Lower Colorado River Multi-Species Conservation Program

Balancing Resource Use and Conservation

Comparative Survival of Repatriated Razorback Sucker in Lower Colorado River Reach 3

U.S. DEPARTMENT OF THE INTERIOR
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December 2013

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Lower Colorado River
Multi-Species Conservation Program

Comparative Survival of Repatriated Razorback Sucker in Lower Colorado River Reach 3

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ACRONYMS AND ABBREVIATIONS

ABS	acrylonitrile butadiene styrene
AIC	Akaike’s Information Criterion
AIC_c	small sample Akaike’s Information Criterion
amp	ampere
BLM	Bureau of Land Management
CI	confidence interval
CJS	Cormack-Jolly-Seber
cm	centimeter(s)
COR	Contracting Officers Representative
ESA	Endangered Species Act
g	gram(s)
kHz	kilohertz
km	kilometer(s)
LCR MSCP	Lower Colorado River Multi-Species Conservation Program
m	meter(s)
M&A	Marsh & Associates, LLC
mm	millimeter(s)
NFWG	Native Fish Work Group
PIT	passive integrated transponder
PVC	polyvinyl chloride
Reclamation	Bureau of Reclamation
RKM	Reservoir Kilometer
RM	Reservoir Mile
TL	total length
USFWS	U.S. Fish and Wildlife Service
UTM	Universal Transverse Mercator

Symbols

%	percent

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SUMMARY

Persistence of razorback sucker (*Xyrauchen texanus*) in the lower Colorado River below Hoover Dam now relies entirely upon stocking programs. Even so, only a small proportion of stocked fish are ever encountered in the wild. In Lake Havasu (Lower Colorado River Multi-Species Conservation Program Reach 3), recent telemetry studies have found large spawning aggregations of razorback sucker in the upstream, riverine portion outside of the reservoir habitat that is unsuitable for standard net-based sampling that occurs in the lake. Contacting a greater proportion of the population is vital to assess the current at-large population and the factors that affect individual survival.

Remote passive integrated transponder (PIT) scanning has been a successful tool for contacting tagged fish in both riverine and slack waters throughout the lower Colorado River, and this technology was deployed for the razorback sucker spawning periods in January –April 2012 and December – April 2013 in the fast-flowing waters of Reach 3 from Davis Dam downstream to Moabi Regional Park, California. We contacted 652 and 2,092 razorback sucker released with a 134-kilohertz PIT tag in 2012 and 2013, respectively.

The combination of remote PIT scanning and standard fisheries sampling methodologies produced population estimates for 134-kHz PIT-tagged razorback sucker of 2,496 (1,935 to 3,220, 95-percent [%] confidence interval [CI]) and 4,524 (4,027 to 5,081, 95% CI) for 2011 and 2012, respectively.

The season of release and size at release were found to be significant factors in post-stocking survival of razorback sucker released into Reach 3 in an assessment of mark-recapture models using the software package MARK. Actual estimates of survival varied significantly among competing models, and year-to-year variation of post-release survival was significant. Still, post-release survival estimates for razorback sucker released in the spring were twice as high on average compared to autumn releases in all models, and models that incorporated size at release as a covariate were always ranked higher by AIC_c (small sample Akaike's Information Criterion) than models that did not.

Monitoring of the LCR MSCP Reach 3 razorback sucker stocking program should continue and should also emphasize seasonal application of remote PIT tag scanning augmented by biannual physical sampling that utilizes electrofishing and netting. Although remote PIT scanning has significantly increased contact rates for razorback sucker in the reach, precise post-release survival estimates have remained elusive. The variability in post-stocking survival (year to year and season to season) combined with the seasonality and temporal proximity of employing PIT scanning results in imprecise post-stocking survival estimates. Because contacting released razorback sucker in the season after release is required to assess survival during this critical period, PIT scanning will need to

continue for multiple years and across seasons. Recommendations to improve post-release survival should accrue after multiple iterations of data collection, analysis, and interpretation.

INTRODUCTION

Razorback sucker is one of the four "big river" fishes endemic to the Colorado River that were once abundant and widespread throughout the system (Minckley 1973). Its distribution and numbers have dwindled, and the species is currently listed as endangered under the Endangered Species Act (ESA) (U.S. Fish and Wildlife Service [USFWS] 1991). Population decline is largely attributed to dam construction and direct and indirect interactions with non-native species introduced into the main stem (Joseph et al. 1977; Minckley 1979; Bestgen 1990; Minckley et al. 1991; Mueller and Marsh 2002).

The Lower Colorado River Multi-Species Conservation Program (LCR MSCP) was implemented in 2005 to balance the use of water resources and conservation of native species and their habitat in compliance with the ESA (Bureau of Reclamation [Reclamation] 2004). The lower Colorado River has been subdivided into designated planning areas and river reaches to address these goals. Reach 3 is the 135-kilometer (km) section along the Arizona-Nevada and Arizona-California borders between Davis and Parker Dams. The reach includes an 87-km riverine section immediately downstream from Davis Dam and the entirety of Lake Havasu proper, which is impounded by Parker Dam (figure 1).

Minckley (1983) hypothesized that razorback sucker populations experienced highly successful recruitment events immediately following impoundment of reservoirs in the lower Colorado River basin. Lake Havasu was impounded in 1938, and the last documented capture of wild adults was in Laughlin Lagoon in 1986 (Marsh and Minckley 1989). A population persists today only because of annual stocking efforts that began with larval stocking in 1986 (Marsh and Minckley 1989) and continued with nearly 500,000 mostly small razorback sucker stocked between 1986 and 2005 (Schooley and Marsh 2007, unpublished data).

Under guidance of the LCR MSCP, 49,000 larger razorback sucker (>300 millimeters [mm]) have been stocked into Reach 3 since 2006. Post-stocking research and monitoring activities have resulted in capture of very few fish from early stockings, and while individuals from more recent stockings have increased contact rates comparatively, absolute capture rates remain low. Recently released fish have been found to aggregate in major spawning areas from Laughlin, Nevada, downstream to Needles, California (Wydoski and Mueller 2006; Wydoski and Lantow 2012). Capture rates are less than 3 percent (%) of cumulative fish released (table 1), so calculating accurate population estimates and isolating specific factors affecting survival of repatriated razorback sucker in Reach 3 presents a challenge.

Here we report the final results and conclusions on the use of a combination of remote passive integrated transponder (PIT) scanning and capture data

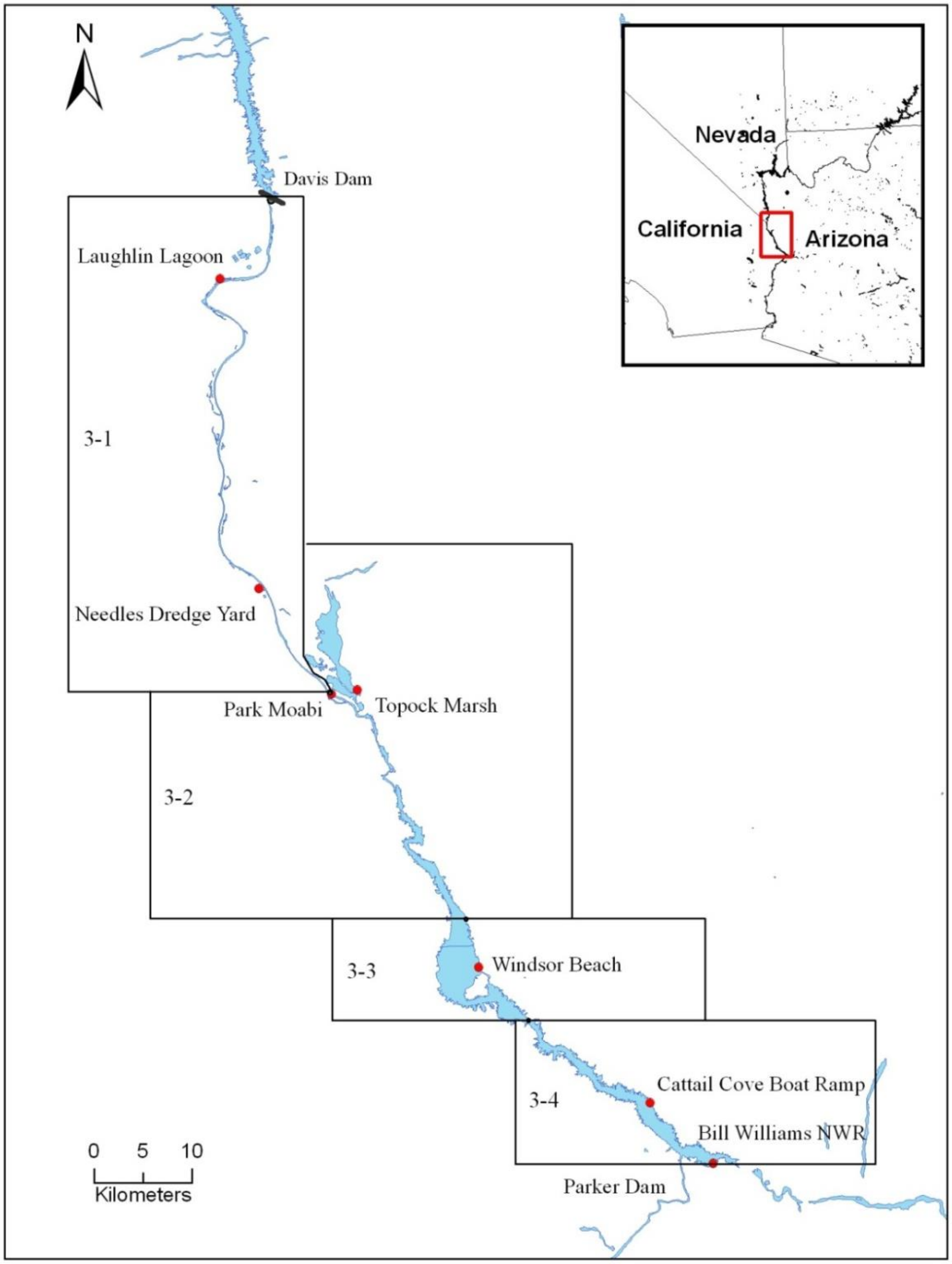

Figure 1.—Overview map of the study area depicting LCR MSCP Reach 3, including general remote PIT scanning and stocking locations, and general zones 3-1 to 3-4 established in the "Methods" section, lower Colorado River, Arizona-California-Nevada.

