Survival and growth of stocked razorback sucker and bonytail in multiple floodplain wetlands of the middle Green River under reset conditions

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Tim Modde and G. Bruce Haines
Colorado River Fish Project
U.S. Fish and Wildlife Service
Vernal, UT

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Keywords: floodplain, larval, razorback sucker, bonytail, survival, growth, non-native

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Executive Summary

This report represents a river reach application of the reset concept to examine survival and growth of larval razorback sucker and bonytail in floodplains. The floodplain reset concept refers to eliminating residual fish populations from floodplains prior to their connection to the river during spring flood flows. Despite drought conditions, sufficient river flows allowed the evaluation of the reset concept to enhance larval razorback sucker *Xyrauchen texanus* and bonytail *Gila elegans* survival during 2003-2004. Species composition in study floodplains shifted from communities dominated by riverine species to to those preferring lentic conditions following recruitment within floodplains. The number, biomass, and age distribution of non-native fishes were much lower in reset floodplains than in sites which held water for multiple years. Following elimination of residual fish populations, razorback sucker and bonytail larvae survived in most study floodplains at rates consistent with sustainable populations. Larval survival was greatest for bonytail which averaged 6.3% in 2003 and 1.3% in 2004, compared to 0.1% and 0.4% for razorback sucker. Growth rates of razorback sucker were greater than bonytail, averaging 0.94 mm/d in 2003 and 0.61 mm/d in 2004 compared to average bonytail growth of 0.53 mm/d and 0.50 mm/d in 2003 and 2004, respectively. Little statistically significant correlation was observed with environmental factors, but the best growth and survival occurred in the deeper floodplains with a greater area of submergent vegetation. A comparison of vulnerability to predation from age-0 non-native fishes indicated that stocked razorback sucker outgrew any threat from age-0 predators , but a portion of stocked bonytail was vulnerable to the largest age-0 black bullhead *Amierus melas* in late July and August.

Conclusions

Razorback sucker and bonytail larvae stocked into inundated floodplains survived in the presence of non-native predators at a rate consistent with sustainable populations (Welcomme 1985, Dey 1981). Juvenile non-native fish predators are more likely the most common predators upon age-0 razorback sucker and bonytail. When floodplains were reset, juvenile non-native fish densities were much lower than occurred in floodplains with residual fish populations. In our study the body depth of all observed razorback sucker, and most of the bonytail stocked were greater than the gape width of age-0 non-natives. Although no statistical significance was observed, higher survival and greater growth of razorback sucker and bonytail occurred in floodplains with greater depth, lower biomass of non-natives and greater percent area of submergent vegetation. No relationship was observed in our study between growth and survival of stocked native fishes and turbidity, dissolved oxygen, and pH. Draining floodplains and initializing fish biomass prior to spring peak flows was an effective tool for increasing growth and survival of stocked razorback sucker and bonytail, and would probably enhance survival of naturally produced endangered fishes in the Green River subbasin.

Recommendations

1. Although all floodplains offer potential nursery habitats for razorback sucker and bonytail, due to their greater margin of error in producing and overwintering fish, the recovery program should develop a plan that implements the resetting all large floodplains which are under the management authority of recovery program partners.
2. Based on larval survival results from this study, and four years of larval drift data, the recovery program should assign equal value to floodplains in the Jensen and Ouray areas for enhancement planning.

3. Because of the encouraging survival rates of bonytail in this study, the use of floodplain habitats in the middle Green River should be explored for its potential to increase the numbers of bonytail in the Green River.

   a. Both larvae and adults should be stocked into floodplains as a means to increase the probability of survival and potential recruitment into the river.

   b. Additional evaluation of bonytail in floodplains should be conducted to determine how long juvenile and adult bonytail remain in floodplains, and how fish may use these sites for reproduction.

Introduction

The decline of razorback sucker and bonytail in the Upper Colorado River Basin has been attributed their inability to recruit (USFWS 2002a and 2002b). Information on habitat use of larval and juvenile razorback sucker *Xyrauchen texanus* and bonytail *Gila elegans* in the natural riverine environment is lacking. Historical accounts indicate that both species were relatively abundant (Quartarone 1993, Minckley et al. 1991) in the Colorado River Basin, and it is logical to assume that habitats then were suitable to support early life stages (Mueller and Marsh 2002). Presumably restoration of, now absent historical features will increase the probability of recovery. However, the ability to recover razorback sucker and bonytail through habitat enhancement has been complicated by the establishment of non-native species which use the same habitats as age-0 razorback sucker and bonytail (Birchell and Christopherson 2002). Some have argued that non-native fishes, even in the presence of quality habitat, will prevent recovery of the 'large river' fishes in the lower Colorado River Basin (Marsh and Pacey 2005), but evidence exists that habitat improvements and management actions can mitigate the effects of some non-native fishes in the Colorado River Basin (Holden et al. 2005, Modde 2005, Wydoski 2005). This report presents data that describes a management action that may mitigate non-native fish influences on survival and growth of age-0 razorback sucker and bonytail in floodplain wetlands in the middle Green River.

Despite the absence of empirical information on habitat needs of age-0 razorback sucker and bonytail, several studies have provided circumstantial evidence on the importance of floodplains as nursery habitat for both razorback sucker (e.g., Modde et al.

2001, Mueller et al. 2004) and bonytail (Mueller et al. 2004). Razorback sucker spawn on the ascending limb of the hydrograph so that larvae emerge during the peak spring flood flows (Muth et al. 1998), which is coincident with floodplain-river connectivity. Little is known of riverine bonytail reproductive behavior, yet they readily spawn in off channel impoundments (Mueller et al. 2004). Regardless of where spawning takes place, floodplain wetlands may to be a key element in the early life history for both razorback sucker and bonytail in large alluvial rivers. However, predation and competition from several non-native fishes have severely limited the usefulness of floodplains as nursery sites in the post-development era of the Colorado River Basin (Birchell and Christopherson 2004, Minckley 1991)

Age-0 razorback sucker were first reported in Green River floodplains with non-native fish when Modde et al. (2001) found juvenile fish in Old Charley Wash in two successive high flow years. However, in a subsequent stocking evaluation in the Stirrup floodplain, Birchell and Christopherson (2004) failed to detect age-0 razorback sucker survival in the presence of non-native fishes, although age-1 (~100 mm TL) fish stocked at the same time showed greater than 50% survival . The primary difference between the two study sites was that Old Charley Wash was shallow, and prevented fish survival over-winter, so fish present in any one year in the floodplain were those that entered from the river during the same year. Conversely, the Stirrup floodplain is deeper and supported residual non-native fish populations for several years prior to the evaluation. Given the results of the above two studies, the next logical step was to try to replicate the results of razorback sucker survival in Old Charley Wash by stocking larvae in sites drained, or ‘reset’, prior to connection of the river during spring flood flows. In 2003, an experimental approach was supported by the Recovery Implementation Program to evaluate the use of the 'reset' approach to determine if razorback sucker and bonytail could survive in the presence of colonizing non-natives. This study determined that . age-0 razorback sucker and bonytail could survived in the presence of an assigned non-native fish assemblage in experimental pens (Christopherson et al. 2004). The present study tests if the reset hypothesis operates in a larger geographical scale with self-colonizing populations of non-native fishes, and attempts to define which floodplain features contribute to higher survival and growth rates. Specifically, the objectives of this study are to:

1. Determine first year growth (absolute growth) and survival of stocked razorback sucker and bonytail larvae in floodplain wetlands of the middle Green River under the 'reset' (2003) and partial 'reset' (2004) conditions.

2 Relate stocked razorback sucker and bonytail survival to non-native fish abundance and composition, temperature, turbidity, pH, dissolved oxygen, depth, size of wetland, type and area of submergent vegetation.

3. Use larval survival and growth results to facilitate prioritizing wetland sites and management actions to maximize razorback sucker and bonytail recruitment.

For the purposes of our study, absolute growth and survival was used as the criteria for evaluation because we felt those sites in which fish survived the longest, even in drought conditions would provide the greatest margin of error in future applications of the reset approach.

Methods

Study Area

The study area lies within the alluvial reach of the middle Green River (Figure 1) between river miles (rm) 305 and 249 (kilometers [rk] 494 and 403). The specific study sites in 2003 included Johnson Bottom (57 ha), Leota Bottom cell-10 (Leota-10) (49 ha), and Old Charley Wash (34 ha) on the Ouray National Wildlife Refuge (rm 264 - 249; rk 427 - 403); and the Bureau of Land Management (BLM) managed floodplains at Above Brennan (17 ha) and Bonanza Bridge (6 ha) located at rm 265 and 289 (rk 429 and 468), respectively. The floodplains on the Ouray National Wildlife Refuge (NWR) are natural depressions in which dikes have been added to enhance impoundment capabilities. Although all floodplains were dry (during the summer of 2002) and devoid of fish at the beginning of this study, Johnson Bottom maintained sufficient water during the winter of 2003-04 to support some fish through the winter and thus was only partially reset in 2004. Flood waters in the Green River can access Johnson Bottom and Old Charley Wash between approximately 5,000 and 9,000 cfs (142 and 255 m^3/s, ,measured at the Jensen, Utah gage) and Above Brennan and Bonanza Bridge at 13,000 cfs (368 m^3/s) . In an effor to focus our study on larger floodplains, only the Ouray NWR and an additional floodplain on the Thunder Ranch were evaluated in 2004. The Thunder Ranch wetland is located near rm 305 (rk 494) and has a base area of approximately 20 ha, with the capability of expanding to over 100 ha when flooded. Thunder Ranch floodplain has maintained water, but has not been connected by surface flow to the Green River since the early 1980's.

Fish Stocking and Collection

Razorback sucker and bonytail were stocked into five floodplains in the spring of 2003 and four floodplains in 2004 (Tables 1a and 1b, and Figures 2a and 2b). In 2003, approximately 1, 945 larval razorback sucker and 1,235 larval bonytail were stocked per ha. Due to a shortage of razorback sucker larval production at the Ouray National Fish Hatchery in 2003, only 25,800 swim-up larvae were stocked into two of five study floodplains (Old Charley Wash and Above Brennan) before June 5. The remaining 289,000 razorback sucker stocked were 5 week old fish (ranging between 12 and 17 mm TL) provided by the native fish propagation facility in Grand Junction on June 16, 2003. Bonytail were provided by Dexter National Fish Hatchery and stocked as swim-up larvae. Because the river had not connected to the wetlands (Figure 2a) when bonytail larvae were available, they were only stocked into the three larger sites that had shallow (less than 0.3 m) water that were either the result of winter snow accumulation or from ground water rising with the river elevation: Johnson Bottom, Leota-10, and Old Charley Wash. Above Brennan and Bonanza floodplains were dry at the time larval bonytail were available, and therefore these sites were not stocked with bonytail. In addition, bonytail adults provided by Wahweap State Fish Hatchery were also stocked in all five floodplain sites after they were connected to the river. In 2004, 6,562 razorback sucker and 1,653 bonytail/larvae per ha were stocked into Leota-10, Johnson Bottom, Old Charley Wash, and the Thunder Ranch floodplain. In 2004, all fish were stocked as swim-up larvae were stocked just prior to peak flows in the Green River (Figure 2b). All razorback sucker stocked in 2004 were provided by Ouray National Fish Hatchery. Bonytail were provided as swim-up larvae by Dexter National Fish Hatchery and Technology Center.

Fish composition in study floodplains was designed to be monitored three times during the growing season, two monitoring collections in June and July and a final population assessement in August or September . Fish were monitored in mid to late June to determine relative abundance and composition of fish accessing study sites from the river, and again in July to monitor the presence of fish stocked and non-native fish reproduction (Figures 2a and 2b). Between three (Bonanza and Above Brennan) and five (Old Charlie Wash, Leota-10, and Johnson Bottom) fyke nets (0.9 m x 1.83 m rectangle opening with 0.6 mm mesh) were set overnight on a single date to sample fishes from each study site. Total length and individual weight data were recorded for all species captured. When large numbers of a species were present in nets, a random subsample was used to estimate the total number that species captured. When catches were subsampled to estimate the numbers of abundant species, fish from the entire catch were inspected to determine the presence of stocked fish. No fish collected during monitoring samples were returned to the floodplains. The final monitoring event was conducted between July and September when fish population estimates of razorback sucker and bonytail were conducted based on depletion rates. Multiple (14 to 20) fyke nets were set daily over a period of three to eight days and it was assumed that fish had an equal chance of capture after each sampling collection. Due to low water levels, minnow traps minnow traps (cylindrical and triform designs) to sample fish in Thunder Ranch in 2004. Total numbers and weights of all fish collected were recorded. Individual lengths were recorded from all stocked fish.

Water quality, zooplankton, and aquatic vegetation

Water quality parameters were measured in each floodplain site between June and July in 2003. Zooplankton was sampled and turbidity measured at approximately two week intervals between June 16 and August 5, 2003. Sites for zooplankton and turbidity samples were randomly selected by placing a numbered grid over an aerial photograph of the site and, using a random numbers table, selecting three (Bonanza and Above BrennanA) to five (Johnson Bottom, Leota-10 and Old Charley Wash) sites. A single vertical zooplankton sample at each site was collected with a 60 micron net with 0.5 m radius. Depths were recorded at each site to determine the volume sampled. A Minisonde and Surveyor 4 hydrolab were programmed to measure dissolved oxygen, pH, and temperature at hourly intervals for a 24 hr period. Due to malfunctions in both units, data were not collected after July 29, 2003. In 2004, the Minisonde hydrolab was set in each floodplain at biweekly intervals between the last week of May and the harvest date. Turbidity at each site was measured with a Hach kit spectrophotometer.

Area of submergent aquatic vegetation was monitored with aerial photographs in 2003. Aerial photographs of all study sites were taken on May 3, July 17, and August 16, 2003 in an attempt to record the greatest area of submergent vegetation. The greatest vegetative area observed among aerial photographs for each study site were selected and the area of submergent vegetation was measured by dividing the aerial photographs into grids and counting the cells that contained submergent vegetation. Because aerial flights were not available in 2004, vegetative data collected in 2003 were used to estimate area of submergent vegetation for both years. During 2004, the same water quality sampling regime was conducted.

Analysis

Average daily growth rates were computed by subtracting the length at stocking, 10 mm for razorback sucker (2004) and 7 mm for bonytail, from capture length divided by the number of days between stocking and capture. Growth rates of razorback sucker in 2003 were corrected for late stocking by subtracting 13.5 mm, the average length of razorback sucker larvae fed for four weeks was 13.5 mm TL (Chuck McAda, USFWS, Personal Communication). Because water quality began deteriorating by August and September and suspected fish mortality occurred prior to final harvest, we back-calculated the estimated number of razorback sucker and bonytail in July, 2003 because in July only fish captured and removed were counted and no estimate of the remaining fish was made until August September, and it is likely some mortality occurred between July and August/September. Back-calculation was determined by adding the number of fish estimated in the final sample to those captured during the July monitoring collection. The back-calculated estimate represents a minimum estimate of the number of razorback sucker and bonytail in July, 2003 because it assumes no mortality occurred between the July monitoring sample and final harvest in August or September. Abundance estimates of fish in 2004 were based on depletion sampling which occurred between early July and late August. The population sizes of stocked fish in wetlands were estimated using a depletion estimator (model M [bh]) in the software program CAPTURE. When this analysis was unable to provide an estimate (i.e., sampling did not produce a depletion), population size was considered to be the total number of fish removed, which most likely greatly underestimated the true population size. Total biomass of non-native fishes in each study floodplain was estimated using linear regression of total biomass captured per day (dependent variable) with cumulative biomass removed (independent variable), similar to the Leslie method with equal units of effort described by Ricker (1975). The X intercept of the regression function represented the estimate of total biomass. Confidence intervals and standard errors were determined using bootstrap methods (Haddon 2001). When comparing area of submergent vegetation with fish densities, area of vegetation was standarized by multiplying the actual percent of area by the largest floodplains size (57 ha).

We used two approaches to describe potential non-native predation threat to age-0 razorback sucker: 1) a comparison of potential predator density in reset and residual floodplains, and 2) a comparison of mouth-gape of potential age-0 predators to body-depth of age-0 razorback sucker and bonytail during mid-summer and final collection periods. Fish numbers and composition from residual floodplains (sites that maintained water and supported fish populations for approximately four years) were compared to reset floodplains to estimate the difference in potential number of predators from the reset (i.e., managed) and non-reset (i.e., unmanaged) environments. The density of small and large bodied fishes in reset floodplains were estimated using fish composition data from floodplains in this study during the June 2003-04 monitoring collections (excluding fish spawned in the floodplain). The density of small and large bodied fishes in residual floodplains were estimated using fish composition data from the floodplains sampled in March 22-23, 1999 with fyke nets in Baeser Bend and Stirrup floodplains, which continously supported fish populations for several years (Birchell and Christopherson 2002). Spring densities were estimated by multiplying the percent composition of fish during the first sampling collection (between March and June) by the standing stock measured during the late summer of the same year, divided by the average weight per individual. This assumes biomass as measured in the summer was comparable to biomass in the spring.

