Demographics and post-stocking survival of repatriated razorback sucker in Lake Mohave

Final Report

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 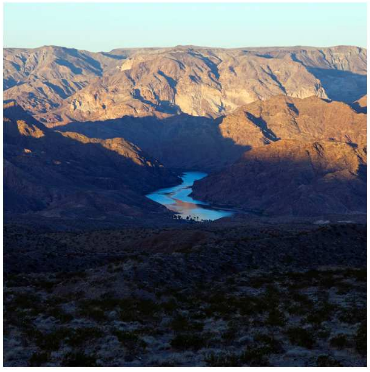 

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between

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Cover photos:

An M&A field crew collects razorback sucker larvae at night (left photo) along the shoreline of Liberty Cove in Lake Mohave. Collections from this and other reservoir reaches contribute toward achieving the yearly larval quota set each January by the Lake Mohave Native Fish Workgroup and sustaining the genetic diversity of the repatriate population.

Upstream from Liberty Cove, Lake Mohave is bound by the steep volcanic topography of Black Canyon (center photo). Within this reach, shallow gravel bars project into the river where a substantial number of repatriates have been documented by specialized underwater remote PIT scanning antennae designed and constructed by M&A.

An adult razorback sucker repatriate (right photo) is prepared for release by an M&A technician near its site of capture in Carp Cove during a March roundup. Valuable growth, health, census, and genetic data are obtained from repatriates captured during bi-annual netting operations.

All photos by APK.

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Summary

The decline of razorback sucker *Xyrauchen texanus* in Lake Mohave has been extensively documented for more than three decades. The development and implementation of a repatriation program has, at least for the time being, captured the genetic legacy of the soon-to-be extirpated wild population; however, persistence of the repatriate population depends entirely on active management and continued augmentation.

We completed a comprehensive, three-year study that focused on the demographics and post-stocking survival of repatriated razorback sucker in Lake Mohave. Five specific areas of inquiry were pursued between October 2008 and May 2011: (1) post-stocking dispersal and fate determined by acoustic telemetry, (2) routine monitoring and population estimation, (3) creel census, (4) ecological modeling, and (5) remote PIT scanning.

In autumn 2008, 20 adult razorback sucker collected from Yuma Cove Backwater and 10 subadults reared at U.S. Fish and Wildlife Service Willow Beach National Fish Hatchery were implanted with acoustic transmitters, released in Fortune Cove and telemetered twice monthly for six months. Over the course of the study, 67% of subadults and 80% of adults remained active. Thirty five percent of all telemetered adults dispersed upstream of Willow Beach where large aggregations of additional razorback sucker were observed. In contrast, no telemetered subadults released in 2008 were detected in this reach. Five transmitters were recovered from the bottom of the reservoir using SCUBA; no fish remains were observed near any recovered transmitters. In a second telemetry study initiated in autumn 2009, 10 adult razorback sucker collected from Lake Mohave near Hoover Dam and 14 adults (2005 year-class) reared at Arizona Game and Fish Department Bubbling Ponds Fish Hatchery were implanted with acoustic transmitters, released near Hoover Dam and at the Willow Beach boat ramp, respectively, and telemetered twice each month for six months. At the conclusion of the study, all fish (100%) from both groups remained active. Approximately 50% of both groups of fish remained upstream of Willow Beach for the entire study.

Routine monitoring during the months of December 2008, March and December 2009, March and December 2010, and March 2011 resulted in the capture of 60 razorback sucker. Population estimates from March roundup data declined for wild fish; however, the repatriate population estimate increased by more than 100% between 2009 and 2010. Wild population estimates declined from 24 fish (9-480 95% confidence interval [CI]) in 2009 to 13 fish (4-250 95% CI) in 2010, and repatriated razorback sucker estimates increased from 1,439 (753-2,805 95% CI) to 2,966 fish (1,509-6,063 95% CI. The current (2010) total population estimate for razorback sucker in Lake Mohave is 2,979.

Eighteen large (greater than 80 cm total length [TL]) striped bass *Morone saxatilis* and two channel catfish *Ictalurus punctatus* have been scanned for PIT tags by Nevada Department of Wildlife (NDOW) creel census personnel since January 2006; none have contained PIT tags. However, a 13.6 kg striped bass reported to NDOW (outside scheduled creel census times) contained an acoustic transmitter from a recently stocked razorback sucker. Creel census monitoring was discontinued by NDOW in 2009, and in response we developed and launched a new web-based forum to serve as a repository for reporting striped bass catch data and to acknowledge and award anglers and spear fisherman for reporting pertinent information.

Stocking simulations based on size-survival relationships and growth and release data from the Lake Mohave Native Fish Work Group database reveal that post-stocking survival for razorback sucker is between four and eight times higher when the target release size is 45 cm TL compared to a target size of 30 cm TL. Uncertainty in results is due to differences in stocking protocols between the 1990s and 2000's including stocking size and location.

Remote PIT-scanners were deployed twice a month in the riverine portion of Lake Mohave upstream of Willow Beach by M&A from February through to September 2011, and in the basin by U.S. Bureau of Reclamation from February through April 2011. These efforts contacted 1044 unique razorback sucker, 730 contacts made in the riverine portion, and 321 in the basin, with 7 individuals being contacted at both locations. Scanning data from 2010 and 2011 along with

March roundup and electrofishing data resulted in zone specific population estimates of 1531 and 1880 razorback sucker for the basin and river zones respectively. Only seven individuals contacted were detected in both river and basin zones, suggesting relatively segregated populations, although those few fish moving between zones may be adequate to maintain gene flow. Continued remote PIT scanning is vital to provide insight into the population of riverine fish previously not included in lake wide population estimation, as well as the movement dynamics of these potential sub-populations.

Bi-annual netting efforts should continue in order to collect growth, health, census, and genetic data for razorback sucker. Size-at-release for all future stocking should be maintained at the largest size possible, in the greatest number possible, given the limits of production. Some or all of these stockings should be directed spatially and temporally with the goal of assessing the metapopulation dynamics and the affect stocking locations has on these dynamics. To this end, stockings from the hatchery should be concurrent and numbers distributed equally between the three known subpopulations. Remote PIT-scanners should be deployed to monitor the three subpopulation centers (River, Liberty, and Basin) with a nominal effort of 200 scanning hours per zone.

Introduction

Lake Mohave is a mainstem lower Colorado River reservoir that once was home to the largest known population of wild razorback sucker *Xyrauchen texanus* (Minckley 1983). Historically, this population contained more than one hundred thousand fish, but numbers have dwindled dramatically in recent years (Marsh et al. 2003, Turner et al. 2007) and it currently is made up of fewer than 50 individuals (Kesner et al. 2010b, Pacey and Marsh 2011).

A repatriation program was established in the early 1990s (Mueller 1995) to conserve the genetic diversity of the wild population (Dowling et al. 1996a, 1996b). The program utilizes wild-produced larvae that are reared in protective captivity to a nominal size of 30 cm total length (TL) or more, and then stocked into the reservoir. The repatriates that now occupy the reservoir depend entirely on the efforts of the Lake Mohave Native Fish Workgroup (NFWG) to maintain its population size and genetic integrity. This ad-hoc group of individuals from federal and state agencies and private organizations began in 1987. Since 2007 major funding for the NFWG has been provided by the Lower Colorado River Multi-Species Conservation Program (LCR MSCP).

Both size-at-release (TL) and total number of razorback sucker stocked in Lake Mohave have contributed to the maintenance of low annual population estimates reported (Kesner et al. 2008b), which are similar to those predicted in earlier models (Marsh et al. 2005). Recent acoustic telemetry and mark-recapture data confirm low initial post-release survival of subadult repatriates, followed by annual survivorship of approximately 75% for the adult at large population (Kesner et al. 2008b).

There have been a number of adjustments to the repatriation program that incorporate new information to improve survival of stocked fish, but results thus far have not met expectations (Marsh et al. 2005). Furthermore, not all recommended changes have been practical to implement. For example, growing thousands of repatriates to 50 cm TL under the current constraints of available lake-side backwaters and limited hatchery space has remained a challenge. Though few adults greater than 50 cm TL have been released to date (Marsh & Associates [M&A] unpublished data), it is essential to further refine the relationship between size at release—including 50+cm fish—and survivorship, and to investigate causes of repatriate mortality.

Estimates of post-stocking survivorship based on multiple years of telemetry can also be used to evaluate the predictions of a mark-recapture model that has relied extensively on data generated from routine monitoring to more thoroughly understand the population dynamics of the repatriate population. However, a considerably larger number of year-round contacts are required to refine our understanding of the variables that affect survivorship. Traditional approaches, such as more intensive trammel netting, are not reasonable strategies due to budget and personnel limitations, habitat constraints (see below), and potential adverse effects to fish health (Hunt 2008; Sykes et al. 2011). Because the repatriate population is now primarily composed of individuals that contain 134 kHz PIT tags, we can utilize the developing field of remote PIT scanning (Kesner et al. 2008c) to generate more accurate population estimates and answer fundamental demographics questions that will improve ongoing conservation strategies.

This report is the concluding document of a three year demographic and post-stocking survival study of repatriated razorback sucker in Lake Mohave. Two rounds of acoustic telemetry were conducted to further evaluate post-stocking mortality of razorback sucker based on previous work (see Kesner et al. 2008b). Population and survival estimates for wild and repatriate populations were updated based on results from standard monitoring. Creel census data on large striped bass *Morone saxatilis* abundance and impact on razorback sucker stockings were evaluated through collaboration with Nevada Department of Wildlife (NDOW) and a new web-based online forum where striped bass anglers and spear fisherman can report pertinent information. Finally, repatriate population estimates were refined by including remote PIT scanning data collected in the basin and lotic portions of the lake.

Methods

Study Area

Lake Mohave is impounded by Davis Dam (Figure 1), constructed by U.S. Bureau of Reclamation (BOR), and completed in 1951. The dam creates a narrow, 107 km^2 reservoir that re-regulates water releases from Hoover Dam (the upstream terminus of Lake Mohave) and facilitates the delivery of Colorado River water to downstream farms and cities in Arizona, California, and Mexico. Clear, hypolimnetic releases from Hoover Dam are perennially cold (~12.8 °C year-round) and vary in volume according to daily municipal power demands; discharge can range between 42.5 m^3sec^{-1} and 991 m^3sec^{-1} over the course of only a few hours (BOR 2011). Sediment from numerous side canyons create gravel bars that project into the shallow river channel between Hoover Dam and Willow Beach, some of which discharge hot spring water (Mueller 1989). As the Colorado River continues its downstream trajectory through Black Canyon towards Chalk Cliffs, surface flows ultimately subside (Paulson et al. 1980) as the reservoir widens. Downstream of Chalk Cliffs, Lake Mohave develops reservoir-like characteristics with open basins and a rocky shoreline. Coves and lakeside backwaters line the shore until Lake Mohave reaches its downstream terminus at Davis Dam.

A suite of nonnative fishes flourish in Lake Mohave (Allan and Roden 1978, Minckley 1983). More than 120,000 rainbow trout *Oncorhynchus mykiss* are stocked yearly by U.S. Fish and Wildlife Service (USFWS) Willow Beach National Fish Hatchery (WBNFH). Nevada Department of Wildlife (NDOW) ended their trout stocking program in 2011. Striped bass first appeared in Lake Mohave in 1981 and their numbers surged in 1983 when excess water was released from Hoover Dam via spillway tunnels (Minckley and Marsh 2009). Striped bass feed on stocked rainbow trout (USFWS 1994) as well as razorback sucker and bonytail (Karam and Marsh 2010).

Since 2007, NDOW has deployed artificial habitat bundles (consisting largely of cut *Tamarix* tied to wooden pallets) to improve recreational fishing opportunities for nonnative sport fishes such as largemouth bass *Micropterus salmoides*, smallmouth bass *Micropterus dolomieu*, striped bass, channel catfish *Ictalurus punctatus*, and bluegill *Lepomis macrochirus* (NDOW 2011).

Post-stocking Dispersal and Fate

Two previous acoustic telemetry studies (see Kesner et al. 2008b) focused on post-stocking survivorship of subadults following their release in Fortune Cove and a hatchery-based transmitter retention experiment (Karam et al. 2008). Data from these studies are cited here or otherwise incorporated in our results when analyzed in conjunction with the telemetry work completed during the timeframe of this report.

2008-09 Acoustic Telemetry

Thirty razorback sucker (10 hatchery-collected subadults, mean TL 38 cm [range 36-43 cm] and 20 backwater-collected adults, mean TL 54 cm [range 50-62 cm]) were implanted with acoustic transmitters, stocked in Lake Mohave, and telemetered twice each month between 6 November 2008 and 5 May 2009.

On 22-23 October 2008, BOR staff harvested adult razorback sucker from Yuma Cove backwater (11S 712763 3933461; Figure 1) using overnight trammel net sets. Captured fish were held in net pens for 24 h due to inclement weather, and on 24 October the 30 largest individuals were removed from net pens, placed in aerated holding tanks filled with local water, and transported by boat to WBNFH. At the hatchery, fish were transferred into two indoor circular raceways, treated by hatchery personnel with salt (1% concentration) and formalin (132 parts per million) to reduce fish stress and as a preventative for *Ichthyophthirius multifiliis* (Mark Olson, USFWS, personal communication), and held for seven days.

On 31 October 2008, 10 subadult razorback sucker were collected from an outdoor raceway and transferred to a separate indoor circular raceway. All adult and subadult individuals had previously received a 134 kHz PIT tag for individual identification. Backwater and hatchery fish were anesthetized with 125 $mg \cdot l^{-1}$ of tricaine methanesulfonate, weighed, measured (TL), scanned for a PIT tag, and surgically implanted (for review, see Kesner et al. 2010b) with an acoustic transmitter (IBT 96-6-I; Sonotronics, Inc.). Following surgery, adult and subadult razorback sucker were placed in separate recovery raceways and monitored to ensure proper health and tag retention.

On 5 November 2008, six Submerged Underwater Receivers (SURs; Sonotronics, Inc.) were deployed at various locations throughout the northern half of Lake Mohave; Fortune Cove (11S 707708 3956019), Chalk Cliffs (11S 708198 3959277), Windy Canyon (11S 707342 3964180)[1], Fire Mountain Lights (11S 707904 3951864), Painted Canyon Lights (11S 711229 3933030), and the entrance to Klondike Cove (11S 710911 3933226). On 6 November 2008, all study fish were placed in two, 1893-L aerated tanks, transported by boat downriver from Willow Beach NFH, and released into Fortune Cove (Figure 1).

Tagged fish were telemetered twice monthly for six months. Manual tracking techniques were modified from Mueller et al. (2000) and described in detail in Karam et al. (2008). Routine tracking information was recorded on waterproof paper as follows: date, 24-h time, transmitter number, transmitter code, UTM coordinates, water depth (m), and location notes. With exception of the SUR originally deployed at Windy Canyon, all others were never relocated from their original location of deployment for the entire study. During each trip, SURs were downloaded into a laptop computer using SURsoft v 6.8.8 telemetry software. Narrative descriptions of SUR downloading events, weather, reservoir condition/river flows, etc. were recorded on data books.

SUR and manual tracking data were incorporated into a Microsoft Excel database. Mean distance traveled per month was determined for both groups of fish by calculating the mean distance traveled by fish during a given month, then interpolating that number to a standardized 30 day period. Contact density maps were constructed using ESRI® ArcMap v 9.1

[1] The SUR deployed at Windy Canyon was relocated on 2 February 2009 to the upper river (11S 706881 3977619) between Big Sand Bar and Horseshoe Rapids, where it remained until the conclusion of the study.

software and were based on the total number of contacts per fish group that occurred in each specific zone (Figure 1; Kesner et al. 2008b) over the course of the study.

If fish remained in the same location for two or more consecutive trips, they were investigated using SCUBA (Karam et al. 2008). All SCUBA observations and transmitter recovery took place on 29-30 April 2009.

2009-10 Acoustic Telemetry

Twenty-four razorback sucker (10 river-collected adults[2], mean TL 61 cm [range 53-67 cm] and 14 hatchery-collected adults[3], mean TL 53 cm [range 51-55 cm]) were implanted with acoustic transmitters, stocked in Lake Mohave, and telemetered twice each month between 4 November 2009 and 3 May 2010.

A boat electrofisher (Smith Root SR-18H package with GPP 7.0 pulsator) was used on 14 October 2009 to collect four adult razorback sucker between RM 60-62 near Hoover Dam (Kesner et al. 2010b), and seven additional fish were collected from the same area on 29 October 2009. On 30 October 2009, 25 adult razorback sucker were collected from Arizona Game and Fish Department Bubbling Ponds State Fish Hatchery (BPSFH) and placed in two, 189-L fish transport tanks filled with local water. All fish were transported to WBNFH, placed in circular raceways, and treated by hatchery personnel with salt (1% concentration) and formalin (132 parts per million).

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[2] River fish were chosen for a number of reasons. Past electrofishing surveys conducted by Reclamation indicated a sizeable population of adult razorback sucker resides between RM 60-62 in Lake Mohave. These robust individuals represent the largest size class of adults used in our telemetry studies to date. Additionally, these fish are thought to be present year-round, but their movement patterns are poorly understood. It was not known whether fish that reside in this upstream stretch of river remain exclusively there, or if they move to downriver portions of the reservoir where larvae of spawning fish are captured for the repatriation program.

[3] Adult razorback sucker reared at BPSFH were chosen because no other hatchery reared adults > 50 cm TL were available in quantities needed for this study. Additionally, because large batch stockings of adult razorback sucker from USFWS Dexter National Fish Hatchery & Technology Center (DNFH; 2006 year-class) and BPSFH (2005 year-class) occurred on 13 and 22 October, 2009, respectively, we were interested to learn more about post-stocking mortality and distribution of these repatriates, given their stocking location at Willow Beach boat ramp.

Four of eight total SURs were deployed on 2 November 2009 in strategic locations between Willow Beach and Hoover Dam. Locations included ~ 1 km downstream of Hoover Dam (11S 703462 3986464), ~ 3 km downstream of Hoover Dam (11S 703596 3985230), ~ 13 km downstream of Hoover Dam (11S 706819 3976903), WBNFH (11S 710815 3972450).
On 3 November 2009, 10 river fish and 14 BPSFH fish were implanted with acoustic transmitters (six of the acoustic transmitters, which did not properly activate prior to surgery, were sent back to Sonotronics and were deemed to have faulty circuitry). Surgeries followed methods previously outlined. All individuals had previously received a 134 kHz full-duplex PIT tag for individual identification. Following surgery, both groups of razorback sucker were placed in separate recovery raceways and monitored for 24-h to ensure proper health and tag retention.

Four remaining SURs were deployed on 4 November 2009 in strategic locations between Painted Canyon Lights and Willow Beach. Locations included Chalk Cliffs (11S 708198 3959277), Fire Mountain (11S 709482 3951864), Painted Canyon AZ (11S 710809 3933111), and Painted Canyon NV (11S 711229 3933030). Later that afternoon, both groups of acoustic-tagged fish were stocked into Lake Mohave. First, the 14 study fish from BPSFH were loaded in a two-chambered live well filled with river water and transported by truck to the Willow Beach boat ramp and released[4]. Approximately 30 minutes thereafter, the live well was drained, placed inside a motorized watercraft, refilled with river water, and all 10 study fish from the river were loaded inside. Fish were boated upstream and released approximately 3 km downstream of Hoover Dam 11S 703596 3985230.

