

**Razorback Sucker Survival and Emigration from the Stirrup Floodplain,
Middle Green River, Utah
2007-2010**

Trina N. Hedrick
Utah Division of Wildlife Resources
152 East 100 North
Vernal, UT 84078

André R. Breton
Insight Database Design & Consulting
610 South Grant Avenue (Unit B)
Fort Collins, CO 80521

and

Steven P. Keddy
Utah Division of Wildlife Resources
152 East 100 North
Vernal, UT 84078

Final Report

February 2012

Prepared for:
Upper Colorado River Basin
Endangered Fish Recovery Program
Project Number: C-6/RZ-RECR

Publication Number 12-10
Utah Division of Wildlife Resources
1594 West North Temple
Salt Lake City, UT 84114

ACKNOWLEDGEMENT AND DISCLAIMER

This study was funded by the Recovery Implementation Program for Endangered Fish Species in the Upper Colorado River Basin. The Recovery Program is a joint effort of the U.S. Fish and Wildlife Service, U.S. Bureau of Reclamation, Western Area Power Administration, states of Colorado, Utah, and Wyoming, Upper Basin water users, environmental organizations, the Colorado River Energy Distributors Association, and the National Park Service.

The authors would like to thank a number of individuals for their help in the field and in developing this project. These individuals include D. Firmage, T. Modde, P. MacKinnon, P. Nelson (deceased), C. Landress, E. Prentice, B. Hayes, M. Montagne and the staff at the Ouray National Fish Hatchery, L. Monroe, M. Swasey, and M. Breen. The authors thank D. Speas, K. Zelasko, A. Webber, and T. Francis for their very thorough reviews of this report.

Mention of trade names or commercial products does not constitute endorsement or recommendation for use by the authors, the U.S. Fish and Wildlife Service, U.S. Department of Interior, or members of the Recovery Implementation Program.

TABLE OF CONTENTS

ACKNOWLEDGEMENT AND DISCLAIMER	ii
TABLE OF CONTENTS	iii
LIST OF TABLES	iv
LIST OF FIGURES	v
LIST OF KEY WORDS	v
EXECUTIVE SUMMARY	vi
INTRODUCTION	9
GOALS AND OBJECTIVES	12
STUDY AREA	13
METHODS	14
Floodplain	14
Fish Stocking	15
Passive Detection	16
Descriptive Analysis	17
Emigration of Stocked Razorbacks.....	18
Other Movement Observations	18
Statistical Analysis	18
Survival and Fidelity of Stocked Razorbacks	18
Additional Observations	20
RESULTS	21
Floodplain Maintenance and Monitoring.....	21
Fish Stocking	21
Floodplain Sampling	21
Floodplain Connections to River	21
Descriptive Analysis	22
Emigration of Stocked Razorbacks.....	22
Other Movement Observations	22
Statistical Analysis	23
Survival and Fidelity of Stocked Razorbacks	23
Additional Observations	24
DISCUSSION	26
CONCLUSIONS	34
RECOMMENDATIONS	36
LITERATURE CITED	38
Appendix 1	60

LIST OF TABLES

Table 1 – Water quality measurements (including temperature, pH, specific conductivity, and dissolved oxygen) recorded at the Stirrup floodplain throughout the project (2007-2010). _____	46
Table 2 - Number, stocking date, age-class, age at stocking, and average length at stocking for all razorback suckers stocked into the Stirrup floodplain 2007-2009. _____	46
Table 3 – Numbers, average total length, length range, catch-per-effort, gear type, and number of razorback sucker recaptured during active sampling efforts at the Stirrup floodplain, 2007-2010. _____	47
Table 4 – Razorback sucker movements by year spawned, year stocked, and year of emigration from floodplain. _____	47
Table 5 – Number of bonytail (BT), Colorado pikeminnow (CS), and razorback sucker (RZ) movements detected in 2009 and 2010, and the percent of movement detected during the night vs during the day by species each year. _____	48
Table 6 – The suite of 16 models fitted to the razorback capture-mark-recapture data from the Stirrup floodplain and breach: S, survival; F, fidelity to the floodplain; p(e), recapture probability by active sampling; p(a), passive detection by the PIT-tag antennas; AIC, Akaike's Information Criterion; ML, model likelihood; AIC weight; np, number of model parameters; logL, log-likelihood; df, degrees of freedom. _____	49
Table 7 – Relative importance weights for constant (no difference among stocking occasions) parameters and parameters varying as a function of stocking occasion: S, survival; F, fidelity to the floodplain; p(e), recapture probability by active sampling; p(a), passive detection by the PIT-tag antennas. _____	50

LIST OF FIGURES

Figure 1 – Aerial view of the Stirrup floodplain. _____	51
Figure 2 – Location of the Stirrup floodplain along the middle Green River within the state of Utah. _____	52
Figure 3 – Antennas spanning the Stirrup breach. _____	53
Figure 4 – Green River flows during the study period in each project year. _____	54
Figure 5 – Movement detections of 63 individual razorback suckers into and out of the Stirrup over the last two years of the study. _____	55
Figure 6 – Movement detections of 10 bonytail into and out of the Stirrup over the last two years of the study. _____	56
Figure 7 – Movement detections of six Colorado pikeminnow into and out of the Stirrup over the last two years of the study. _____	57
Figure 8 - Model-averaged estimates (\pm 95% CI) of survival probabilities for the 3rd (S3) and 5th (S5) stocking cohorts from the suite of 16 models (Table 6) fitted to the razorback capture-mark-recapture data from the Stirrup floodplain and breach. _____	58
Figure 9 - Model-averaged estimates (\pm 95% CI) of fidelity probabilities (to the floodplain) for the 3rd (S3) and 5th (S5) stocking cohorts from the suite of 16 models (Table 6) fitted to the razorback capture-mark-recapture data from the Stirrup Floodplain and breach. _____	58
Figure 10 - Model-averaged estimates (\pm 95% CI) of 2009 active-sampling recapture probabilities for the 3rd (S3) and 5th (S5) stocking cohorts from the suite of 16 models (Table 6) fitted to the razorback capture-mark-recapture data from the Stirrup Floodplain and breach. ____	59
Figure 11 - Model-averaged estimates (\pm 95% CI) of passive detection probabilities from PIT-tag antennas 1-3 for the 3rd (S3) and 5th (S5) stocking cohorts from the suite of 16 models (Table 6) fitted to the razorback capture-mark-recapture data from the Stirrup Floodplain and breach. ____	59

LIST OF KEY WORDS

Stirrup floodplain, recruitment, emigration, middle Green River, razorback sucker, stationary

PIT-tag reader, survival probability, recapture probability, site fidelity

EXECUTIVE SUMMARY

Floodplains of the middle Green River are known to be important habitats for the endangered razorback sucker (*Xyrauchen texanus*). Prior studies have determined that larval razorback suckers enter the riverine drift during peak flows and can become entrained into floodplain habitats. The current study was undertaken to determine how long a stocked razorback sucker would remain in the Stirrup floodplain, a small floodplain located within the alluvial reach of the middle Green River, before moving out to the mainstem. While our results do not provide information on how long a *wild-spawned* larval razorback sucker will remain in the floodplain, they do provide information on how this species utilizes floodplain habitat.

To determine the duration razorback sucker remained in the floodplain and determine the age/year class most likely to emigrate to riverine habitats, the Ouray National Fish Hatchery stocked 7,990 razorback suckers into the Stirrup between 2007 and 2009. Each fish was tagged with a Passive Integrated Transponder (PIT) tag, a unique identifier, and was stocked in summer or fall.

To detect PIT-tagged fish moving out of the floodplain (2008-2010), we installed and maintained a multi-plexing unit with one, two, or three antennas (depending on the year) in the breach. Water quality was monitored and a 6-inch trash pump was used to add river water to the floodplain, and thus improve water quality. Stocked fish were monitored by Utah Division of Wildlife Resources employees through the use of boat electrofishing, trammel netting, and fyke netting on multiple occasions to develop population estimates.

Of the 7,990 razorback sucker stocked into the Stirrup, 48 moved from the floodplain to the river and were detected by the readers. The tag for one of these individuals was not available in our database of stocked fish and therefore could not be attributed to a stocking cohort. Of the

remaining 47 fish, three were age-1 fish (6.4%), 16 were age-2 fish (34.0%), 27 were age-3 fish (57.4%), and one was an age-4 fish (2.1%); 46 of the 47 fish (97.9%) moved out of the Stirrup after spending only one winter there and only one fish (2.1%) was detected moving out of the Stirrup after two winters.

Low numbers of fish movements from floodplain to the river indicated potentially high mortality. Mortality was observed and also presumed through low recapture rates, though some of the fish not detected leaving were confirmed as having remained in the floodplain.

Observations of hundreds of dead fish along the shoreline were noted in spring of 2008 and in spring of 2010. In addition to these winter kills, field observations suggest that avian predation was likely another important factor affecting survival.

Although the study was not designed to estimate survival and fidelity (to the floodplain), the 3rd (S3) and 5th (S5) stocking cohorts provided sufficient data to perform an analysis. These were stocked at age 2-years in summer 2008 and young-of-year in fall 2008, respectively. To model survival and fidelity to the floodplain, we developed our own likelihood based, multinomial, capture-mark-recapture models in program SURVIV. In addition to survival and fidelity parameters, we integrated (into our models) passive detection probabilities for each antenna and recapture probabilities associated with active sampling (electrofishing and trammel netting) in 2009. We assessed two structures for each parameter using an “all possible models” approach (16 models), in which the parameter varies by stocking cohort or is constant, and then used model averaging to estimate probabilities for each parameter that were unconditional on any particular model in our set. We also calculated relative importance weights for each parameter structure (e.g., did evidence favor equal survival among stocking cohorts or variation among cohorts).

Based on our estimates and consistent with other published and non-published estimates for larval and juvenile razorback studies, survival was low for both cohorts, 0.13 ± 0.18 (SE) and 0.20 ± 0.12 for the young-of-year (S5) and the age-2 fish (S3), respectively. Site fidelity estimates were high, and these suggested that age-2 fish moved out at a higher rate (0.87 ± 0.10) than fish stocked at young-of-year (0.97 ± 0.07). The point estimates of recapture probability (electrofishing and trammel netting) were low; the rate was slightly higher for the age-2 cohort (0.16 ± 0.10 vs. 0.14 ± 0.22 , respectively). Estimates of passive detection probabilities through the antennas were also slightly higher for the age-2 fish than for the young-of-year fish. Statistical tests of a difference of *exactly* zero between these cohort rates (survival, fidelity and detection) were not significant based on overlapping confidence intervals. Nonetheless, relative importance weights did provide some evidence that survival, fidelity, and passive detection varied by cohort in the direction suggested by our point estimates (above).

Additional observations include daily timing of movement, species-specific movement (including three of the four big river endangered species), and environmental preferences for native fish movement between river and floodplain (e.g., depth >25 cm, turbidity, etc.). These observations suggested that bonytail and razorback sucker moved predominantly in the evening and that Colorado pikeminnow showed no preference. We also observed associations between high water clarity and a lack of native fish movement through the breach.

INTRODUCTION

The Upper Colorado River Basin (hereafter, "Basin") is home to 11 native fishes (Sigler and Sigler 1996), four of which are listed as federally endangered for a variety of reasons including habitat modification or destruction, introduction of nonnative fishes, and water diversions (United States Fish and Wildlife Service (USFWS) 2002a; USFWS 2002b; USFWS 2002c; USFWS 2002d). These four, the Colorado pikeminnow *Ptychocheilus lucius*, razorback sucker *Xyrauchen texanus*, bonytail *Gila elegans*, and humpback chub *Gila cypha*, have life histories that are adapted to highly variable flow regimes, dominated by snowmelt runoff, characteristic of the Basin's streams and rivers (Muth et al. 2000). It is likely that this specialization to large river habitats with spring peaks resulting from snowmelt runoff and low base flows during the remainder of the year made them especially vulnerable to the changes brought about by water development, and the "taming" of the Colorado River system (Minckley and Deacon 1968; Minckley 1991). Introduction of over 40 nonnative fish species and successful establishment of nearly a dozen of them have added predators and competitors where few existed previously (Hawkins and Nesler 1991; Lentsch et al. 1996; Tyus and Saunders 1996; Tyus and Saunders 2000) and further contributed to their decline (USFWS 2002a; USFWS 2002b; USFWS 2002c; USFWS 2002d).

Razorback sucker require floodplain habitats for a significant part of their life history (Tyus and Karp 1990; Modde 1996; Lentsch et al. 1996; Muth et al. 1998; Wydoski and Wick 1998). Adults spawn and lay eggs in gravel bars in mainstem riverine habitats on or near the ascending limb of the hydrograph (Tyus 1987; Muth et al. 2000; Bestgen et al. 2002). Swim-up larvae enter the drift (Muth et al. 1998) and become entrained in slack-water habitats (Bestgen et al. 2002; Hedrick et al. 2009; USFWS Vernal Colorado River Fisheries Project, unpublished

data), potentially including floodplain habitats, if flow and timing are adequate (Bestgen et al. 2011). It is thought that razorback sucker larvae entrained in floodplain habitats are likely to survive better than those entrained in mainstem, slackwater habitats, given that floodplain habitats are warmer and more productive than mainstem habitats during spring runoff (Modde 1996; Muth et al. 1998; Modde et al. 2001; Bestgen et al. 2002; Bestgen 2008).

In an effort to better understand the utility of floodplain habitats for endangered fishes, the Upper Colorado River Endangered Fish Recovery Program (hereafter, "Program") identified the need to restore floodplain connection in mainstem and major tributary habitats (USFWS 2002a; USFWS 2002b; USFWS 2002c; USFWS 2002d). This project was implemented as "The Green River Floodplain Connection and Levee Removal Project" and was intended "to evaluate the system responses to levee removal and make specific recommendations concerning the value of floodplain re-connection for razorback sucker recovery" (Birchell et al. 2002). Specific fisheries-related uncertainties investigated by the project included larval and juvenile survival rates in floodplains, growth rates of larval and/or juvenile fish in floodplains, and juvenile use of floodplains (Birchell and Christopherson 2004).

