Lower Colorado River Multi-Species Conservation Program

Balancing Resource Use and Conservation

Demographics and Post-stocking Survival of Repatriated Razorback Suckers in Lake Mohave

2007 Annual Report

U.S. DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

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Lower Colorado River Multi-Species Conservation Program

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2007 Annual Report

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ACRONYMS AND ABBREVIATIONS

AIC	Akaike's information criterion
ASU	Arizona State University
CI	confidence interval
cm	centimeter(s)
kHz	kilohertz
km	kilometer(s)
m	meter(s)
mm	millimeter(s)
NDOW	Nevada Department of Wildlife
PIT	passive integrated transponder
scuba	self-contained underwater breathing apparatus
SUR	submersible ultrasonic receiver
TL	total length
Willow Beach NFH	Willow Beach National Fish Hatchery

Symbols

>	greater than
%	percent

CONTENTS

Page

Executive Summary ES-1

Introduction 1
Methods 2
Post-stocking Dispersal and Fate 2
2006–07 Sonic Telemetry and Captive Fish Experiment 2
2007–08 Sonic Telemetry 4
Routine Monitoring 4
Creel Census Data 5
Ecological Modeling 5
Results 7
Post-stocking Dispersal and Fate 7
2006–07 Sonic Telemetry and Captive Fish Experiment 7
2007–08 Sonic Telemetry 9
Routine Monitoring 11
Creel Census Data 14
Ecological Modeling 16
Discussion 18
Post-stocking Dispersal and Fate 18
2006–07 Sonic Telemetry and Captive Fish Experiment 18
2007–08 Sonic Telemetry 19
Routine Monitoring 20
Creel Census Data 20
Ecological Modeling 21
Continuing Studies 22
Acknowledgements 23
Literature Cited 25

Tables

Table Page

1 ASU adult razorback sucker monitoring summary for 2007 by capture month, total number of fish, PIT tag, history, and gender during March, May, and November monitoring events, Lake Mohave, Arizona and Nevada 12

2 ASU adult razorback sucker monitoring summary for 2007 by 15 paired release-capture data per fish PIT tag number with calculated time at large (capture date minus release date then divided by 30 days for months at large or 365 days for years at large) and capture history 13

3 ASU adult razorback sucker monitoring summary for 2007 by 15 paired release-capture data per fish PIT tag number with growth rate (capture TL in mm minus release TL then divided by months at large) 14

4 ASU adult razorback sucker monitoring summary for 2007 by 15 paired release-capture data with rearing type and location, and release and capture sites 15

5 Capture totals for wild (top) and repatriate (bottom) razorback suckers in Lake Mohave divided into four general zones for all years used in multi-site mark-recapture analyses 17

6 Mark-recapture model design and fit (AIC), in ascending AIC order, for wild (top) and repatriate (bottom) razorback suckers in Lake Mohave, Arizona and Nevada 18

Figures

Figure Page

1 Map of study area on Lake Mohave, Arizona and Nevada, for the 2006–07 and 2007–08 razorback sucker sonic telemetry studies. 3

2 General zone names and boundaries used to analyze razorback sucker release, catch, and effort data for Lake Mohave, Arizona and Nevada. 6

3 Summary of active, tagged razorback suckers contacted between September 27, 2006, and March 16, 2007. 8

4 Summary of active, tagged razorback sucker subadults and adults contacted between October 19 and December 31, 2007. 10

EXECUTIVE SUMMARY

Four general areas of inquiry were pursued relative to razorback suckers (*Xyrauchen texanus*) in Lake Mohave during the period covered by this report: (1) post-stocking dispersal and fate determined by sonic telemetry, (2) routine monitoring, (3) creel census, and (4) ecological modeling. Studies that were initiated prior to, but completed during, the current reporting period are presented first in the summary that follows.

The sonic telemetry study initiated in autumn 2006 was completed in 2007 along with a captive fish study to assess the effects of implanting sonic transmitters in razorback suckers. Twenty razorback suckers were implanted with sonic transmitters and released at Fortune Cove on September 17, 2006. One fish was removed from analysis because it was contacted only once immediately after release. Over the 6-month study period, dispersal was generally confined to the northern half of the reservoir. Sixteen of 19 (84 percent [%]) study fish stopped moving. Thirteen transmitters were recovered from the bottom of the lake by a self-contained underwater breathing apparatus (scuba) diver. No fish remains were observed near any recovered transmitters.

In the captive study, 20 fish were implanted with sonic transmitters and maintained in a raceway at Willow Beach National Fish Hatchery for 3 months. No transmitters were shed, and all fish remained healthy throughout the study. Manual tracking and remote sensing data, in addition to the captive fish experiment results, indicated that subadult fish face almost certain mortality in a relatively short amount of time after being repatriated into Lake Mohave. This is most likely due to the consumption of repatriated fish by striped bass (*Morone saxatilis*).

A second telemetry study was initiated in autumn 2007 to compare survivorship estimates based on telemetry between two size classes of razorback sucker repatriates: subadult razorback suckers similar in size to fish released in 2006 and adult razorback suckers approximately 50 centimeter total length. Fifteen subadult and 17 adult razorback suckers were implanted with sonic transmitters and released at Fortune Cove on October 19, 2007. All tagged fish were contacted post-release, and with the exception of one adult individual, their dispersal was confined to the northern half of the reservoir (upstream of Painted Canyon Lights). As of December 31, 2007, 4 of 15 (27%) tagged subadult fish and 13 of 17 tagged adult fish (77%) were active. Eight transmitters from immobile subadults and four transmitters from immobile adults were inspected by a scuba diver and were subsequently recovered from the bottom of the reservoir.

Arizona State University handled 20 razorback suckers (20 captures, no short-term recaptures) in 2007. Forty-five percent of the captures occurred in November (35% during the March Roundup). Sixteen individuals were passive integrated transponder (PIT)-tagged repatriates, two were wild PIT-tagged fish,

and two were untagged fish. Based on monitoring data from 2006 and 2007, the current wild razorback sucker population in Lake Mohave is estimated at 218 fish (107–1,092; 95% confidence interval). The repatriated razorback sucker population is estimated to number 1,461 (786–2,752; 95% confidence interval), with a 1% estimated survival of all repatriates released as of March 1, 2006. The current total population estimate for razorback suckers in Lake Mohave is 1,679.

Nine large striped bass (*Morone saxatilis*) (greater than 80 centimeter total length) and two large channel catfish (specific size unknown) were processed by the Nevada Department of Wildlife creel census clerk in 2007, and none contained a PIT tag.

Site fidelity appears to have little to no impact on the survival estimates of wild and repatriate razorback suckers in Lake Mohave. Multi-site mark-recapture models failed to increase model fit compared to standard mark-recapture models for both populations of fish. Bias also appeared minimal, with similar survival estimates and overlapping confidence intervals from both model types. Wild razorback suckers in Lake Mohave continue to decline, with an annual survival rate of 70.7%, and “at large” repatriate razorback suckers have an annual survival rate of 85.2%.

INTRODUCTION

Lake Mohave once was home to the largest known population of wild razorback suckers (*Xyrauchen texanus*). Historically, this population contained more than 100,000 fish, but the numbers have dwindled dramatically in recent years, and it currently is made up of fewer than 250 individuals (Marsh et al. 2003; Turner et al. 2007; Kesner et al. – this report). A repatriation program for restoring razorback suckers in Lake Mohave was begun in the early 1990s (Mueller 1995). The program utilized wild-produced larvae that were reared in protective captivity and then repatriated to the lake after growing to a nominal size of 30 centimeters (cm) or more. There have been a number of adjustments to the program that incorporate new information and attempt to increase survival of stocked fish, but results thus far have not met expectations (Marsh et al. 2005). The current (2008) recommended minimum size for stocking is 50 cm.