Manual and SUR tracking techniques and database management followed methods outlined in the 2008-09 telemetry study. However, no SCUBA observations were necessary (see Results).

[4] Acoustic tagged razorback sucker from BPSFH were stocked at the Willow Beach boat ramp because 4,822 adult razorback sucker (2,234 individuals from BPSFH, mean TL 422 mm and 2,588 individuals from DNFH, mean TL 416 mm) were stocked at the same location during the three week period prior to the release of study fish.

Routine Monitoring

Routine monitoring was conducted during December 2008, March and December 2009, March and December 2010, and March 2011. Generally, five to seven trammel nets (91.4 x 1.8 m, 3.8-cm stretch mesh, 30.5 cm bar outer wall) were allowed to fish continuously for 4 to 5 days in the area of Carp Cove (Figure 1) along the Arizona shoreline of Lake Mohave. Nets were checked in the morning and evening daily and natives were removed and processed (measured, sexed, scanned for a PIT tag, tagged if none was present, and examined for general health and condition) and released. A fin clip was taken from a sub-sample of razorback sucker, placed in 1 ml of 95% ethanol in a snap-cap tube, and sent to the genetics laboratory at ASU for genetic analysis (e.g., Dowling et al. 2005; Dowling and Marsh 2011). All relevant data were entered into the comprehensive lower river native fishes PIT tag database maintained by M&A in behalf of the suite of partners working on the lower Colorado River.

Creel Census Data

Creel census data were collected periodically by a NDOW biologist at Cottonwood Landing, Nevada and Willow Beach, Arizona. Since 2006, striped bass longer than 80 cm TL that were brought to the creel station 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 M&A for gut content analysis. Annual effort was variable and no creel data was collected after 2009. From 2006 to 2009, creel census data was collected for 137 days from Willow Beach and 286 striped bass were recorded. For the same time period creel data was collected for 160 days from Cottonwood Cove and 2304 striped bass were recorded.

Ecological Modeling

One major objective of the three year research project was to develop a population dynamic model of razorback sucker repatriation in Lake Mohave that could inform management when considering alternative stocking strategies. This model would rely heavily on parameter estimates of survival based on the results of mark-recapture models and growth data based on total lengths from release and capture records in the NFWG database. An initial mark-recapture model, which was the basis for the size-survival relationship, was assessed in 2004 (Marsh et al. 2005). Mark-recapture models with spatial and temporal components were assessed during the current contracting period to determine their influence on estimates of survival. Although spatial and temporal variation in survival and recapture probability was significant in these models (Kesner et al. 2008b, 2010a, 2010b), as well as in results from acoustic telemetry and remote PIT scanning, data were not adequate to provide accurate estimates of additional parameters at the temporal or spatial scales of significance. Potential input variables that would increase the resolution of the model such as stocking location and cohort size were found to be not significantly correlated to indices of survival or too closely correlated with size at release to be distinguished (Kesner et al. 2008b). Therefore, the initial model of repatriate population dynamics presented here does not include temporal or spatial variation in these parameters, and relies heavily on the size-survival relationship from Marsh et al. (2005) and an updated version of the size-survival relationship based on mark-recapture records from 1992-2011. The population dynamic model was developed to be specific to Lake Mohave, but is flexible enough to incorporate temporal variations in survival when available. The basic structure of the model can also be expanded to a metapopulation model with separate subpopulations within the lake when data on dispersal and exchange rates become available from future remote PIT scanning.

Model and assumptions

The model is a discrete model, on the scale of one year per time increment, which estimates the population size at the beginning of the year based on the surviving at large population from the previous year and surviving recruits. At the beginning of the year (time t) the population (P_t) is a vector of surviving individuals at time t, distributed among five size classes based on total length; size class one – 30.0 cm or less, two – 30.1 to 35.0 cm, three – 35.1 to 40.0 cm, four – 40.1 to 45.0 cm, five – 45.1 cm or more. This vector is multiplied by an annual survival vector (Φ_t), followed by a growth matrix (G). The 5 x 5 matrix of rows (i) and columns (j) is populated with probabilities of growing (or shrinking) from one size class to the other such that cell G_{ij} is the probability that a fish of size class j will be in size class i by the end of the year. In the model, survival occurs before growth because all available estimates of size based survival for razorback sucker are based on size at release or handling (i.e., at the beginning of the survival period). The result is a population vector for the surviving at large population at the end of year t (A_t):

$$P_t \times \Phi_t \times G = A_t$$

The sole source of recruitment in the model is surviving repatriated razorback sucker (i.e., no natural recruitment assumption). Although natural recruitment may occur in Lake Mohave, it has been undetectable for decades. No untagged razorback sucker shorter than 30 cm TL has been captured in more than 20 years despite netting and shocking efforts that resulted in the capture of over 8,000 razorback sucker in the same time span (Marsh and Minckley 1989; unpublished data, NFWG database). Stocking is modeled to occur six months prior to the end of a model year. Actual stocking has been conducted throughout the year, but the majority of stocking occurs in autumn and winter, which is approximately six months prior to the March Roundup (NFWG database, unpublished data), the annual sampling effort that is the basis of annual population estimates. The stocking vector at time t (S_t) contains stocking numbers distributed among the same five size classes as the at large population. This vector is multiplied by a six month post-release survival vector (Φ_t^R), followed by a six month post-release growth matrix (G^R). The resultant vector is the surviving recruits by size class at the end of year t (R_t).

$$R_t = S_t \times \Phi_t^R \times G^R$$

The population vector at time t+1 (P_{t+1}) is calculated as the sum of the surviving at large population A_t and recruits R_t:

$$P_{t+1} = A_t + R_t = P_t \times \Phi_t \times G + S_t \times \Phi_t^R \times G^R$$

Parameter estimates

Initial values for each size class in the stocking vector (S_t) and post-stocking survival vector (Φ_t^R) were based on actual stocking records from 1992 to 2010 from the NFWG database, and an updated mark-recapture model of the size-survival relationship based on encounter histories from the NFWG database from 1992 to 2010. Stocking records were shifted backwards by 81 days to ensure that any fish stocked from January through March (prior to the March roundup) was counted as stocked in the previous year, since these fish would make up part of the recruiting class in the following March roundup (Table 1). A two age, time varying model with TL at release as a covariate for the first age class was used to provide the parameter estimates for the updated size-survival relationship; the same model was used for the size-survival relationship in Marsh et al. (2005). Although each population model vector contains only five values representing the five size classes, stocking records were initially summed in 1 cm increments per stocking year (Table 1). This was done to accurately assess the mean weighted survival for each size class based on the actual TL (within 1 cm accuracy) of the members that make up that size class for a given stocking year and the updated relationship, instead of using some arbitrary TL value (and subsequent survival estimate) within the size class as representative of survival for that size class (e.g., median TL).

Post-stocking survival has been studied extensively, but little is known about survival for the at large population for all but the largest size class. Adult razorback sucker, which are typically longer than 45 cm, have been estimated to survive between 70 and 85% annually (Marsh et al. 2005, Kesner et al. 2008a, Zelasko et al. 2011). Without comparative data on smaller size classes, one value for survival was used for all size classes in the annual survival vector (Φ_t). Although one value was used for all size classes, three at large annual survival probabilities were evaluated in model output; 70, 75, and 80%.

Growth can be highly variable on an individual basis, but growth at a cohort or population level is fairly consistent for each gender regardless of time at large (Marsh et al. 2005). Growth since release was used for the at large population growth matrix (G) as well as the recruitment growth matrix (G^R). Release and capture TL for razorback sucker that were captured between

120 and 180 days post-release were tabulated into the five size classes to calculate the proportion that grew into each size class (e.g., the probability of growing into size class three from size class two was the total number of fish released at size class two and captured 120 to 180 days post-release at size class three divided by the total number of fish released at size class two and captured 120 to 180 days post-release). Annual growth was determined from the same data set using razorback sucker that were captured between 340 and 380 days post-release. Although growth rates are markedly different among genders in razorback sucker (Minckley 1983, Marsh et al. 2005, NFWG unpublished data), gender determination prior to release of subadult fish is unreliable and size biased, and therefore growth rates were not differentiated in the model by gender.

The model was assessed using Microsoft Excel®. The recruitment vector (R_t) and at large population vector (A_t) were calculated each year and summed to calculate the subsequent year's initial population (P_{t+1}). The total population size at time t (sum of P_t) from model results was compared to annual mark-recapture estimates of abundance for years in which estimates were available.

Simulations

Three different stocking regimes were simulated to estimate long-term stable population size for a given number of annually released fish. Each stocking vector was based on an actual stocking year representing three different size class distributions and a target stocking size. Years in which the majority of fish were at or above target size were chosen to represent the first two stocking regimes. In 2002, 56% of razorback sucker stocked into Lake Mohave were larger than the target size of 30 cm (Table 2). The second regime was based on stocking values from 2005 when 69% of the stocked razorback sucker were larger than the target size of 35 cm. The last simulation was based on the 2008 stocking data when the target size was 50 cm. This target was never achieved in any year with substantial releases, but 56.5% of 978 fish stocked in 2008 were larger than 45 cm at release (largest size class in the model). The equilibrium population was calculated for each simulation based on a constant stocking (S) and post-stocking survival vector (Φ^R). Under this model, abundance and size structure become stable (at equilibrium) when the recruitment vector (R_t) is equal to the difference between the initial population at time t (P_t) and the surviving at large population (A_t), i.e., individuals lost due to mortality during the year are exactly replaced by recruitment.

P_t - A_t = R_t

P_t - P_t x Φ x G = S x Φ^R x G^R

The post-stocking survival vector was taken directly from the values calculated in the initial model assessment for the stocking year chosen to represent the stocking regime (Table 2). The proportion of fish released in each size class was based on the actual proportion in that year per size class, but the number released was varied between simulations to obtain the equilibrium population for a given stocking regime over a range of annual stocking numbers. The relationship between number stocked and equilibrium population size was linear, and so three annual stocking values (4,000, 6,000, and 8,000) were simulated to evaluate the equation of the relationships for each of the three stocking regimes.

Sensitivity

For comparison with results using the updated post-stocking size-survival relationship, the relationship from Marsh et al. (2005) was also evaluated in the model. This was done because the updated relationship is likely negatively biased, and the size-survival relationship from Marsh et al. (2005) is likely inaccurate for the largest size class. The mark-recapture data in Marsh et al. (2005) were based on releases from 1992 to 2000. Only 37 razorback sucker were released at the largest size class through 1999, and 22 of those were released in that year alone (Table 2), leaving little recapture data to resolve the relationship between size and survival for these larger fish. Estimated survival of a razorback sucker released at 50 cm is more than 90%, an unlikely value that is not supported by estimates from at large populations in Lake Mohave or elsewhere (Bestgen et al. 2002, Marsh et al. 2003, Marsh et al. 2005). More than 2,000 razorback sucker in this same size class have been released since 2000. Thus the updated size-survival relationship based on data from 1992 to 2011 is more precise, but not necessarily more accurate. Stocking sites in the early years of the program were near sampling locations (e.g., Yuma Cove). Since then, stocking locations have moved upstream as more and more razorback sucker were raised by WBNFH. Acoustic telemetry and preliminary results from remote monitoring in the Willow Beach area have demonstrated that razorback sucker stocked in the riverine portion of Lake Mohave remain in the area more than six months post-stocking. Therefore post-stocking survival estimates based on mark-recapture data from the basin portion of the lake do not meet the assumption of equal catchability six months post-release, and the resulting size-survival relationship is likely negatively biased (estimated survival is lower than actual survival).

Remote PIT Scanning

Remote PIT scanning systems were deployed between January and September 2011 on shallow gravel bars that extend into the Colorado River upstream of Willow Beach. Two models of PIT scanners were utilized. One type of unit (shore based) is comprised of an antenna and scanner housed in a 2.3 x 0.7 m PVC frame connected by 45.7 m of cable to a waterproof box that protects the logger and battery (55 amp-hours) and is secured to shore. The battery provided power to the scanner to run continuously for 72 hours, eliminating the need for manually removing and charging the batteries. The other unit (submersible) is comprised of a 0.8 x 0.8 m PVC frame antenna attached to a scanner, logger and 3.2 amp-hour battery contained in water-tight PVC and ABS piping. The unit is completely submersible and scans continuously for up to 14 hours. Six of these units were employed throughout the monitoring season.

The use of completely submersible units, which are not easily retrieved from the surface of the water without proper equipment, allowed the deployment of units in relatively high traffic areas such as Lone Palm, Boy Scout, Ringbolt, Bighorn Canyon, and Black Bar (Figure 2). Three submersible scanners were deployed at such locations, and were replaced every 12 hours with three fully charged antennas to ensure continuous coverage at any one site. The larger shore based unit was deployed in one fixed location for 72 hours. Location varied between trips depending on fish concentrations. Scanner units monitored fish presence for three nights and two days each trip.

Routine remote PIT scanning information was recorded on waterproof paper as follows: general location or site name, UTM coordinates, water depth (m), time and date of deployment and retrieval, logger number, logger start and stop times, and the scanning interval. Narrative descriptions of weather, river flows, etc. were recorded on field sheets or data books. Scanning data were downloaded and imported into a Microsoft Access® database at the conclusion of each trip and all information recorded on datasheets was entered into the database and associated with the scanning data for the given effort. Data from remote PIT scanning conducted in the basin by BOR (unpublished data) were also imported into the database and results were derived from both efforts.

Data Analysis

PIT tag contacts from remote scanning in the basin for 2010 and 2011 were used to calculate a mark-recapture estimate of the 134 kHz tagged subpopulation. The modified Peterson formula,

$$\frac{(M+1)(C+1)}{(R+1)} \text{ (Ricker 1975),}$$

was used. The number of individual PIT tags contacted in 2010 was the mark (M), the number contacted in 2011 the capture (C), and the number in common between 2010 and 2011 the recaptures (R). A standard mark-recapture estimate of the subpopulation in the river based on remote scanning was not possible because data were available for only one sample season. Instead, a regression of the proportion of new contacts with total unique fish was used to estimate the population size of the 134 kHz tagged riverine fish. This approach is analogous to a removal study where the rate of captures (new PIT contacts in remote sensing) declines as the total number of fish removed (total unique PIT contacts in remote sensing) increases.

Remote PIT scanning data were also used to describe dispersal for PIT tagged repatriated razorback sucker that were released between 1 October 2008 and 31 January 2011. Release and scanning data were imported into ESRI® ArcMap v 9.1 and assigned spatial location based on general zones (Figure 1). Yuma Cove was treated separately from the rest of the Arizona Bay zone because this location was significantly distant (>20 km) from the nearest upstream remote scanning location (Liberty Cove) within the same zone. Release records were grouped into cohorts based on general zone and month of release, and zone of release and zone of contact was tabulated for all fish contacted by remote PIT scanning between 1 January and 31 May 2011.

Remote PIT scanners also encountered razorback sucker released in 2008 and 2009 as part of the acoustic telemetry study. Telemetry contacts (either active tracking or SUR) for study fish contacted via PIT scanners were assigned to the general zones. The general zone of encounter either by telemetry or remote PIT scanning was then tabulated for these to compare the short (six month post-release) and long-term dispersal patterns of these fish.

Results

Post-stocking Dispersal and Fate

2008-9 Acoustic Telemetry

All ten subadult razorback sucker were contacted post-release for a total of 343 contacts, 307 (90%) of which were made remotely with SURs. One fish was contacted immediately following its release, but was not contacted again for the remainder of the study and therefore is excluded from further analysis.

Subadult survival remained high and six of nine (67%) fish were active at the conclusion of the study. Mean total distance traveled by active subadults was 44 km. Active fish dispersed between Painted Canyon Lights ~ 3 km upstream of Cottonwood Cove and 49 Mile Light (11S

707635 3970098) ~ 5 km downstream of Willow Beach (Figure 3), approximately 17 and 8 km down- and upstream of the release site, respectively. Mean distance traveled per active fish was highest in November (26.1 km ± 4.5 SE) and lowest in May (0 km).

All three subadults that died during this study were dead within 35 days post-stocking. Corresponding transmitters were located and retrieved by a SCUBA diver. Transmitters were recovered from the main river channel (11S 707543 3970126) ~ 3 km upstream of Monkey Hole, near the Arizona shore (11S 708018 3955403) near Oro Cove, and from Camp Thurman Coves (11S 717335 3913860) ~ 3 km downstream of Chemehueve Cove. No fish remains were observed in the vicinity of any transmitter.

All 20 adult razorback sucker were contacted for a total of 1,375 contacts, 1,206 (88%) of which were made remotely with SURs.

Adult survival was exceptionally high throughout the study, and after six months, 16 of 20 (80%) fish were active. Mean total distance traveled by active adults was 116 km. Active fish dispersed between the Arizona shore opposite Cottonwood Cove (11S 711085 3930488) and Nevada Hot Springs (11S 703466 3984640) ~2 km downstream of Hoover Dam (Figure 4), approximately 30 and 35 km down- and upstream of the release site, respectively. Mean distance traveled per active fish was highest in February (47.0 km ± 9.0 SE) and lowest in May (1.6 km ± 1.0 SE). Seven of 20 (35%) adult fish migrated to shallow alluvial gravel bars located between Willow Beach and Hoover Dam where they were observed among large groups of additional razorback sucker (Figure 5).

All four adults that died during this study were dead within 96 days post-stocking. Two of four transmitters were located and retrieved by a SCUBA diver; one from the littoral zone of the Arizona shoreline (11S 708250 3956743) near Oil Pan Cove and the other near Nine Mile (11S 710788 3922310). No fish remains were observed in the vicinity of either transmitter. Another transmitter was recovered from the stomach of a striped bass caught by an angler (see Creel

Census Data, below). Finally, one transmitter stayed in the same location for 85 days near Yuma Cove (11S 712586 3933712) but was never recovered.

2009-10 Acoustic Telemetry

All ten river fish were contacted for a total of 652 contacts, 601 (92%) of which were made remotely with SURs. The highest concentration of contacts occurred in the zone Above Willow Beach (Figure 6). An SUR (11S 703596 3985230) located ~ 3km downstream of Hoover Dam recorded the largest number of contacts (422 [70%]), while an SUR at Painted Canyon (11S 710809 3933111) recorded the least (8[1%]).

All ten river fish (100%) remained active throughout the study. Mean total distance traveled by active adults was 71 km. Fish dispersed between Painted Canyon Lights and 2 km downstream of Hoover Dam. Mean distance traveled per fish was the highest in November (29 km, ± 6.6 SE) and the lowest in May (1 km, ± 0.7 SE).

A small amount of green digestive fluid was noted during surgery at the incision site of one BPSFH fish. That individual never swam away from the boat ramp after its release. Another BPSFH fish was never contacted over the course of the study, despite intensive active and passive tracking efforts in the immediate vicinity of the Willow Beach boat ramp. Both individuals were therefore removed from further analysis.

Twelve of 14 BPSFH fish were contacted for a total of 832 contacts, 761 (91%) of which were made remotely with SURs. The highest concentration of contacts occurred in the zone Above Willow Beach (Figure 6). An SUR (11S 703596 3985230) located ~ 3km downstream of Hoover Dam recorded the highest number of contacts (333 [44%]), while an SUR at Painted Canyon (11S 710809 3933111) recorded the least (9 [1%]).