With the establishment of nonnative fishes in the Basin, floodplain habitats are often dominated by species such as black bullhead *Ameiurus melas*, common carp *Cyprinus carpio*, fathead minnow *Pimephales promelas*, and green sunfish *Lepomis cyanellus*. Each of these species can affect the ability of larval razorback sucker to survive through their first summer in the floodplain, predominantly through high rates of predation. This process is not inevitable, however, if floodplains are "reset" naturally or through nonnative fish removal before floodplain-riverine connection in the spring. Previous work on larval razorback sucker and

bonytail demonstrated that these native species can survive in the presence of low densities of nonnative fish (Christopherson et al. 2004; Brunson and Christopherson 2005; Webber 2010).

Although floodplains, including those associated with the middle Green River, are known to be important habitats for the razorback sucker (Tyus and Karp 1990; Modde 1996; Lentsch et al. 1996; Muth et al. 1998; Wydoski and Wick 1998), it is not known how long young-of-year and juvenile razorback suckers remain in floodplains prior to migration to the river. Floodplains are highly productive (Modde 1996; Muth et al. 1998; Modde et al. 2001; Bestgen et al. 2002; Bestgen 2008) and we speculate that their isolation from the river could provide a natural refuge from predation by native and nonnative fish predators, if conditions are adequate. However, floodplains can also be detrimental to survival due to decomposition of submerged vegetation and phytoplankton, which leads to low dissolved oxygen conditions (Birchell et al. 2002).

In order to evaluate the importance of floodplains as habitat for maturing larval and juvenile razorbacks, we initiated a study to determine how long stocked razorback suckers, fitted with PIT-tags, remained in a floodplain habitat. Razorback suckers were stocked to investigate length of stay (i.e., fidelity) into a small floodplain located within the alluvial reach of the middle Green River known as "the Stirrup floodplain." Our study contributes to ongoing research needs identified in "The Levee Removal Project" completed for the Green River (Green River Study Plan *ad hoc* committee 2007; Birchell et al. 2002).

GOALS AND OBJECTIVES

The goal of this study was to characterize emigration of razorback sucker from floodplain wetlands to the Green River.

The two main objectives were to:

1. Maintain multiple year-classes of razorback sucker in the Stirrup floodplain during the study via stocking and ensure suitable water quality through active water pumping from the river to the Stirrup floodplain.
2. Determine the length of time (stratified by age-class and size) that razorback suckers reside within the floodplain before emigrating to the river. This was done by installing and maintaining appropriate monitoring technology within the floodplain breach.

Specific tasks identified within the scope of work included:

Task 1. Pump water from the river into the Stirrup floodplain.

Task 2. Stock razorback sucker into the Stirrup floodplain.

Task 3. Monitor water quality and/or species assemblage in the Stirrup floodplain.

Task 4. Set up a stationary PIT-tag reader during spring peak flows.

Task 5. Download PIT-tag data and monitor PIT-tag array.

STUDY AREA

The Stirrup floodplain is located within the middle Green River at RM 275.5 (Figures 1-2). In 1997, the floodplain levee was breached, and around that time, FLO Engineering Inc. (1997) confirmed that the Stirrup was 20 surface acres at Green River flows of 13,000 cfs and 28 surface acres at Green River flows of 18,600 cfs. However, based on observations from 2007, when the floodplain did not connect with the Green River during a peak of 12,500 cfs (United States Geological Survey (USGS) Jensen gage #09261000), in addition to Brush Creek and Ashley Creek flows (USFWS unpublished PowerPoint presentation), connection currently occurs at higher river flows than in 1997. This is most likely due to sedimentation within the breach. Depth measurements at the Stirrup in 2006 and 2007 identified a maximum depth of between 4-4.5 ft, depending on whether the floodplain connected to the river that year, although the floodplain average depth is between 3-4 ft.

Breaching of floodplain levees was part of the Program's broader goal to restore floodplain connection in mainstem and major tributary habitats (USFWS 2002a; USFWS 2002b; USFWS 2002c; USFWS 2002d; Birchell et al. 2002). The Stirrup floodplain's only breach is approximately 10-12 feet wide at its widest (Figure 3), and accommodates a multiple-antenna PIT-tag array (see Methods for description of technology).

METHODS

Floodplain Maintenance and Monitoring – Based on 2007 breach and river elevation profiles, the Stirrup floodplain likely connected to the mainstem Green River in at least 11 of the 15 years since the floodplain levee was breached in 1997 (USGS, Jensen gauge #09261000, 1965-2009). In years when little or no connection occurred, we assumed that dissolved oxygen (DO) within the floodplain was likely poor, overall depth was probably quite low, interactions with nonnatives may have been more numerous given less overall space in the floodplain, and survival of fish within the floodplain was potentially compromised. Given these potential negative scenarios, the scope of work for this project included the option to pump water from the river into the floodplain to maintain water quality.

Pumping was initially done in the summer of 2007, with two to three four-inch trash pumps. However, maintenance issues were difficult to address and these pumps were not powerful enough to provide the increase in overall depth to the desired > 4 ft maximum (Modde 2007). All subsequent pumping was done with a six-inch trash pump. This diesel unit had much lower maintenance requirements and increased water levels in the floodplain to the desired depth. Pumping occurred for nearly four weeks in the fall of 2007 to refresh water quality due to lack of connection in spring 2007, for two weeks in the spring (pre-connection) of 2008, and for four weeks during the spring of 2010 to fill the floodplain in preparation for runoff flows predicted to be no higher than 15,000 cfs.

Routine breach maintenance was required during the project. In 2010, in preparation for pumping, we removed sediment from the breach. This sand had accumulated from peak flows in prior years and inhibited our ability to back the pump near enough to the water's edge to achieve maximum efficiency. In addition, to improve access, we removed tamarisk (*Tamarix*

ramosissima) that had grown around the breach. Finally, a large cottonwood tree (*Populus fremontii*) fell into the breach during the winter of 2009-2010 and had to be removed. If left in the breach, this tree may have prevented movement that year, and certainly would have quickened the rate of sedimentation during future peak flows.

Water quality within the Stirrup was monitored using a Hydrolab MS5 (Hach Hydromet, Loveland, CO) with a Luminescent Dissolved Oxygen probe (LDO mg/L), temperature (°C), pH, and conductivity sondes (µS/cm). Water quality was always measured in the same location within the floodplain (the deepest point) and was usually measured at two different depths, one near the bottom and one mid-column; these measurements were averaged for this report. Water quality parameters were normally measured in late morning or early to mid-afternoon when DO was increasing. Water quality in the Stirrup was measured once in 2007 (June), twice in 2008 (February and August), three times in 2009 (August, November, and December), and three times in 2010 (January, March, and April).

Fish Stocking - The Ouray National Fish Hatchery stocked razorback suckers marked with 134.2 kHz passive integrated transponder (PIT) tags (Biomark Inc., Boise, ID) into the floodplain on six separate occasions from 2007-2009. All fish stocked, including age-0 fish (young-of-year), were PIT-tagged, which allowed individual fish to be identified. Age-0 fish were stocked in the fall to allow the fish to reach a size at the hatchery that was adequate for tagging.

Fyke nets were used to sample stocked razorback suckers within the floodplain on one occasion each year in 2007 and 2008. More extensive floodplain sampling was conducted in 2009 and 2010 pre- and post-connection using electrofishing and fyke-netting. On two occasions (pre- and post-connection in 2009), we attempted to mark fish with a fin clip and then recapture the fin-clipped fish to calculate a population estimate. This additional sampling was intended to

determine a point estimate for the number of razorback suckers in the floodplain before and after connection, to improve knowledge of survival in the floodplain during the study, and to increase the number of recaptures over the course of the study for use in a capture-mark-recapture analysis of survival and fidelity.

Passive Detection - To monitor the movement of PIT-tagged fish out of the Stirrup, we installed a Digital Angel FS1001M multi-plexing unit (MUX; Biomark Inc., Boise, ID) within the Stirrup floodplain breach. This technology has been used to monitor Lost River suckers (*Deltistes luxatus*) in the upper Klamath River (Hewitt et al. 2010) and bull trout (*Salvelinus confluentus*) in Trestle Creek, Idaho (Downs et al. 2006).

The MUX was programmed to acknowledge the appropriate number of antennas and each antenna was tuned to detect the 134.2 kHz PIT-tags implanted in each study fish with the highest read range possible. The number of antennas and battery supply varied throughout the study. However, the most successful setup, used in 2010, consisted of four Deka, solarvoltaic, 12 V batteries (East Penn Manufacturing Co., Inc., Lyon Station, PA) connected both in series and parallel, powering the MUX and two 165 W solar panels (SolarWorld, Camarillo, CA). In 2008 and 2009, standard marine deep cycle batteries were changed daily. In all years, the reader was re-tuned as flows entered the breach to help ensure there were no issues with noise or tag detection from increasing water levels.

To minimize power loss, all wiring used was 12 gauge. Antenna construction followed unpublished methods obtained from Mr. Rip Shively and Mr. Brian Hayes of the USGS, Western Fisheries Research Center, Klamath Falls Field Station, Klamath Falls, Oregon. In 2008, we deployed one 10' x 4' antenna, but it became clear that multiple antennas would be beneficial to determine direction of movement and to act as a backup in case noise levels in one antenna were

too high to detect fish. Therefore, two additional antennas (10' x 4' and 12.5' x 3.5') were built and deployed for peak flows in 2009. In 2010, the original antenna was damaged and not functioning adequately; antennas two and three operated normally in both 2009 and 2010.

In each monitoring season (2008, 2009, 2010), the PIT-tag reader was in place in time to capture movement during the entire river-floodplain connection. PIT-tag data was downloaded during each site visit (daily in 2008 and 2009; weekly in 2010). Data was saved as a text file and imported into Microsoft Excel. The MUX was programmed to record test tags associated with each antenna every hour a PIT-tagged fish was *not* detected. Text files included detections of test tags as well as tags associated with stocked razorbacks or any other PIT-tagged fish moving into or out of the floodplain, information on antenna efficiency, and reader functionality at the time the information was downloaded. Upon detecting a PIT-tagged fish moving into or out of the floodplain, the MUX would also record the date and time.

In each study year, the MUX was not set for unique mode. On this setting, if a fish remained in the vicinity of an antenna for an extended period of time, the MUX would continually read the tag (multiple times per second) until the individual moved out of range or until another tag was detected. For this reason, we set the MUX to read a duplicate tag only once per minute to reduce the number of detections for a single fish that remained in range of an antenna. The reader was always set to record all new tags in the vicinity of the antennas and did so without delay (default antenna scanning time < 1 s). The use of antennas, a passive means of detecting a study fish, rather than physical recapture (e.g., by electrofishing) limited our ability to determine fish size when tagged fish migrated out of or into the floodplain.

Descriptive Analysis

Emigration of Stocked Razorbacks – In this section of our analysis we provide counts of fish grouped into four age categories (age-1, age-2, age-3, or age-4), based on their age when they emigrated from the floodplain, and by emigration year (2008, 2009, or 2010). We also provide age-specific counts of fish that spent one or two years in the floodplain. For purposes of determining the age of fish when it moved out of the floodplain, a fish was considered one year older on January 1st. Interpretations, including comparisons and magnitudes, of the counts reported in this section hinge on the assumption that passive detection probabilities (accomplished by the PIT tag readers) were equal (or nearly so) for all stocking cohorts in all years. Failure of this assumption invalidates interpretations of the uncorrected counts of fish moving past the PIT tag antenna array to the river. Given results from our statistical analysis (see below), we suggest caution when making inferences from counts presented in this section of our analysis.

Other Movement Observations – For both 2009 and 2010, movements by razorback sucker, bonytail, and Colorado pikeminnow were summarized as hourly counts; movement in 2008 was inconclusive with one antenna and high noise levels so this year was excluded. Identification to species was confirmed through the Program’s PIT-tag database (USFWS, unpublished data). Because most movement occurred between dusk and dawn, we calculated the percentage of movements by species between the hours of 20:00 and 06:00 in 2009 and between the hours of 21:00 and 06:00 in 2010. These times were based on sunrise and sunset for May 2009 and June 2010, as peak flows in 2010 occurred later than in 2009.

Statistical Analysis

Survival and Fidelity of Stocked Razorbacks – Although the study was not designed to estimate survival and fidelity (to the floodplain), two stocking cohorts provided sufficient data to perform

an analysis. In order to accommodate unique attributes of the study design and to separate the processes of fidelity and survival, we developed our own likelihood-based, multinomial capture-mark-recapture (CMR) models in program SURVIV (Appendix 1; White 1992). As likelihood-based multinomial models, our models are identical to those provided in program MARK including the Cormack-Jolly-Seber model (White and Burnham 1999). The difference is the particular set of parameters in our models versus those available in MARK. Along with survival and fidelity parameters, we integrated passive detection probabilities for each PIT-tag antenna in the breach and recapture probabilities associated with electrofishing and fyke netting in 2009. For each of these parameters (survival, fidelity to the floodplain, passive detection, and recapture) we assessed models where these were allowed to be equal (referred to as “constant”) or varying among stocking cohorts. There were not sufficient data to consider annual variation in any parameter.