Razorback suckers, like many other native fishes of the region, are on a trajectory that soon will lead to their extirpation in the wild in the lower Colorado River. Conservation plans for big river fishes in the lower Colorado River (Minckley et al. 2003; U.S. Fish and Wildlife Service 2005) incorporate a population component that will occupy the main stream, but it may be impractical or impossible to accommodate this conservation strategy. If main channel populations cannot be developed and maintained, the conservation strategy for razorback suckers in the lower Colorado River may depend entirely on populations in off-channel habitats that are free of non-native fishes. It is an objective of this research to provide information needed to determine how each of these strategies should contribute to maintenance of razorback suckers in Lake Mohave and throughout the lower Colorado River. Moreover, the results of the research will provide critical demographic information and management recommendations to help ensure the long-term persistence of a genetically viable stock of adult razorback suckers in Lake Mohave.

This report summarizes the findings for the second year of the project, 2007. A second round of sonic telemetry has provided further evidence of post-repatriation mortality as well as comparative mortality estimates between two size classes of released fish. Population and survival estimates for wild and repatriate populations were updated based on results from standard monitoring. Creel census data on large striped bass abundance and the impact on razorback sucker stockings are currently being provided through collaboration with the Nevada Department of Wildlife (NDOW), and the first results of an ecological model describing the processes of survival and movement of Lake Mohave razorback suckers have shown clear evidence of site fidelity. The impact of site fidelity on survival and population estimates appears low.

METHODS

Post-stocking Dispersal and Fate

2006–07 Sonic Telemetry and Captive Fish Experiment

The initial telemetry study began in 2006, and the methods regarding sonic transmitter implantation and release and tracking of study fish are thoroughly described within the 2006 annual report (Kesner et al. 2007). Therefore, surgical, release, and tracking procedures are only summarized here.

Twenty subadult razorback suckers were implanted with sonic transmitters at Willow Beach National Fish Hatchery (Willow Beach NFH) on September 25, 2006, and were released on September 27, 2006, at Fortune Cove near River Mile[1] 41 (figure 1). Tagged fish were tracked using stationary submersible ultrasonic receivers (SURs), and they were manually tracked by boat at regular intervals. When re-contacts were made in the same location, a self-contained underwater breathing apparatus (scuba) diver was deployed with an underwater diver receiver to locate and attempt to recover the sonic transmitter. Contact locations and transmitter recoveries were used to illustrate dispersal and estimate survival, respectively.

To estimate the impact of post-surgical transmitter retention and mortality, a captive fish study was implemented. A total of 43 razorback suckers was randomly selected from a hatchery stock of subadults on January 10, 2007, and placed in an indoor raceway at Willow Beach NFH. All fish were measured (total length, [TL], nearest millimeter [mm]) and received a 400-kilohertz (kHz) passive integrated transponder (PIT) tag. Twenty individuals (mean TL = 38 cm; range = 37 to 40 cm) were selected from the group to approximate the size of fish used in the telemetry study and implanted with a transmitter following the procedures previously outlined (experimental fish). The remaining 23 fish (mean TL = 35 cm; range = 33 to 40 cm) were handled but not implanted with transmitters (control fish). All 43 fish recovered in an indoor raceway for 3 days, after which they were transferred to an outdoor raceway. Metal screens (5-mm mesh) located at both ends of the raceway prevented fish or transmitters (if shed) from exiting the system.

Study fish were fed weekly between January 10 and April 12, 2007. No antibiotics or prophylaxis were administered. Indepth monitoring of experimental fish was conducted on a bimonthly basis throughout the study. During each visit, the raceway was swept and inspected for dropped transmitters and mortalities. On April 12, 2007, all captive fish were measured (TL) and scanned for a PIT tag. PIT tag number, TL, and sexual condition were recorded for each fish. Fish growth (delta TL) was calculated as the difference in TL from initial measurements on January 10, 2007, to measurements made on April 12, 2007.

[1] River miles are measured upriver (north) from Davis Dam.

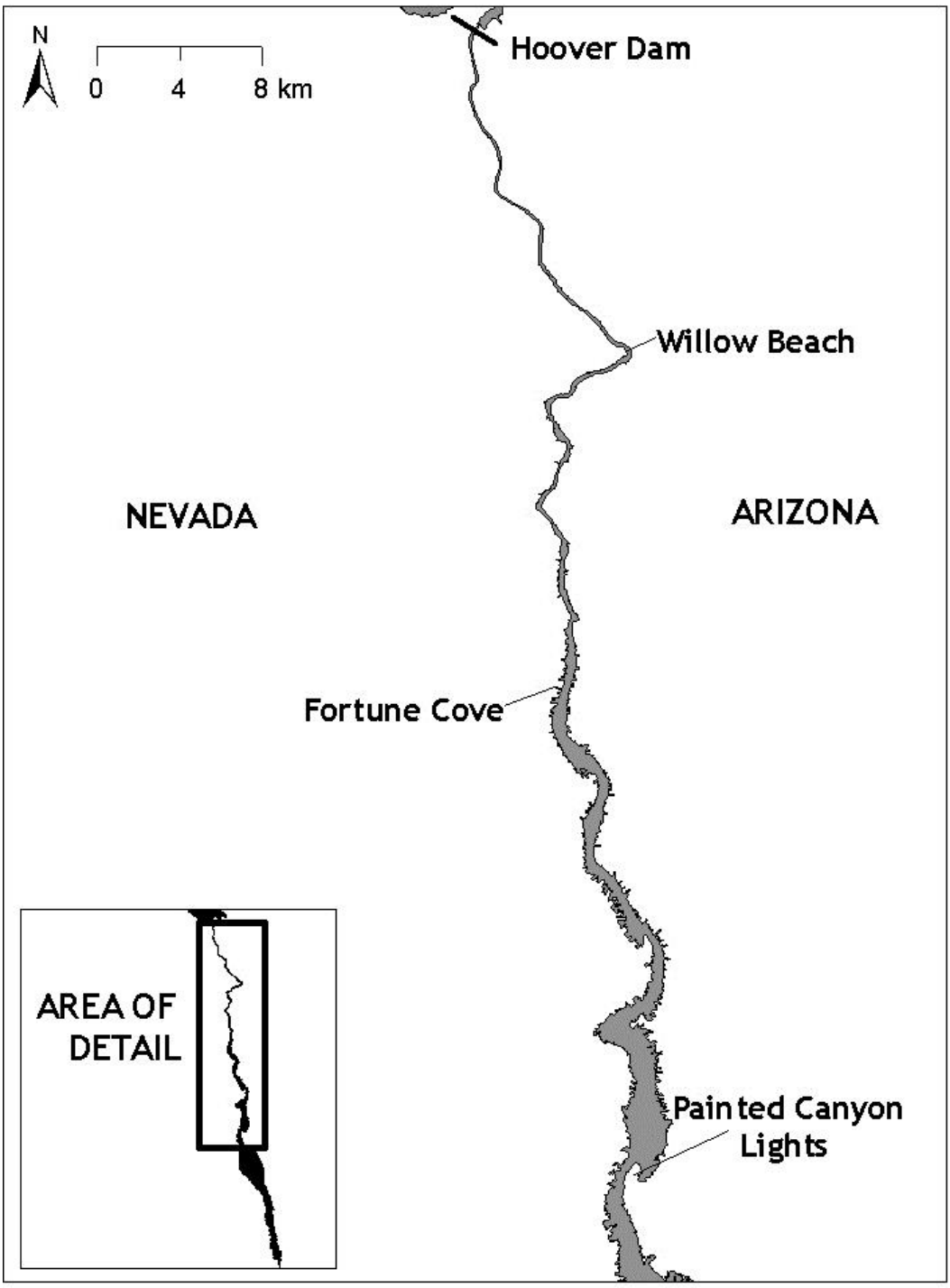

Figure 1.—Map of study area on Lake Mohave, Arizona and Nevada, for the 2006–07 and 2007–08 razorback sucker sonic telemetry studies.