All twelve BPSFH fish (100%) remained active throughout the study. The highest concentration of contacts occurred in the zone Above Willow Beach (Figure 7). Mean total distance traveled by active adults was 128 km. Fish dispersed between Painted Canyon Lights and 2 km downstream of Hoover Dam. Mean distance traveled per fish was the highest in February (38 km, ± 11.2 SE) and the lowest in May (2 km, ± 1.0 SE).

When patterns of fish distribution were grouped according to stocking location and/or release size (adult or subadult), 24% of all telemetered adults stocked at Fortune Cove (2007 and 2008) were contacted in the zone Above Willow and 35% were contacted in the Yuma zone (Figure 8). In contrast, only 7% of subadults released at Fortune Cove (2006, 2007, and 2008) were contacted in the zone Above Willow and 9% were contacted in the Yuma zone (Figure 8). Thirty-two percent of all adults released at Fortune Cove remained exclusively in their zone of capture, either for the entirety of their transmitter life (6 months), or up until the contact made prior to transmitter recovery elsewhere.

Half (50%) of telemetered river adults released near Hoover Dam (2009) were contacted in the Chalk Cliffs zone and 30% were contacted in the Yuma zone (Figure 9). Almost half (46%) of Bubbling Ponds adults released at the Willow Beach boat ramp[5] (2009) were contacted in the Chalk Cliffs zone and 15% were contacted in the Yuma Zone (Figure 9). Fifty percent of all river adults and 54% of all Bubbling Ponds adults remained exclusively in their zone of release throughout that study.

Routine Monitoring

Routine monitoring from 1 December 2008 to 31 March 2011 resulted in capture of 50 razorback sucker consisting of one wild PIT tagged fish and 49 PIT tagged repatriates (Table 3); ten fish not included in this total were suspected repatriates and recorded as such in the NFWG database. These ten fish were either captured without PIT tags, or had PIT tags but could not be linked to a stocking or marking record. The introduction of double-tagging with 134 kHz PIT tags made it difficult for the PIT tag scanners to read the 400 kHz tags when both types were

[5] The stocking location at the Willow Beach boat ramp lies approximately 200 m upstream of the zone boundary between Above and Below Willow.

present, potentially giving a false negative for tag presence. These ten fish were omitted from further analysis. The single wild fish was first tagged 18 years ago March 1993 and captured seven times thereafter.

A majority of the repatriates were reared in off-site facilities (*N*=30) rather than lakeside backwaters (*N*=19) (Table 4). WBNFH fish contributed 67% (*N*=20) of fish from off-site facilities and 41% of total PIT tagged repatriates. Arizona Juvenile and Willow Cove each contributed six fish, Dandy and Chemehueve coves contributed a pair each, and single fish were from Nevada Larvae, North Nine Mile and Willow coves. Mean repatriate time at large was approximately 32 months or nearly three years (range from less than 1 year to approximately 13 years) with a mean TL of 40 cm at release, and overall mean monthly growth rate was 1 cm (Table 5). Complete capture histories are in Appendix A.

Wild population estimates have declined from 24 fish (9-480 95% CI) in 2009 (Kesner et al. 2010a) to 13 fish (4-250 95% CI) in 2010 based on 2010 and 2011 March capture data (Pacey and Marsh 2011). Repatriated razorback sucker population estimates increased from 1,439 (753-2,805 95% CI) in 2009 to 2,966 fish (1,509-6,063 95% CI) in 2010 based on 2010 and 2011 March capture data. The estimated survival as of 1 March 2010 of all repatriates released increased from 1% as reported in Kesner et al. 2010b to 2%. The current total population estimate for razorback sucker in Lake Mohave is 2,979.

Creel Census Data

Eighteen large (greater than 80 cm TL) striped bass and two channel catfish have been scanned for PIT tags by NDOW creel census personnel since January 2006; none have contained PIT tags. Creel census monitoring was discontinued by NDOW in 2009. However, an angler reported to a NDOW creel clerk that he caught 13.6 kg striped bass near Liberty Cove (11S 708503 3953249) on 11 November 2009, which contained an acoustic transmitter in its stomach. The transmitter belonged to a razorback sucker released in Fortune Cove on 6 November 2009.

Ecological Modeling

The updated size-survival relationship based on capture histories for repatriated razorback sucker in Lake Mohave from 1992 to 2010 differed significantly from the relationship in Marsh et al. (2005, Figure 10). Survival estimates at all release sizes were lower in the updated relationship, and the survival estimate for a 50 cm razorback sucker (61%) was well below all estimates of annual survival for at large adult razorback sucker (70 to 80%). The updated relationship also places the greatest increase in survival in the largest size class resulting in dramatic differences in year-to-year estimates of post-stocking survival for this size class in comparison to the modest differences in survival for this size class based on the 2005 relationship (Table 6). Though all values within each table were based on the same size-survival relationship, differences in mean stocking size within a size class among stocking years had a dramatic impact on the survival estimates from the updated relationship. Survival for the largest size class generally declines from 1992 to 2011 due to a decrease in mean size of individuals contributing to the largest size class, but less-so for estimates relying on the 2005 relationship.

Post-release growth was minimal for fish in size classes three through five with at least half of the fish remaining in their release size class (Table 7). Most fish grew out of size class one despite the relatively short time span between release and capture (between 120 and 180 days). Relative growth for fish released at size class two was most similar to size class four with fish almost evenly split between remaining in the size class of release and growing into the next size class, while growth in size class three was relatively lower. This discrepancy may be due to gender specific growth. However, because all values of the at large survival vector were set equal, bias in model results due to a lack of gender specific growth in the model is not possible; only release size has any impact on model output presented in this report. Two fish appeared to shrink a size class (one from size class two to one and one from size class four to three), which may be due to measurement error.

In contrast, fish released in the first three size classes all grew into size class four or five when given a full year to grow post-release (Table 8). All fish in size class four grew to size class five, and all size class five fish remained in that size class (none shrank), resulting in no fish in the first three size classes in the surviving at large population vector (A).

Simulated population size based on the updated size-survival relationship and stocking records from 1992 to 2011 was within confidence limits for the first seven years in which estimates were available (1999 to 2005, Figure 11). This was true regardless of the value used for at large survival (0.70, 0.75, 0.80), although population size began to diverge among these three trajectories after 2005. The 2010 simulated population size was again within the confidence interval of the estimated size for values of at large survival of 0.70 and 0.75, but not for 0.80. Simulated population size based on the 2005 size-survival relationship diverged out of estimated confidence intervals after four years, and only overlaps again in 2005 because the range covered by the estimate's confidence interval is more than an order of magnitude (Figure 12). This population simulation was more consistent with available estimates than the simulation based on the updated size-survival relationship for the first three years for which annual estimates were available (1999 to 2001).

Changes in at large survival when not differentiated among size classes had no impact on the relative effectiveness of each stocking regime. The trajectories (slopes) of simulated stocking regimes increased with increasing values of at large survival (Figure 13), but the relative difference in slope between the three stocking regimes did not change. The slope for the 35 cm target was always 2.56 times greater than the slope for the 30 cm target, and the 50 cm target was always 8.31 times greater. However, one of these relationships changed dramatically with trajectories based on the 2005 size-survival relationship (Figure 14). The slope for the 35 cm target was 2.37 times greater than the slope for the 30 cm target, a small difference, but the slope of the 50 cm target was 4.69 times greater than for the 30 cm target, cutting in half the benefit of annually stocking large fish (e.g., circa 2008).

Remote PIT Scanning

A total of 1044 individual razorback sucker were contacted over the course of the season from river and basin efforts combined. BOR's effort in the basin totaled 1275.5 scan hours and resulted in contact with 321 razorback sucker, while effort in the riverine section totaled 1987 scan hours and resulted in contact with 730 razorback sucker. The actual amount of time required to deploy and retrieve equipment was minimal (approximately 5-10 minutes per scanner) and totaled 14 hours for basin scanning and 38 hours for river scanning in 2011 (excluding travel time). Twenty-six of the 1044 combined unique contacts could not be assigned to a record of marking using the NFWG PIT tag database (as of September 1, 2011), and these were removed from analysis. The data used for all further analysis are restricted to fish stocked with a 134 kHz tag. Contact data from 2011 for abundance estimates were reduced further by removing contacts from fish that were released after March 1, 2010 (after the marking event).

The estimated population of 134 kHz PIT tagged fish in the basin based on remote sensing data was 1086; (390, 188, and 67 for M, C, and R respectively). This estimate cannot be directly compared to the estimate of 2954 (1503 to 6040 95% confidence interval) for repatriate razorback sucker in Lake Mohave derived from March roundup data, unless the proportion of the population comprised of 134 kHz tagged fish in 2010 is estimated as well. This proportion was estimated using 2010 March roundup data; the proportion of razorback sucker captured in March 2010 that were 134 kHz tagged prior to release was 70.9% (183 of 258). If 134 kHz tag fish represented 70.9% of the fish in Lake Mohave in 2010, then (1086/0.709) = 1531 is the estimate of the basin population. Thus, the estimate from remote scanning is lower but within the confidence intervals of the March roundup estimate.

For razorback sucker in the lotic portion of Lake Mohave, the estimate of 1654 fish is the x-axis intercept of the regression line (Figure 15); the point at which no new fish are expected to be contacted if sampling continued. This estimate can be expanded to include 400 kHz tag fish if again the proportion of the population comprised of 134 kHz tagged fish in 2010 is estimated. An electrofishing survey conducted in the river by BOR on 15 June 2011 captured 25 razorback sucker, 22 (88%) of which were tagged at release with 134 kHz tags. If this proportion holds true for the entire subpopulation in the river, then an estimate of the entire population there would be 1880 fish (1654/0.88).

Within a single monitoring season there was evidence of fish movement between general zones and spawning sites. Seven individual razorback sucker were detected in both the River and Arizona Bay/Basin zones between 4 February 2011 and 21 April 2011 (Table 9). A majority of these fish (5 of 7) were from the large release into the river in October 2009. No directional preference was evident as four fish dispersed downstream in the spawning season, while three travelled upstream. Examining the remote PIT scanning data collected by BOR in 2010, there were three additional fish that were first detected in the Basin in the 2010 spawning season and were scanned in the River in the 2011 season. Remote PIT scanning also provided further evidence of fish utilizing multiple spawning locations. Including fish moving between zones, 16% (164 of 1044) of unique fish contacted were detected at two to four different spawning sites in the 2011 spawning season. These sites ranged from 1 to 12 km apart and fish were detected at multiple sites in time frame as short as a few hours.

Different patterns were evident for tagged fish from the two telemetry studies in 2008 and 2009 and remote PIT scanning from 2008-2011 (Figure 16). Fish released in 2008 in the river were contacted in all three zones (River, Arizona Bay, and Basin) 4-27 months post-release. In contrast fish released in the River zone in 2009 that were contacted by remote scanning and telemetry remained in the River zone throughout the sampling period up to 19 months after initial stocking.

Discussion

The separation of at least two subpopulations (basin and river) as determined by remote PIT scanning is strongly related to the location of release, at least within two to three years post-stocking. If release data are combined into “cohorts” by time (month-year) and location (zone) of release, the zone of contact is highly correlated to zone of release (Table 9). The two subpopulations appear to be distinct enough on a year-to-year basis to justify treating them separately when calculating population estimates (less than 1% of contacts are shared between zones), but these subpopulations are likely not distinct genetically (a few fish exchanged per generation is sufficient to maintain mixing).

The apparent separation of the two subpopulations may also only be transient, because the vast majority of razorback sucker contacted in 2011 were released within two years of contact. The only substantial release in 2008 was into the Basin zone (Table 6), and yet these fish were equally contacted in the Basin and River zones (4 contacts). This may indicate homogenization of the two subpopulations after two or more years post-release. This also is indicated by remote PIT scanner contacts in the Basin zone of four razorback sucker released in 2008 into the River zone for acoustic telemetry (Figure 16).

Large adult razorback sucker unequivocally survived better than subadults in all telemetry studies, in agreement with the mark-recapture size-survival relationship, but there also was substantial year-to-year variation in post-stocking mortality (Figure 17). The 2006-07 transmitter retention study (Karam et al. 2008) rejected a hypothesis that our surgical procedure or the acoustic transmitters were responsible for mortality. SCUBA observation during the first two years (Kesner et al. 2008b) often took place within days of transmitters becoming immobile and suggested striped bass were culpable for post-stocking mortality because they are the only predator in the reservoir with a gape large enough to eat these fish (Dennerline and Van Den Avyle 2000). Definitive proof of this inference came in 2008 when a transmitter from a 50 cm adult razorback sucker was recovered from the stomach of a 13.6 kg striped bass only days after stocking. Further, this demonstrated that most razorback sucker stocked in Lake Mohave are vulnerable to predation by striped bass even though larger fish have better odds of surviving than small fish. Because striped bass predation has been identified as a major post-stocking mortality factor, the cyclical abundance of these fish may account for the observed variation in repatriate survival and abundance, and predicting a year during which post-stocking survival would be above average may be possible if the relative abundance of these predators could be tracked.

Acquiring relative abundance information for striped bass has proven difficult. Creel census data have not been consistently collected in the past and gill netting surveys provide reliable data only for smaller, less than 60 cm TL, striped bass (Mike Burrell, NDOW, personal communication). The angler who reported the razorback sucker tag found in a striped bass stomach did not report his findings through a conventional creel clerk. In addition, many anglers, especially those targeting trophy striped bass, visit Lake Mohave at night when creel clerks are not active. Based on the success of gleaning information by direct contact with striped bass fishermen during the past four years of Lake Mohave monitoring and from reading other online fish forums, a novel approach to gathering information on large striped bass catch and stomach contents using an interactive web based forum was initiated in April 2011: www.LakeMohaveStripers.com.

Anglers and spear fishers can register at the forum and receive a tiered award based on photo submissions of striped bass (4.5 kg or greater) caught in Lake Mohave (for more information visit the website). Minimum information required for submission includes location and date and time of capture, total length, weight, and girth of the striped bass, and photographs of the fish. Stomach content photographs increase award amount (tier system). Fifteen striped bass have been reported thus far, eight with trout in their stomachs. We attribute lack of reports of predation on razorback sucker to the fact that no large scale stockings of native fishes have taken place since the website was launched. The website will eventually aid in assessing food habits and how striped bass respond to the stocking of native (razorback sucker and bonytail) and nonnative (rainbow trout) fish in Lake Mohave, and may prove useful in identifying years in which large striped bass abundance is relatively low thereby predicting “good” years to stock native fishes.

The ability to predict “good” stocking years and thus avoid “bad” years may increase overall survival of stocked fish, but it would likely not significantly change relative slope estimates between the different stocking regimes (i.e., the most effective management strategy), and it also would not account for differences in size-survival relationships based on decades of data that are representative of long-term “mean” conditions. Decade-to-decade variation in survival could be more representative of a gradual increase in large striped bass abundance from the 1990s to the 2000s, or other unidentified and thus unstudied environmental changes that may have negatively impacted post-stocking survival of razorback sucker over time. The population buildup (1992 to 1998) and first few comparative population estimates from the simulation (1999-2001) based on the 2005 relationship more closely correlated with reality than the simulation based on the updated relationship. These are the years upon which the 2005 size-survival relationship was based. The updated relationship, although based on all years from 1992-2011, relies heavily on recent data because the vast majority of stocking in absolute numbers has occurred since 2001. This relationship accurately predicts the population size from 2003 onward. If there has been an actual decrease in post-stocking survival for all sizes, simulations based on the updated size-survival relationship would better inform management decisions.

It also is likely that sources of bias and uncertainty inherent to the current mark-recapture models are impacting each size-survival relationship, and differences between them are at least partially due to differences in number and level of these sources. The top end of the size-survival relationship in Marsh et al. (2005) was made up of a few very large fish (only 47 fish longer than 45 cm), and is therefore likely less precise than the updated model given the few fish available for recapture. Size at release has gradually increased since 2001, and the largest size class was heavily stocked in the last few years. Although the updated size-survival relationship may be more precise at the larger size classes due to additional stockings, the location of these fish stockings is a likely source of bias.

The mark-recapture models that these relationships are based on assume that all fish are equally available for capture, but telemetry and remote PIT scanning have demonstrated that most fish released in the lotic portion of the lake tend to stay there for at least six months post-release (up to two years), making them unavailable for capture in the basin. MARK survival estimates for post-stocking survival would likely be biased low for years with stockings in the lotic region because these fish were not available for capture in the basin six months after stocking, the capture period for which the size-survival relationship is assessed. This would likely impact the updated size-survival relationship more than the 2005 one given the greater number of releases in the lotic region after 1998.

The most efficient stocking strategy from a management perspective should be implemented regardless of the difficulties inherent in mitigating sources of post-stocking mortality. Simulation results may provide enough information to determine this strategy, depending on the relative difference in costs (money, time, and hatchery space) among differing stocking regimes. If costs for raising 45 cm fish (the target release size for 2008) are nearly four times that of raising fish to 30 cm (the target for 2002) and nearly twice that for 2005 target of 35 cm, then the results from the model are definitive; stocking at the 45 cm target size is the most efficient because the difference in cost is less than the minimal gain in survival expected from model results for raising fish to the larger size. On the other hand, if costs are greater than eight times as much to target 45 cm and four times as much to target 35 cm, then stocking at 30 cm is the most efficient because costs are greater than the maximum expected gain in survival. If costs are between these values, then results are indeterminate, and a definitive strategy cannot be identified without additional information.

In comparison, Zelasko et al. (2011) estimated that it would take an annual stocking of nearly 42,900 razorback sucker at 30 cm to maintain a population of 7,540 in the upper Colorado River basin. This result is similar to the simulation for Lake Mohave when adult survival is 70%, the same value used for the upper basin model, and the updated size-survival relationship is used (grey dashed lines in Figure 13). If the equilibrium line is projected out to 42,900 annual releases, the resultant equilibrium population is 8,019.

Model accuracy and confidence in simulation results and stocking regime decisions would all increase if metapopulation dynamics and year to year variation in post-stocking survival for razorback sucker in Lake Mohave were measured. Remote PIT scanning is a technique that allows for contact with a large portion of the at large population without impacting fish health, and it avoids bycatch. It is also one of the few techniques available to sample the lotic portion of the reservoir. This combination of greater coverage geographically and demographically will result in more accurate and precise mark-recapture models, increasing the ability to make sound stocking choices. This technique should be pursued because maintaining the razorback sucker population in Lake Mohave is currently the only viable solution to maintain the species in the lower basin.

Conclusions

An extraordinary commitment by countless individuals continues to be made on behalf of conserving razorback sucker in Lake Mohave, which would be extirpated without the efforts of the NFWG and MSCP, their multiple partners, and other interested and concerned parties. Monitoring confirms that the repatriate population remains small (between 1,000 and 4,000 fish), but it continues to provide adequate larval production to maintain the stocking program, even as the wild population nears its demise. The development and implementation of novel remote sensing technology contributed to identification of river- and basin components of the population, and to initial insights about relationships between these metapopulations. However, there are significant, continuing difficulties that must be confronted such as low post-stocking survivorship and the fact that even the largest repatriates currently being stocked are vulnerable to predation by striped bass. There may be opportunities to increase post-stocking survival by making adjustments in the repatriation program, and by developing a better understanding of the nature and dynamics of striped bass predation.

Recommendations

Bi-annual netting operations should continue in during autumn and spring roundups to collect growth, health, census, and genetic data from wild and repatriate razorback sucker in Lake Mohave. There currently is no other mechanism to acquire these data.

