SURVIVAL OF HATCHERY-REARED RAZORBACK SUCKERS *XYRAUCHEN TEXANUS* STOCKED IN THE SAN JUAN RIVER BASIN, NEW MEXICO, COLORADO, AND UTAH

By

Kevin R. Bestgen, Koreen A. Zelasko and Gary C. White
Larval Fish Laboratory
Department of Fish, Wildlife, and Conservation Biology
Colorado State University
Fort Collins, Colorado 80523

Final Report

Larval Fish Laboratory Contribution 160

September 2009

Table of Contents

Executive Summary iii
List of Tables vi
List of Figures vii
Key Words viii
Introduction 1
Study Area 4
Methods 4
Results 11
Discussion 21
Recommendations 23
Acknowledgements 25
Literature Cited 26

Executive Summary

We used tag-recapture data collected during field sampling to estimate survival rates of razorback suckers stocked in the San Juan River, New Mexico, Colorado, and Utah, 1995-2008. A total of 43,489 fish were stocked since 1994, with nearly 71% of all fish stocked in 2006 and 2007. Number of fish stocked varied widely by year and among the 17 sources; no fish were stocked in 1999. Mean total length (TL) of all fish stocked was 277 mm (68-560 mm). A total of 1,382 recaptures were made for 1,080 individual fish; some individuals were recaptured up to 4 times and one individual released in 1994 (hatched in 1992) was recaptured in 2008. We analyzed recapture data using Cormack-Jolly-Seber-type models to obtain estimates of apparent survival, ϕ (phi), and probability of recapture, *p*. Covariates in estimating models included an annual effect for 1st-interval in the river (*a1*), to assess survival and recapture rates for razorback suckers from time of release to the first recapture occasion the following year. We also modeled annual survival rates and recapture probabilities for post 1st-interval fish in the river (*post-a1*). Other covariates used to model survival rates included season of stocking (*a1* only), TL and TL^2 at time of stocking (*a1* only), source, and 2nd-interval in the river (*a2*). Covariates to model recapture probabilities included TL and TL^2 at time of stocking (*a1* only) and estimates of sampling that included numbers of sampling hours and trips. Model selection by AIC_c indicated a top model with 35 parameters that included all those described above except source, *a2*, and sampling effort. The 1st-interval in the river effect on survival was the most important and varied by year. Years 1994, 1995, 2001, and 2002 had relatively high 1st-interval survival rates (78-99%), but those stocking years accounted for only 3.5% of all fish released. In those years, total return rates were also high indicating continued survival of those fish in *post-a1* years.

Remaining years had 1st-interval survival rates that were low and low across all seasons: 1.4, 2.4, and 2.6% for fish of average length that were stocked in spring, summer, and autumn, respectively, and 0.02% for fish stocked in winter. Survival rates were particularly low in 2006 and 2007 (0.3 and 1%, respectively, for fish of average length), the years when most razorback suckers were stocked. Even in years with moderately high 1st-interval recapture rates (2000, 2004, 2005), total return rates were low and resulted in low *a1* and *post-a1* survival rates. Fish length at stocking had a large and positive effect on survival, but rates for fish of average length were low. Environmental factors such as stream flow may also affect *a1* survival rates. San Juan River flow regimes characterized by a typical or low spring peak and few or no summer or autumn flow spikes were associated with higher *a1* survival rates. In most other years, aberrant flows, including high and extended releases in early spring (e.g. 2007) or summer/autumn rainstorm-induced flow spikes were associated with lower *a1* survival rates. Annual survival rates of *post-a1* razorback suckers were also variable but averaged about 77%. Probability of recapture was slightly higher for *a1* razorback suckers than *post-a1* fish and varied over years, generally increasing later in the study period. Probability of recapture increased for fish longer than the average length at stocking. Recapture and survival rates of razorback suckers varied dramatically by source, but it was not included as an effect in the top model due to confounding with many other covariates including year and season of stocking and fish length. For example, Uvalde contributed 4,847 razorback suckers that were stocked in winter 2007, but none were recaptured in 2008, indicating low survival. In contrast, Wawheap, and East and West Avocet sources supplied 77% of the total recaptures in the study but contributed only 27% of the total fish stocked. Care must be taken when interpreting even the most straightforward effects produced from this modeling effort, because, like source, many other effects may be confounded in complex ways. Main recommendations from this analysis include: condition fish to river conditions to increase *a1* survival rates; stock larger fish or conduct a cost:benefit analysis of that action; collect more information on stocked fish prior to release; cease stocking in the winter; maintain sampling intensity to maintain or increase probability of recapture; investigate causes of source variation in return rates; and implement a more balanced stocking and sampling design to better understand covariate effects on survival of razorback suckers. These results should assist with management of razorback suckers and enhance prospects for their recovery in the San Juan River Basin.

LIST OF TABLES

Page

Table 1. Number of razorback suckers stocked by year and season in the San Juan River, New Mexico, Colorado, and Utah 29

Table 2. Number of razorback suckers stocked by year and 50-mm total length (TL) group in the San Juan River, New Mexico, Colorado, and Utah, 1994-2007. 30

Table 3. Number of razorback suckers stocked by season and 50-mm total length (TL) group in the San Juan River, New Mexico, Colorado, and Utah, 1994-2007. 30

Table 4. Number of razorback suckers stocked by source and year in the San Juan River, New Mexico, Colorado, and Utah, 1994-2007 31

Table 5. Number of razorback suckers stocked by source and 50-mm total length (TL) group in the San Juan River, New Mexico, Colorado, and Utah, 1994-2007. 31

Table 6. The m_{ij} array produced from Program Mark depicting release year and number of razorback suckers released 32

Table 7. Stocking year and recapture frequency of razorback suckers released in the San Juan River, New Mexico, Colorado, and Utah, 1994-2007. 33

Table 8. Models used to estimate apparent survival (ϕ) and probability of recapture (p) for razorback suckers released into the San Juan River, New Mexico, Colorado, and Utah, 1994-2007 34

Table 9. Logit ϕ (apparent survival) and p (recapture probability) parameter estimates and some standard errors (SE) and 95% confidence limits (CI) for the top top-ranked mean survival model 35

Table 10. Annual survival estimates (standard errors [SE], upper and lower 95% confidence limits [CI], and coefficients of variation [CV, (SE/estimate)*100]) for razorback suckers that were stocked in the San Juan River, New Mexico, Colorado, and Utah, 1994-2007 36

Table 11. Annual probability of recapture estimates (standard errors [SE], upper and lower 95% confidence limits [CI], and coefficients of variation 37

Table 12. Source and recapture rates of razorback suckers stocked in the San Juan River, New Mexico, Colorado, and Utah, 1994-2007 38

Table 13. Variation in recapture frequency of razorback suckers raised at various sources and stocked in the San Juan River, New Mexico, Colorado, and Utah, 1994 and 2004 39

LIST OF FIGURES

Page

Figure 1. Annual survival estimates for razorback suckers stocked in the San Juan River, New Mexico, Colorado, and Utah, 1994-2007......40

Figure 2. Length-dependent survival of razorback suckers in their 1st-interval (*a1*) in the river after stocking in the San Juan River, New Mexico, Colorado, and Utah 41

Figure 3. Percent of razorback suckers in 50-mm-total-length (TL) groups at time of stocking (open bars, n = 687 fish stocked) and percent of fish that were recaptured 42

Figure 4. Length-dependent survival of razorback suckers by season in 2007 for their 1st-interval (*a1*) in the river after stocking, in the San Juan River, New Mexico, Colorado, and Utah. 43

Figure 5. Length-dependent survival of razorback suckers by season in 2002 for their 1st-interval (*a1*) in the river after stocking, in the San Juan River, New Mexico, Colorado, and Utah 44

Figure 6. Annual probability of recapture estimates (bars are 95% confidence limits) for razorback suckers stocked in the San Juan River, New Mexico, Colorado, and Utah, 1994-2007. 45

Figure 7. Length-dependent probabilities of recapture for razorback suckers in their 1st-interval (*a1*) in the river after stocking and constant recapture rates in the *post-a1* period, in the San Juan River, New Mexico, Colorado, and Utah, in 2002 and 2007 46

KEY WORDS

razorback sucker, San Juan River, hatchery propagation, survival rate estimation, demographic parameters, endangered fishes, total length, season, non-native predators

INTRODUCTION

Demographic parameters that describe birth, movement, mortality rates, and population abundance are useful to understand status and dynamics of animal populations. Population responses to biotic or abiotic drivers are of interest to ecologists attempting to understand the fundamental basis for population change. They are also useful to managers attempting to maintain or enhance abundance of free-ranging animal populations.

Razorback sucker *Xyrauchen texanus* is a large, long-lived, and sometimes migratory catostomid endemic to the Colorado River Basin, and it is federally listed as endangered under the Endangered Species Act of 1973, as amended (U. S. Fish and Wildlife Service 2002). Once widespread and abundant throughout warm-water reaches of the basin, wild razorback suckers are rare throughout the Colorado River Basin and presently restricted to Lake Mohave and Lake Mead reservoirs and stocked individuals occupy restricted portions of the Upper Colorado River Basin in the San Juan, Colorado, and Green River sub-basins. Reasons for decline of razorback suckers include negative effects of habitat alteration, river regulation, and nonnative fishes (Minckley 1973; Carlson and Muth 1989). Over 140 main-stem and tributary dams and reservoirs and several trans-basin water diversions provide agricultural and municipal water supplies to a rapidly expanding human population in the Colorado River Basin. As a result, the Colorado River Basin is one of the most tightly controlled water supplies in the world (Iorns et al. 1965; Carlson and Muth 1989). Main-stem dams have been particularly damaging to biota because they restrict movements of mobile fishes, reduce seasonal variability of discharge, water temperature, and sediment load, and increase daily hydrograph variation (Vanicek and Kramer 1969; Holden 1979; Ward and Stanford 1979; Stanford et al. 1996; Poff et al. 1997). No fewer than 60 nonnative fishes have been established in the Colorado River Basin, many of which prey upon or compete with various life stages of native species (Carlson and Muth 1989; Ruppert et al. 1993; Olden et al. 2006). The outcome of these environmental and biotic changes for the highly endemic fish fauna of the Colorado River Basin has been dramatic: two of the 35 native species in the basin are extinct, an additional 18 including razorback sucker are federally listed as threatened or endangered or are very rare, and most others are listed by one or more basin states as declining (Stanford and Ward 1986; Carlson and Muth 1989; Bezzerides and Bestgen 2002; Mueller and Marsh 2002; Valdez and Muth 2005).

Recovery of razorback sucker requires “genetically and demographically viable, self-sustaining populations” in the Upper Colorado River Basin but status of most populations, which are established largely via repatriation of stocked hatchery individuals, is poorly known. The U.S. Fish and Wildlife Service (2002) requires that each of the Upper and Lower Colorado River basins maintain two such populations for a five-year period before downlisting the razorback sucker to threatened status. In the UCRB, one population is required for the Green River subbasin and the other is to occur in either the upper Colorado River subbasin or the San Juan River subbasin, and abundance of adults in each population is to exceed 5,800 individuals. Population stability and abundance levels must be sustained for another three years after downlisting as minimally sufficient conditions for delisting to occur. The UCRB recovery effort is partitioned into two recovery programs: (1) the Upper Colorado River Endangered Fish Recovery Program (UCRRP), which includes the Green and Colorado River subbasins, and (2) the San Juan River Basin Recovery Implementation Program (SJRRIP). Each cooperative program includes multiple management strategies addressing habitat, instream flow, and nonnative species. However, depleted populations of wild razorback suckers in most areas requires stocking of hatchery-produced razorback suckers to progress towards recovery (U.S. Fish and Wildlife Service 2002).

