Lower Colorado River Multi-Species Conservation Program

Balancing Resource Use and Conservation

Razorback Sucker Studies on Lake Mead, Nevada and Arizona
2010–2011 FINAL ANNUAL REPORT

U.S. DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

October 2011

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EXECUTIVE SUMMARY

In 1996 the Southern Nevada Water Authority (SNWA) and Colorado River Commission of Nevada, in cooperation with the Nevada Department of Wildlife (NDOW), initiated a study to develop information about the Lake Mead razorback sucker (*Xyrauchen texanus* [Abbott]) population. BIO-WEST, Inc. (BIO-WEST), under contract with SNWA, designed the study and had primary responsibility for conducting it. In 2005 the Bureau of Reclamation (Reclamation) became the principal funding agency, and the study became primarily a long-term monitoring study in 2007. This report provides information and observations from the 15th year (2010–2011) of this long-term monitoring study.

During the 15th field season, the habitat use and movements of 13 sonic-tagged fish were monitored, providing a total of 72 location points. Five of these fish remain from the 2008 tagging event, and the other eight fish were from the tagging event in January 2011. By using data gathered from sonic-tagged fish, in conjunction with trammel-netting and larval-sampling data, information regarding spawning sites was again obtained from the three main study areas within Lake Mead. Along with spawning-site information, sonic-tagged fish provided valuable data on movement patterns within and between Las Vegas Bay, the Muddy River/Virgin River inflow area, Echo Bay, and areas of Lake Mead not regularly explored (i.e., the Virgin Basin). In fact, one sonic-tagged fish (originally from the Muddy River/Virgin River inflow area) was located in Bonelli Bay after it had resided in Las Vegas Bay for several months. Sonic-tagged fish continue to provide invaluable data regarding the movement patterns and habitat use of razorback sucker in Lake Mead and have aided field crews in monitoring study areas.

Trammel netting for juvenile/subadult ("subadult" has been defined in our report as a sexually immature razorback sucker typically less than 450 mm in total length) and adult fish during the spawning period continued, and 86 razorback suckers—9 from Las Vegas Bay, 15 from Echo Bay, and 62 from the Muddy River/Virgin River inflow area—were captured. Interestingly, five of the razorback suckers collected were subadults (all from Las Vegas Bay). Of the 86 total razorback suckers collected, 14 were recaptured fish. The capture of 62 razorback suckers at the Muddy River/Virgin River inflow area, a highlight of the 15th field season, suggests the Muddy River/Virgin River inflow area of Lake Mead is becoming more important for razorback sucker production and recruitment.

Average annual growth during this field season, as determined from six recaptured fish, was 24.7 mm/year. Mean growth rates could not be calculated for the Las Vegas Bay or the Muddy River/Virgin River inflow areas because too few fish were recaptured in those areas; however, mean annual growth for Echo Bay fish was 11.8 mm. Growth rates of Lake Mead razorback sucker continue to be substantially higher overall than those recorded from other populations, suggesting the Lake Mead razorback sucker populations are able to maintain a fairly strong cohort of young, fast-growing fish.

Fin ray sections were removed from 73 razorback suckers for age determination during the 15th field season which, when combined with the 287 fish aged during previous field seasons, brings the total number of fish aged during the study to 360. Of particular interest is the continued documentation of recent (2000–2007) recruitment. Past collections and analyses identified

recruitment through 2006; however, fin ray material obtained during this field season indicates continued recruitment in Lake Mead as recent as 2008. Age-determination techniques continue to show that recruitment pulses in Lake Mead can be associated with relatively high, stable lake elevations. Based on data collected from 2007–2011, we have also observed strong pulses in recruitment that coincided with low, declining lake elevation trends and a large, high-flow event from the Virgin River in 2004–2005. Data collected to date indicate Lake Mead razorback sucker recruitment occurs nearly every year. This report reiterates the need to further our understanding of conditions that promote the unique recruitment pattern of razorback suckers in Lake Mead.

In addition to the efforts and findings reported above, BIO-WEST also worked collaboratively with biologists from the NDOW in a continued effort to collect additional larval razorback sucker for Lake Mead repatriation efforts. These fish will allow for increased razorback sucker presence in Lake Mead, additional research opportunities to test hypotheses concerning lake levels and cover, and increased understanding of recruitment patterns during future field seasons.

During the 2010–2011 field season, primary spawning sites were identified in all long-term monitoring areas, and these sites moved only slightly when compared with previous years. An overall increase of adult captures and larval abundance was noted for many of the long-term monitoring areas, and spawning near the Muddy River/Virgin River inflow area was successfully documented again in 2011. For the second time, trammel-netting capture rates in the Muddy River/Virgin River area eclipsed those of other, more extensively studied, long-term sites.

Given the potential for lake levels to continue to fluctuate in 2011 and 2012, general research objectives for the 2012 field season include continuing to monitor razorback sucker at the three main study areas, continuing to age individual razorback sucker from Lake Mead, continuing to study subadult razorback sucker habitat use throughout the long-term monitoring areas of Lake Mead, and maintaining a sonic-tagged fish presence as needed.

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INTRODUCTION

The razorback sucker (*Xyrauchen texanus* [Abbott]) is one of four endemic, large-river fish species (the others are Colorado pikeminnow [*Ptychocheilus lucius*], bonytail chub [*Gila elegans*], and humpback chub [*Gila cypha*]) of the Colorado River Basin presently considered endangered by the U.S. Department of the Interior (USFWS 1991). Historically widespread and common throughout the larger rivers of the basin (Minckley et al. 1991), the razorback sucker's distribution and abundance have been greatly reduced. One of the major factors causing the decline of razorback sucker and other large-river fishes has been the construction of mainstem dams and the resultant cool tailwaters and reservoir habitats that replaced a warm, riverine environment (Holden and Stalnaker 1975, Joseph et al. 1977, Wick et al. 1982, Minckley et al. 1991). Competition and predation from nonnative fishes in the Colorado River and its reservoirs have also contributed to the decline of these endemic species (Minckley et al. 1991). Razorback sucker persisted in several reservoirs constructed in the Lower Colorado River Basin; however, these populations consisted primarily of adult fish that apparently recruited during the first few years of reservoir formation. The population of long-lived adults then disappeared 40–50 years following reservoir creation and the initial recruitment period (Minckley 1983). The largest reservoir population, estimated at 75,000 individuals in the 1980s, occurred in Lake Mohave, Arizona and Nevada, but it had declined to less than 3,000 individuals by 2001 (Marsh et al. 2003). Mueller (2005, 2006) reported the wild Lake Mohave razorback sucker population to be near 500 individuals, while the most recent 2011 estimate of Lake Mohave razorback sucker, based on annual razorback sucker round-up data, determined there are approximately 13 wild fish remaining (Marsh and Associates 2011).

Adult razorback sucker are most evident in Lake Mohave from January–April when they congregate in shallow shoreline areas to spawn, and larvae can be numerous soon after hatching. However, the Lake Mohave population today is largely supported by periodic stocking of captive-reared fish (Marsh et al. 2003, Marsh et al. 2005). Predation by bass (*Micropterus* spp.), common carp (*Cyprinus carpio*), channel catfish (*Ictalurus punctatus*), sunfish (*Lepomis* spp.), and other nonnative species appears to be the principal reason for lack of razorback sucker recruitment (e.g., Minckley et al. 1991, Marsh et al. 2003, Carpenter and Mueller 2008, Schooley et al. 2008a).

The Lake Mead razorback sucker population appeared to follow the trend of populations in other Lower Colorado River Basin reservoirs. Lake Mead was formed in 1935 when Hoover Dam was closed, and razorback sucker were relatively common in the lake throughout the 1950s and 1960s, apparently from reproduction soon after the lake was formed. Lake Mead razorback sucker numbers became noticeably reduced in the 1970s, approximately 40 years after closure of the dam (Minckley 1973, McCall 1980, Minckley et al. 1991, Holden 1994, Sjoberg 1995). From 1980 through 1989, neither the Nevada Department of Wildlife (NDOW) nor Arizona Game and Fish Department (AGFD) collected razorback sucker from Lake Mead (Sjoberg 1995). This may have been partially due to changes in the agencies' lake sampling programs; however, there was a considerable decline from the more than 30 razorback suckers collected during sport fish surveys in the 1970s. These results are not surprising and fit well within the pattern of razorback sucker population declines approximately 40–50 years following reservoir development, as was seen in other Lower Colorado River Basin reservoirs.

After receiving reports in 1990 from local anglers that razorback sucker were still found in Lake Mead in two areas (Las Vegas Bay and Echo Bay), NDOW initiated limited sampling. From 1990–1996, 61 razorback sucker were collected, 34 from the Blackbird Point area of Las Vegas Bay and 27 from Echo Bay in the Overton Arm (Holden et al. 1997). Two razorback suckers larvae were collected near Blackbird Point by an NDOW biologist in 1995, confirming suspected spawning in the area. In addition to the captures of these wild fish, NDOW also stocked a limited number of subadult (sexually immature individuals less than 450 mm total length [TL], as defined in the Methods of this document) razorback sucker into Lake Mead. Twenty-six razorback suckers were stocked into Las Vegas Bay in 1994, and 14 were stocked into Echo Bay in 1995. All of these stocked fish were implanted with passive integrated transponder (PIT) tags, and all originated from the Dexter National Fish Hatchery 1984 year-class that was reared at Floyd Lamb Park at Tule Springs (Floyd Lamb Park) in Nevada. Collection of razorback sucker in the 1990s raised many questions about Lake Mead razorback sucker: How large is the population? Are the Las Vegas Bay and Echo Bay groups separate populations? Does razorback sucker recruitment occur in the lake? How old are the fish in Lake Mead, and are the Las Vegas Bay and Echo Bay groups different in age structure? In 1996, the Southern Nevada Water Authority (SNWA) in cooperation with NDOW initiated a study to attempt to answer some of these questions. BIO-WEST, Inc. (BIO-WEST) was contracted to design and conduct the study with collaboration from SNWA and NDOW. Other cooperating agencies included the Bureau of Reclamation (Reclamation), which provided funding, storage facilities, and technical support; the National Park Service (Park Service), which provided residence facilities in their campgrounds; the Colorado River Commission of Nevada; and the U.S. Fish and Wildlife Service (USFWS).