Predation threat of age-0 non-native fishes was estimated by assuming that fish were vulnerable to predation if their body depth was less than the gape (mouth width) of the predator (Hambright 1991, Einfalt and Wahl 1997). Mouth-width to total body length relationships for non-native predators, and body depth to total body length relationship for razorback sucker and bonytail were developed empirically from fish captured in Leota-10 and razorback sucker provided by Ouray NFH. Using the developed relationships, mouth widths and body depths (bonytail, $y= 0.1829x - 0.406$, $R^2=0.934$; razorback sucker, $y= 0.2028x + 0.39$, $R^2=0.98$) were determined from total length distributions of fish in Leota-10 during the monitoring sample (July 27) and harvest collections (August 26-September 2, 2004) were compared to determine the vulnerability of stocked razorback sucker and bonytail to age-0 predators reared in the floodplain.

Results

River connectivity with floodplains and water quality

In 2003, peak flows in the Green River reached 19,000 cfs (538 m^3/s) and allowed surface flow connection of all study floodplains to the river for at least 16 days (Figure 2a). However, floodplains on the Ouray NWR connected to the river via water control structures that allowed partial filling and non-native fish access at flows lower than surface connection . River flows entered Old Charley Wash through its water control structure at approximately 5,000 cfs (142 m^3/s) and allowed limited non-native fish access for 39 days. Leota-10 and Johnson Bottom water control structures began connecting to the river between 5,300 cfs (150 m^3/s) and 9,000 cfs (255 m^3/s), which allowed limited non-native fish access for at least 30 days in 2003. Although all floodplains connected to the river in 2003, the subsequent dry weather resulted in declining water depths (Figure 3a) through time with only Above Brennan and Johnson Bottom retaining water into the fall.

In 2004, mean daily spring flood flows of the Green River peaked at 11,500 cfs (326 m^3/s) on May 13. Water volume was insufficient to flow over floodplain dikes in 2004 (Figure 2b), but did access three of the four study wetlands via artificial drain and inlet structures. Water from the inlet and outlet structures was inadequate to completely fill Johnson Bottom, and Old Charley Wash, and Thunder Ranch received no direct river recharge in 2004. The water control structure in Old Charley Wash was open in early April and flows sufficient to provide enough water to stock larvae entered on April 11 and 12, prior to peak run-off. Johnson Bottom maintained sufficient water from the previous year to support stocked and non-native fish prior to spring runoff (partial reset). Due to declining river elevation, water control structures were closed at the three refuge floodplains on May 17. Thus, Old Charley was connected to the river via its drainage canal for a total of 13 days, and both Johnson Bottom and Leota Bottom were connected to the river for 8 days. Water in Leota-10 was supplemented by water transfer from Pelican Lake (beginning March 22) and direct pumping from the Green River through the summer. In 2004, depth declined rapidly in all study sites except Leota-10. Leota-10 maintained high water levels ($\geq$ 1.0 m) through the spring and summer, but a breach in a dyke occurred in late August that drained approximately half the volume of the floodplain (Figure 3b).

Water quality in most wetlands during 2003 was suitable to support fish in June with dissolved oxygen remaining above 4.0 mg/l (Figure 4) . Dissolved oxygen in all but Leota-10 was above 2.0 mg/l through late July. In Leota-10 dissolved oxygen decreased to 1.8 mg/l on July 23. However, environmental conditions changed dramatically after late July in Leota-10, Bonanza, and Johnson Bottoms. Dead adult carp *Cyprinus carpio* and bonytail were observed in Leota-10 as early as July 28. While harvesting fish in the Bonanza floodplain on August 12, most fish in the overnight sets from several fyke nets were dead at the time of net retrieval. Several dead adult bonytail were observed in Johnson Bottom in the month of August. Unfortunately, the hydrolab instruments used to measure water quality earlier in the summer of 2003 malfunctioned while recording data in early August so the precise time of changes in water quality was not determined. During the spring and summer, pH varied between 7.63 and 9.95 among study floodplains (Appendix Figure 1). With the exception of one measurement of 150 NTU's in Old Charley Wash in early July, turbidity was fairly low and little variation was observed among sites (Appendix Figure 2). Temperatures exceeded 30^{o} C in late July briefly in the Bonanza and Old Charley Wash floodplains (Appendix figure 3) .

In 2004, water quality deteriorated earlier than the previous year as water elevation dropped rapidly in all but Leota-10 (Figure 4). Leota-10 maintained high water levels through the spring and summer, but a breach in a dyke occurred on, or just before, August 2 that drained approximately half the volume of the floodplain. Supplemental pumping from the river restored much of the elevation drop within two weeks. Dissolved oxygen was above 3.0 mg/l in Old Charley Wash and Leota-10 in spring and summer, but fell below 1.0 mg/l as early as June in Thunder Ranch and in Johnson Bottom in late July (Figure 5). As in 2003, the pH of most floodplains was very basic, with several floodplains approaching 10.0 (Appendix Figure 4). Turbidity was variable but highest in Old Charley Wash and Johnson Bottom (Appendix Figure 5). Temperature was similar among floodplains in June, but temperatures exceeding 30^0 C were measured in Old Charley Wash and Thunder Ranch (the two shallower sites) during July (Appendix Figure 6).

Zooplankton and vegetation

Average zooplankton densities in 2003 ranged from 0.6 to 11.7 individuals/L during the spring and summer. Densities in all study floodplains showed a characteristic peak, ranging in timing between June 2 and July 8, 2003 and declining afterward to densities below 2.0/L by the last sample on August 5 (Figure 6). The higher zooplankton densities occurred in the two smallest floodplains, Bonanza and Above Brennan, whereas the lower densities occurred in the two larger floodplains, Johnson Bottom and Leota-10.

Aerial photographs were taken at approximately monthly intervals between May and August 2003 in an effort to estimate when the maximum area of submergent vegetation occurred in study floodplains. Maximum vegetative area was gained on July 17, 2003. Prior to the July flight, vegetation was still actively growing, whereas the maximum area of plant growth was believed to be present during the July flight. Three floodplains, Johnson Bottom, Leota-10, and Bonanza were almost entirely covered by either submergent or emergent vegetation. Only Above Brennan and Old Charley Wash possessed open water without thick stands of either submergent or emergent vegetation. Percent area of submergent vegetation was positively related to total area of floodplains (Figure 7). Percent of submergent vegetation varied from as low as 1% in the smaller floodplains to as high as 51% of the total area in Johnson Bottom.

Fish composition in floodplains

Fish composition within the five study floodplains through the summer of 2003 showed a change in composition from riverine fish initially colonizing floodplains to one dominated numerically by non-native, age-0 fishes spawned in the floodplain (Table 2a, Appendix Table1.). In most floodplains, red shiner *Cyprinella lutrensis* represented the majority of fish numbers captured in June that were not spawned in the floodplains. In Johnson Bottom age-0 carp spawned in the floodplain were most abundant, followed by smaller cyprinids. Through the summer, the numerical and weight percentage of lentic species such as fathead minnow *Pimephales promelas*, green sunfish *Lepomis cyanellus* and black bullhead *Amierus melas* increased. Nonetheless, carp still represented the greatest biomass in Old Charley Wash, Johnson Bottom and Leota-10. Fish composition of the three Ouray NWR floodplains in 2004 was similar to 2003 (Table 2b) but the total number and weight of fish captured was less in all wetlands than collected the previous year (Appendix Table 2). The lower catch rates corresponded with a shorter period of connection to the river. The species composition of Thunder Ranch was unique to all other floodplains reflecting the absence of a connection to the river for two decades. Other than razorback sucker stocked in the spring, the only other species present in the Thunder Ranch wetland were green sunfish and three spine stickleback *Culea inconstans*. Because the river did not connect to Thunder Ranch floodplain and water quality deteriorated rapidly, it was excluded from further fisheries analysis.

Abundance, growth, and survival of stocked bonytail and razorback sucker

During 2003, stocked age-0 bonytail were found in four of five floodplains while stocked razorback sucker were collected in all five floodplains during the study (Table 3). Survival of stocked bonytail through July 2003 ranged from 1.6% and 13.6%, with survival greatest in Johnson Bottom (Table 4). Razorback sucker survival ranged from 0.0% and 0.4% in July. Densities of stocked age-0 bonytail in July ranged from 21 to 195 fish/ha, whereas stocked razorback sucker ranged from only 0.9 to 5.6 fish/ha. Stocked adult bonytail reproduced in the Above Brennan floodplain, and a cluster of small individuals (less than 40 mm) in late August in Leota-10 suggested bonytail reproduced there as well (Figure 8). Growth rates of razorback sucker were a little greater than bonytail in July, and rates were nearly double bonytail by mid to late summer (Table 5a and 5b). Growth rates of bonytail in July ranged from 0.58 to 0.80 mm/d compared to razorback sucker rates of 0.71 to 1.08 mm/d. However, at the end of the field season, growth rates of razorback sucker ranged from 0.77 to 0.83 mm/d compared to 0.71 to 1.08 mm/d through the entire summer.

Razorback sucker were found in all floodplains again in 2004, and bonytail were found in all but Thunder Ranch wetland. Two razorback sucker were collected from Thunder Ranch floodplain during the June monitoring collections, but none were collected in minnow traps set in July. Depletion estimates from the remaining floodplains calculated the number of surviving age-0 razorback to be between 229 in Leota-10 and 1,523 in Johnson Bottom (Table 3). Razorback sucker survival rates were similar among the three refuge sites varying between 0.1% and 0.7% (Table 4). Bonytail abundance estimates showed greater variability ranging between 3 in Old Charley Wash and 2,647 in Johnson Bottom. Survival rates of age-0 bonytail ranged from <0.1% (Old Charley Wash) to over 2.8% (Johnson Bottom). Significant depletion occurred among all abundance collections except for bonytail in Johnson Bottom. The high degree of uncertainty in the Johnson Bottom estimate indicated that the number of fish present was probably higher than estimated. A separate regression analysis of catch per unit effort estimated 8,960 bonytail (as opposed to the maximum likelihood estimate in Table 3), which was more in line with the higher density estimated for age-0 bonytail in 2003. The survival rates in Leota-10 are minimum estimates of survival because a breach in the coffer dam blocking the drainage canal occurred in early August that resulted in approximately half the volume lost in the floodplain. Because the catch rate of 18.2 razorback suckers/net was similar to those in Old Charley Wash and Johnson Bottom in July (19.3 and 24.3 fish/net), but much lower (3.2 fish/net) during the depletion sampling in August/September, it is probable that fish were lost during the draining incident (Appendix Table 2). In general, survival of age-0 razorback sucker was higher in 2004 and bonytail higher in 2003.

Estimates of age-1 razorback sucker and bonytail in Johnson Bottom were 22 (Profile Likelihood Interval = 20 - 54) and 6 (total captured), respectively. It is likely intense avian predation in the shallow water of the floodplain at the time the estimates were made (approximately 150-200 white pelicans), surely contributed to the low numbers found.

Growth of stocked fish in 2004 was variable with outstanding growth observed in Leota-10, and low growth observed in Old Charley Wash (Table 5b). Growth rates in 2004 were similar to those in 2003 and ranged between 0.4 and 0.8 mm/d for both species (Table 5b). Growth rate was greatest in Leota-10 for both species and the length of razorback sucker at harvest was the greatest observed during the study with 21% of fish harvested $\geq$ to 125 mm TL. Because fish were relatively small (i.e., $\leq$ 1.0 g), condition factors could only reliably be determined for age-0 razorback sucker and bonytail in Leota Bottom and age 1 fish in Johnson Bottom. Condition factor (K) for age-0 razorback sucker and bonytail in Leota-10 at the end of August were 0.970 and 0.625 respectively, and age-1 razorback sucker and bonytail condition in Johnson Bottom were 1.032 and 0.720, respectively for razorback sucker and bonytail.

Factors associated with stocked razorback sucker and bonytail survival

Total non-native fish biomass was estimated during harvest collections for each floodplain during both years of the study (Table 6). Total non-native biomass was higher in 2003 (mean= 25.9 kg/ha) than 2004 (mean = 8.2 kg/ha) which coincided with the longer duration wetlands were connected to the river in the first year of the study. Neither razorback sucker or bonytail survival showed a significant linear relationship to either non-native biomass or area of submergent vegetation (Table 7). Despite not showing a significant predictive relationship (regression), bonytail survival was associated with submergent vegetation in both years and non-native biomass in 2004 by simple correlation (Figures 9a and 9b). Area of submergent vegetation was significantly related to total floodplain area (F=36.4, df=3, P=0.009, Figure 7); thus, the influence of area and submergent vegetation was confounded. The small sample size may have been a factor in the absence of a significant linear relationship between bonytail survival and environmental variables.

Both the number and composition of small bodied predators in reset floodplains was dramatically different than those floodplains with residual fish populations (Figure 10a). The number of small bodied fishes that were able to prey on age-0 razorback sucker in floodplains with residual fish populations in 1999 was well over an order of magnitude greater than those in floodplains reset in 2004, and nearly order of magnitude greater than those reset in 2003. Small bodied fishes in residual populations consisted primarily of fathead minnow and black bullhead (Birchell and Christopherson 2002), whereas in June, small bodied fishes in reset floodplains were numerically dominated by red shiners and carp in 2003. In 2004, when densities of small bodied non-natives were extremely low, red shiners (Leota 10 and Johnson Bottom), and age-0 carp (Old Charley Wash) were more abundant during June monitoring collections in reset floodplains The difference between the number of larger fish predators in reset and residual floodplains was even more dramatic than for small-bodied fishes, representing differences of several orders of magnitude (Figure 10b).

Razorback sucker stocked in Leota-10 grew quickly and were never vulnerable to non-native age-0 predators in the floodplains during the middle or late in the growing season (Figure 11a -11b). Bonytail were not vulnerable to non-native age-0 predators during the July monitoring sample, but using the criteria of body depth to mouth-width relationship, a portion of the population was vulnerable to the large age-0 non-natives. Mouth-width to body depth relationship showed that 16.7%, 3.4% and 0.2% of bonytail were vulnerable to predation by age-0 black bullhead, carp and green sunfish, respectively, in Leota-10 in late August.

Discussion

Despite drought conditions, study floodplains provided suitable environments to sustain fish through at least a portion of the 2003 and 2004 growing seasons. In 2003, floodplains connected to the river for at least 16 days and filled each depression; however, depth and water quality declined through the summer in most study sites with only Johnson Bottom and Above Brennan maintaining water into September. In 2004, study floodplains did not fill completely and the water quality in Old Charley Wash, Johnson Bottom and Thunder Ranch degraded rapidly and did not support stocked razorback sucker or bonytail beyond late July or late August.

Fish composition among floodplains was similar among sites, although carp were more abundant in the larger floodplains in the Ouray NWR. Initial species composition following riverine connection to floodplains was dominated numerically by riverine species such as red shiners, sand shiners and carp. However, as the summer progressed, age-0 fish spawned in the floodplain. Fathead minnow, black bullhead, and green sunfish, in particular, became more abundant. Modde (1997) observed a similar seasonal change in fish composition of Old Charley Wash, which was reset in three consecutive years. The importance of red shiners declined through the year and was replaced numerically by fathead minnow, green sunfish, black bullhead and juvenile carp. Changes in species composition observed through the first growing season persist if floodplains remain inundated for several years. Burchill and Christopherson (2002) reported that fish composition of several middle Green River floodplains that maintained water for several years was dominated by black bullhead, green sunfish and fathead minnow. Thus, if residual non-native fish populations are maintained in floodplains, the fish composition shifts from a generalized riverine dominance (i.e., shiners and carp) to a lentic composition dominated numerically by black bullhead, green sunfish and fathead minnow. The shift from riverine to lentic species composition takes place rapidly in the first growing season and remains as long as the floodplains maintain sufficient water to overwinter fishes.

In addition to compositional transformation, the standing stock of fishes in floodplains also changes with time, and is related both to the time of connection to the river and the ability of a floodplain to overwinter fish populations. Estimates of standing stock in the present study ranged between 6.5 and 68.3 kg/ha (average = 19.3 kg/ha) when floodplains connected to the river between 0 and 20 days, respectively. Modde (1997) reported that standing stock of fish in Old Charley Wash, which is reset annually, ranged between 126.7 and 71.4 kg/ha, consisting largely of adult carp entering from the river when the floodplain was inundated by the river for 48 and 38 days, respectively, in 1995 and 1996. Burchell and Christopherson (2002) reported fish standing stock in three middle Green River floodplain wetlands that had been connected to the river by spring flood flows for four consecutive years averaged 245 kg/ha (one, Above Brennan appeared to have partially winter-killed, i.e., reduced biomass). Fish numbers in these sites, that supported fish populations for multiple years, were dominated by fish reared in the floodplain. Fish populations in these residual floodplains maintained a higher biomass of non-native predators than reset floodplains, and tended to be represented by all size classes, including juveniles. Juvenile fish, due to their larger numbers and greater bioenergetic returns (compared to larger fish), are likely to be a greater threat to razorback sucker and bonytail larvae. By contrast, fishes colonizing reset floodplains are primarily adults which probably represent a lesser threat to larval fish. Because razorback sucker spawn before other species in the river and grow faster than most species, they are less vulnerable to predation and can persist even in the presence of a substantial invasion from non-native fishes (Minckley et al. 1991). In our study no razorback sucker and few bonytails were small enough to be consumed by age-0 non-native predators in the middle of the growing season. However, bonytails in this study were spawned in early May which is earlier than would occur in the middle Green River. Even though bonytail would be smaller if spawned locally, the higher survival rates than razorback sucker in this study suggest that factors other than size (i.e., behavior, use of cover, or other factors) may function to reduce mortality.