Evaluation of management actions, including stocking, is needed to estimate progress toward recovery and to determine conservation status of subject populations. A thorough analysis of survival of razorback suckers has recently been completed for a portion of the Upper Colorado River Basin, in the Green and Colorado River subbasins (Zelasko 2008). A similar analysis of data collected to date in the San Juan River subbasin was deemed prudent given the relatively large number of fish released and recaptured, and because of potential differences in the size of those systems (San Juan smaller), differences in flow management, and potential differences due to sources or sizes of razorback suckers stocked. Estimates of vital rates of populations of stocked animals would assist with evaluating efforts aimed at re-establishing self-sustaining populations such as in the San Juan River Basin, New Mexico, Colorado, and Utah (U.S. Fish and Wildlife Service 2002).

The goal of this study is to provide a comprehensive, basin-wide assessment of demographic parameters for razorback sucker in the San Juan River based on release of hatchery-reared razorback suckers beginning in 1994 and recapture data collected through 2008. The objectives of this study are to:

1. compile and proof stocking and recapture data for razorback suckers stocked into the San Juan River Basin,
2. identify covariates for data analysis,
3. analyze data in Program MARK to obtain unbiased and precise survival rate estimates possible,
4. compare survival rates to others available,

5. make recommendations based on results of analyses.

Results will be useful to managers attempting to restore razorback sucker in the San Juan River and may also guide future production and stocking strategies for hatcheries.

STUDY AREA

The study area is the San Juan River in warm water reaches downstream of Navajo Reservoir, in New Mexico, Colorado, and Utah.

METHODS

Parameter estimation

Data proofing.—Various San Juan River Basin researchers provided monitoring data to describe population status of razorback suckers. Data consisted of records of PIT-tagged razorback suckers released after grow-out in hatcheries or other sources from 1994-2007 and recapture information for fish gathered during field sampling in the period 1995-2008. Through 2007, a total of 43,489 tagged razorback suckers had been released, and field sampling through 2008 yielded 1,382 recapture records, which included multiple recaptures for some individuals. Additional data for stocked fish included hatchery agency and source, Passive Integrated Transponder (PIT) tag number, length (mm total length [TL]) and weight (g) when available, year class (year of hatching), and release date and location. Field recapture information included sampling agency, recapture date and location, PIT tag number, and fish length, weight, sex, reproductive condition, and status (live or dead).

Error-checking of both hatchery and field recapture data was extensive and required about 1.5 person months to complete. A series of queries was used to detect errors within and among records including missing PIT tag numbers; PIT tag numbers with omitted or extra digits or incorrect characters; duplicate records; and recapture records with no associated stocking data. Individual PIT tag numbers linked hatchery release data to recapture data collected during field sampling. Exceptions would be where the first capture record of a razorback sucker was for a wild fish, or for a hatchery fish that was not tagged or had a missing or non-functional tag. The fish would receive a new tag that would not link back to hatchery release data, and because we were primarily interested in understanding survival of hatchery-released fish, that animal would not be included in further analyses. There were approximately 800 such records. Because such fish may represent recruitment, reduction of tagging errors should be emphasized.

Covariate identification.—Analysis covariates were selected based on factors hypothesized to affect survival or recapture probability of hatchery-reared razorback suckers including: fish TL, season, year, hatchery of origin (source), and sampling effort. We designated data as individual or environmental, and continuous or categorical covariates. Stocking location was not used as a covariate in this analysis because most razorback suckers were stocked at a single location, river mile (RM) 158.6.

Based on previous investigations (Zelasko 2008), we suspected fish length would affect recapture probabilities as well as survival rates. Therefore, when individual length data were not available for released fish, we assigned lengths to batches of fish based on the mean length of razorback suckers from samples taken prior to release. For fish reared at the Uvalde National

Fish Hatchery, we estimated mean length of the entire group of fish from a mean weight estimate (length:weight equation from McAda and Wydoski 1980). We compared the resulting mean length for those Uvalde razorback suckers (316 mm total length, TL) for which only a mean weight was known, to the mean length of fish of similar weight from other sources for which both length and weight were known. The resulting estimate of 317 mm TL gave us confidence that the estimated length of Uvalde fish was appropriate.

Stocking season was assigned based on the period when fish were stocked as follows: spring (March through May), summer (June through August), autumn (September and October), and winter (November and December); no fish were stocked in January or February. Season designation was based on subjective assessments of water temperatures: moderate in spring and autumn, warm in summer, and cold in winter. Thus, the covariate stocking season may be a surrogate measure of other conditions that vary seasonally for those periods, including discharge, water temperature, and habitat availability. Year effects were modeled explicitly and produced time-specific parameter estimates.

The 17 sources of fish included: 24 Road (Grand Valley Endangered Fish Facility, USFWS, Grand Junction, Colorado), an “Aquarium” source, “Six-pack ponds” 1 through 6, East and West Avocet, Hidden, and Ojo ponds, Dexter (Dexter National Fish Hatchery, Dexter, New Mexico), Ouray (Ouray National Fish Hatchery, USFWS, Vernal, Utah), Uvalde (Uvalde National Fish Hatchery, Uvalde, Texas), Wahweap (Wahweap Warmwater Hatchery, Utah Division of Wildlife Resources, Big Water, Utah), and Willow Beach (Willow Beach National Fish Hatchery, Arizona).

Because we suspected annual sampling effort may affect return rates of tagged razorback suckers, we included a sampling effort covariate for probability of recapture. Hours of electrofishing as well as the number of annual sampling trips, both estimated only from areas where razorback suckers were stocked or recaptured, were provided by researchers.

Data summaries were produced to understand number of razorback suckers stocked across years, seasons, and sources, which allowed us to assess the balance of data. Any groups, covariates, or combinations lacking data were identified in order to correctly interpret inestimable parameters or unreliable estimates.

Encounter history creation.—An encounter history is a series of 1's (individual recaptured in the occasion of interest) and 0's (individual not recaptured) that describes the recaptures of an individual animal over the duration of the study, and is the primary data input format. We constructed razorback sucker encounter histories by building a Microsoft Access query that returned stocking year and subsequent recapture years for every stocked fish in the hatchery release table. Recapture occasions occurred annually and the time interval between recapture occasions for this study was defined as one year; thus, recaptures of all fish within a calendar year (regardless of date) were considered part of a single recapture occasion and multiple within-year recaptures of a single fish were considered only as a single recapture. Variable stocking regimes and sampling efforts caused the actual length of time intervals between recapture occasions to vary among years. Relatively few razorback suckers encountered in consecutive calendar years were at large <6 months between those encounters. However, regardless of the time at large for newly stocked razorback suckers, recaptures of individuals that occurred in consecutive calendar years (e.g., 2003 and 2004) were considered two occasions, even though they may have been at large <12 months (e.g., stocked in September 2003, recaptured in May 2004).

We acknowledge that varying interval lengths and recapture efforts may violate underlying assumptions of analysis. The need to retain as many recapture records as possible to contribute to parameter estimation outweighed the aim of strictly meeting assumptions. Furthermore, differential survival as a function of time-at-large, if present, should become apparent through analyses of seasonal stocking effects.

Statistical modeling.—Data were analyzed in Program MARK (White and Burnham 1999) using the Cormack-Jolly-Seber (CJS) open population model (Cormack 1964, Jolly 1965, Seber 1965) which assumes: tagged individuals are representative of the population to which inference is made, numbers of releases are known, tagging does not affect survival, no tags are lost and all tags are read correctly, releases and recaptures are made within brief time periods relative to intervals between tagging, recapture does not affect subsequent survival or recapture, fates of individuals within and among cohorts are independent, individuals in a cohort have the same survival and recapture probability for each time interval, and parameter estimates are conditional on the model used (Burnham et al. 1987).

Parameters of interest in CJS models for this study are apparent survival and recapture probability. Apparent survival, ϕ_j (also "phi"), is the conditional probability of survival in interval j, given the individual is alive at the beginning of interval j and in the study area available for recapture. Thus, $(1 - \phi)$ represents those animals that die or emigrate. Recapture probability, p_j, is the conditional probability of recapture in year j, given the individual is alive at the beginning of year j. The number of individuals released in year i, R_i, is known and includes releases of newly tagged individuals, plus releases of recaptured individuals. The random variable, m_{ij}, is the number of recaptures in year j from releases in year i.

A priori model set development.—After preparing the final dataset for input, we used the previously identified covariates to build an a priori model set. Additional effects were modeled directly within MARK. For each parameter, effects would be modeled individually, additively, or as interactions. Survival rate, ϕ, model structures included the following effects:

constant (.) - no variation; constant survival rate for all individuals and intervals across the study period;

time variation (*t*) - each survival interval has a unique annual survival rate estimate which is for all fish present in the system regardless stocking year, except for 1^{st}-year fish (below);

1^{st}-interval in the river (*a1*) - 1^{st}-interval in the river survival rates are different from subsequent-interval rates (i.e., for a given interval, fish have a different survival rate if it is their 1^{st}-interval in the river after stocking than if it is a subsequent interval) because those fish may lack predator avoidance, current conditioning, or other survival attributes. An *a2* effect was also estimated to determine if the second interval in the river affected survival;

source - survival rate estimates vary by hatchery source of fish;

season (season) - 1^{st}-interval survival rate estimates vary by season when fish were stocked (spring, summer, autumn, winter);

total length at stocking (TL) - 1^{st}-interval survival rates are (linearly) related to TL at time of stocking; a squared term (TL^2) was also used to determine if survival changed other than linearly as length increased.

Recapture probability, *p*, model structures included the following effects:

constant (.) - no variation; constant recapture probability for all individuals and occasions across the study period;

time variation (*t*) - each recapture occasion has a unique recapture probability;

1st-interval in the river (*a1*) - 1st-occasion recapture probabilities are different from subsequent-occasion probabilities (i.e., for a given recapture occasion (year), fish have a different recapture probability if it is their first recapture occasion in the river after stocking than if it is a subsequent occasion); fish may be more or less active or occupy different habitat in the new environment due to displacement or disorientation, resulting in higher or lower recapture probabilities;

total length at stocking (TL) - 1st-occasion recapture probabilities are (linearly) related to total length at time of stocking; a squared term (TL^2) was added to determine if recapture probability changed other than linearly as length increased;

effort (eff) - recapture probability of fish stocked into a river reach varied by the sampling effort (as electrofishing hours or # of trips) expended in the study area.

Run procedure and model selection.—We used a previous survival analysis conducted for razorback suckers stocked in the Green and Upper Colorado River subbasins, Upper Colorado River Basin, Utah and Colorado, to guide which candidate models seemed most plausible (Zelasko 2008). Relatively simple models with few parameters were estimated first, and more complex models were subsequently built as additional information (e.g., sampling effort, fish source) became available.

Model selection was conducted using Akaike's Information Criterion (AIC, Akaike 1973). Models with lower AIC values are considered more parsimonious and closer to the unknown "truth" that produced the data (Burnham and Anderson 2002). The AIC values reported by Program MARK are based on a modified version of the criterion, denoted AIC_c, which adjusts for small sample size bias (Sugiura 1978, Hurvich and Tsai 1989, Burnham and Anderson 2002) and converges with AIC when sample size is large. We also scrutinized estimates produced by individual models to determine if possible confounding existed. If models or estimates were deemed unreliable (many effects whose confidence limits overlapped zero), potentially confounded, or yielded inexplicable effects, those were eliminated from the model set. This will be discussed in more detail particularly in light of potential source effects on survival that may be confounded with other covariates.