At the start of the project in October 1996, the primary objectives were to:

- determine the population size of razorback sucker in Lake Mead,
- determine habitat use and life history characteristics of the Lake Mead population, and
- determine use and habitat of known spawning sites.

In 1998, Reclamation agreed to contribute additional financial support to the project to facilitate fulfillment of Provision #10 of the Reasonable and Prudent Alternative generated by the USFWS's Final Biological and Conference Opinion on Lower Colorado River Operations and Maintenance-Lake Mead to Southerly International Boundary (USFWS 1997). In July 1998, a cooperative agreement between Reclamation and SNWA was completed, specifying the areas to be studied and extending the study period into 2000.

Additional study objectives added to fulfill Reclamation's needs included the following:

- search for new razorback sucker population concentrations via larval light-trapping outside the two established study areas, and

- enhance the sampling efforts for juvenile razorback sucker at both established study sites.

If potential new populations were located by finding larval razorback sucker, trammel netting would be used to capture adults and sonic tagging would be used to determine the general range and habitat use of the newly discovered population. In 2002, Reclamation and SNWA completed another cooperative agreement to extend Reclamation funding into 2004. In 2005 a new objective of evaluating the lake for potential stocking options and locations was added to the project as a response to a growing number of larval fish that had been and were slated to eventually be repatriated to Lake Mead. Also in 2005, Reclamation became the primary funding agency and requested a monitoring protocol be established to ensure the success and continuity of the long-term, growing database maintained by BIO-WEST that stems from Lake Mead collections made during this more than decade-long course of studies. In response, BIO-WEST developed a monitoring protocol that helped raise data collection efficiency levels while maintaining the amount of information that would be gained studying various razorback sucker life phases during future monitoring and research efforts on Lake Mead (Albrecht et al. 2006a). In 2007, the project became primarily a monitoring study. In 2008 Reclamation and SNWA completed another cooperative agreement, extending monitoring efforts and following monitoring protocols developed by Albrecht et al. (2006a) through 2011.

This Annual Report presents the results of the 15th field season (February 2011–April 2011 monitoring data) and sonic-tagged razorback sucker data from July 2010–June 2011, in accordance with the results reported by Albrecht et al. (2008a), Kegerries et al. (2009), Albrecht et al. (2010c), and other past annual reports. Other information and data from previous years and reports are included, as applicable. This report presents data and findings from the long-term monitoring locations on Lake Mead, which include Echo Bay, Las Vegas Bay, and the Muddy River/Virgin River inflow area (the part of Lake Mead near Fish Island in the northernmost portions of the Overton Arm).

It should be noted that in 2010 and 2011 efforts were expanded to determine the presence or absence of razorback suckers in the Colorado River inflow area (CRI) using study methodologies developed during the past 15 years. Those efforts are not reported herein; they are reported in a stand-alone document that serves as a companion to this report. Readers interested in the CRI investigations are encouraged to obtain and read those documents (Albrecht et al. 2010b, Kegerries and Albrecht 2011).

SUMMARY OF EARLIER STUDY RESULTS, 1996–2010

Since the Lake Mead Razorback Sucker Study began in 1996, netting efforts have resulted in more than 807 razorback suckers captures and/or stocking events, represented by 506 individuals. Throughout the 15 years of study, PIT tags have proven valuable in assessing growth, movement patterns, and population size of the Lake Mead razorback sucker. Over 323 razorback suckers have been recaptured at least once, and through their recaptures, greater understanding of life history processes specific to Lake Mead has been attained. In 1997, four subadult razorback suckers were captured in Echo Bay, indicating that relatively recent, natural recruitment had occurred within the Lake Mead population. Seventeen additional wild subadult razorback suckers were captured in the Blackbird Point area of Las Vegas Bay through 2005. From 2006–2010, an additional 75 subadult razorback suckers were captured in Lake Mead, indicating continued, natural recruitment. Beginning in 1999, small sections of fin rays were removed from wild razorback sucker for age determination, and through 2010 a total of 287 razorback suckers have been aged (Albrecht et al. 2010c). Adult fish collected to date have ranged in age from approximately 3–36 years, and subadult fish have ranged in age from 2–6 years. We have hypothesized that lake-level fluctuations promote growth and the inundation of shoreline vegetation has been largely responsible for the initiation of recruitment observed in Lake Mead's razorback sucker population. The inundated vegetation likely serves as protective cover that, along with turbidity, allows young razorback sucker to avoid predation by nonnative fishes. Recent nonnative introductions, such as quagga mussels (*Dreissena rostriformis bugensis*) and gizzard shad (*Dorosoma cepedianum*), could also affect the razorback sucker population in Lake Mead, but the nature and severity of these new potential stressors remains unknown.

During the last decade, declining lake elevations in Lake Mead have affected razorback sucker at spawning sites such as Echo Bay. At Echo Bay from 1997–2001, aggregations of sonic-tagged adults, redd locations, and larval concentrations indicated that spawning was occurring at the westernmost extent of Echo Bay along the south shore. Specifically, it appeared that adult razorback sucker were spawning at the base of a 50 ft (15.24 m) tall cliff; at the end of the May 2001 spawning season, this site was dry. As lake levels further declined during the next several years and sites from previous years were left dry, the Echo Bay population continued to utilize new spawning sites down the Echo Bay Wash. At Las Vegas Bay during the first 9 years of this study, most razorback sucker larvae were captured along the western shore and at the tip of Blackbird Point. This seasonal return of individuals and annual reproductive activity suggested that Blackbird Point was an important spawning site. However, as lake levels dropped, depths off the western shore of Blackbird point changed dramatically. At higher lake elevations in the late 1990s, the spawning site was thought to be near a depth of 80 ft (24.39 m). By 2003, the spawning depth was closer to 20 ft (6.10 m), and by the end of 2004 the area was completely desiccated. As a result, spawning was not observed at the Blackbird Point spawning area during the 2003–2004 field season, and only four larval razorback suckers were captured during the entire season at Las Vegas Bay, a site that once harbored the largest razorback sucker population in Lake Mead. Though access to the Blackbird Point spawning area was again made possible in 2005, as Lake Mead elevations rose more than 20 ft (6.10 m) during the spawning period (January–April), subsequent years of declining lake levels effectively cut off razorback sucker individuals from this area. In response to lowered lake conditions in 2006 and 2007–2009, the spawning aggregate at Las Vegas Bay shifted spawning sites from Blackbird Point to the southwestern shoreline of Las Vegas Bay. As lake levels decreased further, spawning aggregates continued to retreat down the bay, much like those in the Echo Bay spawning area, where the local population adjusted spawning sites in accordance with lake elevation.

In 2003–2004, larval sampling was conducted at the Muddy River/Virgin River inflow areas and throughout the Overton Arm of Lake Mead. Despite having habitat characteristics similar to Echo and Las Vegas bays (in terms of turbidity, vegetation, and gravel shorelines), no larval razorback suckers were captured in the Overton Arm north of Echo Bay. However, after following movements of a single, sonic-tagged fish in 2005, adult and larval sampling was reinitiated at the Muddy River/Virgin River inflow area. The result was the documentation of spawning activities in this area of Lake Mead. Since 2006, razorback suckers have been documented spawning successfully near the Muddy River/Virgin River inflow area, and in the last several years this area has rivaled and surpassed subadult and adult captures in Las Vegas and Echo bays (Albrecht et al. 2010c).

During the first 6 years of the Lake Mead razorback sucker study, 42 wild fish were equipped with internal or external sonic tags. Approximately half of these tags, implanted in 1997 and 1998, had a 12-month battery life; the other half had a 48-month battery life. Sonic telemetry revealed a seasonal habitat-use pattern within the lake. At Las Vegas Bay, fish concentrated near Blackbird Point during the spawning period but moved farther out into the main portions of the bay during the nonspawning period (June–November), mainly in habitat on the north shore of Las Vegas Bay between Blackbird Point and Black Island. A similar pattern was seen at Echo Bay; fish left the Echo Bay spawning area and regularly used Rogers Bay and other points north of Echo Bay along the western shore of the Overton Arm. In January 2003 (7th field season), four razorback suckers (two in Echo Bay and two in Las Vegas Bay) were captured during standard trammel netting and implanted with 48-month sonic tags. Though the majority of these individuals were last contacted in 2003 (8th field season), one remaining fish from the 2003 sonic-tagging effort was contacted several times during the early part of the 2004–2005 field season, offering movement and habitat-use information for subsequent field seasons.