Historically, the large floodplains of the middle Green River have undergone regular flooding and drying cycles since the last ice age (Heitmeyer and Fredrickson 2005). Heitmeyer and Fredrickson (2005) described the floodplains of the Ouray NWR as seasonally and semipermanent wetlands, which fill and drain on a regular basis. Thus, the pattern of filling and dewatering floodplains in the middle Green River is a natural process which has been occurring since the most recent occupation of that area by razorback sucker and bonytail (Hansen 1985). As such, razorback sucker and bonytail have existed in these ephemeral sites and have the ability to survive in environments marginally suitable for most fish. Brouder and Jann (2004) observed that razorback sucker can survive in dissolved oxygen concentrations less than 1.0 mg/l. Survival of both species in sites such as Johnson Bottom, in which dissolved oxygen was reduced to less than 0.75 mg/l in the summer and a maximum depth of 0.3 m of water through the winter, indicate these fish are adapted to the harsh biological environment of floodplain wetlands.

Since the closure of Flaming Gorge Dam, mean peak flood flows have declined from 24,000 cfs to 17,000 cfs and the frequency of floodplain connection to the river has decreased from essentially every year to about 2 of every 5 years (Flo Engineering 1996). The reduced frequency of floodplain connection to the together with an influx of non-native fishes into wetlands (Tyus and Saunders 1996) have reduced both the availability of floodplain nursery habitat and the probability of survival when environmental conditions are favorable. Following the high flood flows of 1983-84, limited recruitment was reported in the Green River razorback sucker population (Modde et al. 1996). However, flood events of this magnitude are rare occasions and if natural events of this magnitude are necessary for periodic recruitment, recovery of razorback sucker and bonytail will likely not occur. Thus, the present rate of floodplain connection to the river, together with influx of non-native fishes creates an environment in which larval razorback sucker and bonytail are unlikely to recruit.

In the absence of non-native predators, razorback sucker and bonytail readily spawn and recruit. Mueller et al. (2004) reported multiple year classes of razorback sucker and bonytail in a small off-channel impoundment devoid of non-native fishes along the Colorado River on Cibola National Wildlife Refuge in Arizona. Successful recruitment of razorback sucker has also been documented in reduced non-native fish concentrations. Minckley (1983) described large populations of razorback sucker that initially colonized several lower Colorado River Basin reservoirs together with non-native sport fishes (Lakes Roosevelt, Saguaro, Mead, Havasu and Mohave) but populations declined and eventually disappeared due to lack of recruitment after the lakes filled. These large year classes of razorback sucker recruited when the reservoirs were filling before non-native fish biomass reached carrying capacity. In a more recent observation of razorback sucker recruitment, Welker and Holden (2004) observed younger fish whose appearance coincided with higher water elevation of Lake Mead. Resetting floodplains resembles the environment in newly impounded or expanding reservoirs in that the magnitude of non-native predation and competition on age-0 razorback sucker and bonytail is temporarily reduced. The larval and juvenile survival rates of both razorback sucker and bonytail in this study were similar to those reported for sustainable riverine fish populations (Dey 1981, Welcomme 1985), suggesting that reset floodplains offer a potential for increasing recruitment of both razorback sucker and bonytail. The results of this study indicates that the management practice of initializing fish biomass in floodplains is a practical approach to increase larval survival of razorback sucker and bonytail on a river reach scale in the middle Green River.

Sample size of study floodplains was small and prevented assigning statistical confidence to the factors affecting growth and survival. Nonetheless, the greatest growth and survival occurred in the largest, deepest floodplains with the greatest percent area of submergent vegetation (i.e., Johnson Bottom and Leota-10). Our data suggests that bonytail may use cover to avoid predation and is consistent with behavior observed for adult bonytail by Mueller et al. (2004). Cover may be more important to age-0 bonytail because fish were vulnerable to a portion of abundant age-0 predators in floodplains. Cover was not a detectable factor in survival of age-0 razorback sucker during this study, but may be more important in the survival of age-1 fish when they are more likely to be pursued by larger predators entering from the river following spring flooding.

Using the reset management concept, floodplains offer substantial potential for rearing both stocked and wild produced age-0 razorback sucker and bonytail. Given the recent recommendations for management on Ouray NWR (Heitmeyer and Fredrickson 2005), approximately 325 hectares of additional floodplain could be available to drifting razorback sucker larvae and spawning bonytail Leota Bottom together with the existing 57 ha in Johnson Bottom. However, using a modeling approach, Valdez and Nelson (2004) estimated a 99% loss of drifting razorback sucker larvae within 58 river kilometers of the spawning bar, suggesting that few if any larvae would reach the Ouray NWR floodplains, approximately 80 river kilometers downstream of the primary razorback sucker spawning area. Given this assessment, the larger floodplains on the Ouray NWR are of little value to the recovery of endangered fishes. However, the modeled approach by Valdez and Nelson (2004) is contrary to existing empirical data. Muth et al. (1998) reported that catch rates of razorback sucker larvae in the Ouray reach of the Green River were similar to those captured in Jensen between 1993 and 1996. A paired t-test of razorback sucker catch rates from Jensen and Ouray during the four year period (1993-1996) showed no significant difference ($t = 1.57$, 3 df, $P \geq 0.05$). This lack of difference existed even though a greater effort was given in the Ouray reach trying to find additional sampling sites, which reduced the average catch rate (personal observation of GBH). Thus, empirical data show that the number of razorback sucker larvae available to floodplains both immediately below the spawning site and 80 kilometers downstream are comparable despite the linear distance between the sites. Given the results of this study and available larval drift data, larger, deeper floodplains, such as Stewart Lake, Johnson Bottom and Leota Bottom, hold the greatest management opportunity for survival and growth of age-0 razorback sucker and bonytail, and linear distance from the spawning site, at least through the Ouray reach, appears to have little affect on larval access.

Conclusions

Razorback sucker and bonytail larvae stocked into inundated floodplains survived in the presence of non-native predators at a rate consistent with sustainable populations. Juvenile non-native fish predators are more likely the most common predators upon age-0 razorback sucker and bonytail. When floodplains were reset, juvenile non-native fish densities were much lower than occurred in floodplains with residual fish populations. In our study the body depth of all observed razorback sucker, and most of the bonytail stocked were greater than the gape with of age-0 non-natives. Although no statistical significance was observed, higher survival and greater growth of razorback sucker and bonytail occurred in floodplains with greater depth, lower biomass of non-natives and greater percent area of submergent vegetation. No relationship was observed in our study between growth and survival of stocked native fishes and turbidity, dissolved oxygen, and pH. Draining floodplains and initializing fish biomass prior to spring peak flows was an effective tool for increasing growth and survival of stocked razorback sucker and bonytail, and would probably enhance survival of naturally produced endangered fishes in the Green River subbasin.

Recommendations

1. Although all floodplains offer potential nursery habitats for razorback sucker and bonytail, due to their greater margin of error in producing and overwintering fish, the recovery program should develop a plan that implements the resetting of all large floodplains which are under the management authority of recovery program partners.

2. Based on larval survival results from this study, and four years of larval drift data, the recovery program should assign equal value to floodplains in the Jensen and Ouray areas for enhancement planning.

3. Because of the encouraging survival rates of bonytail in this study, the use of floodplain habitats in the middle Green River should be explored for its potential to increase the numbers of bonytail in the Green River.

    a. Both larvae and adults should be stocked into floodplains as a means to increase the probability of survival and potential recruitment into the river.

b. Additional evaluation of bonytail in floodplains should be conducted to determine how long juvenile and adult bonytail remain in floodplains, and how fish may use these sites for reproduction.

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Table 1a. Stocking record in 2003 for razorback sucker and bonytail among sites, connection duration to the river, and reset status for each floodplain.

				2003			
Floodplain	Connection to the river	Reset	Hectares	Number of RZ	Larvae BT	BT adults	Date Stocked
Johnson	30 d	Yes	56.7		81,500		05/02/03
				105,304[1]			06/16/03
						2,400[3]	05/23/03
OCW	39 d	Yes	34.4		45,000		05/02/03
				45,000[1]			06/16/03
				18,800[2]			05/23/03
						2,400	05/23/03
L-10	30 d	Yes	48.6		75,000		05/02/03
				106,719[1]			06/16/03
						3,600	05/23/03
Bonanza	16 d	Yes	5.7			3,480	05/23/03
				12,000[1]			06/16/03
Above Brennan	16 d	Yes	16.6			120	05/27/03
				20,000[1]			06/16/03
				7,000[2]			06/04/03
Total			161.9	314,823	201,500	12,000	
Density/ha				1,944	1,235	74	

[1] Razorback sucker stocked 6/16 were 5 week old larvae (12-17 mm) originating from Grand Junction Native Fish Propagation Facility.
[2] Razorback sucker stocked were swim-up larvae from Ouray National Fish Hatchery.
[3] All bonytail stocked were swim-up larvae from Dexter National Fish Hatchery and Technology Center.

Table 1b. Study floodplain stocking record in 2004 for razorback sucker and bonytail swim-up larvae among sites, as well as connection duration to the river and reset status.

				2004 Number of Larvae		
Floodplain	Connection to the river	Reset	Hectares	RZ[1]	BT[2]	Date Stocked
Johnson	8 d	No	57	360,000		4/26/2004
					93,750	5/3/2004
OCW	13 d	Yes	34	240,000		4/26/2004
					57,000	5/3/2004
L-10	8 d	Yes	49	300,000		4/26/2004
					80,250	5/3/2004
Thunder R	0 d	No	20	150,000		4/26/2004
					33,500	5/3/2004
Total			160	1,050,000	264,500	
Density/ha				6,566	1,654	

[1] Razorback sucker stocked were swim-up larvae from Ouray National Fish Hatchery.

[2] All bonytail stocked were swim-up larvae from Dexter National Fish Hatchery and Technology Center.

Table 2a. Percent of fish numbers captured/net in five study floodplains during the summer of 2003. BO = Bonanza, AB = Above Brennan, OCW = Old Charley Wash, L-10 = Leota 10, JB = Johnson Bottom.

Species	**June**					**July**					**Harvest**				
	AB	BO	OCW	L-10	JB	AB	BO	OCW	L-10	JB	AB	BO	OCW	L-10	JB
red shiner	65.3	11.2		52.3	15.2		62.1					57.5			
sand shiner	27.6	85.3					10.7								
fathead minnow						84.7		40.2	53.6		52.4		28.8	9.6	65.8
green sunfish (juv)							18.9	12.8	15.0	26.2	29.7	16.6		32.2	13.8
age 0 carp			93.0	45.0	83.5			37.3	23.1	43.5			63.5	45.1	12.1
age 0 black bullhead											13.9	14.9			
Age 0 bonytail										19.2					

Table 2b. Percent of fish numbers captured/net in four study floodplains during th summer of 2004. BO OCW = Old Charley Wash, L-10 = Leota 10, JB = Johnson Bottom, TH = Thunder Ranch. Rectangle during July at OCW represents a composite of all three species.

Species	**June**				**July**				**Harvest**			
	OCW	L-10	JB	TH	OCW	L-0	JB	TH	OCW	L-10	JB	TH
red shiner	18.7	30.6	42.0									
sand shiner					69.5							
fathead minnow		17.2	17.9	9.7		10.0	16.6				53.8	
green sunfish (juv)						51.5					19.2	
green sunfish (ad)		19.5		30.3								
age 0 carp	78.2				23.7		70.8					
age 1 carp												
> age 2 carp												
age 0 black bullhead		14.3	19.1			22.9					23.5	
Three spine stickleback				60.1				100.0				

Table 3. Minimum abundance estimates and densities of age-0 bonytail and razorback sucker in five study floodplains during 2003 and 2004. Abundance estimates during the July monitoring sample are based on absolute numbers collected, harvest abundance are depletion estimates. Numbers in parenthesis represent Profile Likelihood interval.

	2003				2004			
	Bonytail		Razorback Sucker		Bonytail		Razorback sucker	
July Monitoring	Total No.	Fish/Ha	Total No.	Fish/Ha	Total No.	Fish/Ha	Total No.	Fish/Ha
Bonanza	0	0.0	17	2.8	NA	NA	NA	NA
Above Brennan	2[1]	0.1	95	5.6	NA	NA	NA	NA
Old Charley Wash	666	19.6	133	3.9	3	0.1	91	2.7
Leota-10	2,134	43.6	66	1.3	57	1.2	154	3.1
Johnson Bottom	6,361	111.6	15	0.3	3	0.1	146	2.6
July/August Harvest								
Bonanza	0	0.0	0	0.0	NA	NA	NA	NA
Above Brennan	0	0.0	1[2]	0.1	NA	NA	NA	NA
Old Charley Wash	34 (31 - 55)	1.0	0	0.0	0	0.0	1563 (1,523 - 1,622)	46.0
Leota-10	625 (510 - 968)	12.8	12 (9 -240)	0.2	687 (650 - 773)	14.0	229 (222 - 255)	4.7
Johnson Bottom	4,736 (4,617 - 4,884	83.1	220[3]	3.9	2,647 (417- 52,940)	46.4	1523 (1,484- 1,587)	26.7

[1]Offspring of stocked adults.
[2]Hatchery stocked fish 341 mm TL that accessed floodplain from the river.
[3] Absolute number captured (no confidence interval)

Table 4. Percent survival of stocked age-0 bonytail and razorback sucker in five study floodplains in 2003 and 2004. Estimates in 2003 were based on fish alive during July monitoring collections (numbers collected during July monitoring plus harvest estimates), 2004 estimates based on harvest estimates between July and August. NA = Not Applicable, T < 0.1%.

	Bonytail		Razorback sucker	
Floodplain	**2003**	**2004**	**2003**	**2004**
Bonanza	NA	NA	0.1	NA
Above Brennan	NA	NA	0.4	NA
Old Charley Wash	1.6	0.0	T	0.7
Leota – 10	3.7	1.0	T	0.1
Johnson Bottom	13.6	2.8	0.2	0.4

Table 5a. Number (N), average length (TL) in mm, and average growth rate in mm/d (in parentheses) for native stocked fish collected in study floodplains on the Green River in 2003 during monitoring and harvest collections.

Species/Age	Bonanza		Above Brennan		Old Charley Wash		Leota 10		Johnson Bottom	
	7/29	8/12	7/28	9/3	7/22	8/26	7/21	8/18	7/24	9/12
Razorback age-0	N=8 60.8 (1.08)	N=0	N=67 54.5 (0.95)	N=0	N=98 53.4 (1.08)	N=0	N=62 38.9 (0.71)	N=8 62.9 (0.77)	N=15 51.7 (0.98)	N=225 86.9 (0.83)
Bonytail age-0	N=0	N=0	N=1 73.0 (0.8)	N=0	N=149 60.1 (0.69)	N=31 61.4 (0.49)	N=93 50.8 (0.58)	N=350 48.7 (0.41)	N=80 55.4 (0.61)	N=300 62.6 (0.43)

Table 5b. Number, average length (TL) in mm, and average growth rate in mm/d (in parentheses) for fish collected in study floodplains on the Green River in 2004 during monitoring and harvest collections.

Species/Age	Old Charley Wash	Johnson Bottom	Leota-10	
	7/13	7/28	7/27	8/28
Razorback age-0	N=821 48.2 (0.48)	N=696 65.0 (0.58)	N=59 81.3 (0.77)	N=282 106.9 (0.77)
Razorback age-1	--	N=20 243.5	--	--
Bonytail age-0	N=3 36.3 (0.40)	N=87 57.8 (0.58)	N=42 63.5 (0.66)	N=665 68.9 (0.52)
Bonytail age-1	--	N=6 150.0	--	--

Table 6. Total non-native fish biomass (kg/ha) from study floodplains in 2003 and 2004. Ninety-five percent confidence intervals are in parentheses.

Floodplain	2003	2004
Bonanza	15.5 (8.3 – 18.3)	--
Above Brennan	16.8 (13.6 - 25.9)	--
Old Charley Wash	68.3 (31.6 - 175.7)	9.5 (7.1 –35.1)
Leota - 10	14.6 (8.8 - 71.4)	8.7 (7.3 – 12.3)
Johnson Bottom	14.2[1]	6.5[1]

[1] No significant slope and total biomass considered to be the same as the total biomass collected.

Table 7. Analysis of variance results of linear regression of non-native biomass and submergent vegetation with razorback sucker and bonytail survival.