Four parameters, each with two possible structures (varying by stocking cohort or constant) resulted in 4^2 or 16 models. We fitted each of these models to the data and then used model averaging to estimate probabilities of survival, fidelity, passive detection and (active) recapture that were unconditional on any particular model in our set (see Akaike's Information Criterion (AIC), AIC weights and related statistics in Burnham and Anderson 2002). We also calculated relative importance weights (Burnham and Anderson 2002) for each parameter structure (e.g., do these weights suggest that survival was equal or varying among stocking cohorts?). This was accomplished by summing the weights among all models where one particular parameter structure (e.g., survival varying among stocking cohorts) occurred. Note that AIC weights sum to one across our suite of 16 models, hence, importance weights are relative.

We assessed the fit of our general model (all parameters a function of stocking occasion) using a χ^2 statistic and associated p-value.

Out of six cohorts stocked into the Stirrup floodplain, two provided sufficient data to be included in this analysis: cohort three (S3) stocked 1 July 2008 and cohort five (S5) stocked 9 October 2008. Given that S3 razorbacks were age-2 and S5 were young-of-year when stocked, we predicted that the former would have higher survival. In contrast, we predicted that the age-2 fish would be more likely to migrate to the river which would be reflected in lower fidelity to the floodplain. Based on electrofishing theory (Snyder 2003), we predicted that the larger age-2 fish would have higher recapture probabilities during the 2009 electrofishing effort in the Stirrup floodplain. Through the passive PIT-tag antennas, we predicted that S3 razorback suckers, being larger fish, would be less likely to avoid detection by a PIT-tag antenna and thus have higher detection probabilities when passing through the breach. Based on preliminary modeling which demonstrated that the probability of detection by the third PIT-tag antenna was 1.0, we fixed this parameter to 1.0 in our suite of 16 models to aid estimation of the other parameters.

Additional Observations

In an effort to determine minimum depth required for native fish movement, we measured depth of water within the breach and in the area between the breach and floodplain daily from breach inundation on 14 May 2009 until the first native fish movement out of the floodplain was recorded on 22 May 2009.

RESULTS

Floodplain Maintenance and Monitoring – Dissolved oxygen (DO in Table 1) levels in the floodplain were low (e.g., < 2.0 mg/L) during the summer of 2007 (no spring connection to the river) and during winter each year when measurements were available. Low dissolved oxygen in the Stirrup during the winters of 2007-2008 and 2009-2010 (Table 1) were followed with observations of hundreds and tens of dead fish respectively (both carp and razorback sucker) along the south and east shorelines after ice-off. The winter kill between 2007 and 2008 appeared much more severe, based on the larger (though uncounted) number of dead individuals observed after ice-off. No measurements were taken in the 2008-2009 winter due to a malfunctioning probe; however, no dead fish were observed after ice-off in 2009.

Fish Stocking- In 2007, 1,632 age-3 fish and 1,633 age-2 fish were stocked (Table 2). In 2008, an additional 952 age-2 fish, 1,047 age-1 fish, and 1,000 young-of-year (age-0) fish were stocked (Table 2). One additional cohort was stocked in 2009, 1,727 age-1 fish. All fish stockings occurred post-connection within the calendar year. All fish were stocked in June, July, and/or October, depending on the year.

Floodplain Sampling – Table 3 provides number, average total length, length range, and catch rates for active sampling throughout the project. Electrofishing and fyke-netting were the most productive active-sampling methods. The majority of fish sampled, especially via electrofishing, were fish over 300 mm, though some smaller fish were also captured during this effort. No fin-clipped razorback suckers were recaptured in any of these efforts; therefore, we were unable to estimate abundance of stocked razorbacks in the floodplain using this method.

Floodplain Connections to River – In 2008, floodplain connection occurred from 20 May to 14 June; however, antenna malfunctions reduced our detection capabilities from 23 May to 1 June

and from 8 June to 9 June. In 2009, connection occurred from 22 May to 6 June. In 2010, connection occurred on 31 May and lasted thru 16 June. Figure 4 shows annual runoff as recorded at the Jensen gage (USGS gage #09261000) during these time periods.

Descriptive Analysis

Emigration of Stocked Razorbacks – Of the 7,990 razorback suckers stocked into the Stirrup over the course of the study, 48 razorback suckers were detected moving out of the floodplain, though one could not be definitively linked to a specific stocking group. Three age-1 fish (6.4%), 16 age-2 fish (34.0%), 27 age-3 fish (57.4%), and one age-4 fish (2.1%) moved out of the floodplain (Table 4). Forty-six fish (97.9%) moved out of the Stirrup after one winter, one fish (2.1%) was detected moving out of the Stirrup after two winters in the floodplain.

Only one razorback sucker stocked in 2007 (of n=3265) was detected leaving the floodplain; this fish was two-years-old when it emigrated in 2008 (Table 4). Thirty-one razorback suckers stocked in 2008 (of n=2998) were detected leaving the floodplain (30 in 2009 and 1 in 2010); 28 of these fish were spawned in 2006 and three in 2008; they were mostly age-3 when leaving the floodplain (n=27), though three were age-1 and one was age-4. Fifteen razorback suckers stocked in 2009 were detected leaving the floodplain in 2010 (of n=1727); all 15 of these fish were age-2 when leaving the floodplain and had been in the floodplain one year before moving out.

Other Movement Observations – In addition to stocked razorbacks, we detected individuals from four species in the Stirrup breach that had been PIT-tagged and released elsewhere in the Basin. Six Colorado pikeminnow, 11 bonytail, seven razorback sucker originally stocked into Baeser floodplain (2.5 river miles downstream from the Stirrup; Figure 2), eight razorback suckers initially stocked into the river, and one roundtail chub were recorded moving into the Stirrup. Of

the six Colorado pikeminnow detected, four were detected moving into the Stirrup in both 2009 and 2010. Of the eight razorback suckers originally stocked into the river, one was detected entering the Stirrup in both 2008 and 2010.

In 2009, 31% of all tag detections were from bonytail, 40% were from Colorado pikeminnow, and 28% were from razorback sucker. All razorback sucker detected in the breach in 2009 had been stocked into the Stirrup floodplain; thus, movement of fish from the river to the floodplain was dominated by bonytail (44%) and Colorado pikeminnow (56%). In 2010, overall tag detections were distributed more evenly between bonytail (21%), Colorado pikeminnow (32.5%), and razorback sucker (46.5%), even after emigrating razorback suckers were removed (24.5%, 38%, and 37.5% respectively). In both years, however, far fewer individual bonytail and Colorado pikeminnow were detected, meaning that each individual of these species made many more movements within the breach than razorback suckers (Table 5).

Figures 5-7 show hourly counts of detections by species for 2009 and 2010. Based on the graphical results and passive detections in 2009 and 2010, most movement occurred overnight between dusk and dawn for both bonytail (66.7% and 58.3% for 2009 and 2010 respectively; Table 5) and razorback sucker (78.8% and 65.8% for 2009 and 2010 respectively; Table 5), though movement was more evenly distributed on a diel basis for Colorado pikeminnow (52.8% and 53.2% for 2009 and 2010 respectively; Table 5). This pattern was also more pronounced during 2009 than during 2010. No additional measurements were taken (e.g., depth of breach, temperature, turbidity, etc.) that might have clarified these patterns.

Statistical Analysis

Survival and Fidelity of Stocked Razorbacks – Our general model (see † in Table 6) fit the data well: $\chi^2 = 20.80$, p -value = 0.94. Relative importance weights (Table 7) provided strong evidence

that fidelity was a function of stocking cohort (relative weight cohort structure, 0.86). The relative importance weights also provided strong evidence that detection through the passive PIT-tag antennas was independent of stocking cohort (relative weight for constant structure, 0.76). Relative importance weights suggested a moderate difference in survival among stocking cohorts (relative weight cohort structure, 0.61) and a weak difference in recapture probability (relative weight cohort structure, 0.59).

Consistent with our predictions, though no differences were statistically significant based on the null hypothesis of a difference that is *exactly* equal to zero, model averaged probabilities of survival were higher for razorback suckers stocked at age-2 (S3) than razorbacks stocked as YOY (S5) (0.20 ± 0.12 (SE) vs. 0.13 ± 0.18 , respectively; Figure 8); probabilities of fidelity were lower for razorbacks stocked at age-2 (S3) than razorbacks stocked as YOY (S5) (0.87 ± 0.10 vs. 0.97 ± 0.07 , respectively; Figure 9); probabilities of recapture by electrofishing and fyke netting were slightly higher for razorbacks stocked at age-2 (S3) than razorbacks stocked as YOY (S5) (0.16 ± 0.10 vs. 0.14 ± 0.22 , respectively; Figure 10); and similarly, passive detection probabilities by both PIT-tag antennas was slightly higher for razorbacks stocked at age-2 (S3) than razorbacks stocked as YOY (S5) (0.78 ± 0.16 vs. 0.75 ± 0.32 , respectively, for antenna one and 0.91 ± 0.10 vs. 0.85 ± 0.34 , respectively, for antenna two; Figure 11).

Additional Observations

In 2009, native fish were not detected moving out of the floodplain until the shallowest depth reading exceeded 25 cm. The shallowest area was consistently located between the breach and the floodplain, but would not have been depth-limiting if the floodplain were full. Carp were visually observed moving between the breach and floodplain in water shallower than 25 cm. We detected two bonytails, the first on 15 May when minimum depth between the breach and

floodplain was 17 cm. One of these fish moved back and forth between the three antennas, only to return to the river 24 hours later. The other bonytail remained in the breach for approximately 13 hours (based on its last detection by the antennas closest to the floodplain) and likely entered the floodplain; we assume this did not occur until a depth of 25 cm was achieved. The first stocked razorback suckers were observed leaving the floodplain on 22 May. Green River flows at this time were 17,700 cfs (Figure 4; plus flows from Ashley and Brush creeks) and the shallowest part of the breach on this date exceeded 25 cm.

Also in 2009, flows were receding towards the end of May and anecdotal notes from daily activities at the floodplain (e.g., changing batteries) stated that flows were visibly receding, which led to sediment deposition and clearing of water within the breach. After this observation, only two native fish (both were Colorado pikeminnow) were recorded in the breach.

In 2010, flows peaked twice in the middle Green River. After coming up and connecting to the Stirrup on 1 June, river flows went down on 2 June. On 3 June, we observed clear water (ground beneath water was visible) > 25 cm deep, as the river was still high enough for connection but was declining, causing water to gradually flow out of the floodplain. Carp were observed moving within the breach on this day, but no tagged fish were detected moving through the breach. Flows came back up the following day, bringing with it increased turbidity (no longer able to observe ground beneath water). Tags were again detected by the MUX that day.

DISCUSSION

Survival estimates from our capture-mark-recapture analysis suggested that survival was higher for razorbacks stocked into the floodplain (0.13 or 0.20) than razorbacks stocked into the river as reported by Zelasko et al. (2011) (0.09¹). Our point estimates also suggest that the age-2 cohort (S3) may have survived at a higher rate than those stocked as YOY (S5) though this difference, like all others reported herein, was not statistically significant based on overlapping 95% confidence intervals. When interpreting these potential differences, it is important to note that cohorts three (S3) and five (S5) were stocked at different times of the year so were exposed to potentially different environmental stocking conditions. In the absence of environmental covariates, which we were unable to integrate into our models, we cannot conclude that the difference in 'age' between the two stockings, YOY vs. age-2, was the factor, in part or exclusively, responsible for the difference in our point estimates of survival. Nonetheless, the fact that age-2 fish were stocked first and in the summer, which would have exposed them to additional bird predation relative to the fall-stocked YOY cohort, suggests that this cohort survived at a higher rate due to their age.

From our estimate of survival of the age-2 (S3) stocking cohort (0.20), of the 952 fish stocked, 190 (952 x 0.2) with 95% confidence interval 76 – 305 survived through the first year and 38 of the 190 (190 x 0.2) with 95% confidence interval 7 – 98 survived for two years. Our estimates suggest that fewer fish, about 17 (95% CI 0 – 96), survived the full two years from the YOY (S5) cohort. Based on our point estimates (S3: 190, 38; S5: 17), 14.2% of the S3 fish moved out the first year (27 of 190 available) and 2.6% moved out the second year (1 of 38

¹ This is the first interval survival rate for average-sized razorback suckers (301.5 mm TL) reared by any method, when averaging across stocking year, season, and reach for each method.

available). Of the YOY (S5) cohort, 2.3% moved out the first year (3 of 130 available) and none of the remaining 17 fish available were detected moving out the second year.

A number of prior studies estimated survival rates of larval and juvenile razorback suckers in floodplain ponds. However, to our knowledge, only one study quantified survival rates over multiple winters. Osmundson and Kaeding (1989) stocked juvenile razorback suckers at 54.8 mm into Humphrey Pond in Colorado. They followed these fish over two years and recorded a 99.3% survival rate due in part to the absence of nonnative predators in the pond. In contrast, their experiments with Colorado pikeminnow in Humphrey Pond and other nearby ponds recorded very different results. Survival rates for this species ranged from 0% to 4.7%; potential reasons for low survival were cited as cannibalism, bird predation, disease, starvation, poor water quality, and high levels of H₂S. Winterkill was not observed to be a problem. Many of these mortality factors were observed or suspected in our study as well.

In the single-season studies, Papoulias and Minckley (1992) observed swim up to eight-week survival rates for razorback sucker of 67.4% to 89.8% when the mean number of zooplankton per liter was between 12.5 and 43.3 in pond habitats. Modde and Wick (1997) ran three to four week survival experiments in Old Charley Wash, Leota Bottoms, and Sheppard Bottoms. They found varying survival rates based on treatment type: 67% survival in Leota and Sheppard bottoms with much lower survival in Old Charley Wash due to disease and parasitism (0-10%), 0% in predation experiments with red shiner, and 33% in competition experiments with smaller red shiner. Brunson and Christopherson (2005), despite difficulties with maintaining integrity of study enclosures in Baeser floodplain, observed larval survival rates between 0% and 11% between June and August 2003 and 2% to 58% between April and July 2004. Christopherson et al. (2004) observed low rates of larval survival (e.g., <1%) between May and

June in the Stirrup in treatments with nonnative fish, but higher rates (e.g., near 10%) in control groups with no nonnatives present. And Modde and Haines (2005) observed low larval survival (e.g., <1% in both 2003 and 2004) in their studies at Johnson Bottoms, Leota-10, Old Charley Wash, Above Brennan, and Bonanza Bridge, which were rendered fishless by the drought in 2002.

