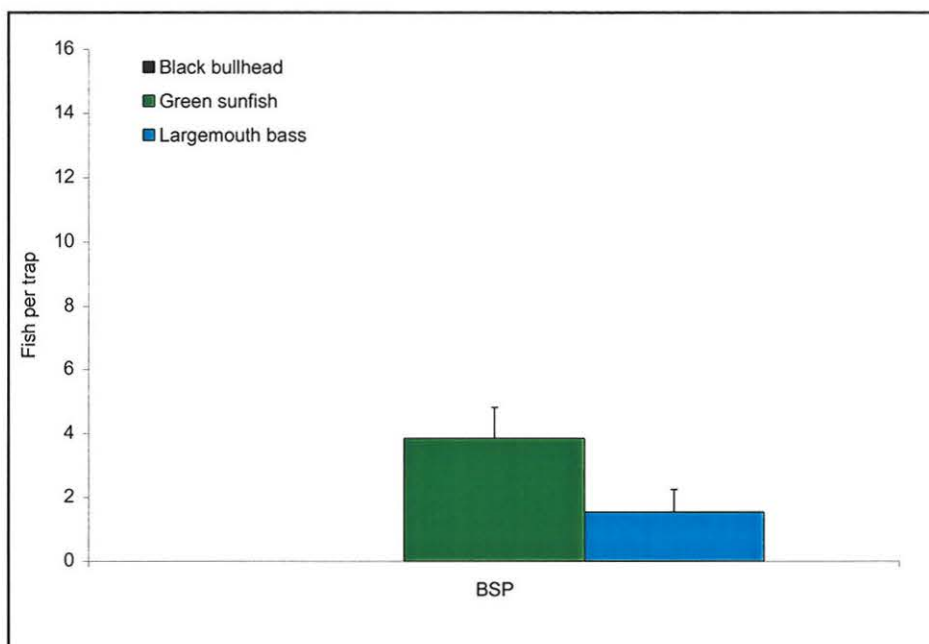


Figure 16. Catch-per-trap night for nonnative fishes captured with minnow traps in Berry Springs Pond.

Evaluating Effectiveness

Evaluations of the ineffectiveness of the mechanical removal methods were the lack of depletion we saw in sampling the beaver dam complex and the higher numbers of black bullhead we saw during electrofishing. Numbers of nonnative fishes captured in the Washington Fields Diversion-Johnson Diversion reach during the salvage efforts prior to the treatment were similar to the numbers we removed in September 2001. This result also suggests that our mechanical removal methods were ineffective (Table 17). An examination of data collected from the reach over the prior 18 months suggested that numbers of the target nonnative species captured during sampling are highly variable. The variability is probably related to their affinity for cover and habitats that are difficult to sample, differences in flow levels, and connections to off-channel areas. Many of the collections with high numbers of nonnative species coincided with very low flows and, in some cases, standing pools. The December 13, 2000, sample shows eight black bullhead were caught in 35 seine hauls. The entire reach was treated with rotenone on December 6, 2000. Therefore, either black bullhead quickly colonize from upstream areas, or the treatment was ineffective at removing all black bullhead from the reach.

Table 17. Number of target nonnative species collected during UDWR sampling of the Washington Fields to Johnson Diversion reach from March 2000 to October 2001.