Table 1.—Proportion of fish captured in each year based on the cumulative number of fish released up to the previous years' end, LCR MSCP Reach 3, lower Colorado River, Arizona-California-Nevada
(From the Native Fish Work Group PIT tag database)

Release year	Number released	Cumulative number released	Capture year	Number captured	Proportion captured
2006	4,082	4,120	2007	89	0.022
2007	6,721	10,803	2008	69	0.006
2008	3,167	13,970	2009	109	0.008
2009	5,868	19,838	2010	141	0.007
2010	5,415	25,253	2011	186	0.007
2011	10,842	36,095	2012	213	0.006
2012	8,267	44,362	2013	7	0.000
2013	6,595	46,875			

(December 2011–2013) to assess the current Reach 3 razorback sucker population and evaluate the effects of size, location, and timing of release on post-stocking survival. This information is integral in formulating a cost-effective, efficient method to restore the population in Reach 3. Specific objectives from the study period include:

1. Contact razorback sucker using remote PIT scanning units in zones 3-1 and 3-2
2. Assimilate all Reach 3 razorback sucker release and capture data collected by any entity
3. Estimate the current repatriate razorback sucker population
4. Estimate survival of razorback sucker released in Reach 3 based on size, location, and season of release since 2005
5. Participate in annual multi-agency native fish surveys

This information will aid in completion of LCR MSCP Work Task C33: comparative survival of 500-mm razorback sucker released in Reach 3.

METHODS

Study Area

Lake Havasu is impounded by Parker Dam, which was closed in 1938. The reservoir has a 7.98 x 10^8 cubic meter storage capacity regulated by releases at the upstream terminus (Davis Dam), downstream terminus (Parker Dam), and less significantly through releases into the Bill Williams River from Alamo Dam. For this work, Reach 3 has been separated into four distinct zones based largely on habitat types (see figure 1). Moving downstream from Davis Dam, the first zone, 3-1, encompasses clear moving waters of the riverine section from the dam downstream to Reservoir Kilometer (RKM) 70.6 (Reservoir Mile, [RM] 43.9). The shoreline is low lying and relatively well developed. Zone 3-2 is characterized by slower waters and canyon-like shoreline, and it contains the highest concentration of backwater habitat in Reach 3. Zone 3-2 encompasses Moabi Regional Park, Topock Marsh, and the Lake Havasu delta region from RKM 70.6 (RM 43.9) downstream to RKM 39.7 (RM 24.7). Zone 3-3 has gently sloping surrounding shoreline and is the open water portion of the reservoir from the bottom of the delta, RKM 39.7 (RM 24.7), to directly upstream of Copper Canyon where the reservoir once again narrows at RKM 23.3 (RM 14.5). The fourth zone, 3-4, extends from Copper Canyon downstream to Parker Dam and includes the Bill Williams River National Wildlife Refuge.

Electrofishing

Potential razorback sucker habitat between Davis Dam and Needles, California, was electrofished during the period January 9 to March 7, 2012, to assess the proportion of razorback sucker occupying the area where PIT scanning was to take place. These electrofishing efforts targeted native fish and were located in areas where no non-native species were previously netted. Night electrofishing events occurred under the supervision of the project Contracting Officers Representative (COR) with up to four netters present. All suckers captured (flannelmouth sucker [*Catostomus latipinnis*] and razorback sucker) were enumerated, measured for total length (TL) (mm) and weight (grams [g]), sexed, assessed for sexual ripeness, scanned for a wire tag, scanned for a 125- or 134-kilohertz (kHz) PIT tag, and tagged with a 134-kHz PIT tag if either a wire tag or no tag was detected. A right pectoral fin clip was taken from all razorback sucker, placed in 1 milliliter of 95% ethanol in a snap-cap tube, and sent to the Conservation Genetics Laboratory at Arizona State University for analysis. All fish were returned to the water close to their point of capture. Data were entered into the comprehensive lower Colorado River Native Fish Work Group (NFWG) PIT tag and stocking database maintained by Marsh & Associates, LLC (M&A)

on behalf of all partners engaged in conservation activities for big river fishes in the lower Colorado River. These razorback sucker capture data were used for population estimation.

Remote PIT Scanning

2012

Remote PIT scanning units were deployed from January 9 to April 5, 2012, between Davis Dam and Needles, California. Two models of PIT scanners were utilized: one large, shore-based unit and seven completely submersible units. The shore-based unit was comprised of a 1.9 x 0.8 meter (m) polyvinyl chloride (PVC) antenna frame with a built-in scanner connected by 27.4 m of cable to a shore-based, waterproof box housing a "black box" logger and 21 ampere (amp)-hour battery. The battery was capable of continuously powering the scanner for up to 68 hours, and this unit was deployed the first afternoon we arrived to the field site and retrieved the last morning of sampling before departing the field site. Submersible units consisted of a 0.8 x 0.8 m PVC antenna frame with a scanner and "mini logger" contained in PVC/acrylonitrile butadiene styrene (ABS) piping and a 9 amp-hour battery held in a water tight OtterBox® with a 24-hour powering capacity. The battery box was secured in one-half of a dual-sided sandbag holder used to keep the unit in place under water. These antennas were retrieved approximately every 24 hours and downloaded onsite; the battery was replaced before redeployment. Five to seven of these units were employed throughout the scanning season; each unit was assigned and labeled with a four-character alpha-numeric code (unit ID, e.g., RT03) for individual identification. This allowed data downloads to be matched with deployment locations.

The shore-based unit was deployed at a single location, Razorback Island, all season (figure 2). At this location, the waterproof box was easily hidden and was accessible only by boat. Submersible units were deployed at 10 different general areas (moving downstream): Laughlin Bridge, Laughlin Lagoon, Razorback Island, and Razorback Riffle near Laughlin, Nevada, and Palms, Cliffs, Cabana, Tower, White Wall, and Power Lines near Needles, California (figure 2). The locations that were monitored varied from trip to trip based on fish concentrations, but each trip consisted of 3 nights and 2 days of continuous scanning.

2013

Eight to 13 units were deployed across 6 scanning events. Remote PIT scanners were deployed from December 10, 2012, to April 11, 2013, between Davis Dam and Moabi Regional Park, California. In addition to the two models of scanners employed in the early 2012 monitoring, a modified submersible unit with a 10.4 amp-hour lithium-ion battery pack contained in a watertight, 2-inch ABS pipe also was employed.