Collectively, these single-season studies reveal highly variable survival rates that appear to be a function of life stage (larval swim up, etc) as well as environmental conditions associated with each study area. The results of Christopherson et al. (2004) are most applicable to our own study as this work was also conducted at the Stirrup. Rates observed by Christopherson et al. (2004), which deployed larval fish at the time of stocking were lower than our estimates which deployed age-2 and mature YOY (age-0) fish. Thus, despite many years between our study and theirs, different environmental conditions, crews and gear types, survival rates in the Stirrup were lowest for larval YOY fish followed by razorback sucker stocked as mature YOY and then as age-2 years (our study). This biologically intuitive and sensible result provides us with additional confidence that the differences in survival among our age-2 and YOY cohorts was in large part a function of age at stocking rather than environmental conditions when each cohort was stocked.

Estimates of fidelity from our capture-mark-recapture analysis were high for both stocking cohorts suggesting that fish had a high likelihood of remaining in the Stirrup even when given the chance to move out through the breach. Though the difference between fidelity estimates for the two stocking cohorts was not statistically significant based on overlapping 95% confidence intervals, the fidelity point estimate was lower for the age-2 stocking cohort than the age-YOY cohort suggesting that age may have contributed to the decision to move through the

breach and into the Green River. Nonetheless, we suggest caution in interpreting this difference. As with the other comparisons from our analysis, we cannot differentiate the effect of age at stocking from the effect of the environment experienced when the fish were stocked. Although both cohorts experienced the same environment starting in the fall of 2008, the difference between the environments when each cohort was stocked (summer vs. fall) may have affected the emigration process.

Higher recapture by electrofishing for the larger age-2 fish is consistent with electrofishing theory which predicts that the epileptic response responsible for immobilization is a function of fish length (Snyder 2003). But in general, recapture probabilities for both age-classes were low, which support previous observations that floodplain sampling for this species can be difficult (Williams, pers. comm.). Although passive detection was higher for the age-2 stocking cohort than those stocked at age-YOY, the difference was small, possibly due entirely to sampling error.

Floodplains provide better habitat (warmer water, more food, etc.) for fish spawned earlier in the season than less productive mainstem habitats (Modde 1996; Muth et al. 1998; Modde et al. 2001; Bestgen et al. 2002; Bestgen 2008). However, increased productivity also makes floodplains less likely to maintain high overwinter survival rates for razorback sucker as low dissolved oxygen conditions can occur due to decomposition of submerged vegetation and phytoplankton (Birchell et al. 2002). Low oxygen overwinter was an apparent problem in two of the three winters of this project. However, the winter kill between 2007 and 2008 appeared more severe, based on the larger (though uncounted) number of dead individuals observed after ice-off. Had our pumping in fall 2007 been more effective at adding fresh water to the floodplain, we suspect that the observed winterkill would have been far less severe. And due to the floodplain-

riverine connection in 2009, we did not feel it was necessary to pump water into the floodplain in fall 2009, though in hindsight, pumping may have reduced that year's winterkill as well.

In addition to problems with survival overwinter, we also observed predation by piscivorous birds (white pelicans *Pelecanus erythrorhynchos*, and double-crested cormorants *Phalacrocorax auritus*) which likely contributed to problems with summer survival. We could not determine species consumed, only that birds were consuming fish. Other ponds near the Stirrup (e.g., the Ouray National Wildlife Refuge hatchery ponds) have also experienced high rates of bird predation. In addition, Schramm et al. (1987) observed great blue herons (*Ardea herodias*), double-crested cormorants, and white pelicans (all of which are found in northeastern Utah during spring migration and potentially throughout the summer) consuming 340, 247, and 416 g of fish per day, respectively. To put these numbers into context, razorback suckers stocked into the Stirrup in 2007 averaged 217 g. A great blue heron can consume about 1.5 stocked razorback suckers in one day, a cormorant about one fish per day, and a pelican about two fish per day. On any given visit to the Stirrup, we observed at least one great blue heron, two to three cormorants, and flocks of white pelicans with up to 30 birds. Essentially, predatory birds at the Stirrup could consume approximately 62 stocked razorback suckers if they focused solely on this species, and decimate an entire cohort of stocked razorback suckers in less than one month.

Biologists with the USFWS Vernal Colorado River Fisheries Project observed high survival rates of stocked razorback sucker in the Baeser Bend floodplain through winter (e.g., 60% for fingerlings and higher for adult fish), but much lower rates of survival over the summers of 2009 and 2010 (A. Webber pers. comm.). While researchers could not identify the likely cause of differential survival, their hypotheses included bird predation, water quality problems, and predation by nonnative cyprinids (Webber 2009; Webber 2010). Additionally, before placing

netting over their grow-out ponds, biologists at the Ouray National Fish Hatchery regularly observed summer survival rates as low as 10%, which they attributed, through observation, to bird predation. Note that these ponds were deeper than the Stirrup and Baeser Bend (8-10 ft deep; M. Fry, pers. comm.). The stocking goal identified in the Integrated Stocking Plan (Nesler et al. 2003) was met for the first time in 2006 after Ouray biologists placed nets over ponds, suggesting bird predation may have been the most significant mortality factor.

Low survival and detection probabilities of razorback suckers were constraints that limited our data analysis options as these processes resulted in very few detections (passive or active). Inconsistency in stockings including variation in the age of fish among stockings and environmental conditions at the time of each stocking, limited our ability to make inferences from the data. The study design also lacked replication and randomization. Interpretation and analysis of results would have been greatly improved in the absence of these shortfalls, though low survival may have been unavoidable given the age classes of fish used in the study. With these shortfalls in mind, we suggest caution when comparing our estimates of survival or fidelity to other floodplains. And for the Stirrup floodplain, our estimates may only apply to the years that the study was conducted. Additional work would be necessary to know how well our results represent survival and fidelity of stocked razorbacks suckers in the Stirrup floodplain and other floodplains on the Green River.

We recommend that any future study on the value of floodplains to young razorback suckers consider one of the floodplain sites identified for nursery purposes in the Interim Green River Subbasin Floodplain Management Plan (Modde 2007). These floodplains include Johnson Bottom, Leota, Thunder Ranch, and Stewart Lake. Of these, Stewart Lake can be managed as a flow-through wetland, meaning entrainment of larval fish would be high (Hedrick et al. 2009)

and results observed there may be pertinent to wild-spawned razorback sucker as well. Stewart Lake also has an inlet and outlet gate, meaning the floodplain could be managed to maintain a depth of 8-12 ft. The Stewart Lake floodplain is much larger than the Stirrup, 570 vs. 28 acres (Valdez and Nelson 2004), and we speculate that the spatial extent and depth of the floodplain may contribute positively to the survival of razorbacks and other entrained native fishes. As floodplains increase in spatial extent and depth, entrained larval and juvenile fish have more area to avoid piscivory and depth to avoid avian predation. Greater depth and extent may also reduce risks of fish die-offs from overwinter dissolved oxygen deficiencies. Stewart Lake is not without its problems, however, as it is currently being managed to reduce soil selenium levels. This management entails filling and draining at least once each year to flush and dry soils (M. Hanberg, pers. comm.). Managers have identified the potential for use of the floodplain for research on razorback suckers pending a further declining trend in soil selenium levels after the 2011 water year.

Based on passive detections by our PIT-tag antennas of fish PIT-tagged elsewhere (i.e., not stocked into the Stirrup), Colorado pikeminnow and bonytail were always the first and second tagged fish species detected. They were also more likely than razorback suckers to enter the breach even before they could access the floodplain. Colorado pikeminnow were more likely to enter the breach (from the river) than either bonytail or razorback sucker regardless of time of day. Bonytail and razorback sucker were more likely to enter the breach during times with lower light levels, suggesting that they may use lower light levels as cover. As noted in previous flow recommendation studies (Modde and Keleher 2003), our anecdotal observations of fish moving from the river into the breach suggested that depth also played a role in this process. We attribute the lack of movement into the breach from the river in both 2009 and 2010 to a lack of turbidity.

Perhaps turbidity, like depth, functions as cover for fish moving into the breach from the river. During the evening of 2 June 2010, the day when flows and turbidity increased, fish were again detected moving through the breach.

Our study confirmed the use of a floodplain habitat by all endangered species present in the middle Green River except humpback chub. We also confirmed floodplain use by roundtail chub, a species listed as sensitive by the State of Utah (UDWR 2006). Further information on each of the fish moving into the floodplain from the river, including when and where they were originally tagged can be found in the annual reports for this project (Hedrick 2008; Hedrick 2009; Hedrick 2010). We suspect that Colorado pikeminnow may be using floodplains for feeding opportunities as their movements into and out of the floodplain were regular throughout the course of a day. Bonytail were always the first species to be detected at the floodplain, and while we cannot surmise their intention, hypotheses include utilization of a more productive habitat, a desire to use the floodplain for spawning habitat as observed in the ponds at Wahweap (Q. Bradwisch, pers. comm.), or retreat from high mainstem flows to conserve energy. Razorback sucker originally stocked into other floodplains or into the river entered the Stirrup floodplain as well. The purpose of these movements is also unclear, but may include utilization of more productive habitats, retreat from high mainstem flows, or spawning as noted in Lake Mead and the Cibola ponds in the lower Colorado River Basin (Mueller et al. 2005; Albrecht et al. 2008).

CONCLUSIONS

- Due to a combination of adequate overwinter precipitation and releases from Flaming Gorge Dam by the Bureau of Reclamation that were conducive to river-floodplain connections, the Stirrup breach flooded in all years of the study.
- Stationary PIT-tag reader technology was effective at monitoring movement of tagged fish into and out of floodplain habitat.
- Traditional sampling techniques (e.g., electrofishing, trammel netting, and fyke-netting) within the floodplain resulted in no recaptures of fin clipped razorbacks. Thus, floodplain population estimates could not be calculated using this method. This sampling, however, did contribute recaptures of PIT-tagged razorbacks which were critical for informing the survival and fidelity analysis performed in program SURVIV.
- Numbers of stocked razorback sucker moving out of the floodplain were lower than we expected given that nearly 8,000 fish were stocked; analysis with program SURVIV suggested that fidelity in two groups of stocked fish was high for the relatively few fish that survived.
- Adult native fish moved at a higher rate between the river and floodplain at flows of 17,700 cfs than flows of 15,000 cfs. Based on our observations, until the floodplain was full, the depth of the water flowing through the breach may have been too shallow to accommodate movement of adult fish. If the Stirrup was full upon initial connection, a Green River flow of 15,000 cfs may have been adequate for movement.
- Constant, annual survival rates for YOY and age-2 razorback suckers stocked into the Stirrup in 2008 (0.13 and 0.20, respectively) were higher than the mean survival rate

(0.09) for 301.5-mm-TL razorback sucker stocked directly into Basin rivers from 2004-2007.

- Of those razorback suckers that survived and emigrated, most moved out after just one winter in the Stirrup.
- Based on detections of fish moving from the river to the Stirrup floodplain, Colorado pikeminnow and bonytail made more movements between the river and the floodplain than adult razorback suckers.
- Bonytail and razorback sucker movements through the passive antenna array were more likely to occur during hours of low-light.
- All endangered fish species found in the middle Green River, excluding humpback chub which have rarely been detected in this reach, were recorded entering and/or exiting the Stirrup. These observations demonstrate that adult Colorado pikeminnow, bonytail, razorback sucker (regardless of stocking location), and roundtail chub used available floodplain habitat during peak flows.
- According to observations from this study, it appears that depth > 25 cm and high turbidity were supportive of native fish movement between the river and the Stirrup.
- While the Stirrup floodplain remains useful for research into endangered fish life histories, other floodplain locations may be more suitable for long-term management activities intended to enhance natural recruitment.

RECOMMENDATIONS

- Floodplains with stocked fish should be managed to prevent extensive bird predation. Management could entail use of mesh coverings, noise makers or other dispersant techniques. Besides mesh coverings, other forms of cover could be utilized, though the Program should be careful to not add vegetation that could further decrease dissolved oxygen levels during winter.
- Because survival results included herein are only applicable to the Stirrup and a larger floodplain may provide better survival for stocked razorback suckers, we recommend the Program implement a similar study (see next recommendation) at the Stewart Lake floodplain or other large floodplain habitat in the middle Green River.
- Keeping in mind that the study presented herein was not intended to provide information on survival, any future study on the fidelity and survival of stocked razorback suckers in floodplains should receive a peer-review of the study design prior to implementing the work. The peer-review should be both internal (Recovery Program) and external and include a biometrician with a background in fisheries.
- During any future studies on fish movement or survival related to floodplain use, additional environmental variables within the breach such as depth, temperature, turbidity, etc. should be recorded during connection to better understand factors affecting a fish's decision to move through the breach.
- Routine and regular maintenance of floodplain habitat may be required in floodplains with stocked fish. This recommendation entails maximizing survival probability of stocked fish through pumping (or other methods) to increase dissolved oxygen levels overwinter, dredging of sediment or installation of inlet and/or outlet gates to increase

overall depth in floodplains and could also ensure access to floodplains during high flows via dredging of breaches to their original elevation. The specific action would be dependent upon the goal of the project or study and the needs of the specific floodplain.