In 2004, a drastic decline in larval fish abundance was observed, spurring questions about where the Las Vegas Bay population was spawning, if at all. Welker and Holden (2004) proposed tagging six razorback suckers from Floyd Lamb Park as an experiment, hoping that these fish would integrate with the wild population in Las Vegas Bay and help identify new spawning areas. Hence, six fish from Floyd Lamb Park were tagged during the 2004–2005 field season, and sonic surveillance of these individuals produced interesting results. Though contact with the four fish introduced into Las Vegas Bay was lost within 1 month due to tag failure, the two fish introduced into Echo Bay appeared to integrate with the wild population and were followed throughout the 2004–2005 field season. Of the Echo Bay individuals, one spent the majority of the field season in the westernmost end of Echo Bay, while the other individual moved from Echo Bay to the Overton Arm of Lake Mead. To compensate for sonic-tag failure in 2004–2005, an additional 10 sonic-tagged fish were stocked into Lake Mead in 2005. Similarly, one of the 2005 individuals stocked into Echo Bay moved from Echo Bay to the Overton Arm and then to Las Vegas Bay (Albrecht et al. 2006b, 2007, and 2008a). As sonic tags from the 2005 event were approaching their longevity threshold, the decision was made to tag and release 12 additional fish from Floyd Lamb Park (four at each study area) in Lake Mead in December 2008. This group of fish has provided extensive movement and habitat-use data, which continues to date; five individuals were contacted in 2010 and two individuals are still being contacted in 2011. This report contains movement information for two of the fish tagged in 2008.

Overall, the sonic-telemetry data collected during this study have provided valuable information on razorback sucker spawning, movement patterns, and shifts in habitat use and spawning-site selection. These data have also demonstrated that tracking hatchery-reared, sonic-tagged razorback suckers can be highly effective in locating new spawning areas and monitoring known spawning sites used by wild razorback sucker populations. Hence, monitoring sonic-tagged fish can increase the efficiency of field efforts.

STUDY AREAS

All 2011 Lake Mead study activities occurred at the locations used during the 1996–2010 portions of the study (Holden et al. 1997, 1999, 2000a, 2000b, 2001, Abate et al. 2002, Welker and Holden 2003, 2004, Albrecht and Holden 2005, Albrecht et al. 2006a, 2006b, 2007, 2008a, 2008b, 2010a, 2010c, Kegerries et al. 2009). The two most frequently sampled areas were Echo Bay and Las Vegas Bay (Figure 1). Razorback sucker activity was also monitored at the Muddy River/Virgin River inflow area (Figure 1).

Most areas of the lake, including the Overton Arm, Boulder Basin, and Virgin Basin, were searched using ultrasonic-telemetry equipment. Larval sampling and trammel netting were performed in Echo Bay, Las Vegas Bay, and the Muddy River/Virgin River inflow area.

Specific definitions for the various portions of the Las Vegas Bay and Las Vegas Wash in which the study was conducted were given in Holden et al. (2000b). The following definitions are still accurate for various portions of the wash:

- Las Vegas Wash is the portion of the channel with stream-like characteristics. In recent years this section has become a broad, shallow area that is generally inaccessible by boat.

- Las Vegas Bay begins where the flooded portion of the channel widens and the current velocity is reduced. Las Vegas Bay can have a flowing (lotic) and nonflowing (lentic) portion. The flowing portion is typically short (200–400 yards [183–366 m]) and transitory between Las Vegas Wash proper and Las Vegas Bay. Because lake elevation affects what is called the wash or bay, the above definitions are used to differentiate the various habitats at the time of sampling.

Throughout this report three portions of Las Vegas Bay may be referred to using the following terms:

- flowing portion (the area closest to, or within, Las Vegas Wash);

- nonflowing portion (usually has turbid water but very little, if any, current); and

- Las Vegas Bay (the majority of the bay that is not immediately influenced by Las Vegas Wash and is lentic in nature).

Additionally, the location of wild adult and larval razorback suckers in the northern portion of the Overton Arm necessitates a description of these areas. These location definitions follow those provided in Albrecht and Holden (2005):

- Muddy River/Virgin River inflow area (the lentic and littoral habitats located around the Muddy River confluence and Virgin River confluence with Lake Mead at the upper end of the Overton Arm);

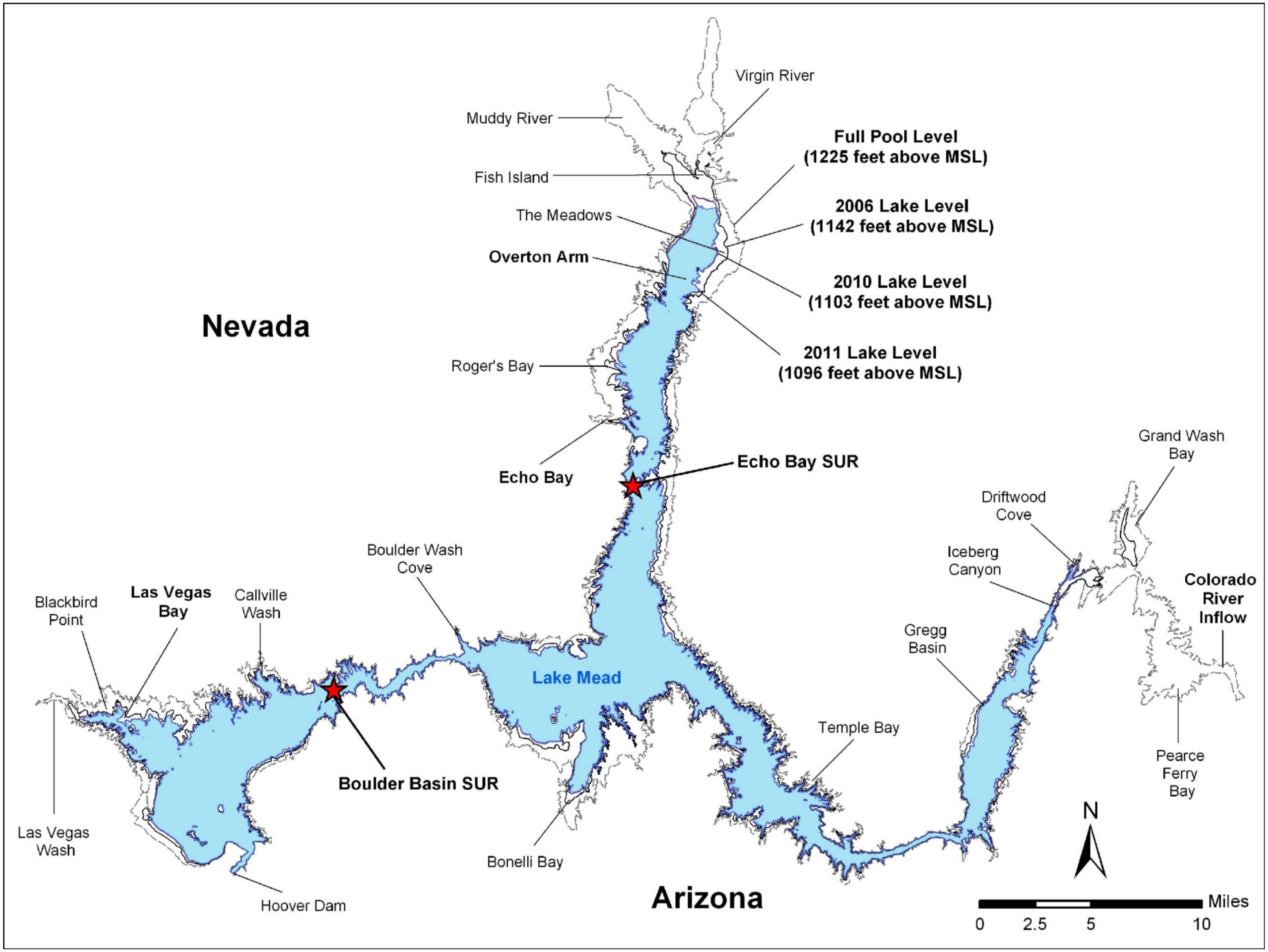

Figure 1. **Lake Mead general study areas. Locations of long-term monitoring submersible ultrasonic receivers (SUR) are denoted by red stars.**

- Fish Island (located between the Muddy River and Virgin River inflows, bounded on the west by the Muddy River inflow and on the east by the Virgin River inflow; depending on lake elevation, this area may or may not be an actual island); and

- Muddy River and Virgin River proper (the actual flowing, riverine portions that comprise the Muddy and Virgin rivers, respectively).

METHODS

Lake Elevation

Month-end lake elevations for the 2011 field season (July 1, 2010–June 30, 2011) were measured in feet above sea level (ASL) and obtained from Bureau of Reclamation's Lower Colorado Regional Office website (USBR 2011). The effect of fluctuating lake levels on razorback sucker habitat was also documented by written observations and photographs during sampling trips to the study sites.

Sonic Telemetry

Sonic Tagging

Eight razorback suckers held in ponds at Floyd Lamb Park were captured using trammel nets on the morning of January 3, 2011. The NDOW provided assistance in obtaining access to Floyd Lamb Park and helped with sampling of Mulberry Pond for razorback suckers. Four male and four female razorback suckers were implanted with Sonotronics Model CT-05-48-I (48-month) tags. The 48-month tags used in 2011 had a water weight of 12 g and measured 79 mm long by 15.6 mm in diameter. The tags used frequencies of 70, 72, 73, 74, 76, and 77 kHz. Because each tag had a unique code, individual fish could be readily distinguished. The NDOW provided hauling equipment to transport the razorback suckers from Floyd Lamb Park to Echo Bay and Las Vegas Bay.