Seven experimental fish (five males and two females) were randomly selected and sacrificed to locate and retrieve the implanted transmitters. All others were returned to the hatchery raceway.

2007–08 Sonic Telemetry

The second round of telemetry was designed to compare survivorship estimates based on telemetry between two size classes of released razorback sucker: subadult razorback suckers similar in size to fish released in 2006 and adult razorback suckers of approximately 50 cm TL. Thirty-two razorback suckers (15 subadults [average TL = 38 cm; range = 36 to 41 cm] and 17 adults [average TL = 50 cm; range = 48 to 51 cm]) were collected on October 17, 2007, from Willow Beach NFH. All individuals had previously received a 134-kHz PIT tag for individual identification. Fish were transferred into an indoor raceway and allowed to acclimate for 24 hours prior to surgery. Each individual was anesthetized, measured (TL), scanned for a PIT tag, and surgically implanted with a sonic transmitter following the same procedures as reported by Kesner et al. (2007). All fish were returned to the indoor raceway for a period of 2 days to ensure proper health and transmitter retention.

All study fish were placed in two, 1,893-liter aerated tanks on October 19, 2007, along with 485 additional subadult razorbacks, transported by boat downriver from Willow Beach NFH, and released into Fortune Cove (see figure 1). All fish contained 134-kHz PIT tags.

Manual and SUR tracking techniques, scuba observations, transmitter recovery, and database management all followed the methods as previously reported (Kesner et al. 2007).

Routine Monitoring

Arizona State University (ASU) personnel routinely occupy a field camp on Lake Mohave at Carp Cove, Arizona, near River Mile 20. Trammel netting and other program-related activities, such as razorback sucker larval collections, are implemented from that site. From March 12–16, 2007, five trammel nets (91.4 meter [m] x 1.8 m, 3.8-cm stretch mesh) were fished continuously along the Arizona shoreline from Pot Cove upstream to Carp Cove. Six trammel nets (same dimensions and mesh) were deployed in the same general area from May 7–11, 2007, and seven nets were deployed along both shorelines (Arizona and Nevada) in the same area from November 26–30, 2007.

Native fishes encountered were processed (measured, sexed, scanned for a PIT tag and tagged if none was present, and examined for general health and condition) and released. A fin clip was taken from a subsample of razorback

suckers, placed in 1 milliliter of 95-percent (%) ethanol in a snap-cap tube, and returned to the laboratory for genetic analyses (reported elsewhere). All relevant data were entered into the comprehensive lower Colorado River Native Fish PIT tag database maintained by ASU. Population estimates were based on the modified Peterson method (Ricker 1975).

Creel Census Data

Creel census data were collected periodically by a NDOW biologist at Cottonwood Cove, Nevada, and Willow Beach, Arizona. All striped bass greater than 80 cm TL encountered by the biologist were scanned for PIT tags. If a PIT tag was found, the stomach was to be removed and sent to the Native Fish Lab at ASU.

Ecological Modeling

In 2006, a simple contingency analysis of spatially explicit mark-recapture data demonstrated statistically significant site fidelity for wild and repatriate razorback suckers in Lake Mohave (Kesner et al. 2007). For that analysis, capture data were spatially distributed among four general zones within Lake Mohave and designated as follows, down- to upstream: lower lake, basin, Arizona Bay, and river (figure 2). In 2007, these general zones were used in a multi-site mark-recapture model to estimate survivorship and movement among the four general zones for wild and repatriate fish. All records of capture could not be used for the analysis due to a lack of complete effort data. Without complete effort data, the number of parameters to estimate would be in the thousands. Therefore, capture data were restricted to the month of March so that most, if not all, sampling years could be used. A separate analysis that focuses only on the most recent years in which accurate effort data are available and incorporates year-round data will be conducted in 2008.

Capture histories were generated from the lower Colorado River Native Fish PIT tag database from March 1991 to March 2007 for wild capture data and March 1996 to March 2007 for repatriate capture data (22 captures of repatriates between 1993 and 1995 were excluded due to sparse data). Each capture history was expressed as a series of zeros and ones (or characters A, B, C, or D, representing a zone of capture). Repatriate release data were ignored, so the first nonzero value in each history (wild or repatriate) was an “at large” capture, and all subsequent values were recaptures. The database is as consistent as possible considering the number of agencies involved, but it still contains errors or missing data; therefore, some capture histories could not be included. The actual number of individual capture histories derived from the database was 8,373 for wild fish and 1,076 for repatriates. Full details of the derivation of these capture histories can be provided upon request.