RESULTS

Dataset summary.—A total of 43,489 razorback sucker records were available for analysis for fish stocked in the period 1994-2007 (Table 1). Nearly 71% of all razorback suckers were stocked in 2006 (n = 13,759) and 2007 (n = 16, 908). Fewer than 1,000 fish were stocked in 7 of 14 years in the period, with no fish stocked in 1999, and only 16 in 1995. Nearly half (47%) of all razorback suckers were stocked in summer; remaining fish were stocked in about equal proportions across other seasons. Prior to 2001, most of the relatively few fish stocked were released in only one or two different seasons annually (1998 is the exception); from 2002-2007 fish were stocked in 2 or 3 different seasons annually. The unbalanced pattern of fish stocking over seasons and time has potential to confound time or season effects.

Mean TL of all fish stocked was 277 mm (68-560 mm, Table 2). The most-commonly stocked length-group of razorback suckers was 300-349 mm TL, followed by 250-299 mm TL, and 200-249 mm TL. Few fish < 150 mm TL or > 449 mm TL (3.5% total) were stocked. Mean length of fish stocked varied by year ranging from 192 mm TL in 1997 to 424 mm TL in 1995 (16 fish). Pearson product moment correlation of year of stocking and individual fish length (r = 0.17) was weak but positive, indicating slightly increased size of fish at stocking over time.

Mean TL of stocked razorback suckers was smallest in autumn (240.2 mm), intermediate in summer (276.6 mm) and spring (281.9), and largest in winter (308.8 mm, Table 3).

Stocked fish originated from 17 sources, with several contributing fish only a few times and in widely varying numbers (Table 4). For example, only 24 fish were from the Aquarium source, with up to 9,199 from the East Avocet source in a single year; 15,701 razorback suckers were from the Six-Pack ponds over all years. Uvalde contributed 4,847 razorback suckers and all were stocked in winter 2007.

Further, mean TL of stocked razorback suckers varied widely by stocking source (Table 5). The Aquarium source produced the smallest fish (131 mm TL, n = 24), and Wahweap produced the largest fish (mean TL = 373 mm). Even the mean TL of fish produced from the various proximal Six-Pack ponds were substantially different; smallest mean TL razorback suckers were from Pond #1 (241 mm) and the largest were from Pond # 6 (370 mm). Ages (year classes) of fish from the various sources were sometimes different and may account for some variation in length or survival by source. However, we did not use year class as an analysis variable because we assumed most of that variation would be accounted for with fish length.

The m_{ij} array produced from Program Mark was informative to depict recapture data over time for each year that razorback suckers were released in the San Juan River in New Mexico, Colorado, and Utah, 1994-2007 (Table 6). The year and number of razorback suckers released, R(i), and the number recaptured and re-released in each subsequent sampling year are organized across rows. The R(i) is the total number of fish stocked that year, plus the number of fish recaptured during sampling and released from previous fish stockings. Thus, a recapture occasion for a fish released in 1994 and recaptured in 2008 will only show as a recapture in the array in 2008 if it was not recaptured in the 1995-2007 interval.

Of the 1,382 recaptures, 1,080 individual fish were recaptured once, 237 were recaptured twice, 54 were recaptured three times, and 8 were recaptured four times. One individual from the 1992 year class and stocked in 1994 was recaptured in 1998, 2003, and 2008 and so was 16 years old. Recapture data showed that 1st-interval (number of first-time recaptures regardless of year) and total return rates (cumulative recaptures including first-time and multiple recaptures) were relatively high for fish stocked in 1994 and 1995, low for fish stocked from 1996-1998 (e.g., 0.2% in 1997) and 2000 (no fish were stocked in 1999), high again in 2001-2002 (e.g., 31% in 2001), and with the exception of 2004, low from 2003-2007 (Table 7). The Pearson product moment correlation of % total return and TL was 0.70 indicating a positive association of fish length and number of fish recaptured that were stocked in a particular year. Pearson product moment correlation coefficients for the relationships between 1st-interval and total recapture rate with 1st-interval survival rates were 0.75 and 0.85, respectively, suggesting a close and positive relationship between recapture rates and 1st-interval survival. The relatively low total return rates for the large number of fish stocked in 2006 (0.7%) and 2007 (1.1%) may be partially a function of the few recapture occasions following release. However, comparison of 1st-interval recapture rates of razorback suckers stocked in 2001 and 2002, for example, were 6.3% and 9.3%, respectively, in years when survival rates were higher, suggesting that 2006 and 2007 may have low total return rates and survival rates in the future.

Model selection produced a top model with 35 parameters that carried >99% of the weight and was nearly 16 AIC_c units distant from the next nearest model (Table 8). The next two closest models varied from the top model only by absence of quadratic effects of TL on survival and probability of recapture, respectively. Because of the high weight of the top model and its relative similarity to the second and third models, we chose to interpret only the top model.

Important covariates for survival estimates in the top model included season of stocking, 1st-interval in the river (*a1*), fish length at stocking (includes TL and TL^2 effects, and each are estimated only for 1st-interval [*a1*] fish, not *post-a1* fish), and time (variable survival over years for *a1* and *post-a1* fish). The numerically largest logit ϕ effect was for *a1*, and indicated a negative effect on survival of razorback sucker in the 1st interval after they are stocked (Table 9). Length effects were also important, and the coefficients indicated a positive relationship between fish survival in the 1st interval and fish length at time of stocking. The negative TL^2 effect indicated a flattening of the survival curve as it approached asymptote. Time effects were also important. Logit ϕ estimates were lowest in 1996, 1999, 2003, and 2006; the 1999 effect is only for *post-a1* fish (fish from previous stocking years) because no fish were stocked in 1999 to allow 1st-interval survival estimates that year. The 2007 survival rate for 1st-interval fish is the intercept, and includes the summer season effect. Estimating the 2007 effect by itself requires including the other seasonal effects when back-transforming the logit estimates. The large negative covariate for winter indicated low survival in that season, followed by increasing survival in spring, summer, and autumn.

Mean annual survival over the study period for razorback suckers in their 1st-interval in the river varied considerably from 0.2% for fish stocked in 2003 to nearly 99% for fish stocked in 1995, when only a few (n = 16) large fish were stocked (Figure 1, Table 10). The 1st-interval survival of razorback suckers was also relatively high for fish stocked in 1994, 2001, and 2002 and estimates for those higher survival years were relatively precise, with mean CV at about 11%. However, the number of fish stocked in those years of high 1st-interval survival rates was low; only 3.5% of all fish stocked in the study period were released in 1994, 1995, 2001, or 2002. Thus, the higher 1st-interval survival rate estimates for razorback suckers in some years should be interpreted with caution.

Mean 1st-interval survival rates of razorback suckers stocked in other years were lower and better reflected survival rates for the average fish. For example, 1st-interval survival from 2003-2007 averaged only 0.9%; this period was also when most fish (84%) were stocked. Estimates in years when 1st-interval survival rates were relatively low were relatively imprecise, with CV's ranging from 22.4 to 52.4%. We anticipated a higher 1st-interval survival rate for fish stocked in 2004 because 1st-year return rates were relatively high and on par with other years when such return rates produced higher survival (e.g., 1994, Table 7). Potential explanations for low 1st -interval survival are discussed below when possible source effects are considered.

Fish length also had a large effect on survival of razorback suckers in the 1st interval in the river (Figure 2). In a typical year (e.g., 2007) when 1st- interval survival of razorback suckers was low, fish of average stocking length (277 mm TL) had survival rates that were 1.0%, when averaged across all seasons. Survival rates increased as fish length at stocking increased, but were only about 10.5% when averaged across all seasons for a 400 mm TL razorback sucker, a size that was rarely stocked. By comparison, in years when 1st-interval survival rates were high (1994, 1995, 2001, 2002), fish of average stocking length (277 mm TL) had average survival rates of 78%. In those same higher survival years, the estimated survival rate for a 400 mm TL razorback sucker, when averaged across all seasons, increased to 97.5%, further emphasizing the effects of time and fish size on stocked razorback suckers. Examination of the size distribution of fish stocked compared to the size distribution of fish at the time of stocking that were recaptured again supported the notion that larger fish were recaptured more often and likely survived better than small fish (Figure 3).

Season of stocking also affected survival rates of razorback suckers in 1st interval in the river. In a typical year with lower 1st-interval survival (e.g., 2007), fish of average length at stocking (277 mm TL) had mean survival rates of 1.4, 2.4, and 2.6% in spring, summer, and autumn, respectively, but survival rate of razorback suckers of that length stocked in winter was very low at 0.02% (Figure 4). Low survival rates for fish stocked in winter were mainly from two sources, a group of 1,129 Dexter fish stocked in 2006 (mean TL = 305 mm), and 4,847 Uvalde fish stocked in 2007 (mean TL = 316 mm), collectively 88.2% of all fish stocked winter. None of those fish were detected again.

Survival rates of razorback suckers increased as fish length increased in a manner described above; the additive (not interacting) nature of covariates kept the shape of the seasonal relationships the same. Survival rates for a 400 mm TL razorback sucker were 21, 23, and 14% when stocked in summer, autumn, and spring, respectively, but remained negligible (0.2%) for a 400 mm TL fish stocked in winter. In a more atypical year when 1st-interval survival was higher (e.g., 2002), razorback suckers of average stocking length (277 mm TL) had mean survival rates of 89, 90, and 83% when stocked in summer, autumn, and spring respectively, but only 6.5% for fish of that size stocked in winter (Figure 5). Survival rates were even higher for razorback suckers that were larger at stocking in high survival years, but again, only a relatively small number of fish were stocked in those years.

Mean survival over the study period for razorback suckers in the post-1st interval (*post-a1*) period was 77%, but varied considerably across years from 42% in the 2003-2004 interval to over 99% in 1995-1996, 2001-2002, and 2002-2003 intervals (Figure 1, Table 10). *Post-a1* survival rates were also relatively high in the 2000-2001 and 2004-2005 intervals, but were lower in other years. It should be noted that these *post-a1* survival rates are not for fish stocked in a particular year (as were the 1st-interval in the river estimates), but instead are for all *post-a1* razorback suckers present in the river for that estimation year, regardless of previous stocking year. Thus, the *post-a1* rates may reflect annual factors that affect survival of those older fish such as environmental conditions in the river during that period.

Important covariate effects for probability of recapture (*p*) were time (for 1st-interval and post 1st-interval fish), 1st-interval in the river (*a1*), and fish length at stocking (*a1* fish only, Tables 8, 9). Logit values for probability of recapture were variable over time and were an important covariate effect. The intercept is the estimate for 2008; there is no *p* for 1994, the first year when fish were stocked. The values of *p* also tended to increase over time, indicated by the increasingly smaller negative values of the logits of estimates. The covariate *a1* for *p* was positive, indicating fish were more susceptible to recapture during their 1st-interval in the river than in the *post-a1* period. The negative TL value for *p* indicated a declining probability of recapture as fish increased from small to moderate size and then *p* increased for larger fish due to the TL^2 term (see below). The negative relationship for smaller fish was due to an artifact of the quadratic term and represented an unlikely relationship. We attempted to fit a TL^3 term for *p*, to achieve a more realistic relationship of *p* increasing as fish size increased, but the model failed to converge.

Probability of recapture for 1st-interval razorback suckers in the San Juan River, 1995-2008, varied considerably over years (0.069-0.32, Figure 6, Table 11). The Pearson product moment correlation coefficient of year and *p* was 0.81, supporting the notion that *p* (and likely sampling effort) increased over time. Precision of estimates of probabilities of recapture for 1st-

interval razorback suckers stocked in the San Juan River as measured by CV's were moderately good, with a mean value of 22.7% (13.2-40.1%).

Mean annual probability of recapture for *post-a1* razorback suckers in the San Juan River, 1995-2008 also varied over years (0.057-0.32), and was slightly lower than for *a1* fish. Precision of estimates of probabilities of recapture of *post-a1* razorback suckers stocked in the San Juan River were moderately good and slightly better than precision of estimates for *a1* fish, with a mean CV value of 20.4% (9.3-39.3%).