- If the Stirrup or other floodplain is stocked with endangered fish, a PIT tag reader should be deployed to ascertain movement out of the floodplain.
- Flow requests for floodplain movement studies should be greater than simple floodplain to river “connection” and must take into account the current status of the floodplain (e.g., whether it is full or not, river-floodplain connection elevation, etc.).
- Stationary PIT-tag technology could be used to increase knowledge and understanding of the life history requirements of bonytail (and other species utilizing the floodplain) as they pertain to floodplain habitats. A study at Stewart Lake, where bonytails have been known to reside during the summer (Utah Division of Wildlife Resources, Vernal, unpublished data), should also be able to provide information on this species’ habits, especially if coupled with monitoring and habitat sampling.

LITERATURE CITED

- Albrecht, B., T. Sanderson, and P.B. Holden. 2008. Razorback sucker studies in Lake Mead, Nevada and Arizona: 1996-2007 Comprehensive Report. Submitted to the Bureau of Reclamation and Southern Nevada Water Authority, by BIO-WEST, Inc., Logan, UT. PR 1093-2.
- Bestgen, K. R. 2008. Effects of water temperature on growth of razorback sucker larvae. *Western North American Naturalist* 68(1):15-20.
- Bestgen, K.R., G. B. Haines, R. Brunson, T. Chart, M. Trammell, R. T. Muth, G. Birchell, K. Christopherson, and J. M. Bundy. 2002. Status of wild razorback sucker in the Green River Basin, Utah and Colorado, determined from basin-wide monitoring and other sampling programs. Final report to the Upper Colorado River Recovery Implementation Program, Project Number 22D.
- Bestgen, K.R, G.B. Haines, and A.A. Hill. 2011. Synthesis of floodplain wetland information: Timing of razorback sucker reproduction in the Green River, Utah, related to stream flow, water temperature, and floodplain wetland availability. Final report to the Colorado River Recovery Implementation Program, project nos. 22F and FR-FP Synthesis.
- Birchell, G.J. and K.D. Christopherson. 2004. Survival, growth and recruitment of larval and juvenile razorback suckers (*Xyrauchen texanus*) introduced into floodplain depressions of the Green River, Utah. Final report to the Upper Colorado River Endangered Fish Recovery Program. Utah Division of Wildlife Resources, Vernal, Utah.
- Birchell, G.J., K.D. Christopherson, C. Crosby, T.A. Crowl, J. Gourley, M. Townsend, S. Goeking, T. Modde, M. Fuller, and P. Nelson. 2002. The Levee Removal Project: Assessment of floodplain habitat restoration in the middle Green River. Final report completed for the

Upper Colorado River Endangered Fish Recovery Program. Publication 02-17, Utah Division of Wildlife Resources, Salt Lake City, Utah.

Bradwisch, Q. Wahweap Hatchery Manager, multiple in-person and telephone communications between April 2006 and 2008.

Brunson, R.E. and K.D. Christopherson. 2005. Larval razorback sucker and bonytail survival and growth in the presence of nonnative fish in the Baeser floodplain wetland of the middle Green River. Final report completed for the Upper Colorado River Endangered Fish Recovery Program. Publication 05-26, Utah Division of Wildlife Resources, Vernal, Utah.

Burnham, K. P., and D. R. Anderson. 2002. Model Selection and Multi-model Inference: A practical information-theoretic approach, 2nd ed. Springer, New York, NY, 488 pp.

Christopherson, K.D., G.J. Birchell, and T. Modde. 2004. Larval razorback sucker and bonytail survival and growth in the presence of nonnative fish in the Stirrup Floodplain. Final report to the Upper Colorado River Endangered Fish Recovery Program. Utah Division of Wildlife Resources, Vernal, Utah.

Downs, C.C., D. Horan, E. Morgan-Harris, and R. Jakubowski. 2006. Spawning demographics and juvenile dispersal of an adfluvial bull trout population in Trestle Creek, Idaho. *North American Journal of Fisheries Management* 26(1):190-200.

FLO Engineering, Inc. 1997. Green River floodplain habitat restoration investigation – Bureau of Land Management sites and Ouray National Wildlife Refuge sites near Vernal, Utah. Final Report of FLO Engineering, Inc., to Upper Colorado River Endangered Fish Recovery Program, Denver, Colorado.

Fry, M. Hatchery Technician, Ouray National Fish Hatchery. Telephone communication, December 2010.

- Green River Study Plan ad hoc committee. 2007. Study plan for the implementation and evaluation of flow and temperature recommendations for endangered fishes in the Green River downstream of Flaming Gorge Dam. Coordinated by Upper Colorado River Endangered Fish Recovery Program. February 8, 2007. 84 pp.
- Hanberg, M. Habitat Program Manager, Utah Division of Wildlife Resources, Vernal.
- Hawkins, J.A. and T.P. Nesler. 1991. Nonnative fishes of the Upper Colorado River Basin: an issue paper. Final Report of Colorado State University Larval Fish Laboratory, Department of Fish, Wildlife, and Conservation Biology to Upper Colorado River Endangered Fish Recovery Implementation Program, Denver, Colorado.
- Hedrick, T. 2008. Upper Colorado River Endangered Fish Recovery Program, annual report project C-6/RZ-RECR RBS Recruitment, <http://coloradoriverrecovery.org/documents-publications/work-plan-documents/arpts/2008/hab/RZ-RECRrev.pdf>.
- Hedrick, T. 2009. Upper Colorado River Endangered Fish Recovery Program, annual report project C-6/RZ-RECR RBS Recruitment, <http://coloradoriverrecovery.org/documents-publications/work-plan-documents/arpts/2009/hab/C6-RZ-RECR.pdf>.
- Hedrick, T. 2010. Upper Colorado River Endangered Fish Recovery Program, annual report project C-6/RZ-RECR RBS Recruitment, <http://coloradoriverrecovery.org/documents-publications/work-plan-documents/arpts/2010/hab/RZ-RECR.pdf>.
- Hedrick, T.N., K.B. Bestgen, and K.D. Christopherson. 2009. Entrainment of semi-buoyant beads and razorback sucker, *Xyrauchen texanus*, larvae into flood-plain wetlands of the middle Green River, Utah. Final Report to the Upper Colorado River Basin Endangered Fish Recovery Program, Project Number: C-6/RZ-ENTR, Utah Publication Number 09-05, Larval Fish Laboratory Contribution 153, Salt Lake City, UT. 93pp.

- Hewitt, D.A., E.C. Janney, B.S. Hayes, and R.S. Shively. 2010. Improving inferences from fisheries capture-recapture studies through remote detection of PIT-tags. *Fisheries* 35(5):217-231.
- Lentsch, L., T. Crowl, P. Nelson, and T. Modde. 1996. Levee removal strategic plan. Utah Division of Wildlife Resources, Salt Lake City, UT. 21 pp.
- Minckley, W.L. and J.E. Deacon. 1968. Southwestern fishes and the enigma of 'endangered species': man's invasion of deserts creates problems for native animals, especially freshwater fishes. *Science* 159:1424-1432.
- Minckley, W.L. 1991. Native fishes of the Grand Canyon region: an obituary? Pages 124-177 in National Research Council, Committee to Review the Glen Canyon Environmental Studies, Water Science and Technology Board. *Colorado River Ecology and Dam Management*. National Academy Press, Washington D.C.
- Modde, T., K.P. Burnham, and E.J. Wick. 1996. Population status of the razorback sucker in the middle Green River. *Conservation Biology* 10:110-119.
- Modde, T., and E. J Wick. 1997. Investigations of razorback sucker distribution, movements, and habitats used during spring in the Green River, Utah. Final report to the Upper Colorado River Basin Endangered Fish Recovery and Implementation Program, project no. 49.
- Modde, T., R.T. Muth, and G.B. Haines. 2001. Floodplain wetland suitability, access and use by juvenile razorback sucker in the middle Green River, Utah. *Transactions of the American Fisheries Society* 130:1095-1105.
- Modde, T. and C. Keleher. 2003. Flow recommendations for the Duchesne River with a synopsis of information regarding endangered fish. Draft Final Report Submitted to the Upper Colorado River Basin Endangered Fishes Recovery Implementation Program, Project No. 84-01.

Modde, T., and G.B. Haines. 2005. Survival and growth of stocked razorback sucker and bonytail in multiple floodplain wetlands of the middle Green River under reset conditions. Final report to the Upper Colorado River Endangered Fish Recovery and Implementation Program, project no. C-6-bt/rz.

Modde, T. 2007. Interim Green River Subbasin Floodplain Management Plan. 11pp.

Mueller, G.A., J. Carpenter, and P.C. Marsh. 2005. Cibola High Levee Annual Report 2004. U.S. Geological Survey, Biological Resources Discipline, open file report 2005-1975, 46pp.

Muth, R.T., G.B. Haines, S.M. Meismer, E.J. Wick, T.E. Chart, D.E. Snyder, and J.M. Bundy. 1998. Reproduction and early life history of razorback sucker in the Green River, Utah and Colorado, 1992 – 1996. Final Report submitted to the Recovery Implementation Program for Endangered Fish Species in the Upper Colorado River Basin. U.S. Fish and Wildlife Service, Denver, CO. 62 pp.

Muth, R.T., L.W. Crist, K.E. LaGory, J.W. Hayse, K.R. Bestgen, T.P. Ryan, J.K. Lyons, and R.A. Valdez. 2000. Flow and temperature recommendations for endangered fishes in the Green River downstream of Flaming Gorge Dam. Final Report FG-53 to the Upper Colorado River Endangered Fish Recovery Program. U. S. Fish and Wildlife Service, Denver, Colorado.

Nesler, T.P., K. Christopherson, J.M. Hudson, C.W. McAda, F. Pfeifer, and T.E. Czapla. 2003. An Integrated Stocking Plan for Razorback Sucker, Bonytail, and Colorado pikeminnow for the Upper Colorado River Endangered Fish Recovery Program. Addendum to State Stocking Plans.

Osmundson, D.B., and L. Kaeding. 1989. Colorado squawfish and razorback sucker grow-out pond studies as part of conservation measures for the Green Mountain and Ruedi Reservoir water sales. Final report submitted to the U.S. Fish and Wildlife Service and U.S. Bureau of Reclamation.

Papoulias, D. and W.L. Minckley. 1992. Effects of food availability on survival and growth of larval razorback suckers in ponds. *Transactions of the American Fisheries Society* 121:340-353.

Schramm, H.L., M.W. Collopy, and E. A. Okrah. 1987. Potential problems of bird predation for fish culture in Florida. *Progressive Fish Culturist* 49:44-49.

Sigler, W.F. and J.W. Sigler. 1996. *Fishes of Utah: A natural history*. University of Utah Press, Salt Lake City, 375pp.

Snyder, D. E. 2003. Electrofishing and its harmful effects on fish, Information and Technology Report USGS/BRD/ITR--2003-0002: U.S. Government Printing Office, Denver, CO, 149 pp.

Tyus, H. M. 1987. Distribution, reproduction, and habitat use of the razorback sucker in the Green River, Utah, 1979–1986. *Transactions of the American Fisheries Society* 116:111–116.

Tyus, H. M., and C. A. Karp. 1990. Spawning and movements of razorback sucker, *Xyrauchen texanus*, in the Green River basin of Colorado and Utah. *Southwestern Naturalist* 35:427–433.

Tyus, H.M. and J.F. Saunders, III. 1996. Nonnative fishes in natural ecosystems and a strategic plan for control of nonnatives in the Upper Colorado River Basin. Draft Report. Center for Limnology, University of Colorado, Boulder, Colorado. For the Recovery Implementation Program for Endangered fish Species in the Upper Colorado River Basin. Cooperative Agreement No. 14-48-0006-95-923, U.S. Fish and Wildlife Service, Denver, Colorado.

Tyus, H.M. and J.F. Saunders, III. 2000. Nonnative fish control and endangered fish recovery: lessons from the Colorado River. *Fisheries* 25(9):17–24.

U.S. Fish and Wildlife Service. 2002a. Bonytail (*Gila elegans*) Recovery Goals: amendment and supplement to the Bonytail Chub Recovery Plan. U.S. Fish and Wildlife Service, Mountain-Prairie Region (6), Denver, Colorado.

U.S. Fish and Wildlife Service. 2002b. Colorado pikeminnow (*Ptychocheilus lucius*) Recovery Goals: amendment and supplement to the Colorado Squawfish Recovery Plan. U.S. Fish and Wildlife Service, Mountain-Prairie Region (6), Denver, Colorado.

U.S. Fish and Wildlife Service. 2002c. Humpback chub (*Gila cypha*) Recovery Goals: amendment and supplement to the Humpback Chub Recovery Plan. U.S. Fish and Wildlife Service, Mountain-Prairie Region (6), Denver, Colorado.

U.S. Fish and Wildlife Service. 2002d. Razorback sucker (*Xyrauchen texanus*) Recovery Goals: amendment and supplement to the Razorback Sucker Recovery Plan. U.S. Fish and Wildlife Service, Mountain-Prairie Region (6), Denver, Colorado.

U.S. Fish and Wildlife Service. 2007. Unpublished PowerPoint presentation showing information on Green River flows and connection to floodplains at various flows.

U.S. Fish and Wildlife Service. Annual larval razorback sampling, middle Green River. Vernal Colorado River Fisheries Project, unpublished data.

U.S. Fish and Wildlife Service. Upper Colorado River Endangered Fish Recovery Program PIT tag database. Unpublished data.

Utah Division of Wildlife Resources. 2006. Conservation and management plan for three fish species in Utah; Addressing needs for roundtail chub, bluehead sucker, and flannelmouth sucker. Publication No. 06-17. Salt Lake City, UT. 82 p.

Utah Division of Wildlife Resources. Unpublished data collected on tagged fish leaving the Stewart Lake floodplain 2008. Northeastern Regional Office, Vernal.

Valdez, R.A. and P. Nelson. 2004. Green River Subbasin floodplain management plan. Final report of the Upper Colorado River Endangered Fish Recovery Program, Denver, CO.

