Entrainment of Semi-Buoyant Beads and Razorback Sucker, *Xyrauchen texanus*, Larvae into Flood Plain Wetlands of the Middle Green River, Utah

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Entrainment, beads, flood plain wetlands, middle Green River, razorback sucker, drift, Thunder Ranch, Stewart Lake, Bonanza Bridge, the Stirrup, Leota L-7

EXECUTIVE SUMMARY

The razorback sucker, *Xyrauchen texanus* was formerly widespread throughout warmwater reaches of the Colorado River Basin, but is currently federally listed as endangered due to negative impacts from physical habitat alteration and introduction and proliferation of nonnative fishes. Flood plain wetlands are presumed important habitat for early life stages of razorback sucker. Therefore, the Upper Colorado River Basin Endangered Fish Recovery Program initiated actions to 1) identify key flood plain areas and breach levees to increase river connections to them and 2) develop and implement flow recommendations to enhance those connections.

We released semi-buoyant beads and marked razorback sucker larvae into the Green River during spring run-off in 2004, 2005, and 2006 to evaluate drift characteristics of larvae and beads into flood plain wetlands. Based on drift rates and capture patterns, our findings from 2004 main channel only sampling suggested that beads and tetracycline-marked fish larvae were reasonable surrogates for one another based on similarities in drift capture patterns. We also captured substantial numbers of unmarked, wild-produced razorback sucker larvae in 2004. This demonstrated that stocked adult fish were successfully reproducing and that another spawning area may exist downstream from Razorback Bar (now named “Escalante Bar”), an hypothesis later verified by independent sampling of ripe adult fish.

Based on 2004 and 2005 captures of two different colored beads released on different sides of the river, complete cross-channel mixing of drift particles did not occur until at least 22 kilometers (km) downstream of release sites over the range of flows we tested. Mixing is likely to occur more quickly at higher flows. This conclusion was supported by the collection of a greater number of orange beads released upstream and on the opposite side of the river of

Thunder Ranch wetland in near shore and breach nets during higher flows in 2005 compared to low flows in 2004. Beads were well mixed downstream of release sites in the Green River at the Stirrup wetland in 2005. Maximum entrainment occurred in wetlands nearest to and on the same side of the river as release or production areas for larvae. For example, Thunder Ranch wetland would be expected to entrain the most larvae produced from Escalante Bar because they are in close proximity and on the same side of the river.

Beads released at Razorback Bar and Escalante Bar in 2005 were collected in all downstream breaches and as far downstream as Leota wetlands, 85 km downstream, which supported the notion of long-distance downstream dispersal of beads and larvae from release sites. Drift particle density declined downstream, based on recaptures of released beads and marked larvae because beads dispersed longitudinally, were retained laterally, and were transported into flood plain wetlands. This suggested that wetlands closer to production areas can potentially contribute greater numbers of razorback suckers to the population. However, downstream bead densities and fish captures were substantial and suggested that sufficient numbers of razorback sucker larvae may drift from upstream production areas to populate flood plain wetlands well downstream. Accordingly, wetlands would ideally be present in a mosaic of locations up and down the river and on each side of the river to maximize potential entrainment.

Entrainment rates of beads, water, and presumably fish were relatively low in single breach wetlands and declined dramatically or ceased when those wetlands (e.g., Stewart Lake when outlet is closed, Stirrup, Leota L-7 [L-7]) were filled. Those same breaches and wetlands would theoretically release water and some drift material as river flows recede, as was observed at L-7 in 2005. Thus, it is clear that simply connecting flood plain wetlands with the river is not adequate to effect substantial recruitment because large numbers of razorback sucker larvae must be transported from the river into the wetlands.

In contrast to single breach wetlands, entrainment rates of beads, water, and presumably fish larvae were relatively high in flow-through wetlands. Entrainment of beads and water increased with higher flows in the river; although entrainment rates (beads entrained per volume of flow entrained) were not always highest at the highest flow (this was true at Thunder Ranch in 2006, but not at Thunder Ranch in 2005 or Stewart Lake in 2006). We suspect that entrainment of drift material would continue to increase as flow levels increased over those we observed.

Bead and flow entrainment rates in flow-through wetlands were similar on the ascending and descending limbs of the hydrograph. In wetlands with multiple breaches (e.g., Thunder Ranch), the upstream breach captured more beads than downstream breaches. This was especially true as flows increased and the upstream breach became more effective at entraining beads, thereby leaving fewer beads available to become entrained downstream.

These data collectively suggest that higher spring peak flows may be beneficial to connect flood plain wetlands with the river and enhance entrainment of razorback sucker larvae. However, timing spring peaks to coincide with production of larvae is critical, as is the need to provide overwinter habitat for fish in wetlands.

A primary recommendation is to synthesize entrainment data with other physical and biological data collected in the middle Green River, so that a cohesive strategy for flood plain management and recovery of razorback suckers can be achieved. Other direct recommendations from the results of this study include determining whether alterations to breach configuration are necessary (including single breach wetlands) to maximize entrainment and exploring the tradeoff between connecting flood plain wetlands and river flows with short-term, higher peak flows compared to connecting wetlands with lower peaks over a longer duration.

Recommendations resulting indirectly from results of this study include ranking flood plain wetlands according to management priority to help allocate limited funding, developing a sediment management plan to for high priority wetlands to maintain utility of these areas long term, and protecting known and potential razorback sucker spawning areas from impacts such as sedimentation and potential effects from energy development. Such information will allow managers to revise management strategies for middle Green River flood plain wetlands and evaluate efficacy of flow recommendations implemented in 2006 to increase entrainment and recruitment of razorback sucker.

INTRODUCTION

The razorback sucker, *Xyrauchen texanus*, is a relatively long-lived member of the family Catostomidae (Minckley 1983; McCarthy and Minckley 1987; Bestgen 1990; Minckley et al. 1991). Endemic razorback sucker was formerly widespread throughout warmwater reaches of the Colorado River Basin but its current range is much reduced due to physical habitat alteration and proliferation of nonnative fishes (Minckley et al. 1991). Declines in distribution and abundance prompted federal listing of razorback sucker as endangered in 1991 (U.S. Fish and Wildlife Service 1991). Substantial populations (e.g., > 200) of razorback sucker in the lower Colorado River Basin are presently restricted to Lake Mohave Reservoir and Lake Mead Reservoir (Minckley et al. 1991; Marsh et al. 2003; Holden and Abate 2000). Substantial populations in the Green and Colorado rivers in the Upper Colorado River Basin also exist, mostly a result of stocked hatchery fish (Bestgen et al. 2002; Zelasko 2008).

Flood plain wetlands are presumed important habitat for early life stages of razorback sucker in the middle Green River (Modde et al. 1996; Wydoski and Wick 1998; Muth et al. 1998; Modde et al. 2001; Bestgen 2008). Reproduction by razorback suckers in the middle Green River occurs before or during the ascending limb of the spring hydrograph when water temperatures are 10–18°C (Tyus 1987; Muth et al. 2000; Bestgen et al. 2002) and produces razorback sucker larvae when flows are high and flood plain wetlands may be accessible. These habitats can be 3-8°C warmer than the river, are food-rich, and may promote higher survival of larvae and recruitment to juvenile and adult life stages (Modde 1996; Muth et al. 1998; Modde et al. 2001; Bestgen et al. 2002; Bestgen 2008). Flood plain habitats are also thought to benefit two of the other Colorado River Basin endangered fishes: Colorado pikeminnow *Ptychocheilus* *lucius*, and bonytail *Gila elegans* (Lenstch et al. 1996; Modde 1996; Modde and Irving 1998; Mueller 2003).

Two main management actions initiated by the Upper Colorado River Basin Endangered Fish Recovery Program (Program) have been responsive to the need to increase flood plain wetland availability for early life stages of razorback sucker. The first was a program to identify key flood plain wetlands within drainages of the Upper Colorado River Basin (Irving and Burdick 1995). High priority areas (e.g. depression wetlands) identified were downstream of known or suspected razorback sucker spawning areas in the middle Green River, Utah, located at Razorback Bar (River Kilometer [RKM] 500.9) (Appendix I converts most river kilometers, water volumes, and water velocities referenced from metric to the English equivalents), and Escalante Spawning Bar (RKM 493.7), whose proximity to spawning bars may enhance entrainment of drifting larvae into flood plain wetlands (Karp and Tyus 1990; Modde et al. 1996; Muth et al. 2000, Bestgen et al. 2002, Valdez and Nelson 2004). Increased river connection and functioning of eight high priority flood plain habitats was effected via removal or breaching of levees in 1997 and 1998 (Birchell et al. 2002).

A second main management action to increase flood plain wetland availability for early life stages of razorback sucker was to implement flow recommendations to enhance river-flood plain connections in the Middle Green River (Muth et al. 2000). This was needed because spring discharge levels of the Green River have been reduced due to impoundment and storage of flows in Flaming Gorge Reservoir. To increase the frequency of flood plain wetland connections, the flow recommendations implemented were designed to match spring peak and post-peak flow of the mostly unregulated Yampa River with releases from Flaming Gorge Dam. Recommendations sought to increase those connections mainly in average, moderately wet, or wet hydrologic conditions (Muth et al. 2000) because flows in moderately dry or dry years are usually insufficient to achieve substantial river-flood plain connections. These flow recommendations were implemented in 2006; therefore, their evaluation was not originally identified as an objective for this project. However, because implementation of recommendations overlaps with one year of this study and are consistent with the study objectives, there may be some potential to evaluate efficacy of recommendations.

Because provision of flood plain habitat to benefit native fishes is mainly an hypothesis, research and monitoring is ongoing to test that hypothesis. Flow recommendations list uncertainties regarding the response of native fishes to certain flow and temperature regimes (Muth et al. 2000). Specific uncertainties include whether there is a need for increased flows and the suitability of release durations to link the Green River with flood plain wetlands, especially in average flow years (U.S. Department of the Interior 2005). Recommendations in average hydrologic conditions, which occur in about four of every 10 years, call for flows in Reach 2, the middle Green River from downstream of the Yampa River to the head of Desolation Canyon, Utah, to meet or exceed 527 m^3/sec (18,600 cubic feet per second [ft^3/sec]) in one of two average flow years, and that flow level should be maintained for at least two weeks in one of every four years. Some resource managers have questioned recommendations that would be implemented during average hydrologic conditions, mainly because lowering or removal of levees may enhance riverine connections sufficiently without the need for increased Flaming Gorge Dam flow identified in the recommendations (Green River Study Plan *adhoc* Committee 2007). No recommendations were made for the upper limit of any peak flow under any hydrologic condition because a greater extent of flood plain inundation was viewed as beneficial to native fishes.

This study was initiated to evaluate larval razorback sucker drift characteristics and use the resulting data to revise management of middle Green River flood plain wetlands. The objectives for this study were to:

1 Evaluate larval drift and entrainment patterns downstream from Razorback Bar;
2 Evaluate drift and entrainment of larvae into flood plains from other potential spawning sites;
3 Continue to evaluate the effectiveness of breach connections for entraining drift at various flows over the spring hydrograph; and
4 Provide data to refine the Flood Plain Drift Model (Valdez and Nelson 2004) and to test various flood plain management scenarios.

This study (2004 – 2006) built upon information collected in previous years regarding patterns of reproduction, larval drift, and entrainment into flood plain wetlands. For example, results from preliminary sampling in 2003 suggested that increasing entrainment of razorback sucker larvae may be a complex process and that assessing drift patterns based on capture of wild larvae may be inefficient (Appendix II). As a result, semi-buoyant beads and marked razorback sucker larvae were used rather than wild larvae, to increase the number of particles available for capture. Specifically, we sought to better understand: 1) the relationship between flow, bead, and larvae entrainment rates into flood plain wetlands as a function of flow; 2) entrainment rate variation during increasing or decreasing portions of the hydrograph; 3) breach connections and configurations to enhance entrainment; 4) drift and behavior patterns of razorback sucker larvae relative to beads; 5) the required proximity of larvae to the flood plain breaches in order for entrainment to occur; and 6) whether a configuration exists that allows for entrainment, but does not increase sedimentation into the flood plain habitats. This report presents the results of a three-year study designed to answer aspects of these relationships in an effort to better manage flows to enhance recovery of razorback sucker in the middle Green River, Utah.

STUDY AREA

The Green River study area is near the town of Vernal in northeastern Utah (Figure 1). Flow of the Green River is partially controlled by Flaming Gorge Dam, located near the Utah-Wyoming border. Green River flow is supplemented by tributary flow, particularly that from the Yampa River, which is confluent with the Green River in Dinosaur National Monument. The Green River downstream of the Yampa River is designated critical habitat for recovery of the razorback sucker (U. S. Fish and Wildlife Service 1991; U. S. Fish and Wildlife Service 2002). The flow pattern of the Green River near Jensen, Utah, is dominated by a large spring peak generated from snowmelt runoff in the headwaters of the Green and Yampa rivers, and has a relatively low base flow during the rest of the year (Figure 2). Post-dam Green River flows have lower and shorter duration flow peaks than during the pre-dam period. Reach 2 of the middle Green River (Muth et al. 2000) is mostly an alluvial reach downstream with two known spawning areas and many well-developed flood plain areas thought important for survival of razorback sucker larvae and recruitment. The two known spawning bars in this reach are at Razorback Bar and Escalante Spawning Bar, both of which are just upstream of the Thunder Ranch (RKM 492.1) flood plain wetland (Figure 3). Over the course of the study, five flood plain sites were sampled: Thunder Ranch, Stewart Lake (RKM 482.8), Bonanza Bridge (466.2), the Stirrup (443.4), and Leota-7 (414.9) (L-7).

METHODS

Given difficulties with capturing sufficient numbers of wild larvae to assess entrainment patterns in 2003 pilot studies, we used both beads and hatchery-produced and marked razorback sucker larvae released prior to sampling events to increase capture rates. Beads were semi-buoyant, gelatinous in texture, biodegradable, and three to six mm in diameter (manufactured by Key Essentials, Inc.). Number of beads released was estimated by counting beads in subsamples of a known volume and estimating bead number by scaling that ratio to volume per barrel. Different bead colors were sometimes used at different release locations to understand cross-channel bead mixing rates as beads were captured downstream.

Razorback sucker larvae used in releases were produced at Ouray National Fish Hatchery (Ouray Hatchery). Larvae were produced in temporally spaced batches by sequentially spawning groups of adults. We released larvae that were approximately as old as those captured in the wild during the post-spawning period (9 to 15 days old; Muth et al. 1998), although we did release slightly older fish (21 days old) in the first release in 2006. We marked larvae to distinguish hatchery-released larvae from those produced in the wild. Larvae were marked when they were about seven days posthatch or older and just after swim-up (Muth and Meismer 1995). Fish larvae were placed in a reduced volume of water in hatchery tanks or pails and allowed to acclimate for one to two hours (hr). Dissolved oxygen levels were monitored at intervals and maintained at greater than five milligrams/liter (mg/L). Marking was conducted inside and away from any source of ultraviolet light, as light in that wavelength degrades the tetracycline marking compound (Muth and Bestgen 1991). In 2006 we experimented with commercially available tetracycline hydrochrloride (TC) powder (Sigma Chemical T3383), available in feed stores and used for livestock treatments. That compound worked successfully in tests and since it was less expensive than reagent grade TC, commercially available TC was used for fish marking that year. A 6.2 gram amount of TC was dissolved in 800 milliliter (ml) of deionized water and was sufficient to achieve a marking solution of 350 mg/L, when added to the 19 liter (L) of water in the marking container. The solution was buffered with tris (Trizma hydrochloride, Sigma Chemical T-3253), a few grains at a time, to a pH of about 7.0. After acclimation, the TC solution was added to the marking container and gently mixed. Fish were immersed in the marking solution for four to five hr, a time sufficient to mark otoliths at those concentrations (Muth and Meismer 1995). A small amount of air or oxygen was bubbled through the marking solution; over-aeration produces excess foam. The solution was flushed to a waste drain (not recirculated because antibiotic TC may affect biofilters in the hatchery) and fish were put back into holding tanks. A few (about 10) larvae were preserved in 100% ethanol just post-marking and then again two to three days later to ensure that fish were adequately marked. Examination of otoliths of fish immersed in the TC solution showed that 100% of fish were marked and marks were bright yellow and clear (Muth and Bestgen 1991). In 2005, we double-marked one batch of larvae so that fish from different release batches could be differentiated after capture in the wild. This was accomplished by conducting the standard marking at eight days post-hatch, followed by another mark application at 11 days post-hatch. The three-day interval was sufficient to allow for the marks to be spatially well-separated (not overlapping) on the otolith. Number of larvae released was estimated volumetrically in the hatchery; larvae were placed in plastic bags with a large headspace of oxygen, and transported to release sites the morning of releases.

In 2005, based on our recommendation, hatchery personnel attempted to mark a batch of razorback sucker larvae with alizarin complexone (AC), a compound successfully used in other marking studies that produces a fluorescent red mark (Muth and Meismer 1995). We attempted

AC marking to have yet another uniquely marked batch of larvae for release into the river. Personnel at Ouray Hatchery noted complete mortality of larvae marked with AC. We investigated potential reasons for mortalities by conducting additional tests with seven-day-old fathead minnow, *Pimephales promelas,* larvae and older razorback suckers and did not observe mortalities. Thus, we reached no conclusions regarding reasons for mortality of razorback suckers marked at Ouray Hatchery (Appendix III). We did not attempt marking additional larvae with AC.

We present release and field sampling information for each year separately because protocols changed with flow level and as we gained more information about the behavior of these systems relative to entrainment. Basic summary data are presented to assist reader understanding of the different release sites, conditions, and techniques used each year (Table 1).