DATE	NUMBER OF SAMPLES	GEAR	BB ^a	LB	GS	CC
03/10/2000	53	Seine	0	0	0	0
03/13/2000	46	Seine	4	0	0	0
05/16/2000	100	Seine	0	0	0	0
06/02/2000	35	Seine	2	2	0	0
06/27/2000	20	Seine	6	8	0	0
07/05/2000	18	Seine	0	15	0	0
07/18/2000	20	Seine	0	0	0	0
08/17/2000	15	Seine	50	16	0	0
09/15/2000	10	Seine	0	0	0	0
09/19/2000	46	Seine	0	0	0	0
10/19/2000	10	Minnow traps	0	0	4	0
11/17/2000	20	Seine	0	0	0	0
11/21/2000	10	Seine	0	0	0	0
12/04/2000	265	Seine/ minnow traps/ hoop nets	1	1	0	0
12/13/2000	35	Seine	8	0	0	0
02/15/2001	12	Seine	0	0	0	0
03/15/2001	71	Seine	0	0	0	0
04/05/2001	2	Seine	0	0	0	0
04/10/2001	12	Seine	0	0	0	0
04/12/2001	58	Seine	0	0	0	0
05/25/2001	14	Seine	0	0	0	0
08/02/2001	?	Seine	2	24	0	0
08/16/2001	7	Seine	6	2	0	0
09/04/2001	51	Seine	26	0	0	0
09/05/2001	16	Seine	0	0	0	0
10/12/2001	6	Hoop nets	18	0	0	0
10/12/2001	102	Seine	0	0	0	0
10/15/2001	?	Seine	6	1	0	0

^a BB = black bullhead, LB = largemouth bass, GS = green sunfish, CC = channel catfish.

The rotenone treatment gave us an opportunity to obtain an almost-complete sample of both the Washington Fields Diversion-Johnson Diversion reach and the beaver dam complex. Table 18 shows the actual number of fish observed in the river from Washington Fields Diversion to Johnson Diversion, during the rotenone treatment, by one individual walking the reach from 3.5 hours after the treatment started until 9 hours after the treatment started. Additionally, numbers of fish collected by Brigham Young University researchers are also included in this total (Derek Houston, BYU, personal communication). The number of fish shown for the beaver dam complex is derived from a one-time visual estimate at the two biggest ponds. Obviously, all of these numbers have some amount of inherent error. The native fishes seemed to be impacted more quickly by the rotenone. We feel that our counts of native fishes are probably underestimates, because fish drifted downstream, were covered by sedimentation, or possibly were scavenged before they could be counted. After discussions with UDWR personnel, we think that our counts, with the addition of numbers from other collectors, probably represent 50-70 % of the actual numbers of native fishes killed during the treatment.

Table 18. Number of fish of each species counted/estimated during the October 16, 2001, rotenone treatment of the Washington Fields to Johnson Diversion reach and some off-channel areas in September 2001.

REACH	BB	CC	DS	FM	GS	LB	MF	RC	RS	SD	VS	WF
WF-JD	700	0	70	94	4	1	23	79	142	53	15	43
BDC	5,000	0	0	0	0	0	0	0	0	0	0	0
TOTAL	3,200	0	70	94	4	1	23	79	142	53	15	43

Fish abbreviations: BB = black bullhead, CC = channel catfish, DS = desert sucker, FM = flannelmouth sucker, GS = green sunfish, LB = largemouth bass, MF = mosquitofish, RC = Virgin River chub, RS = red shiner, SD = speckled dace, VS = Virgin spinedace, WF = woundfin.

Reach abbreviations: WF = Washington Fields Diversion reach, JD = Johnson Diversion reach, BDC = beaver dam complex.

The nonnative species seemed to resist the effects of the rotenone longer, but we still suspect our counts are underestimates. Additionally, many mosquitofish and red shiner were still finding refugia while we walked upstream. The UDWR personnel quickly neutralized these refugia and estimated that at least 500-1,000 mosquitofish and more than 1,000 red shiner were killed (Kevin Wheeler and Rick Fridell, UDWR, personal communication). Our count of black bullhead in the river seemed fairly accurate, and we think that about 75 % of what was actually killed was counted. Numbers of black bullhead killed in the beaver dam complex easily exceeded 5,000. Very few green sunfish and largemouth bass were seen, but based on our past sampling, few were present.