The following surgical protocol was established from procedures developed by Valdez and Nilson (1982), Kaeding et al. (1990) and Valdez and Trinca (1995) for humpback chub; Tyus (1982) for Colorado squawfish (pikeminnow); and Valdez and Masslich (1989) for Colorado squawfish (pikeminnow) and razorback sucker. A transmitter air weight to fish weight of 2% (Bidgood 1980, Marty and Summerfelt 1990) was used as a guideline to ensure the tags were not too large for the fish being tagged. Surgery was performed on shore and involved one surgeon and two assistants. The assistants recorded data, captured pertinent photographs, and monitored fish respiration. Dr. Chris Bunt of BIOTACTIC, Inc., assisted with the surgeries, demonstrated current surgical practices, and provided instruction on updated tagging methodologies to the field biologists. Prior to surgery each fish was placed in a live well containing fresh pond water. All surgical instruments were cold sterilized with iodine and 90% isopropyl alcohol and allowed to air dry on a disposable sterile cloth. Razorback suckers were initially anaesthetized in 30 L of lake water with a 50 mL/L^{-1} clove oil/ethanol mixture (0.5 mL clove oil [Anderson et al. 1997] emulsified in 4.5 mL ethanol) (Bunt et al. 1999). After anesthesia was induced, TL, fork length, standard length, and weight were recorded. Fish were then placed dorsal-side down on a padded surgical cradle for support during surgery. Head and gills were submerged in 20 L of fresh pond water with a maintenance concentration of 25 mL/L^{-1} clove oil/ethanol anesthetic (Bunt et al. 1999). Following fish introduction to the maintenance anesthetic, the surgeon made a 2–3 cm incision on the left side, posterior to the left pelvic girdle. A PIT tag was inserted into the incision followed by the transmitter, which was pushed between the pelvic girdle and urogenital pore. The incision was closed with two to four 3-0 Maxon absorbable poliglecaprone 25 monofilament sutures using an attached PS-1 reverse-cutting, curved needle. Surgery times typically ranged from 2–5 minutes per fish.

Once surgical implantation was complete, fish were allowed to recover in a floating net pen in Floyd Lamb Park prior to transport to Lake Mead. Upon arrival at Echo Bay, four (2 male and 2 female) fish were hauled via boat to the Muddy River/Virgin River inflow area for release near the 2010 primary spawning area. The remaining four (2 male and 2 female) sonic-tagged fish were transported via boat to Las Vegas Bay and released into a quiet cove on the north side of the bay near the wash/lake interface. Prior to release on January 3, 2011, all fish were reexamined for signs of stress. Tracking ensued immediately after release and continued intensively for 48 hours; detailed tracking continued for several weeks following surgery.

Active Sonic Telemetry and Tracking

During the intensive field season associated with the spawning period (January–May), sonic-tagged fish were located weekly (or sometimes daily), depending on the field schedule and weekly project goals. During the remainder of the year, sonic-tagged fish were typically located monthly. Fish searches were largely conducted along shorelines with listening points spaced approximately 0.5 mi (0.8 km) apart, depending on shoreline configuration and other factors that could impact signal reception. Sonic equipment is line-of-sight and any obstruction can reduce or block a signal; also, the effectiveness of a sonic-telemetry signal is often reduced in shallow, turbid environments. Active tracking consisted of listening underwater for coded sonic tags using a Sonotronics USR-08 or earlier model of ultrasonic receiver and DH4 hydrophone. The hydrophone was lowered into the water and rotated 360 degrees to detect sonic-tagged fish presence. Once detected, the position of the sonic-tagged fish was pinpointed by moving in the direction of the fish until the signal was heard in all directions with the same intensity. Once pinpointed, the fish's tag number, GPS location, and depth were recorded. In all cases when sonic-tagged fish were located within shallow habitats or within inflow riverine portions of Lake Mead (e.g., Las Vegas Wash, Virgin River inflow), individual fish locations were recorded at the closest point accessible by boat.

Passive Sonic Telemetry and Submersible Ultrasonic Receiver Data Collection

Along with the active tracking methods, submersible ultrasonic receivers (SUR) were deployed in various locations throughout Lake Mead during the end of the field season. The advantage to using SURs is their ability to record continuous telemetry data without field crews being present. With an approximate 9-month battery life and the ability to passively detect transmitters, SURs save valuable field time while collecting additional telemetry data. Most importantly, they allow us to gain an understanding of large-scale razorback sucker movements during the summer.

Each SUR was programmed to detect implanted, active sonic-tag frequencies using Sonotronic's SURsoft software. The semibuoyant SURs were then suspended from an anchor (rock, anchor, block) using approximately 18 in of rope. A lead of vinyl-coated cable was secured to the anchor as the SUR was deployed. The cable was allowed to sink to the lake bottom, secured on shore, and concealed. The SURs were downloaded frequently by pulling them up into the boat and downloading the data via Sonotronic's SURsoft software. The data were processed through Sonotronic's SURsoftDPC software to ascertain the time, date, and frequency of positive sonic-tagged fish detections within 2 millisecond-interval units (e.g., a range of 898–902 for a 900-interval tag).

In exploring additional methods of razorback sucker detection, a remote PIT-tag reader was employed at Lake Mead in 2011. The reader, similar to those used on Lake Mohave (Marsh and Associates 2010, 2011), was deployed in Echo Bay in a trial application to assess its feasibility and effectiveness in Lake Mead. Due to the preliminary nature of data retrieved from the remote reader, only anecdotal results are presented in this report.

Adult Sampling

Trammel Netting

The primary gear used to sample adult fish were 300 ft (274.4 m) long by 6 ft (1.8 m) deep trammel nets with an internal panel of 1 in (2.54 cm) mesh and external panels of 12 in (30.48 cm) mesh. Nets were generally set with one end near shore in 5–30 ft (3.05–9.15 m) of water, with the net stretched out into deeper areas. All trammel nets were set in late afternoon (just before sundown) and pulled the next morning (shortly after sunrise), with a single net comprising one net-night. Netting locations were selected based on the locations of sonic-tagged fish, the location or presence of concentrated larval fish, and knowledge of previous adult razorback sucker capture locations.

Fish were removed from nets, and live fish were held in 100-quart (94.6 L) coolers filled with lake water. Razorback suckers and flannelmouth suckers (*Catostomus latipinnis*) were isolated from other fish species and held in aerated live wells. All but the first five common carp and first five gizzard shad were enumerated and returned to the lake, while other species (including five common carp and five gizzard shad) were identified, measured for TL, weighed, and released at the capture location. Razorback suckers, flannelmouth suckers, or suspected razorback sucker x flannelmouth sucker hybrids were scanned for PIT tags, PIT tagged if they were not recaptured fish, measured (TL, standard length, and fork length), weighed, and assessed for sexual maturity and reproductive readiness. Individuals less than 450 mm TL that were not sexually defined and did not exhibit sexual maturity (e.g., lack of nuptial tubercles, lack of color, lack of ripeness) were labeled as subadult. Individuals less than 450 mm TL that were sexually defined were labeled as their respective sex. Native sucker species selected for age determination were anesthetized with MS-222 and placed dorsal-side down on a padded surgical cradle for support while a segment of the second pectoral fin ray was collected. As requested by the Lake Mead Interagency Work Group, genetic material was also removed from some of the razorback suckers; a small bit of material was obtained from the caudle fin, preserved in 95% ethanol, and delivered to Reclamation biologists. After all necessary information was collected, fish were released at the point of capture.

Growth

Razorback sucker annual growth information was gathered from recaptured individuals in trammel netting collections. Recaptured individuals were not used if they had been captured more than once during the 2011 field season or if less than 1 year (365 days) had passed between the date of their original capture or stocking and their last date of capture. These individuals were excluded from the data set and analyses to account for discrepancies in environmental conditions (e.g., a hatchery individual stocked into a wild environment) and to allow for the yearly cycles of gonadal and somatic growth. Annual growth for razorback suckers was calculated for each individual using the difference in TL (mm) between capture periods. If the data were available, mean annual growth was calculated separately for stocked and wild individuals; fish recaptured from Las Vegas Bay, Echo Bay, and the Muddy River/Virgin River inflow area; and razorback suckers from Lake Mead as a whole.

Larval Sampling

Our larval-sampling methods followed those developed by Burke (1995) and other researchers on Lake Mohave. The procedure uses the positive phototactic response of larval razorback suckers to capture them. After sundown, two to four 12-volt "crappie" lights were connected to a battery, placed over each side of the boat, and submerged in 4–10 in (10.2–25.4 cm) of water. Two to four netters equipped with long-handled aquarium dip nets were stationed to observe the area around the lights. Larval razorback suckers that swam into the lighted area were dip-netted out of the water and placed into a holding bucket. The procedure was repeated for 15 minutes at each location, and 4–12 sites were customarily sampled on each night attempted. Larvae were identified and enumerated as they were placed in the holding bucket and then released at the point of capture when sampling at a site was completed.

Spawning Site Identification and Observations

We have found that multiple methods are needed to identify and pinpoint annual spawning sites in Lake Mead. The basic, most effective spawning-site identification procedure has been to track sonic-tagged fish and identify the most frequented areas. Once a location is identified as being heavily used by sonic-tagged fish, particularly during crepuscular hours, trammel nets are typically set in the area in an effort to capture adult razorback suckers. Captured fish are then evaluated for signs of ripeness indicative of spawning. After the initial identification of a possible spawning site through sonic-tagged razorback sucker habitat use and other, untagged subadult or adult trammel-net captures, larval sampling is conducted to validate whether successful spawning occurred. Examples of the effectiveness of these techniques are evident in the descriptions provided by Albrecht and Holden (2005) regarding the documentation of a new spawning aggregate near Fish Island in the Overton Arm of Lake Mead. This same general approach was also used at the long-term monitoring locations in 2011.

Age Determination

For age determinations, we used a nonlethal technique employing fin ray sections developed in 1999 (Holden et al. 2000a). As in past years, an emphasis in our 2011 long-term monitoring efforts involved collecting fin ray sections from razorback suckers for aging purposes. A sample was also obtained from a single flannelmouth sucker for age determination.