<u>2004</u>

In 2004, Green River peaks flows were low (161 cubic meters per second [m^3/sec]) (Figure 2) and river-flood plain connections, including those at Thunder Ranch and Stewart Lake, were non-existent. Thus, 2004 sampling was conducted primarily to determine drift rates for beads and larvae, assess cross-channel mixing of beads downstream from release sites, and to evaluate whether beads were adequate surrogates for hatchery-reared razorback sucker larvae in main channel drift. Such information was deemed useful to guide sampling designs in years when flows were high enough to create a river-flood plain connection. Beads and marked larvae were released downstream from the island at Razorback Bar on 26 May, which was mostly a river right location. Two conical drift nets (four m long, 500 micron mesh size) equipped with General Oceanics (GO) Model 2030R mechanical flow meters and cod-end capture buckets were set 1.6 kilometers (km) and 8 km downriver near each river bank (no mid-channel nets) to capture drifting larvae and beads. The GO flow meter incorporates a rotor coupled directly to a six-digit counter, which registers each revolution of the rotor and displays it in a fashion similar to that of an odometer. The counter is located within the body of the instrument and is displayed through the plastic housing. It is the value of the final meter reading less the initial meter reading that is used to calculate flow velocity and ultimately, the total flow sampled by the net.

Drift nets were cleared of debris as frequently as needed to prevent net backflow (as sample buckets filled, sample material would interfere with amount of flow through the net) and samples were collected for up to seven hr post-release. Drift net samples were picked to remove sucker larvae and beads. Sucker larvae were preserved in 100% ethanol, otoliths were removed and mounted on microscope slides, observed under a compound microscope equipped with UV illumination, and presence of a mark was noted to differentiate marked hatchery-produced razorback sucker larvae from wild-produced larvae. Numbers of beads and larvae captured were used to determine rate of downstream drift, differences in rates of bead and larvae transport, and mixing of beads across the channel.

<u>2005</u>

In 2005, Green River flows reached over 538 m^3/sec at the Jensen gage (Gage # 09261000; figures 2 and 3, gauge located a few kilometers upstream of Razorback Bar) and each of the target flood plain wetlands connected to the river. Therefore, drift net sampling was conducted in the river channel as well as in flood plain wetland breaches. Approximately 1,517,000 beads and different-sized batches of razorback sucker larvae were released simultaneously into the river at three different flows (on the ascending limb, the peak, and on the descending limb of the hydrograph) and at two different spawning bars (Razorback Bar, which is on river right, and Escalante Bar on river left). Flow requests from Flaming Gorge Dam were carefully coordinated with the U. S. Bureau of Reclamation and other agencies, including those participating in the sampling, and were held at requested levels for two or more days to accommodate sampling. During that time, flow releases were adjusted based on levels of the tributary Yampa River to keep Green River flows stable and near requested targets, and flow managers should be commended for their efforts.

The three releases occurred on 20, 24, and 31 May, 2005 (Table 1). Orange beads were released at Razorback Bar and yellow beads at Escalante Bar. Five drift net stations were established over the entire distance of the study area for each release. Net stations were located 1.6 km downstream of Razorback Bar and at each of four different flood plain locations: Thunder Ranch (multiple inflow breaches and an outflow), Stewart Lake (outlet gate was closed in 2005 so had only one breach that acted as inflow and outflow depending on river stage), the Stirrup (a single downstream breach that acted as inflow and outflow depending on river stage), and L-7 (a nonfunctional upstream inflow breach, and a downstream outflow breach that acted as an inflow when river elevation overtopped the breach and when flows were increasing in 2005).

At sites 1.6 km downstream of release sites, nets were set at channel margins (one on the far shoreline and two on the near shoreline) and in the midchannel (one net only) for a total of four main channel nets. At flood plain sites, one drift net was set across the channel on the far river bank (relative to the flood plain inlets), one or two at mid channel depending on the site, and one in the river immediately downstream of the flood plain breaches. Two additional nets were set in the breaches. Because beads were easily observed in the drift samples, their presence was used to estimate drift rates and to determine when sampling at downstream sites should begin. As in 2004, all drift nets were equipped with a GO Model 2030R mechanical flow meter suspended in the center of the net. Samples were collected for up to five hr at each drift net station and over 36 hours during each release when all sites were considered, which was ample time to allow beads to travel the 85 km from the release sites to the site furthest downstream. Depth and velocity measurements were taken across a transect within each wetland breach using a Marsh-McBirney flow meter, usually at the beginning of the sampling period, but sometimes at the end as well if flow stage changed by > 1.5 cm. Depth and velocity measurements allowed for the calculation of the total flow entrained into the breach. On 21 and 25 May, Tetra Tech (2005) measurements were used at the Stirrup as this information was not taken during the sampling period. Main channel flows were recorded using measurements from the USGS gauging station near Jensen, Utah. Significant tributary inflows (e.g., Ashley Creek (Gage # 09266500) and Brush Creek (Gage # 09261700)) were added to Green River flows in appropriate locations to properly estimate river flows near breaches. In addition, travel times were taken into account for the Stirrup and Leota sites, as it takes over 24 hours for flows to reach these sites from the Jensen gage.

Samples were kept in a cooler following collection with the intention of picking larvae immediately. The number and size of samples did not allow for immediate processing so samples were stored in a refrigerated environment for up to several months. Because larvae were stored too long and likely disintegrated over the storage time, larvae were lost from nearly all 2005 samples. Immediate sorting of one sample from a Thunder Ranch breach by one of us (KRB) revealed that six razorback sucker larvae were captured, demonstrating that larvae were transported downstream and entrained into that flood plain wetland.

After sorting through drift samples and counting beads and larvae captured in the main channel, these numbers were used to determine patterns of drift downstream from release sites. Location of capture (left bank, right bank, or main channel) was noted, as was timing of capture (relative to release), and numbers of beads and larvae captured within the breaches. The few fish captured were identified and TC marked otoliths from early life stages of razorback sucker were verified. However, we make only passing mention of the fish data collected in 2005 and 2006 because preservation issues, especially in 2005, limited the number of fish recovered from samples. Even though more fish were preserved and recovered from 2006 samples, we could not establish which samples were well preserved and which were not, which made it difficult to know if fish presence or abundance data were reliable.

In addition, it became clear upon reviewing sampling data that the GO Model 2030R flow meters did not accurately measure velocities at lower flows in drift net samples. Without backup flow velocity information such as Marsh-McBirney flow measurements in net mouths, we had a number of gaps in data used to estimate the amount of flow sampled by nets. Because of this, results from 2005 were used to calculate only the percent of released beads captured in breach samples as well as to estimate the percent of flow entrained at various sites and at various river stage levels. This data portrays the patterns of bead and flow entrainment over different flow levels but not entrainment rates or densities of beads (e.g., beads per cubic meter of water entrained), which would allow extrapolation of entrainment to the entire breach over the entire sampling period. Because we were unable to extrapolate total bead entrainment, the best measure of entrainment effectiveness then became calculating the percentage of beads entrained into the breach over the different flows. In 2005, this value was calculated using the total number of beads captured in breach samples divided by the total number of beads captured in all samples at the site. Data were also used to estimate distance and travel rate of beads and larvae, and spatial patterns and mixing of beads across the channel over the longitudinal distance between capture sites.

2006

Consistent with changes in other years, the sampling design in 2006 was altered from 2005 to provide new information. Emphasis in 2006 was placed on understanding specific entrainment rates at breaches of flow-through flood plain wetlands. This was accomplished by releasing beads and larvae just upstream from (e.g., 1.6 km upstream), and near the channel margin of, breaches of Thunder Ranch, Stewart Lake, and Bonanza Bridge wetlands. Stewart Lake was limited to a single inflow with no outlet in 2005, but managers from the Utah Division of Wildlife Resources (UDWR) (K. Christopherson, S. Brayton, UDWR, pers. comm.) assured us that the outlet would remain open until Green River flow peaked in 2006. Thus, unlike during 2005 sampling, all sampling efforts in 2006 at Stewart Lake occurred during flow-through conditions until peak flow in the Green River was reached, after which the outlet was closed. Thus, no sampling was conducted at Stewart Lake during flows on the descending limb of the hydrograph.

Thunder Ranch

Approximately 540,000 beads were released upstream of each of the flood plain sites on various dates between 17 and 30 May in 2006. Tetracycline-marked razorback sucker larvae were released only at Thunder Ranch and only on the first three sampling occasions, because numbers were insufficient for other releases there or at other locations. Yellow beads and larvae were released upstream of Breach 3 at Thunder Ranch (Figure 4), which nearly coincided with the location of the Escalante spawning bar. Four drift nets were set in Breach 3, four in Breach 5 (which has a slightly higher river stage connection than 3), and four downstream from Breach 5 on the near shore. Drift nets sampled all or nearly the entire breach water column because breach depths were typically shallow; depth of flow sampled was noted for all net sets. All drift nets were again equipped with a GO Model 2030R mechanical flow meter suspended in the center of the net to determine flow velocity and ultimately, the amount of flow being sampled. If flow readings appeared incorrect (i.e., the end number was less than the beginning number), crews noted the inaccuracy on the data sheet and replaced the flow meter. Depth and flow measurements were also taken across a breach transect to estimate flow entrainment rates. If the water stage in the breach was more than 1.5 cm different from the start to the finish of sampling (generally a two to three hour timespan), depth and velocity measurements were taken again at the end of the sampling period.

Due to difficulties noted in 2005 with the GO flow meters, crew members also took flow readings at the mouth of each net using the Marsh-McBirney flow meter on most sampling occasions (13 of 18 occasions at all sites, breaches, and dates; net readings were taken at both breaches on all Thunder Ranch sampling dates [n = 7] except on 21 May in Breach 3). Because of the overwhelming number of problematic GO readings, we used only Marsh-McBirney meter readings when available or transect-estimated net velocities (explained below) to calculate water velocity at drift net mouths and the amount of water sampled. Where Marsh-McBirney meter readings were taken to replace GO meter readings, they were taken only once at each net per sampling occasion; that velocity was assumed to be the mean velocity of water flowing into the net over the sampling period.

At Breach 3 on 21 May, we estimated water velocity at the net mouth using flow velocities from breach transect measurements taken with the Marsh-McBirney flow meter. This was accomplished here and at other sites where net flow velocities were missing (N = five of 18 sites) by estimating net locations across transects via investigator recollections or photographs. Each net mouth velocity was then estimated by averaging the velocities from the three transect velocity measurements nearest the net.

We validated this technique of estimating net flows at sites, breaches, and dates by comparing both transect data and Marsh-McBirney flow measurements at net mouths when both were collected at sites. Using transect data to estimate net mouth flow velocities was accurate, as transect data measurements at Thunder Ranch were on average only 5.4% (-20.4 to 31.3%, n = 5) higher than the actual net mouth flow velocities. Similarly, transect measurements at Stewart Lake were only 4.5% higher (2 and 7%, n = 2) than net mouth flow velocities measured directly with the Marsh-McBirney flow meter. Transect measurements to estimate net mouth flow velocities at Bonanza Bridge were on average 11.1% less (-17.7 to 2.2%, n = 4) than Marsh-McBirney flow meter readings. Accuracy of the transect method to estimate average flow velocity at net mouths led us to use this method for the five occasions (one at Thunder Ranch [Breach 3], two at Stewart Lake, and two at Bonanza Bridge [Breach 3]) when Marsh-McBirney flow meter reading in net mouths were not available.

Samples from two nets from each breach were designated specifically to obtain well-preserved larvae in 95% ethanol. Remaining samples were picked for beads to estimate bead densities (ethanol dissolves beads) and the remainder of the sample was preserved in alcohol and later examined for fish larvae. All larval fish collected in 2006 were examined at the Larval Fish

Lab at Colorado State University for identification to species and otoliths from larvae were examined to determine presence of a TC mark.

Stewart Lake

At Stewart Lake, four drift nets were set in the single inlet breach midway in the water column and two were set immediately downstream of the inlet in the Green River near shore (Figure 5). All drift nets were equipped with a GO Model 2030R mechanical flow meter suspended in the center of the net to determine velocity of water sampled. Meters showing incorrect readings were replaced. Depth and flow measurements were also taken within the breach with the Marsh-McBirney flow meter and were used to estimate breach flows. The Marsh-McBirney flow meter was used to record flow passing through the nets on 18 and 24 May, but not on 17 or 21 May.

On two sampling intervals on 18 May, additional drift nets were stacked on top of the two center drift nets (for a total of six nets set within the breach that day) such that the bottom net was placed on the substrate and the second net, placed immediately on top of the bottom net, was about 45 cm below the surface of the water. These additional nets were used to increase sample size. The middle of the top net (flow meter position) was 45 centimeters (cm) above the substrate, and the middle of the lower net was 15 cm above the substrate. Despite sampling less flow, collections near the bottom captured many more beads than the mid-column net. Because of this, an adjustment was made in entrainment rates to account for differences in bead density at each position. This was accomplished by estimating the total entrainment rate of beads in the lower cell of water measured by the lower two nets as well as estimating entrainment rate in the upper portion of the water column measured by the upper four nets. We assumed that bead density was uniform in the portion of the water column above a horizontal line across the breach consistent with the top of the two lower nets. Entrainment rates of beads were then estimated for the volume of water carried in each of the lower and upper cells of the inlet canal.

Because previous unpublished laboratory tests showed that semi-buoyant beads similar to the ones used were heavier than water at temperatures below about 18°C, and because all samples were collected at water temperatures lower than that, we adjusted entrainment rates of Stewart Lake samples accordingly using the proportion of beads carried in the lower cell compared to the upper. This proportion varied at each sampling period by the amount of water carried in the upper cell relative to that in the lower. At higher flows the upper cell was a greater percentage of the total inflow; at flows lower than those observed on 18 May 2006, the percentage was lower because the thickness of the lower layer did not change for each sampling occasion. Flows in the two mid-column nets (16 and 20 cm/sec, mean = 18 cm/sec) on 18 May were on average two cm/sec faster than the two lower-column nets (14 and 18 cm/sec, mean = 16 cm/sec) so for sampling occasions other than on 18 May, lower-column cell flow rates were assumed only 89% (16 cm/sec mean velocity in the lower cell divided by 18 cm/sec in the upper cell * 100 = 89%) of that estimated from upper cell rates. The lower cell flow rates were used as the average velocity in the lower cell, and bead entrainment rates were adjusted accordingly.

Bonanza Bridge

Bonanza Bridge was sampled on only three days (23, 25, and 27 May, Table 1) due to its higher flow connection to the river (approximately 453 m^3/sec). Connection at Bonanza Bridge occurred on 22 May. However, the inflow into Breach 2 (the largest breach) was only 0.1 m^3/sec so the site was not sampled until the following day when flows were higher. Red beads were released 1.6 km upstream of the site (Figure 6). Three or four drift nets (number dependent upon space available within the breach, which increased with inflow between the first and second sampling occasions) were set within Breach 2, two in Breach 3, and two downstream from Breach 3 on the near shore. All drift nets were equipped with a GO Model 2030R mechanical flow meter suspended in the center of the net to determine the amount of flow passing through the net. Meters showing incorrect readings were replaced. Depth and flow measurements were also taken within the breach with the Marsh-McBirney flow meter at the beginning and at the end of the sampling period if flows changed. The Marsh-McBirney flow meter was also used to record flow passing through the net at some point during the sampling occasion. This was done on each sampling occasion at Bonanza Bridge except for the first and last sampling times at Breach 3, during which little or no entrainment occurred. Samples were collected from nets as often as needed to prevent backflow, bagged into one-gallon bags, and processed for beads over the next few weeks.

Total number of beads entrained in the breach was estimated by dividing the breach flow volume by the total volume of flow sampled by drift nets and multiplying that number by the total number of beads captured in the nets. Entrainment was usually portrayed as the percent of flow in the river or percent beads released. Effectiveness of the breach to entrain passive drift material was portrayed as the percent of total beads captured in the breach compared with the total number of beads captured at that site.

RESULTS and DISCUSSION

Results and Discussion are presented together and ordered by year to aid reader understanding of the various combinations of flows and treatments and implications of results.

2004

Recall that because none of the flood plains connected to the Green River during 2004, captures of beads and larvae were only from nets set in the main channel. A total of 4,506 beads (0.30% of the number released) and 253 marked larvae (0.36% of the number released) was collected. Approximately 0.28% of the river flow was sampled, based on flow meter data from drift nets. The first marked larvae arrived at the sampling site 1.6 km downstream from the release site approximately 32 minutes after release (Figure 7). This first sampling interval also documented the peak in drift abundance because the highest density of beads and larvae were at the leading edge of the mass of particles released. Nearly all larvae were captured during the first two sampling periods (about 1 hr) although some were collected nearly two hr after release. The first beads were also collected approximately 36 minutes after release although peak bead abundance did not occur until one hr after release. All beads and most marked larvae (n = 185, 98%) were collected on the right bank (no mid-channel sampling) which leads us to believe that beads and larvae were released just below the island at Razorback Bar on the right half of the river rather than across the channel as was formerly believed. Most beads (n = 3,207, 72%) and marked larvae (n = 188, 74%) captured during 2004 sampling were captured 1.6 km downstream of the release site, with the balance captured 8 km (the most downstream sampling location in 2004) downstream adjacent the Thunder Ranch wetland.

Similar patterns for bead and marked larvae captures were observed at the sampling site 8 km downstream of the release location. The first marked larvae arrived at the site approximately 197 minutes after release (Figure 8); the peak in abundance of marked larvae occurred within the next 60 minutes. Marked larvae were present in samples for only about an hr after they first appeared. The first beads collected at the site also arrived at a maximum of 197 minutes after release; peak bead abundance occurred within the next 60 minutes but beads were detected for nearly four hr after the first beads were detected at this site. Nearly all beads (n = 1,295, 99.7%) and all marked larvae (n = 65) were collected on the right bank.