Webber, A. Fisheries Biologist, USFWS Vernal Colorado River Fisheries Project, email communication, December 2010.

- Webber, A. 2010. Upper Colorado River Endangered Fish Recovery Program, annual report project C-6/Baerer, <http://www.coloradoriverrecovery.org/documents-publications/work-plan-documents/arpts/2010/prop/C6Baerer.pdf>.
- Webber, A. 2009. Upper Colorado River Endangered Fish Recovery Program, annual report project C-6/Baerer, <http://coloradoriverrecovery.org/documents-publications/work-plan-documents/arpts/2009/prop/C6-Baerer.pdf>.
- White, G. C., and K. P. Burnham. 1999. Program MARK: survival estimation from populations of marked animals. *Bird Study* 46 Supplement:120-138.
- White, G.C.. 1992. PC SURVIV Users Manual. Dept. of Fishery and Wildlife Biology, Colorado State University, Fort Collins, CO.
- Williams, B., Native fish biologist, Utah Division of Wildlife Resources, multiple in-person interviews, 2008-2009.
- Wydoski, R.S. and E.J. Wick. 1998. Ecological value of floodplain habitats to razorback suckers in the Upper Colorado River Basin. Final Report submitted to the Recovery Implementation Program for Endangered Fish Species in the Upper Colorado River Basin. U.S. Fish and Wildlife Service, Denver, CO. 55 pp.
- Zelasko, K.A., K.R. Bestgen, and G.C. White. 2011. Survival rate estimation of hatchery-reared razorback suckers *Xyrauchen texanus* stocked in the Upper Colorado River Basin, Utah and Colorado, 2004-2007. Final Report of Colorado State University Larval Fish Laboratory, Department of Fish, Wildlife, and Conservation Biology to Upper Colorado River Endangered Fish Recovery Implementation Program, Denver, Colorado.

Table 1 – Water quality measurements (including temperature, pH, specific conductivity, and dissolved oxygen) recorded at the Stirrup floodplain throughout the project (2007-2010).

		Temp [°C]	pH	Specific Conductivity [µS/cm]	DO [mg/l]
2007	June	-	-	-	< 2.0
2008	February	-	-	-	< 1.0
	August	21.42	-	-	10.72
2009	August	25.3 (25.18 - 25.51)	10.39 (10.35 - 10.42)	856.5 (856 - 857)	6.0 (5.45 - 6.28)
	November	5.02 (4.97 - 5.11)	10.5 (10.29 - 10.61)	539.5 (537 - 543)	Probe malfunction
	December	3.3 (3.04 - 3.57)	11.5 (9.02 - 13.9)	594	3.7 (2.19 - 5.2)
2010	January	2.69 (2.52 - 2.86)	6.67 (6.31 - 7.03)	644	0.46 (0.38 - 0.54)
	March	1.58 (0.43 - 2.73)	7.68 (7.49 - 7.87)	685.5 (685 - 686)	1.21 (0.55 - 1.87)
	April	12.61 (12.58 - 12.63)	7.61 (7.19 - 8.02)	611 (578 - 644)	3.7 (1.78 - 5.61)

Table 2 - Number, stocking date, age-class, age at stocking, and average length at stocking for all razorback suckers stocked into the Stirrup floodplain 2007-2009.

Number stocked	Stocking date	Age-class	Age at stocking	Average Length (mm)
1632	25-Jun-07	2005	2	274
1633	16-Oct-07	2006	1	278
952	1-Jul-08	2006	2	306
1047	23-Jul-08	2007	1	203
1000	9-Oct-08	2008	YOY	130
1727	10-Jun-09	2008	1	295

Table 3 – Numbers, average total length, length range, catch-per-effort, gear type, and number of razorback sucker recaptured during active sampling efforts at the Stirrup floodplain, 2007-2010.

Sampling Occasion	Number RZ captured	Average TL (mm)	Length range (mm)	Catch per Effort	Gear Type	No. RZ recaptured during active effort
2007	84	313.80	264 - 359	24.7 / net night	Fyke nets	0
Apr-08	0	-	-	-	Fyke nets	0
Apr-09	17	292.50	117 - 349	8.3 / hour	Electrofishing	0
Apr-09	29	244.10	113 - 376	1.9 / net night	Fyke nets	0
Jun-09	10	334.10	190 - 380	6.2 / hour	Electrofishing	0
Apr-10	11	336.30	294 - 365	1.4 / net night	Trammel net	0
Jun-10	0	-	-	-	Electrofishing	0

Table 4 – Razorback sucker movements by year spawned, year stocked, and year of emigration from floodplain.

Yr spawned	Yr stocked	Year of Emigration		
		2008	2009	2010
2005	2007	0	0	0
2006	2007	1	0	0
	2008	0	27	1
2007	2008	0	0	0
2008	2008	0	3	0
	2009	0	0	15

Table 5 – Number of bonytail (BT), Colorado pikeminnow (CS), and razorback sucker (RZ) movements detected in 2009 and 2010, and the percent of movement detected during the night vs. during the day by species each year. Information from 2008 is not included (see text for details).

	BT		CS		RZ	
	2009	2010	2009	2010	2009	2010
Number of movements	126	72	159	109	113	161
Number of overnight movements	84	42	84	58	89	106
Number of fish	5	5	4	6	32	31
Average Number of movements / fish	25.2	14.4	39.8	18.2	3.5	5.2
Percent of movement overnight	66.7%	58.3%	52.8%	53.2%	78.8%	65.8%

Table 6 – The suite of 16 models fitted to the razorback capture-mark-recapture data from the Stirrup Floodplain and breach: S, survival; F, fidelity to the floodplain; p(e), recapture probability by active sampling; p(a), passive detection by the PIT-tag antennas; AIC, Akaike's Information Criterion; ML, model likelihood; AIC weight; np, number of model parameters; logL, log-likelihood; df, degrees of freedom. The third and fifth stocking occasions were included in the analysis, these fish were stocked at age-2 and age-YOY, respectively. See text for more details.

Model Parameters and Structure				Fit Statistics								
S	F	p(e)	p(a)	AIC	Δ AIC	ML	AIC ω	np	logL	df	χ^2	p-value
constant	stocking	stocking	constant	67.4147	0.0000	1.0000	0.2635	7	-26.71	35	22.62	0.95
stocking	stocking	constant	constant	67.4527	0.0381	0.9812	0.2586	7	-26.73	35	22.66	0.95
stocking	stocking	stocking	constant	69.3322	1.9176	0.3834	0.1010	8	-26.67	34	22.54	0.93
constant	stocking	stocking	stocking	69.6746	2.2599	0.3231	0.0851	9	-25.84	33	20.88	0.95
stocking	stocking	constant	stocking	69.7126	2.2979	0.3170	0.0835	9	-25.86	33	20.92	0.95
stocking	constant	stocking	constant	69.8934	2.4788	0.2896	0.0763	7	-27.95	35	25.10	0.89
†stocking	stocking	stocking	stocking	71.5921	4.1774	0.1238	0.0326	10	-25.80	32	20.80	0.94
constant	stocking	constant	constant	71.8075	4.3928	0.1112	0.0293	6	-29.90	36	29.01	0.79
stocking	constant	constant	constant	71.9672	4.5525	0.1027	0.0271	6	-29.98	36	29.17	0.78
stocking	constant	stocking	stocking	72.1533	4.7386	0.0935	0.0247	9	-27.08	33	23.36	0.89
constant	stocking	constant	stocking	74.0674	6.6527	0.0359	0.0095	8	-29.03	34	27.27	0.79
stocking	constant	constant	stocking	74.2271	6.8124	0.0332	0.0087	8	-29.11	34	27.43	0.78
constant	constant	stocking	constant	91.4729	24.0582	0.0000	0.0000	6	-39.74	36	48.68	0.08
constant	constant	stocking	stocking	93.7328	26.3181	0.0000	0.0000	8	-38.87	34	46.94	0.07
constant	constant	constant	constant	93.7826	26.3680	0.0000	0.0000	5	-41.89	37	52.99	0.04
constant	constant	constant	stocking	96.0425	28.6278	0.0000	0.0000	7	-41.02	35	51.25	0.04

†The general model - all parameters are a function of stocking occasion.

Table 7 – Relative importance weights for constant (no difference among stocking occasions) parameters and parameters varying as a function of stocking occasion: S, survival; F, fidelity to the floodplain; p(e), recapture probability by active sampling; p(a), passive detection by the PIT-tag antennas. The third and fifth stocking occasions were included in the analysis; these fish were stocked at age-2 and age-YOY, respectively. See text for more details.

	S	F	p(e)	p(a)
constant	0.3875	0.1368	0.4167	0.7558
stocking	0.6125	0.8632	0.5833	0.2442



Figure 1 – Aerial view of the Stirrup floodplain. A red circle denotes the downstream breach for this floodplain. Flow in the river is moving left to right.

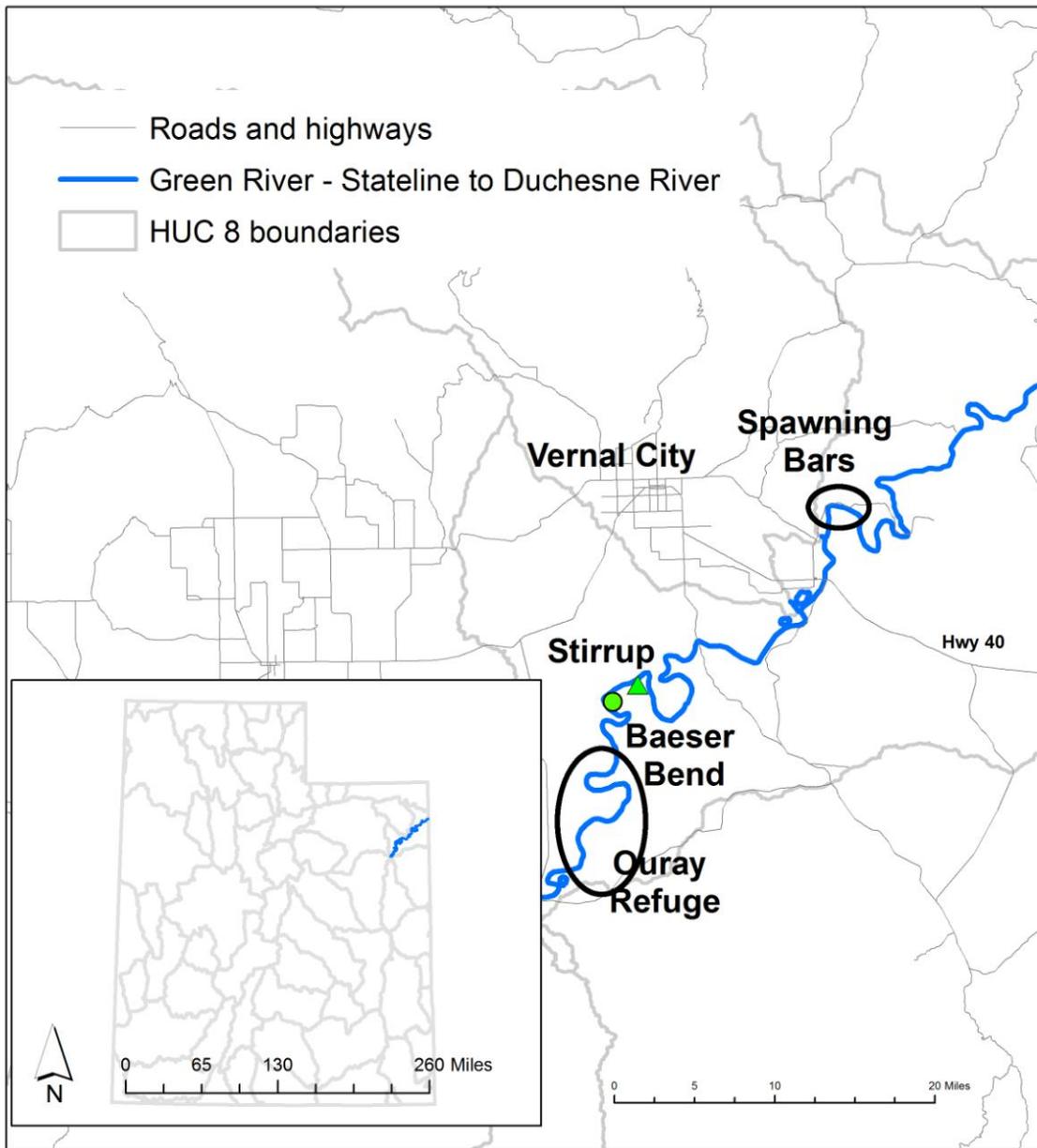


Figure 2 – Location of the Stirrup floodplain along the middle Green River within the state of Utah. The green triangle denotes the location of the Stirrup floodplain and the green circle denotes the location of Baeser Bend. The middle Green River spawning bars and the Ouray refuge are circled on the map.



Figure 3 – Antennas spanning the Stirrup breach. The photograph illustrates the width of the breach relative to the width of the antenna.