Length-dependent probabilities of recapture for *a1* razorback suckers and length-independent recapture rates in the *post-a1* period varied among years. For example, we found higher estimates in 2007, a year with lower 1^{st}-interval survival, than in 2002, a year with higher 1^{st}-interval survival (Figure 7). Estimates were truncated at 250 mm total length (TL) because of the spurious quadratic term effect that caused increased recapture rates for smaller razorback suckers.

Hatchery source produced wide variation in 1^{st}-interval and total return rates (Table 12). It should be noted that return rates, by source or otherwise, are somewhat biased by year of stocking, because fish stocked earlier in the study period should be recaptured at higher rates than fish stocked more recently; no adjustments were made for year of stocking because of the complexity of releases made over time. No fish were recaptured from Aquarium or Uvalde sources; the former was just a few fish but Uvalde was 4,748 fish stocked in winter 2007. The Six-Pack ponds collectively averaged only 1.0% 1^{st}-interval return rates, and 24-Road, Hidden, Ojo, Ouray, and Willow Beach sources all had < 1.0% 1^{st}-interval return rates. Dexter and East Avocet sources had moderate 1^{st}-interval return rates of 3.8 and 5.0%, respectively, while 1^{st}-interval return rates for West Avocet and Wawheap sources were relatively high at 12.1 and

14.6%, respectively. Nearly 77% of total recaptures in the study period were made from only three source populations, East and West Avocet and Wawheap, even though they contributed only 27% of total fish stocked, underscoring the large effect that source may have on survival of razorback suckers stocked in the San Juan River.

We fit models that included source to directly estimate effects of hatchery on survival. A model that included source plus all covariates in the top model (50 total parameters) and that model minus season effects (47 total parameters) were fit and each had higher AIC_c scores than the top model we chose to interpret. However, none of the individual source effects were estimated well and the confidence limits of each estimate overlapped zero. Also, inclusion of source reduced the importance of time such that many year effects that were formerly significant subsequently had confidence limits that overlapped zero. Thus, source appeared to be confounded with time in some cases.

We also discovered that source may be confounded with other effects. For example, Uvalde produced 4,847 fish, all in 2007, and all those fish were stocked in winter. Because none of those fish were recaptured in the single post-stocking recapture year, 2008, we inferred those fish may have suffered high mortality. The apparent low survival of Uvalde fish (and Dexter fish stocked in 2006) had a large influence on the low survival estimate for fish stocked in winter, because Uvalde fish were a large percentage (72%) of the total fish stocked in that season. In contrast, fish stocked in 1994, particularly those from Wawheap, had relatively high 1^{st}-interval return rates (Tables 13) and likely, high subsequent survival (Table 10, Figure 1) even though most were stocked in winter. This was likely due to the large size of Wawheap fish at stocking (mean TL = 392 mm); Ouray fish were small, had low 1^{st}-interval return rates, and likely low survival. The relatively high survival of that small number of fish stocked in winter

1994 was overwhelmed by the large number of Uvalde fish stocked in 2007 and Dexter fish stocked in 2006 to produce the low overall estimate for winter season survival; annual survival rates for 1st-interval razorback suckers stocked in 1994 and 2007 were high and low, respectively. Those data illustrate yet another example of the potential for complex confounding, here with year, season of stocking, and fish length, that underlies much of this data.

High variation in return rates for razorback suckers by source were also evident even when most factors thought to affect survival were consistent. For example, 1st-interval recapture rates of razorback suckers stocked in 2004 ranged from 2.4-3.4% for three Six-Pack ponds, 12.9% for Wawheap, to nearly 16% for East Avocet (Table 13). This high variation occurred even though razorback suckers were stocked in the same year, in similar seasons, and all were relatively large and similar-sized fish. Further, post 1st-interval recaptures in 2004 were different even among those sources with higher 1st-interval recapture rates, as evidenced by the higher frequency and proportion (0.05, 72 post 1st-year recaptures/ 1453 fish stocked) of East Avocet fish that were recaptured compared to Wawheap (0.017), sample size differences notwithstanding.

Given all the factors that interacted to influence survival by source, including fish lengths, inconsistent season and year of stocking, and other factors previously discussed, we decided against interpreting models that included source. That source was apparently not considered as important an effect to managers as other effects such as season, and that some source areas, including the Six-Pack ponds, will not be used to produce fish in the future, provided further justification to not include it in models. This is not to say that source effects do not merit further investigation, especially for sources that will continue to used for production.

Discussion

Nearly all covariates estimated in models importantly affected survival rates of razorback suckers stocked in the San Juan River, New Mexico, Colorado, and Utah, in 1994-2007. However, caution is urged when interpreting what appear to be even straightforward effects because of potential confounding with one or more other covariates. Potential sources of confounding are discussed below.

Perhaps the biggest effect on survival of razorback suckers in the San Juan River is the 1^{st}-interval in the river, where with a few exceptions, fish mortality approaches 98% or more, regardless of stocking season. Razorback suckers are apparently poorly prepared to cope with riverine conditions in the San Juan River in the 1^{st}-interval after stocking. A similar effect was apparent in the Green and Colorado River subbasins, where 1^{st}-interval effects produced lower but still substantial mortality rates of 91-92% for razorback suckers stocked in autumn, winter and spring, and mortality rates exceeded 98% in summer (Zelasko 2008). Similarly, Marsh et al. (2005) found first-year survival of razorback suckers that were 300 mm TL and stocked in Lake Mohave reservoir to be about 10% (interpolated from graph). The 1^{st}-interval effects were reduced as fish size increased so perhaps consideration should be given to growing razorback suckers larger before stocking. Similar to recommendations for managers in the Green and Colorado subbasins, a cost:benefit analysis that incorporates fish size at stocking with hatchery costs and other factors associated with extended growth periods needed to grow larger razorback suckers may also be useful. Managers may also wish to consider efforts to better acclimate razorback suckers to the riverine environment prior to stocking, to reduce high mortality rates.

Much variation in survival over time was evident, particularly for 1st-interval fish. Those survival rates were generally very low except in four years, 1994, 1994, 2001 and 2002, but those years constituted only 3.5% of the fish stocked. Even post 1st-interval razorback suckers showed variable survival rates over time. Thus, it would be prudent to assess what factors may be responsible for high survival in a few years but not others, to the extent that confounding with other effects can be eliminated. For example, razorback sucker stocked in 2005 showed very low 1st-interval survival rates, even though fish were large (mean TL = 355 mm) and stocked in spring and summer when survival rates were relatively high (i.e., not the winter season). Even post 1st-interval razorback suckers showed lower than average survival in that year, suggesting an environmental effect such as river flow level (relatively high that year) may be responsible.

The post 1st-interval razorback suckers had variable survival rates over years in the study period but overall were quite high, averaging about 77%. This was similar to post-1st-interval survival rates for razorback suckers stocked in the Green and Colorado River subbasins (75%) and for wild adult razorback in the Green River (71-76%) in two separate efforts (Modde et al. 1996, Bestgen et al. 2002).

Underlying much of the variation in survival rates is fish size. Large fish consistently survive better in their 1st-interval in the river regardless of year or season effects, 2005 data notwithstanding. This was aptly demonstrated on many occasions including in the first stocking effort in 1994, when the few but large Wawheap fish returned in subsequent sampling at a very high 30% rate. Mean length for fish stocked in that year was quite low (251 mm TL), but the fish that contributed most of the recaptures were large, averaging nearly 400 mm TL. This was in spite of fish being stocked in winter, when in other years fish stocked in winter typically had very low apparent survival.

Stocking season played a role in 1st-interval survival as well, with the main effect being low survival in winter. This was caused mainly by two stocking events that contributed 88% of the fish, but none were recaptured in subsequent years. Alternatively, the few and large Wawheap fish stocked in winter 1994 survived well, so even this effect is not clear-cut. It is clear however, that poor survival of razorback suckers stocked in winter is not due to stocking small fish because the mean length of fish stocked then was the largest of all seasons. It may be prudent to reduce or eliminate winter stocking until further information is available to support that action, such as an explicit and appropriately controlled experiment.

Stocking source played a complex but potentially important role in survival of razorback suckers in the San Juan River. The role is complex because different sources contributed different numbers of fish in many different years and seasons, when intrinsic survival rates likely varied regardless of source. Razorback suckers also varied substantially in size among the various sources, and perhaps also in quality or condition of fish, which contributed to highly variable recapture rates. Highest return rates for razorback suckers stocked in the San Juan River study area were for Wawheap and East and West Avocet sources, some of which were large fish (Wawheap) and others of which were fish of nearly average length (Avocet sources).

RECOMMENDATIONS

1. Collect more information on fish size and condition at time of stocking. Minimally, lengths should be taken on all fish to aid analyses such as these, and collect lengths and weights on a representative sample for comparison among years and to recaptured fish.

2. Continue sampling at a similar intensity to maintain or increase recaptures and probabilities of recapture. This will enhance ability to conduct abundance estimates, perhaps in the next few years, if large numbers of large fish continue to be stocked, and demographic closure assumptions (e.g., no differential mortality of fish in estimation period) can be met.
3. Minimize tag/tag detection errors so that recruitment can be estimated with higher certainty at some point in the future.
4. Cease winter stocking until more evidence to support that activity emerges.
5. Continued stocking in autumn, summer, and spring may be the most beneficial but with appropriate considerations for confounding of those effects and the importance of fish size.
6. Examine effects of stocking sites on dispersal, crowding, site fidelity, and perhaps other factors.
7. Consider stocking larger fish.
8. Conduct cost:benefit analysis of growing larger razorback suckers for stocking.
9. Consider methods to acclimate or condition fish to river conditions to increase 1^{st}-interval survival.
10. Investigate causes of source variation in return rates.
11. Consider more balanced stocking and sampling designs to answer relevant questions about effects of fish size, season of stocking, environmental conditions, and source on 1^{st}-interval and post 1^{st}-interval survival.

ACKNOWLEDGEMENTS

Many participants in the San Juan River Recovery Program contributed sampling and recapture data to make this project possible; main contributors were D. Ryden, D. Elverud, and J. Davis. S. Durst assisted with database organization and M. McKinstry provided funding, project administration, report review, and encouragement.

LITERATURE CITED

Bestgen, K.R., G.B. Haines, R.Brunson, T. Chart, M. Trammell, G. Birchell, and K. Christopherson. 2002. Decline of the razorback sucker in the Green River Basin, Utah and Colorado. Report submitted to the Recovery Implementation Program for Endangered Fishes in the Upper Colorado River Basin. Contribution 126 of the Larval Fish Laboratory, Colorado State University. 73 pp.

Bezzerides, N., and K. R. Bestgen. 2002. Status of roundtail chub *Gila robusta*, flannelmouth sucker *Catostomus latipinnis*, and bluehead sucker *Catostomus discobolus* in the Colorado River Basin. Report submitted to the U. S. Bureau of Reclamation, Salt Lake City, Utah. Colorado State University, Larval Fish Laboratory Contribution 118.

Burnham, K. P. and D. R. Anderson. 2002. Model selection and multimodel inference: a practical information-theoretic approach. 2nd edition. Springer, New York City.

Burnham, K. P., D. R. Anderson, G. C. White, C. Brownie, and K. H. Pollock. 1987. Design and analysis methods for fish survival experiments based on release-recapture. American Fisheries Society Monograph **5**:1–437.

Carlson, C.A., and R.T. Muth. 1989. The Colorado River: lifeline of the American Southwest. Canadian Special Publication of Fisheries and Aquatic Sciences 106:220–239.