We make stocking recommendations both to optimize survival of repatriated fish and to provide opportunities to acquire population data needed to inform and improve the program's success and to better understand this dynamic system. Limitations of hatchery space, personnel, and other vital resources may constrain what actually can be accomplished. Stocking of razorback sucker into Lake Mohave should continue at the largest size possible and in the greatest number possible. Some or all stockings should be directed spatially and temporally with the goal of assessing razorback sucker metapopulation dynamics and the effect stocking locations has on these dynamics. The recommended stocking and monitoring plan for the next fiscal year (FY 2012 - October 2011 to September 2012) is divided spatially by zones that are modifications to the general zones originally proposed in Kesner et al. (2008a). These zones have been refined based on remote scanning and telemetry results to better distinguish the centers of subpopulations (Figure 18).

Stocking should be concurrent and numbers distributed equally between the three known subpopulations (River, Liberty, and Basin). Fish repatriated at each location should be as close as possible to the same mean size and total number, and releases among the three zones should be within a few days to at most a few weeks of each other. This will require some additional inventory control at the hatchery or grow-out location; for example, PIT tag "lots" will have to be maintained so that the location and timing of release for each PIT tagged fish is known.

As above, stocking of razorback sucker into Lake Mohave should continue at the largest size possible, in the greatest number possible. Stocking at least 500 fish per location and stocking time will likely supply adequate future PIT scanning contacts for analysis. Although no formal power analysis has been conducted, approximately 50% of the at large population in the River was contacted in 2011. Scanning effort is expected to be expanded in FY 2012 (see below) and is expected to contact at least the same proportion as contacted in 2011. Depending on release size, post-stocking survival may be as low as 10%. Even at this rate, a mean of 25 razorback sucker would be contacted per stocking event (50% of the 50 surviving fish), and more would likely be contacted immediately after stocking (before mortality is significant).

The goal of the Lake Mohave razorback sucker repatriation program is to maintain or increase the population. The objective of the recommendations above is to use release date and time, and contact date and time for individual fish to determine exchange rates among subpopulations. To this end, PIT scanning deployments could be conducted twice monthly with effort distributed among the three zones. Each zone could be sampled with a minimal effort of 200 scanning hours per sample trip. This is close to the mean scanning hours from efforts in 2011 for basin and river scanning (212 and 210 scanning hours per trip respectively) although actual scan time may be considerably more in 2012 depending on available resources. Location of deployments would be based on past results and continued input from visual surveys as well as supplemental PIT scanner deployments in new locations and zones (Katherine) as equipment and time permit.

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Table 1. Stocking totals in 1-cm increments for repatriated razorback sucker in Lake Mohave from 1992 to 2010. Stocking dates were shifted backwards by 81 days so that fish released prior to March roundup were placed in the previous year's stocking totals. Row headings are the maximum TL of fish released in that size class (12.0 cm includes fish from 11.1 to 12.0 cm in total length).

TL (cm)	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
10.0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11.0	0	50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12.0	0	61	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13.0	0	76	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14.0	0	92	4	0	0	0	0	0	0	0	2	0	0	1	0	0	0	0	0
15.0	0	110	8	0	0	0	0	0	0	0	3	0	0	2	0	0	0	0	0
16.0	0	195	41	0	0	0	0	0	0	0	2	0	0	9	0	0	0	0	0
17.0	0	161	105	0	0	0	0	0	0	0	9	0	0	6	0	0	0	0	1
18.0	0	97	185	0	0	0	0	1	0	0	3	1	0	9	0	0	0	0	0
19.0	0	45	193	0	1	1	0	8	0	0	13	0	0	13	0	0	0	0	0
20.0	0	23	207	0	1	126	2	23	0	0	23	0	0	23	0	0	0	0	0
21.0	0	34	198	2	1	355	4	67	2	1	20	0	1	19	0	0	0	0	2
22.0	0	46	186	3	1	329	15	146	0	2	21	0	2	28	0	0	0	4	3
23.0	0	74	204	10	12	270	39	377	2	1	9	2	1	18	0	0	0	1	7
24.0	0	134	214	21	17	340	199	862	6	4	13	1	5	20	0	2	0	3	7
25.0	2	62	159	47	77	589	615	2834	288	9	31	9	14	29	0	0	0	6	11
26.0	0	22	72	88	249	853	663	2763	707	28	39	13	28	29	0	1	0	4	9
27.0	2	6	45	163	411	814	539	2146	753	153	57	21	40	26	0	3	0	20	2
28.0	7	1	32	164	411	873	688	1603	656	750	242	51	57	29	2	4	0	28	0
29.0	8	6	35	152	395	894	899	1351	563	1257	965	92	333	26	0	13	0	39	0
30.0	3	15	45	137	384	775	867	1083	731	2287	2327	1617	420	10	2	21	2	205	166
31.0	2	10	43	125	322	527	761	750	623	2010	2070	3023	473	51	8	51	2	556	434
32.0	5	10	72	153	244	381	582	566	479	1454	1514	3097	543	86	14	87	1	882	556
33.0	12	7	57	153	194	240	450	370	411	1103	1191	3356	2165	173	25	77	2	1159	592
34.0	19	6	46	157	101	195	365	260	327	750	955	2868	2078	400	56	103	1	1311	586
35.0	20	0	6	124	93	118	287	194	264	489	671	2605	2320	1707	188	74	1	1347	459
36.0	28	2	2	67	46	63	186	154	172	333	430	2020	2186	3021	327	52	2	1358	405
37.0	26	0	0	19	31	34	144	148	87	245	287	1422	1579	3060	332	29	0	1312	323
38.0	12	1	1	9	20	15	129	125	83	167	166	961	1153	2632	283	25	6	1066	220
39.0	4	0	4	2	10	5	66	94	59	93	97	630	648	1985	233	16	4	1260	168

Table 1. Continued.

TL (cm)	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
40.0	1	0	4	2	6	5	38	83	43	71	51	400	371	1331	186	22	30	2078	152
41.0	0	0	4	1	3	1	19	59	47	56	31	267	213	942	148	43	57	1118	91
42.0	0	0	2	0	3	2	10	33	37	46	12	130	120	634	130	55	53	924	94
43.0	0	0	0	0	0	0	10	33	42	35	20	80	55	431	66	71	77	845	105
44.0	0	0	1	0	0	0	0	11	39	34	13	33	26	292	52	87	97	725	85
45.0	0	0	0	0	0	1	2	17	45	25	9	26	15	155	39	105	90	681	103
46.0	0	0	0	0	0	0	0	5	21	29	3	16	5	57	23	84	87	553	105
47.0	0	0	0	0	0	0	0	8	25	15	11	3	5	18	18	56	83	396	89
48.0	0	0	0	1	0	0	0	4	30	17	5	1	3	10	14	59	65	279	106
49.0	0	0	0	1	0	0	0	3	24	8	12	0	1	10	6	27	42	149	86
50.0	0	0	0	4	0	0	0	0	14	10	4	1	0	11	4	36	46	91	68
51.0	0	0	0	0	0	0	0	1	5	6	3	1	1	10	9	26	47	56	37
52.0	0	0	0	0	1	0	0	1	2	12	3	0	0	5	6	11	37	30	23
53.0	0	0	0	1	0	0	0	0	3	2	4	2	0	7	3	13	34	17	13
54.0	2	0	0	0	0	0	0	0	0	2	2	1	0	0	4	13	42	16	9
55.0	0	0	0	0	1	0	0	0	1	1	0	0	1	0	5	4	22	3	10
56.0	0	0	0	0	0	0	0	0	0	1	1	0	2	1	1	8	15	5	7
57.0	0	1	0	0	1	0	0	0	0	0	0	0	1	0	0	1	15	6	5
58.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	9	3	2
59.0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	3	3	1	2
60.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	2
61.0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	3	0	1
62.0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
63.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0
Sum	153	1353	2176	1606	3037	7806	7580	16183	6591	11506	11344	22750	14866	17326	2184	1283	978	18538	5146

Table 2. Stocking numbers (top) and proportion of stocked (bottom) for repatriated razorback sucker within five size classes for Lake Mohave from 1992 to 2010. Stocking dates were shifted backwards by 81 days so that fish released prior to March roundup were placed in the previous year's stocking totals. Size classes were based on TL at release; One - 30.0 cm or less, Two - 30.1 to 35.0 cm, Three - 35.1 to 40.0 cm, Four - 40.1 to 45.0 cm, Five - 45.1 cm or more.

Size Class	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
One	22	1316	1934	787	1960	6219	4530	13264	3708	4492	3779	1807	901	297	4	44	2	310	208
Two	58	33	224	712	954	1461	2445	2140	2104	5806	6401	14949	7579	2417	291	392	7	5255	2627
Three	71	3	11	99	113	122	563	604	444	909	1031	5433	5937	12029	1361	144	42	7074	1268
Four	0	0	7	1	6	4	41	153	210	196	85	536	429	2454	435	361	374	4293	478
Five	2	1	0	7	4	0	1	22	125	103	48	25	20	129	93	342	553	1606	565
Sum	153	1353	2176	1606	3037	7806	7580	16183	6591	11506	11344	22750	14866	17326	2184	1283	978	18538	5146

Size Class	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
One	0.144	0.973	0.889	0.490	0.645	0.797	0.598	0.820	0.563	0.390	0.333	0.079	0.061	0.017	0.002	0.034	0.002	0.017	0.040
Two	0.379	0.024	0.103	0.443	0.314	0.187	0.323	0.132	0.319	0.505	0.564	0.657	0.510	0.140	0.133	0.306	0.007	0.283	0.510
Three	0.464	0.002	0.005	0.062	0.037	0.016	0.074	0.037	0.067	0.079	0.091	0.239	0.399	0.694	0.623	0.112	0.043	0.382	0.246
Four	0.000	0.000	0.003	0.001	0.002	0.001	0.005	0.009	0.032	0.017	0.007	0.024	0.029	0.142	0.199	0.281	0.382	0.232	0.093
Five	0.013	0.001	0.000	0.004	0.001	0.000	0.000	0.001	0.019	0.009	0.004	0.001	0.001	0.007	0.043	0.267	0.565	0.087	0.110

Table 3. Adult razorback sucker monitoring summary by capture month, total number of fish, PIT tag, history, and gender from 1 December 2008 through 31 March 2011 monitoring events, Lake Mohave. Ten fish omitted from this analysis, see text for more information.

Capture		Total *N* Fish (% of Total)	History (% Total *N* Fish)		Gender (%Total *N* Fish)	
Year	Month		Repatriate	Wild	Female	Male
2008	December	5 (10)	5 (100)	0	2 (40)	3 (60)
2009	March	10 (20)	9 (90)	1 (10)	8 (80)	2 (20)
	December	1 (2)	1 (100)	0	0	1 (100)
2010	March	22 (44)	22 (100)	0	14 (64)	8 (36)
	December	2 (4)	2 (100)	0	2 (100)	0
2011	March	10 (20)	10 (100)	0	5 (50)	5 (50)
	Total (% of Total)	50	49 (98)	1 (2)	31 (62)	19 (38)

Table 4. Adult razorback sucker monitoring summary for 49 paired release-capture data per fish PIT tag number by rearing type and location in Lake Mohave.

Rearing		*N* fish
Type	Location	(% Total; % Grand Total)
Lakeside backwater	Arizona Juvenile	6 (32; 12)
	Dandy Cove	2 (11; 4)
	Nevada Larvae	1 (5; 2)
	North Chemehuevi Cove	2 (11; 4)
	North Nine Mile Cove	1 (5; 2)
	Willow Cove	1 (5; 2)
	Yuma Cove	6 (32; 12)
	Total (% Grand Total)	19 (39)
Off-site facility	Achii Hanyo	3 (10; 6)
	Boulder City Wetlands Park	4 (13; 8)
	Bubbling Ponds FH	3 (10; 6)
	Willow Beach NFH	20 (67; 41)
	Total (% Grand Total)	30 (61)
	Grand Total	49

Table 5. Adult razorback sucker monitoring summary for 49 paired release-capture data per fish PIT tag number with growth rate [capture total length in cm minus release TL in cm then divided by months at large (MAL)], Lake Mohave. Data are in order of MAL. Years at large (YAL) and gender are also included.

PIT tag	TL (cm)		Growth Rate/Month (cm)	MAL	YAL	Gender[a]
	Release	Capture				
1C2D05A544	47	47	1	1	< 1	M
1C2D6C7A10	42	45	< 1	2	< 1	F
1C2D012FF9	43	41	1	2	< 1	M
1C2D639BE3	37	38	1	2	< 1	M
1C2D695C4D	41	42	-1[b]	2	< 1	F
1C2D69B1DA	40	40	< 1	2	< 1	M
1C2D6D0A48	35	34	1	2	< 1	M
1C2D676D61	33	34	18	2	< 1	M
1C2D67C42F	31	31	< 1	2	< 1	M
1C2D69774C	37	37	< 1	2	< 1	M
1C2D70F78B	47	47	< 1	2	< 1	F
1C2D63A441	39	39	< 1	2	< 1	M
1C2D677362	31	32	< 1	2	< 1	M
1C2D683A73	35	36	< 1	2	< 1	F
1C2D696B8B	42	44	< 1	2	< 1	F
1C2D74797A	35	36	1	2	< 1	F
1C2D7490C0	35	35	< 1	2	< 1	M
1C2D683175	35	36	< 1	3	< 1	M
1C2D697064	39	39	< 1	3	< 1	F
1C2D62D042	47	109	< 1	3	< 1	F
1C2D64370C	47	47	< 1	3	< 1	F
1C2D643869	47	47	1	5	< 1	F
1C2C36F04C	49	52	< 1	5	< 1	F
1C2D6BCD74	41	43	< 1	5	< 1	F
257C62EDE3	54	54	< 1	5	< 1	M
257C611F6B	45	49	< 1	5	< 1	U
1C2D697739	45	47	< 1	5	< 1	F
1C2D6933AD	45	47	< 1	6	< 1	F
1C2D697BED	49	49	2	6	< 1	F
1C2C38C46D	45	49	< 1	6	< 1	F
1C2D696720	46	48	< 1	6	< 1	F
1C2D622913	45	57	< 1	12	1	F
1C2D681C34	35	49	< 1	15	1	M
1C2C33ACE1	53	59	< 1	16	1	F

Table 5. Continued.

PIT tag	TL (cm)		Growth Rate/Month (cm)	MAL	YAL	Gender[a]
	Release	Capture				
1C2C336A7E	49	59	< 1	18	1	F
257C60E10E	43	55	1	18	1	F
4637701373	35	58	1	38	3	F
4647776409	37	54	< 1	48	4	F
533277004B	37	59	< 1	70	6	F
42407B0943	29	59	< 1	91	7	F
5325721921	29	55	1	94	8	F
5326044B70	31	65	< 1	95	8	F
520E524F15	37	61	< 1	103	8	F
532623435E	38	57	< 1	103	8	F
53240E7138	34	58	< 1	130	11	M
42016D2D60	35	65	< 1	134	11	F
2037213454	34	59	< 1	159	13	M
201D603C27	37	61	< 1	159	13	M
7F7A075250	33	67	< 1	164	13	F
Mean	40	50	1	32	3	-

[a]M is male, F is female and U is unknown.
[b]Any negative growth rate is likely due to measurement error when time at large is less than six months.

Table 6. Estimated post-stocking survival for five size classes of repatriated razorback sucker in Lake Mohave based on the updated size-survival relationship (top) or the relationship from Marsh et al. (2005, bottom) and stocking records from 1992-2010. Size classes were based on TL at release; One - 30.0 cm or less, Two - 30.1 to 35.0 cm, Three - 35.1 to 40.0 cm, Four - 40.1 to 45.0 cm, Five - 45.1 cm or more. A dash indicates that no stocking records were available for the given year-size class.

Size Class	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
One	0.025	0.005	0.009	0.023	0.024	0.019	0.023	0.019	0.023	0.030	0.030	0.033	0.029	0.014	0.028	0.029	0.034	0.030	0.029
Two	0.069	0.052	0.055	0.060	0.053	0.053	0.055	0.053	0.055	0.053	0.054	0.059	0.067	0.077	0.075	0.061	0.057	0.064	0.060
Three	0.116	0.111	0.158	0.108	0.121	0.114	0.125	0.133	0.126	0.124	0.120	0.124	0.123	0.132	0.134	0.130	0.175	0.145	0.129
Four	-	-	0.246	0.220	0.237	0.276	0.253	0.268	0.295	0.280	0.275	0.253	0.251	0.265	0.269	0.312	0.306	0.285	0.296
Five	0.769	0.855	-	0.607	0.820	-	0.939	0.498	0.526	0.539	0.574	0.487	0.571	0.511	0.552	0.549	0.603	0.498	0.552

Size Class	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
One	0.075	0.013	0.024	0.069	0.071	0.057	0.067	0.055	0.068	0.090	0.092	0.100	0.089	0.039	0.086	0.087	0.103	0.091	0.089
Two	0.216	0.163	0.172	0.188	0.167	0.165	0.172	0.166	0.174	0.167	0.171	0.185	0.210	0.240	0.236	0.193	0.178	0.200	0.188
Three	0.350	0.337	0.446	0.330	0.360	0.345	0.372	0.390	0.373	0.368	0.359	0.368	0.366	0.387	0.392	0.380	0.483	0.417	0.379
Four	-	-	0.606	0.569	0.596	0.644	0.617	0.635	0.669	0.651	0.645	0.616	0.613	0.631	0.636	0.690	0.684	0.657	0.671
Five	0.959	0.979	-	0.903	0.969	-	0.993	0.847	0.862	0.865	0.884	0.834	0.872	0.850	0.869	0.868	0.891	0.845	0.871

Table 7. Captures (left) and proportion of captures (right) among five size classes of release (columns) and capture (rows) for repatriate razorback sucker in Lake Mohave during the March roundup that were released between 120 and 180 days prior to capture. Proportion of captures is the based on the value of a cell divided by the sum of the column. Size classes were based on TL at release; One - 30.0 cm or less, Two - 30.1 to 35.0 cm, Three - 35.1 to 40.0 cm, Four - 40.1 to 45.0 cm, Five - 45.1 cm or more.

Size Class	One	Two	Three	Four	Five
One	3	1	0	0	0
Two	14	24	0	0	0
Three	4	26	19	1	0
Four	1	4	7	18	0
Five	0	0	2	17	52
Sum	22	55	28	36	52

Size Class	One	Two	Three	Four	Five
One	0.136	0.018	0.000	0.000	0.000
Two	0.636	0.436	0.000	0.000	0.000
Three	0.182	0.473	0.679	0.028	0.000
Four	0.045	0.073	0.250	0.500	0.000
Five	0.000	0.000	0.071	0.472	1.000

Table 8. Captures (left) and proportion of captures (right) among five size classes of release (columns) and capture (rows) for repatriate razorback sucker in Lake Mohave during the March roundup that were released between 340 and 380 days prior to capture. Proportion of captures is the based on the value of a cell divided by the sum of the column. Size classes were based on TL at release; One - 30.0 cm or less, Two - 30.1 to 35.0 cm, Three - 35.1 to 40.0 cm, Four - 40.1 to 45.0 cm, Five - 45.1 cm or more.