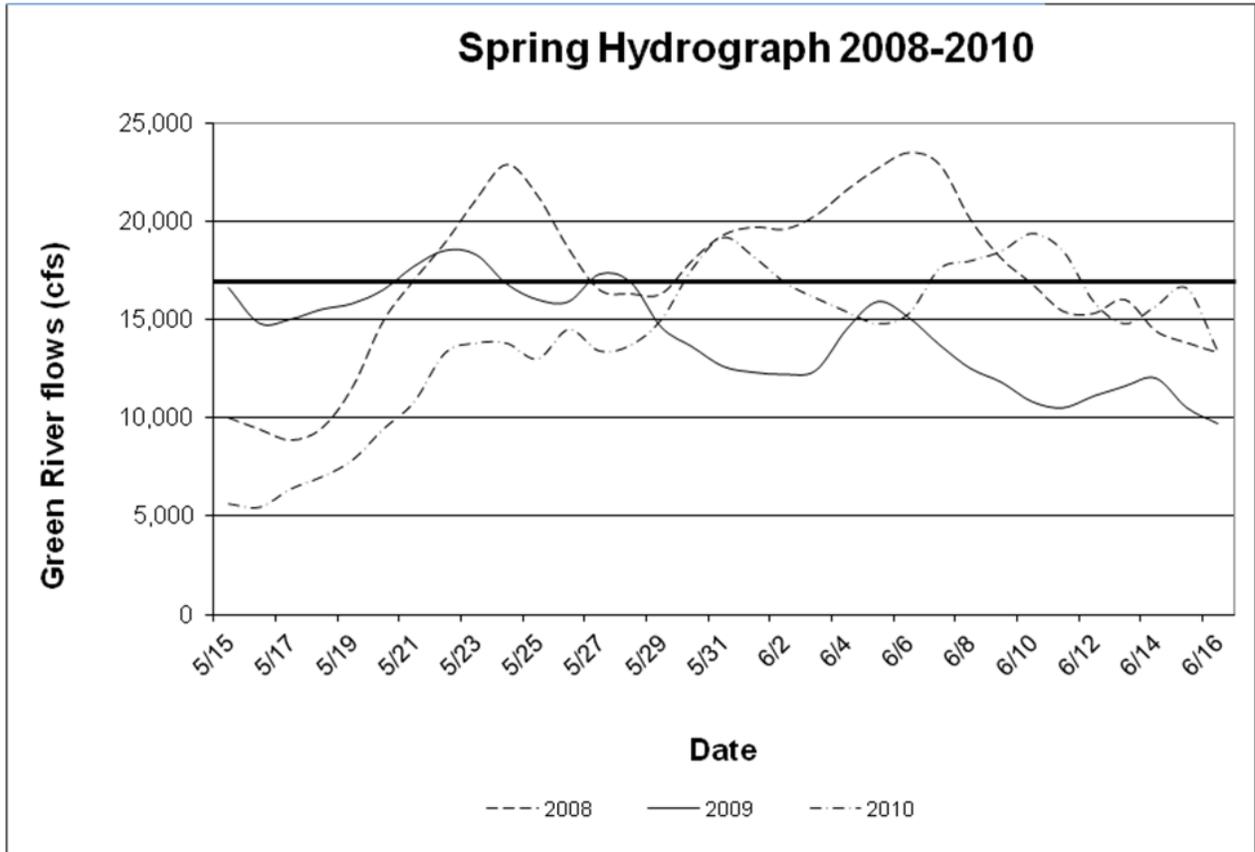


Figure 4 – Green River flows during the study period in each project year. Data is taken from the USGS water data site for the Green River gage at Jensen (gage #09261000). The gray line at 17,500 cfs represents the determined “connection flow” in all three years. Note that these occurred on different dates each year (Brush and Ashley creek flows not considered) and also that Jensen gage flows take a full day to reach the Stirrup. Connection dates were 20 or 21 May 2008 (estimated this year, not measured or confirmed through fish detections), 22 May 2009, and 31 May 2010. Note that flow on 22 May 2009 does not correspond as cleanly with 17,500 cfs as in other years. This is likely due to the lack of inclusion of Brush and Ashley creek flows and a lack of specific timing of arrival of 17,500 cfs at the Stirrup.

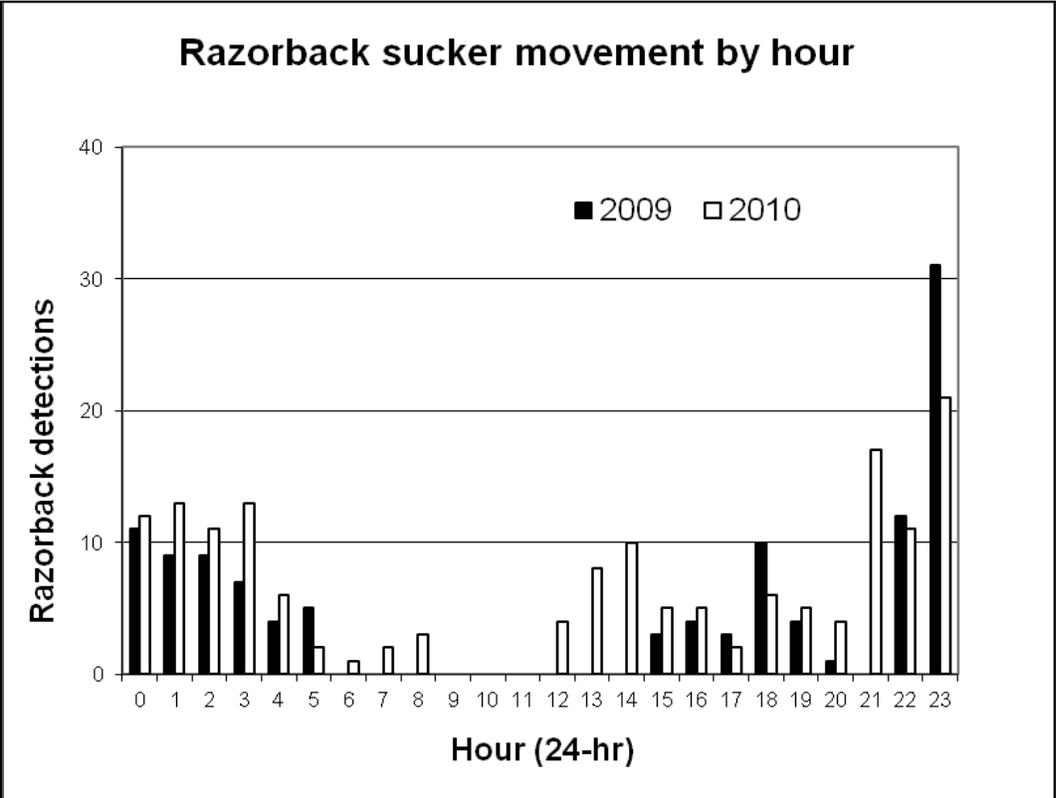


Figure 5 – Movement detections of 63 individual razorback suckers into and out of the Stirrup over the last two years of the study. Of the 63, 47 were stocked into the Stirrup, 15 were stocked into the river, and the origin of one was unknown.

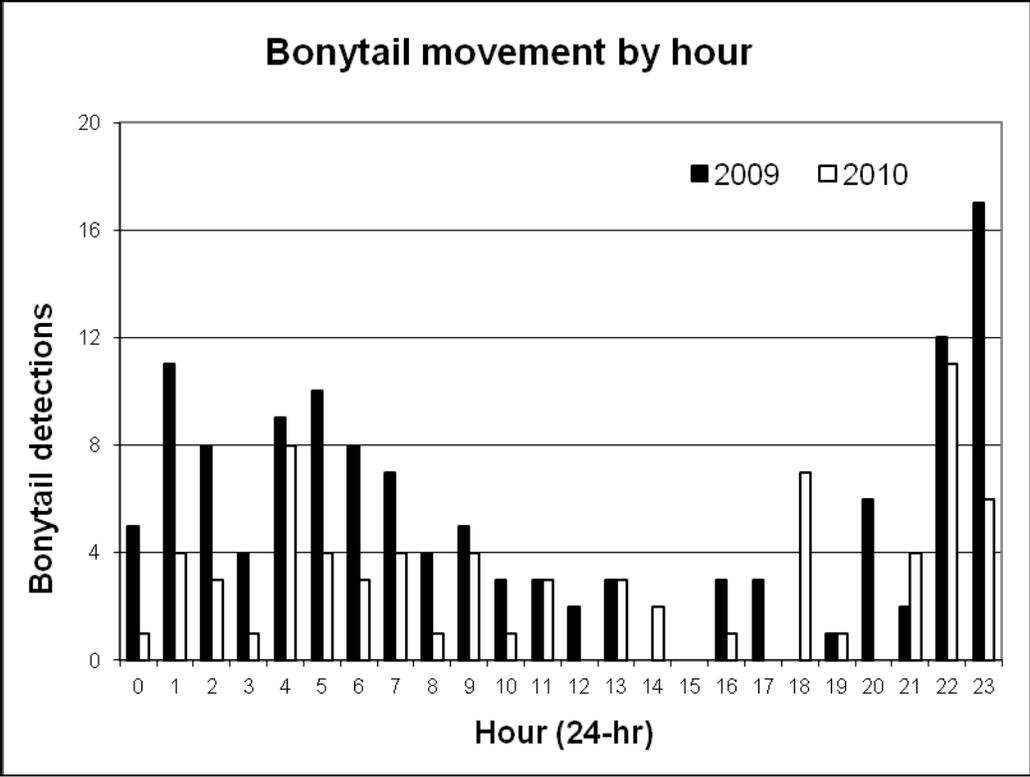


Figure 6 – Movement detections of 10 bonytail into and out of the Stirrup over the last two years of the study.

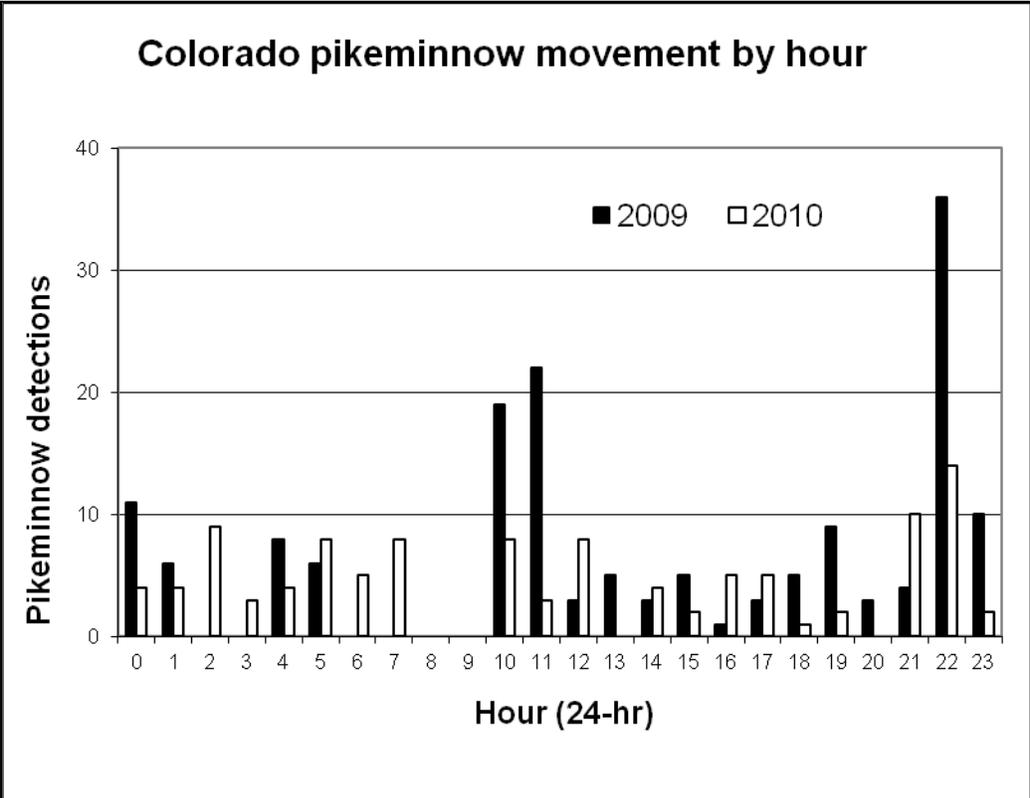


Figure 7 – Movement detections of six Colorado pikeminnow into and out of the Stirrup over the last two years of the study.

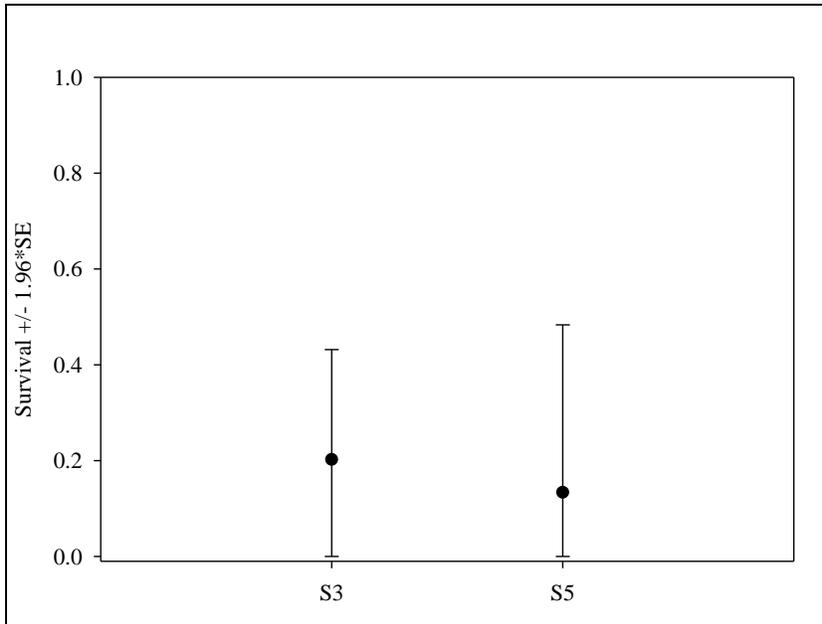


Figure 8 - Model-averaged estimates (\pm 95% CI) of survival probabilities for the 3rd (S3) and 5th (S5) stocking cohorts from the suite of 16 models (Table 6) fitted to the razorback capture-mark-recapture data from the Stirrup Floodplain and breach. Fish from the S3 cohort were stocked at age two years in the summer, S5 as mature young-of-year fish (age-0) in the fall.