During the 2011 monitoring period, selected suckers captured via trammel netting were anesthetized and a single (approximately 0.25 in long) segment of the second left pectoral fin ray was surgically removed. Fish were anesthetized with a lake-water bath containing MS-222, NaCl, and slime-coat protectant to reduce surgery-related stresses, speed recovery, and avoid accidental injury to fish that may thrash during surgical procedures. During the surgery standard processing was conducted (i.e., weighing, measuring, PIT-tagging, photographing), and a sample was surgically collected using custom-made bone snips originally developed by BIO-WEST. This surgical tool consists of a matched pair of finely sharpened chisels welded to a set of wire-stripping pliers. The connecting membrane between rays was cut using a scalpel blade, and the section was placed in a labeled envelope for drying. All surgical equipment was sterilized before use, and subsequent wounds were packed with antibiotic ointment to minimize post-surgical bacterial infections and promote rapid healing. All native suckers undergoing fin ray extraction techniques were immediately placed in a recovery bath of fresh lake water containing slime-coat protectant and NaCl, allowed to recover, and released as soon as they regained equilibrium and appeared recovered from the anesthesia. Vigilant monitoring was conducted during all phases of the procedure.

In the laboratory fin ray segments were embedded in thermoplastic epoxy resin and heat cured. This technique allowed the fin rays to be perpendicularly sectioned using a Buhler isomet low-speed saw. Resultant sections were then mounted on microscope slides, sanded, polished, and examined under a stereo-zoom microscope. Each sectioned fin ray was aged independently by at least two readers. Sections were then reviewed by the readers in instances where the assigned age was not agreed upon. If age discrepancies remained after the second reading, a third reader viewed the structure and all three readers collectively assigned an age. For further information regarding the development of our fin ray aging technique, please refer to Albrecht and Holden (2005), Albrecht et al. (2006b), Albrecht et al. (2008a), and other annual Lake Mead razorback sucker reports.

Population Estimates

Netting data collected by BIO-WEST from 2009–2011 were used to calculate abundance estimates for razorback sucker populations in Lake Mead. Two models from the program CAPTURE (Rexstad and Burnham 1992) and estimates from the model-selection procedure were used for this analysis. Additionally, in 2011 the program MARK (Cooch and White 2010) was used to verify estimates obtained using the program CAPTURE. Stocked fish were not used in the population estimates unless they had survived at least 1 year in Lake Mead. It was assumed that an adult stocked fish that had survived 1 year in the wild was able to reproduce and contribute progeny to the population (Albrecht and Holden 2005, Modde et al. 2005). Similar methods used to run CAPTURE were also used to run MARK, and the same population estimators were selected for comparison purposes between the two programs.

The two abundance estimators used were Chao's M_h (Chao 1989) and Model M_o (Otis et al. 1978). The Model M_o typically produces the most reliable estimates for endangered western fishes (R. Ryel 2001, pers. comm.), but it assumes equal catchability of individuals. Chao's M_h is a good estimator for sparse data, but unlike Model M_o it assumes heterogeneity of capture probabilities. If the estimators gave very different numbers, a reliable estimate was believed to lie somewhere between the two numbers. However, as shown in past reports, close agreement between the models indicated a fairly reliable estimate.

Population estimates were calculated for three locations within Lake Mead. A lake-wide estimate consisting of razorback sucker netting data from all sites sampled throughout Lake Mead in 2011 is provided in the results section. In an effort to be more fully representative of the entire lake, this estimate also includes razorback sucker capture data from the CRI obtained this year (Albrecht et al. 2010b, Kegerries and Albrecht 2011). Furthermore, the long-term monitoring sites were analyzed as two unique populations: Las Vegas Bay and the combination of Echo Bay and the Muddy River/Virgin River inflow area. Results from the various models are presented in this report.

As indicated in Albrecht et al. (2006b), we had planned to forego reporting population estimates for Lake Mead razorback sucker because of the nature of the data collected and the violation of many of the assumptions critical to closed-model population estimation techniques. However, we decided to include population estimates in this report simply to compare them to past results. Basing any management decisions solely on the population estimates provided in this document is strongly discouraged due to the violation of many of the model assumptions, more fully described by Albrecht et al. (2006b).

RESULTS

Lake Elevation

In contrast to the lake elevation trends seen in the past decade, including 2010 (14th field season), lake elevations during 2011 (15th field season) increased overall (Figure 2). From a starting elevation in January 2011 of approximately 1,092 ft (332.8 m) ASL, lake elevations increased in February, leveled slightly at the end of March at 1,096 ft (334.1 m) ASL, and peaked through June at 1,102 ft (335.9 m) ASL. Lake elevations increased nearly 4 ft (1.2 m) throughout the spawning period, creating new habitat for razorback suckers (Figure 2). We observed the wetting of littoral areas and the inundation of expanses of terrestrial vegetation within Las Vegas Bay. Similar observations were made at the Muddy River/Virgin River inflow and at Echo Bay, where areas too shallow to be effectively sampled were made deep enough for access during the latter part of the spawning period.

Causes for lake elevation increases in 2011 include the high-flow event in the Virgin River in December 2010 and an above-average snowmelt runoff in spring 2011 throughout the Upper Colorado River Basin (Figure 3). Inflow into Lake Mead is mainly derived from the Colorado

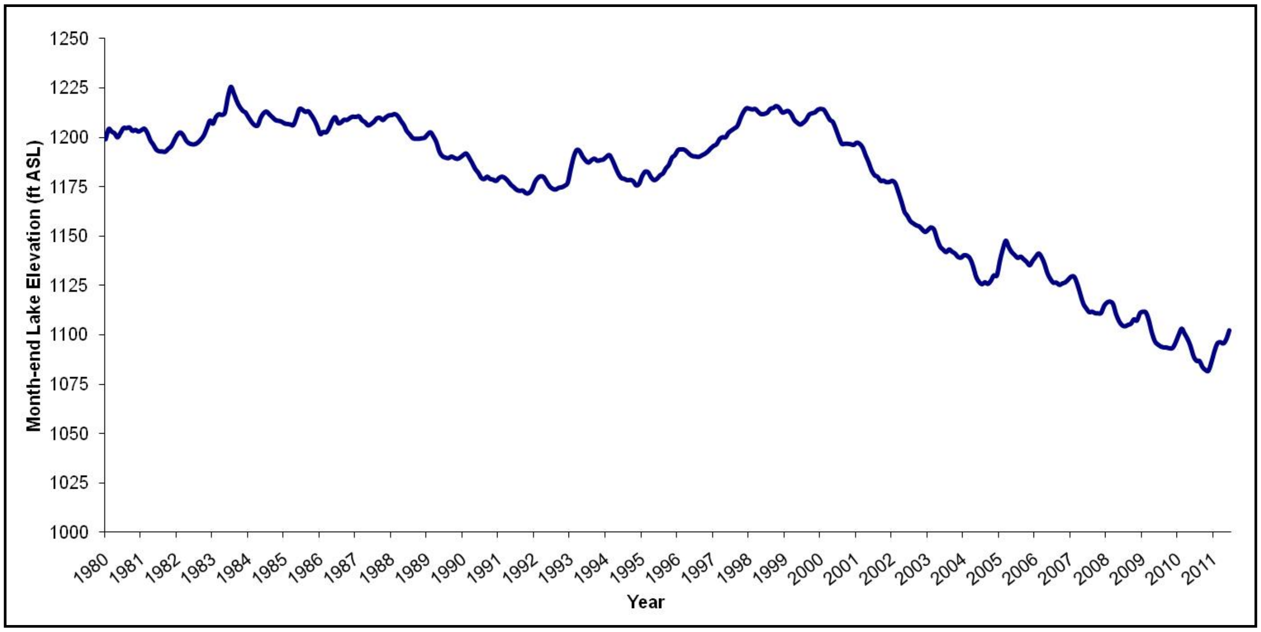

Figure 2. Lake Mead month-end lake elevations in ft above sea level (ASL), January 1980–June 2011.

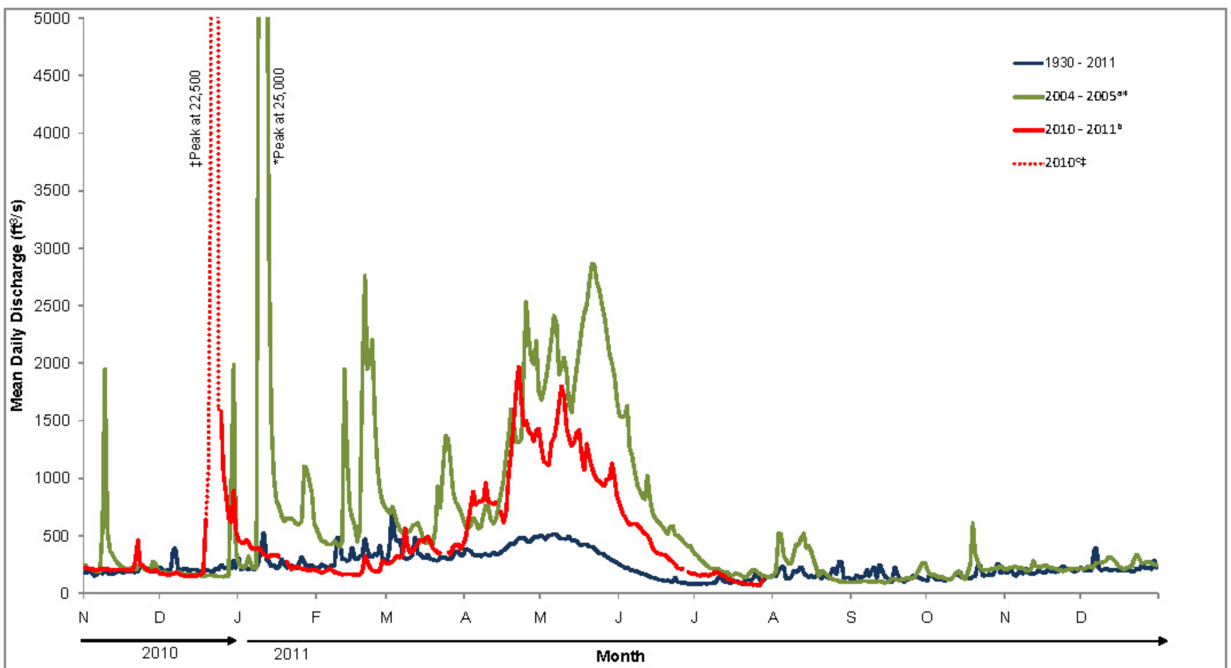

Figure 3. Mean daily discharges (ft^3/s [cubic ft per second]) for the Virgin River at Littlefield, Arizona (USGS gauge 09415000), for 1930–2011, 2004–2005, and 2010–2011.