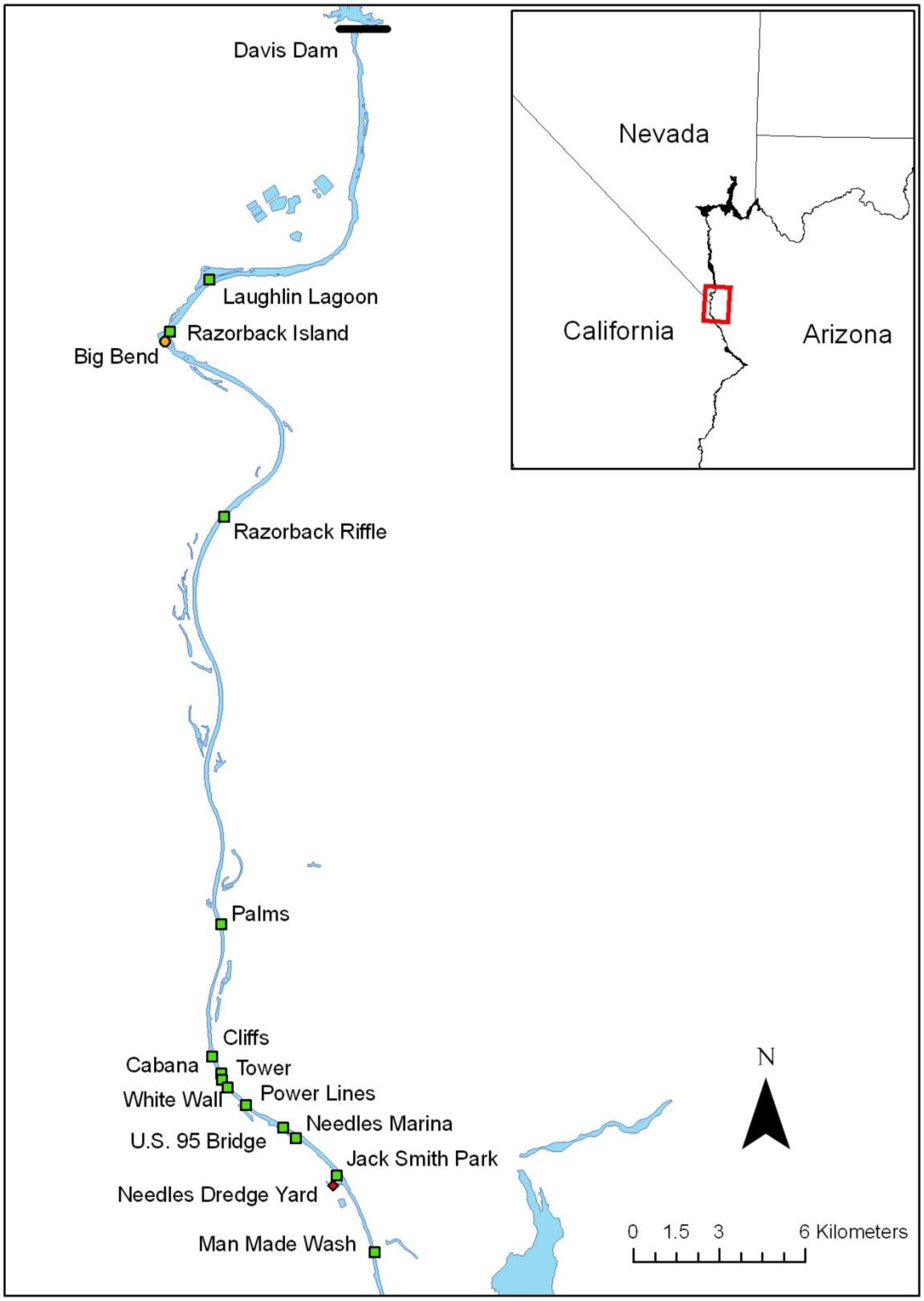

Figure 2.—Location of remote PIT scanning deployment by M&A (green square), Reclamation (red diamond), or both (orange circle) in LCR MSCP Reach 3, zone 3-1, between January 1, 2012, and April 30, 2012, and December 1, 2012, and April 30, 2013, lower Colorado River, Arizona-California-Nevada.

The shore-based unit was deployed in Moabi Regional Park. Submersible units were deployed at the same locations as in early 2012 with the addition of eight new locations between Moabi Regional Park, California, and Big Bend of the Colorado State Recreational Area, Nevada (see figure 2).

Remote PIT scanning information for each individual deployment was recorded on waterproof data sheets as follows: location, river right or river left, unit deployed, battery deployed, Universal Transverse Mercator (UTM) zone, UTM easting, UTM northing, depth (m) of deployed unit, date and time deployed, date and time retrieved, start time of scanner (S), end time or run interval of scanner (E), stop interval (I), scan time in minutes, unit orientation in water (horizontal or vertical), purpose of scanning, comments, and a check box to indicate if any equipment malfunctioned.

PIT scanning in zone 3-2 (figure 3) was conducted by Reclamation (Rick Wydoski). Scanning data, along with location and effort information, were provided by the COR, and all data acquired from PIT scanning on Reach 3 were incorporated into a MySQL database maintained by M&A and hosted by Hostmonster.com (http://www.hostmonster.com/). Summary reports of scanning data and all raw data files are available through a password-protected section of the M&A Web site (http://www.nativefishlab.net). Microsoft® Access 2010 was used for data management.

Routine Monitoring

M&A biologists assisted with trammel netting in six of nine fixed reaches (USFWS 2012) and with electrofishing in two of nine reaches during the multi-agency Native Fish Roundup on Lake Havasu on February 6–9and November 5–8, 2012. In conjunction with roundup efforts in zones 3-2 and 3-3, M&A associates deployed PIT scanners throughout zone 3-1 on February 11–14, 2013, in replacement of electrofishing efforts usually carried out in that section. Up to four multifilament nylon trammel nets (45.7 or 91.4 m x 1.8 m, 3.8 centimeter (cm) stretch mesh, 30.5 cm bar outer wall) were deployed in overnight sets in reach 3-2, retrieved the following morning, and redeployed in new locations within the reach for 4 consecutive nights according to a standard protocol reported elsewhere by Reclamation. In general, nets are subjectively set based on historic catch and accessible backwaters and placed a minimum of 50 m apart (J. Lantow, Reclamation, personal communication). All fish were removed and processed. At a minimum, non-native species were enumerated, and TL was measured (mm). Native species were processed as described above, and a fin clip was taken from a subsample of razorback sucker for genetic examination (see above). For detailed methods of the Native Fish Roundup, see USFWS (2012).

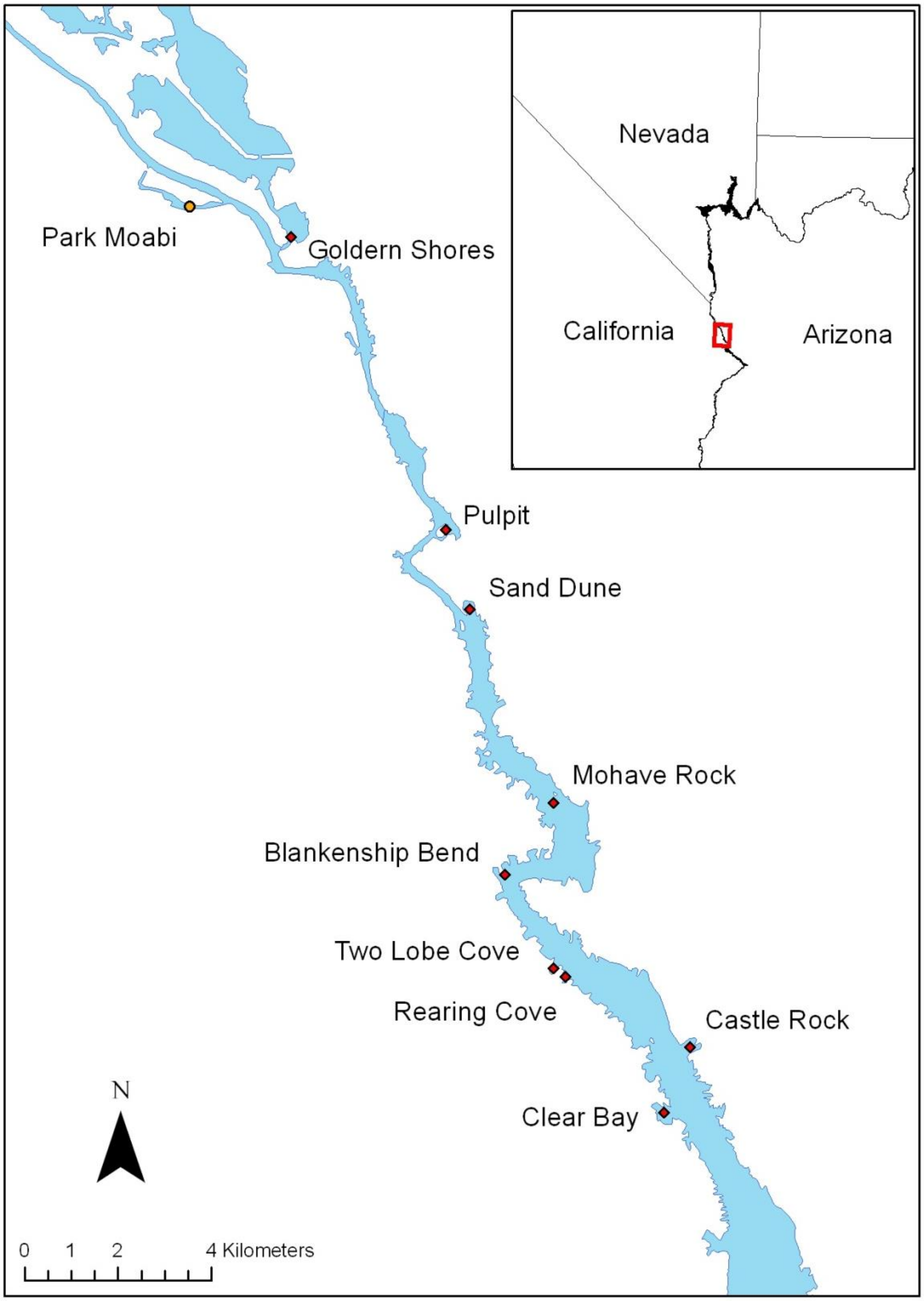

Figure 3.—Location of remote PIT scanning deployment by Reclamation (red diamond) or both Reclamation and M&A (orange circle) in LCR MSCP Reach 3, zone 3-2, between January 1, 2012, and April 30, 2012, and December 1, 2012, and April 30, 2013, lower Colorado River, Arizona-California-Nevada.