2003	**F value**	**d.f.**	**P value**	**R^2**
Razorback sucker vs Non-native Biomass	0.72	3	0.46	.19
Razorback sucker vs Submergent Vegetation	0.23	3	0.67	.07
Bonytail vs Non-native Biomass	0.69	1	0.56	.41
Bonytail vs Submergent Vegetation	3.72	1	0.30	.79
2004				
Razorback sucker vs Non-native Biomass	0.07	1	0.83	.06
Razorback sucker vs Submergent Vegetation	0.56	1	0.59	.36
Bonytail vs Non-native Biomass	99.9	1	0.06	.99
Bonytail vs Submergent Vegetation	11.8	1	0.18	.92

Figure 1. Map of study area showing locations of study floodplains on the Green River.

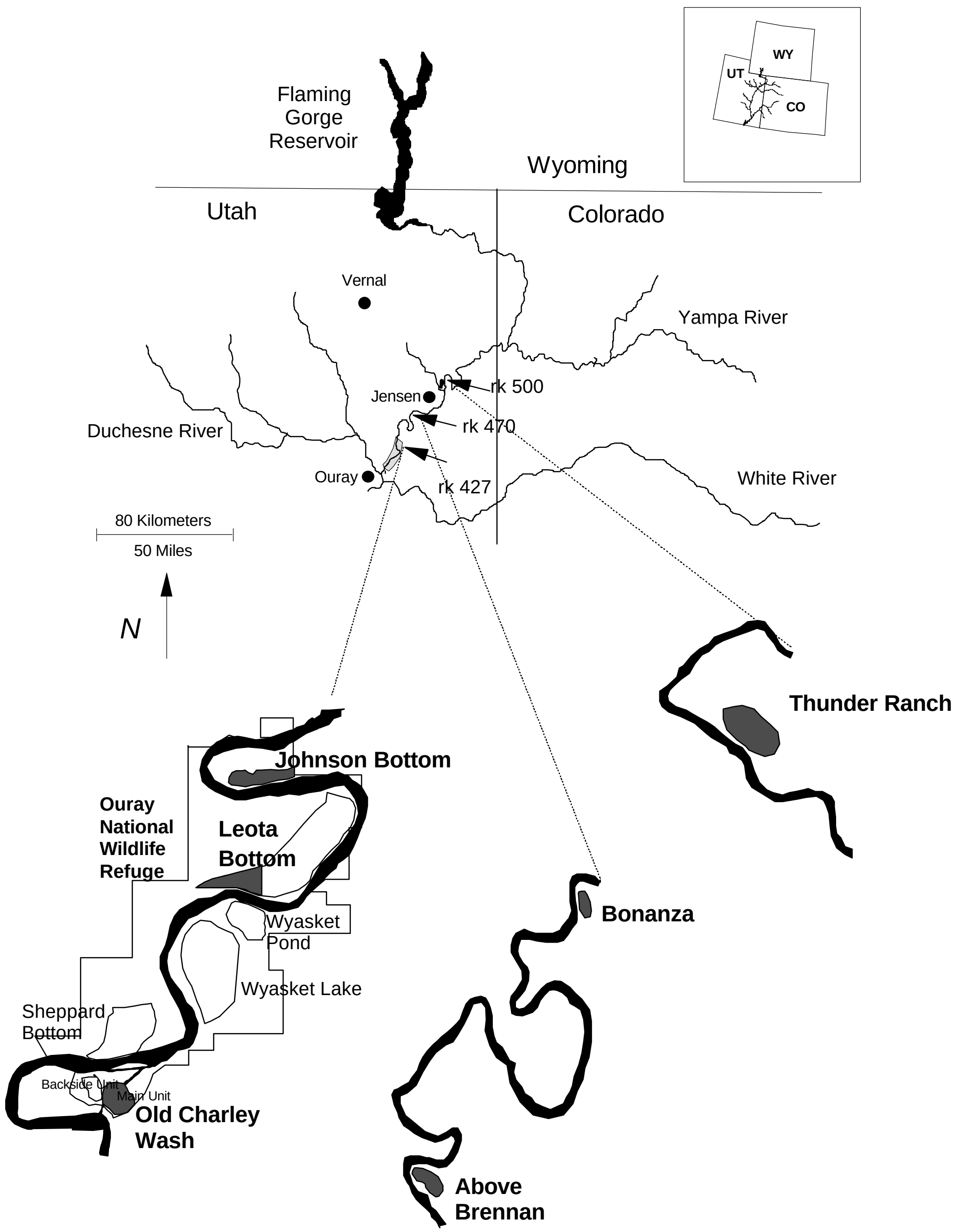


Figure 2a. Sampling schedule and hydrology of floodplain study in 2003.

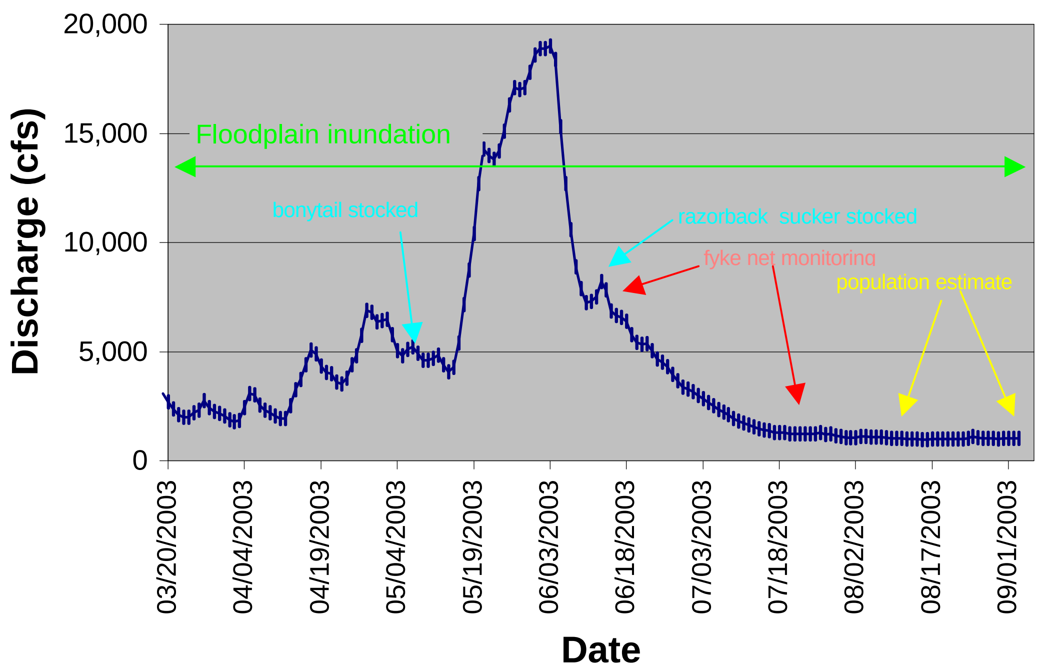


Figure 2b. Sampling schedule and hydrology of floodplain study in 2004.

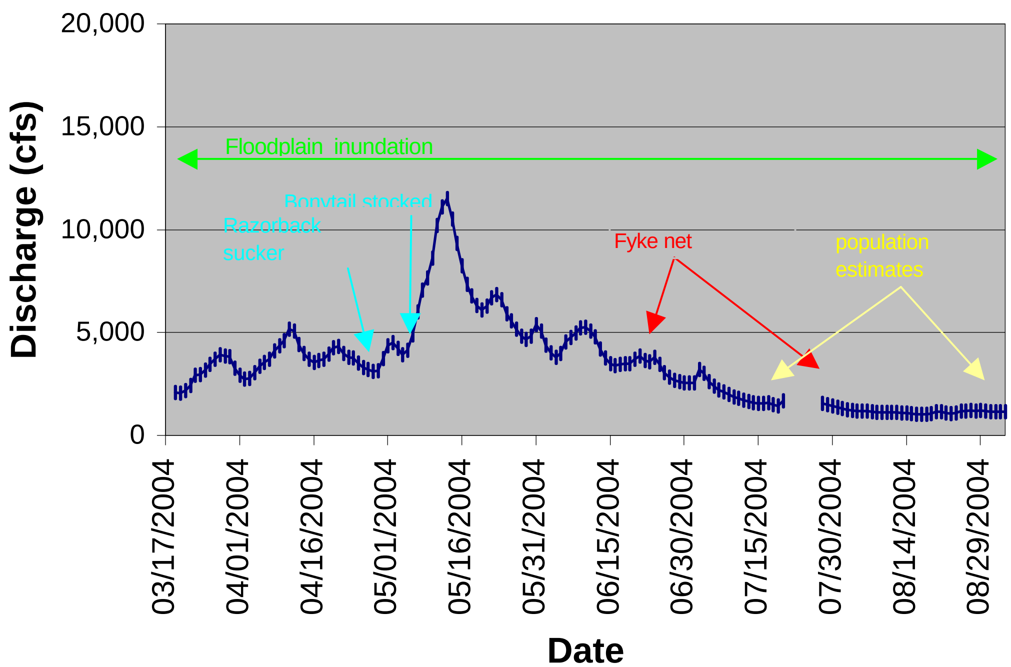


Figure 3a. Maximum depth of study floodplains during 2003.

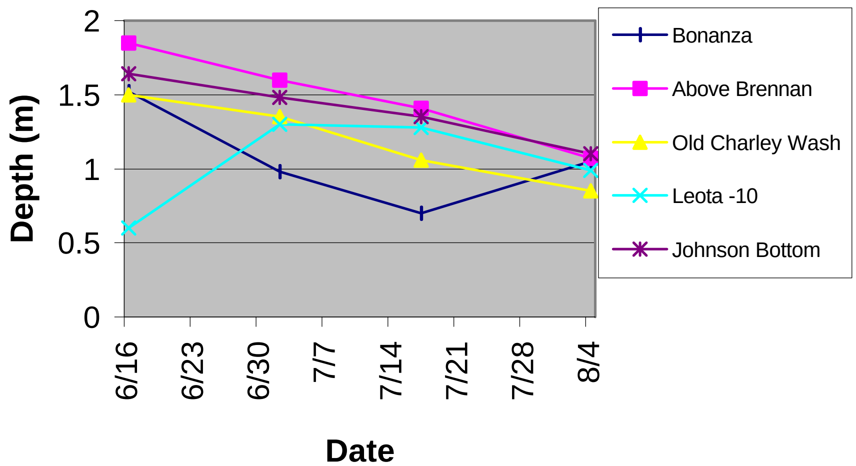


Figure 3b. Maximum depth of study floodplains during 2004.

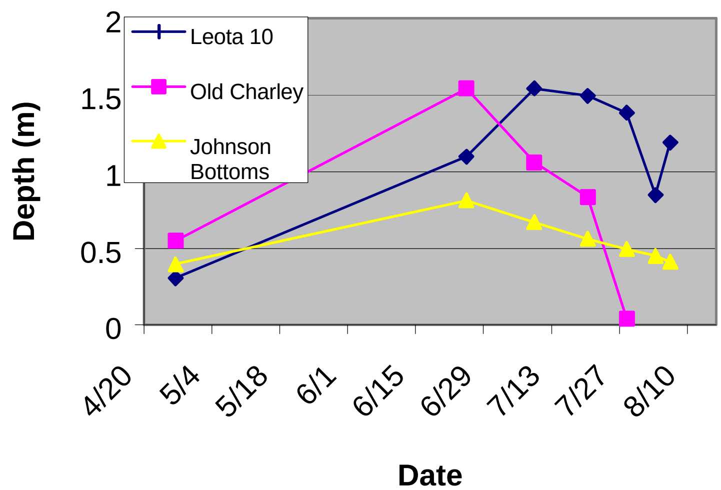


Figure 4. Dissolved oxygen monitored over 24 h in five study floodplains along the Green River in 2003. OCW = Old Charely Wash.

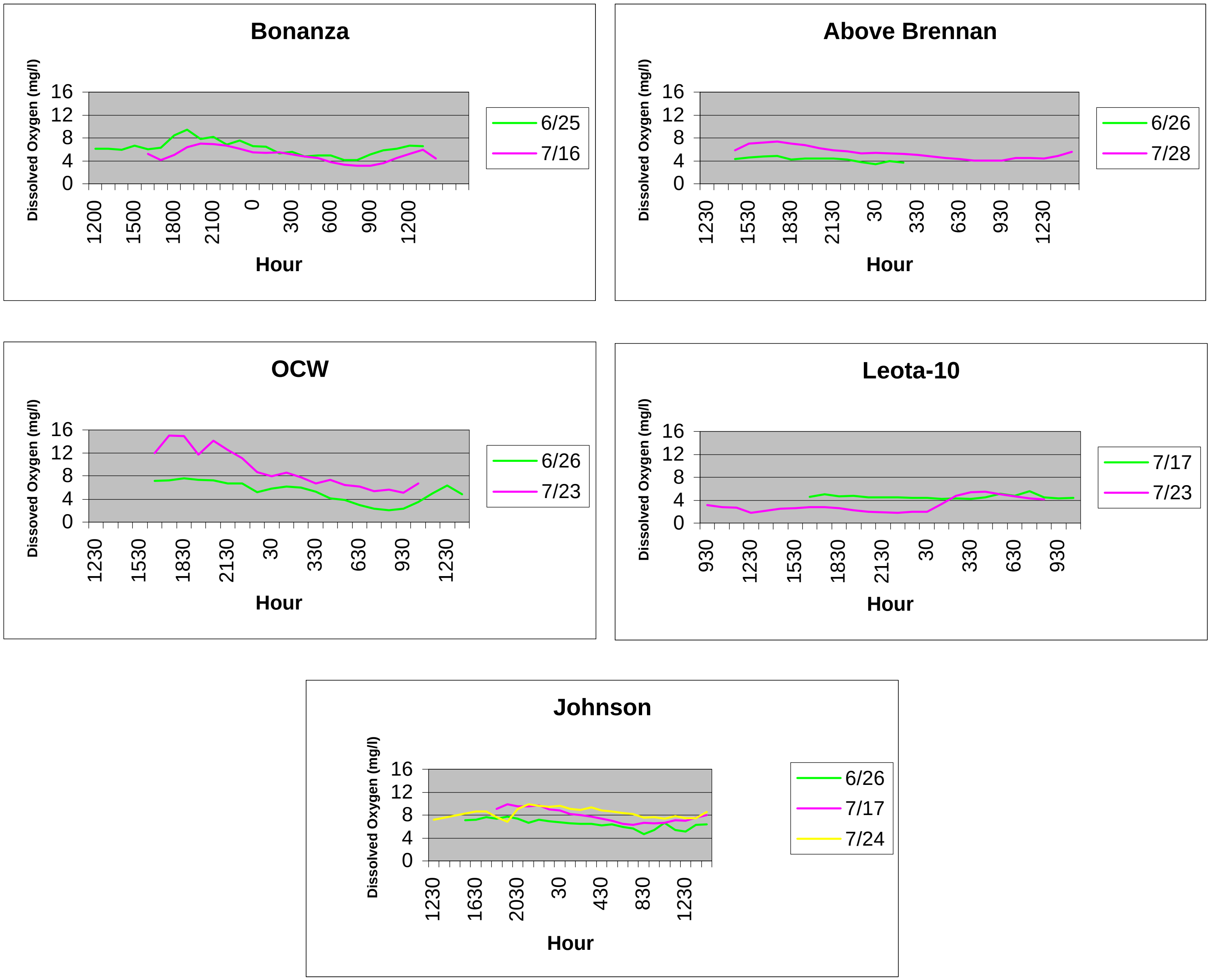
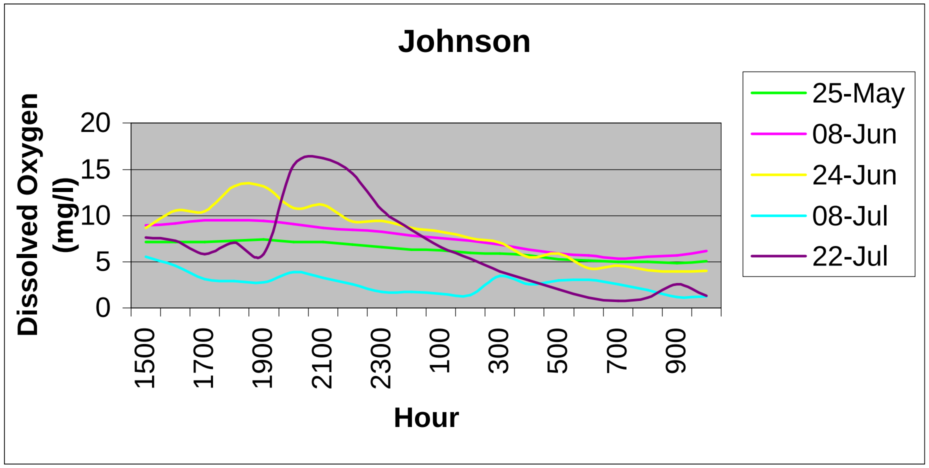
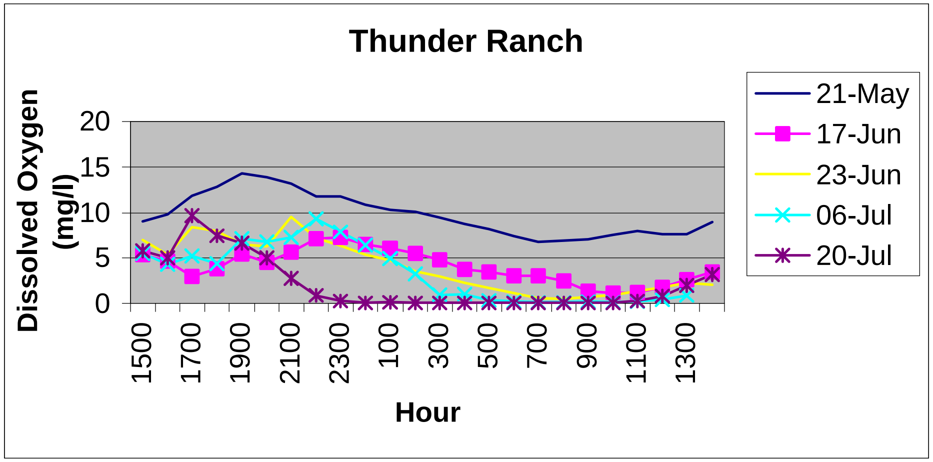
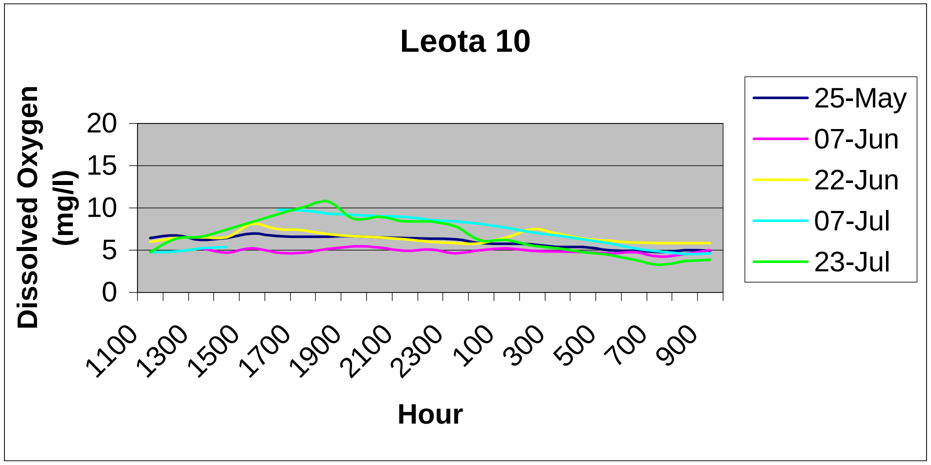