Cormack, R. M. 1964. Estimates of survival from the sighting of marked animals. Biometrika **51**:429–438. Hurvich, C. M. and C.-L. Tsai. 1989. Regression and time series model selection in small samples. Biometrika **76**:297–307.

Holden, P. B. 1979. Ecology of riverine fishes in regulated stream systems with emphasis on the Colorado River. Pages 57–74 *in* J. V. Ward and J. A. Stanford, editors. The ecology of regulated streams. Plenum, New York.

Hurvich, C. M. and C.-L. Tsai. 1989. Regression and time series model selection in small samples. Biometrika **76**:297–307.

Iorns, W. V., C. H. Hembree, and G. L. Oakland. 1965. Water resources of the upper Colorado River basin—Technical report. U.S. Geological Survey Professional Paper 441.

Jolly, G. M. 1965. Explicit estimates from capture-recapture data with both death and immigration stochastic model. Biometrika **52**:225–247.

Marsh, P. C., B. R. Kesner, and C. A. Pacey. 2005. Repatriation as a management strategy to conserve a critically imperiled fish species. North American Journal of Fisheries Management **25**:547–556.

Minckley, W.L. 1973. Fishes of Arizona. Arizona Game and Fish Department, Phoenix. 293 pp.

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.

Olden, J.D., N.L. Poff, and K.R. Bestgen. 2006. Life-history strategies predict fish invasions and extirpations in the Colorado River Basin. Ecological Monographs 76(1):25-40.

Poff, N.L., J.D. Allan, M.B. Bain, J.R. Karr, K.L. Prestegaard, B.D. Richter, R.E. Sparks, and J.C. Stromberg. 1997. The natural flow regime. BioScience 47:769–784.

Seber, G. A. 1965. A note on the multiple recapture census. Biometrika **52**:249–259.

Sugiura, N. 1978. Further analysts of the data by Akaike's information criterion and the finite corrections. Communications in Statistics - Theory and Methods **7**:13 – 26.

Ruppert, J.B., R.T. Muth, and T.P. Nesler. 1993. Predation on fish larvae by adult red shiner, Yampa and Green rivers, Colorado. Southwestern Naturalist 38:397–399.

Stanford, J. A., and J. V. Ward. 1986a. The Colorado River system. Pages 385–402 *in* B. R. Davies and K. F. Walker, editors. The ecology of river systems. Dr. W. Junk Publishers, Dordrecht, The Netherlands.

Stanford, J.A., J.V. Ward, W.J. Liss, C.A. Frizzell, R.N. Williams, J.A. Lichatowich, and C.C. Coutant. 1996. A general protocol for restoration of regulated rivers. Regulated Rivers: Research and Management 12:391–413.

U.S. Fish and Wildlife Service. 2002. 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.

Valdez, R.A., and R.T. Muth. 2005. Ecology and conservation of native fishes in the Upper Colorado River Basin. American Fisheries Society Symposium 45:157-204.

Vanicek, C. D., and R. H. Kramer. 1969. Life history of the Colorado squawfish, *Ptychocheilus lucius*, and the Colorado chub, *Gila robusta*, in the Green River in Dinosaur National Monument 1964–1966. Transactions of the American Fisheries Society 98:193–208.

Ward, J. V., and J. A. Stanford (editors). 1979. The ecology of regulated streams. Plenum Press, New York.

Zelasko, K. A. 2008. Survival rate estimation and movement of hatchery-reared razorback suckers *Xyrauchen texanus* in the Upper Colorado River Basin, Utah and Colorado. M.S. thesis, Colorado State University, Fort Collins.

Table 1. Number of razorback suckers stocked by year and season in the San Juan River, New Mexico, Colorado, and Utah, 1994-2007. Stocking season was defined as spring (March through May), summer (June through August), autumn (September and October), and winter (November and December); no fish were stocked in January or February.

Year Stocked	Spring	Summer	Autumn	Winter	totals
1994	15		15	657	687
1995			16		16
1996			237		237
1997			2883		2883
1998	124		1151		1275
1999					
2000			1044		1044
2001			572	116	688
2002	115			25	140
2003	202		685		887
2004	1269	1703			2972
2005	633	1224	136		1993
2006		12630		1129	13759
2007	7174	4887		4847	16908
totals	9532	20444	6739	6774	43489

Table 2. Number of razorback suckers stocked by year and 50-mm total length (TL) group in the San Juan River, New Mexico, Colorado, and Utah, 1994-2007. Mean TL of all fish released was 277 mm.

Year	Total length (TL, mm) group 50-99	100-149	150-199	200-249	250-299	300-349	350-399	400-449	450-499	500-549	550-600	total	mean TL (mm)
1994		124	171	130	42	18	95	107				687	251
1995							1	14	1			16	424
1996				5	32	115	73	12				237	336
1997		184	2023	602	52	20	1	1				2883	192
1998			7	1120	23	2	22	93	8			1275	250
1999												0	
2000		98	652	80	2	17	172	14	6	3		1044	214
2001					1	30	477	66	100	13	1	688	395
2002		11	2	1	46	32	18	24	6			140	319
2003		10	1		226	466	63	99	22			887	327
2004				13	302	1142	984	434	84	12	1	2972	353
2005				30	379	489	612	414	64	5		1993	355
2006	7	299	1992	1975	5995	2135	781	466	100	9		13759	261
2007		55	2218	3631	2862	6189	1498	138	316	1		16908	280
total	7	781	7066	7587	9962	10655	4797	1882	707	43	2	43489	
% of total	< 0.1	1.8	16.2	17.4	22.9	24.5	11.0	4.3	1.6	0.1	< 0.1		

Table 3. Number of razorback suckers stocked by season and 50-mm total length (TL) group in the San Juan River, New Mexico, Colorado, and Utah, 1994-2007. Stocking season was defined as spring (March through May), summer (June through August), autumn (September and October), and winter (November and December); no fish were stocked in January or February.

Season	Total length (TL) group 50-99	100-149	150-199	200-249	250-299	300-349	350-399	400-449	450-499	500-549	550-600	total	Mean TL
spring		66	1770	2047	1520	1865	1812	368	81	2	1	9532	281.9
summer	7	309	2443	3585	8032	2144	2121	1276	505	22		20444	276.6
autumn		282	2682	1826	378	626	696	120	112	16	1	6739	240.2
winter		124	171	129	32	6020	168	118	9	3		6774	308.8
total	7	781	7066	7587	9962	10655	4797	1882	707	43	2	43489	277.1

Table 4. Number of razorback suckers stocked by source and year in the San Juan River, New Mexico, Colorado, and Utah, 1994-2007.

Source	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	total
24 RD				1628											1628
AQUARIUM									13	11					24
6-PACK #1										158		5	565	2034	2762
6-PACK #2										536		75	423	1567	2601
6-PACK #3									2			202	504	3073	3781
6-PACK #4									1	1	294	351	1001	1794	3442
6-PACK #5										4	714	285	260	338	1601
6-PACK #6										7	208	581	530	188	1514
EAST AVOCET							430	194	6	7	1453	494	6435	180	9199
WEST AVOCET							606	490	6	42				271	1415
HIDDEN								3	10				2912	1272	4197
OJO					1151		8	1							1160
DEXTER													1129	1344	2473
OURAY	478			227											705
UVALDE														4847	4847
WAHWEAP	209	16	237		124				102	121	303				1112
WILLOW BEACH				1028											1028
total	687	16	237	2883	1275		1044	688	140	887	2972	1993	13759	16908	43489

Table 5. Number of razorback suckers stocked by source and 50-mm total length (TL) group in the San Juan River, New Mexico, Colorado, and Utah, 1994-2007.

	Total length (TL) group												
Season	50-99	100-149	150-199	200-249	250-299	300-349	350-399	400-449	450-499	500-549	550-600	total	Mean TL
24 RD		184	1000	370	52	20	1	1				1628	185.4
AQUARIUM		21	3									24	130.6
6-PACK #1		8	623	949	829	325	27	1				2762	240.7
6-PACK #2		16	286	625	718	650	224	77	5			2601	275.8
6-PACK #3		8	1106	1323	503	416	370	55				3781	245.0
6-PACK #4			49	425	1265	1224	356	102	21			3442	299.7
6-PACK #5		23	151	124	205	585	375	130	8			1601	312.7
6-PACK #6				6	222	275	474	471	65	1		1514	369.5
EAST AVOCET		94	733	1069	4849	587	946	638	249	34		9199	279.6
WEST AVOCET		59	452	146	89	55	540	56	18			1415	280.2
HIDDEN	7	244	1462	1061	1083	294	27	3	12	4		4197	222.0
OJO			7	1120	23	1			5	3	1	1160	234.0
DEXTER						1129	1061		283			2473	359.0
OURAY		124	171	356	31	13	10					705	202.3
UVALDE						4847						4847	316.0
WAHWEAP				8	93	234	386	348	41	1	1	1112	373.2
WILLOW BEACH			1023	5								1028	193.1
total	7	781	7066	7587	9962	10655	4797	1882	707	43	2	43489	277.1

Table 6. The m_{ij} array produced from Program Mark depicting release year and number of razorback suckers released, R(i), and the number of recaptured (multiply recaptured fish reappear in a different row total after first recapture because they were released again in a different year) and re-released fish in each subsequent sampling year in the San Juan River, New Mexico, Colorado, and Utah, 1994-2007. The R(i) is the total number of fish stocked that year, plus the number of fish recaptured and re-released from previous fish stockings in that same year (e.g., the 1995 R(i) = 43 is the sum of the 16 fish stocked that year plus the 27 fish recaptured and released in 1995 from the group of fish stocked in 1994). The R(i) of 19 for 1999 when no fish were stocked is the sum of the razorback sucker recaptures from previous stockings made in 1999. The "Total" column indicates the by-row sum of all fish recaptured in all years from a particular R(i) group. The mean total length (TL) of fish in a particular year is from stocking information only and does not include the lengths of fish that were recaptured that year from previous stockings and rereleased.

Release		# recaptured and released/year															
Year	R(i)	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	Total	TL
1994	687	27	12	9	3	5	5	5	1	0	0	0	0	0	0	67	251
1995	43		3	0	1	3	2	3	2	0	0	0	0	0	0	14	424
1996	252			3	2	1	0	1	1	1	0	0	0	0	0	9	336
1997	2895				3	2	1	2	1	0	0	0	0	0	0	9	192
1998	1284					8	4	3	4	3	0	1	1	0	0	24	250
1999	19						1	1	1	0	0	0	0	0	0	3	
2000	1057							27	6	7	5	6	3	2	2	58	214
2001	730								47	67	45	26	20	14	7	226	395
2002	203									23	12	4	4	3	1	47	319
2003	988										31	8	6	6	4	55	327
2004	3065											194	83	44	18	339	353
2005	2232												89	44	21	154	355
2006	13965													97	41	138	261
2007	17118														239	239	280

Table 7. Stocking year and recapture frequency of razorback suckers released in the San Juan River, New Mexico, Colorado, and Utah, 1994-2007. The 1st-interval (year) recaptures are those fish recaptured in the first calendar year subsequent to stocking; total recaptures are those made in all sampling years subsequent to the 1st year. The 1st-interval survival rates estimated from recapture data are shown for comparison to recapture rates and fish length.