Substantial numbers of wild (unmarked) razorback sucker larvae (n = 232) were also collected in the samples, but their distribution differed from that of TC marked, hatchery-produced larvae. Forty-four wild razorback sucker larvae (19%) were captured at the upstream 1.6 km site; 43 were captured on the right river bank but only one was captured near the left river bank supporting the notion that particles released at the bar tend to remain on river right. About 81% of wild larvae (n = 188) were collected at the site 8 km downstream of the release site; 61% of those (n = 144) were collected on the left side of the river and 39% (n = 44) were collected on the right side of the river. Wild razorback sucker larvae were present for the duration of the sampling period, about 4.5 hr.

From this 2004 effort, we learned that the marking technique was valid and that larvae from a relatively small batch of fish could be detected in reasonable numbers up to 8 km downstream. Minimum transport rate at the site 1.6 km downstream of the release point was about 0.8 m/sec. This is consistent with the transport rate of 0.78 m/sec estimated for larvae captured at the site 8 km downstream from the release point. Fish densities, based on capture rates, declined in a downstream direction, but substantial numbers of larvae were captured 8 km downstream. Because a large portion of fish may occur in the middle of the channel, we determined that sampling should also occur there in future efforts to be able to detect their presence. Also, releases larger than those in this test may allow for detections much further downstream. Significantly, average drift rates of beads and larvae were similar (0.62 m/sec vs. 0.44 m/sec, respectively, for the 1.6 km site; 0.37 m/sec vs. 0.32 m/sec, respectively, for the 8 km site). Total capture rates were also similar: 0.3% vs. 0.36% respectively for percent of released materials captured. Although average transport rates were similar, larvae always arrived more quickly than beads (likely a result of the larvae's ability to actively swim). This indicated that beads may be a suitable surrogate for fish larvae, should larvae not be available for all test releases in the future.

Cross-channel distribution of beads and marked larvae suggested little mixing over the 8 km distance downstream of the release site because nearly all beads and marked larvae were captured on the right side of the river. This may be explained at the 8 km site by the sharp left turn in the river a short distance downstream from Razorback Bar that likely maintained most drifting particles down the right side of the channel with the thalweg. However, our ability to infer patterns of cross channel distribution of drift material in 2004 is limited due to a small sample size (only one release this year) and uncertainty surrounding the exact release points. Additional releases and additional sampling sites further downstream than 8 km from release sites are needed to better assess mixing across the channel.

The few captures of marked larvae adjacent to breaches at the Thunder Ranch wetland complex suggested that, at 2004 flow levels and channel dynamics, few larvae from Razorback Bar would be available for entrainment, even if the breaches had connected to the main channel at these flow levels. Flow dynamics and entrainment rates of additional wild-produced larvae in higher flow years (when river-flood plain connections are achieved) are unknown. However, if, during higher flow years, razorback sucker larvae from Razorback Bar are carried up to nine kilometers further downstream, they would likely be available for entrainment into Stewart Lake.

In addition to marked larvae, wild larvae were also captured at the 8 km sampling site adjacent to the Thunder Ranch flood plain, predominantly on river left (Figure 9). The large number of wild razorback sucker larvae captured during this study was surprising, especially given the relatively short sampling time at each site. The number captured in a few hr of drift net sampling was equivalent to the number captured in entire seasons of light trapping in backwaters in the middle Green River area in some years (Bestgen et al. annual reports, project 22f). If one assumes that our near-shore only samples were representative for razorback sucker larvae density across the entire channel, and that we sampled about 0.12% of the flow at the 8 km site, from the 188 unmarked larvae that we captured, we estimated that about 156,600 ([100%/0.12%]*188) razorback sucker larvae were transported downriver in that five-hr sampling period. Given that few wild adult razorback suckers were likely remaining in the middle Green River in 2004 (Bestgen et al. 2002), capture of many unmarked larvae presents unequivocal evidence that hatchery-produced and stocked adults are successfully spawning.

Spatial distribution of marked and wild larvae, and spatial distribution of beads released at Razorback Bar suggested that there was an additional spawning area downstream from Razorback Bar and located on river left, but the exact location was not known. This uncertainty was resolved in 2005 when ripe and presumably spawning adults were located at Escalante Bar, which is just upstream of the Thunder Ranch wetland complex on river left. This location is outside of Dinosaur National Monument and thus has a high probability for seeing human impacts in the future. Northeastern Utah is also an area of high natural gas and oil exploration and pipelines frequently must go underneath the river. Disturbance of this area, however, has a high likelihood of reducing razorback sucker larvae production from this spawning bar and should be minimized.

2005

Cross-channel bead distribution

Bead distribution patterns across the river channel were different at different river flow levels in 2005. For example, beads were not evenly distributed across the channel of the Green River for the first and third releases until beads had traveled six to 21 km downstream (Tables 2, 3, and 4, Figures 10 and 11). Bead distribution during the second and highest flow release was more even across the channel. In general, and similar to 2004 results, beads released at Razorback Bar (orange) remained on river right for over 22 RKM, bypassing Thunder Ranch almost entirely (Figure 10). In addition, the majority of beads released on river left at Escalante Bar (yellow) remained on river left for over 10 km (difference in distance due to yellow beads being released farther downstream) and thus accounted for the largest number of beads entering the Thunder Ranch site at all flows (Figure 11). At the two highest flows during the second and third releases, a few orange beads from the Razorback Bar release were detected at Thunder Ranch. Similarly, during the second release at the highest flow, beads released on river left were detected at all three cross-channel sampling sites, unlike during the first and third releases at lower flows, where yellow beads were detected only on river left and at the midchannel sampling site. This suggested faster cross-channel mixing at higher and perhaps more turbulent flows.

Beads released at Razorback Bar were reasonably well mixed across the channel near Stewart Lake but beads released further downstream at Escalante Bar were not as well mixed, maintaining a predominantly river left or midchannel location. Beads apparently began mixing more thoroughly at some point between Stewart Lake and the Stirrup (no drift net stations were set between these two flood plains) because both the Stirrup and Leota sites entrained relatively similar numbers of orange and yellow beads at each sampling occasion.

Cross-channel bead distribution patterns support the general notion that multiple spawning bars and multiple high priority flood plain locations on each side of the river and up and down the reach are essential for maximum entrainment to occur.

Flood plain connections and sampling, 2005

Thunder Ranch, the upstream most flood plain wetland in the middle Green River complex, likely connected to the river on 19 May 2005. River flow on this day reached 393.8 m^3/sec at the USGS gauge near Jensen, the gauge nearest to the site (Figure 3). Stewart Lake connected to the river at the lowest flow of all the flood plains sampled (around 227 m^3/sec), likely on 12 or 13 May. Stewart Lake connected at a much lower flow because it is a man-made habitat, built as a mitigation wetland as a result of wetland loss when Flaming Gorge Dam was built. The Stirrup and Leota flood plain wetlands likely connected to the river on 20 May, the day after flows reached 393.8 m^3/sec at the Jensen gauge.

The first bead and larvae release occurred on 20 May when Green River flow reached 390.8 m^3/sec, the second release was on 24 May when Green River flows reached 538 m^3/sec, and the third release was on 30 May when Green River flows had receded from the peak down to 470.1 m^3/sec. Drifting beads were captured at all sites including L-7, which is 85 km downstream of release sites.

Thunder Ranch, 2005

Thunder Ranch wetland, Breach 3 (no other breaches were sampled at Thunder Ranch in 2005), entrained the largest number of beads of any wetland over the 2005 sampling period. Flow volume entrained and the number of beads captured was positively correlated with Green River flow levels (Table 5, Figure 12) such that the largest number of beads and the highest percentage of beads entrained occurred at the highest flow sampled. Beads entrained per volume of water in the river followed this similar pattern, although beads entrained per volume of water entrained did not. At the lowest flow sampled, Thunder Ranch was minimally connected to the river and as a result, relatively little water and few beads were entrained. At the two higher flows, the percentage of beads captured (only those captured in nets in the breach, not the total entrained), as well as the number per unit volume of water entrained and the number per unit river flow, were much higher (Table 5).

As flows increased at Thunder Ranch, Breach 3 became more effective at entraining beads. For example, on the first release, 934 yellow beads were captured in the near shore nets and had already passed the breach. On that same day, 577 yellow beads were entrained at the breach. At the peak flow, the near shore nets captured only 42 yellow beads, but the breach entrained 3,052 yellow beads (Tables 2, 3, and 4). The percentage of total beads captured in the near shore net location during the highest flow level at the peak release was only 1% (the majority of beads captured were in the breach), but increased to 61% (first release) and 35% (third release) for the other two releases at lower flows.

In addition to increased bead entrainment effectiveness, Breach 3 became more effective at entraining mainstem flow at higher river stages (Figure 12). Breach 3 inflow increased from 0.67 m^3/sec to 2.01 m^3/sec between the first release and the second, and the percentage of the mainstem flow entrained rose from 0.17% to 0.37%. This relationship is mirrored by the percentage of beads entrained into the flood plain site, which increased from 0.04% during the first release to 0.2% during the second release. Total entrainment (as reflected only by net captures as opposed to entrainment throughout the entire breach extrapolated from bead and flow samples) reveals essentially the same pattern. Higher entrainment levels at higher flows suggested that entrainment of razorback sucker larvae produced at upstream spawning areas would be higher with higher discharge levels.

Some orange beads (released at Razorback Bar on river right) were entrained at Thunder Ranch on each release occasion; however, these numbers were low on all occasions again suggesting that Razorback Bar will contribute only a handful of larval razorback sucker to the total entrained into Thunder Ranch. The majority of beads entrained was yellow and had been released at Escalante Bar on river left. This supported the importance of Escalante Spawning Bar as a source of larvae for entrainment at Thunder Ranch.

Stewart Lake, 2005

Entrainment rates of water and beads at Stewart Lake in 2005 were confounded by lake management priorities that dictated a closed outlet for the duration of the sampling period, including during the ascending limb of the Green River hydrograph. Therefore, Stewart Lake was not a flow-through site in 2005. This resulted in declining entrainment of water and beads (and presumably larvae) as sampling progressed during higher flow levels later in the season (Table 6, Figure 13). For example, 321 beads were entrained and captured during the first sampling period at a relatively low flow but only 32 were captured during the sampling period when the highest flow occurred. The correlated metrics of beads entrained per unit water entrained and beads entrained per unit river flow also declined at higher flows. Based on what we observed at Thunder Ranch in 2005, these results would not be the expectation at a flow-through site. Presumably this occurred because as Stewart Lake filled and water elevation increased, inflows declined or ceased even at the highest river flows. It was surprising that any flow entered the inlet breach during the last sampling period because water should have been draining at that time.

Because of its location on river right, Stewart Lake entrained predominantly orange beads, although some yellow beads were entrained on the first and third releases. No yellow beads were entrained on the second release, likely due to very low overall entrainment during this release. This was despite increased cross-channel mixing of beads at higher flows.

The percentage of orange beads captured in the near shore nets relative to the total number of orange beads captured at Stewart Lake remained constant from the first to the second release (32%) and increased in the third release (46%) (Tables 2, 3, and 4). No yellow beads were captured in the near shore nets in the first release; percentage of yellow beads captured in the near shore nets increased on the second release to 12% and then declined to only 2% during the third release.

Stirrup, 2005

The Stirrup flood plain had only one breach, which when overtopped by the Green River, entrained flows as the river was rising and drained as flows receded until connection ceased. The Stirrup wetland entrained the least amount of water and the fewest beads of any wetland in the study area during 2005 (Table 7, Figure 14). Highest flow entrainment rates were during the first two releases during filling. Similar to Stewart Lake, lowest flow entrainment rates at the

Stirrup wetland were during the last release, likely because the wetland was full. We can not explain why no beads were captured during the second release when some water was entrained, and why a few beads (74) were captured on the third release when nearly no water was entrained.

The Stirrup wetland is downstream of the zone where orange and yellow beads have mixed across the channel. As a result, yellow and orange beads were collected in relatively even numbers on both the ascending and descending limb of the hydrograph (Tables 2, 3, and 4). No beads were collected in the breach at peak Green River flows. The percentage of flow entrained and the percentage of beads entrained also mirror one another, similar to the relationship observed at the other flood plain breaches. Numbers of beads captured in the near shore nets remained relatively constant from the first release to the last.

Based on the number of beads collected at all sites and in all locations (breach, near shore, mid-channel, far shore), it appears that the Stirrup was not sampled at the time when most beads were passing the site. More beads were collected downstream at the Leota site, suggesting that sampling time at the Stirrup was either too early or too late. Thus, we believe data collected at this site are flawed. Sampling at the proper time would likely have resulted in entrainment patterns for water and beads that were similar to other wetland sites with single openings.

Leota 7, 2005

The L-7 wetland entrained relatively little water and captured few beads during 2005 sampling (Table 8, Figure 15). This was due, in part, to the greater distance downstream from the release site and subsequent lower bead density as the beads, concentrated at release, spread out. More importantly, L-7 had only a single connection during our sampling and water was not flowing into the wetland during the first sampling occasion, and was draining during the third sampling occasion (R. Brunson, UDWR, pers. comm.). Beads captured on the first and third sampling occasions were captured near shore in an eddy near the breach mouth and can not correctly be considered entrainment. During the second release, water was flowing rapidly into L-7 over the downstream breach (if the upstream inlet breach had not been occluded with vegetation and sediment, the downstream breach would have been the outlet) and flows were up to 0.5 m deep, and up to 0.5 m/sec velocity. Thus, only during the second sampling occasion were beads and water actively entrained. During the first sampling occasion, flows were apparently stable and not of sufficient stage for water to be entrained into L-7. During the third sampling occasion, river stage was declining so the wetland was draining. One of us (KRB) witnessed a yellow bead (apparently from release two) exiting L-7 during the third release sampling, supporting the notion that water and beads were not being entrained at that time. This may be a typical pattern for single breach wetlands, which entrain water, beads, and fish larvae only when filling, but during equilibrium or declining river stage, do not entrain anything or drain. Although some entrainment likely occurs in single breach wetlands when daily flows pulse up and down in the spring runoff period, the amount of flow and particles entrained is likely low when wetlands are mostly filled.

Beads and larvae were captured in the Green River at L-7 during each release. Larvae detected in the near and far shore nets were not necessarily marked larvae from the study. However, because the only known spawning bars in this reach of river are in the Jensen area, those larvae likely traveled a long distance to be captured in our nets. Although not many larvae were observed in these samples, we did capture many beads, and these observations may point to a need to refine the Flood Plain Drift Model (Valdez and Nelson 2004) that predicts that only 1% of larval fish will remain in the drift 58 kilometers downstream from the spawning bars.

In general, wetlands with single breaches (Stirrup, L-7, Stewart Lake with the outlet closed) entrain water only during increasing flow stage, compared to multiple breach wetlands such as Thunder Ranch, Bonanza Bridge, and Above Brennan, which entrain flow at all river stages when breaches are inundated. Entrainment of razorback sucker larvae is likely much higher over a season in a flow-through wetland because water is flowing through at all times. Single breach wetlands receive inflow only when filling, so relatively fewer razorback sucker larvae would be entrained. The sporadic, pulsed, and unpredictable nature of razorback sucker reproduction suggested that wetlands that entrain water throughout the reproductive period for razorback suckers would have highest entrainment rates of larvae.

It is possible that larvae, once entrained into a flow-through wetland, could be transported through it and back to the river, thereby resulting in reduced net entrainment rates. We did not sample outflows of flow-through wetlands during this study so we can not directly estimate exit rates of beads or larvae. However, we think loss of larvae to the flood plain outflow following entrainment is low because flood plain wetlands likely act as a filter and depositional area for particles (flood plains are depositional by definition), including beads and larvae. This is because breach sites are long distances from outflows, and the intervening area, the main body of the wetland, is typically large, structurally complex with vegetation and other velocity breaks, and has very low current velocity. In the main wetland area, fish larvae are likely capable of finding low velocity refuges and are able to remain there even during higher flows, because the wetland area and low velocity channel margin and benthic areas also expand. Velocity tube swimming experiments have shown that razorback sucker larvae the size of individuals that are typically available for entrainment into flood plain wetlands (9-12 mm TL) are capable of swimming up to 15 cm/sec for 5-15 sec, and are capable and persistent swimmers at lower water velocities as well (unpublished data, KRB). Current velocity is increased in the immediate vicinity of the outflow, but those areas are small and are unlikely to harbor an important percentage of entrained larvae. Even if small numbers of larvae are transported through the wetland, flow-through wetlands still offer the greatest opportunity for entrainment, retention, and survival of razorback sucker larvae under the flow conditions we tested.

<u>2006</u>

Building on findings in 2005 that suggested flow-through wetlands had higher entrainment rates compared to single breach wetlands, we focused on estimating entrainment rates of beads and water in flow-through wetlands in 2006.

Thunder Ranch, 2006

In 2006, Thunder Ranch connected at about 402.1 m^3/sec, a connection level consistent with observations in 2005. Sampling began on 21 May when flows at the Jensen gauge read 420.0 m^3/sec.

Four sampling occasions were conducted at Thunder Ranch in 2006, three on the ascending limb of the hydrograph, and one on the descending limb. Both Breach 3 and 5 were sampled in 2006 (versus only Breach 3 in 2005) to obtain better estimates of entrainment; breaches 3 and 5 were the only inlets to this wetland sampled in 2006. Flow and bead entrainment increased as river stage increased (Tables 9 and 10, Figure 16), and the correlation between percent flow and bead entrainment was high (0.98). Percent flow and bead entrainment also increased as river stage increased. For example as river flow increased 45-50 m^3/sec between the first and second, and second and third releases, the percent of flow entrained approximately doubled and the percent of beads entrained more than doubled. Total bead entrainment (number entrained through the entire breach per amount of flow through the entire breach, not just beads and flow sampled by the nets) of 14.5% during the third (peak) release was high, a surprising rate even considering that beads were released just upstream and mostly near the river bank.