Figure 5. Dissolved oxygen monitored over 24 h in five study floodplains along the Green River in 2004.







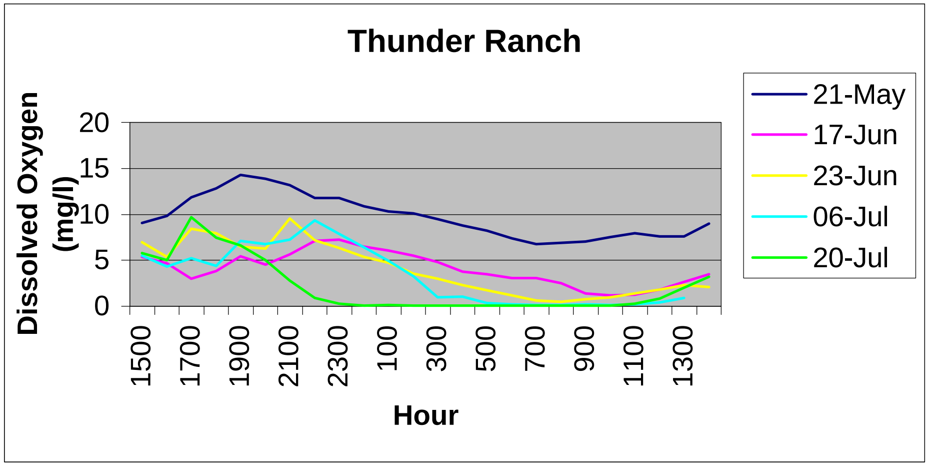


Figure 6. Zooplankton densities in five study floodplains during the spring and summer of 2003.

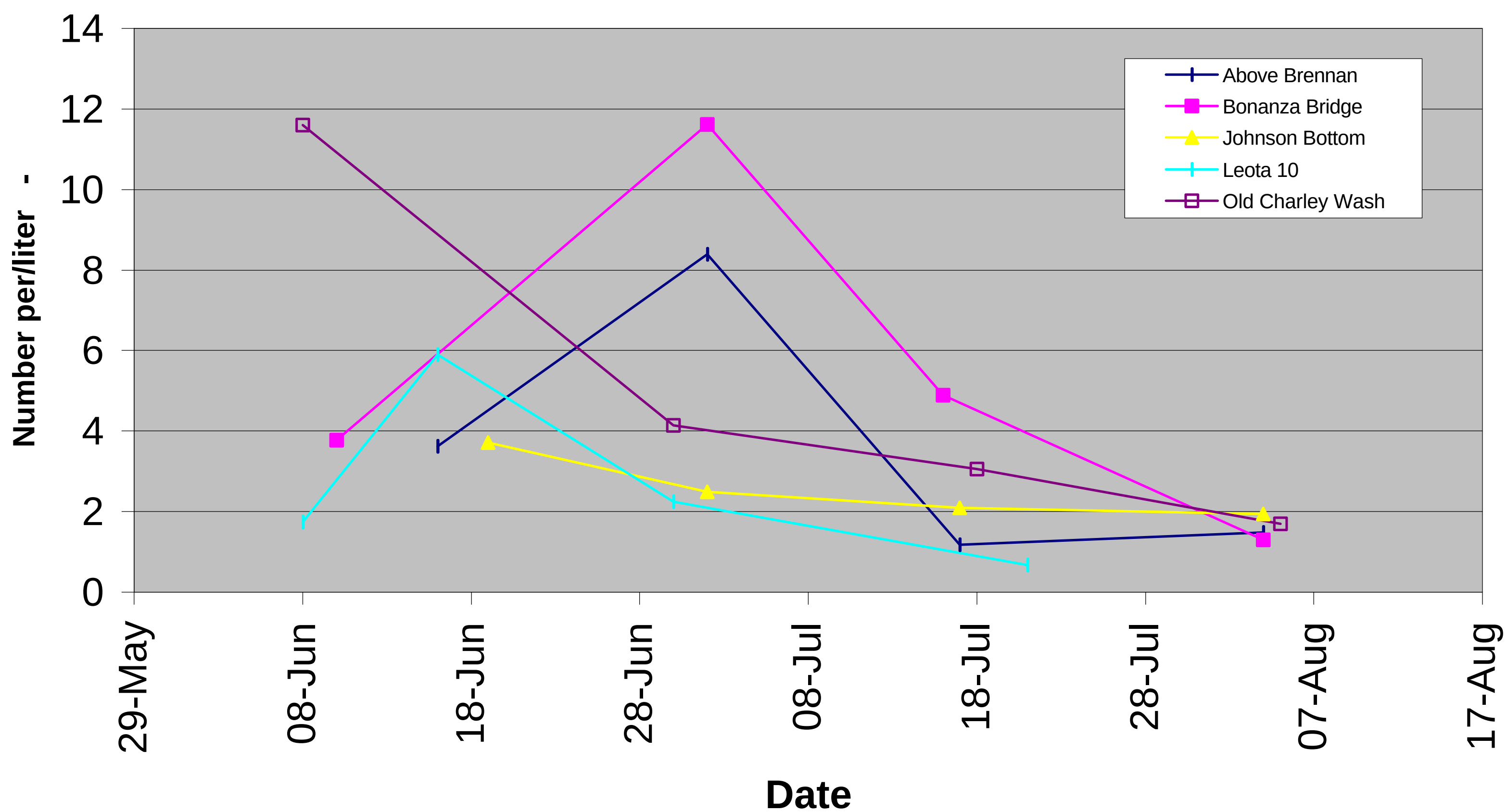


Figure 7. Percent and absolute area of submergent vegetation in study floodplains in 2003.

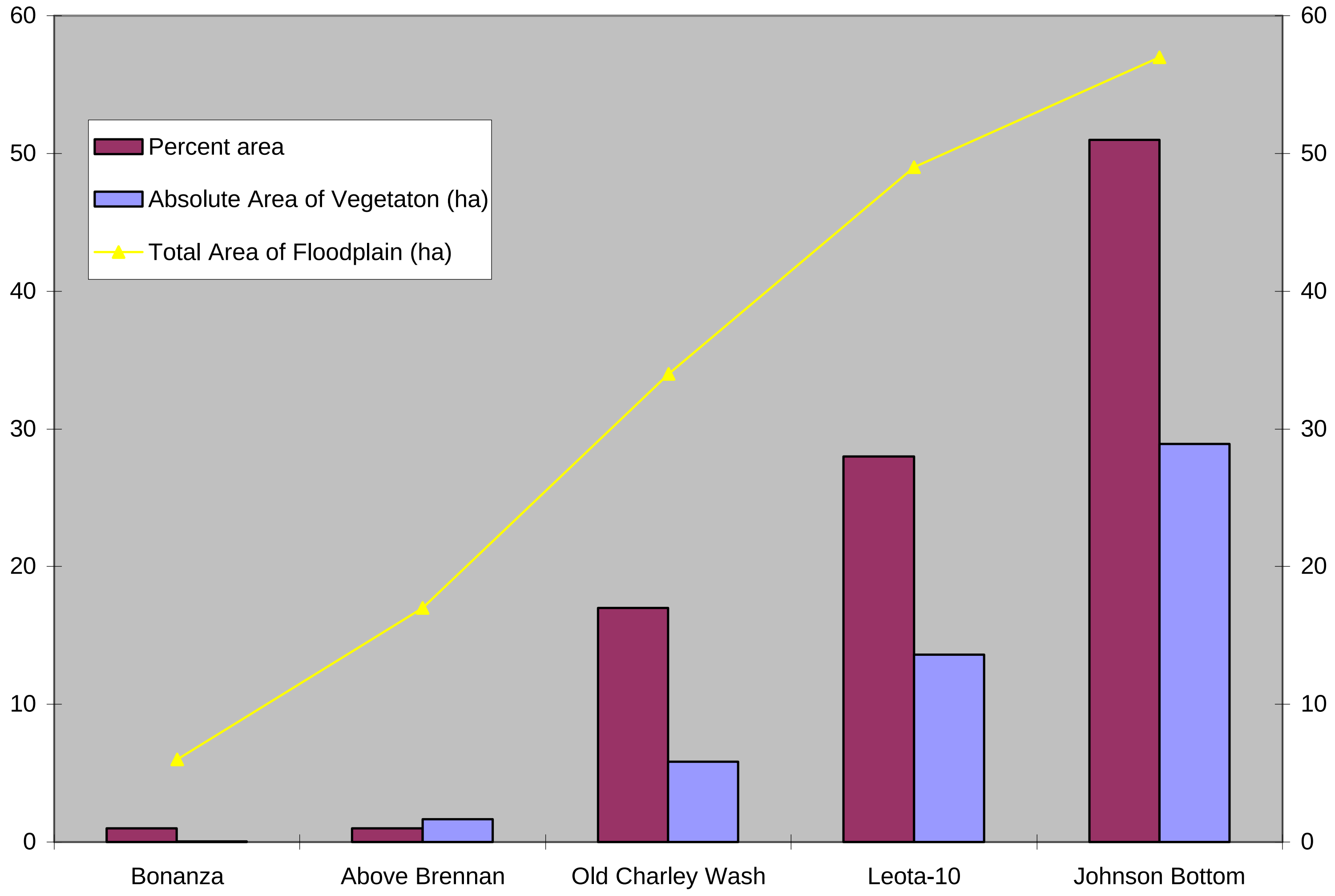


Figure 8. Length frequency of juvenile bonytail collected during harvest from three study floodplains at the Ouray National Wildlife Refuge during 2003.

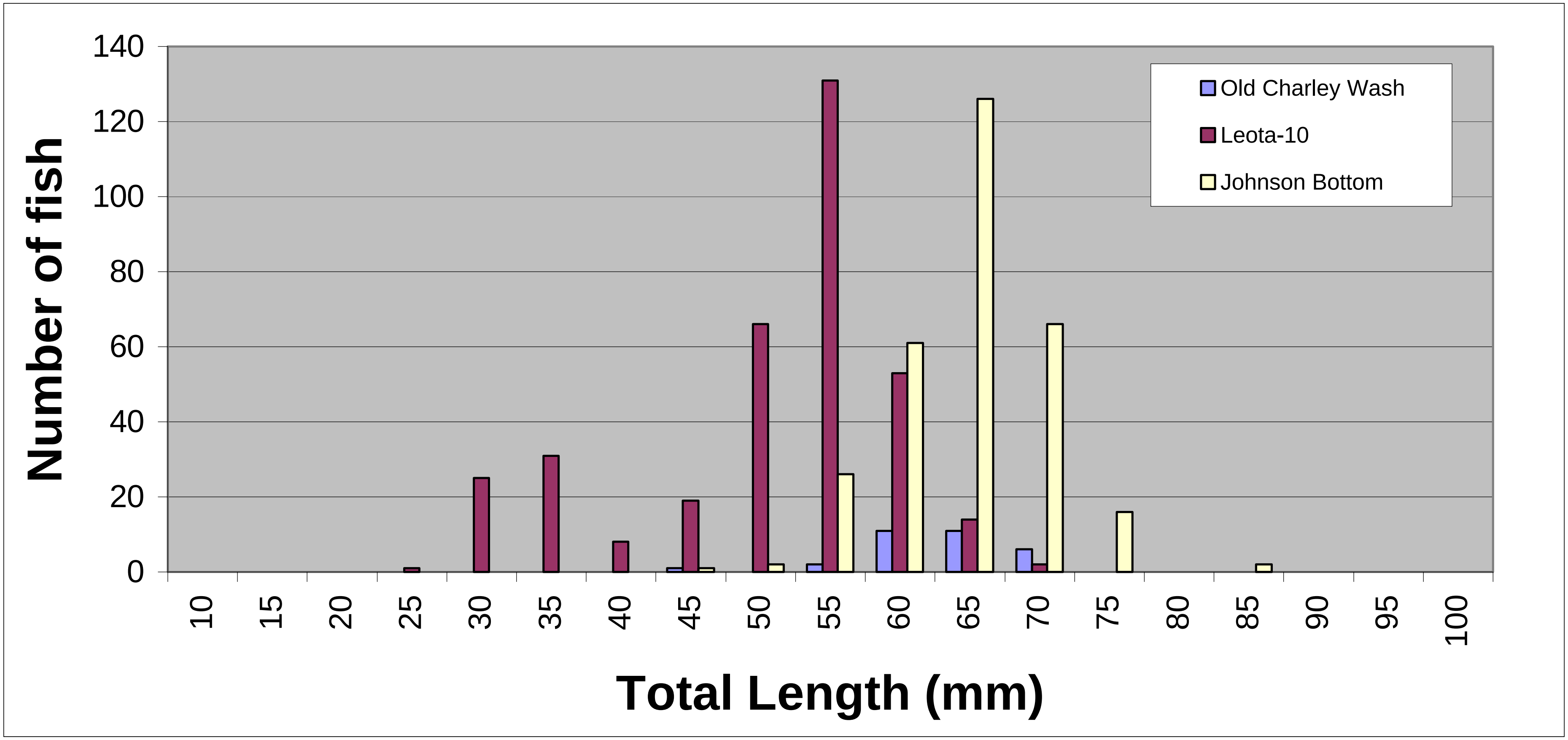


Figure 9a. Relationship of stocked age-0 bonytail survival to biomass of age-0 non-natives (at harvest) in study floodplains in 2003 and 2004.

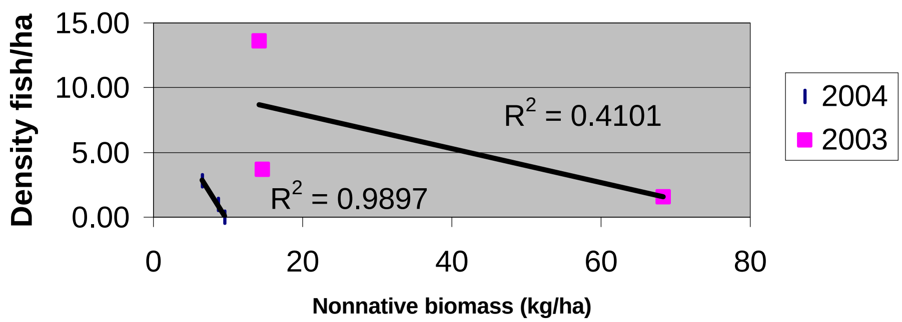


Figure 9b. Relationship of stocked age-0 bonytail survival to standardized area of submergent vegetation in study floodplains during 2003 and 2004.