Using nets in both August and September 2001, we captured 42 (4.2 %) of the estimated 1,000 black bullhead killed during the rotenone treatment. If we assume that the reach between Washington Fields Diversion and Johnson Diversion is 6 miles long, and averages 15 feet in width, then the catch-per-unit area of river for black bullhead using the rotenone treatment would be

approximately 0.21 black bullhead per 100 square feet. Figure 17 shows that the density of black bullhead seen during the rotenone treatment was about 7 times higher than our estimate of density from Washington Fields Diversion to Johnson Diversion, using combined data from the August 2001 and September 2001 sampling.

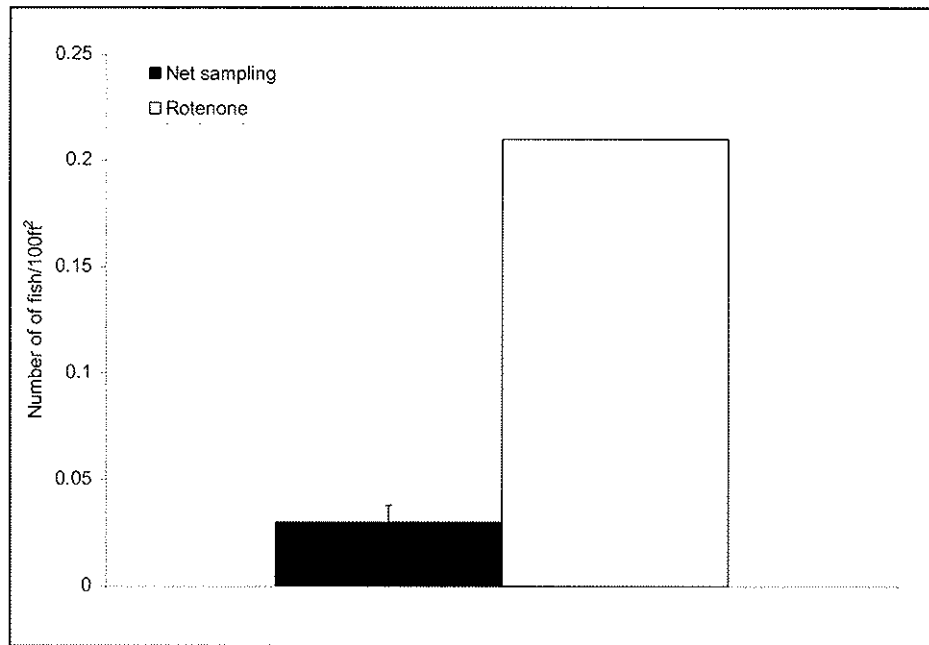


Figure 17. Estimated density of black bullhead in the Washington Fields Diversion to Johnson Diversion section from net sampling and rotenone treatment.

Summary

We evaluated our effectiveness between our prior sampling in August 2001, September 2001, and numbers of nonnative fishes seen during a rotenone treatment of the reach by the UDWR for control of red shiner in October 2001. First pass catch-per-unit area was lower in September 2001 than in August 2001. We felt that this difference was probably caused by reduced sampling efficiency in September and not by our August sampling effectively reducing numbers of nonnative fishes. The number of nonnative fishes we observed during the rotenone treatment was equivalent to almost seven times the density estimated by our mechanical removal efforts, indicating that our methods were of limited effectiveness for capturing many of the nonnative fishes in the river. Numbers of nonnative fishes caught in the beaver dam complex sampling did not show a depletion over 3 nights of sampling, and numbers seen during the rotenone treatment were 5-10 times greater than those seen during the September 2001 sampling.