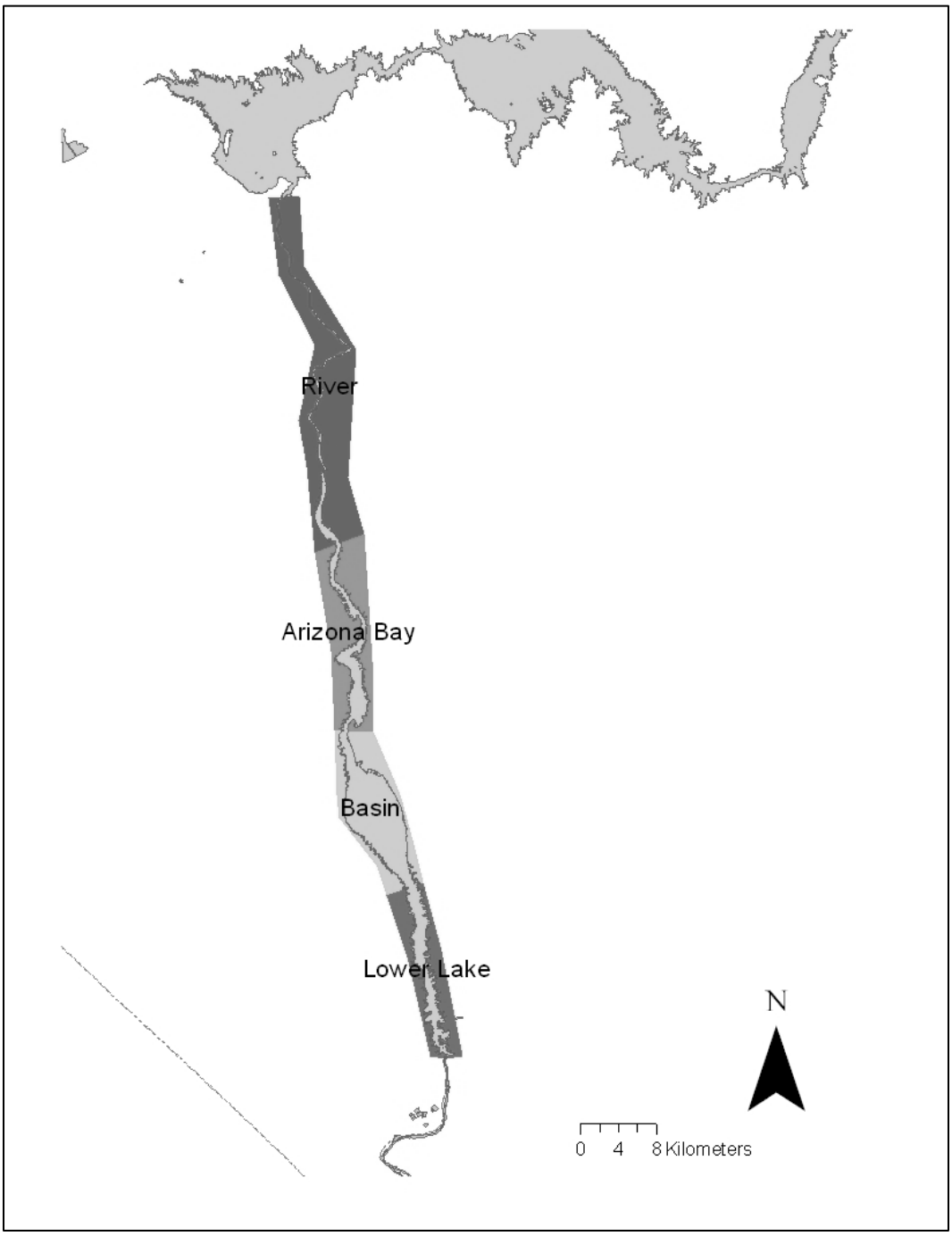

Figure 2.—General zone names and boundaries used to analyze razorback sucker release, catch, and effort data for Lake Mohave, Arizona and Nevada.

Effort in the lower lake zone was restricted to the years 1991–93 and resulted in the capture of only 30 wild razorback suckers. Capture and survival parameters for this zone would be based on little or no data for most years. Therefore, the lower lake zone was eliminated from analysis, and wild captures from that zone were recoded as basin zone captures. In addition, effort data for March were not complete for all years and, therefore, could not be used as an input variable. Instead, when no effort was applied to a particular Lake Mohave zone, the capture rate for that year and zone was fixed at zero. This resulted in a slight reduction in the number of estimated parameters.

The multi-site model is very general and can be configured in multiple variations with differing numbers of parameters. The basic structure is made up of three parameter groups: Φ_i^x – the probability of an individual surviving from year i to year $i + 1$ in zone x, p_i^x – the probability of being recaptured in zone x in year i, and Ψ_i^{xy} – the probability of moving from zone x to zone y during the period i to $i + 1$. Each parameter can vary by time, age, site (zone), cohort, and individual covariate. A portion of the total model configurations was chosen for analysis based on previous mark-recapture studies. At the most parameterized, all three parameter groups can vary by zone and year. The "best" multisite model was determined by lowest Akaike's information criterion (AIC) score (Akaike 1974). In addition, the mark-recapture model without zones used in previous publications (Marsh et al. 2003) was analyzed with current data to compare model results and best fit.

RESULTS

Post-stocking Dispersal and Fate

The results presented for the 2006–07 sonic telemetry study are reported for the period beginning September 27, 2006, and ending on April 16, 2007. The results from the 2007–08 sonic telemetry study are reported for the period between October 19, 2007 and December 31, 2007. The final results for the latter study are pending its conclusion during April 2008.

2006–07 Sonic Telemetry and Captive Fish Experiment

All 20 tagged fish were contacted, for a total of 247 individual contacts. Of the 247 total contacts, 82 (33%) were made remotely with SURs. With the exception of one individual, which briefly entered the open basin south of Painted Canyon Lights (River Mile 24), tagged fish movements were confined to the northern half of the reservoir. On two separate trips, the entire lake was surveyed (all 148 listening stations), confirming that no fish had moved past the downstream-most SUR, which was deployed at Painted Canyon Lights. One individual was

contacted immediately after stocking but was never contacted again for the remainder of the study. This individual was subsequently removed from further analysis.

At the conclusion of the study, 16 of 19 (84%) tagged fish had stopped moving (figure 3). Of those 19 individuals, 13 transmitters were recovered from the bottom of the lake by a scuba diver. No fish remains were observed near any recovered transmitters. No observations were made of three fish that stopped moving, but those individuals remained motionless for the remainder of the study and were presumed dead. All 16 deceased fish had a prior history of actively swimming and were frequently contacted by manual and SUR tracking prior to becoming stationary.

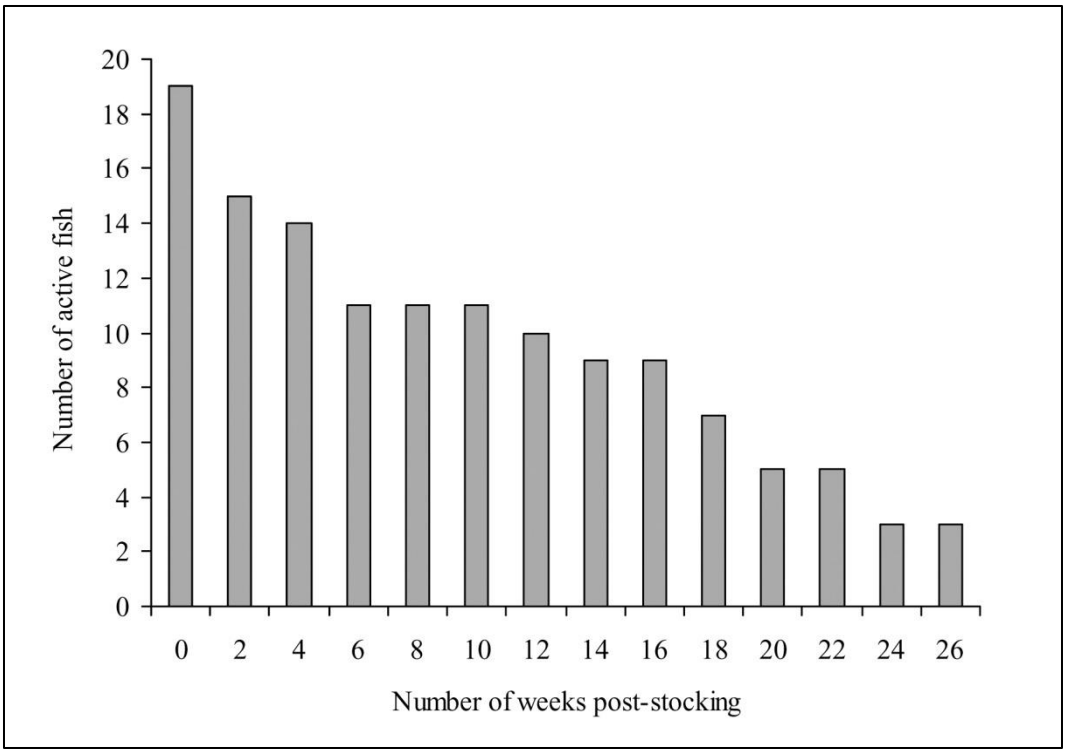

Figure 3.—Summary of active, tagged razorback suckers contacted between September 27, 2006, and March 16, 2007.
Number of active fish is the total number of fish without a documented dead contact for a given bimonthly survey.