[a] Peak discharge outside of displayed range.

[b] Provisional data subject to USGS revision.

[c] Peak value from recent maximum discharge on 12/23/2010, values from 12/20/2010–12/24/2010 estimated from provisional instantaneous data subject to USGS revision.

River (98%) while the remainder comes from the Muddy River/Virgin River inflow and Las Vegas Wash (Baker and Paulson 1980). Provisional discharge peaks in the Virgin River rose to 22,500 cubic ft per second (cfs) near Littlefield, AZ (USGS gauge 09413700), with a maximum daily mean of 6,120 cfs at Lake Mead near Overton, NV (USGS gauge 09415250), in late December 2010. The timing and magnitude of these conditions were similar to those seen in 2004–2005 on the Virgin River (Figure 3), a notable year for razorback sucker recruitment. These high-flow events help transport large amounts of nutrients and woody debris into the Muddy River/Virgin River inflow area and subsequently into the Overton Arm of Lake Mead, possibly increasing available habitat and refugia for adults, subadults, and larvae. Turbidity can also increase spatially in the Muddy River/Virgin River inflow area during these high flows, providing cover for razorback suckers. Additionally, the distribution of such cover can often be increased by the common disturbance of high winds at Lake Mead.

Sonic Telemetry

Active Sonic Telemetry and Tracking

Over the course of this study (1997–2011), 82 fish (38 wild and 44 hatchery-reared) have been equipped with sonic tags for the purpose of long-term monitoring and research at Las Vegas Bay, Echo Bay, and the Muddy River/Virgin River inflow area. During the 2010–2011 field season, contact was made with 13 sonic-tagged fish; five of these fish were from the 2008 tagging event in which 12 fish were sonic tagged, and the other eight fish were from the January 2011 tagging and stocking effort (Table 1).

Because sonic-tagged razorback suckers were often located in areas of Lake Mead inaccessible by boat (e.g., shallow peripheral habitats, flowing portions of inflow areas), the figures below may not fully display the range of sonic-tagged fish movements into all habitat features. Additionally, as fish moved into shallower habitat their tag signals became harder to hear. Throughout the year, large expanses of very shallow habitat, specifically in Las Vegas Bay and the Muddy River/Virgin River inflow area, formed as the lake level increased, inundating new habitat and submerging terrestrial vegetation.

The following narrative describes observations of habitat use made in 2010–2011 for the remaining razorback suckers with active sonic tags that were implanted during the December 2008 and the January 2011 sonic-tagging events. Table 1 shows the origin, tagging, and current-status information of all sonic-tagged fish from these two events. Sonic-telemetry data from July 2010–June 2011 are presented in an effort to remain consistent with data reporting procedures for this project.

Table 1. Lake Mead razorback sucker tagging and stocking information, location and date of last contact, and status of sonic-tagged fish gathered during July 2010–June 2011 monitoring.

CAPTURE LOCATION[a]	DATE TAGGED	TAG CODE	TOTAL LENGTH (mm)	SEX[b]	STOCKING LOCATION[a]	LAST LOCATION[a]	DATE OF LAST LOCATION	CONTACTS MADE 2010–2011	CURRENT TAG STATUS
					2008				
FDLB	12/2/2008	365	496	M	EB	EB	11/9/2010	17	Active
FDLB	12/2/2008	678	492	M	EB	EB	5/24/2011	23	Active
FDLB	12/2/2008	3,386	193	F	EB	OA	2/3/2009	0	Unknown
FDLB	12/2/2008	376	198	M	EB	EB	8/25/2010	13	Active
FDLB	12/2/2008	345	515	M	OA	OA	12/7/2008	0	Unknown
FDLB	12/2/2008	366	479	M	OA	OA	3/10/2009	0	Unknown
FDLB	12/2/2008	488	534	F	OA	OA	6/23/2009	0	Tag Expired
FDLB	12/2/2008	3,354	506	F	OA	OA	4/26/2011	26	Active
FDLB	12/3/2008	3,355	483	M	LB	LB	8/18/2009	0	Tag Expired
FDLB	12/3/2008	377	479	M	LB	LB	6/23/2009	0	Unknown
FDLB	12/3/2008	465	520	F	LB	CRI	5/26/2010	0	Unknown
FDLB	12/3/2008	677	529	F	LB	LB	10/14/2010	14	Active
					2011				
FDLB	1/4/2011	334	564	F	LB	LB	6/20/2011	12	Active
FDLB	1/4/2011	3,545	556	F	LB	LB	6/20/2011	9	Active
FDLB	1/4/2011	3,584	519	M	LB	LB	6/20/2011	8	Active
FDLB	1/4/2011	3,775	516	M	LB	LB	6/20/2011	9	Active
FDLB	1/4/2011	448	502	M	OA	LB	6/23/2011	6	Active
FDLB	1/4/2011	555	504	M	OA	LB	6/22/2011	19	Active
FDLB	1/4/2011	3,578	541	F	OA	OA	5/24/2011	13	Active
FDLB	1/4/2011	3,667	552	F	OA	OA	4/11/2011	11	Active

[a] FDLB = Floyd Lamb Park, EB = Echo Bay, OA = Overton Arm (Muddy River/Virgin River inflow area), LB = Las Vegas Bay, CRI = Colorado River inflow area.

[b] F = female, M = male.

Fish Sonic Tagged in 2008

Twelve sonic-tagged fish were stocked in Lake Mead in December 2008, four at each of the three primary spawning sites (Las Vegas Bay, Echo Bay, and the Muddy River/Virgin River inflow area). During the 2010–2011 field season, 34 contacts (including two contacts made on SURs) were made with five of these fish, spanning much of Lake Mead (Table 1, Figures 4, 5, and 6). Many contacts of 2008 fish occurred from February–April 2011 as razorback suckers were spawning in Lake Mead; however, an almost equal number of contacts occurred outside the more rigorous sampling period as individuals moved throughout the lake in summer and fall. As stated in past reports (e.g., Kegerries et al. 2009), sonic-tagged fish have become a valuable tool for identifying spawning sites and learning about habitat use in Las Vegas and Echo bays; in