DISCUSSION

Baseline sampling of the Virgin River from the State Route 9 bridge below Pah Tempe Springs to the Johnson Diversion showed that nonnative fishes other than red shiner and mosquitofish pose a potential threat to native fishes in this area. Black bullhead, green sunfish, and largemouth bass densities from above Gould's Wash to the Hurricane Bridge were higher than those between Washington Fields Diversion and the Johnson Diversion. Native fishes were present in 63 % of samples containing nonnative fishes, indicating that when these nonnative fishes are found they are often in association with native fishes, thereby increasing the potential for negative interactions. We found a few reaches of the Virgin River that had few or no nonnative fishes in the Study Area. We collected very few nonnative fishes in the Pah Tempe reach section and no nonnative fishes in the Hurricane Bridge reach section. The Pah Tempe reach had the most pool habitat, but much of that habitat had swift moving water and larger substrate. Most of the Pah Tempe reach of the Study Area has a fairly narrow floodplain constrained by cliff walls on either side of the river channel, which results in higher water velocity. Our examination of the habitats utilized by the nonnative fishes we captured over the course of the project showed that nonnative fishes appeared to prefer lower-velocity habitats with silt and sand substrate, which could explain why few nonnative fishes were found in the swifter pool habitats of the Pah Tempe reach.

The Hurricane Bridge reach also seemed to have slightly less habitat conducive to the target nonnative species. However, it seems unlikely that no target nonnative fishes are present the Hurricane Bridge reach, since target nonnative fishes were found upstream and downstream of this reach. The elevated flow and turbidity on the day we sampled the Hurricane Bridge reach may have lowered our sampling efficiency; it definitely reduced our ability to make comparisons of this reach with the other reaches sampled. The potentially large influence that this spate had on our collection efforts highlights our baseline sampling limitations. Conducting one sampling trip only provides data for a "snapshot" in time.

While the spate may have reduced our sampling efficiency for the target nonnative fishes in the Hurricane Bridge section, our efficiency in other areas may have been increased by the flow conditions present during August 2001. The sampling took place when nonnative fishes were most likely to be utilizing the main stem of the Virgin River. The low-flow conditions present in late summer and early fall provide the most habitat for nonnative fishes in the main channel of the river. It is possible that at other times of the year nonnative fishes are utilizing off-channel refugia habitat and that these species are only present in large numbers in the main channel when flow conditions are ideal. Our data do not provide information on the potential seasonal dynamics of nonnative fish populations the Study Area. Conversely, during our September 2001 removal efforts between Washington Fields Diversion and Johnson Diversion, flows that appeared during the August 2001 sampling seemed to decrease our sampling efficiency, especially for black bullhead. In short, nonnative fish densities may be higher or lower than shown by our sampling, because we only sampled each area under a limited set of conditions.

While habitat differences may partially explain the differences in nonnative fish densities between reaches, the amount of off-channel area populations may also impact river densities. The Gould's Wash reach, Stratton Pond reach, Washington Fields Diversion reach, and Johnson Diversion reach all have off-channel areas with at least the potential to be significant sources of nonnative fishes. Quail Creek Reservoir, Stratton Pond, Berry Springs Pond, Quail Creek seepage pond, and the beaver dam complex all have populations of the target nonnative species. Berry Springs Pond, Quail Creek seepage pond, and the beaver dam complex all have direct connections to the river, and Quail Creek Reservoir and Stratton Pond release water into the Virgin River. Gould's Wash and several other inflows also have the potential to be sources for nonnative fishes. Gould's Wash has a potential refuge for nonnative fishes where it forms a plunge pool as it spills over cliffs onto the floodplain (Thom Hardy, Utah State University, personal communication). Conversely, the Pah Tempe reach has few off-channel sources. Several ponds do exist off of Ash and LaVerkin creeks, some of which contain nonnative fishes (Steve Meisner, Virgin River Resource Management & Recovery Program, personal communication; Jim McMahon, Grand Canyon Trust, personal communication). These ponds and/or the impoundment above Quail Creek Diversion may have been the source for larger numbers of the target nonnative species historically seen in the Pah Tempe reach.

Other researchers have indicated that off-channel areas are the most likely source for black bullhead, green sunfish, and largemouth bass found in western rivers (Cross 1975, Hawkins and Nesler 1991, Lentsch et al. 1996). Given the habitat preferences of the species in question, vegetated, low-velocity off-channel areas would provide ideal refugia and nursery habitat. Our sampling confirmed the potential for these off-channel areas to be major sources of nonnative fishes. We found that off-channel refugia contained hundreds to thousands of black bullhead, green sunfish, and largemouth bass. Whenever these off-channel areas have a direct connection to the river, we would expect nonnative fishes to exploit whatever riverine habitat is suitable to their needs.