Size Class	One	Two	Three	Four	Five
One	0	0	0	0	0
Two	0	0	0	0	0
Three	0	0	0	0	0
Four	2	1	3	0	0
Five	2	6	14	12	20
Sum	4	7	17	12	20

Size Class	One	Two	Three	Four	Five
One	0.000	0.000	0.000	0.000	0.000
Two	0.000	0.000	0.000	0.000	0.000
Three	0.000	0.000	0.000	0.000	0.000
Four	0.500	0.143	0.176	0.000	0.000
Five	0.500	0.857	0.824	1.000	1.000

Table 9. Summary data for razorback sucker stockings of more than 100 fish between 1 October 2008 and 31 January 2011 in Lake Mohave and the number and location of 134 kHz PIT tagged fish that were detected with remote PIT-scanners between 1 January and 31 May 2011. Contact zones are based on general zones established in Kesner et al. (2008b). Arizona Bay was split between Yuma Cove and elsewhere because the general stocking and scanning contacts within this zone were separated by more than 10 miles (16 km).

				2011 Contact Zone			
Release Zone	Release Month & Year	Number Released	Mean TL (mm)	Basin	Arizona Bay - Yuma Cove	Arizona Bay	River
Basin	October 2008	554	441	4	1	0	4
	March 2009	334	491	10	8	1	0
	September 2009	246	457	3	3	0	0
	December 2009	413	448	9	24	0	9
	January 2010	2564	346	11	14	1	1
	September 2010	226	426	6	3	0	0
	October 2010	246	432	1	6	0	0
	January 2011	1892	341	0	1	0	0
Arizona Bay - Yuma Cove	October 2009	187	424	3	5	0	2
	December 2009	1611	329	2	1	0	0
	May 2010	101	478	4	16	1	3
	October 2010	209	466	8	33	1	3
Arizona Bay	December 2009	3335	378	5	18	4	15
	January 2011	1896	339	0	0	0	0
River	October 2009	4830	418	6	19	4	397
	December 2009	1436	347	2	4	0	0
	January 2010	3571	386	0	1	0	95
	December 2010	2013	342	0	0	0	26
Totals		25664	377*	74	157	12	555

*Mean TL

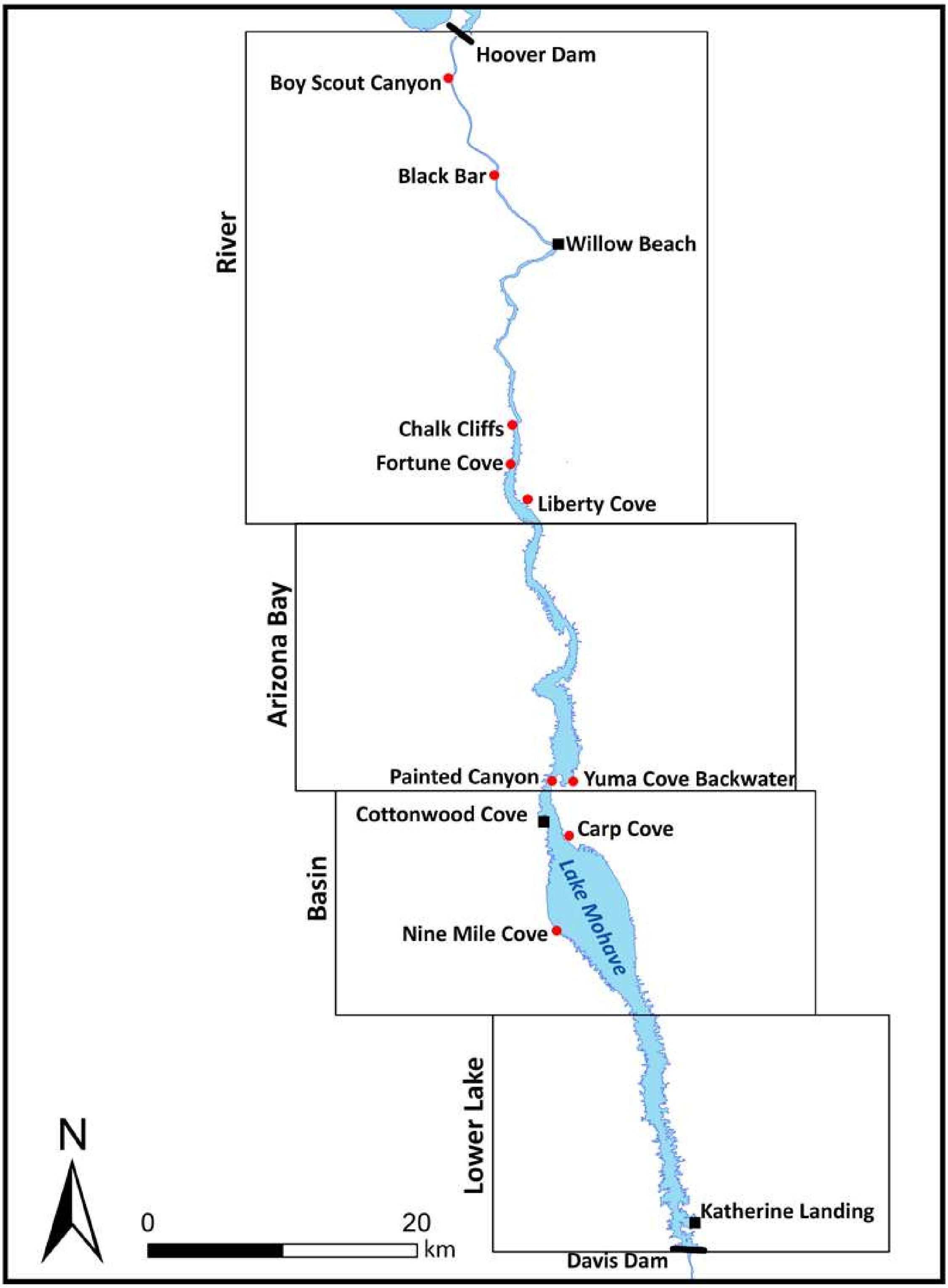

Figure 1. Overview map of study area depicting Lake Mohave including relevant sampling areas (red dots), and marinas (black squares), and general zones established in Kesner et al. (2008b).

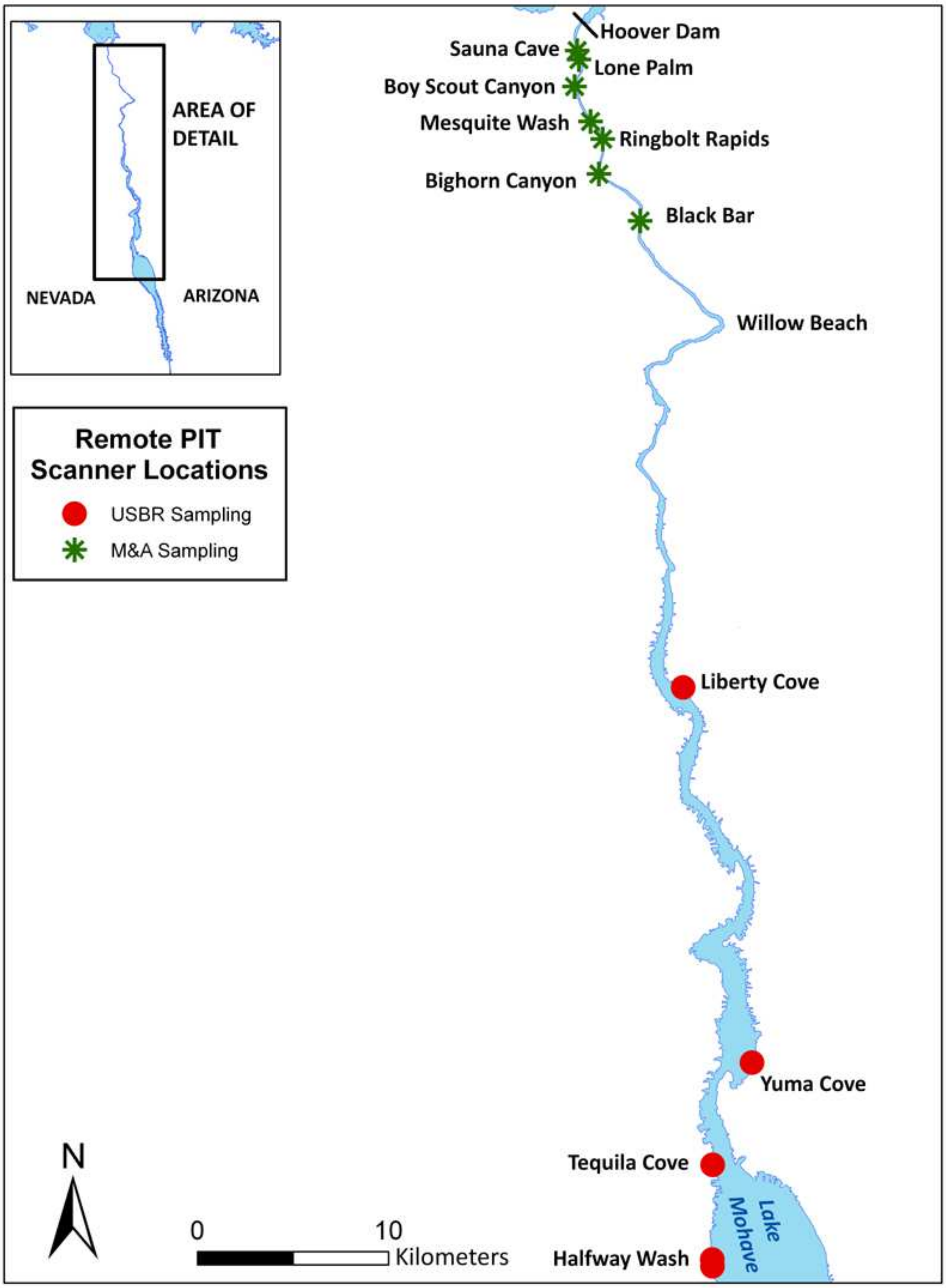

Figure 2. Location of remote PIT scanning units deployed in Lake Mohave by M&A (February 2011-May 2011) and BOR (February 2008-April 2011).

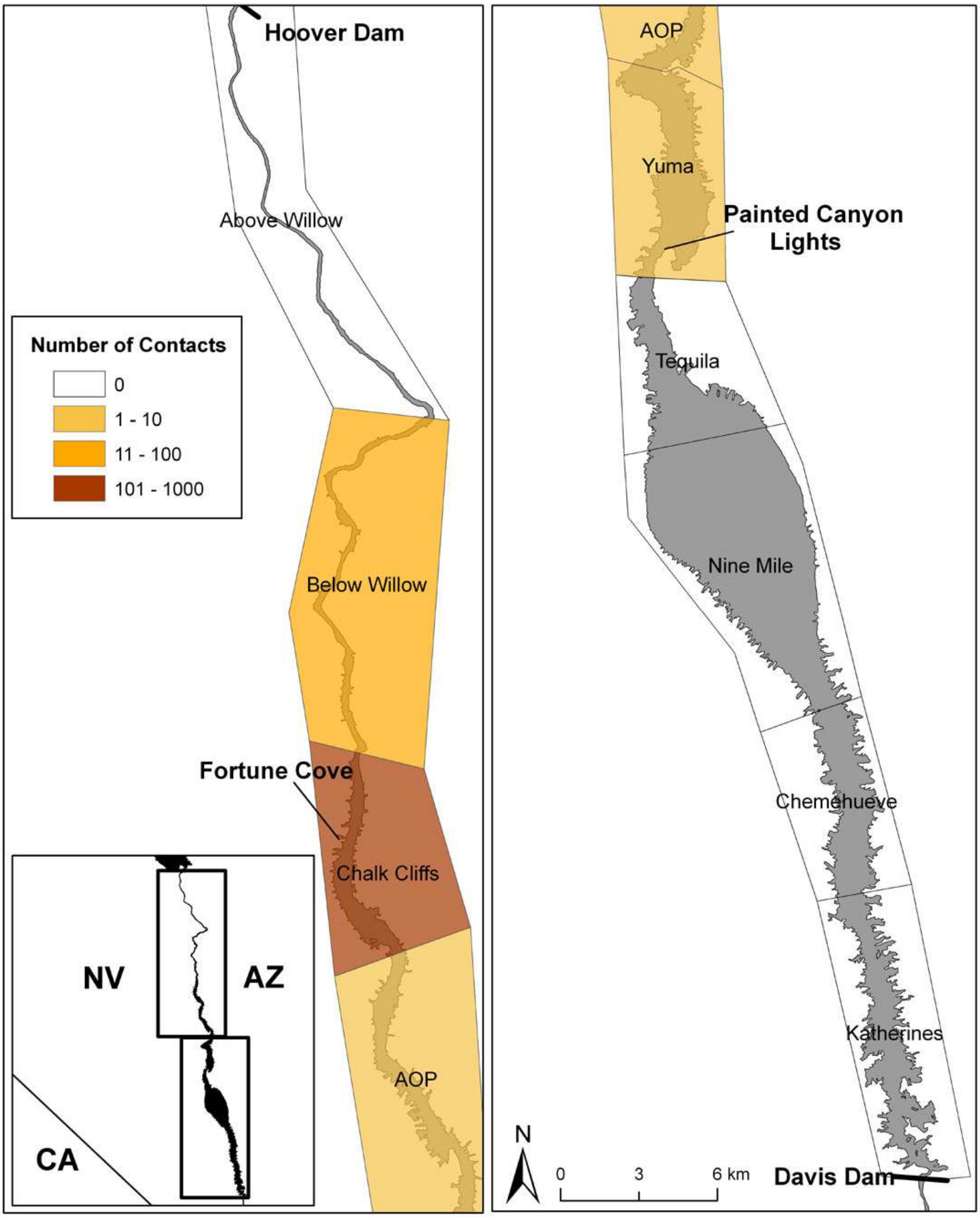

Figure 3. Contact densities by specific zone in Lake Mohave for all subadult razorback sucker still living (n = 6) at the end of the six month telemetry study (6 November 2008 to 5 May 2009).

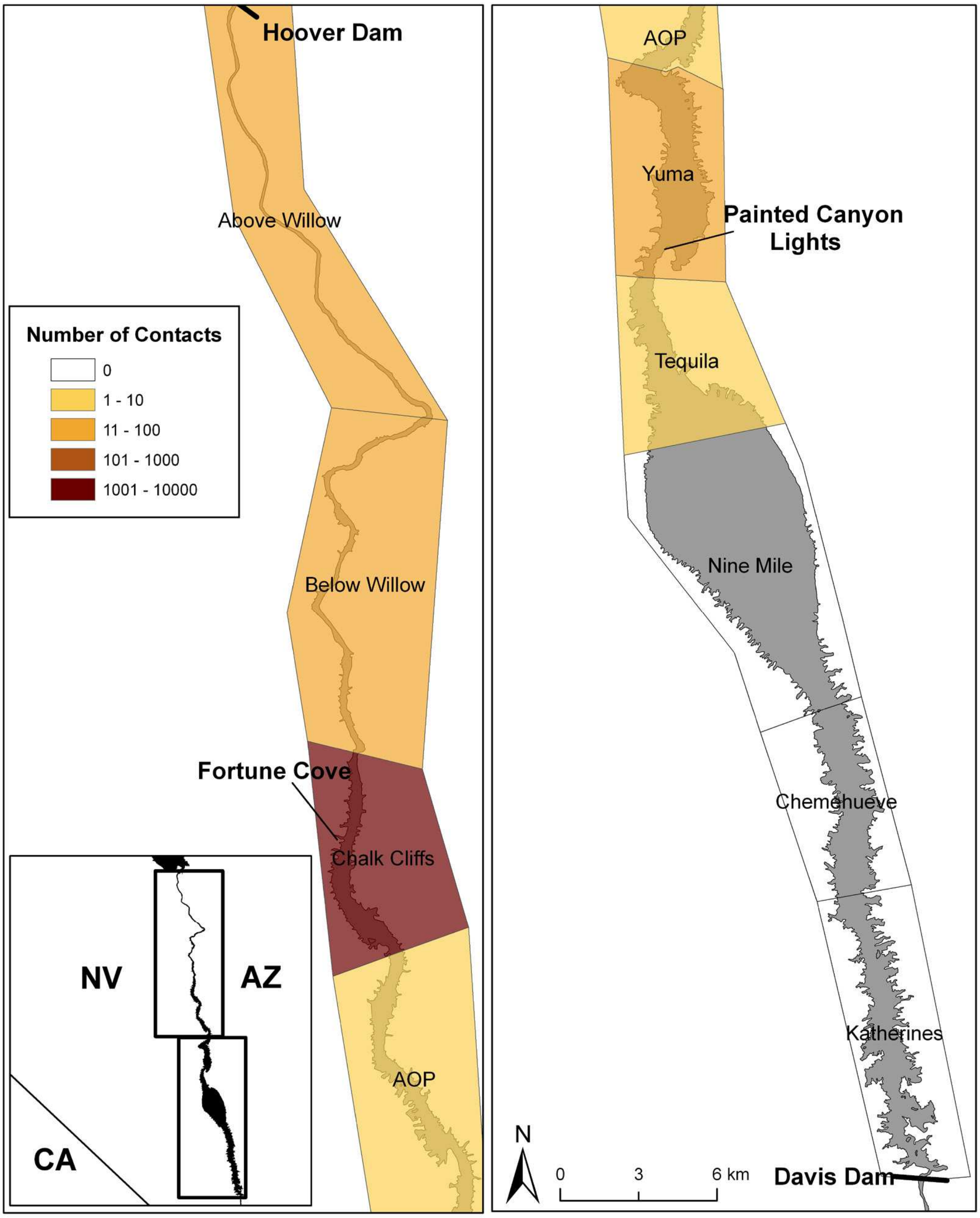

Figure 4. Contact densities by specific zone in Lake Mohave for all adult razorback sucker still living (n = 16) at the end of the six month telemetry study (6 November 2008 to 5 May 2009).