Data Analysis

Population Estimation

We employed the modified Petersen formula (Ricker 1975) on paired census data (January 1 through March 31) to calculate a single census population estimate (N^*) for razorback sucker in 2011:

$$N^* = \frac{(\mathrm{M}+1)(\mathrm{C}+1)}{\mathrm{R}+1}$$

Fish to be included in the estimate must have been released any year previous to the sampling year used as the mark, that is, before January 1, 2011, for the 2011 estimate, and before January 1, 2012, for the 2012 estimate. We included both fish released with a 134-kHz PIT tag in the NFWG PIT tag database and fish that did not have a release record but were captured for the first time on record and tagged with a 134-kHz tag before the beginning of the mark period. All releases were into the main stem or reservoir or into backwaters connected to the river; none were into habitats permanently isolated from the river. The stocking locations and number of fish released used in this analysis are in table 2.

Definitions for M, C, and R from Ricker (1975) have been modified for our purposes. M is not the number of fish tagged and placed into a water body, but the number of fish contacted in the designated mark period (January 1 to March 31, 2011). Catch, C, is the number of fish contacted in the second period of the paired data (January 1 to March 31, 2012), and R is the number of fish contacted in both mark and catch periods for the 2011 estimate. For the 2012 population estimate, mark and catch periods were December 1, 2011, to April 30, 2012, and December 1, 2012, to April 30, 2013, respectively. Fish contacted more than once in mark or catch periods were only included in the analysis for their first encounter event in each timeframe. Confidence intervals (CI) were derived using Poisson approximation tables, with R as the entering variable (Seber 1973).

To be unbiased, the model should meet three assumptions when applying the Chapman modified Petersen estimate (Pollock et al. 1990): (1) the population is closed to both deletions and additions, (2) no tags are lost or omitted, and (3) equal catchability of all individuals, and these all are met under the current application.[1] This project only includes known individuals added to the system with a 134-kHz PIT tag before the period of the mark (M) and individuals that

[1] Tag loss and emigration are distinct possibilities, but they both can be considered losses to the population just as natural mortality. The lost tag issue is only important if fish that lost tags were improperly counted as part of C and not R when they actually were recaptures. Because we do not include fish without tags in either M or C, if a fish loses a tag between mark and capture, it would be the same as if the fish died between M and C. These factors all have the same effect on the population estimate and make no difference except to validate the estimate for the marking period.

Table 2.—Stocking location and number of fish released into LCR MSCP Reach 3, lower Colorado River, Arizona-California-Nevada, used in the 2011 razorback sucker population estimation

Stocking location	No. fish stocked
Avi	2
Avi Hotel	6
Avi to Willow Valley	4
Below Davis Dam	33
Big Bend State Park to Avi	1
Bill Williams River National Wildlife Refuge	439
Blankenship Bend	2
BLM[1] Partner's Point Work Camp	26
Boyscout Camp Lagoon	10
Boyscout Point	1
Catfish Bay Cove	1
Catfish Paradise in Topock Marsh	3,243
Cattail Cove Boat Ramp	1,971
Clear Bay Cove	1
Davis Dam to Riverside launch	1
Fort Mojave	1
Golden Shores/mouth of Topock Gorge	2
Lake Havasu	1
Laughlin Lagoon	6,151
Laughlin Lagoon and Needles Dredge Yard	3,229
Mesquite Bay (north of)	2
Needles	299
Needles (north of)	38
Needles Bridge (south of)	1
Needles Dredge Yard	4,215
Needles to Laughlin	16
Office Cove area and bridge at Bill Williams National Wildlife Refuge	2,124
Moabi Regional Park	6,447
Moabi Regional Park Marina	1
Parker Dam (north of)	1
Pulpit Rock Cove	3
Razorback Riffle to Willow Valley	4
Standard Wash Cove	5
Topock Marina boat launch	250
Trampas Cove	2
Willow Valley	3
Windsor Beach State Park	7,983

[1] Bureau of Land Management.

were captured without a 134-kHz tag and had one implanted before January 1, 2011. Emigration out of Lake Havasu by passing through Parker Dam or deletion of fish through water intake structures is negligible in this system because razorback sucker have only been found to occupy regions of the reservoir upstream of these structures (Wydoski et al. 2010). PIT tags are considered a permanent tag (Zydlewski et al. 2003); thus, deletion due to natural mortality is the only factor present, and this does not bias the estimate. Efforts employed to sample razorback are diverse both methodologically and geographically, which imparts equal catchability of individuals.

Factors Affecting Survival

The effect of size at release on survival was evaluated for all razorback sucker released with a 134-kHz PIT tag between January 1, 2006, and January 1, 2012. Fish were divided into the following six size classes based on TL at release: one – ≤299 mm, two – 300 to 349 mm, three – 350 to 399 mm, four – 400 to 449 mm, five – 450 to 499 mm, and six – ≥500 mm. Fish released without a TL measurement were excluded from analysis. Razorback sucker released between January 1, 2006, and January 1, 2012, and contacted in 2012 (January 1, 2012, and April 30, 2012) and 2013 (December 1, 2012, and April 30, 2013) were tabulated.

Relative capture rates (number contacted/number released) were evaluated for each size class. The correlation between size at release and relative capture rates was estimated by calculating the Pearson correlation coefficient (r),

$$r = \frac{\sum_{i=1}^{n} (X_i - \bar{X})(Y_i - \bar{Y})}{\sqrt{\sum_{i=1}^{n} (X_i - \bar{X})^2} \sqrt{\sum_{i=1}^{n} (Y_i - Y)^2}}$$

where X represents the size class at release, and Y represents the relative capture rate of fish in each size class. Due to the non-linear nature of the relationship (exponential), data were log transformed before correlation analysis.

The influence of release size and zone of release was examined by tabulating the number of fish released, mean release size (TL), and number of fish contacted through remote PIT scanning per release cohort (razorback sucker released within the same zone and month). Cohorts released with a 134-kHz PIT tag between October 2006 and May 2012 were included. PIT scanning data included were collected in 2012 (January 1, 2012, and April 30, 2012) and 2013 (December 1, 2012, and April 30, 2013).

Ecological Modeling

An analysis was conducted using mark-recapture data to test for the effect of size (TL at release) and season on post-release survival of repatriated razorback sucker. The Cormack-Jolly-Seber (CJS) open population model was the basis for the analysis assessed by the computer program MARK (Cooch and White 2013). Zone (location) of release was not included as a factor due to a lack of consistent stockings among the four zones since 2006. Release and capture data were separated into "seasons" based on whether they were released/captured in January through June (spring) or July through December (autumn). TL at release was significantly correlated with encounter rate in this study and is a consistent factor for survival of razorback sucker elsewhere (Marsh et al. 2005). Therefore, TL at release was included as a covariate in this analysis (any fish released without a release TL was excluded).

Both release and capture histories were generated for all razorback sucker released with a 134-kHz PIT tag from the comprehensive NFWG database and consisted of fish released from July 1, 2006, through December 30, 2012, and captured from January 1, 2007, through June 30, 2013. Contact histories from remote PIT scanning were generated from the online remote sensing database and included alongside capture data from the NFWG database for a complete post-release "capture" history of each razorback sucker released. Each history was expressed as a series of zeros and ones, with the initial non-zero value representing the release (e.g., history "10000000100001" represents a fish released in the first time period and captured in the 9th and 14th time period). Each time period represented a year and season starting with autumn 2006 and ending with spring 2013. Further details on the derivation of these captures can be provided upon request.

The model structure of the "live recaptures only" CJS model within MARK is based on two groups of "real" parameters: (1) Φ_i – the probability of an individual surviving from interval i-1 to i and (2) p_i – the probability of being recaptured in interval i. Each parameter group is a half matrix of parameters, with the number of rows and columns equaling the number of recapture occasions (13). Rows represent different release occasions, and columns represent recapture occasions. The original CJS model of time varying survival and recapture rates can be coded by varying each parameter group by column, but any combination or parameters can be modeled. The first diagonal of the matrix represents the first time period after release for each release group (year and season) or cohort and is the key parameter for assessing immediate post-stocking survival. The "real" parameters are probability values that are constrained between 0 and 1, but the models are assessed based on beta parameters that are back-transformed to provide the "real" estimates. This connection between the beta and "real" parameters is represented as a matrix that is typically an identity matrix for most general models (time varying, age structured). Complexity to this parameter matrix is added for this study to include TL at release as an individual covariate. TL at release was modeled as a linear regression within the parameter matrix (one parameter for the y-intercept and one for the slope). The back transformation of the y-intercept and slope into real estimates of probability results in a sigmoidal curve of survival probability between 0 and 1 for a range of TL at release values.

For the Reach 3 analysis, recapture rates were set to vary by time for all models (we assumed time varying recapture probability [i.e., stocked fish have unequal probability of being recaptured in any period post-release across all models]). Potential factors affecting survival, season of release, cohort, and the individual covariate (release TL) were evaluated within MARK. The effect of season was evaluated by comparing models with a seasonal component in the first two periods post-release with either a fixed (one parameter) model or a time varying (different parameters for each release cohort) model. Age structure was also modeled similar to the structure used for Lake Mohave (Marsh et al. 2005) and in the Upper Colorado River Basin (Zelasko et al. 2011): separate parameters of survival for the first (two age model) or for the first and second (three age model) time period after release in addition to an adult survival parameter group. Models with release TL as a covariate of survival in the first period after release were compared to models without to determine the significance of size. Sampling was grouped into 6-month time periods, and estimates of adult survival were converted to annualized rates by raising the biannual rate to the second power. Post-release survival for the first time period (two age model) or for the first two time periods (three age model) were reported as is (6-month survival estimates), making them directly comparable to results from Lake Mohave studies (Kesner et al. 2011). Model selection was based on the Akaike’s Information Criterion (AIC) score (Akaike 1974) as calculated within MARK. This value reported in MARK is a modified value (AIC_c) that adjusts for small sample sizes (Burnham and Anderson 2002). The lowest AIC_c value represents the most parsimonious model, but model averaging was considered if AIC_c values of competing “best” models were similar (Johnson and Omland 2004).