We feel that the fact that these nonnative species are present and are at higher densities than we originally thought is a cause for concern. However, their presence alone does not confirm any negative impact on the native fishes of the Virgin River. All four of the species found during historical sampling and our baseline sampling of the Virgin River between Pah Tempe Springs and Washington Fields Diversion are known to be predators of native fishes. Black bullhead and channel catfish are omnivorous, feeding on invertebrates, plant material, detritus, and fish (Tabata et al. 1965, Cross 1975, Sigler and Sigler 1987). Largemouth bass and green sunfish are generally more carnivorous, feeding mainly on invertebrates and fish (Carlander 1977). Brandenburg and Gido (1999) noted that black bullhead and largemouth bass consumed larvae of native dace and suckers in the San Juan River. Marsh and Douglas (1997) found humpback chub (*Gila cypha*) remains in channel catfish and black bullhead stomachs taken from the Little Colorado River. Green sunfish have been shown to feed on razorback sucker and Colorado pikeminnow larvae (Osmundson 1987, Marsh and Langhorst 1988). Channel catfish have been observed feeding on razorback sucker eggs (Holden et al. 1999). Schwemm and Unmack (2001) found largemouth bass preying upon native suckers in the lower Salt River in Arizona. Channel catfish and largemouth

bass predation on native suckers has been observed in the lower Virgin River by the authors and Jim Heinrich (NDOW, personal communication). In reviews investigating the impact of nonnative fish species, channel catfish and green sunfish, and to a lesser extent largemouth bass and black bullhead, have been identified as threats to the native fishes of the Colorado River (Hawkins and Nesler 1991, Lentsch et al. 1996). The presence of these species in the Virgin River and their documented negative effects on native fishes in other systems has earmarked them as a potential threat to the native and endangered fishes in the Virgin River above Washington Fields Diversion.

We documented piscivory by black bullhead, green sunfish, and largemouth bass in the Virgin River above Washington Fields Diversion. Green sunfish showed the highest amount of piscivory, but all as a result of cannibalism in off-channel areas. The fish from off-channel areas were captured using fyke nets and hoop nets that were set for at least 12 hours. Trapping the fish in a confined space for that duration probably facilitated the cannibalism by green sunfish, but it also demonstrated the potential piscivory of that species. We also saw predation on native fishes, including woundfin, by largemouth bass and black bullhead in the river channel. While we can only confirm predation upon native fishes in 1.6 % of the stomachs collected, we feel that this is probably an underestimate of the amount of predation. The stomachs we collected from green sunfish and largemouth bass in the Study Area were skewed toward smaller age classes of fish. Many of the larger fish (e.g., 295-mm-, 251-mm-, and 232-mm-long largemouth bass, and a 370-mm-long channel catfish) we caught in the Study Area had empty stomachs. Other researchers have indicated that the larval and juvenile stages of native fishes are the life stage most prone to predation (Osmundson 1987, Marsh and Langhorst 1988, Hawkins and Nesler 1991, Gido and Propst 1999). We did not sample when larval fish were an available prey item. Therefore, while we confirmed that predation on native fishes is occurring, we can not be sure to what degree this predation impacts the native fish community.

Our baseline sampling and stomach analysis provided evidence that the target nonnative species pose a potential threat to the native fishes above Washington Fields Diversion. Our experiment with potential mechanical removal methods from Washington Fields Diversion to the Johnson Diversion and in the beaver dam complex showed that we were relatively ineffective at reducing the number of nonnative fishes in either area. Our catch-per-net night of black bullhead in the beaver dam complex increased on the third night of sampling in that area, indicating large numbers of black bullhead were present and that we were not effective at lowering their numbers. Two black fyke nets caught over 90 % of the fish captured in the beaver dam complex. If mechanical removal of black bullhead in off-channel areas is attempted in the future, we suggest using black fyke nets with long runners instead of hoop nets.