Throughout the 3-month duration of the captive fish study, all 43 individuals (20 experimental, 23 control) remained active and healthy, and no transmitters were shed. All incisions in experimental fish had healed, and there were no signs of infection. Minor irritation was observed at the site of some sutures. At the conclusion of the study, both male and female fish showed visible signs of milt or egg production. Transmitters from sacrificed fish were located near the incision

site, either between the ventral abdominal wall and gut lumen or between folds of the intestine. There was no evidence of transmitter encapsulation by connective tissue or intestinal loops.

Growth regressions for control and experimental fish were not significant (linear regression $r^2 = 0.09$, $p > 0.1$; $r^2 = 0.03$, $p > 0.1$, respectively); therefore, growth rates could not be compared. Fish growth was positive for both groups, but variability was high. Individual experimental fish grew 2 to 9 mm (mean delta TL = 6 mm), while control fish grew 0 to 11 mm (mean delta TL = 5 mm).

2007–08 Sonic Telemetry

All 15 subadult razorback suckers were contacted, for a total of 144 contacts, 76 (53%) of which were made remotely by SURs. Subadult dispersal was confined exclusively to the northern half of the reservoir (upstream of Painted Canyon Lights).

Thirty-three percent of subadult fish were immobile by the end of the second week post-stocking, and the number of stationary transmitters subsequently increased over time. By December 31, 2007, 4 of 15 (27%) tagged subadult fish were still active (figure 4). Of those, eight transmitters were inspected by a scuba diver and were subsequently recovered from the bottom of the reservoir. No fish remains were present near any recovered transmitter (recovery of the remaining three transmitters is planned for April 2008). Of the 11 sessile transmitters, 10 were located in the main channel (mean distance was 6 kilometers [(km] from the release site [range 1 to 19 km], mean depth was 8 m [range 3 to 18 m]), and one was located in a cove (3 km from the release site; depth was 4 m).

All 17 adult razorback suckers were contacted, for a total of 328 contacts, 233 (71%) of which were made remotely by SURs. With the exception of one tagged individual, fish dispersal was confined exclusively to the northern half of the reservoir (upstream of Painted Canyon Lights).

The number of active adult fish remained high (100%) 2 weeks following stocking, and by the end of the first month, 13 of 17 (77%) tagged fish were still active (figure 4). Thereafter, the number of active, tagged adult fish remained consistent through December 31, 2007. All four immobile transmitters were inspected by a scuba diver and were subsequently recovered from the bottom of the reservoir. No fish remains were present near any recovered transmitter. Of the four sessile transmitters, three were located in the main channel (mean distance was 8 km from the release site [range 1 to 21 km], mean depth was 10 m [range 6 to 19 m]) and one was located in a cove (54 km from the release site; depth was 21 m).

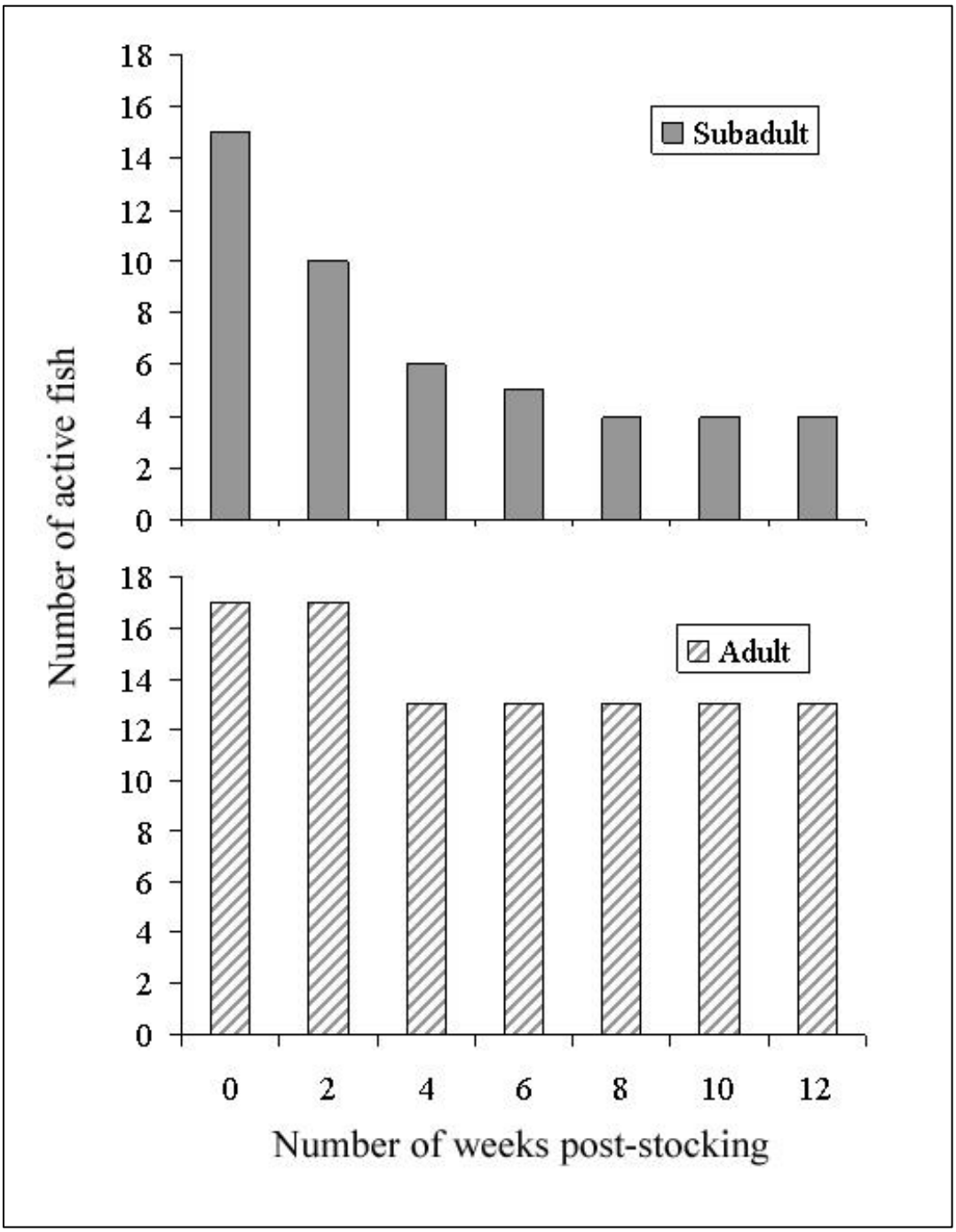

Figure 4.—Summary of active, tagged razorback sucker subadults and adults contacted between October 19 and December 31, 2007.
Number of active fish is the total number of fish without a documented dead contact for a given bimonthly survey.

Routine Monitoring

ASU handled 20 razorback suckers (all captures) in 2007. November and March monitoring activities accounted for 45 (n = 9) and 35% (n = 7) of the captures, respectively (table 1). Eighteen individuals had PIT tags, and two fish did not. Of the two fish without PIT tags, one was suspected to be a repatriate due to its small size and overall condition, and the other untagged fish was deemed wild from field notes that remarked it was an "old" fish. Both fish were noted as such in the database and included in this summary as such for a total of 17 repatriated and 3 wild fish. The majority of fish captured were female. The two true wild fish were females initially captured 9 and 7 years earlier in 1998 and 2000, respectively, near Nine Mile Cove and Half-way Wash, Nevada, in the basin zone, approximately 3 river miles south and across the lake from the ASU monitoring area. For purposes of this report, only the 15 repatriated fish with paired release-capture data will be discussed further; data were omitted from the suspected repatriates captured without a tag and from one fish released 7 days prior to its capture.