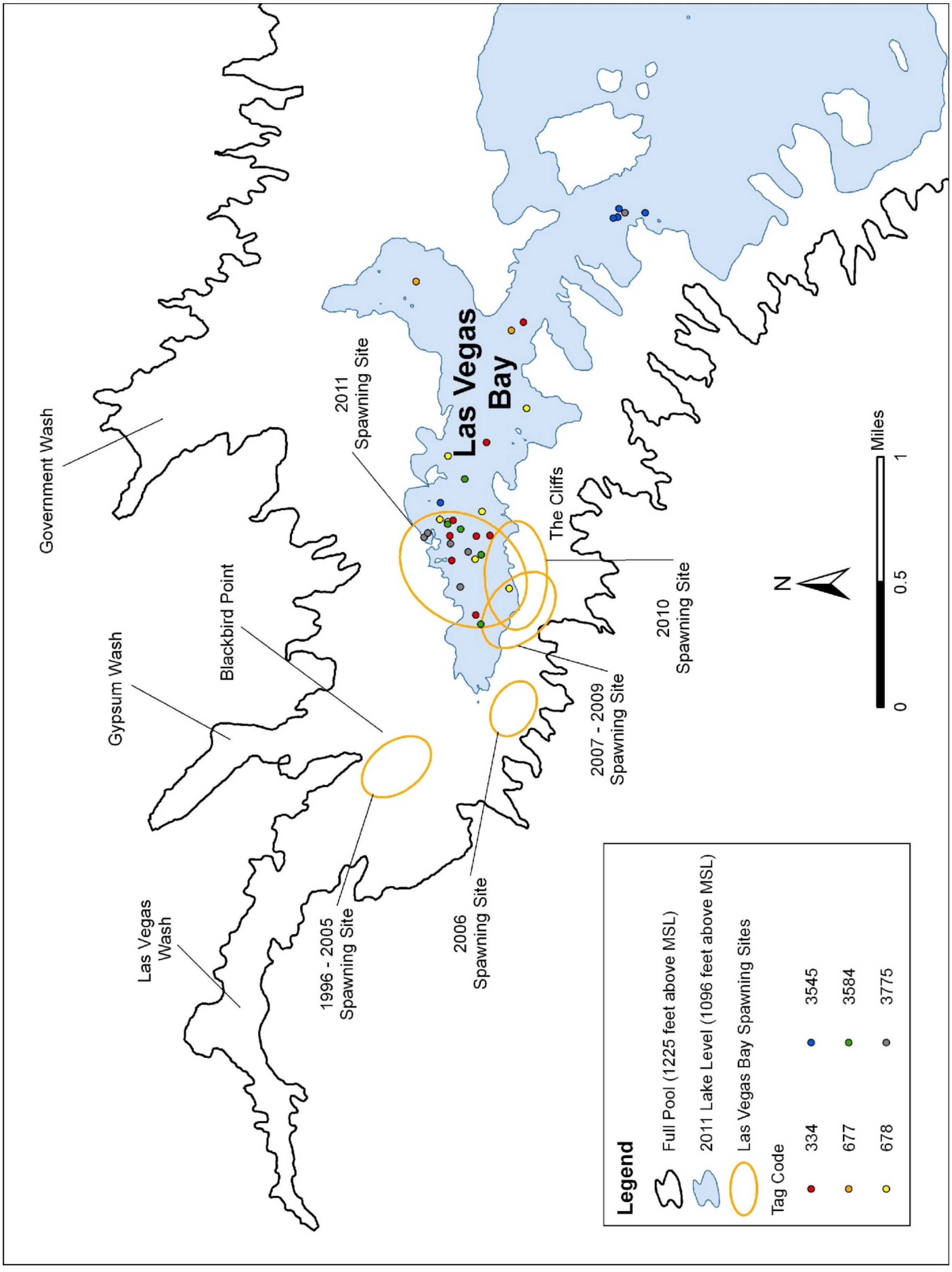

Figure 4. **Distribution of sonic-tagged fish located in Las Vegas Bay during the July 2010–June 2011 Lake Mead field season.**

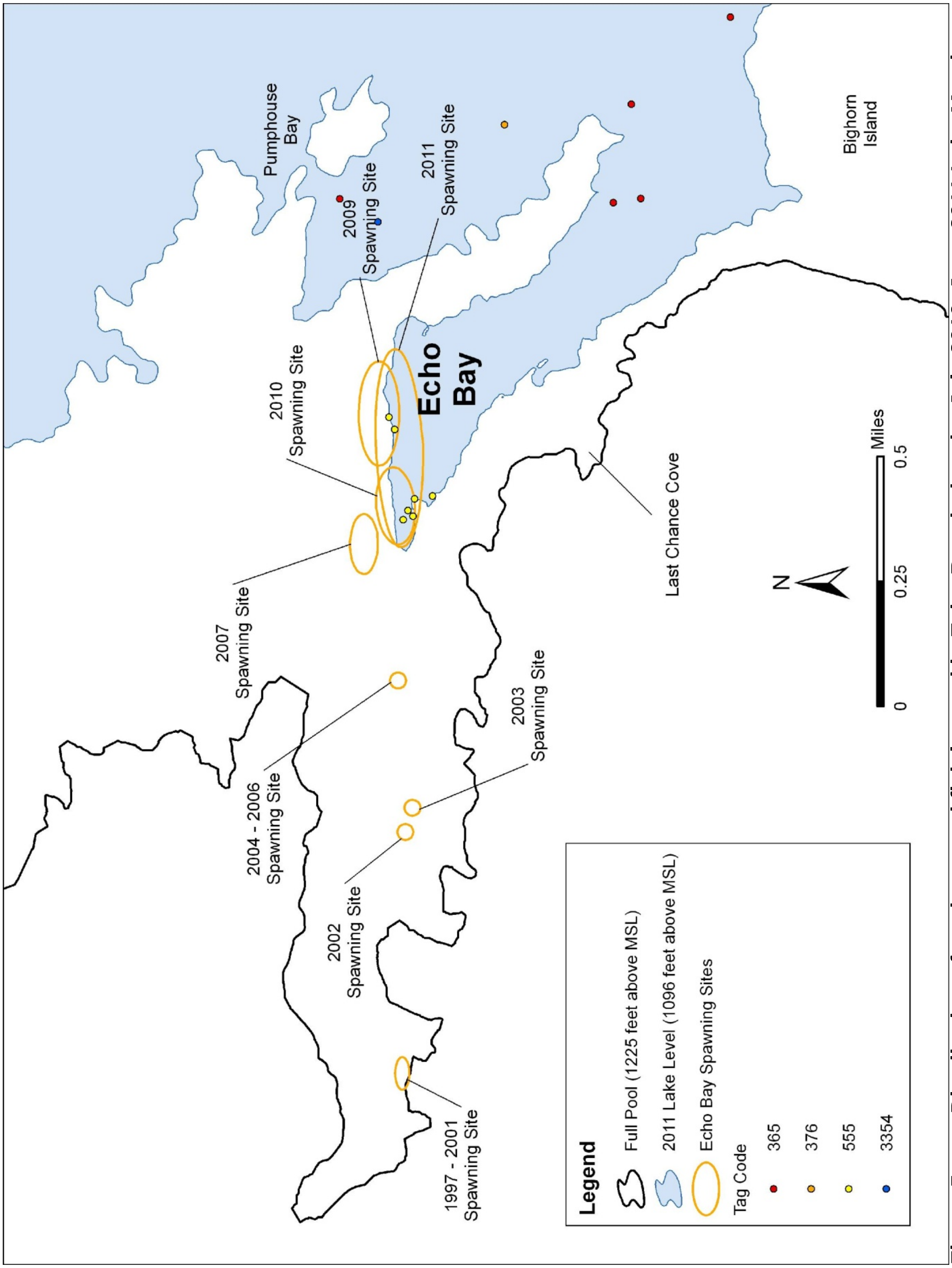

Figure 5. Distribution of sonic-tagged fish located in Echo Bay during the July 2010–June 2011 Lake Mead field season.

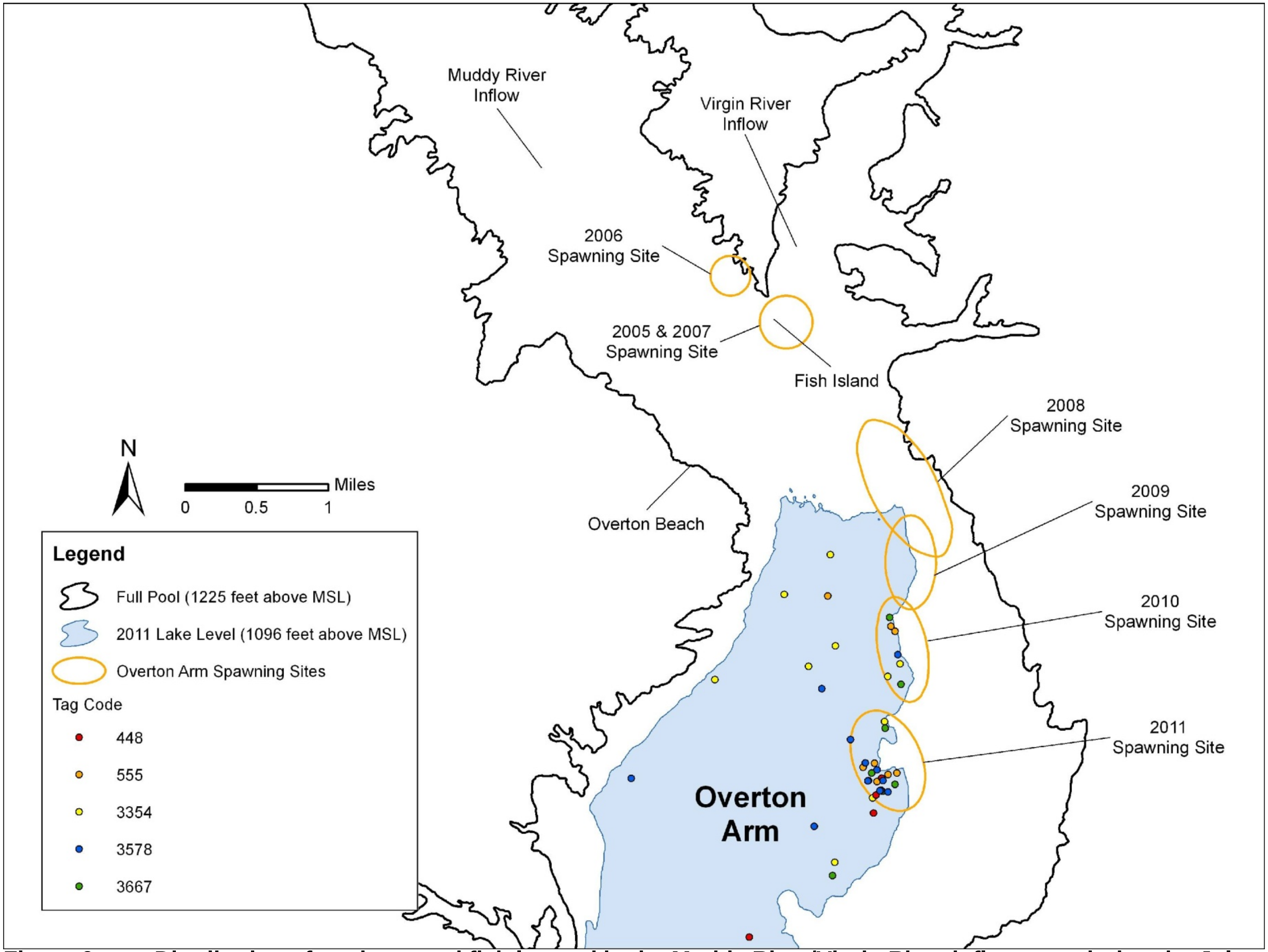

Figure 6. **Distribution of sonic-tagged fish located in the Muddy River/Virgin River inflow area during the July 2010–June 2011 Lake Mead field season.**