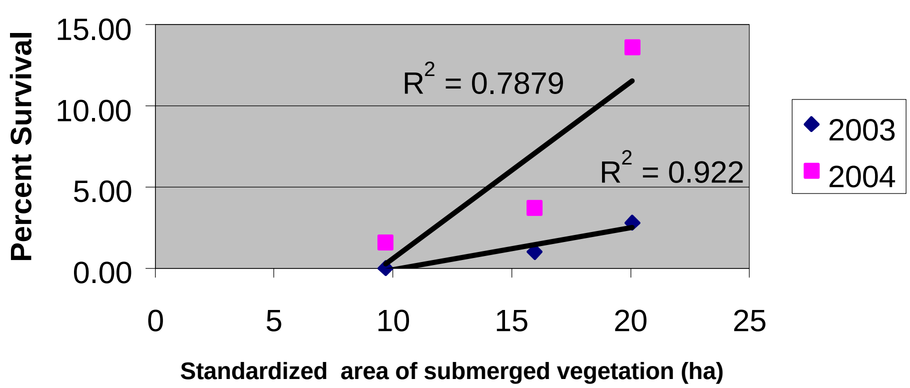


Figure 10a. Comparison of the density of non-native, small bodied fishes between reset floodplains, at the time of larval razorback sucker arrival, with those containing residual populations of non-native fishes (Birchell and Christopherson 2002).

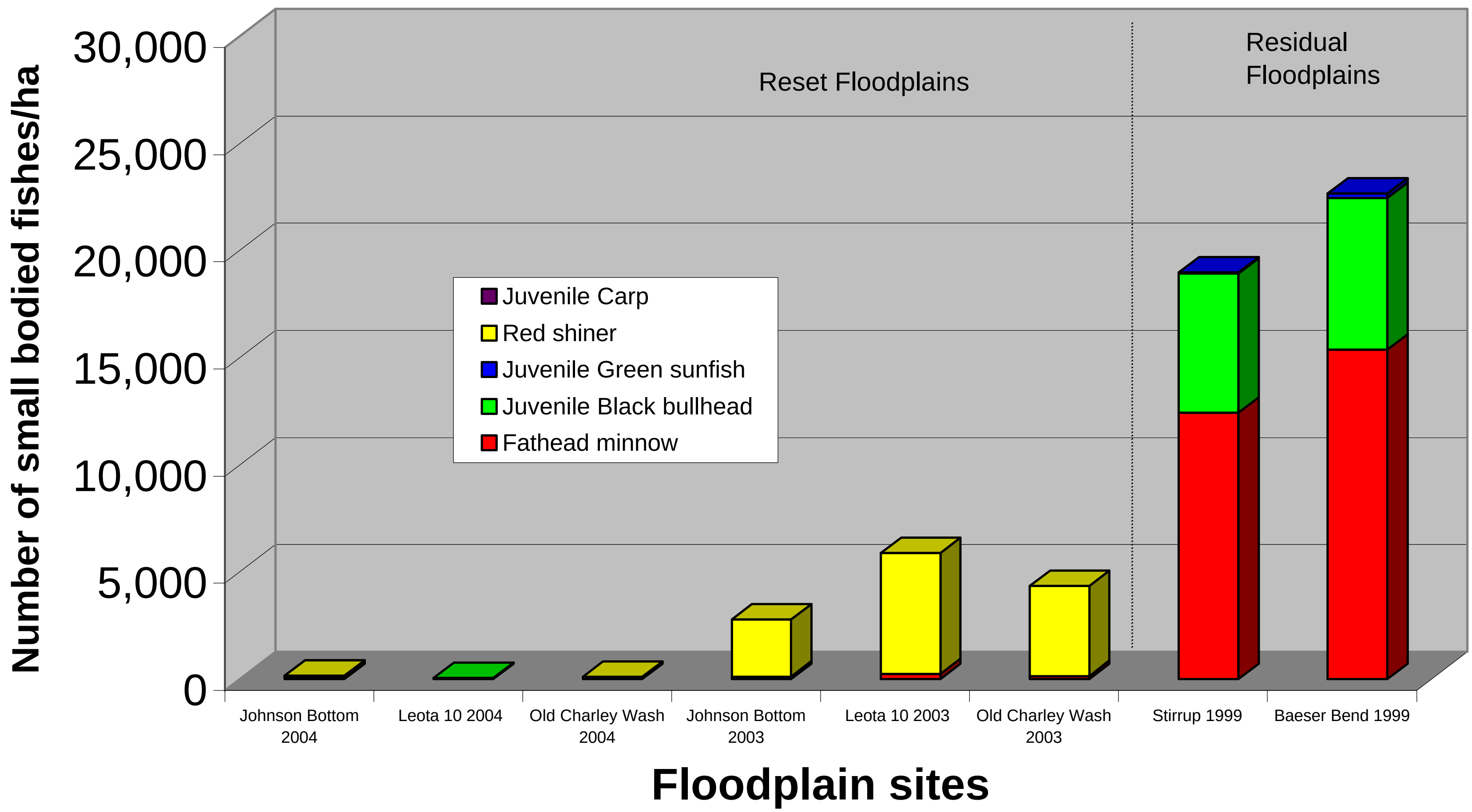


Figure 10b. Comparison of the density of adult, non-native fishes between reset floodplains with those containing residual populations of non-native fishes (Birchell and Christopherson 2002).

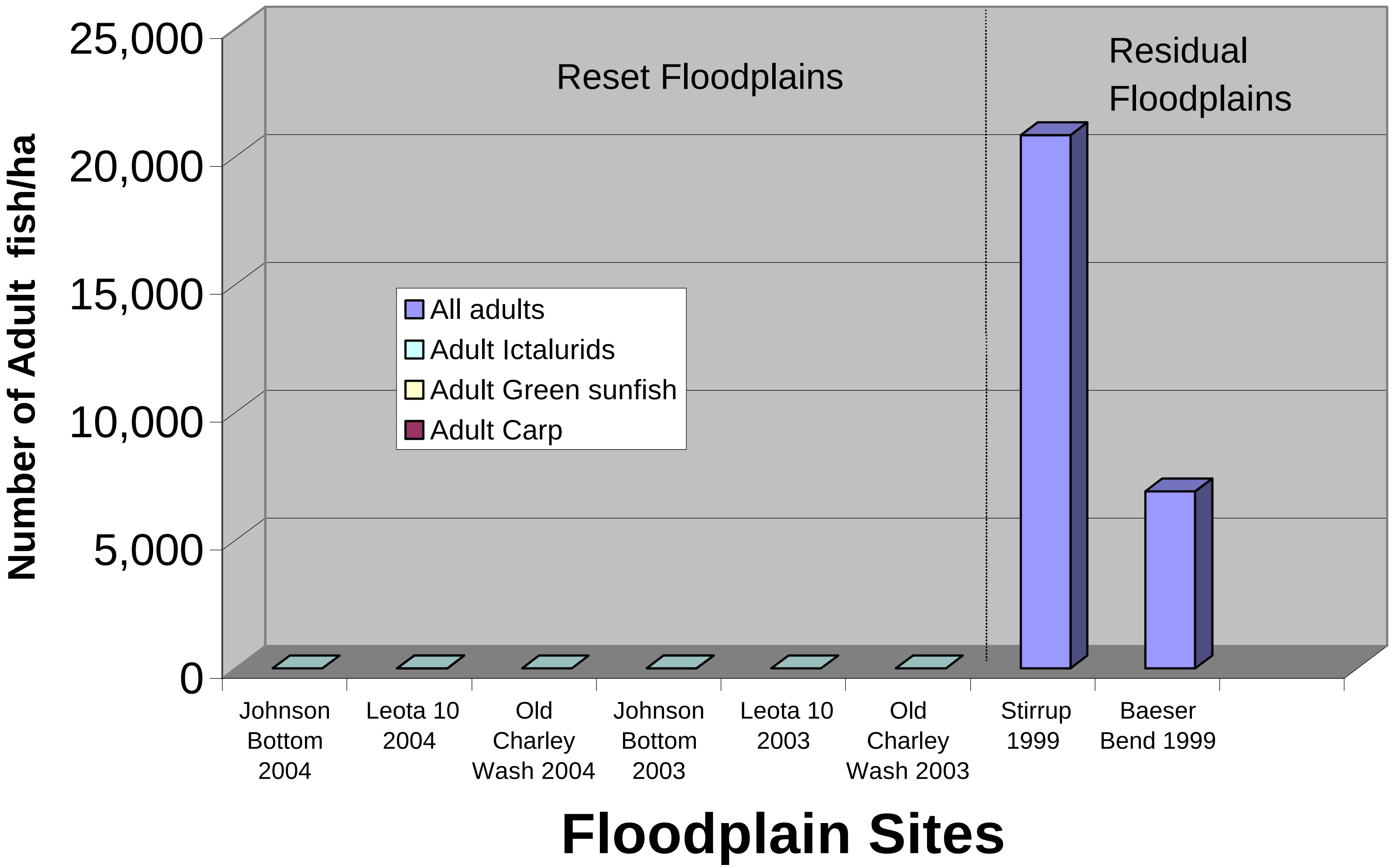


Figure 11a. Mouth width (MW) relationship of the dominant age-0 predators in Leota 10 to the body depth (BD) of stocked razorback sucker and bonytail on July 27, 2004.

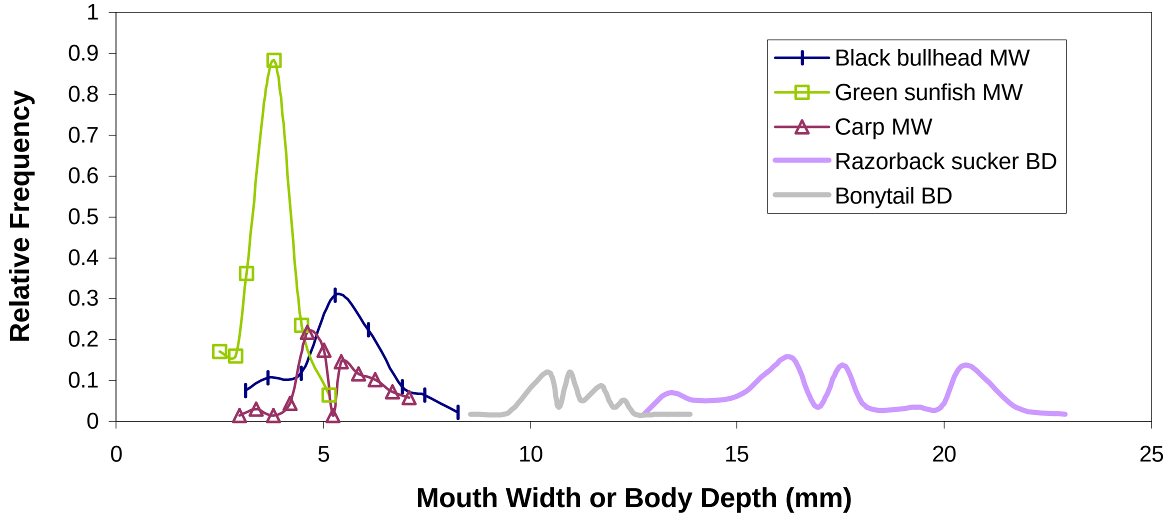
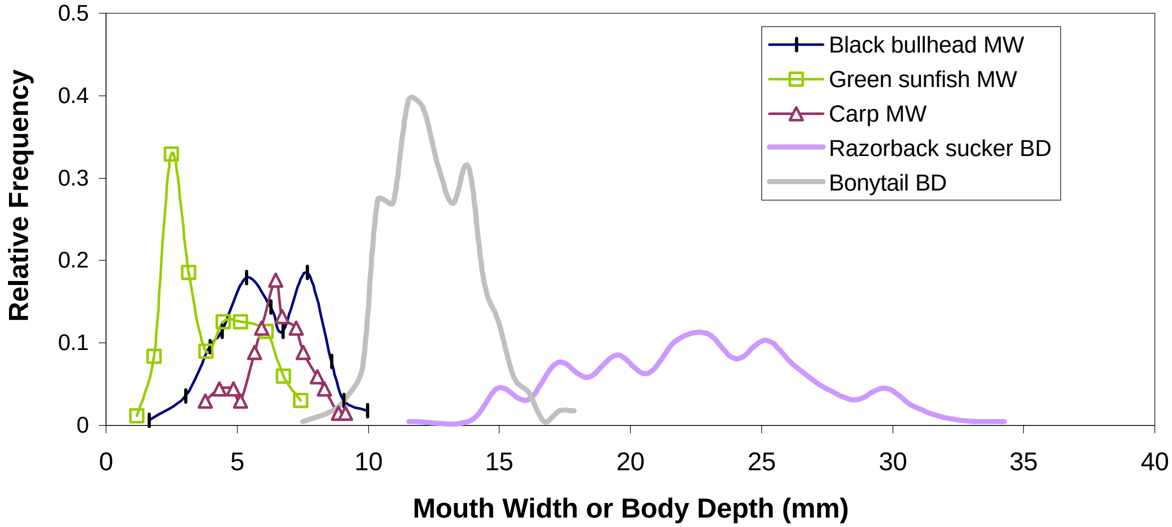


Figure 11b. Mouth width (MW) relationship of the dominant age-0 predators in Leota 10 to the body depth (BD) of stocked razorback sucker and bonytail between August 26 and September 2, 2004



Appendix Tables and Figures

Appendix Table 1. Average number and biomass (g) of fish collected per fyke net (and their respective percentages) captured from study floodplains during the two monitoring collections and final harvest in 2003. Ad = adults only, Juv = juveniles.

Above Brennan	June				July				Harvest			
	No.	%	Wt.	%	No.	%	Wt.	%	No.	%	Wt.	%
Pimephales promelas	563.2	5.7	1191.0	11.2	5045.4	84.7	2540.0	57.1	1239	52.4	1181.0	15.5
Lepomis cyanellus (Ad)					4.8	0.1	249.6	5.6				
Lepomis cyanellus (Juv)	9.4	0.1	210.6	2.0	475.6	8.0	391.6	8.8	703	29.7	3130.0	41.0
Amierus melas (Ad)	0.2	0.0	32.8	0.3	3	0.1	198.0	4.4	0.5	0.0	68.5	0.9
Amierus melas (Age-0))	0.6	0.0	2.6	0.0	280.8	4.7	342.4	7.7	329	13.9	957.5	12.5
Cyprinus carpio (Ad)	0.6	0.0	602.4	5.6								
Cyprinus carpio (Age-1))					19	0.3	331.4	7.4				
Cyprinus carpio (Age-0)									90	3.8	2294.0	30.0
Notropis lutrensis	6417	65.3	6584.0	61.7	87.6	1.5	203.0	4.6	2	0.1	3.0	0.0
Richardsonius balteatus	0.8	0.0	0.8	0.0								
Notropis stamineus	2709	27.6	1792.0	16.8	12.8	0.2	26.8	0.6				
Gila elegans (Ad)	0.2	0.0	4.8	0.0								
Gila elegans (Age-0)					0.4	0.0	0.0	0.0				
Xyrauchen texanus)Age-0)					19	0.3	42.3	1.0				
Catostomus latipinnis (Age-0)	6.8	0.1	62.2	0.6	3.2	0.1	6.3	0.1				
Pomoxis nigromaculatus (Ad)	0.2	0.0	14.0	0.1								
Pomoxis nigromaculatus (Age-0)												
Prosopium williamsoni (age-0)	109.8	1.1	179.0	1.7								
Ictaluris punctatus (Ad)												
Rhinichthys osculus	2	0.0	0.8	0.0								
Culea inconstans												
Catostomus commersoni (Age-0)					3.8	0.1	118.5	2.7				
Overall Mean	9819		10677.0		5955.4		4449.9		2364		7634.0	

Bonanza	June				July				Harvest			
	No.	%	Wt.	%	No.	%	Wt.	%	No.	%	Wt.	%
Pimephales promelas	180.4	3.0	495.0	7.6	330	9.2	345.0	3.0	70.5	5.3	53.5	1.6
Lepomis cyanellus (Ad)	6.4	0.1	172.4	2.7	9.3	0.3	359.3	3.1	0.5	0.0	26	0.8

	June No.	%	Wt.	%	July No.	%	Wt.	%	Harvest No.	%	Wt.	%
Lepomis cyanellus (Juv)					680	18.9	360.0	3.1	224	16.6	353.5	10.7
Amierus melas (Ad)	0.2	0.0	20.4	0.3	4.3	0.1	148.5	1.3				
Amierus melas (Age-0))					6.7	0.2	59.8	0.5	200	14.9	200.5	6.1
Cyprinus carpio (Ad)	0.2	0.0	249.0	3.8					0.5	0.0	503.5	15.3
Cyprinus carpio (Age-1))					245.7	6.8	5748.7	49.6	9.5	0.7	274.5	8.3
Cyprinus carpio (Age-0)	4.8	0.1	0.8	0.0					128	9.5	914	27.7
Notropis lutrensis	676.2	11.2	1230.0	18.9	2230	62.1	3482.0	30.0	772	57.5	965	29.2
Richardsonius balteatus					4.3	0.1	4.6	0.0				
Notropis stamineus	5137	85.3	4104.0	63.1	382.6	10.7	423.0	3.6	10	0.7	9	0.3
Gila elegans (Ad)	4.8	0.1	131.4	2.0	10.3	0.3	281.2	2.4				
Gila elegans (Age-0)												
Xyrauchen texanus)Age-0)					5.7	0.2	4.7	0.0				
Catostomus latipinnis (Age-0)	11.6	0.2	88.0	1.4								
Pomoxis nigromaculatus (Ad)												
Pomoxis nigromaculatus (Age-0)												
Prosopium williamsoni (age-0)	1.6	0.0	2.0	0.0								
Ictaluris punctatus (Ad)	0.2	0.0	11.2	0.2	1	0.0	105.0	0.9				
Rhinichthys osculus												
Culea inconstans												
Catostomus commersoni (Age-0)					10.3	0.3	272.2	2.3				
Overall Mean	6023		6504.2		3590.2		11594.0		1343		3299.5	