We estimated lower densities of the target nonnative species from the Washington Fields Diversion to the Johnson Diversion during September 2001 sampling than during the August 2001 sampling. However, we do not believe that our August sampling lowered numbers of nonnative species in the reach. Instead, we believe that this was product of decreased sampling efficiency in September. While the flow data from the Hurricane, Bloomington, and Saint George gauges all show slightly higher flows during the September sampling trip, we believe that actual flows below Washington

Fields Diversion were lower, perhaps a result of larger amounts of diverted water. The lower flows made sampling more difficult, because most of the deeper areas were associated with debris and/or cover that made sampling with nets inefficient. Our qualitative electrofishing confirmed our inefficiency using the seine and trammel net. While electrofishing, we sampled less than 30 % of the area sampled with nets and captured/observed the same number of black bullhead. Almost all black bullhead observed were associated with undercut banks or woody debris that would have been unsampleable with nets. Unfortunately, the high conductivity associated with the low flows also made electrofishing inefficient at capturing fish. Sampling with as many different gear types as possible under the ideal flow conditions may be the only way to successfully lower numbers of nonnative fishes by mechanical means.

Our observations of nonnative fish numbers during the rotenone treatment also showed the limitations of our mechanical removal. We estimated that approximately 1,000 black bullhead were killed in the Washington Fields-Johnson Diversion reach during the rotenone treatment. If this estimate is accurate, then our sampling with nets in August and September only removed 4.2% of the black bullhead observed during the treatment, and the estimate of black bullhead density from our net sampling was seven times lower than the estimate made from the rotenone treatment. Our inability to mechanically remove a large number of black bullhead is probably the result of the ineffectiveness of using nets to sample areas with woody debris and undercut banks. The large beaver dam complex population of black bullhead, which apparently provides a large source of black bullhead to the river, could have also inhibited our ability to lower numbers of black bullhead in the river. Our experiments indicate that mechanical removals would be relatively ineffective for black bullhead without more intense and sustained removals, and even then it is unclear whether a large proportion of the populations could be removed.

Few centrarchids were found between Washington Fields Diversion and the Johnson Diversion. Therefore, we can not judge the effectiveness of our mechanical removals on green sunfish and largemouth bass. Since higher numbers of largemouth bass and green sunfish were seen above Washington Fields Diversion, this presents a limitation in our data. The large numbers of centrarchids in Berry Springs Pond and Quail Creek seepage pond would likely limit the effectiveness of mechanical removal methods in lowering fish numbers in the river. Intense sustained removals using minnow traps, fyke nets, and rod and reel (for adult largemouth bass) would be necessary possibly reduce numbers of centrarchids in the Quail Creek seepage pond and Berry Springs Pond. Until such off-channel areas are brought under control, it is unlikely that we will be able to control nonnative fish numbers in the Study Area.

CONCLUSIONS AND RECOMMENDATIONS

The threat that nonnative species pose to native fish populations in the upper Virgin River will not end if and when chemical treatment is successful at removing red shiner from Washington Fields Diversion downstream to the Utah border. Black bullhead, green sunfish, and largemouth bass are present in high enough numbers upstream of Washington Fields Diversion to recolonize the reclaimed reaches. The habitat requirements of these species are more stringent than those of red shiner, and they are not likely to persist in the Virgin River at high numbers year round. However, during low-flow periods these fishes will move into the river channel from any off-channel refugia. Low-flow periods are likely to congregate native fish species into deeper habitats frequented by the nonnative predators, thereby exacerbating the negative effects of the nonnative species.