Stocking year	Recaptures 1st year	Recaptures all years	Total released	% 1st year recaptures	% total recaptures	1st year survival	Mean TL (mm)
1994	27	67	687	3.9	9.8	0.913	251
1995	3	7	16	18.8	43.8	0.989	424
1996	1	2	237	0.4	0.8	0.006	336
1997	3	7	2883	0.1	0.2	0.019	192
1998	8	22	1275	0.6	1.7	0.027	250
1999	No fish stocked						
2000	26	56	1044	2.5	5.4	0.043	214
2001	43	215	688	6.3	31.3	0.957	395
2002	13	28	140	9.3	20.0	0.778	319
2003	11	18	887	1.2	2.0	0.002	327
2004	174	301	2972	5.9	10.1	0.024	353
2005	43	75	1993	2.2	3.8	0.007	355
2006	72	93	13759	0.5	0.7	0.003	261
2007	189	189	16908	1.1	1.1	0.010	280

Table 8. Models used to estimate survival (phi) and probability of recapture (p) for razorback suckers released into the San Juan River, New Mexico, Colorado, and Utah, 1994-2007. Covariates used to estimate effects on phi and *p* are enclosed in parentheses for each model description. Covariate descriptions are as follows: t = year specific ϕ or *p*; season = seasonal differences in phi; *a1* = effects of 1st-interval in the river on phi or *p*; TL or TL^2 = total length or its quadratic term effects on phi or *p*; source = effects of hatchery source on phi; Hours and Trips = effects of sampling effort, measured as sampling hours or number of sampling trips respectively, on *p*; a2 = effect of 2nd-interval in the river on phi; and . = constant phi or *p* over the sampling period. The AIC_c, and Delta AIC_c scores and model weights are used for model selection, Num. Par. is the total number of parameters estimated by the model, and the model deviance describes the change in model fit as parameters are added or subtracted.

Model	AICc	Delta AICc	AICc Weights	Num. Par	Deviance
{phi(t + season + a1 + TL^2) p(t+a1 + TL^2)}	11100.635	0	0.99938	35	11030.578
{phi(t+season+a1+TL) p(t+a1 + TL^2)}	11116.989	16.3539	0.00028	34	11048.935
{phi(t+season+a1+TL) p(t+a1 + TL)}	11118.448	17.8138	0.00014	33	11052.398
{phi(t+season+a1+TL^2) p(t+a1 + TL)}	11119.033	18.3979	0.0001	34	11050.979
{phi(t+season+a1+TL) p(t+a1)}	11119.106	18.4718	0.0001	32	11055.059
{phi(t+season+a1+TL) p(t)}	11130.037	29.402	0	31	11067.992
{phi(t+season+a1+TL) p(Hours+a1 + TL)}	11218.252	117.6171	0	22	11174.229
{phi(t+season+a1+TL) p(Trips+a1 + TL)}	11223.221	122.5861	0	22	11179.198
{phi(t+season+a1) p(t)}	12274.975	1174.3402	0	30	12214.933
{phi(t+a1) p(t)}	12486.19	1385.5554	0	27	12432.156
{phi(source+a1) p(t)}	12588.007	1487.3719	0	32	12523.959
{phi(t) p(t)}	13507.966	2407.3309	0	26	13455.934
{phi(season+a1) p(t)}	13545.955	2445.3205	0	19	13507.938
{phi(a1) p(t)}	13566.944	2466.3096	0	16	13534.932
{phi(a2) p(t)}	13568.051	2467.4161	0	17	13534.037
{phi(source(a1)+a1+TL^2) p(t+a1 + TL^2)}	13919.144	2818.5096	0	37	13845.081
{Phi(.) p(.) PIM}	14778.173	3677.5387	0	2	14774.173

Table 9. Logit ϕ (survival) and *p* (capture probability) parameter estimates and some standard errors (SE) and 95% confidence limits (CI) for the top top-ranked mean survival model to predict survival rates and probability of recapture of razorback suckers released in the San Juan River, New Mexico, Colorado, and Utah, 1994-2007. The estimates are by year, where the logit ϕ intercept represents the effects for 2007 in summer, *a1* is the first year in the river effect, TL = total length (mm), and autumn, winter, and spring are the remaining seasonal effects. The logit *p* values are recapture estimates by year; the logit *p* intercept represents the effect for 2008 in summer, *a1* is the first year in the river effect, and TL is as described above. There is no logit *p* value for 1994 because no recaptures that were included in modeling had taken place in that first year of stocking.

	Survival				Capture probability			
Effect	Estimate	SE	lower 95% CI	upper 95% CI	Estimate	SE	lower 95% CI	upper 95% CI
intercept	2.8946	0.3054	2.2960	3.4931	-0.7927	0.2445	-1.2718	-0.3135
1994	5.1780	0.8997	3.4146	6.9414				
1995	3.1640	2.8082	-2.3401	8.6682	-1.2299	0.3614	-1.9383	-0.5216
1996	-2.2582	0.5009	-3.2398	-1.2765	-1.7208	0.3767	-2.4591	-0.9825
1997	-1.1135	0.5250	-2.1425	-0.0845	-1.5941	0.4327	-2.4421	-0.7461
1998	-0.7582	0.4671	-1.6737	0.1573	-2.0110	0.4751	-2.9422	-1.0799
1999	-3.2008	0.6062	-4.3890	-2.0127	-1.6151	0.4247	-2.4475	-0.7827
2000	-0.2577	0.3974	-1.0365	0.5212	-0.8939	0.4175	-1.7122	-0.0756
2001	5.9763	1.0688	3.8816	8.0711	-0.5750	0.3336	-1.2288	0.0789
2002	4.0472	0.7661	2.5457	5.5488	-2.0191	0.2939	-2.5951	-1.4431
2003	-3.2170	0.3568	-3.9164	-2.5176	-1.3588	0.2682	-1.8844	-0.8332
2004	-0.8515	0.3133	-1.4656	-0.2373	-0.4652	0.3023	-1.0577	0.1273
2005	-2.1818	0.3196	-2.8083	-1.5554	-0.5710	0.2898	-1.1390	-0.0030
2006	-2.8255	0.3278	-3.4679	-2.1831	-0.4202	0.2652	-0.9400	0.0996
2007					0.0205	0.1842	-0.3406	0.3815
a1	-13.743	1.173	-16.042	-11.444	4.3882	1.4253	1.5946	7.1819
TL	0.0405	0.0068	0.0272	0.0538	-0.0260	0.0079	-0.0415	-0.0104
TL^2	0.0000	0.0000	-0.0001	0.0000	0.0000	0.0000	0.0000	0.0001
autumn	0.0857	0.2802	-0.4634	0.6348				
winter	-4.7613	0.9370	-6.5978	-2.9248				
spring	-0.5421	0.1140	-0.7655	-0.3186				

Table 10. Annual survival estimates (standard errors [SE], upper and lower 95% confidence limits [CI], and coefficients of variation [CV, (SE/estimate)*100]) for razorback suckers that were stocked in the San Juan River, New Mexico, Colorado, and Utah, 1994-2007, based on recaptures of tagged fish. Estimates are from Program MARK for razorback suckers in their 1st-interval (*a1*) in the river after stocking, and post 1st–interval (*post-a1*). No SE was estimated for fish released in 1995 because few fish were stocked but recapture rates were very high. There was no 1st-interval estimate for 1999 because no razorback suckers were stocked. There was no estimate for *post-a1* razorback suckers stocked in 1994 because that was the first year of stocking (e.g., no *post-a1* fish were available).

	1st-interval survival					Post 1st-interval survival				
Effect	Estimate	SE	lower 95% CI	upper 95% CI	CV	Estimate	SE	lower 95% CI	upper 95% CI	CV
1994	0.913	0.078	0.607	0.986	8.5					
1995	0.989	0.000				1.000	0.000			
1996	0.006	0.003	0.002	0.015	49.4	0.647	0.100	0.437	0.812	15.4
1997	0.019	0.010	0.007	0.053	52.4	0.860	0.064	0.683	0.946	7.5
1998	0.027	0.012	0.011	0.065	46.3	0.894	0.045	0.770	0.956	5.0
1999						0.424	0.120	0.219	0.659	28.4
2000	0.043	0.016	0.020	0.087	37.2	0.933	0.022	0.873	0.965	2.4
2001	0.957	0.048	0.695	0.996	5.0	1.000	0.000	0.998	1.000	0.0
2002	0.778	0.146	0.401	0.948	18.7	0.999	0.001	0.994	1.000	0.1
2003	0.002	0.001	0.001	0.004	30.1	0.421	0.036	0.352	0.492	8.5
2004	0.024	0.005	0.016	0.036	20.7	0.885	0.015	0.853	0.911	1.7
2005	0.007	0.002	0.004	0.010	24.0	0.670	0.034	0.600	0.734	5.1
2006	0.003	0.001	0.002	0.005	22.4	0.516	0.052	0.415	0.616	10.1
2007	0.010	0.003	0.006	0.018	27.0	0.766	0.055	0.643	0.856	7.1

Table 11. Annual probability of recapture estimates (standard errors [SE], upper and lower 95% confidence limits [CI], and coefficients of variation [CV, (SE/estimate)*100]) for razorback suckers based on recaptures of tagged fish that were stocked in the San Juan River, New Mexico, Colorado, and Utah, 1994-2007. Estimates are from Program MARK for razorback suckers in their 1st-interval (*a1*) in the river after stocking, and post 1st-interval (post-a1). There was no 1st-interval estimate for 2000 because no razorback suckers were stocked in 1999. There was no estimate for *post-a1* razorback suckers in 1995 because that was the first year after stocking (e.g., no *post-a1* fish were available).

	1st-interval probability of capture					Post 1st-interval probability of capture				
Effect	Estimate	SE	lower 95% CI	upper 95% CI	CV	Estimate	SE	lower 95% CI	upper 95% CI	CV
1995	0.138	0.033	0.085	0.217	24.1					
1996	0.089	0.027	0.049	0.157	30.1	0.074	0.020	0.044	0.123	26.5
1997	0.101	0.036	0.050	0.195	35.1	0.085	0.028	0.044	0.157	32.6
1998	0.069	0.028	0.031	0.147	40.1	0.057	0.022	0.026	0.120	39.3
1999	0.099	0.034	0.049	0.189	34.8	0.083	0.027	0.042	0.155	33.3
2000						0.156	0.044	0.087	0.263	28.4
2001	0.236	0.046	0.158	0.338	19.6	0.203	0.036	0.140	0.283	18.0
2002	0.068	0.013	0.047	0.099	19.1	0.057	0.009	0.042	0.077	15.5
2003	0.124	0.021	0.089	0.170	16.6	0.104	0.010	0.086	0.126	9.9
2004	0.257	0.041	0.185	0.346	16.0	0.221	0.027	0.174	0.278	12.0
2005	0.237	0.033	0.179	0.307	13.8	0.203	0.022	0.164	0.249	10.7
2006	0.266	0.038	0.198	0.346	14.2	0.229	0.021	0.190	0.274	9.3
2007	0.362	0.048	0.275	0.460	13.2	0.318	0.038	0.248	0.397	12.0
2008	0.357	0.067	0.239	0.496	18.8	0.313	0.054	0.218	0.427	17.3

Table 12. Source and recapture rates of razorback suckers stocked in the San Juan River, New Mexico, Colorado, and Utah, 1994-2007. First-time recaptures are the total number of fish recaptured once; total recaptures are the cumulative recapture events of all fish ever recaptured, including multiple recaptures of individuals. Total razorback suckers released and the % of fish released from each site, and their mean total length (TL) are also reported.