Johnson Bottoms	June				July				Harvest			
	No.	%	Wt.	%	No.	%	Wt.	%	No.	%	Wt.	%
Pimephales promelas	95.4	0.7	168.6	1.4	265.2	4.0	332.0	2.9	2646	65.8	1693	34.0
Lepomis cyanellus (Ad)	1.2	0.0	82.0	0.7	5.2	0.1	180.5	1.6	0.5	0.0	16.5	0.3
Lepomis cyanellus (Juv)	0.6	0.0	20.6	0.2	1739.8	26.2	1457.6	12.8	554	13.8	664	13.3
Amierus melas (Ad)	0.4	0.0	22.6	0.2	0.8	0.0	28.0	0.2				
Amierus melas (Age-0))					110	1.7	73.5	0.6	66	1.6	59.5	1.2
Cyprinus carpio (Ad)	0.2	0.0	382.8	3.3	0.2	0.0	238.0	2.1				
Cyprinus carpio (Age-1))												
Cyprinus carpio (Age-0)	11807	83.5	8530.0	73.0	2886.4	43.5	6971.6	61.1	488	12.1	2320.5	46.6
Notropis lutrensis	2197	15.5	2353.0	20.1	350.6	5.3	497.0	4.4	239	5.9	197.5	4.0
Richardsonius balteatus												

Notropis stamineus	30	0.2	9.0	0.1	2	0.0	1.5	0.0				
Gila elegans (Ad)	3.8	0.0	122.0	1.0	1	0.0	21.0	0.2				
Gila elegans (Age-0)					1272	19.2	1528.5	13.4	6	0.1	11.3	0.2
Xyrauchen texanus)Age-0)					3	0.0	5.2	0.0	1	0.0	7	0.1
Catostomus latipinnis (Age-0)												
Pomoxis nigromaculatus (Ad)												
Pomoxis nigromaculatus (Age-0)									18.5	0.5	14	0.3
Prosopium williamsoni (age-0)												
Ictaluris punctatus (Ad)					0.2	0.0	9.6	0.1				
Rhinichthys osculus												
Culea inconstans												
Catostomus commersoni (Age-0)					2.4	0.0	63.7	0.6				
Overall Mean	14136		11690.6		6638.8		11407.7		4019		4983.3	

Leota 10	June				July				Harvest			
	No.	%	Wt.	%	No.	%	Wt.	%	No.	%	Wt.	%
Pimephales promelas	43.2	2.0	102.8	4.1	5145.8	53.6	2038.2	18.3	217	9.6	288	5.1
Lepomis cyanellus (Ad)	0.2	0.0	2.4	0.1								
Lepomis cyanellus (Juv)					1441.1	15.0	1426.2	12.8	729	32.2	1097.5	19.6
Amierus melas (Ad)	0.2	0.0	8.8	0.3	0.8	0.0	29.2	0.3				
Amierus melas (Age-0))									110	4.8	223.3	4.0
Cyprinus carpio (Ad)					0.3	0.0	817.0	7.3				
Cyprinus carpio (Age-1))					0.2	0.0	1.8	0.0				
Cyprinus carpio (Age-0)	959.6	45.0	804.0	32.0	2224	23.1	5606.0	50.4	1020	45.1	3668.5	65.5
Notropis lutrensis	1114	52.3	1352.8	53.8	424.3	4.4	714.5	6.4	187	8.3	322.5	5.8
Richardsonius balteatus												
Notropis stamineus	8.4	0.4	8.4	0.3								
Gila elegans (Ad)	4.2	0.2	229.2	9.1	4.7	0.0	58.4	0.5				
Gila elegans (Age-0)					355.7	3.7	391.8	3.5	1.5	0.1	1.8	0.0
Xyrauchen texanus (Age-0)					11	0.1	8.2	0.1				
Catostomus latipinnis (Age-0)	0.6	0.0	5.6	0.2								
Pomoxis nigromaculatus (Ad)												
Pomoxis nigromaculatus (Age-0)												
Prosopium williamsoni (age-0)	0.4	0.0	0.5	0.0	0.2	0.0	0.0	0.0				

	June No.	%	Wt.	%	July No.	%	Wt.	%	Harvest No.	%	Wt.	%
Ictaluris punctatus (Ad)												
Rhinichthys osculus												
Culea inconstans					0.3	0.0	0.5	0.0				
Catostomus commersoni (Age-0)					0.2	0.0	26.7	0.2				
Overall Mean	2130		2514.5		9608.6		11118.5		2263		5601.6	

Old Charley Wash	June				July				Harvest			
	No.	%	Wt.	%	No.	%	Wt.	%	No.	%	Wt.	%
Pimephales promelas	102.4	0.2	199.0	0.5	6051.2	40.2	5780.0	26.0	1388	28.8	1241	5.7
Lepomis cyanellus (Ad)	1	0.0	30.6	0.1	1	0.0	38.6	0.2				
Lepomis cyanellus (Juv)					1921.4	12.8	1668.2	7.5	116	2.4	411.5	1.9
Amierus melas (Ad)	0.4	0.0	33.7	0.1	0.4	0.0	30.2	0.1				
Amierus melas (Age-0))					5.8	0.0	4.6	0.0	20.5	0.4	34	0.2
Cyprinus carpio (Ad)					1.2	0.0	1393.0	6.3	1	0.0	13200	60.1
Cyprinus carpio (Age-1))									3	0.1	99.5	0.5
Cyprinus carpio (Age-0)	41362	93.0	33619.6	88.5	5623.8	37.3	11176.2	50.3	3062	63.5	6874	31.3
Notropis lutrensis	3002	6.8	3972.0	10.5	1213.6	8.1	1676.0	7.5	184	3.8	57	0.3
Richardsonius balteatus												
Notropis stamineus					74.6	0.5	95.8	0.4				
Gila elegans (Ad)	0.4	0.0	25.0	0.1								
Gila elegans (Age-0)	0.2	0.0	0.2	0.0	133.2	0.9	238.4	1.1				
Xyrauchen texanus)Age-0)					26.6	0.2	46.6	0.2				
Catostomus latipinnis (Age-0)	0.8	0.0	10.8	0.0								
Pomoxis nigromaculatus (Ad)					0.4	0.0	28.0	0.1				
Pomoxis nigromaculatus (Age-0)					2.8	0.0	2.0	0.0	50.5	1.0	43	0.2
Prosopium williamsoni (age-0)												
Ictaluris punctatus (Ad)	0.4	0.0	57.6	0.2								
Rhinichthys osculus												
Culea inconstans												
Catostomus commersoni (Age-0)	2.4	0.0	34.4	0.1	2.4	0.0	63.0	0.3				
Overall Mean	44472		37982.9		15058		22240.6		4824		21960	

Appendix Table 2. Average number and weight of fish collected per fyke net (and their respective percentages) captured from study floodplains during the two monitoring collections and final harvest in 2004. Ad = adults only, Juv = juveniles.

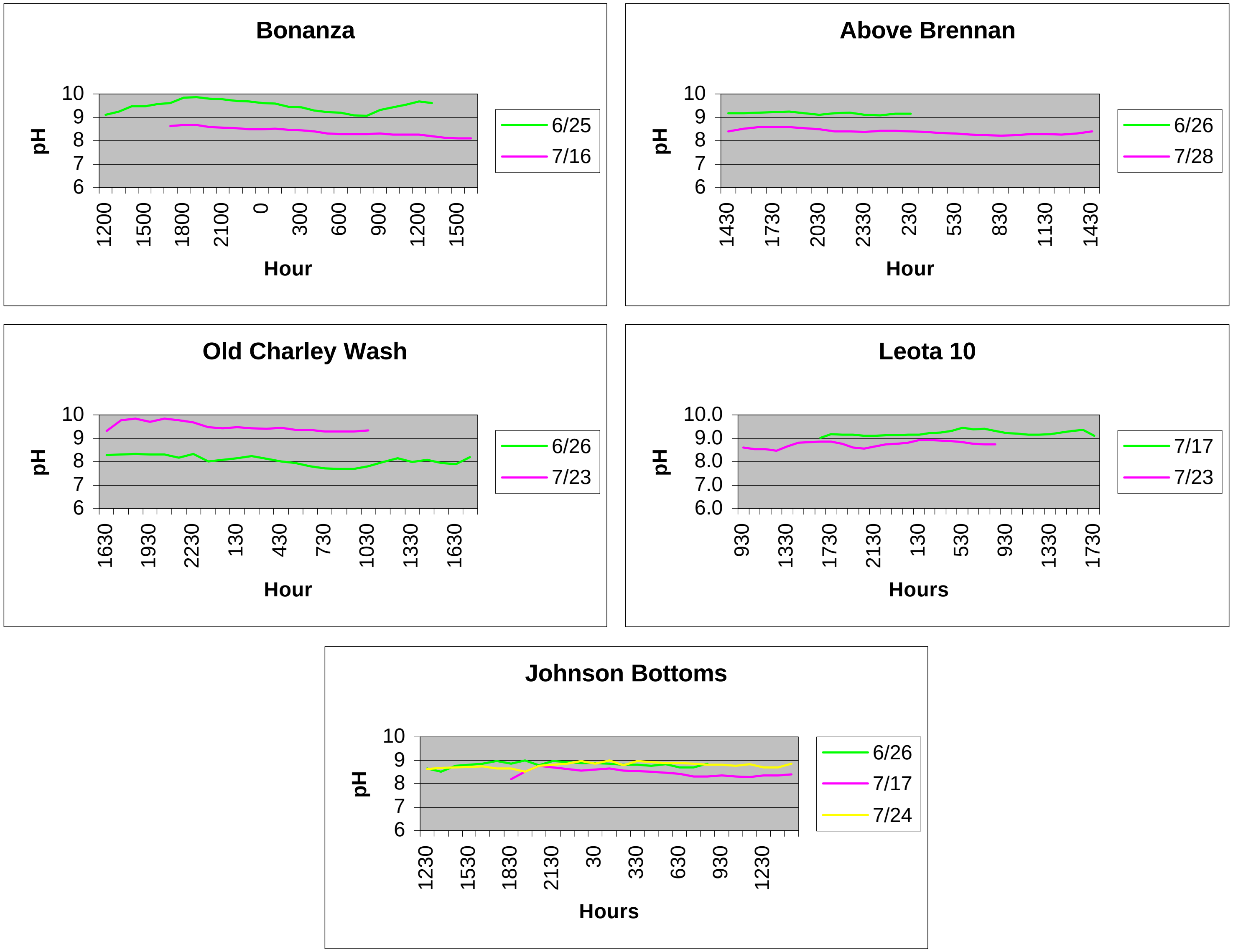
Thunder Ranch [1]	**June**				**July**							
	No.	**%**	**Wt**	**%**	**No.**	**%**	**Wt**	**%**				
Pimephales promelas	6.7	9.7	27.0	4.3								
Lepomis cyanellus (Ad)	21	30.3	562.0	89.0								
Lepomis cyanellus (Juv)												
Amierus melas (Ad)												
Amierus melas (Juv)												
Amierus melas (Age-0))												
Cyprinus carpio (Ad)												
Cyprinus carpio (Age-1))												
Cyprinus carpio (Age-0)												
Cyprinella lutrensis												
Notropis stamineus												
Gila elegans (Ad)												
Gila elegans (Age-0)												
Xyrauchen texanus (Age-0)												
Xyrauchen texanus (Age-1)												
Pomoxis nigromaculatus (Ad)												
Pomoxis nigromaculatus (Age-0)												
Ictaluris punctatus (Ad)												
Ictaluris punctatus (Juv)												
Culea inconstans	41.7	60.1	42.7	6.8	60.3	100.0	172.4	100.0				
Overall Mean	69.4		631.7		60.3		172.4					
Johnson Bottom	**June**				**July Harvest**							
	No.	**%**	**Wt**	**%**	**No.**	**%**	**Wt**	**%**				
Pimephales promelas	25.8	17.9	48.2	2.2	141.8	16.6	138.7	4.3				
Lepomis cyanellus (Ad)	9.8	6.8	135.4	6.3	0.5	0.1	8.2	0.3				
Lepomis cyanellus (Juv)	2	1.4	5.4	0.3	5.0	0.6	6.0	0.2				
Amierus melas (Ad)	10.4	7.2	275.6	12.8	1.2	0.1	23.0	0.7				
Amierus melas (Juv)	27.4	19.1	234.0	10.8	0.4	0.0	5.4	0.2				
Amierus melas (Age-0))					17.7	2.1	15.2	0.5				
Cyprinus carpio (Ad)	0.6	0.4	1112.0	51.5	1.2	0.1	1889.2	58.2				

Cyprinus carpio (Age-1))	3.2	2.2	134.0	6.2	0.7	0.1	61.3	1.9				
Cyprinus carpio (Age-0)					603.5	70.8	927.2	28.6				
Cyprinella lutrensis	60.4	42.0	102.4	4.7	53.8	6.3	67.7	2.1				
Notropis stamineus	2.6	1.8	3.2	0.1	0.3	0.0	0.2	0.0				
Gila elegans (Ad)												
Gila elegans (Age-0)					0.5	0.1	0.8	0.0				
Xyrauchen texanus (Age-0)	0.8	0.6	1.0	0.0	24.3	2.9	76.5	2.4				
Xyrauchen texanus (Age-1)	0.2	0.1	9.0	0.4								
Pomoxis nigromaculatus (Ad)												
Pomoxis nigromaculatus (Age-0)					1.5	0.2	1.0	0.0				
Ictaluris punctatus (Ad)	0.4	0.3	80.0	3.7	0.2	0.0	26.7	0.8				
Ictaluris punctatus (Juv)	0.2	0.1	17.6	0.8								
Culea inconstans												
Overall Mean	143.8		2157.8		852.6		3247.1					
Old Charley Wash				**June**	**July Harvest**							
	No.	**%**	**Wt**	**%**	**No.**	**%**	**Wt**	**%**				
Pimephales promelas	12.6	1.2	17.4	0.6	5.3	0.4	2.3	0.1				
Lepomis cyanellus (Ad)	0.6	0.1	30.0	1.1								
Lepomis cyanellus (Juv)					25.0	2.0	7.8	0.4				
Amierus melas (Ad)					0.1	0.0	2.6	0.1				
Amierus melas (Juv)	0.2	0.0	2.0	0.1								
Amierus melas (Age-0))												
Cyprinus carpio (Ad)	0.8	0.1	1292.0	47.2	0.6	0.0	1475.0	66.9				
Cyprinus carpio (Age-1))	0.4	0.0	48.0	1.8	0.4	0.0	19.5	0.9				
Cyprinus carpio (Age-0)	816	78.2	752.0	27.5	293.5	23.7	497.3	22.6				
Cyprinella lutrensis	195	18.7	184.0	6.7	22.5	1.8	13.4	0.6				
Notropis stamineus	15.2	1.5	15.2	0.6	5.6	0.5	4.3	0.2				
Gila elegans (Ad)												
Gila elegans (Age-0)					.1	0.0	.1	0.0				
Xyrauchen texanus (Age-0)	0.8	0.1	0.8	0.0	19.3	1.6	21.5	1.0				
Xyrauchen texanus (Age-1)	0.6	0.1	140.0	5.1								
Pomoxis nigromaculatus (Ad)												
Pomoxis nigromaculatus (Age-0)					5.4	0.4	3.9	0.2				
Ictaluris punctatus (Ad)	0.2	0.0	256.0	9.3								
Ictaluris punctatus (Juv)	0.2	0.0	2.0	0.1								
Culea inconstans												
Misc. YOY cyprinids					861.9	69.5	156.4	7.1				