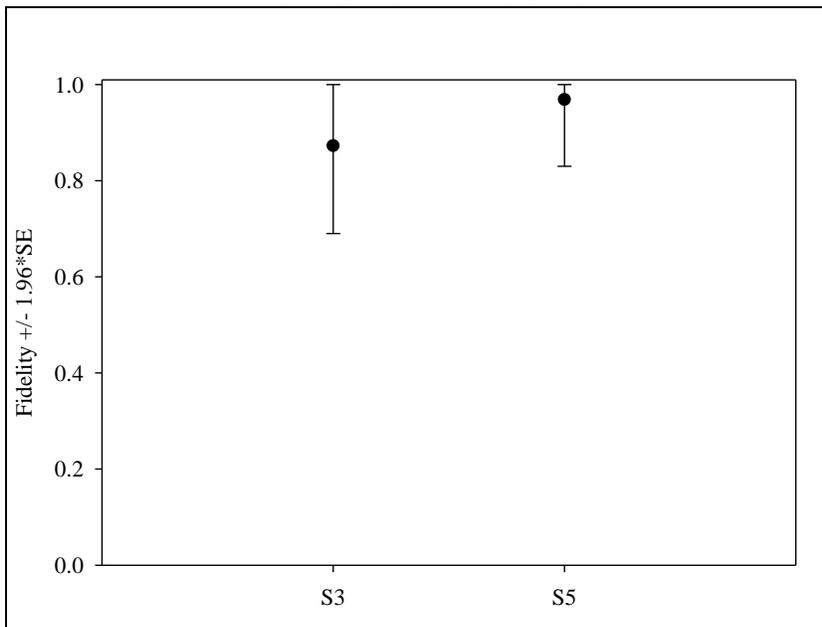


Figure 9 - Model-averaged estimates (\pm 95% CI) of fidelity probabilities (to the floodplain) for the 3rd (S3) and 5th (S5) stocking cohorts from the suite of 16 models (Table 6) fitted to the razorback capture-mark-recapture data from the Stirrup Floodplain and breach. Fish from the S3 cohort were stocked at age two years in the summer, S5 as mature young-of-year fish (age-0) in the fall.

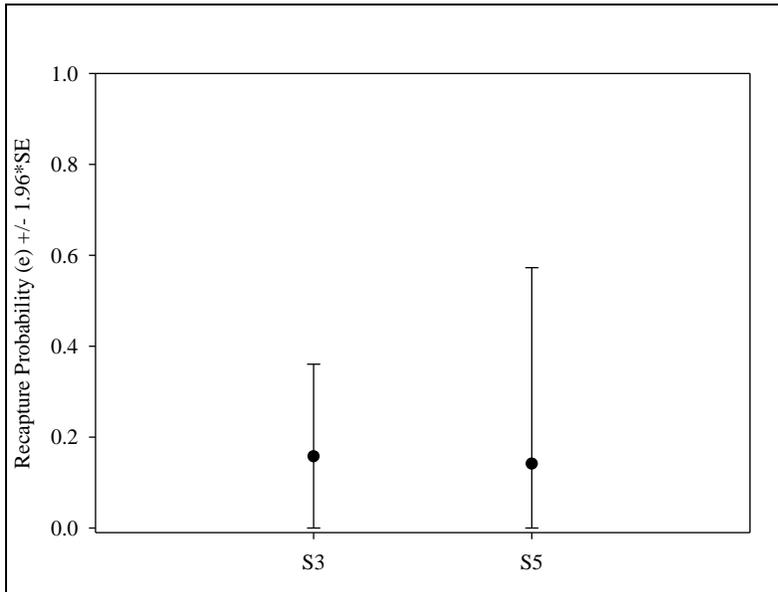


Figure 10 - Model-averaged estimates (\pm 95% CI) of 2009 active-sampling recapture probabilities for the 3rd (S3) and 5th (S5) stocking cohorts from the suite of 16 models (Table 6) fitted to the razorback capture-mark-recapture data from the Stirrup Floodplain and breach. Fish from the S3 cohort were stocked at age two years in the summer, S5 as mature young-of-year fish (age-0) in the fall.

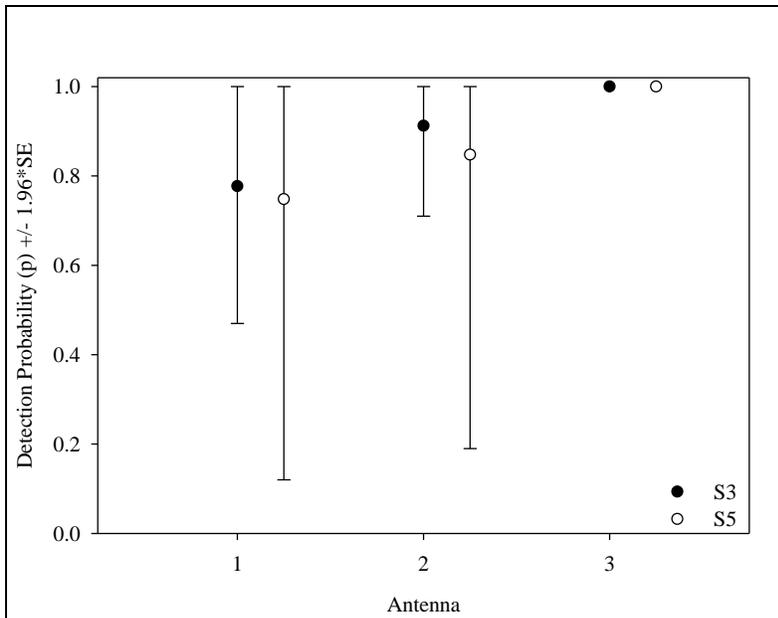


Figure 11 - Model-averaged estimates (\pm 95% CI) of passive detection probabilities from PIT-tag antennas 1-3 for the 3rd (S3) and 5th (S5) stocking cohorts from the suite of 16 models (Table 6) fitted to the razorback capture-mark-recapture data from the Stirrup Floodplain and breach. Fish from the S3 cohort were stocked at age two years in the summer, S5 as mature young-of-year fish (age-0) in the fall.

Appendix 1

An example of script used to specify models in program SURVIV (White 1992). Specific model constraints are applied under “proc estimate”. In this example, constraints specify the following model: survival ($S_3=S_5$); fidelity ($S_3 < S_5$); recapture ($S_3=S_5$); passive detection ($S_3=S_5$). See White (1992) for more details.

```
proc title 'Hedrick et al. Razorback Sucker 2008-10';
```

```
proc model npar = 28;
```

```
    cohort = 952 /* 3rd Stocking (age 2) 7-1-08 1st Release */;
```

```
    31:S(1)*S(7);
    21:S(1)*(1.-S(7))*(1.-S(9))*S(17)*S(18)*S(19) /* 111 */;
    0:S(1)*(1.-S(7))*(1.-S(9))*S(17)*S(18)*(1.-S(19)) /* 110 */;
    0:S(1)*(1.-S(7))*(1.-S(9))*S(17)*(1.-S(18))*(1.-S(19)) /* 100 */;
    0:S(1)*(1.-S(7))*(1.-S(9))*S(17)*(1.-S(18))*S(19) /* 101 */;
    0:S(1)*(1.-S(7))*(1.-S(9))*(1.-S(17))*S(18)*(1.-S(19)) /* 010 */;
    3:S(1)*(1.-S(7))*(1.-S(9))*(1.-S(17))*S(18)*S(19) /* 011 */;
    2:S(1)*(1.-S(7))*(1.-S(9))*(1.-S(17))*(1.-S(18))*S(19) /* 001 */;
    1:S(1)*(1.-S(7))*S(9)*S(2)*(1.-S(10))*S(18)*S(19) /* -11 */;
    0:S(1)*(1.-S(7))*S(9)*S(2)*(1.-S(10))*S(18)*(1.-S(19)) /* -10 */;
    0:S(1)*(1.-S(7))*S(9)*S(2)*(1.-S(10))*(1.-S(18))*S(19) /* -01 */;
```

```
    cohort = 31 /* 3rd Stocking (age 2) 7-1-08 2nd Release */;
```

```
    1:(1.-S(11))*S(20)*S(21)*S(22) /* 111 */;
    0:(1.-S(11))*S(20)*S(21)*(1.-S(22)) /* 110 */;
    0:(1.-S(11))*S(20)*(1.-S(21))*(1.-S(22)) /* 100 */;
    0:(1.-S(11))*S(20)*(1.-S(21))*S(22) /* 101 */;
    0:(1.-S(11))*(1.-S(20))*S(21)*(1.-S(22)) /* 010 */;
    1:(1.-S(11))*(1.-S(20))*S(21)*S(22) /* 011 */;
    0:(1.-S(11))*(1.-S(20))*(1.-S(21))*S(22) /* 001 */;
    0:S(11)*S(3)*(1.-S(12))*(1.-S(21))*S(22) /* -01 */;
    0:S(11)*S(3)*(1.-S(12))*S(21)*S(22) /* -11 */;
    0:S(11)*S(3)*(1.-S(12))*S(21)*(1.-S(22)) /* -10 */;
```

```
    cohort = 999 /* 5th Stocking (age yoy) 10-9-08 1st Release */;
```

```
    15:S(4)*S(8);
    2:S(4)*(1.-S(8))*(1.-S(13))*S(23)*S(24)*S(25) /* 111 */;
    0:S(4)*(1.-S(8))*(1.-S(13))*S(23)*S(24)*(1.-S(25)) /* 110 */;
    0:S(4)*(1.-S(8))*(1.-S(13))*S(23)*(1.-S(24))*(1.-S(25)) /* 100 */;
    0:S(4)*(1.-S(8))*(1.-S(13))*S(23)*(1.-S(24))*S(25) /* 101 */;
```

0:S(4)*(1.-S(8))*(1.-S(13))*(1.-S(23))*S(24)*(1.-S(25)) /* 010 */;
 0:S(4)*(1.-S(8))*(1.-S(13))*(1.-S(23))*S(24)*S(25) /* 011 */;
 1:S(4)*(1.-S(8))*(1.-S(13))*(1.-S(23))*(1.-S(24))*S(25) /* 001 */;
 0:S(4)*(1.-S(8))*S(13)*S(5)*(1.-S(14))*(1.-S(24))*S(25) /* -01 */;
 0:S(4)*(1.-S(8))*S(13)*S(5)*(1.-S(14))*S(24)*(1.-S(25)) /* -10 */;
 0:S(4)*(1.-S(8))*S(13)*S(5)*(1.-S(14))*S(24)*S(25) /* -11 */;

cohort = 15 /* 5th Stocking (age yoy) 10-9-08 2nd Release */;

0:(1.-S(15))*S(26)*S(27)*S(28) /* 111 */;
 0:(1.-S(15))*S(26)*S(27)*(1.-S(28)) /* 110 */;
 0:(1.-S(15))*S(26)*(1.-S(27))*(1.-S(28)) /* 100 */;
 0:(1.-S(15))*S(26)*(1.-S(27))*S(28) /* 101 */;
 0:(1.-S(15))*(1.-S(26))*S(27)*(1.-S(28)) /* 010 */;
 0:(1.-S(15))*(1.-S(26))*S(27)*S(28) /* 011 */;
 0:(1.-S(15))*(1.-S(26))*(1.-S(27))*S(28) /* 001 */;
 0:S(15)*S(6)*(1.-S(16))*(1.-S(27))*S(28) /* -01 */;
 0:S(15)*S(6)*(1.-S(16))*S(27)*(1.-S(28)) /* -10 */;
 0:S(15)*S(6)*(1.-S(16))*S(27)*S(28) /* -11 */;

Labels;

S(1) = S S3-R1 2008-09;
 S(2) = S S3-R1 2009-10;
 S(3) = S S3-R2 2009-10;
 S(4) = S S5-R1 2008-09;
 S(5) = S S5-R1 2009-10;
 S(6) = S S5-R2 2009-10;
 S(7) = p S3-R1 2009 electrofishing;
 S(8) = p S5-R1 2009 electrofishing;
 S(9) = F S3-R1 2009;
 S(10) = F S3-R1 2010;
 S(11) = F S3-R2 2009;
 S(12) = F S3-R2 2010;
 S(13) = F S5-R1 2009;
 S(14) = F S5-R1 2010;
 S(15) = F S5-R2 2009;
 S(16) = F S5-R2 2010;
 S(17) = p Antenna S3-R1-1;
 S(18) = p Antenna S3-R1-2;
 S(19) = p Antenna S3-R1-3;
 S(20) = p Antenna S3-R2-1;
 S(21) = p Antenna S3-R2-2;
 S(22) = p Antenna S3-R2-3;
 S(23) = p Antenna S5-R1-1;
 S(24) = p Antenna S5-R1-2;
 S(25) = p Antenna S5-R1-3;

```
S(26) = p Antenna S5-R2-1;  
S(27) = p Antenna S5-R2-2;  
S(28) = p Antenna S5-R2-3;
```

```
proc estimate NSIG=5 MAXFN=1000;
```

```
initial;
```

```
CONSTRAINTS;
```

```
S(1)=S(2);  
S(2)=S(3);  
S(3)=S(4);  
S(4)=S(5);  
S(5)=S(6) /* survival constant */;  
S(9)=S(10);  
S(10)=S(11);  
S(11)=S(12) /* fidelity S3 */;  
S(13)=S(14);  
S(14)=S(15);  
S(15)=S(16) /* fidelity S5 */;  
S(17)=S(20);  
S(20)=S(23);  
S(23)=S(26) /* antenna 1 */;  
S(18)=S(21);  
S(21)=S(24);  
S(24)=S(27) /* antenna 2 */;  
S(19)=1;  
S(22)=1;  
S(25)=1;  
S(28)=1 /* antenna 3 */;  
S(7)=S(8) /* electrofishing */;
```

```
proc test /* no modifiers */;
```

```
PROC STOP /* stops execution. */;
```