Nine fish were captured in 2007 for the first time since their release into the lake, while six fish had two to five prior captures (table 2). Four fish were tagged in the 1990s, with the oldest tag from 1995. All of the remaining fish were tagged since 2000. Eight fish were at large 3 years or less, while seven were at large for 7 years or more, with four of these fish at large for 10 or more years. Five fish with year class information ranged from approximately 2 to 4 years old at stocking, with most of these fish at large from 1 to 3 years at time of capture in 2007.

Five fish were less than 35.0 cm TL at release, 10 fish were greater than 35.0 cm TL at release, and all fish were greater than 49.5 cm TL upon capture, with the exception of a fish that was only at large 33 days. Of the fish at large for 1 year or less, growth ranged from 0.5 to 1.0 cm TL per month. Growth for fish at large 2 to 3 years and 7 or more years ranged from 0.6 to 0.7 cm and 0.2 to 0.3 cm TL per month, respectively (table 3). With the exception of one individual, all fish had specific genders at the time of capture in 2007.

Sixty percent of total fish captured in 2007 originated from lakeside backwaters (table 4). Yuma and North Chemehuevi Coves and Arizona Juvenile contributed two fish each from lakeside backwaters, totaling 40% of the total fish captured. Offsite rearing facilities contributed 40% of the total fish captured, with the majority reared at Willow Beach NFH. One fish released at Davis Cove traveled the furthest, approximately 32 km upstream to the ASU monitoring area. Others traveled 2 to 20 km from their release sites on both sides of the reservoir, while one fish traveled less than 1.6 km from Pot Cove, Arizona.

Table 1.—ASU adult razorback sucker monitoring summary for 2007 by capture month, total number of fish, PIT tag, history, and gender during March, May, and November monitoring events, Lake Mohave, Arizona and Nevada

Capture month	Total N fish (% of total)	PIT tag? (% of total)		History (% of total)		Gender (% of total)		
		Yes	No	Repatriate	Wild	Female	Male	Juvenile
March	7 (35)	6 (33)	1[a]	6 (35)	1	3 (25)	4 (57)	–
May	4 (20)	3 (17)	1[b]	3 (18)	1	2 (17)	2 (29)	–
November	9 (45)	8 (44)	–	8 (47)	1	7 (58)	1	1
Total (% of total N fish)	20	18 (90)	2 (10)	17 (85)	3 (15)	12 (60)	7 (35)	1 (5)

[a] One fish without a tag was suspected to be a repatriate, and its history was marked as such in the database.
[b] One fish without a tag was suspected to be a wild adult, and its history was marked as such in the database.

Table 2.—ASU adult razorback sucker monitoring summary for 2007 by 15 paired release-capture data per fish PIT tag number with calculated time at large (capture date minus release date then divided by 30 days for months at large or 365 days for years at large) and capture history

(Data are in order by number of captures and also include year class information where available. Release date is when fish, generally juveniles, were stocked into Lake Mohave. Data from two repatriates were omitted: one fish suspected as a repatriate captured without a tag and from the one fish released 7 days prior to its capture.)

PIT tag	Release date	Capture date	Days at large	Months at large	Years at large	Capture history	
						Number of captures	Comments
1C2C3726CC	6/5/2007	11/27/2007	175	6	0	1	First capture in 2007
1C2C2F95DB	9/19/2007	11/27/2007	69	2	0	1	First capture in 2007
1C2C2F759A	10/26/2007	11/28/2007	33	1	0	1	First capture in 2007
4647310E0B[a]	1/10/2006	3/13/2007	427	14	1	1	First capture in 2007
46454D0758[c]	1/13/2006	11/29/2007	685	23	2	1	First capture in 2007
46466B287F[c]	1/11/2006	11/30/2007	688	23	2	1	First capture in 2007
4646422D12[b]	3/31/2005	11/30/2007	974	32	3	1	First capture in 2007
5325614D23	7/27/2000	3/16/2007	2,423	80	7	1	First capture in 2007
201D5C5512	11/20/1995	5/8/2007	4,187	138	11	1	First capture in 2007
45714D7326[b]	3/29/2005	5/11/2007	773	25	2	2	First capture in 2005, second capture in 2007
5326686D70	7/13/2000	11/28/2007	2,694	89	7	2	First capture in 2000, second capture in 2007
7F7A075004	10/9/1996	3/16/2007	3,810	125	10	3	First capture in 1998, second capture in 2000, third capture in 2003, fourth capture in 2007
1F6C06046B	11/15/1995	3/13/2007	4,136	136	11	3	First capture in 1996, second capture in 2004, third capture in 2007
2240311A0A	9/18/1996	3/13/2007	3,828	126	10	4	First capture in 2000, second capture in 2001, third capture in 2003, fourth capture in 2007
5204137512	9/26/2000	5/11/2007	2,418	79	7	5	First capture in 2001, second capture in 2003, third capture in 2004, fourth capture in 2005, fifth capture in 2007

[a] 2002 year class, reared at Willow Beach NFH.
[b] 2001 or 2003 year class, reared at Willow Beach NFH.
[c] 2003 year class, reared at Willow Beach NFH.

Table 3.—ASU adult razorback sucker monitoring summary for 2007 by 15 paired release-capture data per fish PIT tag number with growth rate (capture TL in mm minus release TL then divided by months at large)

(Data are in order of years at large. Release date is when fish, generally juveniles, were stocked into Lake Mohave. Data from two repatriates were omitted: one fish suspected as a repatriate captured without a tag and from the one fish released 7 days prior to its capture.)

PIT tag	TL (mm)			Months at large	Years at large	Gender
	Release	Capture	Growth rate/month			
1C2C2F759A	495	500	0.5	1	0	U
1C2C2F95DB	290	312	1.0	2	0	M
1C2C3726CC	440	495	1.0	6	0	F
4647310E0B	455	550	0.7	14	1	F
46454D0758	430	590	0.7	23	2	F
46466B287F	450	575	0.6	23	2	F
45714D7326	415	585	0.7	25	2	F
4646422D12	400	620	0.7	32	3	F
5204137512	350	583	0.3	79	7	M
5325614D23	415	550	0.2	80	7	M
5326686D70	485	627	0.2	89	7	F
7F7A075004	320	590	0.2	125	10	F
2240311A0A	282	548	0.2	126	10	M
1F6C06046B	260	595	0.2	136	11	M
201D5C5512	345	658	0.2	138	11	F

Based on monitoring data from 2006 and 2007, the current wild razorback sucker population in Lake Mohave is estimated at 218 fish (107–1,092; 95% confidence interval [CI]). The repatriated razorback sucker population is estimated at 1,461 (786–2,752; 95% CI), with a 1% estimated survival of all repatriates released as of March 1, 2006. The current population estimate for razorback suckers in Lake Mohave is 1,679.

Creel Census Data

In July 2007, a creel census was initiated at Willow Beach by the NDOW. From July through December 2007, nine large (greater than 80 cm TL) striped bass and

Table 4.—ASU adult razorback sucker monitoring summary for 2007 by 15 paired release-capture data with rearing type and location, and release and capture sites
(Data are in alphabetical order of rearing type and rearing location. The release site is where fish were stocked into Lake Mohave. Data from two repatriates were omitted: one fish suspected as a repatriate captured without a tag and from the one fish released 7 days prior to its capture.)