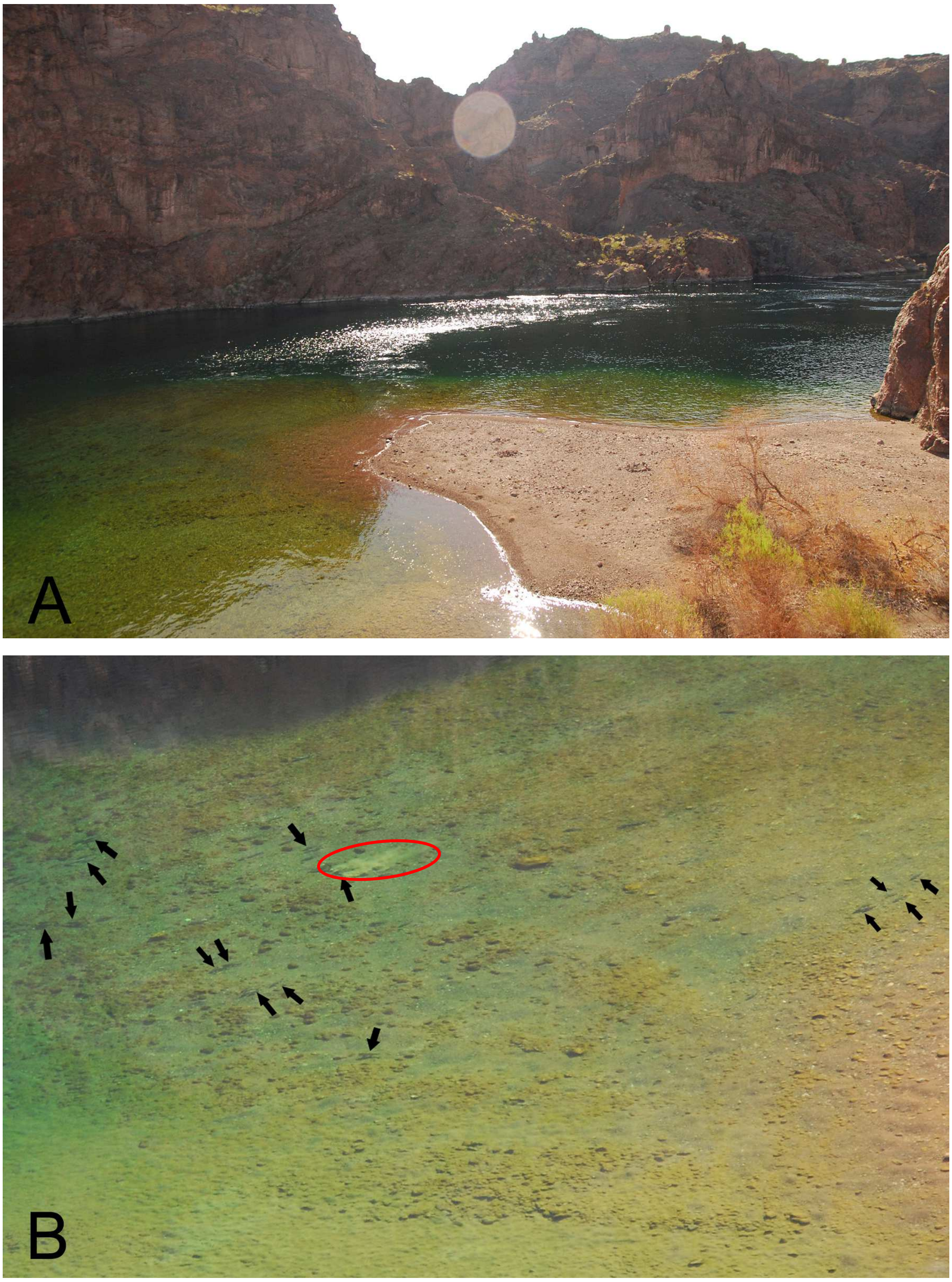

Figure 5. Black Bar extends into the main channel of the Colorado River upstream of Willow Beach (A), where telemetered adult razorback sucker were located during the course of the six month telemetry study. Razorback sucker shown congregating (black arrows) and spawning (red oval) on the gravel (B).

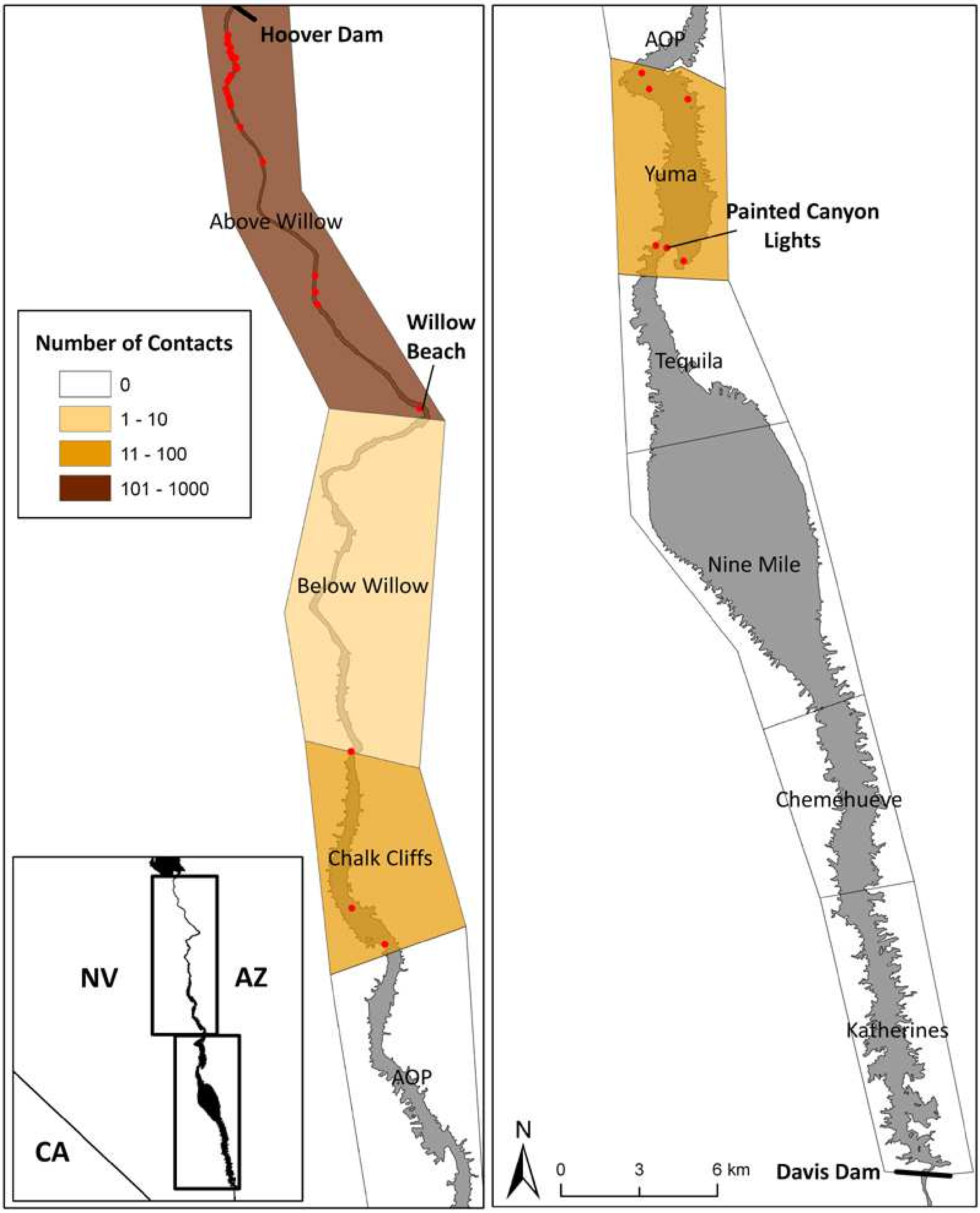

Figure 6. Contact densities by specific zone in Lake Mohave for all acoustic tagged river caught razorback sucker (n=10) over the course of the six month telemetry study (4 November 2009 to 3 May 2010).

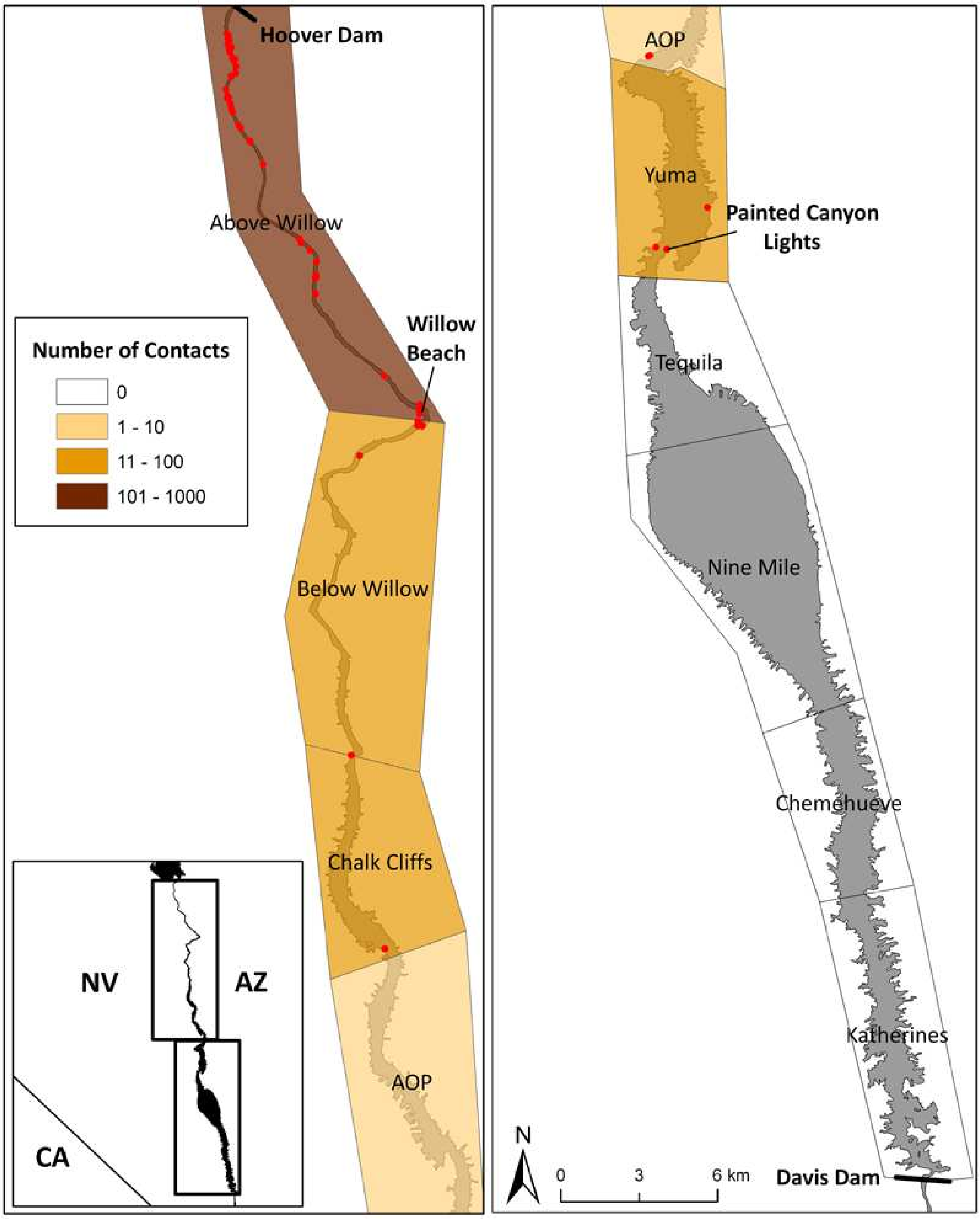

Figure 7. Contact densities by specific zone in Lake Mohave for all acoustic tagged BPSFH reared razorback sucker over the course of the six month telemetry study (4 November 2009 to 3 May 2010).

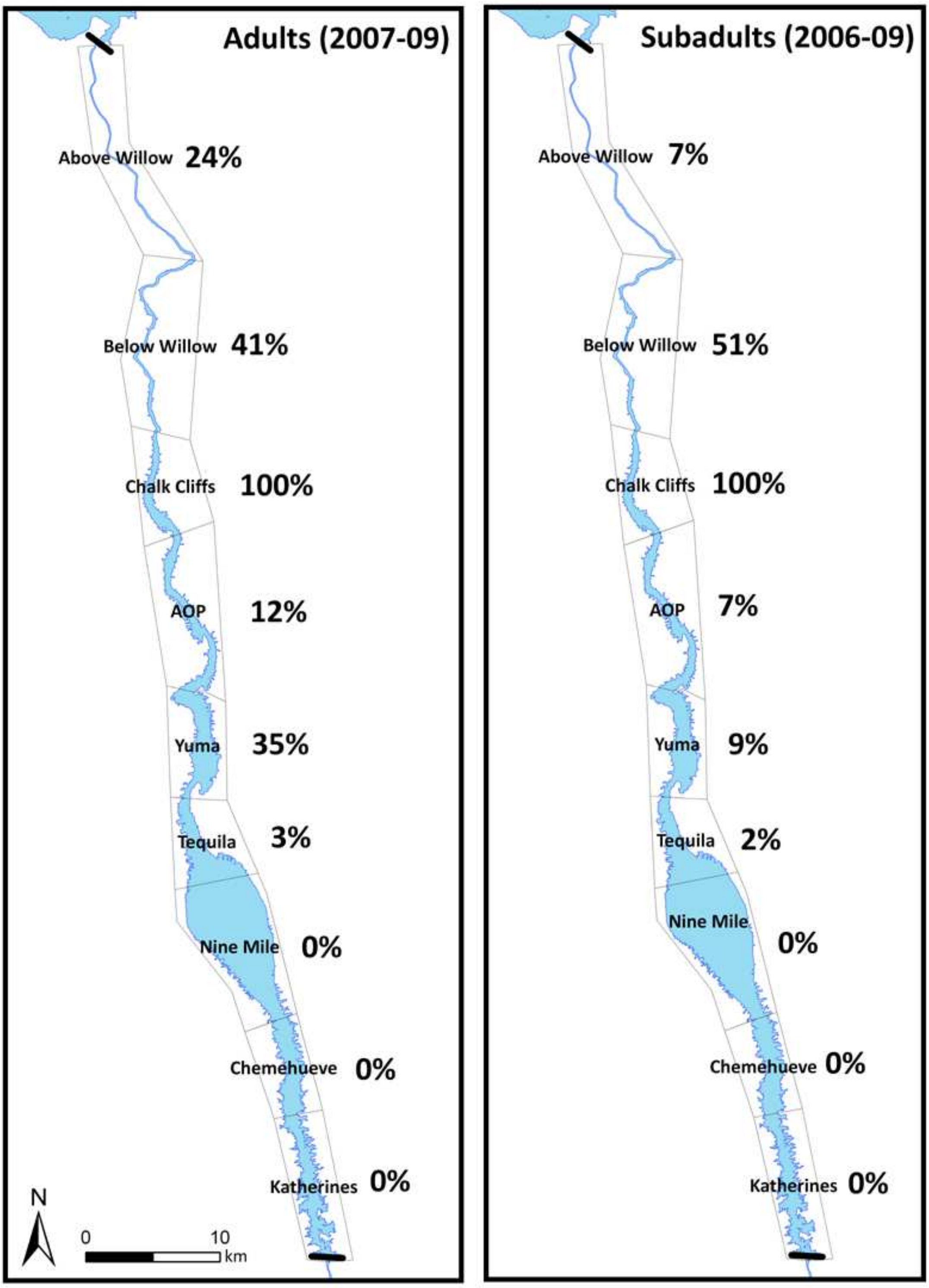

Figure 8. Combined proportion of adult (2007 and 2008 releases) and subadult (2006, 07 and 08 releases) telemetry fish released at Fortune Cove and contacted in specific zones in Lake Mohave. For details related to 2006 and 2007 releases see Kesner et al. 2008b.

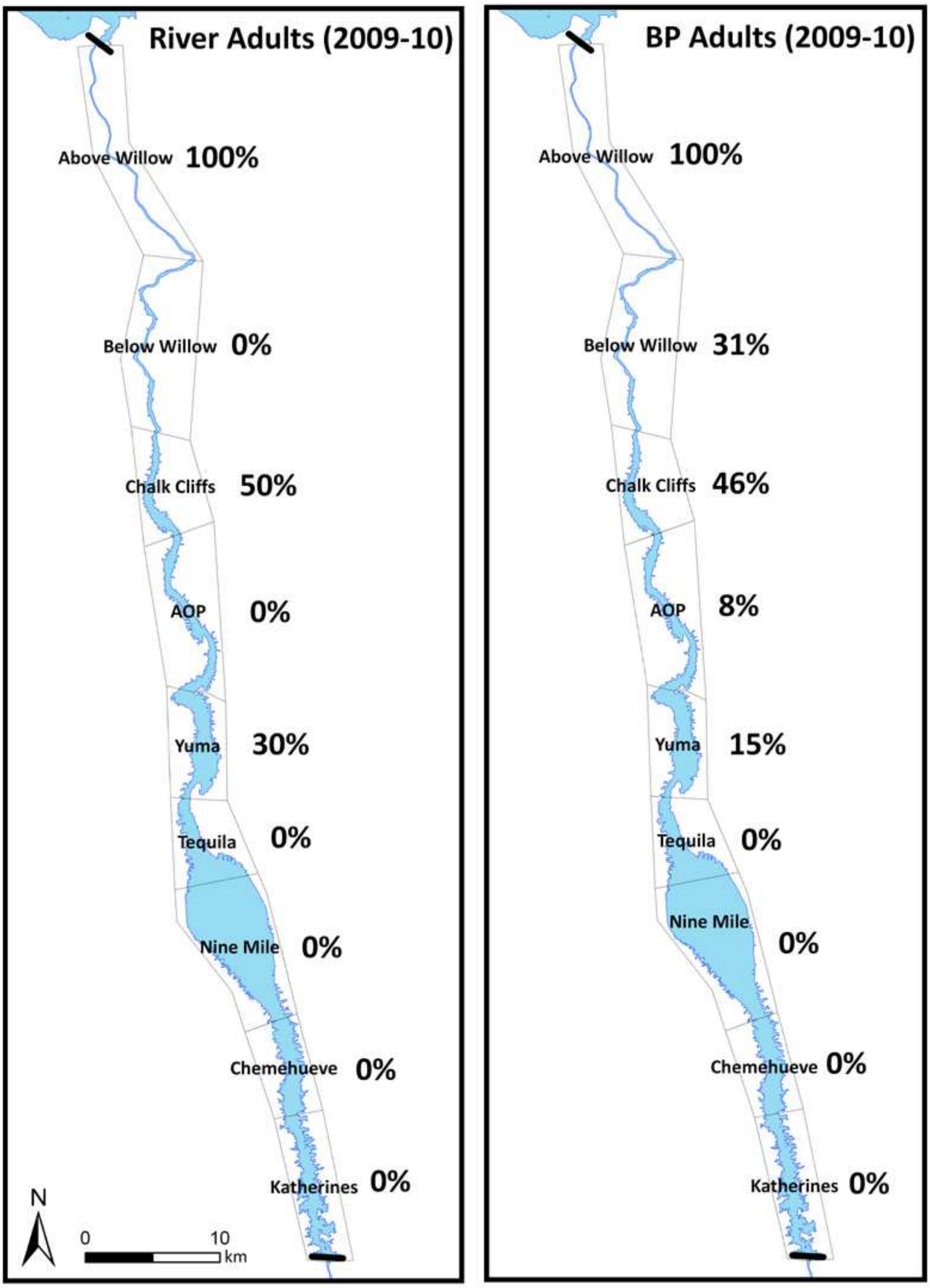

Figure 9. Combined proportion of river and Bubbling Ponds adult telemetry fish (2009 release) released near Hoover Dam and Willow Beach, respectively, and contacted in specific zones in Lake Mohave.