During Thunder Ranch sampling on the ascending and descending limb of the hydrograph (first and fourth releases), when river stage was similar (420 m^3/sec and 403 m^3/sec, respectively), we also observed similar flow (0.3 and 0.4%, respectively) and bead entrainment (0.7 and 0.9%, respectively). This suggested that wetlands with this connection configuration are efficient at entraining water and fish at a variety of flow levels, regardless of whether flows are increasing or decreasing.

Breaches 3 and 5 had different entrainment rates, with Breach 3 connecting at lower river flows than Breach 5. As flows increased, Breach 5 entrained more water but bead entrainment did not increase (Tables 9 and 10). This may have been due to advection (transport in fluids) of most beads that were available into the wetland at the upstream Breach 3, leaving relatively few beads for entrainment at downstream Breach 5. At the lowest flow level during the fourth release, number of beads entrained into Breach 5 was particularly low.

Similar to 2005, the breaches became more effective at entraining beads as flows increased (Table 12). On 21 May, only 25% of the beads captured were captured within the breach, the remaining 75% of beads were captured in the near shore nets. On the next two sampling occasions (23 and 24 May [peak flow occurred 24 May]), the percentage of beads captured within the breach rose to about 80%, compared to only about 20% in near shore nets in the river.

We can not explain why more water was entrained into Thunder Ranch in 2006 than 2005; the increase in beads entrained in 2006 is likely due to increased flow entrained, but may be due to the release location being so close to the sample site. Even though only Breach 3 was sampled in 2005, comparisons showed that more than twice as much flow was entrained into that single breach in 2006 than 2005. It is possible that breach elevation was higher in 2005 and inhibited flow entrainment, but we have no means to evaluate this hypothesis. Measurement error is also possible but seems unlikely, given the magnitude of the differences and that many of the same personnel were on hand to estimate flow entrainment in a consistent fashion between years. Another possible explanation for vagaries in flows and entrainment rates at this and other sites, is that flow levels fluctuate, sometimes dramatically, within a day. Our use of mean daily flow values would mask effects of those flow variations, which may in fact be responsible for some of the anomalous values we observed.

We also have some evidence that bead entrainment reflects larval fish entrainment as well, because we recovered some fish from Thunder Ranch samples in 2006. For example, on 21 May, the first two samples (29 and 50 min samples, respectively) collected from Net 1 in Breach 3 after release of particles contained 129 beads and one bead, respectively. Those same samples contained 82 and one razorback sucker larvae, respectively. However, there were obvious inconsistencies in fish captures, based on numbers of larvae captured in samples collected side by side at similar times. Such inconsistencies made us cautious and prevented further interpretation of any fish entrainment data.

Stewart Lake, 2006

Stewart Lake, which had an open outlet throughout the 2006 sampling period and thus, was a flow-through site the entire sampling time, began filling from the outlet when flows reached about 227 m^3/sec. This occurred because the outlet was at a sufficiently lower elevation than the inlet and water flowed into the downstream "outlet." Partial filling likely occurred as early as mid-April when Green River flows began increasing. Even though the flood plain was connected with the river at this flow, very little flow was passing through the inlet breach until river stage increased. Therefore, sampling did not begin until flows rose to over 322 m^3/sec (includes flows from Brush Creek) on 17 May.

Four sampling occasions were conducted at Stewart Lake in 2006, all on the ascending limb of the hydrograph. The percentage of flow and beads entrained increased as river stage increased, particularly as river stage increased above 424 m^3/sec (Figure 17). The percentage of beads entrained increased as flows increased, which again suggested that entrainment will increase with higher river flows at Stewart Lake (Table 11). The pattern of entrainment relationships was consistent whether only top channel net samples were used, or if both top and the bottom bead density corrected samples were used; only the magnitude of bead density entrainment differed. Similar to Thunder Ranch, total bead entrainment and percent bead entrainment at Stewart Lake were highest at the highest flows. Interestingly, total beads entrained per flow entrained and total beads entrained per flow in the river were highest at the third sampling occasion (not at the peak). This is similar to Thunder Ranch in 2005, which, before the peak, also showed a higher total bead entrainment per flow entrained though not a higher bead entrainment per amount of flow in the river.

Breach entrainment effectiveness at Stewart Lake rose from 39% of beads captured in the breach during the first sampling period to 70% captured in the breach at the peak (Table 12). This was an improvement over 2005 where entrainment effectiveness decreased as flow increased, which was again due to the outlet being closed.

Bonanza Bridge, 2006

River connection with the Bonanza Bridge wetland occurred on 22 May, when Green River flows at the Jensen gauge reached 442.4 m^3/sec (site flow was 455.8 m^3/sec and includes flows from Brush and Ashley creeks); however, flow going into Breach 2 was only about 0.11 m^3/sec. Thus, sampling was postponed until the following day. The Bonanza Bridge site had the highest breach elevation connection and was therefore sampled the fewest number of times (Tables 13 and 14).

Three bead sampling occasions were conducted at the Bonanza Bridge wetland in 2006, two on the ascending limb of the hydrograph and one on the descending limb. In addition to bead sampling occasions, two additional flow measurements were taken in breaches on the ascending limb of the hydrograph, and one additional one on the descending limb. Breach 2 connected at river flows of 428 m^3/sec on the ascending limb of the hydrograph, but was not connected at 411 m^3/sec on the descending limb of the hydrograph. Breach 3 remained connected with river flows only above 453 m^3/sec. Flow entrainment was approximately an order of magnitude higher in Breach 2 than Breach 3 for all sampling periods.

River flow and bead entrainment were lowest at Bonanza Bridge compared to other wetlands sampled in 2006. Similar to other wetlands, flow entrainment over the six measurement periods was highest at Bonanza Bridge at the highest river stage. Bead entrainment rates were highest at the second highest river flow stage and declined after that (Tables 13 and 14, Figure 18). In addition, entrainment effectiveness (percentage of beads captured in the breach vs. in the near shore nets) was also highest on the first sampling occasion, before the peak (Table 14). We are not sure why this scenario would occur but assume it is due to an anomalous bead distribution, erratic movement during entrainment, or breach elevation and sediment dynamics. There is a large sandbar on river left that begins just upstream of Breach 2 and it is possible that at lower flows, more entrainment can occur and that at higher flows, more beads are swept away from the breaches with the thalweg. Flow entrainment at comparable river flow levels on the ascending and descending limbs of the hydrograph were similar, again suggesting that entrainment rates may not vary for flow-through wetlands whether they are receiving water during the time when river stage is increasing or decreasing.

Implications for flood plain wetland management in the middle Green River

A logical discussion point for future management of flood plain wetlands is what combination of flow-through and single breach types are needed to assist with recovery of razorback sucker in the middle Green River. The evaluation of the Levee Removal Project discussed numerous points regarding the elements of an ideal flood plain wetland (Birchell et al. 2002) and should be included in this discussion. These elements included:

- site configuration to maximize entrainment of drifting razorback sucker larvae;
- refuge from predation by native and nonnative predators;
- high productivity to allow rapid growth of razorback suckers;
- a lack of ability to produce nonnative fish;

- adequate water quality; and
- physically self-sustaining wetlands.

Our research has shown that flow-through wetlands entrain the greatest number of particles and the most flow, which is advantageous for placing larvae into a productive environment and may increase their short-term survival. Thus, to maximize entrainment, flood plain wetlands should have at least one upstream breach and one downstream breach. Research performed to evaluate the Levee Removal Program demonstrated that these flow-through sites were also more efficient at transporting and entraining particulate carbon, one important component of productivity, into the flood plain (Birchell et al. 2002). High productivity, combined with potential for warmer water, should ensure that growth rates of razorback sucker larvae are fast relative to that in main channel environments (Bestgen 2008). It is difficult to ensure that nonnative predators can not infiltrate the site and reproduce. However, prior research has shown that larval razorback sucker can survive in the presence of low numbers of nonnative fishes in a year after a flood plain wetland dries (resets) because the fish community was eliminated (Modde and Haines 2005; Christopherson et al. 2004; Birchell and Christopherson 2004; Brunson and Christopherson 2005).

A negative aspect of flow-through wetlands is that all suspended particles are entrained, including sediment (Heitmeyer and Fredrickson 2005). Therefore, over time, breaches as well as the associated wetland will fill and ultimately, these types of wetlands will not be sustainable without active management. For example, the natural levee at Bonanza Bridge was originally breached at a river stage of 368 m^3/sec. Entrainment studies in 2006 showed that connection now occurs at a higher river stage (minimal connection at 434 m^3/sec). From the high amount of scouring of sediment observed in Breach 2 in 2006, it is not difficult to hypothesize the pattern:

entrainment of flows and sediment, deposition of sediment as flows recede, and scouring of breach sediment occurring the following year that would then move into the flood plain itself. Even single downstream breaches have been shown to accumulate sediment over time (Birchell et al. 2002; LaGory et al. 2003). Filling of wetlands in the flood plain is a natural process of the riverine ecosystem; the question to consider is whether managed Green River wetlands are filling at rates that are unacceptable.

Although we did not see high flow or bead entrainment in single-breach wetlands, there may be opportunity to improve entrainment at these sites. Heitmeyer and Frederickson (2005) make a number of recommendations to the Ouray Refuge to improve flooded bottomland habitat and connectivity to the Green River within the refuge. Their recommendations are based on historical notes that flood plain wetlands within the refuge would flood first via "low elevation sites along natural levees at downstream ends of the wetland and last at higher elevation point bar surfaces on inside bends of the river." They refer to flooding from the downstream end of the flood plain as "backwater" flooding. There are multiple morphological benefits of backwater flooding: reduced sedimentation of entry sites, reduced scouring of exit sites, better retention of nutrients, and promotion of cottonwood regeneration through deposition of fine silt. This moderate amount of silt will also increase flood plain productivity. These downstream breaches are not similar to the one located at the Stirrup flood plain (long and narrow); instead, they recommend widening the 61 m breach (width measurement) at Johnson Bottom and constructing an additional downstream breach also at least 61 m wide. A wider breach or multiple wider breaches will likely behave differently than a long, narrow one and may allow for increased entrainment at least during ascending flows when water is moving into the flood plain.

Applying our findings to all flood plain wetlands discussed in the Green River Flood Plain Management Plan (Valdez and Nelson 2004), flood plain wetlands that will maximize entrainment of larval razorback sucker (because they are flow-through sites) are Thunder Ranch, Stewart Lake, Bonanza Bridge, Above Brennan (RKM 431.3), Johnson Bottom (RKM 422.9), Leota Bottoms (at flows greater than 431.2 m^3/sec), and Old Charley Wash (RKM 402.0) for a total amount of 1034.3 hectares of inundated wetlands (this is the area of wetlands available when flows in the Green River reach 526.7m^3/sec (18,600 cfs)). However, because of the sedimentation issue, the Ouray Refuge will no longer operate its flood plain wetlands as flow-through sites (D. Alonso, Manager, Ouray Refuge, pers. comm.). Thus, the total amount of hectares of wetlands with flow-through breach configuration (when Green River flows are 526.7 m^3/sec) is reduced to only 395.8 hectares.

Remaining flow-through sites (Thunder Ranch, Stewart Lake, Bonanza Bridge [see discussion above], and Above Brennan) may also have issues that reduce their utility. One important component of an ideal flood plain not mentioned in The Levee Removal Program evaluation is the need for razorback suckers to over-winter. This is important because young-of-year razorback sucker in a flood plain wetland in spring would theoretically not be ready or even able to move into the river in autumn because there is no connection with the river. Therefore, while flow-through sites will entrain more razorback sucker larvae, if the flood plain can not sustain those fish over-winter, the flood plain wetland will not contribute to recovery of the species. One of us (TNH) sampled Thunder Ranch in the fall of 2006 to determine whether entrained razorback sucker larvae survived through the summer; none were captured. At least as importantly, however, was the observation that the Thunder Ranch wetland was only 0.3 to 0.5 meters deep at its deepest point in November. Because average low temperatures in the Uintah

Basin are below freezing from November to March, all water bodies freeze for a relatively long period. The longer the area remains below freezing, the greater the depth of ice in these flood plain wetlands. Depth of ice over the Stirrup flood plain wetland was about 0.28 meters in both 2006 and 2007 (deepest point in the Stirrup was 0.76 m in 2006 and 1.2 m in 2007), suggesting that shallow flood plains (e.g., Thunder Ranch) may freeze to the bottom. Single breach wetlands entrain less water and fewer particles, but several (Stirrup, L-7) are deep enough to successfully overwinter fish. This suggests that certain trade-offs or combinations of strategies may be necessary to achieve recovery of razorback sucker through use of flood plain wetlands with different breach configurations.

Stewart Lake may offer both relatively high entrainment rates (when it is a flow-through site) and may be deep enough to overwinter fish. Unfortunately, Stewart Lake suffers from contaminant issues (e.g., high levels of selenium) that may limit its utility as a place for razorback sucker recruitment. The USFWS Ecological Services Office, in Salt Lake City, Utah is currently in the process of testing Stewart Lake for selenium concentrations and UDWR and the U.S. Bureau of Reclamation are in the process of remediating the wetland by filling and draining the area multiple times during the year (Miles Hanberg, UDWR; Nathan Darnall, USFWS, personal communication). When this process is complete, selenium levels should be reduced (limitations of selenium levels for razorback suckers is equivocal) and thus Stewart Lake may contribute to recovery efforts for razorback sucker in five to 10 years. While few are in agreement as to the effects of large amounts of selenium in larval razorback suckers, managers will need to consider all of these factors when formulating an optimal flood plain management strategy in the middle Green River.

CONCLUSIONS

Findings from this study help us draw several conclusions about particle drift patterns, the functioning of wetlands with different breach configurations, and the utility of various wetlands for recruitment of razorback suckers in Green River.

● Based on drift rates and capture patterns, our findings from 2004 suggest that beads and fish larvae are reasonable surrogates for one another and that they can be captured in similar quantities when suspended as drift in the river.

● Capture of substantial numbers of unmarked and wild-produced razorback sucker larvae in 2004 demonstrated that stocked adult fish are successfully reproducing. Distribution and abundance patterns of these wild larvae suggested an additional spawning area was present, in addition to Razorback Bar. Escalante Bar, which is just upstream of Thunder Ranch and on river left, was verified as a spawning area by capture of ripe adults and may be a significant source of larvae for flood plain wetlands, particularly those just downstream of this area on river left.

● Beads were not well mixed downstream of release sites in the Green River until somewhere between Stewart Lake (22 RKM downstream from Escalante Bar) and the Stirrup wetland (51 RKM downstream from Escalante Bar) in 2005, where orange and yellow beads were captured in similar numbers in all nets across the channel.

● Mixing of drift particles is likely to occur more quickly at higher flow rates. This conclusion is supported by the collection of a greater number of orange beads in the Thunder Ranch near shore and breach nets at higher flows in 2005.

● Beads released at Razorback Bar and Escalante Bar in 2005 were collected in all downstream breaches and as far downstream as L-7, 85 km downstream from the release. Some larvae were also captured in the L-7 near and far shore nets at each sampling occasion.

● Wetlands in close proximity to larvae production areas will only see high levels of entrainment if they are located on the same side of the river as the production areas.

● Drift particle density declines downstream, based on recaptures of released beads and marked larvae because beads disperse longitudinally and are retained laterally. This suggests that wetlands closer to production areas can potentially contribute greater numbers of razorback sucker to the population. However, downstream bead densities and fish captures were substantial and suggest that sufficient numbers of razorback sucker larvae may drift from upstream production areas to populate flood plain wetlands well downstream. If wetlands are to be enhanced or improved, candidate wetlands should be present in a mosaic of locations up and down the river and on each side of the river.

● Entrainment rates of beads, water, and presumably fish decline dramatically or cease when single breach wetlands (e.g., Stewart Lake when outlet is closed, Stirrup, L-7) are filled. These same breaches would theoretically release water and some drift material as river flows recede, as was observed at L-7 in 2005.

● Bead entrainment is higher in flow through wetlands and increases as river stage and flows increase. Entrainment of beads, water, and presumably fish larvae would be highest when the greatest volumes of river flow are entrained. We suspect this relationship would remain true for Green River flow at levels higher than those we observed.

● Bead and flow entrainment rates in flow-through wetlands are similar on the ascending and descending limbs of the hydrograph.

● In wetlands with multiple inflow breaches (e.g., Thunder Ranch), the upstreammost breach captured more beads than other inflowing breaches sampled. This especially appeared to be true as flows increased and the upstream breach became more effective at entraining beads that were located nearshore (as in 2006), thereby leaving fewer beads available to become entrained.

● Simply connecting flood plain wetlands with the river is not adequate to effect substantial recruitment because large numbers of razorback sucker larvae must be transported from the river into the wetlands. Higher spring peak flows may be beneficial to maintain connections between flood plain wetlands and the river and enhance entrainment of razorback sucker larvae. Timing spring peaks to coincide with production of larvae is critical.

● Based on observations at Bonanza Bridge in 2006, flood plain wetlands that entrain more razorback sucker larvae (i.e., flow-through sites) may have a shorter life in the absence of active sediment management than wetlands with a single entrance.

● The present area available for razorback sucker larvae in flood plains that maximize entrainment rates, is less than that identified by the Flood Plain Model as required for recovery of the species (Valdez and Nelson 2004). This is due to the current scenario of managing some potential flow-through wetlands as single breach wetlands, but also to the inadequacy of some of the functional flow-through wetlands to maintain fish over-winter.