This study showed that mechanical removal methods are unlikely to result in substantial reductions of nonnative fishes in the river channel or off-channel areas, unless a large amount of man hours are expended. Since the largest numbers of nonnative fishes were concentrated in off-channel areas like the beaver dam complex, Berry Springs Pond, and Quail Creek seepage pond, we feel it makes sense to target these areas for complete reclamation. Removing nonnative fishes from off-channel areas and preventing their reintroduction into the Virgin River from recreational fisheries and private ponds in the area are probably the most effective ways to control nonnative fish species in the Pah Tempe Springs to Washington Fields Diversion section of the Virgin River.

During this study we collected data showing that nonnative fishes are present in the Study Area. We showed that predation on native fishes, including the endangered woundfin, is occurring in the Study Area. We also found that our study had several limitations and that small-scale mechanical removal methods do not appear to be effective at lowering numbers of nonnative fishes. With these conclusions and limitations in mind, we feel that future work focused on reducing the target nonnative species above Washington Fields Diversion can take two directions.

Further research into the impacts of the target nonnative species on native fishes above Washington Fields may be warranted. This study showed that the density of nonnative fish populations (including black bullhead, largemouth bass, and green sunfish) may be nearly as high as some native fish populations in certain areas of the Study Area. However, the one-time sampling effort did not provide a confident estimate of nonnative fish densities throughout the reach. A high-flow event during the baseline sampling may have altered sampling efficiency for at least one of the reaches sampled. The low flow of late summer and early fall provides the best sampling conditions, but it also provides the best conditions for nonnative fishes in the river (Gido et al. 1997, Marchetti and Moyle 2001, Holden et al. 2001). During the higher flows of winter and spring, nonnative fishes may be flushed from the river channel or move into off-channel habitats. As flows recede, nonnative species may recolonize from off-channel areas. The impacts of nonnative species may be limited to certain low-flow periods.

We also found that about 11 % of the stomachs taken from nonnative predators in the river channel and off-channel areas contained fish or fish remains. At least two native fish were found in the stomach samples, including a 55-mm-long woundfin in the stomach of a 111-mm-long largemouth bass. While black bullhead appeared to be omnivorous, largemouth bass were more specialized, consuming a few groups of invertebrates and fish. Most of the centrarchids captured in the river channel were relatively small, and the larger centrarchids that were captured had empty stomachs. Larger centrarchids may be more piscivorous on native fishes. Additionally, all three target nonnative species have been shown to have the highest amount of habitat overlap and impact on larval and juvenile native fishes (Osmundson 1987, Marsh and Langhorst 1988, Hawkins and Nesler 1991, Brandenburg and Gido 1999, Gido and Propst 1999). This study did not occur when larval fish were available as prey items.

Therefore, while we have shown the presence of nonnative fishes above Washington Fields Diversion and demonstrated that largemouth bass and black bullhead prey on native fishes, we are still unsure to what extent these fishes are impacting the native fish fauna. If the Program wishes to investigate this further before proceeding with management actions, then we recommend conducting studies that will clarify the density of nonnative fishes and decipher any seasonal patterns of nonnative fishes density above Washington Fields Diversion. Studies of this type should help identify the magnitude and timing of nonnative fish impacts on native and endangered fishes. We also recommend conducting studies that will clarify the magnitude of predation on native fishes by nonnative fishes, including what life stages of native fish are most vulnerable to predation. Knowing more about the seasonal density and predation habits of nonnative fishes would assist in determining management objectives above Washington Fields Diversion and potentially below Washington Fields Diversion after chemical reclamation removes the nonnative red shiner.

Conversely, we have found nonnative fish species above Washington Fields Diversion that have been implicated in the decline of imperiled fish species in other systems, and we have found evidence that these nonnative fish species are preying upon the imperiled native fish species. If the Program decides that this study has provided enough information to conclude that the target nonnative species are impacting the native and imperiled species of the Virgin River above Washington Fields Diversion, then we recommend the following steps toward removing the target nonnative species from the Virgin River.