Rearing type	Rearing location	Release site	Capture site	Total N fish (% of total)
Lakeside backwater	Arizona Juvenile	Arizona Juvenile	Carp Cove	1
		Chemehuevi Cove	Cottonwood Cove East (1st point south of north point)	1
	Davis Cove	Davis Cove	Waterwheel Cove (north of)	1
	Nine Mile Cove	Nine Mile Cove	Carp Cove (north point)	1
	North Chemehuevi Cove	Chemehuevi Cove	Carp Cove	1
			Waterwheel Cove (first point south of)	1
	Willow Cove	Willow Cove	Waterwheel Cove (north of)	1
	Yuma Cove	Yuma Cove	Carp Cove	2
Lakeside backwater total				9 (60)
Offsite facility	Boulder City Wetlands Park	Cottonwood Cove	Cottonwood Cove East	1
	Willow Beach NFH	Arizona Juvenile	Waterwheel Cove (north of)	1
		Owl Cove	Carp Cove	1
		Pot Cove	Waterwheel Cove (north of)	1
		Red Tail Cove	Carp Cove	1
		Sheeptrail Cove	Cottonwood Island Cove	1
			Offsite facility total	6 (40)
			Grand total	15

two large channel catfish (specific size unknown) were scanned for PIT tags, but none were detected. The NDOW recorded one anecdote of an angler catching a 30-pound striped bass with a razorback in its stomach on November 23, 2007. Since the NDOW began providing creel census data in 2006, 12 large striped bass and 2 large channel catfish have been scanned for PIT tags. No tags have been detected.

Ecological Modeling

There was a total of 10,466 wild razorback sucker capture events out of 8,373 individual capture histories (table 5), leaving 2,093 records of recapture for parameter estimation. In contrast, there was a total of 1,254 repatriate capture events out of 1,076 capture histories, leaving only 178 records of recapture. Therefore, parameter resolution was comparatively poor for all repatriate mark-recapture models, and as a result, only two simple multi-site models were analyzed for repatriate razorback suckers.

Multi-site mark-recapture models consistently produced a poorer fit to the capture data compared to standard mark-recapture models for wild and repatriate razorback suckers (table 6). The difference in AIC scores within standard and multi-site mark-recapture models was an order of magnitude lower than the difference in AIC scores between the two model types. Therefore, multi-site models available through the program MARK do not provide a better fit than standard mark-recapture models for this dataset.

Bias due to site fidelity was not evident in estimates of survival from multi-site and standard mark-recapture models. Both model types produced similar estimates. In the multi-site wild razorback sucker model with one constant survival parameter per zone (wild model 7) (table 6) the annual survival estimates and 95% CI for wild razorback sucker in the three analyzed general zones were: river – 73.6% (67.1–79.2%), Arizona Bay – 69.5% (67.1–71.9%), and basin – 74.6% (71.0–77.8%). In the standard case (wild model 2) (table 6), the survival estimate was 70.7% (69.4–72.0%). There is a similar overlap of survival between the multi-site and standard models for repatriate razorback sucker data, with multi-site estimates and 95% CIs of 73.5% (50.1–88.5%), 61.5% (41.1–78.5%), and 92.0% (79.5–97.1%) for the river, Arizona Bay, and basin zones, respectively (repatriate model 6) (table 6), and 85.2% (78.3–90.2%) for the standard model (repatriate model No. 1) (table 6). Repatriate model 5 fit slightly better than model 6, but the additional parameters increased uncertainty in estimates, and CIs were broad (e.g., 25.9–96.1% for river zone survival).

Table 5.—Capture totals for wild (top) and repatriate (bottom) razorback suckers in Lake Mohave divided into four general zones for all years used in multi-site mark-recapture analyses
(Row totals do not indicate numbers of fish since some fish were captured more than once across years.)

Zone	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	Total
River	0	0	87	136	141	101	102	93	98	70	31	0	0	0	0	20	0	879
Arizona Bay	564	1,000	813	654	505	407	228	160	203	205	241	85	91	59	32	26	8	5,281
Basin	141	511	522	765	525	452	318	231	100	207	188	101	84	76	19	31	5	4,276
Lower lake	2	25	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	30
Total	707	1,536	1,425	1,555	1,171	960	648	484	401	482	460	186	175	135	51	77	13	10,466

Zone	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	Total
River	0	0	1	3	8	3	0	1	0	0	64	0	80
Arizona Bay	14	11	11	52	33	62	30	52	35	35	35	60	430
Basin	19	21	37	44	42	89	90	80	106	49	96	71	744
Lower Lake	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	33	32	49	99	83	154	120	133	141	84	195	131	1,254

Table 6.—Mark-recapture model design and fit (AIC), in ascending AIC order, for wild (top) and repatriate (bottom) razorback suckers in Lake Mohave, Arizona and Nevada

(Model parameters of recapture rate [p], survival [Φ], and transition [Ψ, multi-site only] varied by time or zone as indicated; otherwise, they were constant. Multi-site models are highlighted.)

Model	AIC	Parameters	Deviance
1 – p (time), Φ (time)	17554.74	31	1209.84
2 – p (time), Φ	17574.63	17	1257.86
3 – p, Φ (time)	17585.14	17	1268.38
4 – p, Φ	17652.69	2	1365.98
5 – p (time & zone), Φ (time[1] & zone), Ψ (zone)	20836.75	81	3399.95
6 – p (time & zone), Φ (time & zone), Ψ (zone)	20841.14	94	3377.90
7 – p (time & zone), Φ (zone), Ψ (zone)	20851.95	51	3475.93
8 – p (time[1] & zone), Φ (time[1] & zone), Ψ (time & zone)	20859.07	107	3369.33
9 – p (zone), Φ (zone), Ψ (zone)	20981.99	12	3684.45

[1] Constant for the river zone.

Model	AIC	Parameters	Deviance
1 – p (time), Φ	1500.38	12	208.66
2 – p, Φ	1503.09	2	231.64
3 – p (time), Φ (time)	1511.06	21	200.78
4 – p, Φ (time)	1517.36	12	225.64
5 – p (time & zone), Φ (zone), Ψ (zone)	1706.23	37	419.42
6 – p (zone), Φ (zone), Ψ (zone)	1713.67	13	477.12

DISCUSSION

Post-stocking Dispersal and Fate

2006–07 Sonic Telemetry and Captive Fish Experiment

The loss of one fish early on could represent tag failure or bird predation (Jepsen et al. 1998; Marsh and Minckley 1991), or actual emigration out of Lake Mohave. There are records of individual razorback suckers released into Lake Mohave that have been recaptured in the Colorado River downstream (lower Colorado River Native Fish PIT tag database, unpublished). However, the possible emigration of 1 fish (5% of total released) is minor in comparison to the 17 fish that died during the 6-month telemetry study. In addition, the dispersal patterns of telemetry-tagged fish do not support a general hypothesis that repatriated fish migrate out of the reservoir via Davis Dam.

Manual tracking and SUR data, in addition to the captive fish experiment results, indicate that smaller telemetry fish face almost certain mortality in a relatively short amount of time after being repatriated into Lake Mohave. While recovered transmitters alone are not definitive indicators, 100% tag retention in captive fish suggests that recovered transmitters represented fish mortality. The captive fish study also demonstrated that surgical procedures in no way compromised fish health or behavior. In fact, at the conclusion of the experiment, fish showed obvious reproductive signs in both sexes, suggesting sexual development was not disturbed by the implanted transmitters. Similar observations were made in razorback suckers implanted with radio transmitters on the Green River, Utah (Tyus and Karp 1990; Modde and Irving 1998).