RECOMMENDATIONS

● Synthesize entrainment data with other data collected in the middle Green River that may assist with formulation of a strategy for flood plain management and conservation of razorback suckers.

● Determine if changes in various wetland breach configurations and flows are needed to entrain and retain razorback sucker larvae.

● Determine if retention of larvae in flow-through or single-breach wetlands is a significant problem.

● Based on potential entrainment rates and other information, determine which flood plain wetlands are of the highest management priority. An essential piece of information for that determination is understanding factors that affect overwinter survival of razorback suckers in various wetland types.

● Develop a maintenance plan for high priority wetlands to maintain connection to the river and adequate depth for overwinter survival.

● Examine tradeoffs between connecting flood plain wetlands and river flows with short-term, high magnitude flows compared to connecting wetlands with lower magnitude peaks over a longer duration.

● Continue to protect known and potential razorback sucker spawning areas and flood plain nursery habitats from impacts (i.e., de-watering, sedimentation, development of oil and natural gas reserves, etc.).

● Continue to monitor timing and abundance of wild larvae in the Green River with light trap sampling and determine, with otolith analyses, the optimum timing for flows to maximize entrainment of larvae into desirable wetlands.

● Determine ways to improve entrainment rates of flood plain wetlands with only one breach (i.e. does widening a downstream breach allow for greater entrainment rates?).

● Characterize scouring and sediment deposition rates in breaches of high priority wetlands.

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Table 1. Entrainment study locations, dates, number of beads and larvae released, and river flows in the middle Green River, Utah, 2004-2006.

Year	Date	Flow [b] (m^3/sec)	Release sites and numbers [a]: RZB Bar(RKM 500.9) Beads	RZB Bar(RKM 500.9) Larvae	ESC Bar (RKM 493.7) Beads	ESC Bar (RKM 493.7) Larvae	Near Breach Beads	Near Breach Larvae	Downstream sampling locations (RKM)
2004	26-May	161	1,517,000 (Y)	69,688					MC (499.3), MC (492.9)
2005	20-May	391	1,517,000 (O)	54,000	1,517,000 (Y)	50,000			MC (499.3), TR (492.1)
	24-May	538	"	48,000	"	46,500			SL (482.8), ST (443.4) and L-7 (414.9) during all three sampling periods
	31-May	470	"	212,000	"	183,500			
2006	21-May	420					540,000 (Y)	175,500	TR (RKM 492.1)
	23-May	470					"	125,000	"
	24-May	510					"	225,000	"
	30-May	403					"		"
	17-May	322					540,000 (O)		SL (RKM 482.8)
	18-May	344					"		"
	21-May	424					"		"
	24-May	514					"		"
	23-May	484					540,000 (R)		BB (RKM 466.2)
	25-May	525					"		"
	27-May	453					"		"

[a] Release and sampling locations are indicated by Green River river kilometer (RKM) locations. MC = main channel, RZB Bar = Razorback Bar, ESC Bar = Escalante Bar, TR = Thunder Ranch, SL = Stewart Lake, and BB = Bonanza Bridge sites.

[b] Flows were estimated using the Jensen gauge for all sites; however, flows at sites downstream of Thunder Ranch also incorporate tributary flow. Flows at Stewart Lake also include Brush Creek flows. Flows at Bonanza Bridge include both Ashley and Brush creek flows; and flows at the Stirrup and Leota are estimated using Jensen, Ashley, and Brush Creek flows from the day before to account for the travel time required for these sites.

Table 2. Cross-channel distribution of beads captured in drift nets during the first release, 20 May 2005, at all sampling sites and net locations (see Table 1 for more details).

	Number of beads collected by net location[a]								
	Breach		Near shoreline		Mid-channel		Far shoreline		
	Orange[b]	Yellow[b]	Orange	Yellow	Orange	Yellow	Orange	Yellow	Total
1-Mile	N/A		2811		0		0		2811
Thunder Ranch	7	577	0	934	110	14	662	1	2305
Stewart Lake	321	1	359	0	443	272	1	662	2059
The Stirrup	36	28	20	36	10	9	8	3	150
Leota L7	4	6	128	172	111	96	70	85	672

[a] Net locations are relative to the position of the wetland and breach that was sampled in conjunction with the release; there was no breach sampling for the "1-Mile" site, which was 1.6 river kilometers (RKM) downstream from the release site.

[b] Orange beads were released at Razorback Bar (RKM 500.9) and yellow beads were released at Escalante Bar (RKM 493.7).

Table 3. Cross-channel distribution of beads captured in drift nets during the second release, 24 May 2005, at all sampling sites and net locations (see Table 1 for more details).

	Number of beads collected by net location[a]								
	Breach		Near shoreline		Mid-channel		Far shoreline		
	Orange[b]	Yellow[b]	Orange	Yellow	Orange	Yellow	Orange	Yellow	Total
1-Mile	N/A		2348		0		0		2348
Thunder Ranch	19	3052	14	42	21	2	163	81	3394
Stewart Lake	32	0	71	76	84	252	32	326	873
The Stirrup	0	0	17	28	6	9	8	4	72
Leota L7	137	180	46	55	52	85	23	30	608

[a] Let locations are relative to the position of the wetland and breach that was sampled in conjunction with the release; there was no breach sampling for the "1-Mile" site, which was 1.6 river kilometers (RKM) downstream from the release site.

[b] Orange beads were released at Razorback Bar (RKM 500.9) and yellow beads were released at Escalante Bar (RKM 493.7).

Table 4. Cross-channel distribution of beads captured in drift nets during the third release, 31 May 2005, at all sampling sites and net locations (see Table 1 for more details).

	Number of beads collected by net location[a]								
	Breach		Near shoreline		Mid-channel		Far shoreline		
	Orange[b]	Yellow[b]	Orange	Yellow	Orange	Yellow	Orange	Yellow	Total
1-Mile	N/A		915		0		0		915
Thunder Ranch	16	2102	8	1193	7	71	443	0	3840
Stewart Lake	7	4	259	9	271	207	29	304	1090
The Stirrup	23	51	25	40	106	219	7	11	482
Leota L7	63	83	119	184	174	193	30	27	873

[a] Net locations are relative to the position of the wetland and breach that was sampled in conjunction with the release; there was no breach sampling for the "1-Mile" site, which was 1.6 river kilometers (RKM) downstream from the release site.

[b] Orange beads were released at Razorback Bar (RKM 500.9) and yellow beads were released at Escalante Bar (RKM 493.7).

Table 5. River and breach flows and bead captures for Thunder Ranch in 2005, Green River, near Jensen, Utah.

Sampling Date	**Jensen Flows (m^3/sec)**	**Breach Inflow (m^3/sec)**	**Flow entrained**	**Beads released[a]**	**Breach beads captured**	**Beads captured[b]**	**Beads entrained per m^3/sec entrained[b]**	**Beads entrained per m^3/sec in river[b]**
5/20/2005	390.8	0.67	0.17%	1,517,000	577	0.04%	861.2	1.5
5/24/2005	538.0	2.01	0.37%	1,517,000	3052	0.20%	1518.4	5.7
5/30/2005	470.1	1.03	0.22%	1,517,000	2102	0.14%	2040.8	4.5

a Number of beads released includes only yellow beads, under the assumption that few orange beads were available for entrainment at Thunder Ranch.

b Values for percent beads captured, beads entrained per unit flow volume entrained into the breach, or in the river are for beads captured in drift nets only, not total bead entrainment into the breach.

Table 6. River and breach flows and bead captures for Stewart Lake in 2005, Green River, near Jensen, Utah.

Sampling Date	Jensen Flows (m^3/sec)	Breach Inflow (m^3/sec)	Flow entrained	Beads released[b]	Breach beads captured	Beads captured[c]	Beads entrained per m^3/sec entrained[c]	Beads entrained per m^3/sec in river[c]
5/20/2005	401.0	1.67	0.42%	1,517,000	321	0.02%	192.2	0.8
5/24/2005	549.7	1.19	0.22%	1,517,000	32	0.00%	26.9	0.1
5/30/2005	479.4	0.59	0.12%	1,517,000	7	0.00%	11.9	0.0

[a] The outlet to Stewart Lake was closed for the entire 2005 season.

[b] Number of beads released includes only orange beads, under the assumption that few yellow beads were available for entrainment at Stewart Lake. Flow values include inflow from Brush Creek

[c] Values for percent beads captured, beads entrained per unit flow volume entrained into the breach, or in the river are for beads captured in drift nets only, not total bead entrainment into the breach.

Table 7. River and breach flows and bead captures for the Stirrup wetland in 2005, Green River, near Jensen, Utah.

Sampling Date	Jensen Flows (m^3/sec)[a]	Breach Inflow (m^3/sec)[b]	Flow entrained	Beads released[c]	Breach beads captured	Beads captured[d]	Beads entrained per m^3/sec entrained[d]	Beads entrained per m^3/sec in river[d]
5/21/2005	431.2	0.17	0.04%	3,034,000	64	0.0	376.5	0.2
5/25/2005	589.9	0.20	0.03%	3,034,000	0	0.0	0.0	0.0
5/31/2005	509.9	0.12	0.02%	3,034,000	74	0.0	616.7	0.1

[a] Flow values include inflow from Brush and Ashley creeks.

[b] Breach inflow on 21 and 25 May were taken from Tetra Tech (2005).

[c] Number of beads released includes both orange and yellow beads released from both spawning bars at this site, because beads are well-mixed across the channel.

[d] Values for percent beads captured, beads entrained per unit flow volume entrained into the breach, or in the river are for beads captured in drift nets only, not total bead entrainment into the breach.

Table 8. River and breach flows and bead captures for L-7 in 2005, Green River, Ouray National Wildlife Refuge, Utah.

Sampling Date	Jensen flows (m³/sec)[a]	Breach Inflow (m³/sec)	Flow entrained	Beads released[b]	Breach beads captured	Beads captured[c]	Beads entrained per m³/sec entrained[c]	Beads entrained per m³/sec in river[c]
5/21/2005	431.2	0.01	0.00%	3,034,000	0	0.00%	0	0.0
5/25/2005	589.9	0.56	0.09%	3,034,000	317	0.01%	566.1	0.5
5/31/2005	509.9	0.00	0.00%	3,034,000	0	0.00%	0	0.3

[a] Flow values include inflow from Brush and Ashley creeks.

[b] Number of beads released includes both orange and yellow beads released from both spawning bars at this site, because beads are well-mixed across the channel.

[c] Values for percent beads captured, beads entrained per unit flow volume entrained into the breach, or in the river are for beads captured in drift nets only, not total bead entrainment into the breach.

Table 9. River and breach flows and bead captures for the Thunder Ranch wetland, 2006, Green River, near Jensen, Utah.

Sampling Date	Jensen Flows (m³/sec)	Breach 3 Inflow (m³/sec)	Breach 5 Inflow (m³/sec)	Flow entrained (Total)	Beads released	Breach 3 beads captured	Breach 5 beads captured	Total beads captured
5/21/2006	420.0	1.0	0.3	0.3%	540,000	540	279	819
5/23/2006	470.4	2.5	1.4	0.8%	540,000	2,177	650	2,827
5/24/2006	509.6	4.2	3.3	1.5%	540,000	4,506	587	5,093
5/30/2006	403.2	1.4	0.1	0.4%	540,000	1,545	19	1,564

Table 10. River and breach flows and beads entrained for the Thunder Ranch wetland, 2006, Green River, near Jensen, Utah.

Sampling Date	Jensen Flows (m^3/sec)	Total flow entrained (m^3/sec)	Flow entrained (Both breaches)	Beads released[a]	Total beads entrained	Beads entrained[b]	Beads entrained per m^3/sec entrained[b]	Beads entrained per m^3/sec in river[b]
5/21/2006	420.0	1.3	0.3%	540,000	3,929	0.7%	3,166	9.4
5/23/2006	470.4	3.9	0.8%	540,000	23,834	4.4%	6,209	50.7
5/24/2006	509.6	7.5	1.5%	540,000	78,525	14.5%	10,527	154.1
5/30/2006	403.2	1.5	0.4%	540,000	5,043	0.9%	3,348	12.5

[a] The release site for beads was 1.6 km upstream and near the same shore as wetland breaches.

[b] Values for percent beads entrained, beads entrained per unit flow volume entrained into the breach, or in the river are estimates for total bead entrainment across the entire breach, not just those captured in drift nets.

Table 11. River and breach flows and bead captures for Stewart Lake wetland, 2006, Green River, near Jensen, Utah.

Sampling Date	Jensen Flows (m^3/sec)	Total flow entrained (m^3/sec)	Flow entrained	Beads released[a]	Beads captured[b]	Total beads entrained[c]	Beads entrained[d]	Beads entrained per m^3/sec entrained[d]	Beads entrained per m^3/sec in river[d]
5/17/2006	322.3	0.6	0.2%	540,000	551	8,462	1.6%	14,706	26.3
5/18/2006	344.3	0.8	0.2%	540,000	273	3,381	0.6%	4,185	9.8
5/21/2006	424.4	1.9	0.4%	540,000	737	41,262	7.6%	21,962	97.2
5/24/2006	513.7	3.9	0.8%	540,000	999	48,509	9.0%	12,375	94.4

[a] The release site for beads was 1.6 km upstream and near the same shore as the wetland breach.

[b] Upper water column nets only

[c] Estimated entrainment rates were adjusted for differences in bead density in the upper and lower portions of the water column.

[d] Values for percent beads entrained, beads entrained per unit flow volume entrained into the breach, or in the river are estimates for total bead entrainment across the entire breach, not just those captured in drift nets.

Table 12. Total beads (percent of total) captured in drift nets set in breaches and near shore at Thunder Ranch, Stewart Lake, and Bonanza Bridge wetlands, May 2006.

	River flow at site (m^3/sec)	Thunder Ranch		Stewart Lake[a]		Bonanza Bridge	
		Total breach nets	Total near shore nets	Total breach nets	Total near shore nets	Total breach nets	Total near shore nets
5/17/2006	322.3	-	-	431 (39%)	683 (61%)	-	-
5/18/2006	344.3	-	-	657 (57%)	489 (43%)	-	-
5/21/2006	420/434.2	249 (25%)	729 (75%)	678 (52%)	638 (48%)	-	-
5/23/2006	470.4/484.1	959 (83%)	202 (17%)	-	-	1083 (91%)	108 (9%)
5/24/2006	509.6/513.7	3205 (81%)	758 (19%)	814 (70%)	354 (30%)	-	-
5/25/2006	524.9	-	-	-	-	693 (87%)	101 (13%)
5/27/2006	453.3	-	-	-	-	301 (74%)	104 (26%)
5/30/2006	408.9	639 (49%)	657 (51%)	-	-	-	-

[a] Numbers at Stewart Lake are not adjusted for different entrainment rates between top and bottom nets.

Table 13. River and breach flows and bead captures for the Bonanza Bridge wetland, 2006, Green River, near Jensen, Utah.

Sampling Date	Jensen Flows (m^3/sec)	Breach 2 Inflow (m^3/sec)	Breach 3 Inflow (m^3/sec)	Flow entrained (Total)	Beads released	Breach 2 beads captured	Breach 3 beads captured	Total beads captured
5/21/2006	434.2	0.01	0.00	0.00%	0	0	0	0
5/22/2006	455.8	0.11	0.00	0.02%	0	0	0	0
5/23/2006	484.1	0.64	0.14	0.16%	540,000	1,206	42	1,248
5/25/2006	524.9	0.81	0.10	0.17%	540,000	818	40	858
5/27/2006	453.3	0.34	0.04	0.08%	540,000	332	0	332
5/30/2006	408.9	0.00	0.00	0.00%	0	0	0	0

Table 14. River and breach flows and bead entrained for the Bonanza Bridge wetland, 2006, Green River, near Jensen, Utah.

Sampling Date	Jensen Flows (m^3/sec)	Total Breach Inflow (m^3/sec)	Flow entrained (Total)	Beads released[a]	Breach 2 beads entrained	Beads entrained[b]	Beads entrained per m^3/sec entrained[b]	Beads entrained per m^3/sec in river[b]
5/21/2006	434.2	0.01	0.00%	0				
5/22/2006	455.8	0.11	0.02%	0				
5/23/2006	484.1	0.78	0.16%	540,000	5,831	1.08%	7,518	12
5/25/2006	524.9	0.91	0.17%	540,000	2,147	0.40%	2,361	4
5/27/2006	453.3	0.38	0.08%	540,000	1,032	0.19%	2,745	2
5/30/2006	408.9	0.00	0.00%	0				

[a] The release site for beads was 1.6 km upstream and near the same shore as wetland breaches.

[b] Values for percent beads entrained, beads entrained per unit flow volume entrained into the breach, or in the river are estimates for total bead entrainment across the entire breach, not just those captured in drift nets.