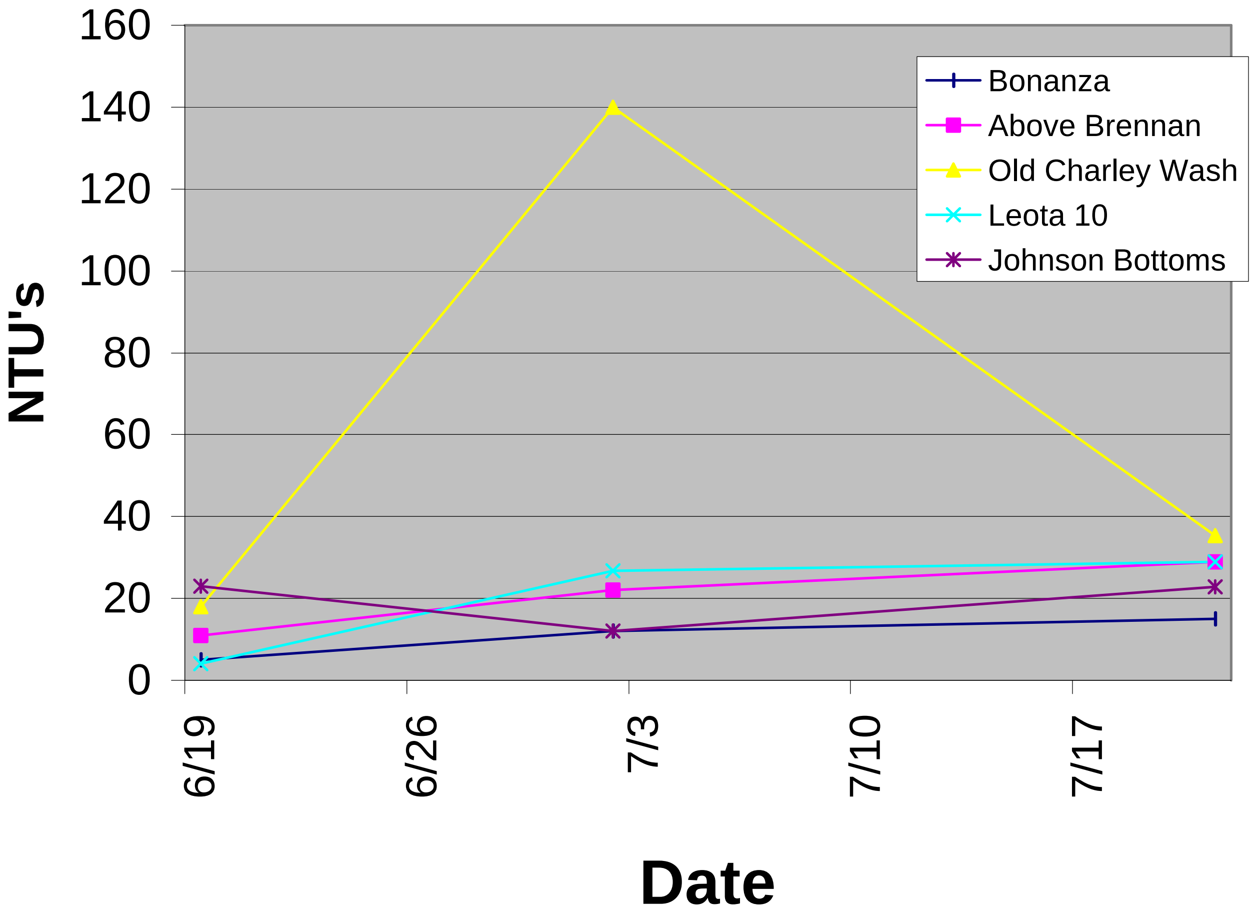
Overall Mean	1043		2739		1240		2204					
Leota-10	**June**				**July**				**August Harvest**			
	No.	**%**	**Wt**	**%**	**No.**	**%**	**Wt**	**%**	**No.**	**%**	**Wt**	**%**
Pimephales promelas	16.4	17.2	40.2	1.6	50.8	10.0	47.0	2.3	905.8	53.8	1116	33.6
Lepomis cyanellus (Ad)	18.6	19.5	404.0	16.0					0.2	0.0	6.7	0.2
Lepomis cyanellus (Juv)					261.0	51.5	311.0	15.1	322.7	19.2	643.8	19.4
Amierus melas (Ad)	2	2.1	168.0	6.7	8.4	1.7	342.6	16.6	4.8	0.3	163.2	4.9
Amierus melas (Juv)	13.6	14.3	100.0	4.0	6.0	1.2	61.0	3.0	4.8	0.3	11.3	0.3
Amierus melas (Age-0)					115.8	22.9	194.4	9.4	395.2	23.5	921.7	27.7
Cyprinus carpio (Ad)	0.8	0.8	1340.0	53.2								
Cyprinus carpio (Age-1)	6.6	6.9	412.0	16.4	6.6	1.3	871.0	42.2	1.3	0.1	231.3	7.0
Cyprinus carpio (Age-0)	1.2	1.3	1.2	0.0	22.2	4.4	91.6	4.4	20.2	1.2	135.7	4.1
Cyprinella lutrensis	29.2	30.6	48.4	1.9								
Notropis stramineus					6.2	1.2	11.0	0.5	13.2	0.8	21.8	0.7
Gila elegans (Ad)												
Gila elegans (Age-0)					11.4	2.3	23.4	1.1	11.0	0.7	29.7	0.9
Xyrauchen texanus (Age-0)	7	7.3	4.0	0.2	18.2	3.6	109.6	5.3	3.2	0.2	41.2	1.2
Xyrauchen texanus (Age-1)												
Pomoxis nigromaculatus (Ad)												
Pomoxis nigromaculatus (Age-0)												
Ictaluris punctatus (Ad)												
Ictaluris punctatus (Juv)												
Culea inconstans												
Overall Mean	95.4		2518		507		2063		1682		3323	

[1]June monitoring collections made with fyke nets, and July collections conducted with minnow traps due to shallow water limitation.

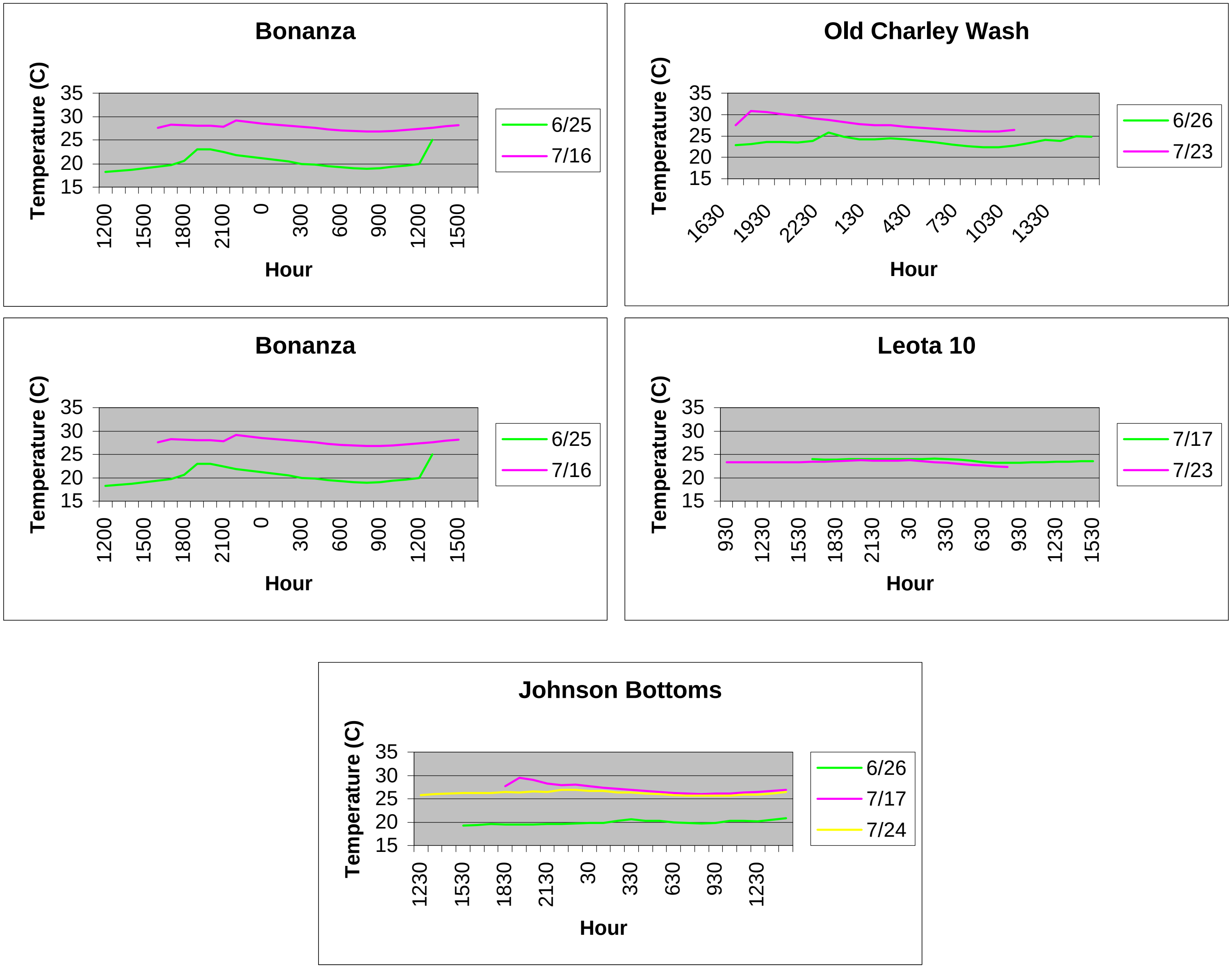
Appendix Figure 1. pH monitored over 24 h periods in five study floodplains in the Green River during 2003.



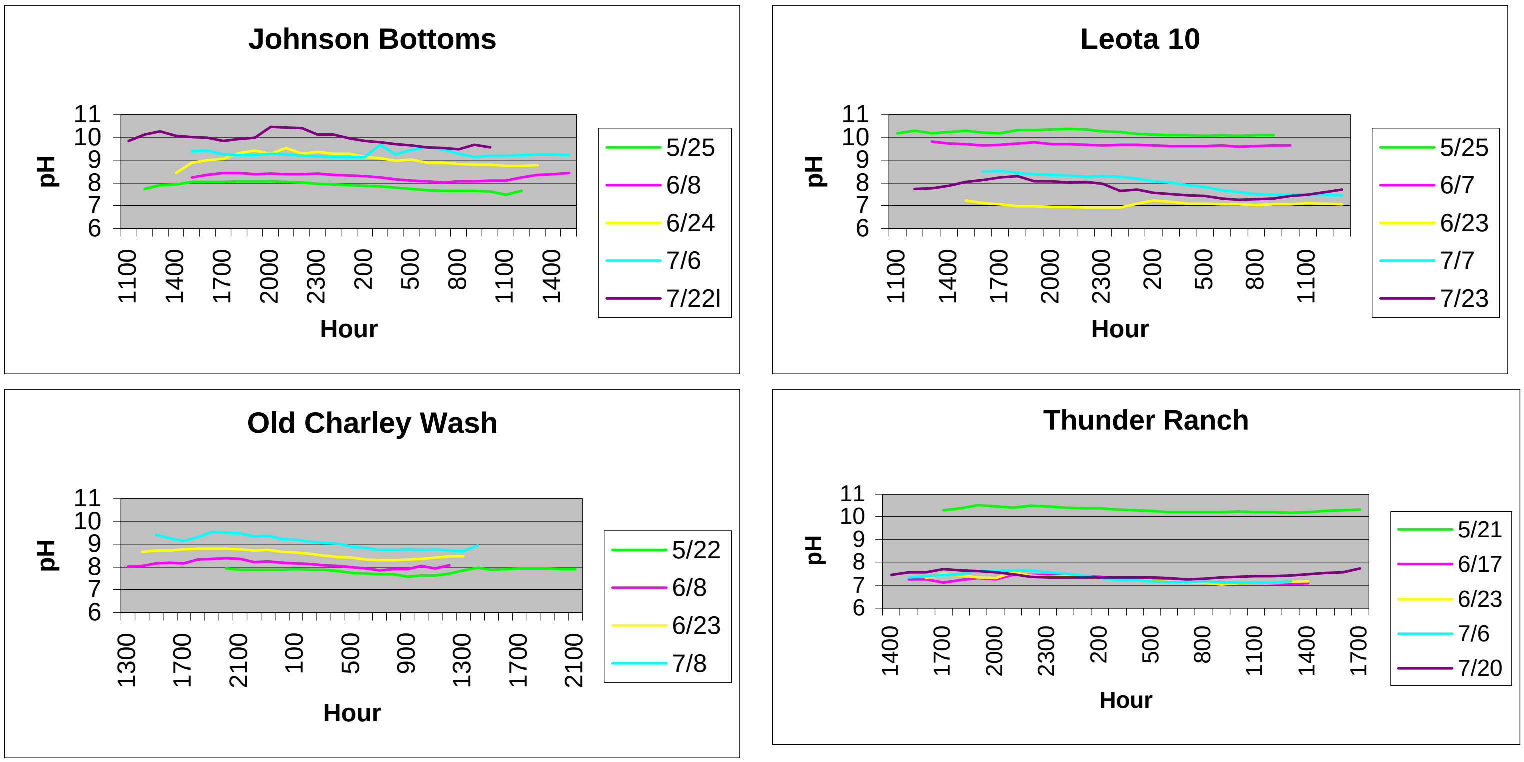
Appendix Figure 2. Turbidity measurements for study floodplains in the Green River during 2003.



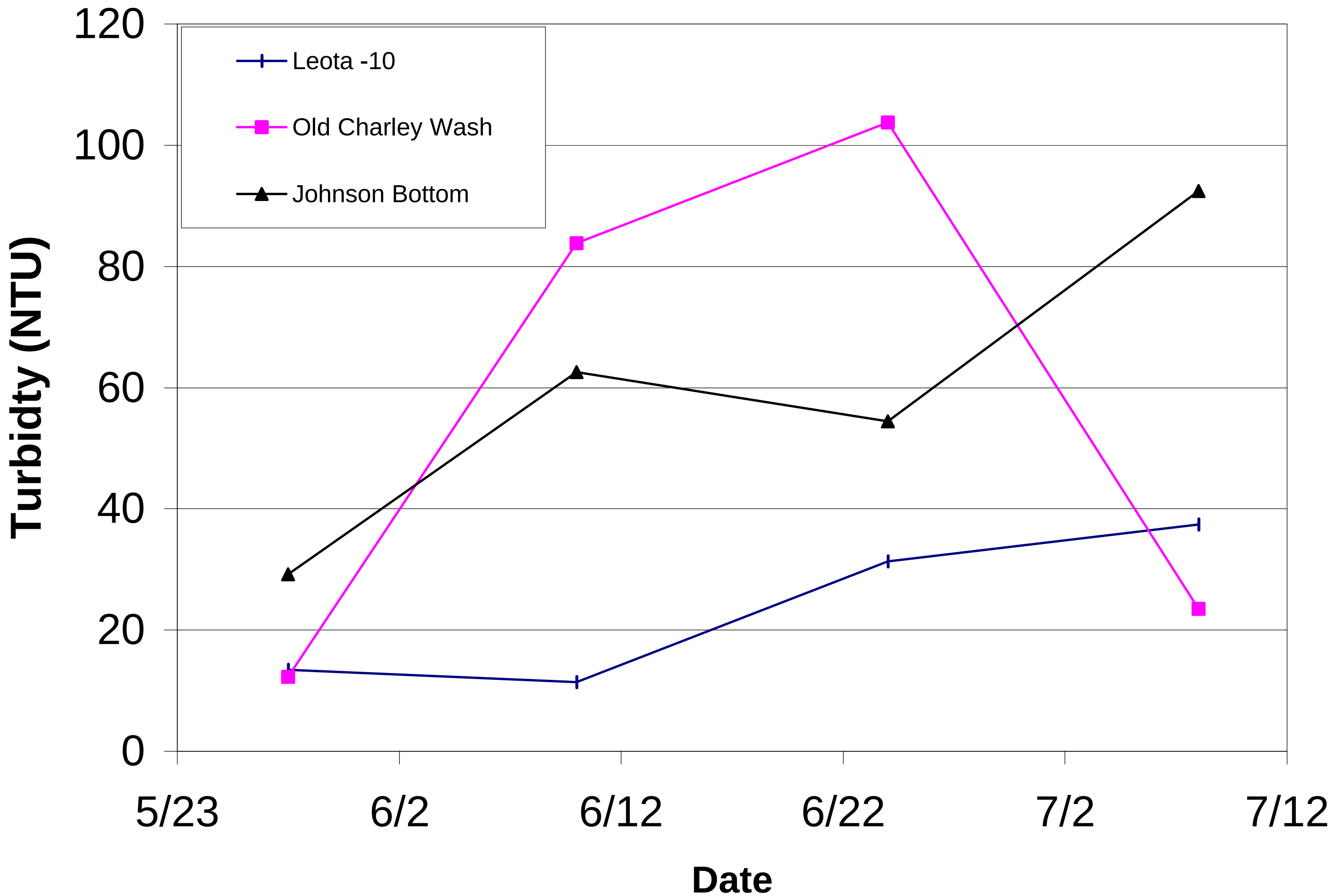
Appendix Figure 3. Temperature profiles measured over 24 h periods for study floodplains in 2003.



Appendix Figure 4. pH monitored during 24h periods from four study floodplains along the Green River during 2004.



Appendix Figure 5. Turbidity in three study floodplains along the Green River in 2004.



Appendix Figure 6. Temperature profiles measured over 24h periods in study floodplains in 2004.