1. Identify and Map All Source Areas

We found that large numbers of nonnative fish, especially largemouth bass and green sunfish, reside in a few off-channel reservoirs, ponds, and wetlands. We mapped some of these off-channel areas, along with wet and dry inflows to the river, along the Study Area. However, not all off-channel areas were sampled during this study. Several areas, such as private ponds, a large plunge pool up Gould's Wash, and the impoundment above Quail Creek Diversion, were identified but not sampled. Not all inflows that were identified were followed to their sources. BIO-WEST, found all target nonnative species in a recent sampling of Ash and LaVerkin creeks, indicating that ponds

near or on tributaries may be sources of target nonnative species. Hawkins and Nesler (1991) and Lentsch et al. (1996) stated that off-channel areas were most likely the seed populations for nonnative fishes, particularly centrarchids, in the Green River and Colorado River. The large numbers of nonnative fishes we found in off-channel areas would probably limit the success of any mechanical removal efforts in the main channel, because the target nonnative species could quickly recolonize from these refuge areas. We recommend a thorough inventory and analysis of the off-channel areas and their fish fauna from Quail Creek Diversion to Washington Fields Diversion. The inventory should assess the threat the area poses as a source of nonnative species in the river and recommend a management action for each area. Identifying and eliminating nonnative species source areas are critical in controlling their densities in the Study Area.

2. Chemically Treat of Problem Off-channel Areas

Since we saw that off-channel areas hold the largest numbers of the target nonnative species, controlling nonnative fishes in these areas is necessary to reducing numbers of nonnative fishes in the river channel. Other researchers have shown that abiotic factors, especially high-flow events, can limit the ability of the target nonnative species to persist in rivers (Moyle and Light 1996, Gido et al. 1997, Marchetti and Moyle 2001). During the higher flows of winter and spring, nonnative species may be flushed from the river channel or move into off-channel habitats. As flows recede, off-channel areas may be the major source of target nonnative species. Eliminating the target nonnative species from off-channel areas may reduce or eliminate their negative impacts on native fish populations in the Virgin River. Hawkins and Nesler (1991) and Lentsch et al. (1996) listed chemical treatment of selected areas with high densities of nonnative fishes as a potential option for reduction of these fishes in the Upper Colorado River. Off-channel areas already known to have high densities of nonnative fishes have the potential to be treated with piscicides to help control nonnative fish populations in the Virgin River above the Washington Fields Diversion. We recommend Berry Springs Pond and the ponds created by seepage from Quail Creek Reservoir as candidates for such control efforts, but an inventory of all off-channel areas, as suggested above, would be necessary to identify any other areas of high concern. We also recommend investigating the feasibility and effectiveness of chemical reclamation at these ponds.

3. Prevention of Further Introductions

As mentioned above, off-channel areas are supplying large numbers of nonnative species to the main river. Data collected during baseline sampling and by UDWR confirm this (Rick Fridell, UDWR, personal communication). Other researchers have also noted that off-channel areas were probably sources for introductions of nonnative species in the Virgin River and other systems (Cross 1975, Hawkins and Nesler 1991, Lentsch et al. 1996). Holden et al. (1997) documented stocking of black bullhead, common carp, largemouth bass, smallmouth bass (*Micropterus dolomieu*), threadfin shad (*Dorosoma petenense*), bluegill sunfish (*Lepomis macrochirus*), brook trout (*Salvelinus fontinalis*), brown trout (*Salmo trutta*), rainbow trout (*Onchorynchus mykiss*), and cutthroat trout (*Onchorynchus clarki*) in Washington County, Utah. They recommended that stocking of such warm water predators where native fishes are already imperiled be discontinued.

Quail Creek Reservoir and Lake Mead are utilized as recreational fisheries. Sand Hollow Reservoir will also support a recreational fishery. Preventing the spread of nonnative fishes from these areas into the Virgin River is critical to controlling nonnative species. We recommend that barriers and screens be designed and constructed to prevent migration or escapement from these impoundments into the Virgin River main stem if stocking of warm water predators in these areas continues.

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