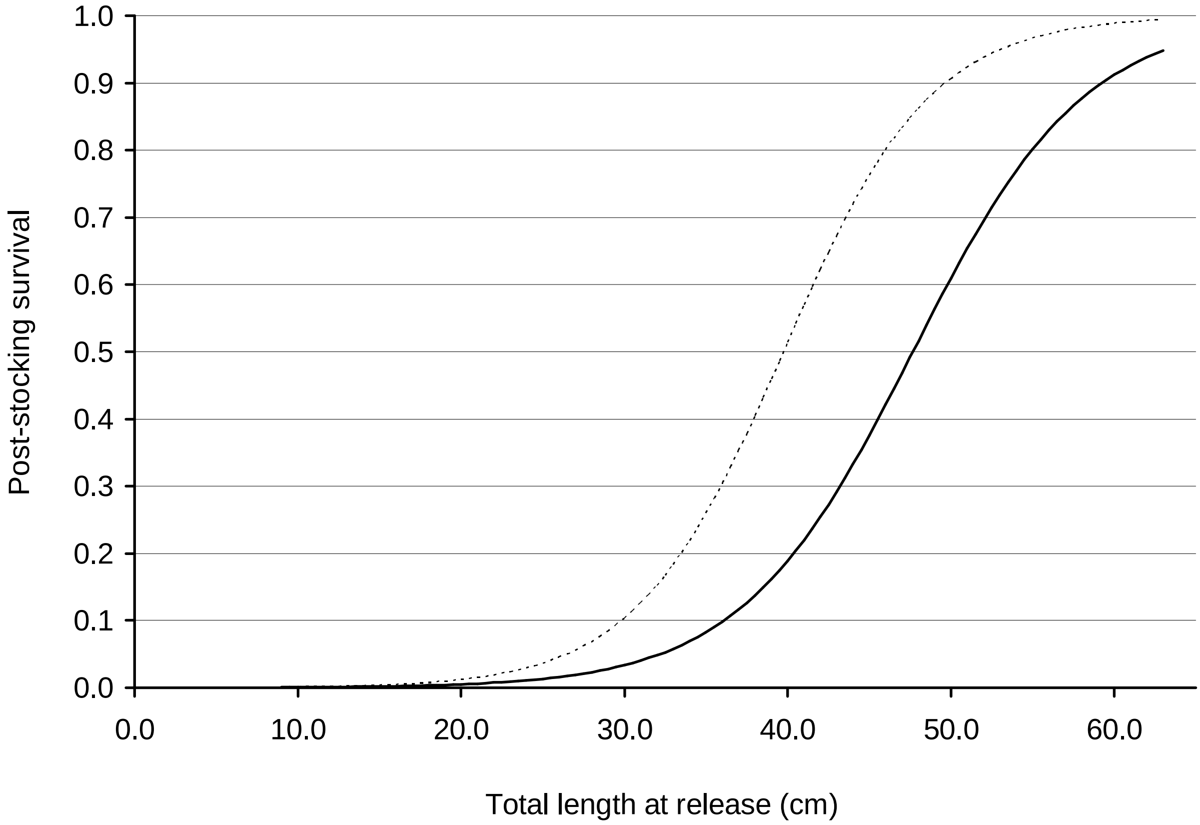

Figure 10. The relationship between post-stocking survival and size at release based on mark-recapture histories of repatriated razorback sucker in Lake Mohave. The relationship was evaluated in the program MARK based on capture histories (1992-2011) with total length at release added as a covariate (solid line). The relationship from Marsh et al. (2005) is represented by the dash curve.

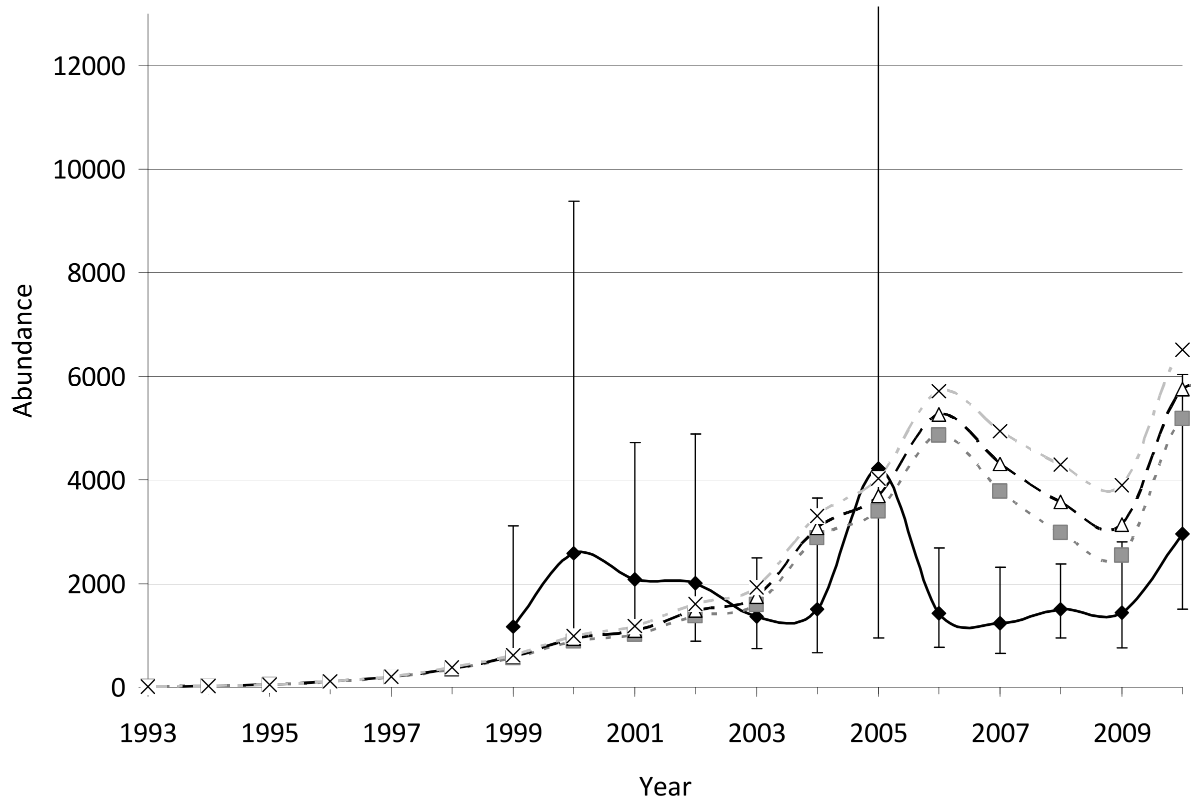

Figure 11. Population estimates (solid diamonds), and simulated populations based on stocking records and an updated size-survival relationship (1992 to 2011 data) for repatriated razorback sucker in Lake Mohave. Three simulations were evaluated based on different values of annual survival for the at large population; 0.70 (shaded squares), 0.75 (open triangles), 0.80 (black X).

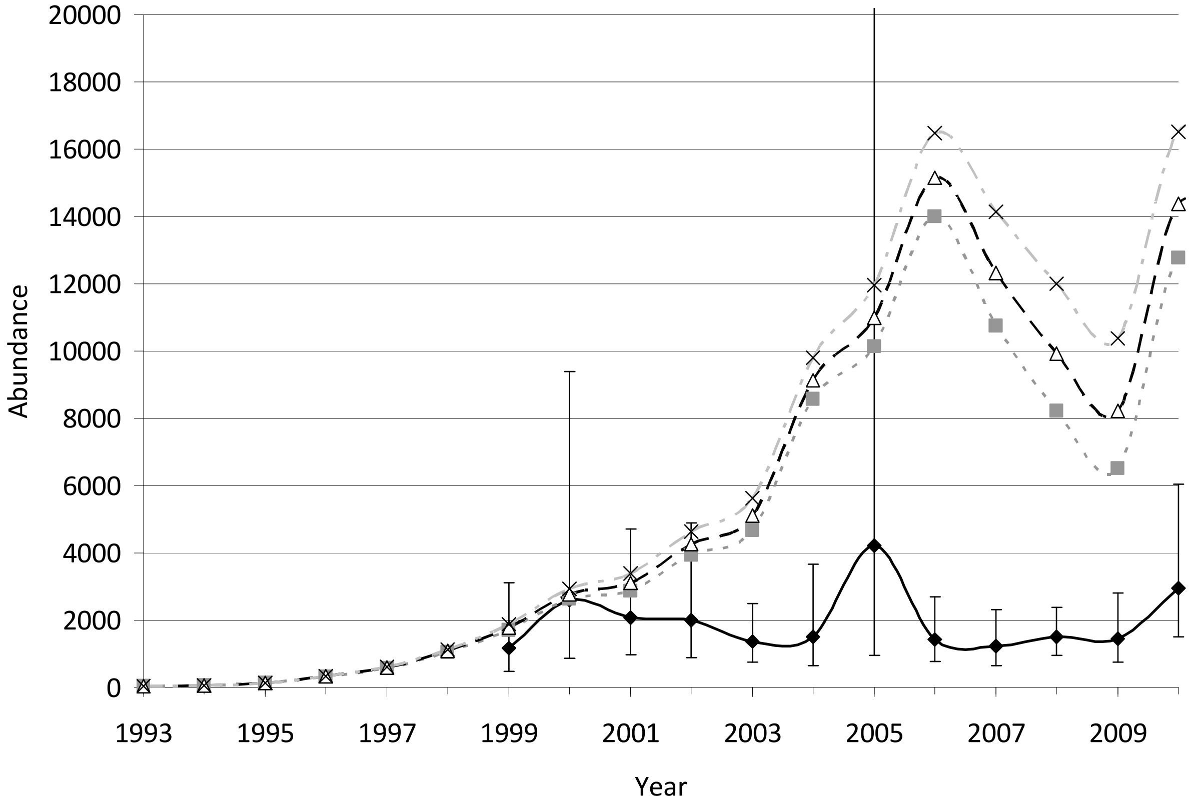

Figure 12. Population estimates (solid diamonds), and simulated populations based on stocking records and the size-survival relationship from Marsh et al. (2005) for repatriated razorback sucker in Lake Mohave. Three simulations were evaluated based on different values of annual survival for the at large population; 0.70 (shaded squares), 0.75 (open triangles), 0.80 (black X).

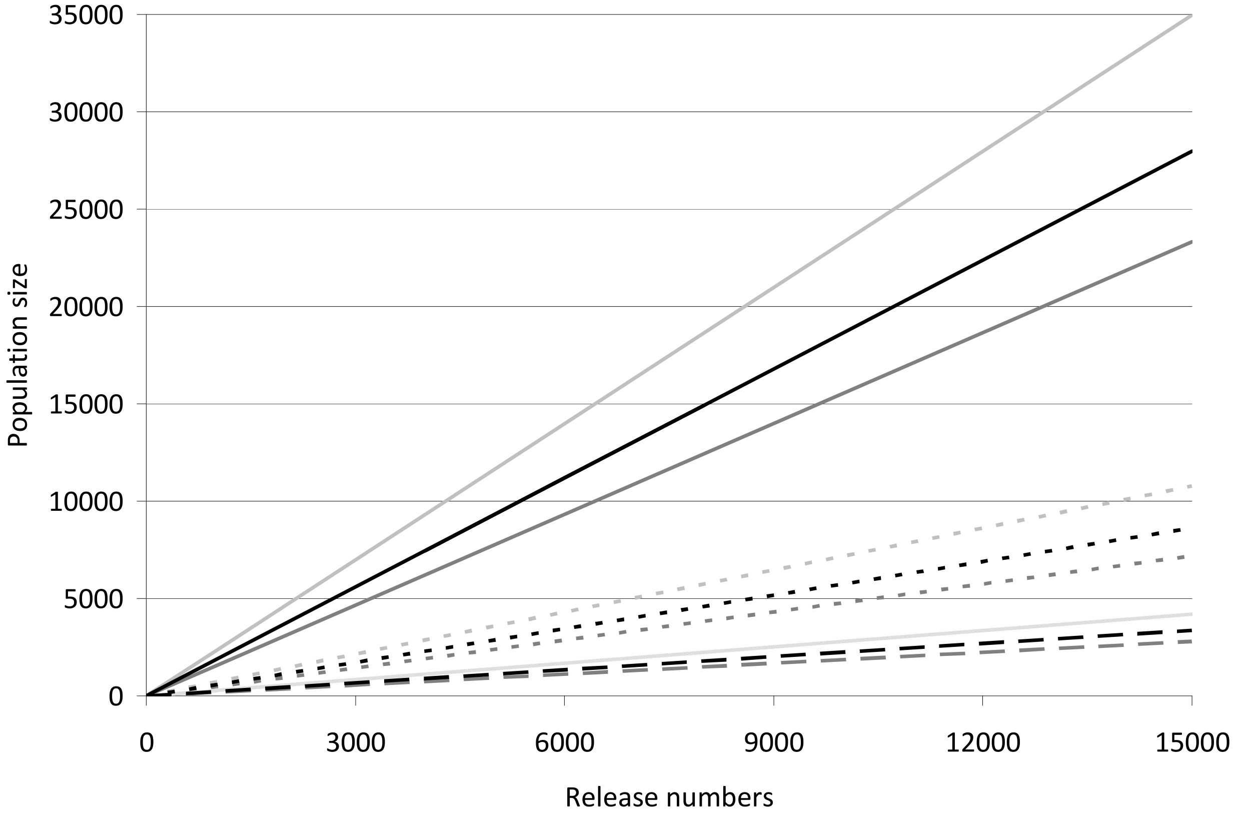

Figure 13. Equilibrium population trajectories for three stocking regimes; target size 30 cm (dashed lines), 35 cm (small dashes), and 50 cm (solid line) based on an updated size-survival relationship for repatriated razorback sucker stocked in Lake Mohave from 1992-2010. Colors indicated different values for at large survival in simulations; 0.70 (dark grey), 0.75 (black), and 0.80 (light grey).

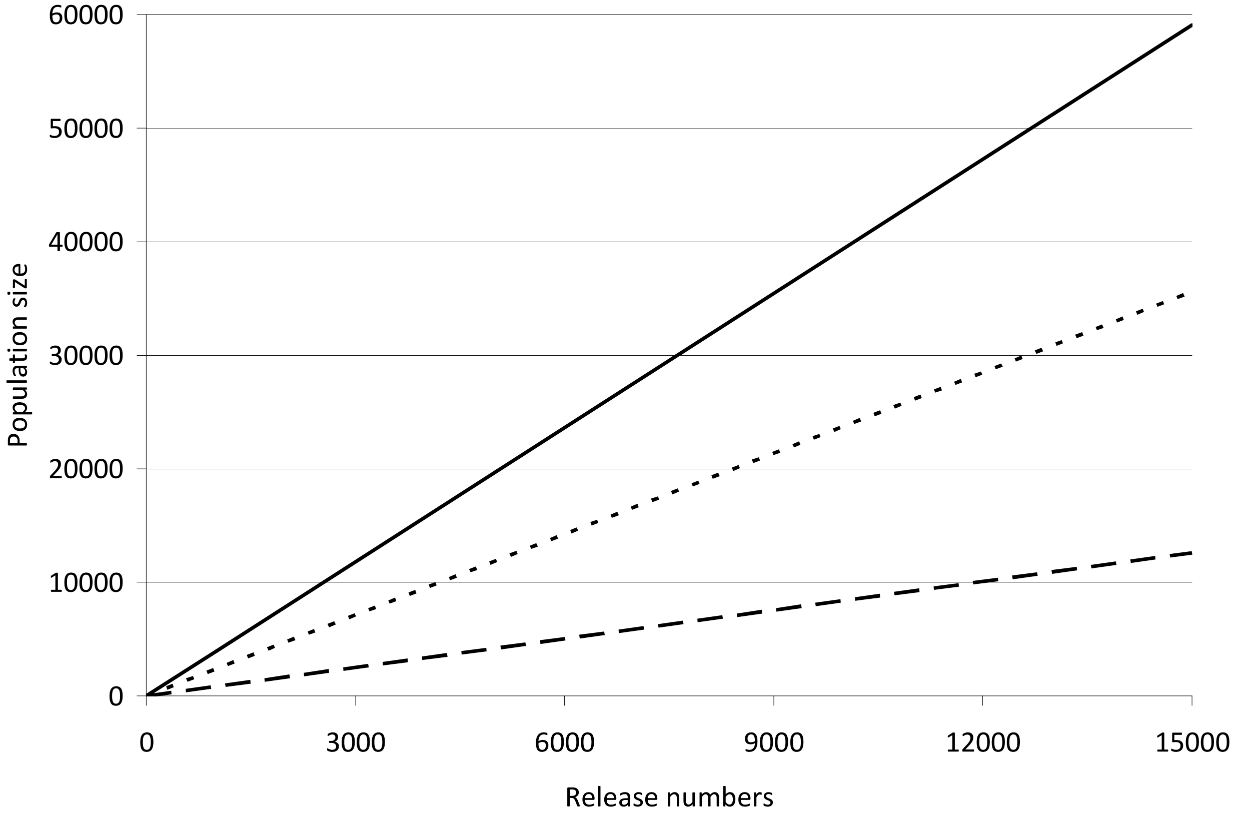

Figure 14. Equilibrium population trajectories for three stocking regimes; target size 30 cm (dashed lines), 35 cm (small dashes), and 50 cm (solid line) based on the size-survival relationship as published in Marsh et al. (2005) for repatriated razorback sucker stocked in Lake Mohave from 1992-2001.

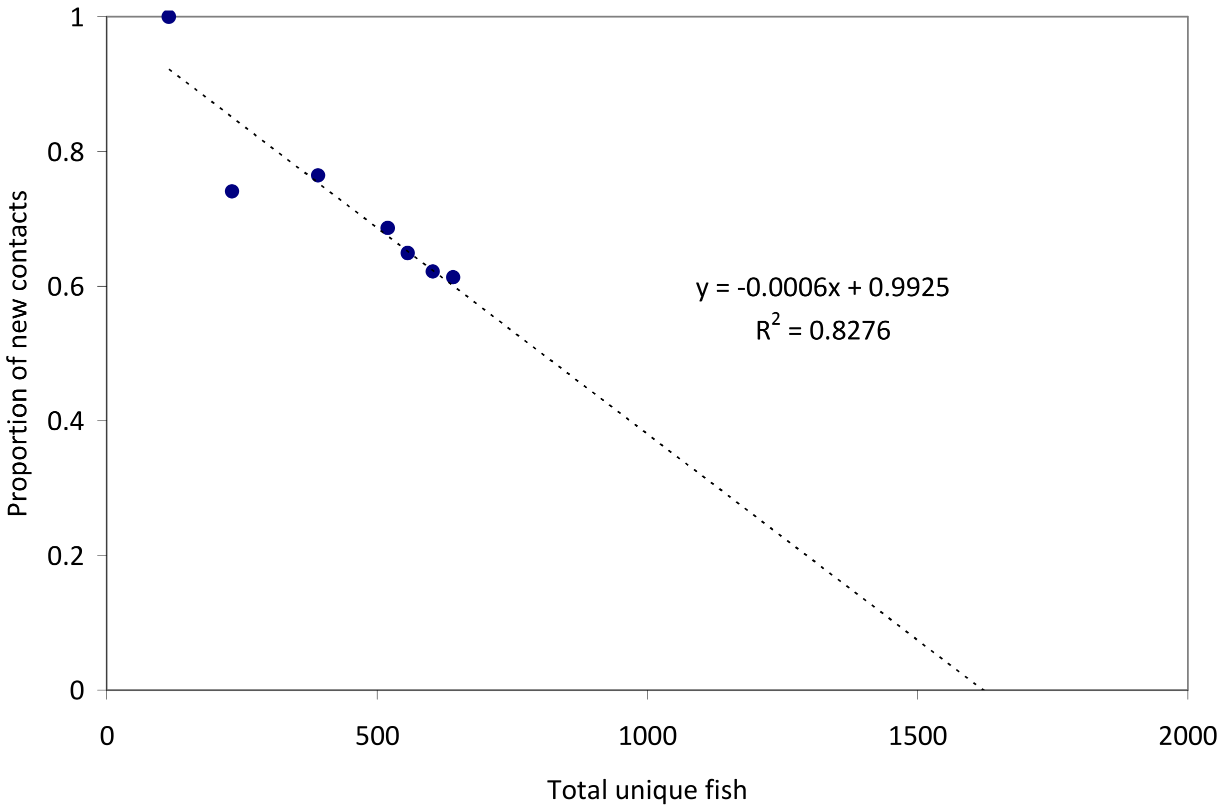

Figure 15. Linear regression (y = -0.0006x + 0.9925) of the proportion of new contacts detected each sampling trip by M&A against cumulative unique fish contacts detected in the river section of Lake Mohave between Willow Beach and Hoover dam between 1 January and 31 May 2011. The intercept with the x-axis represents the estimated abundance (1654) of razorback sucker in the river section of Lake Mohave.