RESULTS

Electrofishing

Electrofishing efforts between January 9 and March 7, 2012, resulted in the capture of 60 razorback sucker and 16 flannelmouth sucker. Effort was conducted in seven events encompassing potential scanning habitats ranging geographically from directly below Davis Dam downstream to Needles, California, for a total of 12,941 seconds. The average output ranged between 9.2 and 10 amps.

The mean TL and weight for razorback sucker were 597 mm (range 461–721 mm) and 2,538 g (range 1,195–4,380 g), respectively. A majority (65%) of razorback sucker captured had a detectable 134-kHz PIT tag, 8 of 60 contained 125-kHz PIT tags, and 13 had no PIT tag and received a 134-kHz tag before release. The proportion of razorback sucker that would be undetectable with remote PIT scanners at the beginning of our sampling period was (21/60) = 0.35.[2]

Remote PIT Scanning

2012

The scanning effort in Reach 3 consisted of 2,243.9 scan hours. The actual time to deploy/retrieve an antenna, download the logger, and change the battery was minimal (approximately 10 minutes per unit) and totaled 18 hours of effort (excluding travel time). Scanning resulted in contact with 763 individuals. Of all fish scanned, 652 had a release record with a 134-kHz PIT tag. The majority (74.5%) of individuals scanned were in size classes two (300 to 349 mm, 34.9%) and three (350 to 399 mm, 39.6%) at release.

2013

Scanning efforts in Reach 3 were undertaken by two entities in 2012–2013: M&A and Reclamation. M&A's scanning effort in Reach 3 consisted of six trips from December 2012 through April 2013 in Reach 3 zones 3-1 and 3-2, with a majority of efforts in 3-1 (see figure 2). This effort resulted in 3,250.6 hours of scanning and the contact of 1,414 individual fish.

Scanning efforts by Reclamation included in this report consisted of nine trips from December 2012 through April 2013 in Reach 3 zones 3-1 and 3-2, with a majority of efforts in 3-2 (see figure 3). Their efforts resulted in 3,466.1 hours of scanning and the contact of 994 individual fish (excludes scanning in waters disconnected from the main stem river).

The combined total of unique fish scanned was 2,168 individuals. Of these, 2,142 had a marking record. A majority of these were razorback sucker (2,131), although bonytail (10) and flannelmouth sucker (1) were also scanned.

Of the 2,148 razorback sucker with a marking record, 2,110 individuals were released with a 134-kHz tag. The majority of individuals scanned was spread across size classes two (300 to 349, 28.7%), three (350 to 399, 34.5%), and four (400 to 449, 21.9%) at release.

[2] This is the proportion of untagged fish (21) in the electrofishing sample of 60 razorback sucker.

Routine Monitoring

A general summary from the Lake Havasu Native Fish Roundup is reported here with a focus on razorback sucker capture. During February 6–10, 2012, 1,683 fish were captured. Of those, 109 (6.5%) were razorback sucker captured from Willow Valley, RKM 93.3 (RM 58) downstream to Mesquite Bay RKM 38.6 (RM 24). The mean TL of razorback sucker sampled was 523 mm (range 247–711 mm). For the full report, see USFWS (2012).

During the survey conducted between November 5–8, 2012, 40 razorback sucker were captured with a mean TL of 466.6 mm (range 405–480 mm). These fish were captured in trammel nets between Moabi Regional Park, RKM 70.0 (RM 43.5), and Castle Rock, RKM 44.3 (RM 27.5). All scanning data collected from efforts associated with the February 2013 native fish round up have been included in the subsequent results and analyses unless otherwise noted.

Population Estimation

2011 Estimate

Data used for the mark (M) were all razorback sucker with a release record and sampled in Reach 3 by netting or electrofishing between January 1 and March 31, 2011, for the 2011 estimate. Capture period data included razorback sucker sampled by all methods (including remote PIT scanning) between January 1 and March 31, 2012. A total of 116 individuals were included in the estimate from netting/electrofishing. Of the 692 individuals scanned remotely, 559 had a release record before January 1, 2011. The remainder (133 fish) either had a release record after January 1, 2011 (112), did not have a release or initial capture record (10), or did not have any record in the NFWG database (11), and they were not included in this analysis. Thirty-three fish were both scanned and contacted, making the capture total for the 2011 estimate 642 (559 + 116-33).

The estimated population of 134-kHz PIT tagged repatriated razorback sucker in Reach 3 in 2011 was 2,496 (1,935 to 3,220, 95% CI) individuals (228, 642, and 59 for M, C, and R, respectively). The estimate from capture data alone (228, 116, and 10 for M, C, and R, respectively) was 2,679, similar to the combined estimate, but the 95% CI was much wider (1,456 to 5,701). The combined estimate was expanded to include razorback sucker that were untagged or tagged with a 125-kHz tag in 2011. Capture data from January 1 to March 31, 2011, found 313 of 326 (96%) fish handled had a 134-kHz tag only. If this proportion holds true for the entire population, then an estimate of the entire population in Reach 3 would be 2,770 fish (2,659/0.96).

2012 Estimate

Data used for the mark (M) and capture (C) periods were all razorback sucker released with a 134-kHz tag and contacted by any means in Reach 3 between December 1, 2011, and April 30, 2012 (M), and the same period for 2012–2013 (C). Only individuals marked/released before December 1, 2011, were included in the 2012 population estimate. Of the 763 individuals remotely scanned between December 1, 2011, and April 30, 2012, 726 were released before the mark (December 1, 2011). The remaining fish were released after the mark (16), had a capture record but no associated release record (10), or lacked any record in the NFWG database (11).

Scanning efforts between December 1, 2012, and April 30, 2013, resulted in scanning of 2,168 individuals. Fish were excluded from the population estimate for not meeting the following criteria: incorrect species (11), razorback sucker released after the mark (820), or had a capture record with no associated release record (27). This left 1,310 fish to be included in the capture (C). Applying the same criteria to fish sampled through netting and electrofishing efforts, as was in place for scanning, 247 and 85 razorback sucker were contacted during the mark and capture periods. There were 39 and 22 razorback sucker captured and scanned during the marking and capture periods, respectively.

The estimated population of 134-kHz PIT tagged repatriated razorback sucker in Reach 3 in 2012 was 4,524 (4,027 to 5,081, 95% CI) individuals (934, 1,373, and 284 for M, C, and R, respectively). Netting and electrofishing data alone did not provide enough recaptures (2) to reliably estimate the population size. The combined estimate was expanded to include untagged or 125-kHz tagged fish. Electrofishing data from 2012 found 65% of fish had a detectable 134-kHz tag. This would expand the population estimate to 6,960 (4,524/0.65).

Factors Affecting Survival

Between January 1, 2006, and January 1, 2012, 36,015 razorback sucker were released with 134-kHz PIT tags and available for contact in Reach 3 during the 2012 and 2013 sampling seasons. Distribution among fish across size classes was not even, with <1% of fish being released in the smallest (≤299 mm) and largest (≥500 mm) size classes (table 3). Most of the fish were released in size classes two (53%) and three (36%, table 3).

In the 2012 (December 1, 2011, to April 30, 2012) and 2013 (December 1, 2012, to April 30, 2013) sampling periods, 2247 repatriated razorback sucker with release histories before January 1, 2012, were contacted through netting, electrofishing, and PIT scanning efforts combined. Comparable to the release data, <1% of contacted fish were from the smallest size class, while 2% of fish contacted were in the largest size class. A majority of contacts were fish released

Table 3.–Number and proportion of 134-kHz PIT tagged razorback sucker released between January 1, 2006, and December 31, 2011, by year and size class (top) and individuals contacted by any means between January 1, 2012, and April 30, 2012, and December 1, 2012, and April 30, 2013 (bottom), LCR MSCP Reach 3, lower Colorado River, Arizona-California-Nevada

(Fish were divided into the following six size classes based on TL at release: one – ≤299 mm, two – 300 to 349 mm, three – 350 to 399 mm, four – 400 to 449 mm, five – 450 to 499 mm, and six – ≥500 mm.)