	1st time recaptures		Total recaptures		Total	% of total	Mean
source	No.	%	No.	%	released	released	TL
24 RD	4	0.2	7	0.4	1628	3.7	185.4
AQUARIUM	0	0	0	0.0	24	0.1	130.6
6-PACK #1	10	0.4	10	0.4	2762	6.4	240.7
6-PACK #2	8	0.3	8	0.3	2601	6.0	275.8
6-PACK #3	35	0.9	37	1.0	3781	8.7	245.0
6-PACK #4	36	1.0	40	1.2	3442	7.9	299.7
6-PACK #5	30	1.9	38	2.4	1601	3.7	312.7
6-PACK #6	27	1.8	31	2.0	1514	3.5	369.5
EAST AVOCET	458	5.0	623	6.8	9199	21.2	279.6
WEST AVOCET	171	12.1	232	16.4	1415	3.3	280.2
HIDDEN	29	0.7	33	0.8	4197	9.7	222.0
OJO	10	0.9	14	1.2	1160	2.7	234.0
DEXTER	93	3.8	93	3.8	2473	5.7	359.0
OURAY	5	0.7	5	0.7	705	1.6	202.3
UVALDE	0	0	0	0.0	4847	11.1	316.0
WAHWEAP	162	14.6	206	18.5	1112	2.6	373.2
WILLOW BEACH	2	0.2	2	0.2	1028	2.4	193.1

Table 13. Variation in recapture frequency of razorback suckers raised at various sources and stocked in the San Juan River, New Mexico, Colorado, and Utah, 1994 and 2004, measured by total number of fish returned in sampling conducted the calendar year after stocking (1st time recaptures, and % of 1st year recaptures of the total razorback suckers released). Stocking season is spring (Spr, March through May), summer (Sum, June through August), autumn (Aut, September-October) or winter (November and December). Mean total length (TL) is average length (mm) at stocking. All but 30 fish stocked in 1994 were released in winter.

Source	Season	1st-time recaptures	% 1st-time recaptures	Number stocked	Mean TL (mm)
1994					
Ouray	Aut-Spr	4	0.8	478	190
Wawheap	Aut-Spr	63	30.1	209	392
2004					
Six Pack ponds					
#4	Spr	7	2.4	294	322
#5	Spr/Sum	24	3.4	714	340
#6	Spr	5	2.4	208	317
East Avocet	Sum	226	15.6	1453	402
Wawheap	Spr	39	12.9	303	361

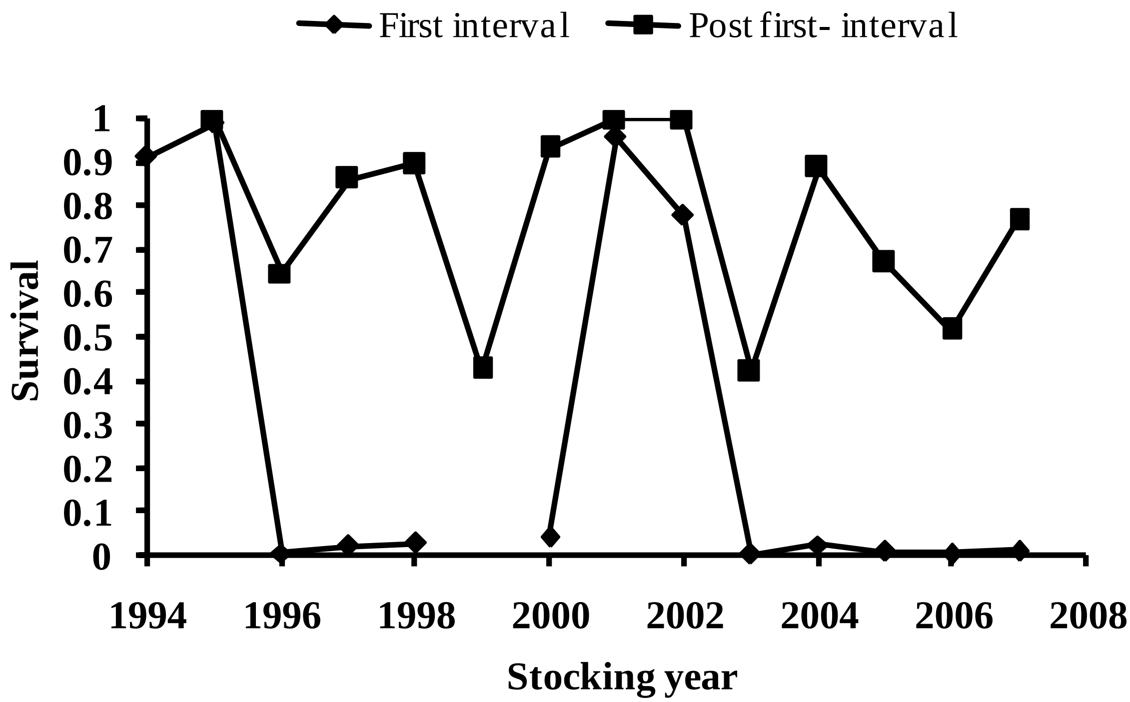

Figure 1. Annual survival estimates for razorback suckers stocked in the San Juan River, New Mexico, Colorado, and Utah, 1994-2007. Survival is estimated for razorback suckers in their 1st-interval (*a1*) in the river after stocking, and post 1st-interval (*post-a1*) using recaptures of tagged fish from 1995-2008 and analyzed in Program MARK. There was no 1st-interval estimate for 1999 because no razorback suckers were stocked. There was no estimate for *post-a1* razorback suckers in 1994 because that was the first year of stocking (i.e., no *post-a1* fish were available).

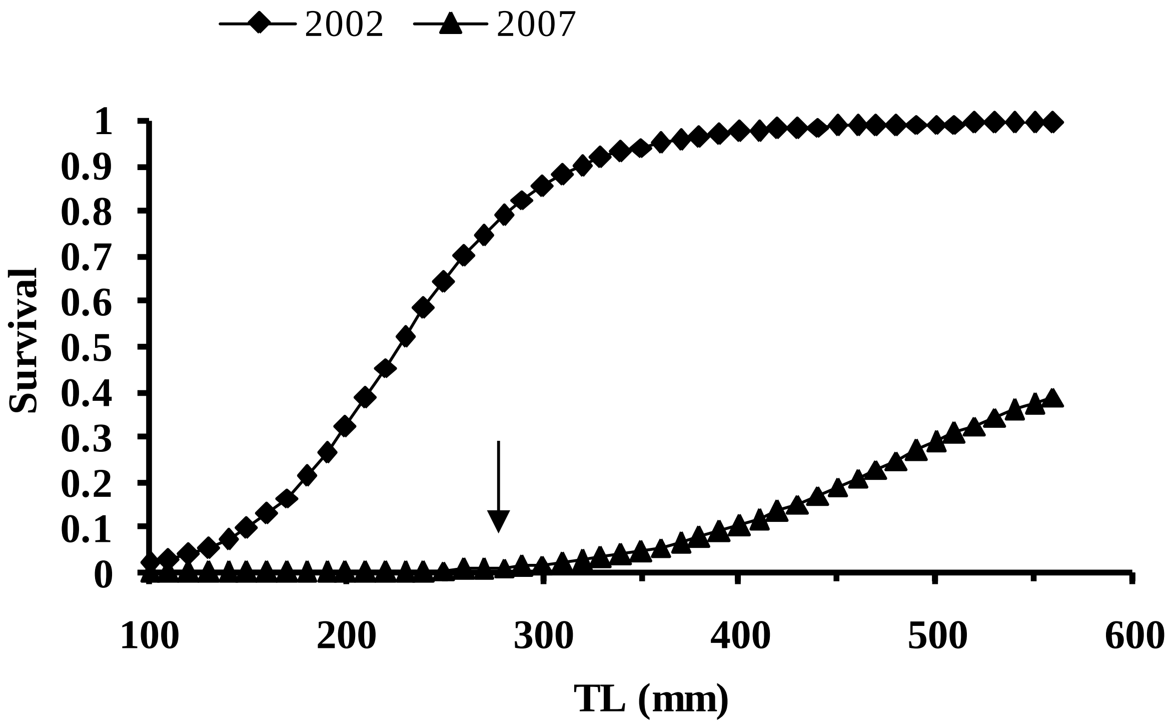

Figure 2. Length-dependent survival of razorback suckers in their 1st-interval (*a1*) in the river after stocking in the San Juan River, New Mexico, Colorado, and Utah, in 2002, an atypical and high survival year, and 2007, a typical low survival year. Survival is estimated over all seasons using recaptures of tagged fish from 1995-2008 and analyzed in Program MARK. The arrow represents the mean total length (TL, 277 mm) of all fish that were stocked.

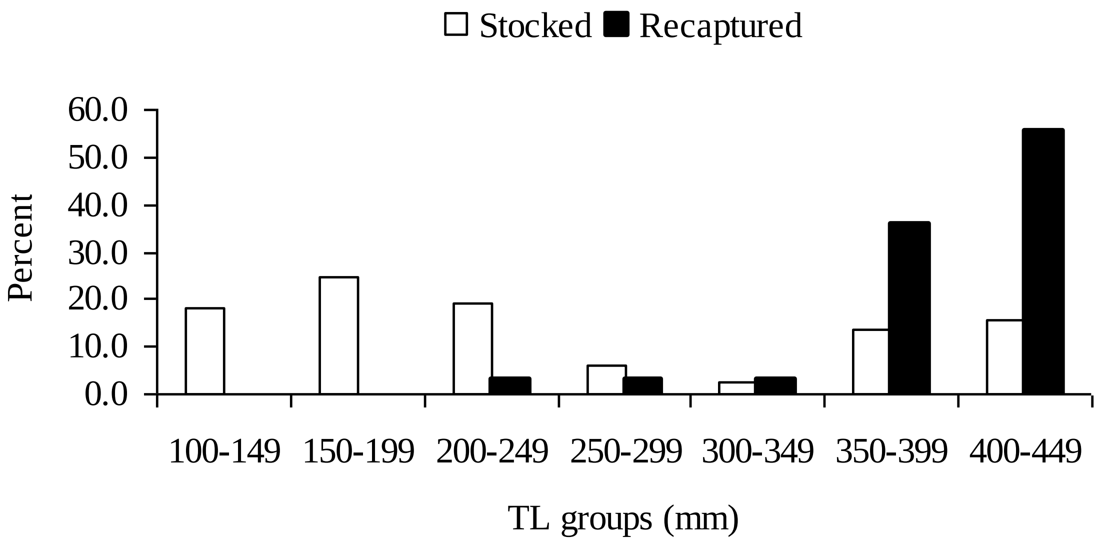

Figure 3. Percent of razorback suckers in 50-mm-total-length (TL) groups at time of stocking (open bars, n = 687 fish stocked) and percent of fish that were recaptured (n = 67, black bars) after stocking in the San Juan River, New Mexico, Colorado, and Utah, in 1994. Mean TL of all fish stocked in 1994 was 251 mm; mean TL of recaptured fish was 392 mm at the time of stocking.