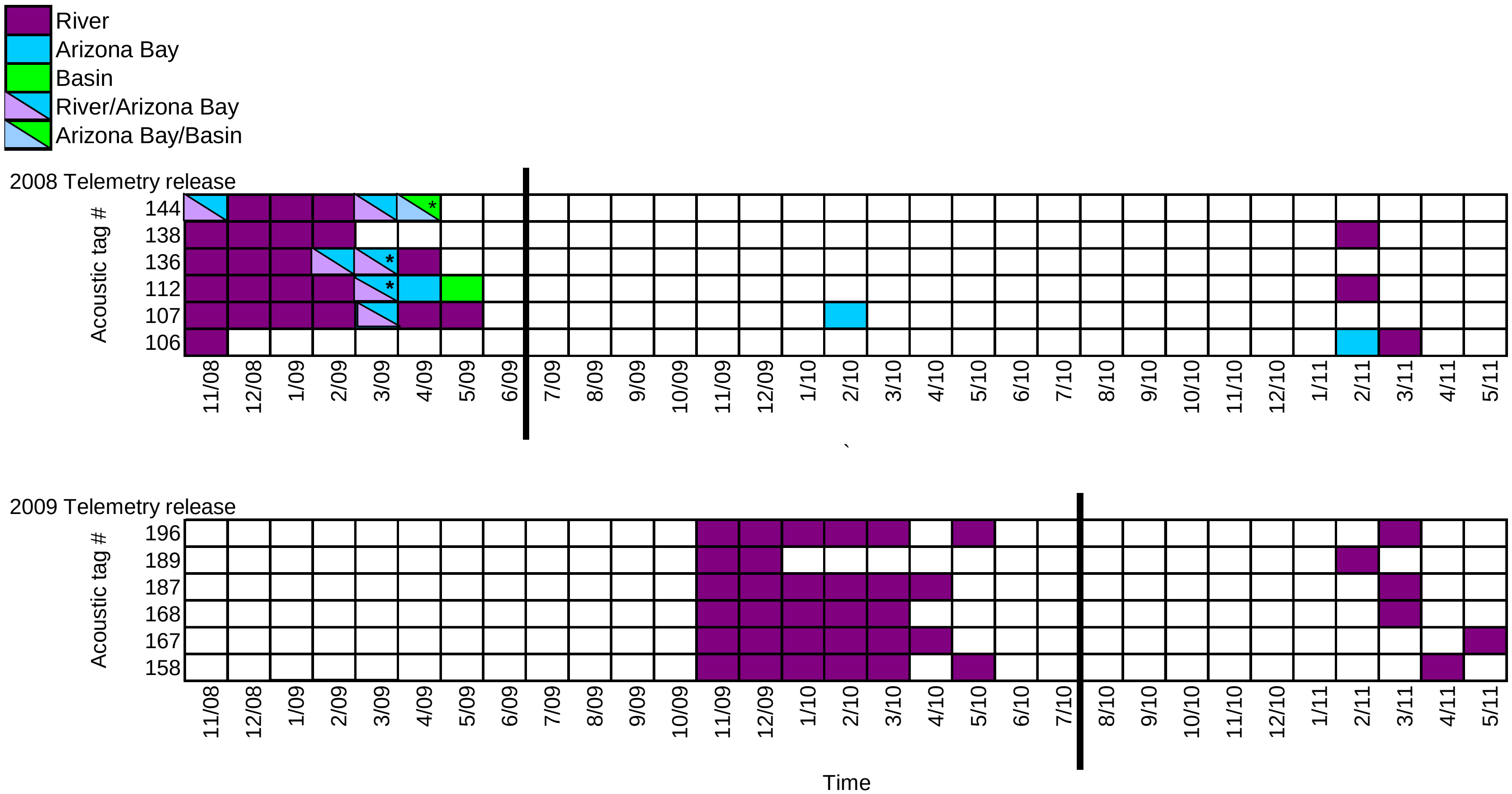

Figure 16. Movement of razorback sucker throughout Lake Mohave zones as detected by acoustic telemetry and remote PIT scanning between November 2008 and June 2011; see Figure 1 for map of zones used in this analysis.

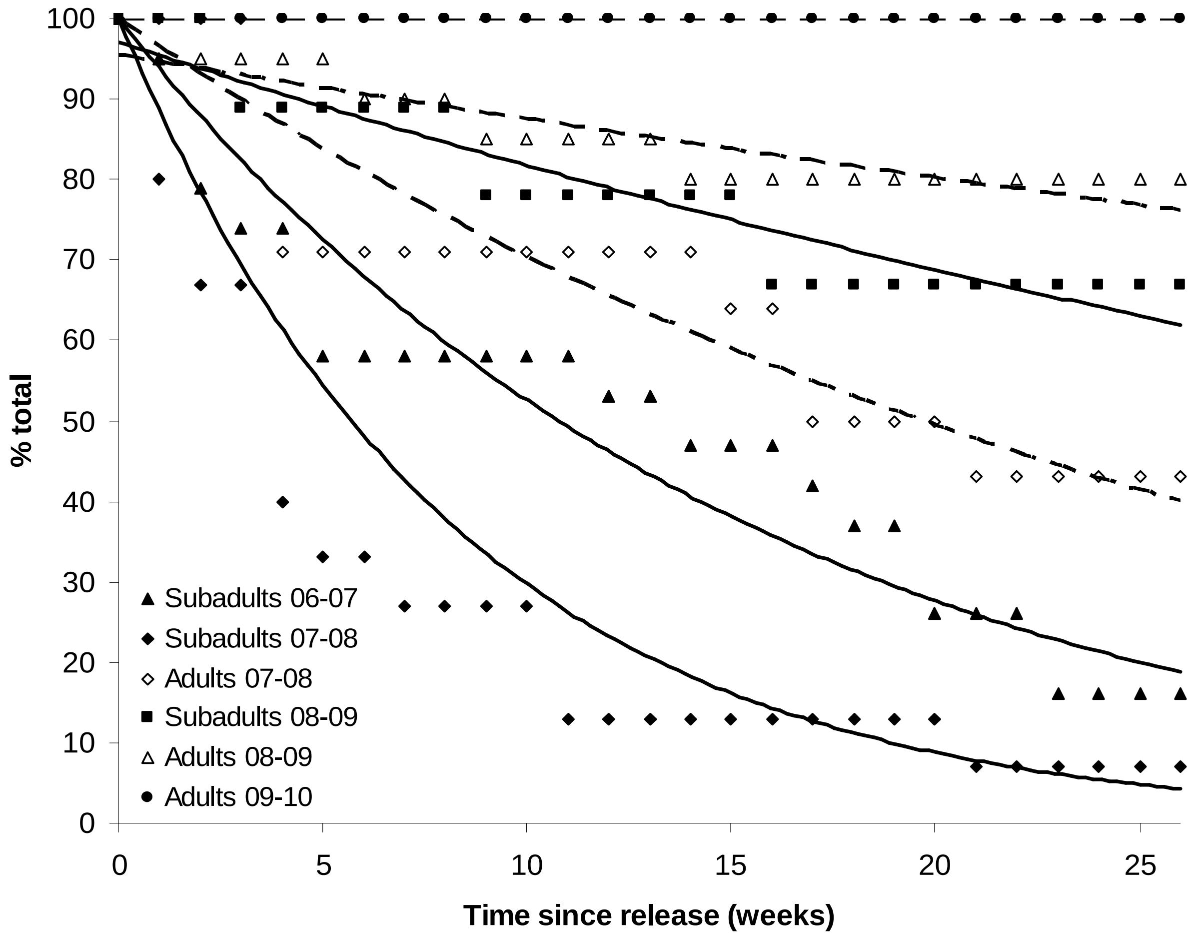

Figure 17. Six month post-stocking survivorship for subadult (solid lines) and adult (dashed lines) razorback sucker during the past four telemetry studies in Lake Mohave (2006-07, 2007-08, 2008-09, and 2009-10). Adults from 2009-10 represent both groups of telemetry-tag implanted razorback sucker (BPSFH and River adults).

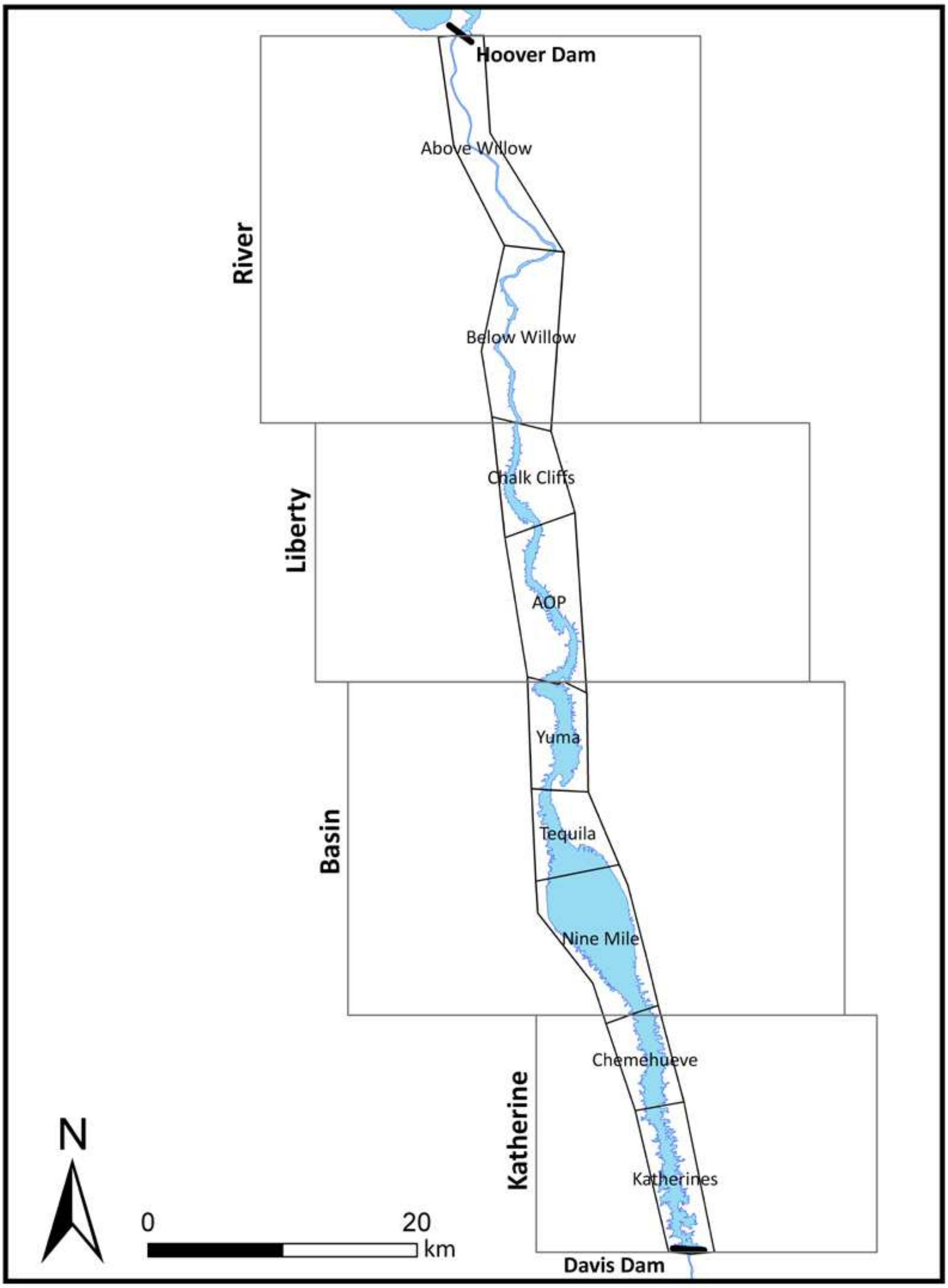

Figure 18. Map of Lake Mohave depicting the specific zones and the newly revised general zones.

Appendix A. Adult razorback sucker monitoring summary for 49 paired release-capture data sets per fish PIT tag number with calculated time at large [capture date minus release date then divided by 30 d for months at large (MAL) or 365 d for years at large (YAL)] and capture history. Data are in order by days at large (DAL) and also include year class information where available. Release date is when fish, generally juveniles, were stocked into Lake Mohave. BPSFH is Bubbling Ponds Fish Hatchery and WBNFH is Willow Beach National Fish Hatchery.

PIT tag	Release Date	Capture Date	Year Class	Rearing Location	DAL	MAL	YAL	Comments
1C2D05A544	10/23/2009	12/2/2009	2005	BPSFH[a]	40	1	0	First capture in 2009
1C2D6C7A10	10/15/2010	12/9/2010	Unknown	Yuma[b]	55	2	0	First capture in 2010
1C2D012FF9	10/6/2008	12/4/2008	Unknown	Nevada Larvae[b]	59	2	0	First capture in 2008
1C2D69B1DA	1/6/2010	3/16/2010	2006	WBNFH[a]	69	2	0	First capture in 2010, second capture short-term capture 2010
1C2D639BE3	1/6/2010	3/16/2010	2006	WBNFH[a]	69	2	0	First capture in 2010
1C2D695C4D	1/6/2010	3/16/2010	2006	WBNFH[a]	69	2	0	First capture in 2010
1C2D6D0A48	1/6/2011	3/16/2011	2007	WBNFH[a]	69	2	0	First capture in 2011
1C2D676D61	1/5/2010	3/16/2010	2005 and 2006	WBNFH[a]	70	2	0	First capture in 2010
1C2D70F78B	1/7/2010	3/19/2010	2005	WBNFH[a]	71	2	0	First capture in 2010
1C2D67C42F	1/5/2010	3/17/2010	2005 and 2006	WBNFH[a]	71	2	0	First capture in 2010
1C2D69774C	1/6/2010	3/18/2010	2006	WBNFH[a]	71	2	0	First capture in 2010
1C2D677362	1/5/2010	3/18/2010	2005 and 2006	WBNFH[a]	72	2	0	First capture in 2010
1C2D683A73	1/5/2010	3/18/2010	2005 and 2006	WBNFH[a]	72	2	0	First capture in 2010
1C2D74797A	1/5/2010	3/18/2010	2005 and 2006	WBNFH[a]	72	2	0	First capture in 2010
1C2D63A441	1/6/2010	3/19/2010	2006	WBNFH[a]	72	2	0	First capture in 2010
1C2D696B8B	1/6/2010	3/19/2010	2006	WBNFH[a]	72	2	0	First capture in 2010
1C2D7490C0	1/5/2010	3/19/2010	2005 and 2006	WBNFH[a]	73	2	0	First capture in 2010

Appendix A. Continued.

PIT tag	Release Date	Capture Date	Year Class	Rearing Location	DAL	MAL	YAL	Comments
1C2D683175	12/18/2009	3/16/2010	2006	WBNFH[a]	88	3	0	First capture in 2010
1C2D697064	12/17/2009	3/17/2010	2006	WBNFH[a]	90	3	0	First capture in 2010
1C2D62D042	12/3/2009	3/16/2010	2008	Achii Hanyo[a]	103	3	0	First capture in 2010, second capture short-term capture 2010
1C2D64370C	12/3/2009	3/16/2010	2008	Achii Hanyo[a]	103	3	0	First capture in 2010
1C2D643869	10/23/2009	3/18/2010	2005	BPSFH[a]	146	5	0	First capture in 2010
1C2C36F04C	10/23/2009	3/19/2010	2005	BPSFH[a]	147	5	0	First capture in 2010
1C2D6BCD74	10/15/2010	3/16/2011	Unknown	Yuma Cove[b]	152	5	0	First capture in 2011
257C62EDE3	10/15/2010	3/16/2011	Unknown	Yuma Cove[b]	152	5	0	First capture in 2011
257C611F6B	10/8/2008	3/17/2009	Unknown	Arizona Juvenile[b]	160	5	0	First capture in 2009
1C2D697739	10/5/2010	3/16/2011	2006	North Chemehuevi[b]	162	5	0	First capture in 2011
1C2D6933AD	9/21/2010	3/15/2011	2006	Arizona Juvenile[b]	175	6	0	First capture in 2011
1C2D697BED	9/21/2010	3/15/2011	2006	Willow Cove[b]	175	6	0	First capture in 2011
1C2C38C46D	9/23/2009	3/18/2010	2006	Dandy Cove[b]	176	6	0	First capture in 2010
1C2D696720	9/21/2010	3/16/2011	2006	Arizona Juvenile[b]	176	6	0	First capture in 2011
1C2D622913	12/3/2009	12/9/2010	2008	Achii Hanyo[a]	371	12	1	First capture in 2010
1C2D681C34	12/18/2009	3/16/2011	2006	WBNFH[a]	453	15	1	First capture in 2011
1C2C33ACE1	11/20/2007	3/17/2009		Yuma Cove[b]	483	16	1	First capture in 2009
1C2C336A7E	9/25/2009	3/15/2011	2006	North Chemehuevi[b]	536	18	1	First capture in 2011
257C60E10E	6/13/2007	12/4/2008	Unknown	Arizona Juvenile[b]	540	18	1	First capture in 2008
4637701373	1/25/2006	3/18/2009	2003 WBNFH	WBNFH[a]	1,148	38	3	First capture in 2009
4647776409	4/1/2005	3/17/2009	2002 WBNFH	WBNFH[a]	1,446	48	4	First capture in 2009
533277004B	6/18/2004	3/19/2010	Unknown	WBNFH[a]	2,100	70	6	First capture in 2010
42407B0943	6/27/2001	12/4/2008	Unknown	Boulder City Wetlands[a]	2,717	91	7	First capture in 2006, second capture in 2008

Appendix A. Continued.

PIT tag	Release Date	Capture Date	Year Class	Rearing Location	DAL	MAL	YAL	Comments
5325721921	6/20/2001	3/18/2009	Unknown	Dandy Cove[b]	2,828	94	8	First capture in 2009
5326044B70	5/30/2001	3/18/2009	Unknown	North Nine Mile Cove[b]	2,849	95	8	First capture in 2009
520E524F15	9/26/2000	3/18/2009	Unknown	Arizona Juvenile[b]	3,095	103	8	First capture in 2009
532623435E	9/22/2000	3/17/2009	Unknown	Boulder City Wetlands [a]	3,098	103	8	First capture in 2008, second capture in 2009
53240E7138	7/27/2000	3/17/2011	Unknown	Boulder City Wetlands[a]	3,885	130	11	First capture in 2011
42016D2D60	3/11/1998	3/18/2009	Unknown	Boulder City Wetlands[a]	4,025	134	11	First capture in 2009
2037213454	11/20/1995	12/2/2008	Unknown	Yuma Cove[b]	4,761	159	13	First capture in 2008
201D603C27	11/20/1995	12/3/2008	Unknown	Yuma Cove[b]	4,762	159	13	First capture in 2008
7F7A075250	10/9/1996	3/19/2010	Unknown	Arizona Juvenile[b]	4,909	164	13	First capture in 2010

[a]Off-site rearing facility
[b]Lakeside backwater