Year	One	Two	Three	Four	Five	Six	Proportion
2006	109	2,122	1,738	77	0	0	0.112
2007	18	3,279	2,603	690	128	0	0.187
2008	64	2,707	334	10	4	19	0.087
2009	25	4,456	1,278	94	1	4	0.163
2010	10	2,032	2,686	670	17	0	0.150
2011	0	4,605	4,396	1360	318	161	0.301
Proportion	0.006	0.533	0.362	0.081	0.013	0.005	1.000

Year	One	Two	Three	Four	Five	Six	Proportion
2006	0	54	165	7	0	0	0.101
2007	0	35	138	48	8	0	0.102
2008	11	201	36	1	0	0	0.111
2009	0	335	190	19	1	1	0.243
2010	0	33	89	44	2	0	0.075
2011	0	261	350	141	34	43	0.369
Proportion	0.005	0.409	0.431	0.116	0.020	0.020	1.000

between 300 and 350 mm (41%), and 350 to 400 mm (43%, table 3). Relative catch rates were strongly correlated ($r = 0.93$) to size class at release, ranging from 0.048 in fish released between 300 and 350 mm to 0.239 for fish released ≥500 mm (figure 4).

The release cohort with the highest proportion of contacts through remote PIT scanning also had the highest mean release TL (613 mm, zone 3-1, February 2007), but the relationship between mean release TL and contact proportion was highly variable (table 4). The top five contact proportions (excluding recent releases in 2012) were all from spring releases in zones 3-1 and 3-4, whereas the five lowest contact proportions represented all four zones, with the majority released in autumn (4 of 5).

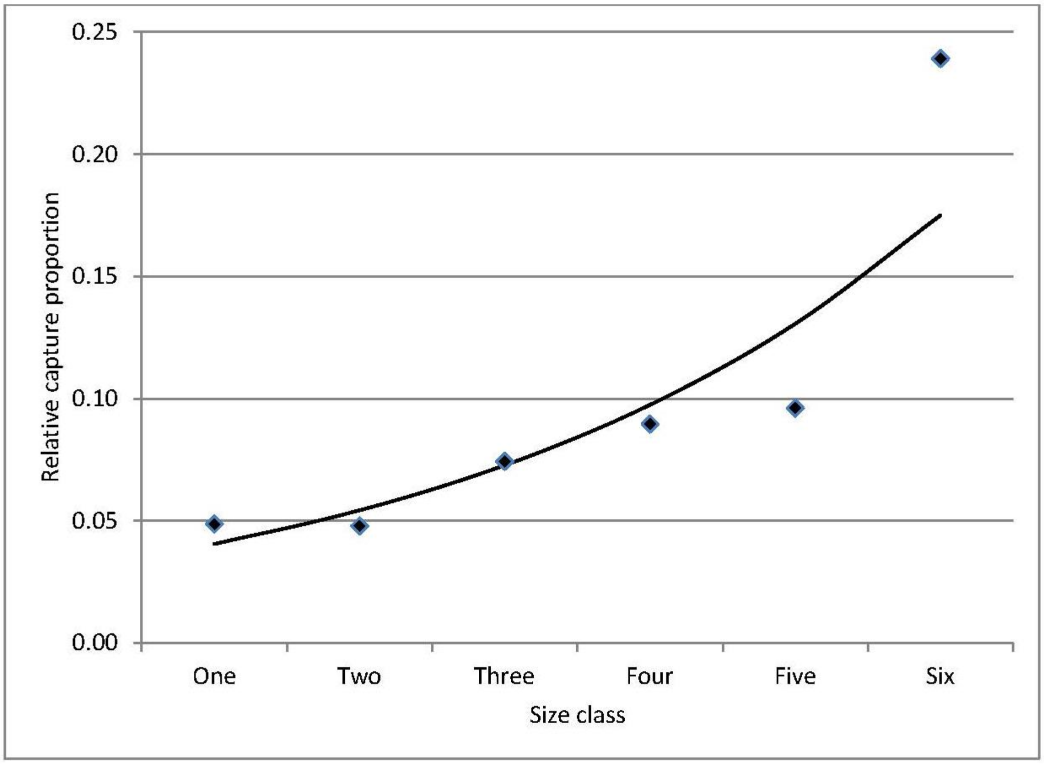

Figure 4.—Relative capture proportion of repatriated razorback released between January 1, 2006, and January 1, 2012, and contacted between January 1, 2012, and April 30, 2012, or December 1, 2012, and April 30, 2013, LCR MSCP Reach 3, lower Colorado River, Arizona-California-Nevada.
Fish were divided into the following seven six classes based on TL at release: one – ≤299 mm, two – 300 to 349 mm, three – 350 to 399 mm, four – 400 to 449 mm, five – 450 to 499 mm, and six – ≥500 mm. The regression line is the best fit (least mean squares) of log transformed capture proportions (r^2 = 0.858).

Ecological Modeling

For the mark-recapture model, a total of 44,255 released fish from autumn 2006 (January – June) through autumn 2012, and 3,069 captures or contacts from spring 2007 (July – December) through spring 2013, were included (table 5). The best fit model with an AIC weight of nearly one (0.996) was a two age structured model with time varying 1st (post-release) and 2nd (adult) age survival parameters and release TL as a covariate. Each model with a seasonal 1st period survival parameter group (separate parameters for spring and autumn) fit better than the comparable model with fixed 1st period survival (single parameter) but not better than the comparable model with time varying 1st period survival (see attachment 1 for complete model comparison). Post-release survival estimates (first season after release) based on release TL were back-calculated and then plotted for 10 of 13 cohorts from the best fit model (figure 5). Two cohorts, autumn 2009 and

Table 4.—Date, number, and mean TL of razorback sucker released into zones 3-1 to 3-4 with a 134-kHz PIT tag and number and proportion of number released that were scanned with remote PIT scanners in zone 3-1 between January 1, 2012, and April 30, 2012, or December 1, 2012, and April 30, 2013, LCR MSCP Reach 3, lower Colorado River, Arizona-California-Nevada

Zone	Release date	Number released	Mean TL (mm)	Number contacted	Proportion contacted
3-1	October 2006	2,011	325	22	0.011
	November 2006	2,009	365	118	0.059
	February 2007	145	613	29	0.200
	April 2007	1,045	380	115	0.110
	November 2007	3,113	343	23	0.007
	March 2008	1,160	320	55	0.047
	October 2008	1,014	324	6	0.006
	January 2011	3,229	366	106	0.033
	March 2012	4,125	366	38	0.009
3-2	March 2008	937	329	94	0.100
	March 2009	1,903	340	255	0.134
	January 2010	3,243	349	32	0.010
	February 2011	3,496	368	439	0.126
	November 2011	250	420	14	0.056
	February 2012	2,887	344	131	0.045
	April 2012	917	364	45	0.049
	May 2012	123	345	0	0.000
3-3	May 2009	1,985	326	130	0.065
	February 2010	2,171	376	86	0.040
	February 2011	1,308	361	18	0.014
	March 2011	2,192	343	119	0.054
	October 2011	327	324	0	0.000
3-4	October 2007	439	435	12	0.027
	November 2007	2,124	339	17	0.008
	February 2009	1,966	330	30	0.015

autumn 2010, were eliminated due to a lack of releases, 0 and 1, respectively, and one cohort, autumn 2008, was eliminated due to a lack of post-release contacts (0 for first four periods post-release). Post-release survival was highest for spring releases from 2006 through 2009. Generally, spring releases had better survival

Table 5.—Number of razorback sucker with a release TL released and/or contacted by any means (netting, electrofishing, scanning) by season from July 1, 2006, through June 30, 2013, in LCR MSCP Reach 3, lower Colorado River, Arizona-California-Nevada (Releases or contacts from January through June were denoted as spring (S) and from July through December as autumn (A). Contacts made within the season of release were removed from analysis.)

Release season	Number released	S 2007	A 2007	S 2008	A 2008	S 2009	A 2009	S 2010	A 2010	S 2011	A 2011	S 2012	A 2012	S 2013	Total contacts
A 2006	4,046	31	13	18	3	21	3	5	4	15	1	86	26	74	300
S 2007	1,045		14	11	3	17	2	8	1	16	0	75	34	60	241
A 2007	5,673			10	2	1	1	2	0	10	0	38	5	20	89
S 2008	2,108				52	10	7	17	13	16	0	71	19	100	305
A 2008	1,030					0	0	0	0	2	0	5	1	2	10
S 2009	5,858						23	54	27	71	2	223	60	268	728
A 2009	0							0	0	0	0	0	0	0	0
S 2010	5,414								8	30	3	66	12	62	181
A 2010	1									1	0	0	0	0	1
S 2011	10,263										18	217	121	551	907
A 2011	577											6	2	11	19
S 2012	8,191												69	199	268
A 2012	49													20	20
Totals	44,255	31	27	39	60	49	36	86	53	161	24	787	349	1,367	3,069