Based on data acquired at the time of transmitter recovery and previous studies of razorback suckers, rapid loss of telemetered fish from this study was most likely due to consumption by predacious fishes. Piscivory has been documented as a cause of mortality for adult and subadult razorback suckers elsewhere in the Colorado River Basin (Marsh and Brooks 1989; Tyus and Nikirk 1990). Absence of fish remains even when tags were recovered a relatively short time after cessation of movement suggests predation and is consistent with other studies of this population (Marsh et al. 2005).

Although piscivory has been considered a threat to this population for some time (Minckley 1983; Minckley et al. 2003), the high rate of loss (16 of 19 fish) is troublesome considering this study accounts for a trivial amount of time (6 months) in the lifespan of fish that can exceed 40 years (McCarthy and Minckley 1987). In addition, the size of fish being consumed is alarming. Razorback suckers more than 40 cm long were readily consumed in this study. Striped bass are the only piscivores in Lake Mohave that have a gape size large enough to ingest fish of this size (Dennerline and Van Den Avyle 2000).

2007–08 Sonic Telemetry

Poor survivorship experienced by subadult fish during the 2006–07 telemetry study was again documented during the first 3 months of the 2007–08 telemetry study. While mortality of subadult razorback suckers in both studies was high, subadults from the 2007–08 study experienced lower monthly survivorship (58% versus 72%). By the end of the third month of the 2007–08 study, only 27% of subadult fish remained active. In contrast, it took an additional 8 weeks for subadults from the previous year's study to reach a similar level of survivorship (26%). First year survival for a 38-cm razorback sucker (the average size of fish released in both studies) has previously been estimated at 40% (Marsh et al. 2005). This is markedly higher than the experienced 16% survivorship of fish in the 2006–07 study (6-month duration) and the 27% survivorship of fish during the first 3 months of the 2007–08 study. Poor survival of subadult razorback suckers in both studies could, in part, explain why recaptures of subadults repatriated into Lake Mohave have occurred so infrequently during monitoring efforts.

Sonic-tagged adult razorback suckers experienced higher survivorship when compared to subadult fish; adult survivorship (77%) was approximately three times greater than subadult survivorship (27%). While preliminary results from the 2007–08 study indicate that hatchery-reared razorback suckers appear to benefit from larger release size prior to their repatriation into Lake Mohave, it is worthy to note that the largest fish implanted with a transmitter (51 cm TL) was consumed in this study. During the time period prior to its consumption, the transmitter moved an exceptional distance (from Black Canyon to Arrowhead Cove near Katherine Landing, approximately 72 km) prior to being recovered by a scuba diver. While no fish in this study appears immune to predation, as a group, larger fish have experienced better survivorship than subadult fish to date.

Routine Monitoring

Population estimates for wild razorback suckers in Lake Mohave had hovered near 500 fish for several years (Marsh et al. 2003, 2005; Turner et al. 2007). This number was possibly artificially maintained by repatriate razorback suckers that had lost their PIT tags and were consequently mislabeled upon capture as wild. The most recent population estimate excludes all tagless fish and therefore accurately reflects the decline in population of previously tagged wild fish (excluding wild fish that lose their PIT tag). This partially accounts for the large decrease, more than 50%, in abundance compared to the 507 fish estimated in 2006 (Kesner et al. 2007). However, the decline in wild fish is real and continues toward complete extirpation.

Repatriates in Lake Mohave continue to outnumber wild adults by almost an order of magnitude. The new protocol, which recommends a minimum stocking size of 50 cm, is expected to increase survivorship dramatically, but to date, few fish have been released at this size. Preliminary results of the 2006–07 telemetry study are encouraging and provide the first evidence of the potential survival of these larger fish.

Creel Census Data

Although no PIT tags have been detected in striped bass or channel catfish stomachs in the last 2 years, few small razorback suckers have been released in the last year, and creel census data that were collected at Cottonwood Cove in 2006 resulted in only three large striped bass scanned. The lack of tag detections is at least partially due to bad timing. Since the increase in target release size, few razorback suckers have achieved this size and have been released. In addition, the fish that have been released from Willow Beach NFH have been large, close to 50 cm.

This size has been targeted to avoid predation by striped bass, and therefore, they are expected to be rarely ingested.

Cooperation with the NDOW is expected to continue and additional data should accrue.

Ecological Modeling

Although site fidelity was statistically significant in a contingency table analysis (Kesner et al. 2007), the incorporation of general zones into the Lake Mohave mark-recapture model did not improve model fit. On the contrary, model fit was worse for all models with zones than for models without zones. Site fidelity may not significantly affect survival estimates because sampling is adequately dispersed, and survival and recapture rates are not significantly different from zone to zone. This may also be a case of model design, and additional models outside the programming capabilities of a "one size fits all" program like MARK will be tested in 2008.

The most sobering fact from the mark-recapture analysis is the lack of recapture data. Initially, 1,254 records of capture appear adequate for analysis, but the vast majority of these records are first-time captures. Without adequate recapture data, little inference can be made on the behavior and survival of repatriated fish. Release data can be used as the first capture or "mark" in some models, but high initial mortality (> 90% on average) results in suspect parameter estimates. Mark-recapture models work best when parameter estimates are near 50% (Lebreton et al. 1992). Sonic telemetry has successfully provided post-release mortality estimates and dispersal data; therefore, the use of mark-recapture data to estimate post-release survival may become unnecessary. Instead, capture data may be used to assess the impact of independent factors, such as stocking site, rearing site, and season, on survival without deriving actual parameter estimates. A contingency analysis, multiple regressions, or a multivariate approach can provide the necessary insights.

Based on the results from the two telemetry studies, post-release survival of 50 cm repatriated razorback suckers appears markedly higher than for 35-cm fish, but both size classes appear to be surviving at a lower rate than predicted by the mark-recapture model of survival in Marsh et al. (2005). That mark-recapture model was based on data through December 31, 2001, at which time only 46 fish had been released at 50 cm or larger (4 of which were recaptured through March 2002). Recently, the target release size was increased to 50 cm, and as these fish become available for recapture, mark-recapture estimates for 50-cm fish will improve. Still, the number of fish released at this size has remained small. As of November 20, 2007, the lower Colorado River Native Fish PIT tag database contains 197 records of 50 cm or greater sized fish released. Due to a lack of

releases, survivorship estimates of 50-cm fish from mark-recapture data will not be available by the end of 2008, the final year of this contract. The apparently lower than predicted survival of 35-cm fish is surprising but may be due to the limitations of the mark-recapture model. The size-survival function was fit to a smooth curve constraining survival between zero and one. However, actual survival as a function of size at release may in reality follow a threshold response function with a sudden increase in survival at an undetermined size. Additional telemetry studies will be conducted to further assess the relationship between size and post-release survivorship.

CONTINUING STUDIES

A telemetry study using target length (50-cm) fish will be performed during autumn-winter 2008–09 to assess and further evaluate variation in post-stocking mortality. Routine monitoring of repatriate and wild stocks will continue annually during March, May, and November and as necessary at other times. Available creel census data will be evaluated relative to piscivory on razorback suckers. Monitoring data will support more refined ecological modeling to include mark-recapture and other population-demographic analyses that will broaden the understanding of razorback sucker population dynamics and help direct species conservation and management.

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