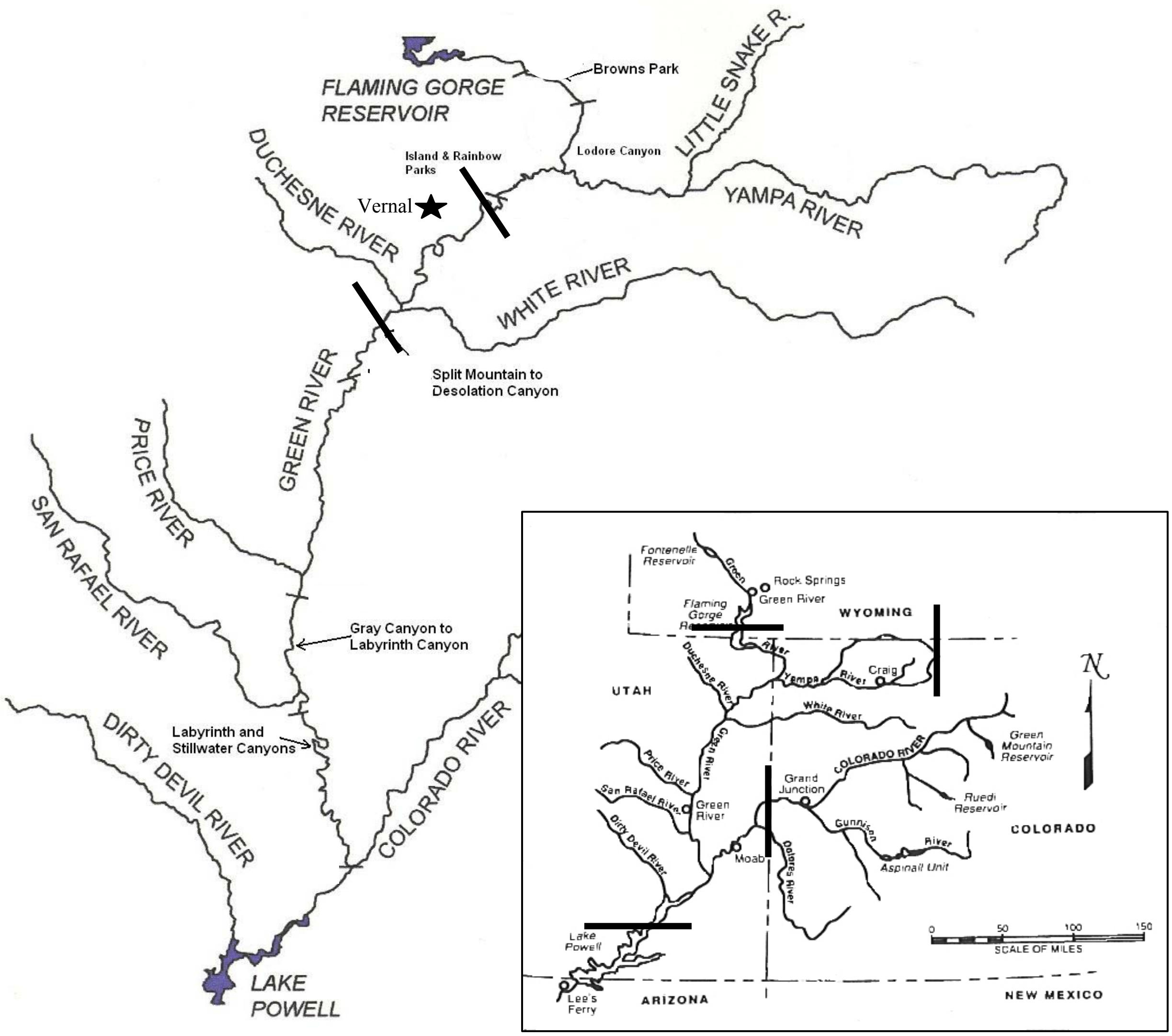

Figure 1. Map of the Green River from Flaming Gorge to the confluence with the Colorado River. Each of the flood plain wetlands in this study is found within the Split Mountain to Desolation Canyon reach. Reproduced with permission (Valdez and Nelson 2004). Inset shows Upper Colorado River Basin. Thick lines in inset denote the extent of the Green River map. Thick lines on the Green River map denote the extent of the Green River shown in Figure 3. Direction of flow is from north to south.

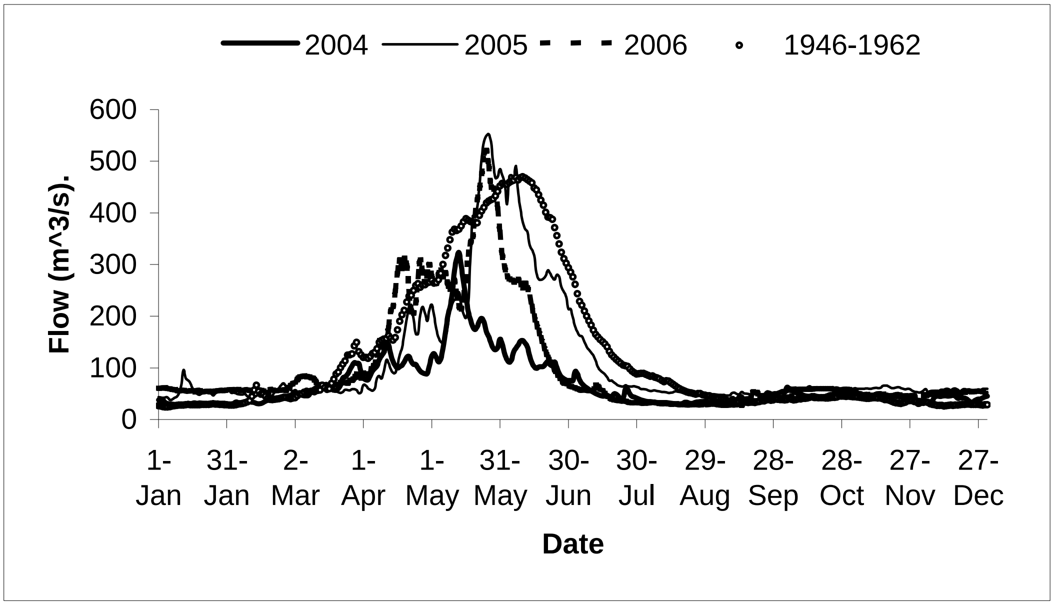

Figure 2. Mean daily average flows for the Green River near Jensen, Utah (gauge # 09261000) for the study period, 2004-2006. Mean daily average flows for the period 1946-1962 (pre-Flaming Gorge Dam) are shown for comparison.

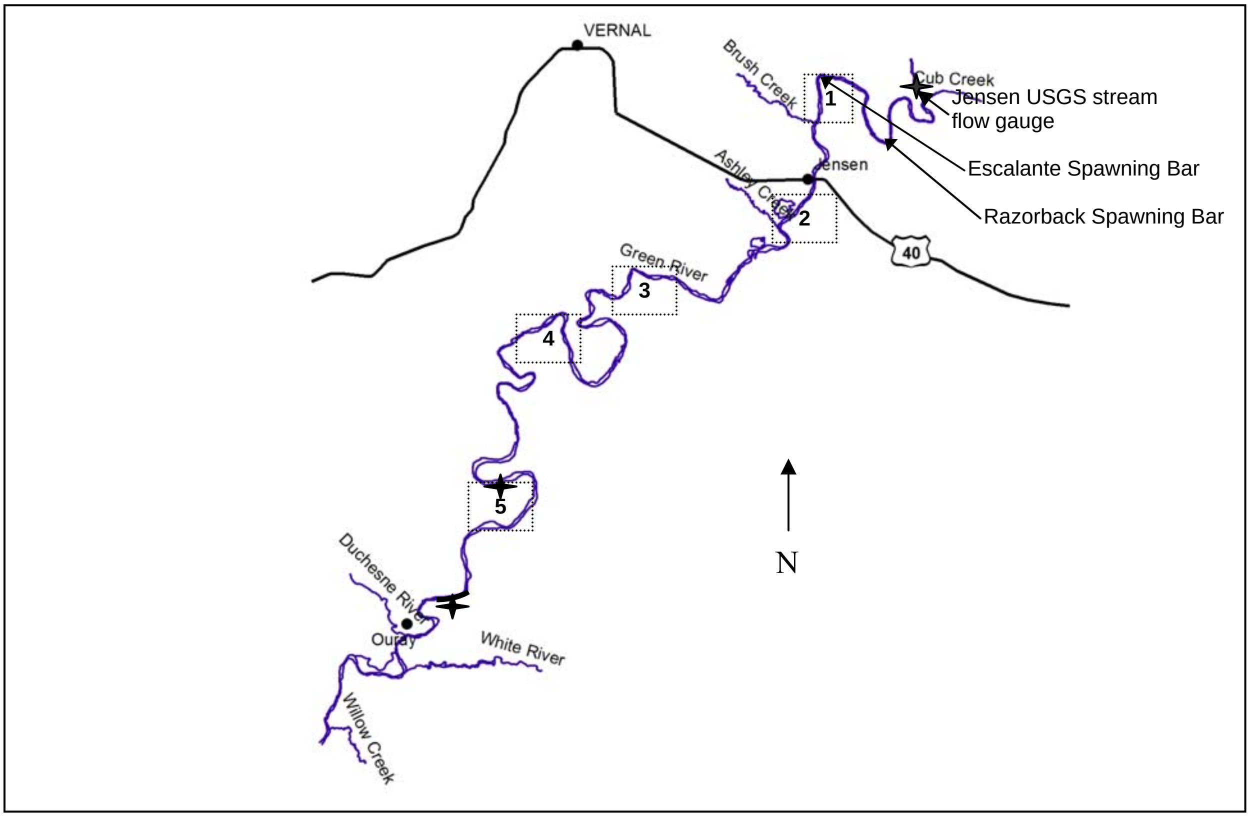

Figure 3. Green River from just downstream of Split Mountain boat ramp to Willow Creek. 1 = Thunder Ranch; 2 = Stewart Lake (actual location is on river right, across from map marker); 3 = Bonanza Bridge; 4 = The Stirrup; 5 = Leota Bottoms. Map courtesy Bureau of Land Management, Vernal office. Upper most star denotes the location of the USGS stream flow gauge. Lower two stars denote the extent of the river contained within the Ouray Refuge. Direction of flow is south and west.

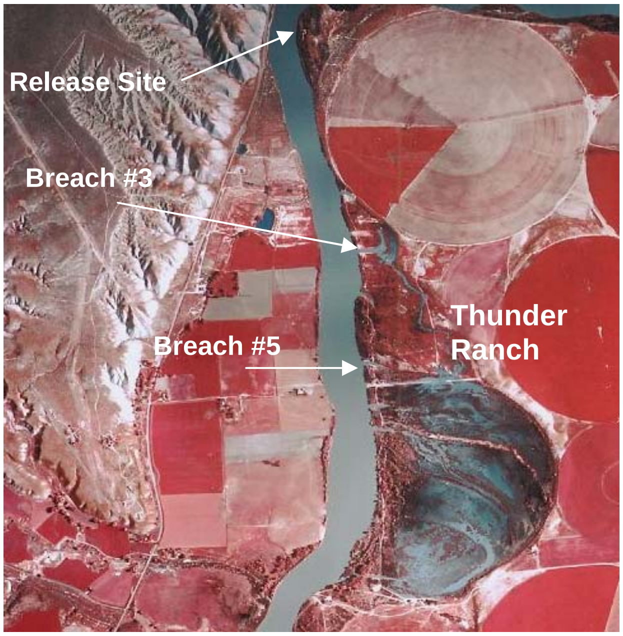

Figure 4. Satellite image of the Thunder Ranch flood plain wetland, the release area, and the two breaches sampled in 2006.

Figure 5. Satellite image of the Stewart Lake flood plain wetland, the release area, and the inlet (breach) sampled in 2006.

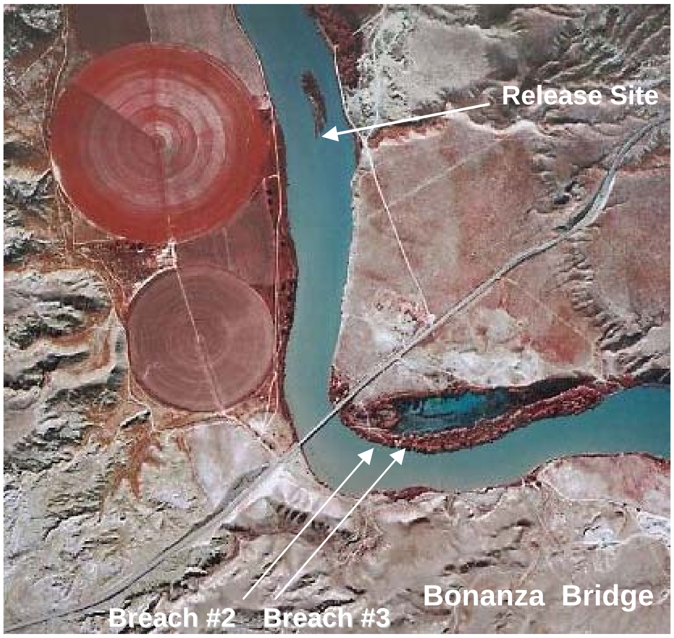

Figure 6. Satellite image of the Bonanza Bridge flood plain wetland, the release area, and the two breaches sampled in 2006.

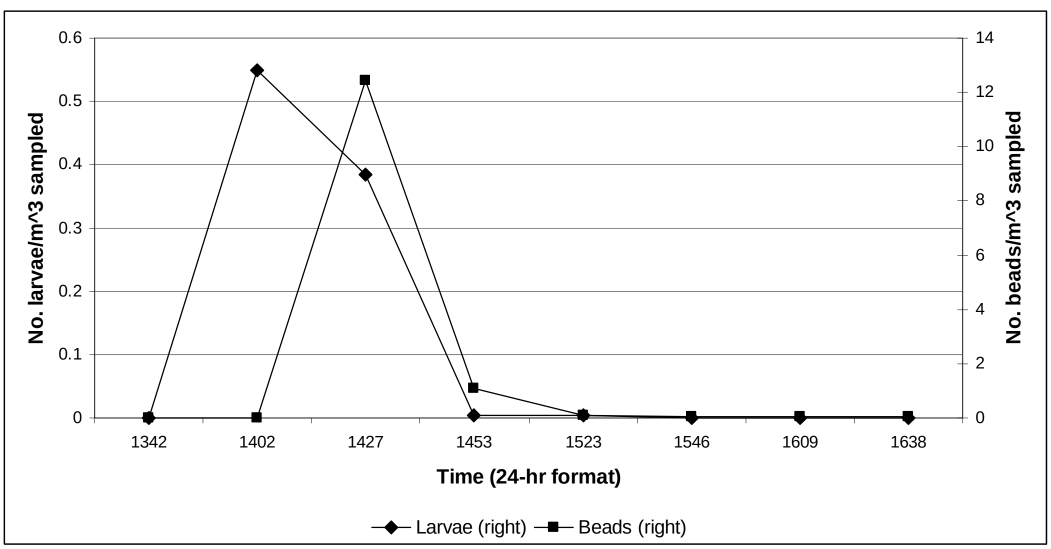

Figure 7. Number of tetracycline-marked razorback sucker larvae and semi-buoyant beads captured in drift nets per m^3 of water sampled in the Green River, near Jensen, Utah, on 26 May 2004. Beads were released at Razorback Bar (RKM 500.9) and captured 1.6 km downstream with drift nets set near each shore. Left or right indicates river shoreline of capture, looking downstream. Release time was 1330 hr. Time along x-axis is not uniformly spaced, but instead reflects actual sampling times. Only two marked larvae and no beads were collected on river left and thus were not included in the figure.

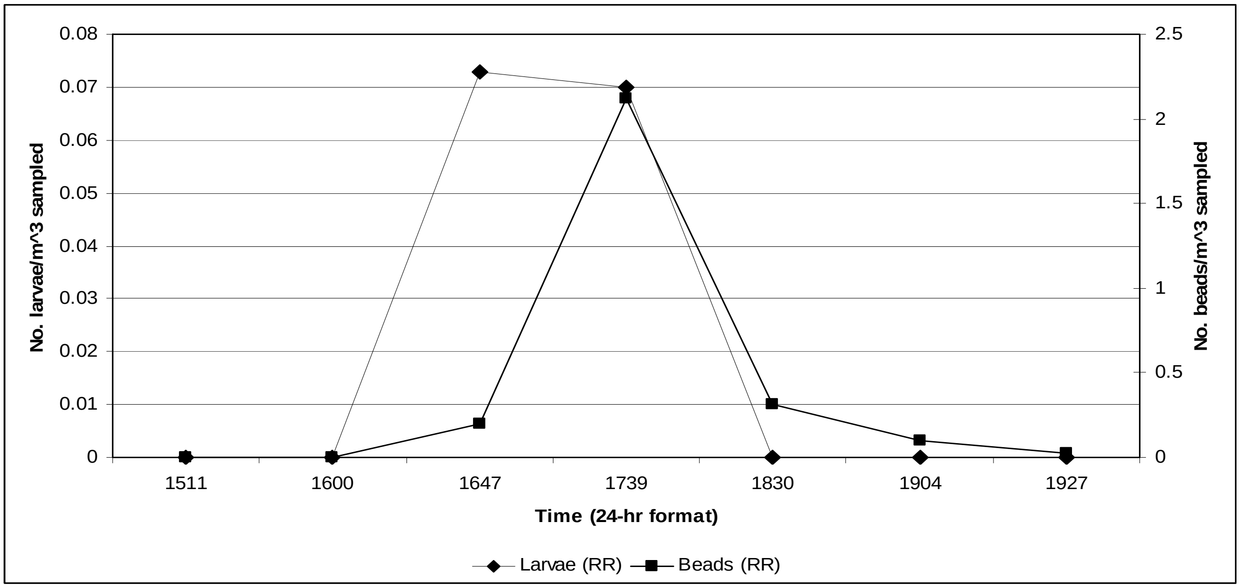

Figure 8. Number of tetracycline-marked razorback sucker larvae and semi-buoyant beads captured in drift nets in the Green River, near Jensen, Utah, on 26 May 2004. Beads were released at Razorback Bar (RKM 500.9) and captured 8 km downstream with drift nets set near each shore. Most beads and marked larvae were captured on the right shoreline, looking downstream. Time of release was 1330 hr. Time along x-axis is not uniformly spaced, but instead reflects actual sampling times. Only four beads and no marked larvae were captured on river left and so were not included in the figure.