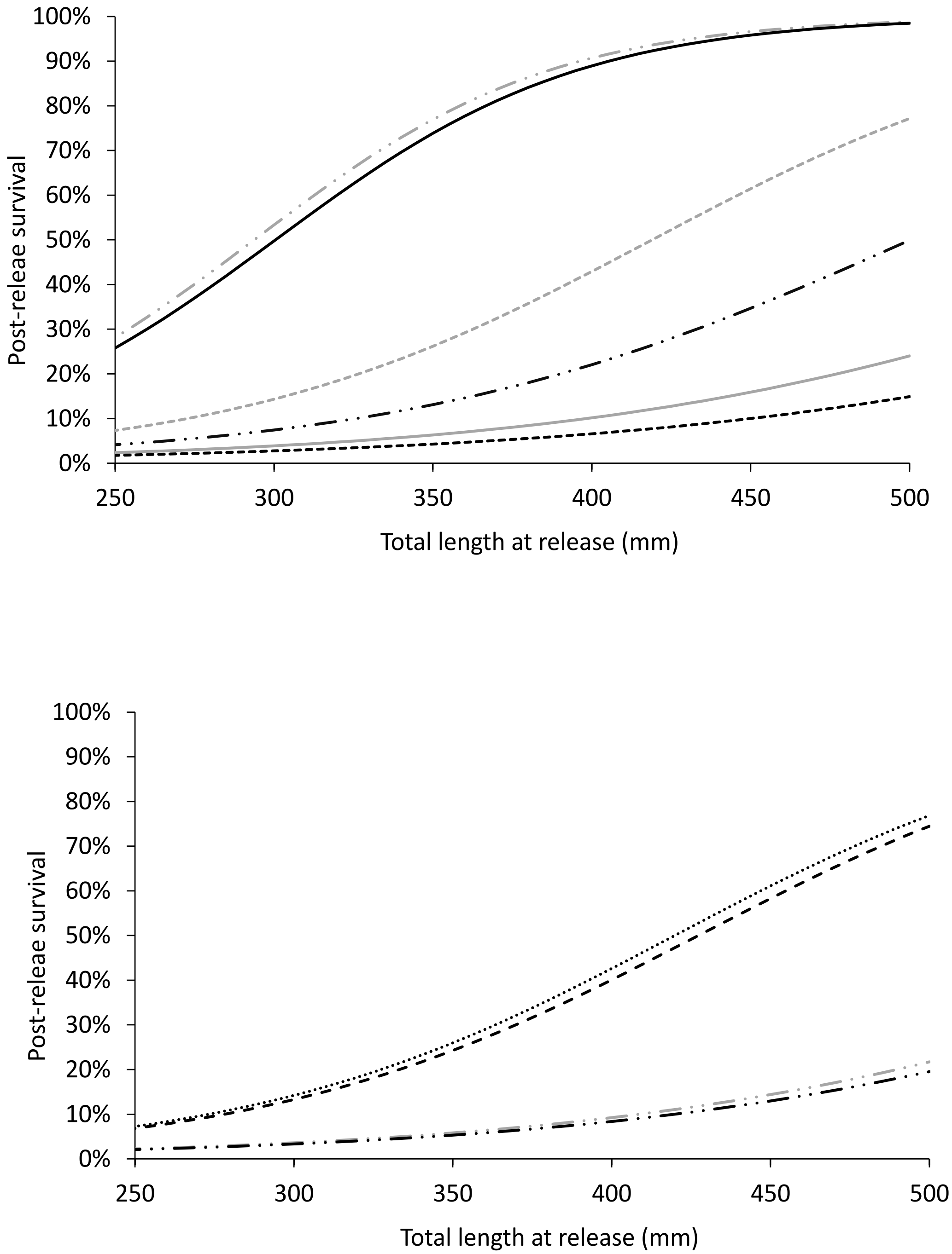

Figure 5.—Post-release (6-month) survival for razorback sucker stocked into Reach 3 in spring (top) and autumn (bottom) from autumn 2006 through spring 2012.
(2006 [black dot], 2007 [grey dash dot], 2008 [solid black], 2009 [grey dash], 2010 [solid grey], 2011 [black dash dot], 2012 [black dash]. Missing year-season combinations had fewer than 10 fish released or post-release contacts.)

for a given size at release compared to autumn, and cohorts before 2010 had higher survival than cohorts after 2010. The cohort with the lowest survival was for the most recent spring release in 2012; this low estimate may be due to the low number of recapture opportunities.

DISCUSSION

Use of remote PIT scanning during this study increased the contact rate of released razorback sucker in Reach 3 by factors of 3.6 and 10.1 for 2012 and 2013, respectively, compared with standard physical sampling methods such as electrofishing and netting. Scanning was employed in both slack and quickly moving waters and provided a cost-effective and efficient method of contact that meets the goals of this and similar projects. This increase in contacts resulted in more precise population estimates and new insights into factors affecting post-stocking survival.

Previous estimates of razorback sucker in Reach 3 were based on relatively few recaptures (e.g., R = 2), resulting in questionable accuracy (Wydoski and Mueller 2006). In contrast, combining capture and remote PIT scanning data in 2012 provided a substantial number of fish sampled in both mark and capture periods (R = 59), which removed the likelihood of statistical bias (due to low recaptures) in the Chapman modified Petersen estimate (Ricker 1975). The base population estimate for 2011 of 2,659 (2,069 to 3,414, 95% CI) is almost double the estimate of 1,400 (894 to 2,196, 95% CI) reported in 2010 (J. Lantow, Reclamation, personal communication), but confidence intervals overlap broadly; therefore, the estimates are not significantly different. The increased number of fish contacted in 2013 resulted in 279 recaptures, boosting the population estimate to 4,156 (3,698 to 4,671, 95% CI). However, the expanded population estimate that includes fish without a 134-kHz PIT tag based on the percentage of 134-kHz tagged fish encountered during electrofishing is likely suspect given the observed year-to-year variation in the percentage of 134-kHz PIT tagged fish. The difference between the 2011 electrofishing percentage of captured fish that contained a 134-kHz tag (96%) and the 2012 percentage (65%) cannot be explained by release records or an average amount of tag loss, but instead may indicate potential bias in estimates due to non-random fish assortment and sampling.

The random assortment of fish between capture events is an assumption of the modified Peterson population estimate as well as the mark-recapture estimates of survival in MARK (Seber 1973; Cooch and White 2013). An examination of the summary data used in mark-recapture analysis (see table 5) illustrates the apparent lack of random assortment. The final sampling event (spring 2013) resulted in substantially more PIT scanning contacts compared to the previous spring (2012), which was the first year PIT scanning was employed. However, when the number of contacts is compared on a per cohort (release season) basis, the number of contacts decreased from spring 2012 to spring 2013 for older cohorts (autumn 2006 and spring and autumn 2007). The relative increase in total contacts for spring 2013 is mostly attributable to a more than 2.5-fold-increase between spring 2012 and spring 2013 in contacts of fish from the spring 2011 cohort. This increase may represent fish reaching sexual maturity 2 years after release; a similar trend can be seen for spring 2007 and spring 2008 releases. Regardless of the cause, this non-random contact rate from one year to the next will bias both population estimates and mark-recapture estimates of survival.

Besides the potential for bias, post-release survival estimates presented in this report suffer from a lack of precision due to sparse data. Although there was a substantial increase in the number of contacts from PIT scanning in spring 2012 and 2013, post-release survival estimates for fish released in spring rely on contacts made in the first autumn after release. Without a significant number of contacts in the autumn, estimates of post-release survival and adult survival varied widely among relatively similar models and especially so in models with unique values for all cohorts (i.e., time varying survival). The lack of precision was also evident within the "best fit" model parameter estimates (table 6). First season post-release survival (Age 1) for a fish released at mean size (352 mm TL) in the spring of 2012 was estimated at 4.4% with a CI between 3.7 to 5.1%, but the second season survival for this same cohort has a confidence interval between 0 and 100%. When survival for the first two seasons (Age 1 and Age 2) is combined, only spring of 2010 and autumn of 2011 appear to have acceptable levels of precision. Although actual post-release survival estimates fluctuated between and within models, post-release survival for razorback sucker released in spring was significantly higher than for autumn releases in all seasonal models. Razorback sucker released in the Green and San Juan Rivers had similar seasonal trends (Bestgen et al. 2009; Zelasko et al. 2011). Seasonal analysis for this study was restricted to only two "seasons" based on the majority of stockings occurring from January through May (spring) and October through November (autumn).

Release location was not found to be a statistically significant confounding factor in assessing population size and post-stocking survival, even when the zone of stocking was 92 RKM (57 RM) away in zone 3-4, but relative rates of contact were at least half in zone 3-4 compared to the other zones of release. Relatively low replication in zones 3-3 and 3-4 likely resulted in low statistical power and a lack of statistical significance. The results from this study should be considered in the context of previous work as well. Telemetry studies of razorback sucker released into the downstream end of Lake Havasu proper found that, given sufficient time (approximately 1 year), fish can and do move upstream to spawning areas near Needles, California (Wydoski and Lantow 2012). Razorback sucker are capable of travelling substantial distances at rates upwards of 20 km per day in Lake Mohave, the reservoir directly upstream of Davis Dam (Mueller and Marsh 1998; Mueller et al. 2000), and elsewhere (Tyus 1987; Tyus

Table 6.—Parameter estimates from the best fit mark-recapture model “2 age, time, time, yes” (see attachment 1) evaluated in MARK
(Survival estimates are for a fish released at the overall mean size (TL) of 352 mm.)