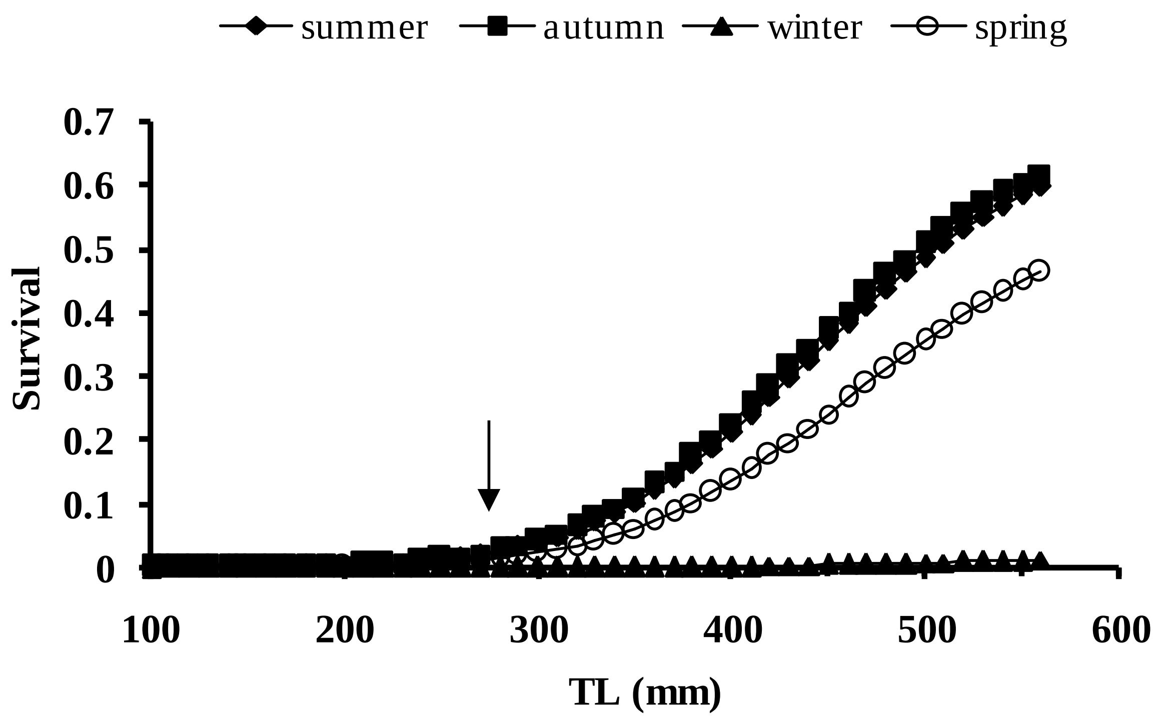

Figure 4. Length-dependent survival of razorback suckers by season for their 1st-interval (*a1*) in the river after stocking in 2007 in the San Juan River, New Mexico, Colorado, and Utah. Estimates use recapture data from tagged fish from 1995-2008 and analyzed in Program MARK; 2007 is a typical, low 1st-interval survival rate year. Stocking season was defined as spring (March through May), summer (June through August), autumn (September and October), and winter (November and December); no fish were stocked in January or February. The arrow represents the mean total length (TL, 277 mm) of all fish that were stocked.

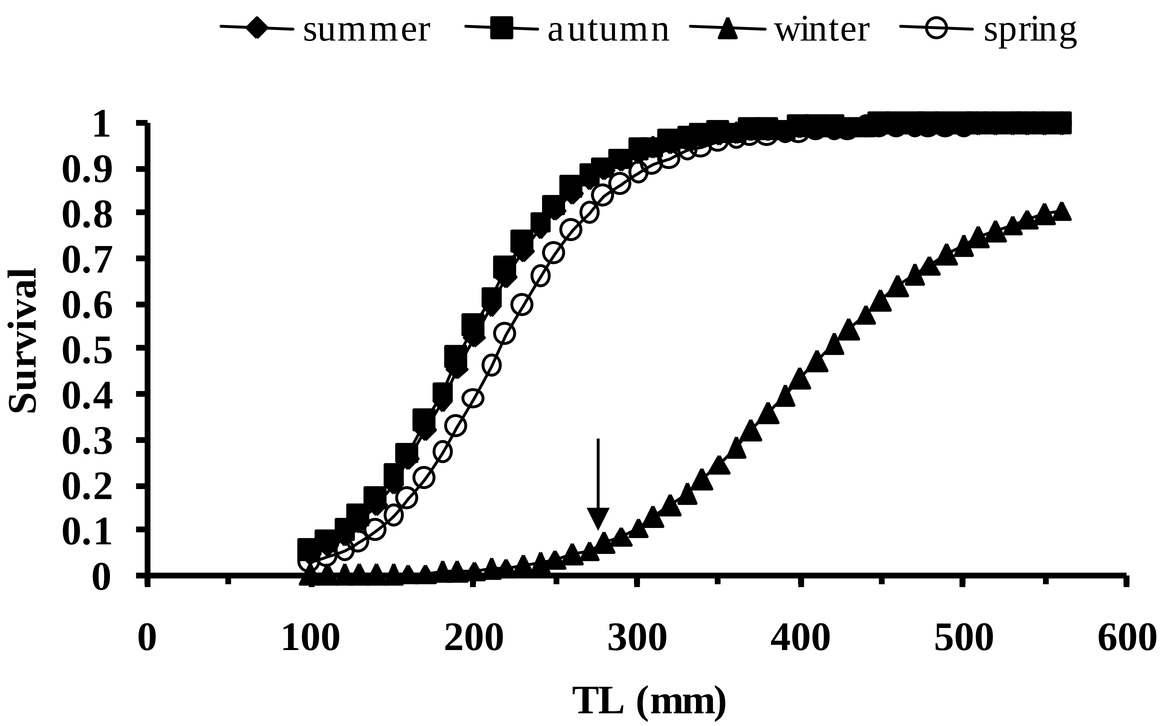

Figure 5. Length-dependent survival of razorback suckers by season for their 1st-interval (*a1*) in the river after stocking in 2002 in the San Juan River, New Mexico, Colorado, and Utah. Estimates use recapture data from tagged fish from 1995-2008 and analyzed in Program MARK; 2002 is an atypical, high 1st-interval survival rate year. Stocking season was defined as spring (March through May), summer (June through August), autumn (September and October), and winter (November and December); no fish were stocked in January or February. The arrow represents the mean total length (TL, 277 mm) of all fish that were stocked.

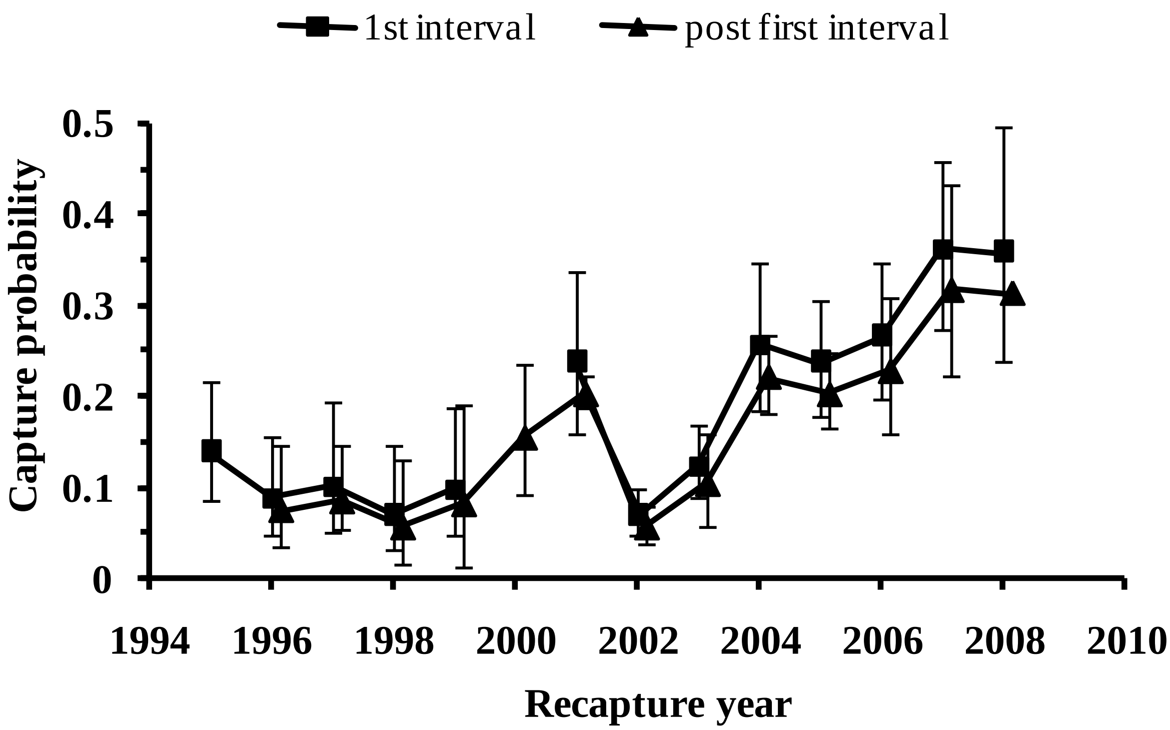

Figure 6. Annual probability of recapture estimates (bars are 95% confidence limits) for razorback suckers stocked in the San Juan River, New Mexico, Colorado, and Utah, 1994-2007. Estimates are for razorback suckers in their 1st-interval (*a1*) in the river after stocking, and in the *post-a1* period, using recaptures of tagged fish from 1995-2008 and analyzed in Program MARK. There was no 1st-interval estimate for 2000 because no razorback suckers were stocked in 1999 and available for recapture in the subsequent year. There was no estimate for *post-a1* razorback suckers in 1995 because no *post-a1* fish were available for recapture in that first year after stocking.

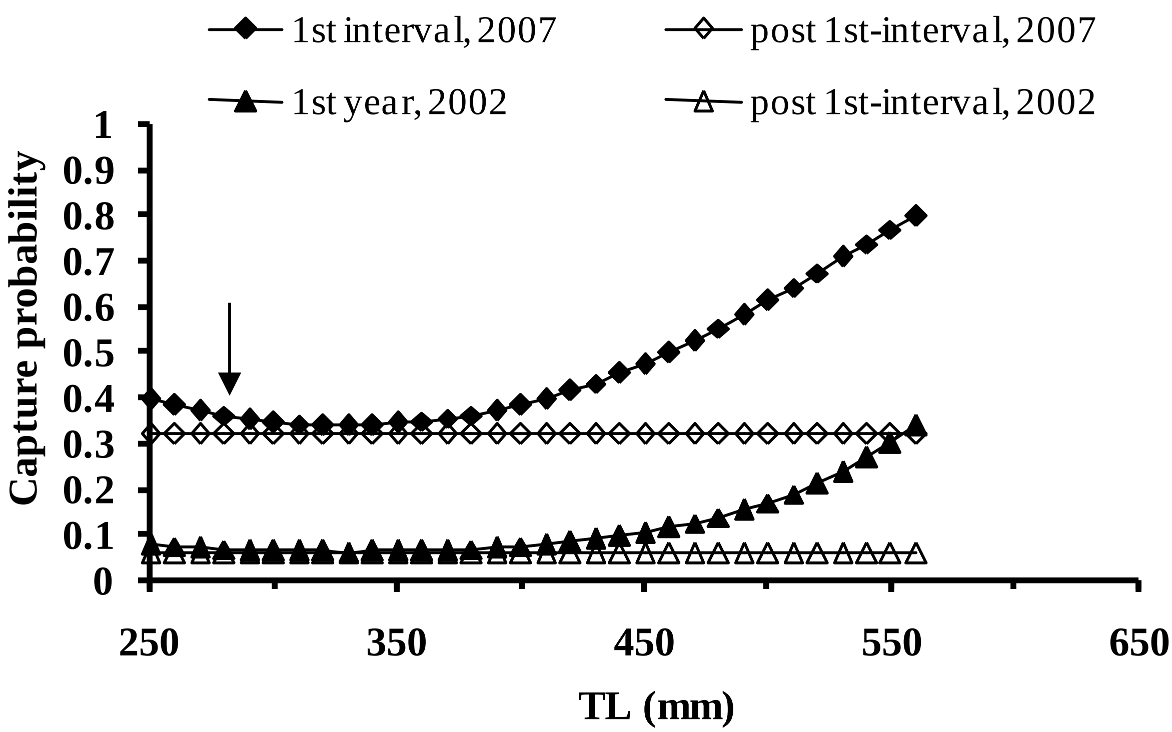

Figure 7. Length-dependent probabilities of recapture for razorback suckers in their 1st-interval (*a1*) in the river after stocking and constant recapture rates in the *post-a1* period, in the San Juan River, New Mexico, Colorado, and Utah, in 2002 and 2007. The arrow represents the mean total length (TL, 277 mm) of all fish that were stocked. Estimates were truncated at 250 mm total length (TL) because the quadratic term in the function caused recapture rates to continue to increase for smaller fish, which we deemed an unlikely outcome.