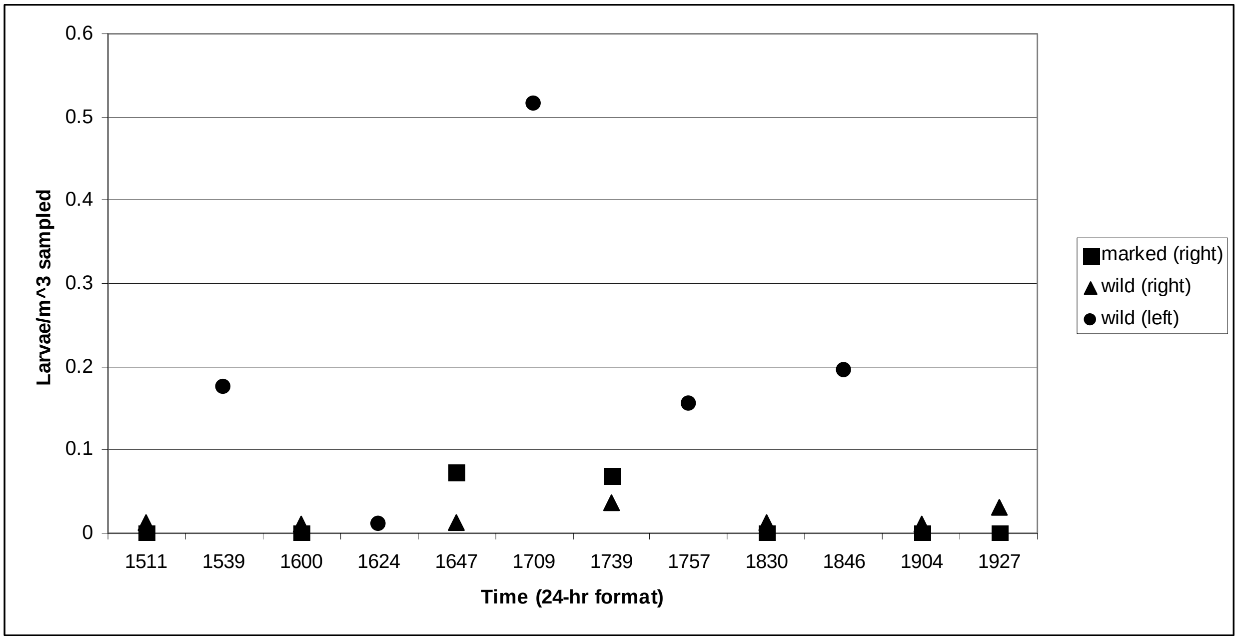

Figure 9. Number of tetracycline-marked and wild razorback sucker larvae (RZB) captured per cubic meter of water sampled in drift nets in the Green River, near Jensen, Utah, on 26 May 2004. Marked larvae were released at Razorback Bar and were captured 8 km downstream with drift nets set near each shore. Left or right indicates river shoreline of capture, looking downstream. Time of release was 1330 hr. Time along x-axis is not uniformly spaced, but instead reflects actual sampling times.

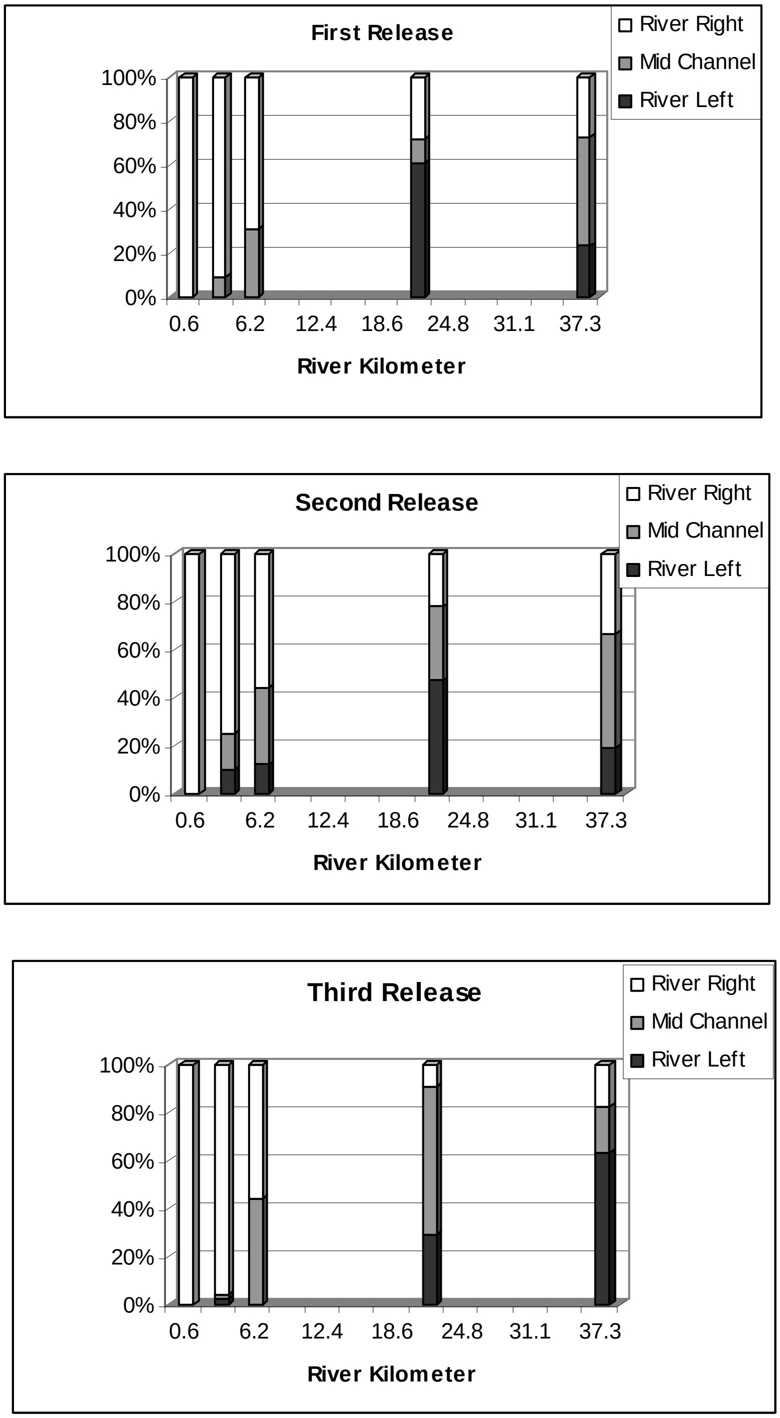

Figure 10. Cross-channel distribution of semi-buoyant bead captures in the Green River, near Jensen, Utah, at various locations downstream of the Razorback Bar release site (RKM 500.9), during releases on 20 (first), 24 (second), and 31 (third) May, 2005. RKMs measured downstream from Razorback Bar. Directions (right or left) are channel locations, looking downstream. Numbers of beads used for percent calculation was standardized by volume of flow sampled.

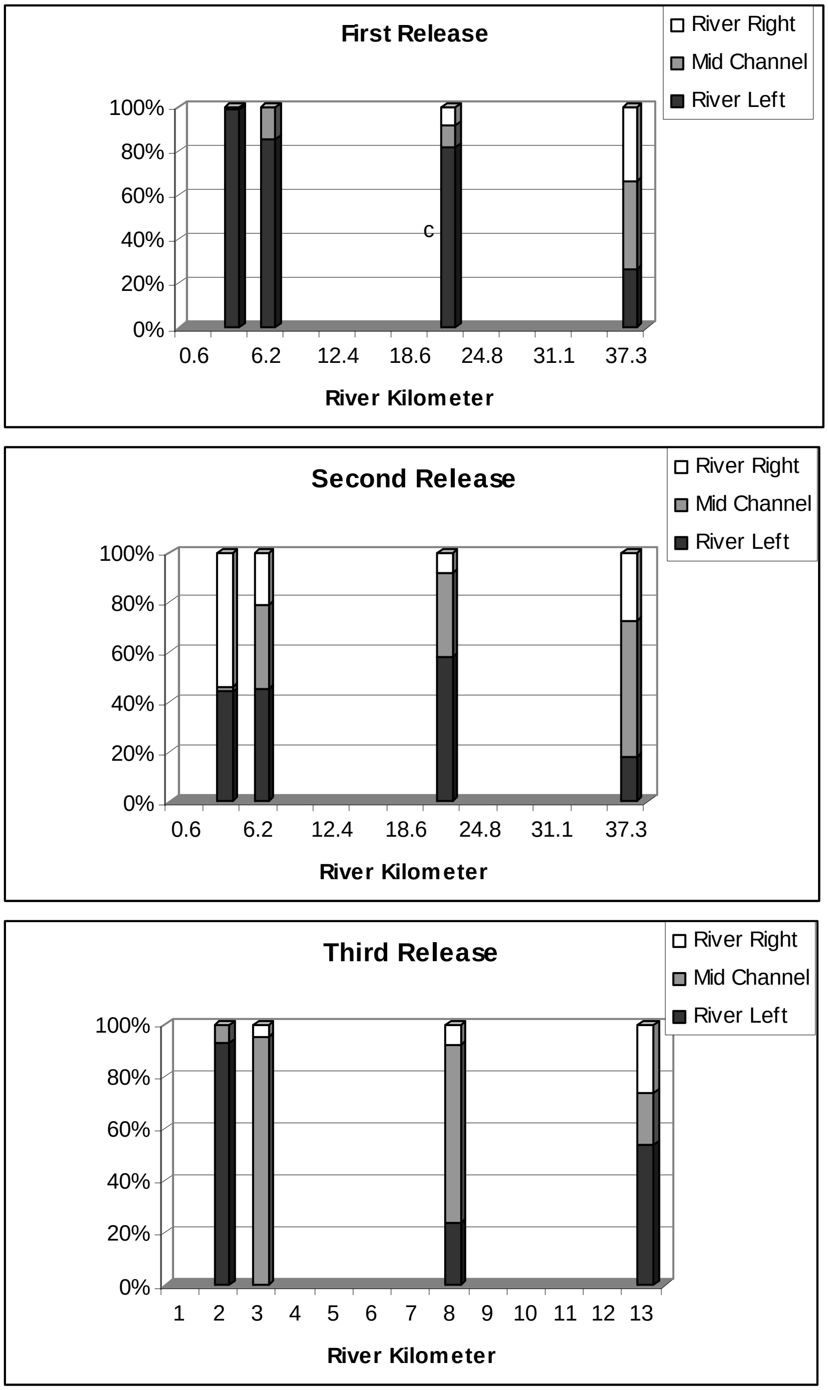

Figure 11. Cross-channel distribution of semi-buoyant bead captures in the Green River, near Jensen, Utah, at various locations downstream of the Escalanate Bar release site (RKM 493.7), during releases on 20 (first), 24 (second), and 31 (third) May, 2005. RKMs measured downstream from Razorback Bar. Directions (right or left) are channel locations, looking downstream. Numbers of beads used for percent calculation was standardized by volume of flow sampled.

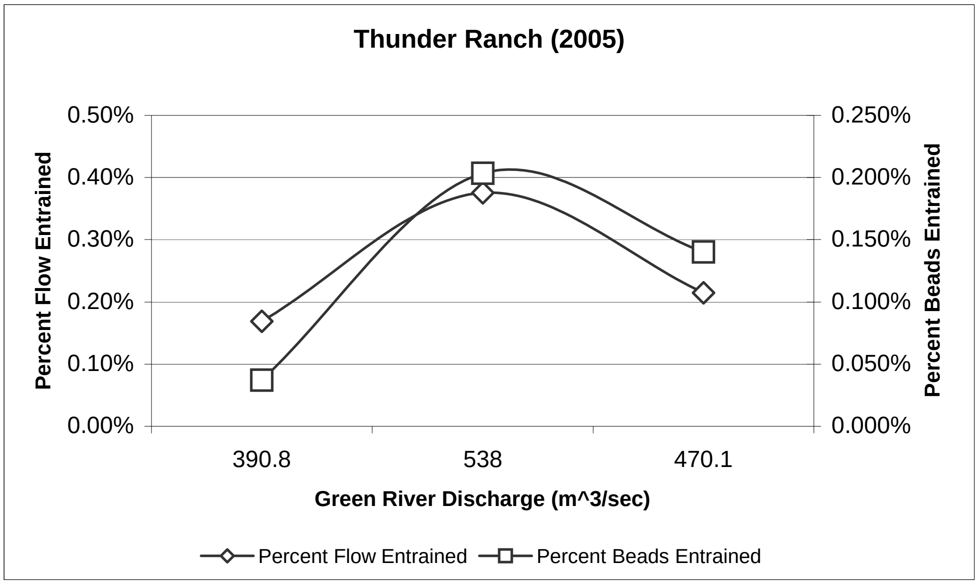

Figure 12. Relationship of percent of flow and semi-buoyant beads released and percent subsequently entrained and captured (Breach 3 only) as a function of Green River discharge (m^3/sec) at Thunder Ranch during three sampling occasions, 20, 24, and 30 May (left to right sequentially), 2005.

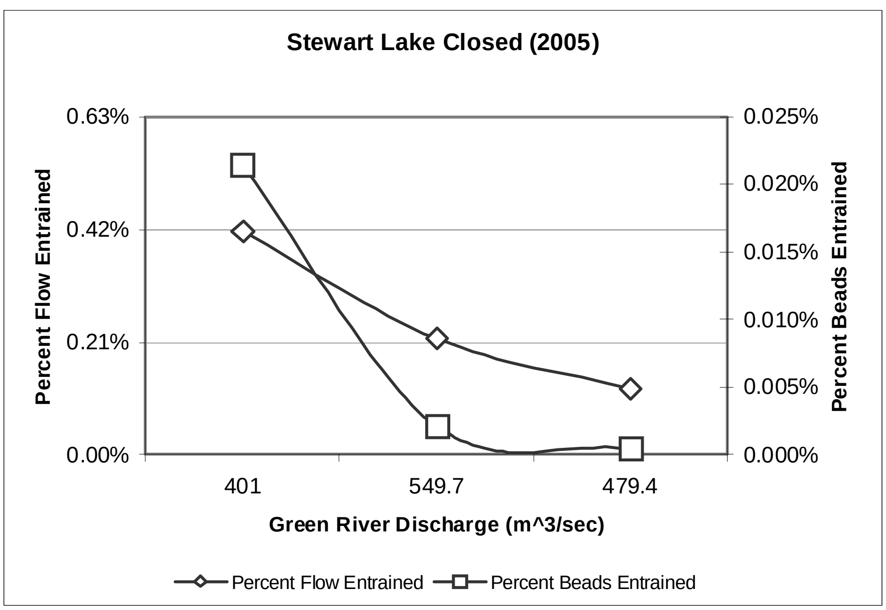

Figure 13. Relationship of percent of flow and semi-buoyant beads released and percent subsequently entrained and captured as a function of Green River discharge (m^3/sec) at Stewart Lake wetland during three sampling occasions, 20, 24, and 30 May (left to right sequentially), 2005. Stewart Lake had no outlet flows for the duration of 2005 sampling.

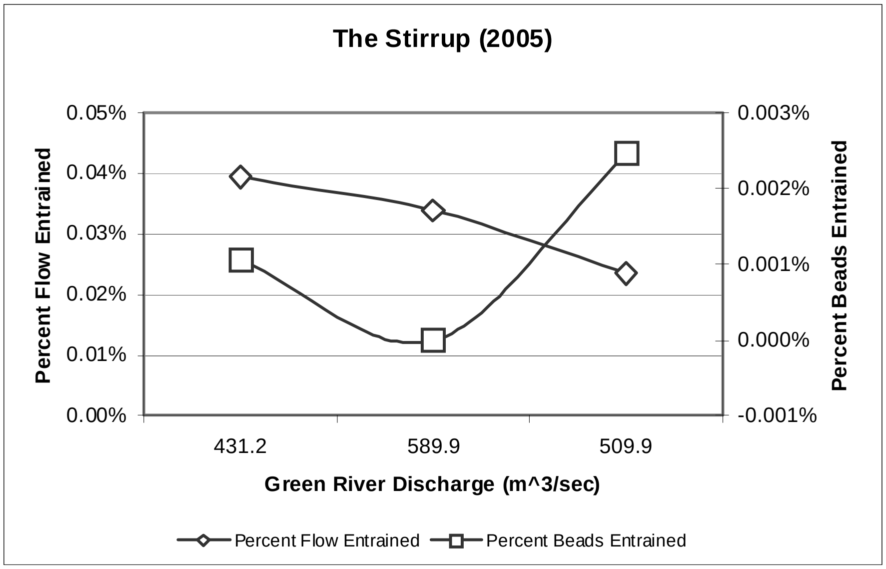

Figure 14. Relationship of percent of flow and semi-buoyant beads released and percent subsequently entrained and captured as a function of Green River discharge (m^3/sec) at the Stirrup wetland during three sampling occasions, 21, 25, and 31 May (left to right sequentially), 2005.