	Parameter	Estimate	SE[1]	95% confidence interval Lower	95% confidence interval Upper
Survival	Age 1 – Autumn 2006	0.26530	0.04130	0.19250	0.35370
	Age 1 – Spring 2007	0.77670	0.17520	0.32440	0.96180
	Age 1 – Autumn 2007	0.05920	0.01240	0.03910	0.08860
	Age 1 – Spring 2008	0.74620	0.10740	0.49180	0.89940
	Age 1 – Autumn 2008	0.01720	0.00680	0.00790	0.03710
	Age 1 – Spring 2009	0.26760	0.02310	0.22480	0.31520
	Age 1 – Autumn 2009	0.00180	0.00000	0.00180	0.00180
	Age 1 – Spring 2010	0.06450	0.00700	0.05210	0.07980
	Age 1 – Autumn 2010	1.00000	0.00000	1.00000	1.00000
	Age 1 – Spring 2011	0.13390	0.00720	0.12050	0.14860
	Age 1 – Autumn 2011	0.05420	0.01150	0.03560	0.08170
	Age 1 – Spring 2012	0.04350	0.00340	0.03730	0.05080
	Age 1 – Autumn 2012	0.24790	0.30520	0.01310	0.89080
	Age 2 – Autumn 2006	1.00000	0.00000	1.00000	1.00000
	Age 2 – Spring 2007	0.80640	0.19090	0.27500	0.97860
	Age 2 – Autumn 2007	1.00000	0.00080	0.00000	1.00000
	Age 2 – Spring 2008	0.38600	0.07790	0.24820	0.54490
	Age 2 – Autumn 2008	1.00000	0.00000	0.00000	1.00000
	Age 2 – Spring 2009	1.00000	0.00000	0.00000	1.00000
	Age 2 – Autumn 2009	1.00000	0.00010	0.00000	1.00000
	Age 2 – Spring 2010	0.76030	0.06800	0.60410	0.86830
	Age 2 – Autumn 2010	0.99930	0.01670	0.00000	1.00000
	Age 2 – Spring 2011	1.00000	0.00000	0.00000	1.00000
	Age 2 – Autumn 2011	0.59810	0.03960	0.51860	0.67270
	Age 2 – Spring 2012	0.73190	0.55610	0.01050	0.99860
Recapture	Spring 2007	0.03030	0.00710	0.01920	0.04770
	Autumn 2007	0.01410	0.00340	0.00880	0.02250
	Spring 2008	0.02070	0.00510	0.01280	0.03330
	Autumn 2008	0.01880	0.00420	0.01210	0.02910
	Spring 2009	0.03930	0.00630	0.02860	0.05370
	Autumn 2009	0.01420	0.00260	0.00990	0.02030
	Spring 2010	0.03400	0.00450	0.02620	0.04390
	Autumn 2010	0.01810	0.00280	0.01330	0.02460
	Spring 2011	0.07250	0.00630	0.06100	0.08580
	Autumn 2011	0.00620	0.00130	0.00410	0.00930
	Spring 2012	0.20080	0.01020	0.18150	0.22150
	Autumn 2012	0.12670	0.00900	0.11000	0.14550
	Spring 2013	0.66810	0.50680	0.02230	0.99440

[1] Standard error.

and Karp 1990). However, extensive netting efforts in the reservoir (Laughlin downstream to Cattail Cove) have generally failed to contact fish released in the lower portion of the reservoir (zone 3-4) (Wydoski and Mueller 2006). These netting efforts were primarily focused in backwaters adjacent to the main channel and to a lesser degree in eddy fences with low current in the main channel. Our remote sensing sampling efforts included the center and side of the main channel with higher current where aggregates of spawning razorback sucker occur, thus increasing contact rates.

RECOMMENDATIONS

We recommend continued monitoring of repatriated razorback sucker in Reach 3, with increased implementation of remote PIT scanner deployment. This methodology, like any other, has limitations, but it has proven to be a far more effective means than standard physical sampling in contacting razorback sucker in the riverine portion of this reach and especially so during the reproductive season. This benefit became more evident during our second season of remote PIT scanning throughout the reach when the number of fish contacted by remote sensing was three-fold greater than conventional methods. Continuation of such efforts in the coming years should provide a dataset with enough clarity to adequately discern the factors affecting survival of razorback stocked into Reach 3. Biannual netting and electrofishing efforts to collect health, growth, census, and genetic data from repatriate razorback suckers should also continue to create a more complete picture of the status of razorback sucker in the reach.

Although the zone in which fish were released and later contacted was not found to be statistically significant between zones, relative rates of contact were at least half in zone 3-4 compared to the other zones of release. Given this difference in contact rates and evidence from previous netting efforts, we suggest future stocking events focus on zones 3-1 through 3-3.

Finally, future availability of multiple seasons of remote PIT scanning data will allow us to make interyear comparisons and provide an opportunity to perform more complete data analysis. Our expectation is that results of these additional analyses will form a foundation upon which to base specific recommendations to adjust the Reach 3 stocking program in ways that will enhance post-release survival of repatriated fish.

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The cover photo of LCR MSCP Reach 3 near Needles, California, was provided by Abraham P. Karam.

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ATTACHMENT 1

Ecological Model Comparison

Model comparison results from the mark-recapture program MARK. Model structure summarized by number of ages, variation in parameterization of ages, and inclusion of release total length (TL) as a covariate in model (e.g., model – {2 age, time, time, yes} = a two age structure model with time varying parameters for the 1st and 2nd ages and release TL as a covariate).

Model	AICc	AICc[1] weight	Number of parameters	Deviance
{2 age, time, time, yes}	27636.60	0.9965	31	27574.56
{3 age, time, fixed, seasonal, yes}	27647.87	0.0036	27	27593.84
{2 age, time, seasonal, yes}	27677.98	0.0000	26	27625.95
{2 age, time, fixed, yes}	27683.47	0.0000	25	27633.45
{3 age, time, fixed, time, yes}	27690.94	0.0000	35	27620.88
{3 age, time, fixed, fixed, yes}	27706.70	0.0000	25	27656.67
{3 age, time, time, time, yes}	27712.51	0.0000	28	27656.47
{3 age, time, fixed, time, no}	27934.28	0.0000	37	27860.22
{3 age, time, time, fixed, yes}	27944.96	0.0000	23	27898.94
{3 age, time, time, seasonal, yes}	27971.26	0.0000	25	27921.23
{3 age, time, fixed, seasonal, no}	27976.18	0.0000	28	27920.15
{2 age, time, time, no}	27980.26	0.0000	37	27906.20
{3 age, time, fixed, fixed, no}	27983.62	0.0000	27	27929.59
{2 age, time, seasonal, no}	28001.88	0.0000	27	27947.85
{2 age, time, fixed, no}	28008.04	0.0000	26	27956.01
{3 age, time, time, time, no}	28049.81	0.0000	36	27977.75
{3 age, time, time, fixed, no}	28132.07	0.0000	25	28082.04
{3 age, time, time, seasonal, no}	28135.62	0.0000	27	28081.59
{2 age, seasonal, time, yes}	28472.89	0.0000	19	28434.88
{3 age, seasonal, fixed, seasonal, yes}	28482.23	0.0000	17	28448.22
{3 age, seasonal, fixed, time, yes}	28482.26	0.0000	19	28444.24
{3 age, seasonal, fixed, fixed, yes}	28487.33	0.0000	18	28451.32
{2 age, seasonal, seasonal, yes}	28545.50	0.0000	16	28513.49
{2 age, seasonal, fixed, yes}	28547.51	0.0000	17	28513.49
{3 age, seasonal, seasonal, fixed, yes}	28561.93	0.0000	16	28529.92
{3 age, seasonal, seasonal, seasonal, yes}	28561.93	0.0000	16	28529.92
{3 age, seasonal, seasonal, time, yes}	28561.93	0.0000	16	28529.92
{2 age, fixed, time, yes}	28616.19	0.0000	21	28574.17
{2 age, seasonal, time, no}	28663.74	0.0000	27	28609.71
{3 age, seasonal, fixed, seasonal, no}	28677.46	0.0000	16	28645.45
{3 age, fixed, fixed, time, yes}	28678.91	0.0000	18	28642.90
{3 age, seasonal, fixed, fixed, no}	28679.46	0.0000	17	28645.45
{3 age, seasonal, fixed, time, no}	28719.88	0.0000	25	28669.85
{2 age, seasonal, fixed, no}	28739.86	0.0000	16	28707.85
{2 age, seasonal, seasonal, no}	28741.55	0.0000	17	28707.54
{3 age, seasonal, seasonal, fixed, no}	28759.29	0.0000	16	28727.28
{3 age, seasonal, seasonal, seasonal, no}	28759.30	0.0000	16	28727.29
{3 age, seasonal, seasonal, time, no}	28772.37	0.0000	26	28720.34
{3 age, fixed, fixed, seasonal, yes}	28805.37	0.0000	17	28771.35
{2 age, fixed, seasonal, yes}	28813.23	0.0000	17	28779.21
{2 age, fixed, fixed, yes}	28846.21	0.0000	16	28814.20
{2 age, fixed, time, no}	28854.87	0.0000	26	28802.84
{3 age, fixed, fixed, fixed, yes}	28856.28	0.0000	17	28822.26
{3 age, fixed, fixed, time, no}	28931.26	0.0000	26	28879.23
{3 age, fixed, fixed, seasonal, no}	29023.71	0.0000	17	28989.70
{2 age, fixed, seasonal, no}	29024.15	0.0000	16	28992.14
{3 age, fixed, fixed, fixed, no}	29047.90	0.0000	16	29015.89
{2 age, fixed, fixed, no}	29065.10	0.0000	15	29035.09

[1] Small sample Akaike's Information Criterion.