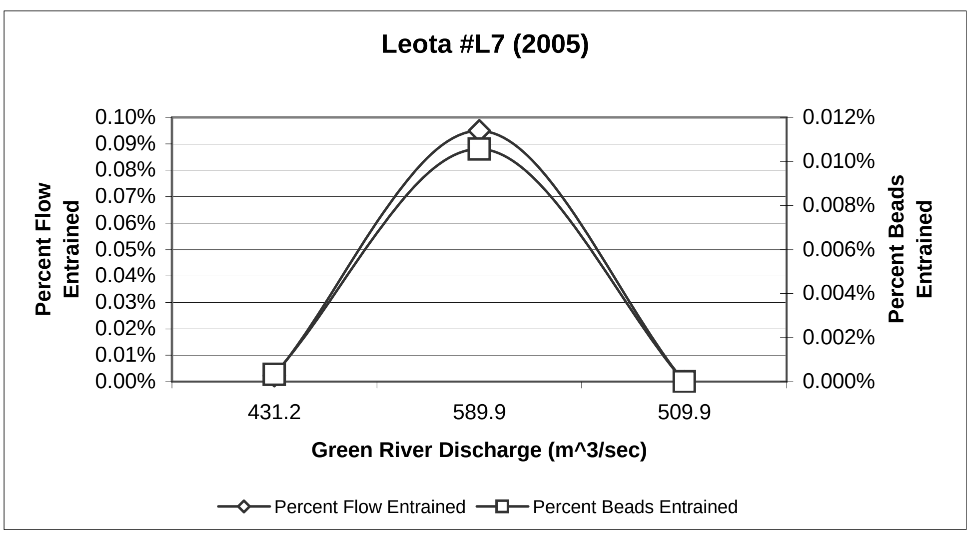

Figure 15. Relationship of percent of flow and semi-buoyant beads released and percent subsequently entrained and captured as a function of Green River discharge (m^3/sec) at L-7 during three sampling occasions, 21, 25, and 30 May (left to right sequentially), 2005. L-7 was draining during the last (509.9 m^3/sec) sampling period.

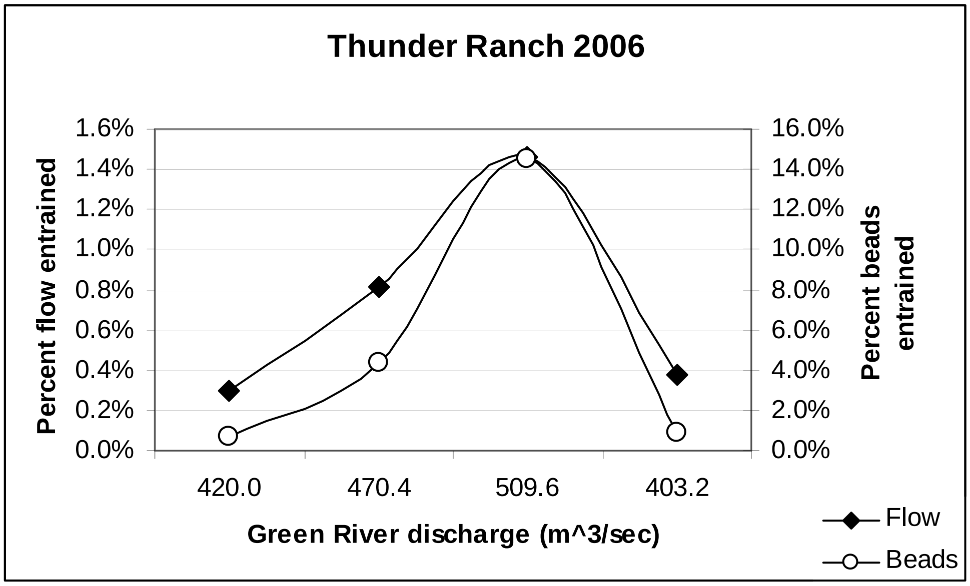

Figure 16. Relationship of percent of flow and semi-buoyant beads released and percent subsequently entrained and captured (Breach 3 and 5) as a function of Green River discharge (m^3/sec) at Thunder Ranch during four sampling occasions, 21, 23, 24 and 30 May (left to right sequentially), 2006.

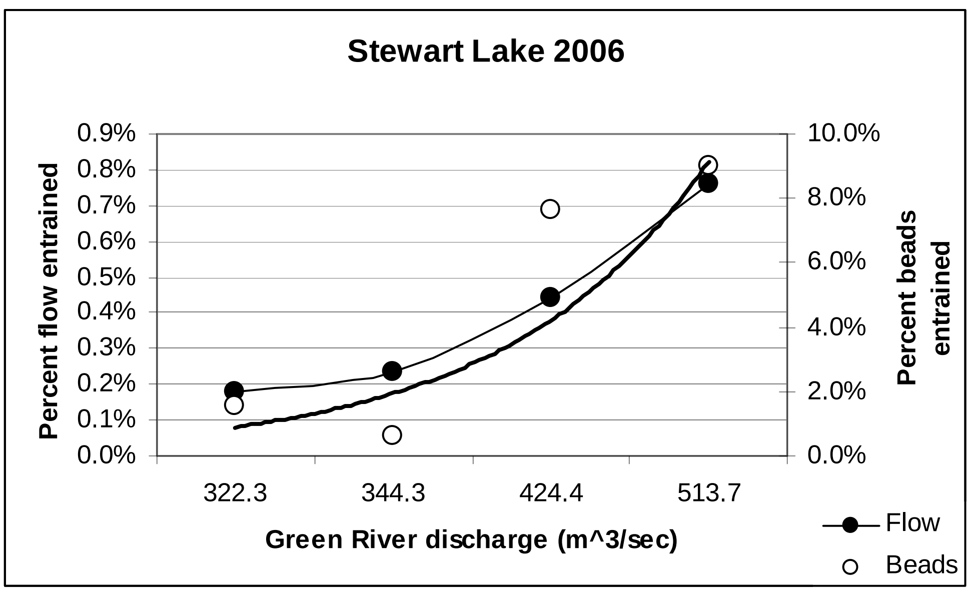

Figure 17. Relationship of percent of flow and semi-buoyant beads released and percent subsequently entrained and captured as a function of Green River discharge (m^3/sec) at Stewart Lake wetland during four sampling occasions, 17, 18, 21, 24 May (left to right sequentially), 2006. Stewart Lake functioned as a flow-through site with an open inlet and outlet during 2006 sampling. Because bead captures decreased from the first to second time period, we have shown the relationship with a trend line rather than a smoothed line.

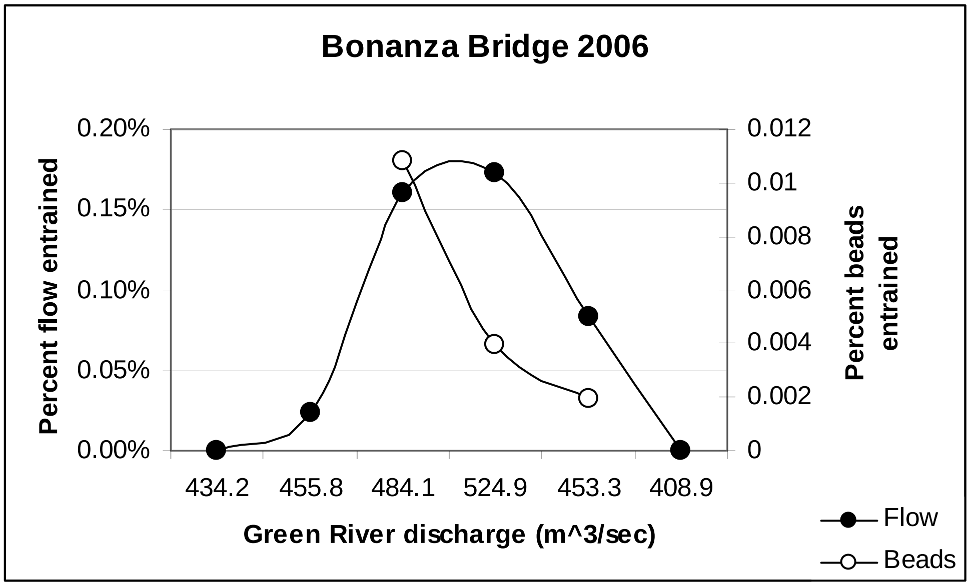

Figure 18. Relationship of percent of flow and semi-buoyant beads released and percent subsequently entrained and captured as a function of Green River discharge (m^3/sec) at Bonanza Bridge during three sampling occasions, 23, 25, 27 May (left to right sequentially), 2006.

APPENDIX I

Metric to English conversion of most river kilometers, water volumes, and water velocities mentioned in the text, figures, and tables

Site	River Kilometer	River Mile
Razorback Bar	500.9	311
Escalante Bar	493.7	306.8
Thunder Ranch	492.1	305.8
Stewart Lake	482.8	300
Bonanza Bridge	466.2	289.7
The Stirrup	443.4	275.5
Leota Bottoms	414.9	257.8

				Breach Sample	
Sampling Date	Sampling Location	m^3/sec	ft^3/sec	m^3/sec	ft^3/sec
5/20/2005	Thunder Ranch	390.8	13,800	0.67	23.65
5/24/2005	Thunder Ranch	538	19,000	2.01	70.95
5/30/2005	Thunder Ranch	470.1	16,600	1.03	36.36

				Breach Sample	
Sampling Date	Sampling Location	m^3/sec	ft^3/sec	m^3/sec	ft^3/sec
5/20/2005	Stewart Lake	401	14,160	1.67	58.95
5/24/2005	Stewart Lake	549.7	19,400	1.19	42.01
5/30/2005	Stewart Lake	479.4	16,900	0.59	20.83

				Breach Sample	
Sampling Date	Sampling Location	m^3/sec	ft^3/sec	m^3/sec	ft^3/sec
5/21/2005	Stirrup	431.2	15,200	0.17	6.00
5/25/2005	Stirrup	589.9	20,800	0.2	7.06
5/31/2005	Stirrup	509.9	18,000	0.12	4.24

				Breach Sample	
Sampling Date	Sampling Location	m^3/sec	ft^3/sec	m^3/sec	ft^3/sec
5/21/2005	Leota	431.2	15,200	0.01	0.35
5/25/2005	Leota	589.9	20,800	0.56	19.77

5/31/2005	Leota	509.9	18,000	0	0.00

Sampling Date	Sampling Location	m^3/sec	ft^3/sec	Breach 3 Sample m^3/sec	Breach 3 Sample ft^3/sec	Breach 5 Sample m^3/sec	Breach 5 Sample ft^3/sec
5/21/2006	Thunder Ranch	420	14,800	1	35.30	0.3	10.59
5/23/2006	Thunder Ranch	470.4	16,600	2.5	88.25	1.4	49.42
5/24/2006	Thunder Ranch	509.6	18,000	4.2	148.26	3.3	116.49
5/30/2006	Thunder Ranch	403.2	14,200	1.4	49.42	0.1	3.53

Sampling Date	Sampling Location	m^3/sec	ft^3/sec	Breach Sample m^3/sec	Breach Sample ft^3/sec
5/17/2006	Stewart Lake	322.3	11,400	0.6	21.18
5/18/2006	Stewart Lake	344.3	12,150	0.8	28.24
5/21/2006	Stewart Lake	424.4	15,000	1.9	67.07
5/24/2006	Stewart Lake	513.7	18,100	3.9	137.67

Sampling Date	Sampling Location	m^3/sec	ft^3/sec	Breach 2 Sample m^3/sec	Breach 2 Sample ft^3/sec	Breach 3 Sample m^3/sec	Breach 3 Sample ft^3/sec
5/21/2006	Bonanza Bridge	434.2	15,300	0.01	0.35	0.0	0.00
5/22/2006	Bonanza Bridge	455.8	16,100	0.11	3.88	0.0	0.00
5/23/2006	Bonanza Bridge	484.1	17,100	0.64	22.59	0.14	4.94
5/25/2006	Bonanza Bridge	524.9	18,500	0.81	28.593	0.1	3.53
5/27/2006	Bonanza Bridge	453.3	16,000	0.34	12.002	0.04	1.412
5/30/2006	Bonanza Bridge	408.9	14,500	0	0	0	0

APPENDIX II

2003 Pilot Study Results

In 2003, crews with the Utah Division of Wildlife Resources set drift nets in upstream breaches of two flood plain locations (Bonanza Bridge [RKM 466.2] and Brennan Bottom [RKM 426.2]) to detect entrainment of wild-spawned larval suckers. To increase their ability to detect passively drifting particles, they concurrently released beads uniformly across the entire channel one mile upstream of each site. Though crews did not detect any larvae in the drift during this effort, the resulting capture rates of beads in relation to the volume of water entrained was unexpected. Although the Brennan flood plain connected to the river at a lower mainchannel flow (340 m^3/sec vs. 425 m^3/sec at Bonanza Bridge) and thus entrained a greater volume of water over the sampling period (666,924 m^3 vs. 23,088 m^3 at Bonanza Bridge), Bonanza Bridge still entrained a larger number of the 690,000 beads released (45 beads vs. 14 at Brennan). While the actual number of beads captured at each site is small, if these numbers are extrapolated over the flow entrained or the entire sampling period, Bonanza Bridge becomes quite effective relative to Brennan Bottom at entraining passively drifting materials. This difference in total beads entrained over the study period points to a potentially interesting relationship between flow/beads entrained and the morphology of the levee breach.

APPENDIX III

Results of alizarin complexone marking to test survival of early life stages of razorback sucker, *Xyrauchen texanus*, and fathead minnow, *Pimephales promelas*, in two water types from Ouray National Fish Hatchery

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Tests were conducted to determine if alizarin complexone (ALC), was toxic to small razorback suckers, *Xyrauchen texanus,* when used in combination with two different Ouray Hatchery well water sources. Alizarin complexone is a calcium stain that can be used for marking early stages of fish because it is incorporated into bony tissue as fish grow. Otoliths examined under ultra-violet light fluoresce when subjected to appropriate concentrations of ALC for appropriate durations of time. Tests were conducted because of mortality of fish in May 2005 when marking of razorback sucker larvae was attempted. Apparently all fish died within 20 minutes of starting the marking period (M. Montagne, pers. comm., Ouray Hatchery). It was hypothesized that high levels of manganese in marking water may have interacted with the potassium in the solution used to dissolve the ALC to create potassium permanganate, a known fish toxicant. Previous tests with razorback suckers (Muth and Meismer 1995, Southwestern Naturalist) showed no toxicity when marked with ALC in combination with well water from the Aquatic Research Laboratory (ARL) at Colorado State University.

We first tested water from an easily accessible well from Ouray Hatchery on 7 July 2005. Apparently that was not the water used to mark fish in. We then tested water on 15 August 2005 that was from a more difficult to access Ouray Hatchery well source that had higher concentrations of metals, including manganese, which was the water that was used to mark the fish. We diluted solutions of ALC, first dissolved in 1-N solutions of KOH and buffered to near neutral (pH = 7.6) with either 50% ARL or Ouray Hatchery water mixed with distilled water (50%) to achieve a marking solution of 50 mg/L. We filled 1-L beakers with marking solutions and aerated them, and added randomly allocated batches of 10 fish to each of the beakers. Tests for each of the ARL, Ouray Hatchery, and reference water types were replicated three times. We allowed fish to remain immersed in the 50 mg/L marking solutions for four hr, which were ALC concentrations and marking durations in the ranges successfully tested by Muth and Meismer (1995). After the four hr marking period, fish were strained from the marking solution with a net and placed into ARL water. Fish mortalities were noted at that time (postmarking), and for 24 and 48 hr post-testing periods. Survival values reported were for the 48 hr duration observations. Reference water tests with each fish species were also conducted using equal portions of ARL, Ouray Hatchery, and distilled water. Reference fish were handled similarly to fish marked in ALC except were not immersed in the marking solution.

Because the razorback suckers that were available for the July and August marking tests were hatched in late April, they were much older and larger than the razorback sucker larvae that were unsuccessfully marked in May 2005. Therefore, we used those larger and older razorback suckers as well as eight-day-old fathead minnows (about six to seven mm TL). Those fathead minnows were similar in age to the razorback suckers marked in May but were smaller than the May razorback suckers. Thus, if younger age or smaller-sized fish have higher toxicity to the ALC solution, that should be apparent from the fathead marking tests, assuming similar tolerance of ALC by the two species at young life stages.

Tests showed high survival of razorback suckers and fathead minnows in ARL, Ouray, and reference water conditions on each marking date (Table A-1). The younger and smaller fathead minnows had slightly lower survival compared to razorback suckers but survival rates of each species in treatment and reference conditions was similar on each date. This suggested that toxicity due to effects of ALC in Ouray Hatchery well water was not a likely source of mortality for the fish that died during marking in May.

A possible confounding factor in August marking tests is that large amounts of hard water elements precipitated out of solution in the hard water used in those experiments. We stirred that water prior to testing to ensure that some of the precipitate was included in test water but it did not re-dissolve. It is unknown if precipitation could have removed the toxic elements before they could interact with the ALC solution. The only means to assess this would be to conduct marking tests with the water immediately after it is drawn. However, it is likely that the water used for fish marking also had some time to precipitate hard water elements before the May marking was conducted. A chemist or water quality expert with experience in hard water chemistry interactions may also be able to give some insight into whether small amounts of KOH could interact to produce toxic effects with constituents present in the hard well water at Ouray Hatchery. Future marking should be conducted with the less hard well source if possible to reduce the chances of creating toxic marking solutions. Test marking a few fish with marking solutions for up to an hr prior to immersing large batches of fish should also be part of the marking protocol.

Table A-1. Percent survival of razorback sucker, *Xyrauchen texanus*, hatched in late April 2005 and eight-day-old fathead minnow, *Pimephales promelas*, on two different test dates. The 7 July test used relatively soft water from Ouray Hatchery, while the 15 August test used hard water from a different, less accessible well source. Survival values were from batches of 10 fish, replicated three times each, for each species, water, and testing date combination. Reference water was a mix of Ouray Hatchery, Aquatic Research Laboratory (ARL), and distilled water in equal portions.

		Percent survival, by water type		
Date	**Species**	**ARL**	**Ouray**	**Reference**
7-Jul-05	razorback sucker	100	100	100
	fathead minnow	100	93	93
			(90 - 100)	(78 - 100)
15-Aug-05	razorback sucker	93	100	97
		(90 - 100)		(90 - 100)
	fathead minnow	97	90	90
		(90 - 100)	(80 - 100)	(80 - 100)