2011 sonic-tagged fish also proved valuable in the Muddy River/Virgin River inflow area. During the 2010–2011 field season, sonic-tagged fish used habitats ranging from 7.0–147.0 ft (2.1–44.8 m) deep, with an average depth of 30.0 ft (9.1 m) at point of contact. All five of the fish from the 2008 tagging event that were contacted in the 2010–2011 field season are presumed to be alive and active; however, similar to individuals tagged in previous years (e.g., 2005), many of these fish have not been located in several months (Table 1). Two individuals were last contacted in October 2010, one in Las Vegas Bay (code 677) and one in Echo Bay (code 376) (Figures 4 and 5). Another individual (code 365) was contacted in Echo Bay in October 2010, was not contacted for several months, and was then contacted by the Echo Bay SUR on March 9, 2011 (Figure 1). It is believed that many of the 2008 tags are reaching the end of their expected battery life as two individuals with dead tags have been captured in 2011 trammel-netting efforts—one individual (code 3355) was caught in February 2011 in Las Vegas Bay, and the other (code 488) was caught in March 2011 in the Muddy River/Virgin River inflow area. Both individuals appeared healthy and showed only remnants of a suture scar. Though no fish were contacted in the Muddy River/Virgin River inflow area in the 2009–2010 field season, one individual (code 3354) was contacted in the area in December 2010 after having been previously observed using other portions of Lake Mead.

In 2010, we postulated that some fish from the 2008 tagging event had moved out of the regularly monitored long-term areas of the lake and into relatively unmonitored areas such as the Colorado River inflow area (CRI) or Virgin Basin (Albrecht et al. 2010c). Tracking efforts in 2011 addressed this possibility and observed individuals frequenting both locations. One individual from the 2008 tagging event (code 3354) was stocked in the Muddy River/Virgin River inflow area in December 2008 and remained there until late February 2009 (Albrecht et al. 2010b). After a span of nearly 14 months, this individual was contacted in the CRI in April 2010, where it remained until October 2010 (Albrecht et al. 2010b, Kegerries and Albrecht 2011). This individual was contacted by the Narrows SUR south of Gregg Basin at the CRI as it moved out of the area; it was briefly contacted again in Echo Bay in November 2010 (Figure 5). This individual was then contacted in the Muddy River/Virgin River inflow area in December 2010, where it remained through April 2011 and the end of the spawning period (Figure 6). For further details regarding the individual (code 3354) contacted in the CRI, please refer to the 2011 CRI razorback sucker investigations companion report (Kegerries and Albrecht 2011). Another individual from the 2008 tagging event (code 678) was stocked in Echo Bay in December 2008, where it remained until late April 2010 (Albrecht et al. 2010c). After 4 months without contact, this individual showed up in Las Vegas Bay in August 2010 (Figure 4). This individual remained in one area for several months until it was last contacted in Las Vegas Bay on April 19, 2011. On May 2, 2011, this individual was contacted by the Boulder Basin SUR (Figure 1), and on May 24, 2011 it was contacted near the southwestern shore of Bonelli Bay in 39.0 ft (11.9 m) of water. Both individuals illustrate seasonal patterns of movement associated with the return to long-term spawning areas.

Fish Sonic Tagged in 2011

Eight razorback suckers were sonic tagged in Lake Mead in January 2011. During the 2011 field season each of these fish was contacted at least six times for a total of 87 contacts (Table 1); 38 contacts were made in Las Vegas Bay (Figure 4), 7 contacts were made in Echo Bay (Figure 5), and 42 contacts were made in the Muddy River/Virgin River inflow area (Figure 6). In 2011, these sonic-tagged fish used habitats ranging from 2.0–127.0 ft (0.6–38.7 m) deep, with an average depth of 22.9 ft (7.0 m) at point of contact. Individuals tended to remain in the area in which they were stocked; however, several Las Vegas Bay individuals (codes 334, 3545, 3584, 3775) likely moved up into the Las Vegas Wash (Figure 4) during the spawning period and were not contacted as frequently as the other four fish. This departure from the lake proper and into Las Vegas Wash somewhat hindered trammel netting efforts, as active sonic-tagged fish were unavailable to help guide net placement. One individual stocked into the Muddy River/Virgin River inflow area (code 555) remained from January 4, 2011, to March 14, 2011; 8 days later it showed up in Echo Bay (Figure 5). This individual stayed in Echo Bay and aided in trammel-netting efforts before leaving the bay on April 26, 2011, and returning to the Muddy River/Virgin River inflow on May 4, 2011, again, 8 days later (Figure 6). The connectivity in habitat between Echo Bay and the Muddy River/Virgin River inflow area may play an important role in seasonal population dynamics, a relationship observed with sonic-tagged individuals in the past (e.g., 2005 and 2008 [Albrecht et al. 2010c]), as well as those from the 2011 tagging event. In 2010, no contacts were made at the Muddy River/Virgin River inflow area (Albrecht et al. 2010c), so the ability to have sonic-tagged fish there again proved valuable in identifying razorback sucker spawning sites and learning about habitat use. Sonic-tagged fish were important in aiding trammel-netting efforts in the Muddy River/Virgin River inflow area in 2011, as several individuals remained in the Meadows area of the Overton Arm, approximately 2.0 mi (3.2 km) south of the Muddy River/Virgin River inflow area along the eastern shoreline. As past efforts have shown, some of the highest numbers of razorback sucker captures during trammel netting have occurred at the Muddy River/Virgin River inflow area. All eight fish from the 2011 tagging event are considered alive and active, although some may have moved into areas of the lake not monitored during this study or into areas inaccessible by boat (Table 1).

Passive Sonic Telemetry and Submersible Ultrasonic Receiver Data Collection

Two SURs were deployed in Lake Mead in addition to those used at the CRI and described by Kegerries and Albrecht (2011). The first SUR was deployed on February 14, 2011, in the northeastern-most portions of Boulder Basin, near the narrows of Boulder Canyon, to track fish moving in and out of the basin (Figure 1). The other SUR was deployed on February 17, 2011, toward the lower extent of the Overton Arm at the constriction point near Ramshead Island and Cathedral Cove, South of Echo Bay (Figure 1). As stated above, two razorback suckers were contacted by these SURs; one at each location.

In addition to sonic-tracking efforts employed at Lake Mead in 2010–2011, a remote PIT-tag reader similar to those used on Lake Mohave (Schooley et al. 2008b) was deployed for 3 nights in Echo Bay. One previously PIT-tagged wild razorback sucker was detected in Echo Bay. The detection occurred off the south shoreline next to the boat ramp. The remote reader's ability to detect tagged fish passively may prove useful in future studies on Lake Mead.

Adult Sampling

Trammel Netting

Trammel netting occurred from January 31–April 22, 2011, in accordance with recommendations for long-term monitoring of Lake Mead razorback sucker (Albrecht et al. 2006a). Netting locations were not as constrained by low lake elevations as they have been in the past. Netting locations were dictated by the capture of multiple razorback suckers, the presence of sonic-tagged fish, or high concentrations of larval fish in a particular area. Netting was conducted for 67 net-nights during the 15th field season, with 21 net-nights spent in the Las Vegas Bay, 24 net-nights in Echo Bay, and 22 net-nights in the Muddy River/Virgin River inflow area (Table 2). Las Vegas Bay trammel netting was conducted near the wash inflow on the north and south shorelines toward the west end of the bay (Figure 7). The primary sampling area of Echo Bay was located at the west end of the bay, near the boat ramp off the north and south shorelines (Figure 8). Trammel netting was also conducted outside of Echo Bay Marina in the main body of the lake. Finally, sampling of the Muddy River/Virgin River inflow area occurred near the Meadows along the eastern shoreline of the north end of the Overton Arm, approximately 2 mi (3.2 km) south of the Muddy River/Virgin River inflow area (Figure 9).

Table 2. Trammel netting effort (net-nights) on Lake Mead during the 15th field season, February 2011–April 2011.

MONTH	LAS VEGAS BAY/ BOULDER BASIN	ECHO BAY	OVERTON ARM	TOTAL
February	8	10	6	24
March	8	8	12	28
April	5	6	4	15
Total	**21**	**24**	**22**	**67**

The first male razorback sucker expressing milt was captured February 1, 2011, and the first female razorback sucker expressing eggs was captured March 1, 2011; both were caught in the Muddy River/Virgin River inflow area (Table 3). Across Lake Mead there were 14 recaptures of 86 total razorback sucker captures (16.3%) in 2011. Recapture rates varied between study areas. At Las Vegas Bay one of the nine (11.1%) razorback suckers caught was a previously captured fish. This sonic-tagged fish (code 3355), which had an inactive tag from 2008, was originally stocked from Floyd Lamb Park as a cooperative effort by BIO-WEST and NDOW. At Echo Bay, 6 of the 15 (40%) razorback suckers caught were recaptures. Of the six recaptures, four were wild fish originally tagged in Echo Bay; the other two were fish originally tagged at the Muddy River/Virgin River inflow area. One wild male tagged in 2009 and one wild female tagged in 2011 moved between the two monitoring sites. The female was tagged in March 2011 at the Muddy River/Virgin River inflow area and was recaptured in April 2011 in Echo Bay. At the Muddy River/Virgin River inflow area, 7 of 62 (11.3%) razorback suckers caught in 2011 were recaptures. Of those seven recaptures, six were fish originally tagged in the Muddy River/Virgin River area, while the other was a recaptured male originally tagged in Echo Bay in 2010. For netting efforts in the 2011 field season, captures from all of the Lake Mead long-term

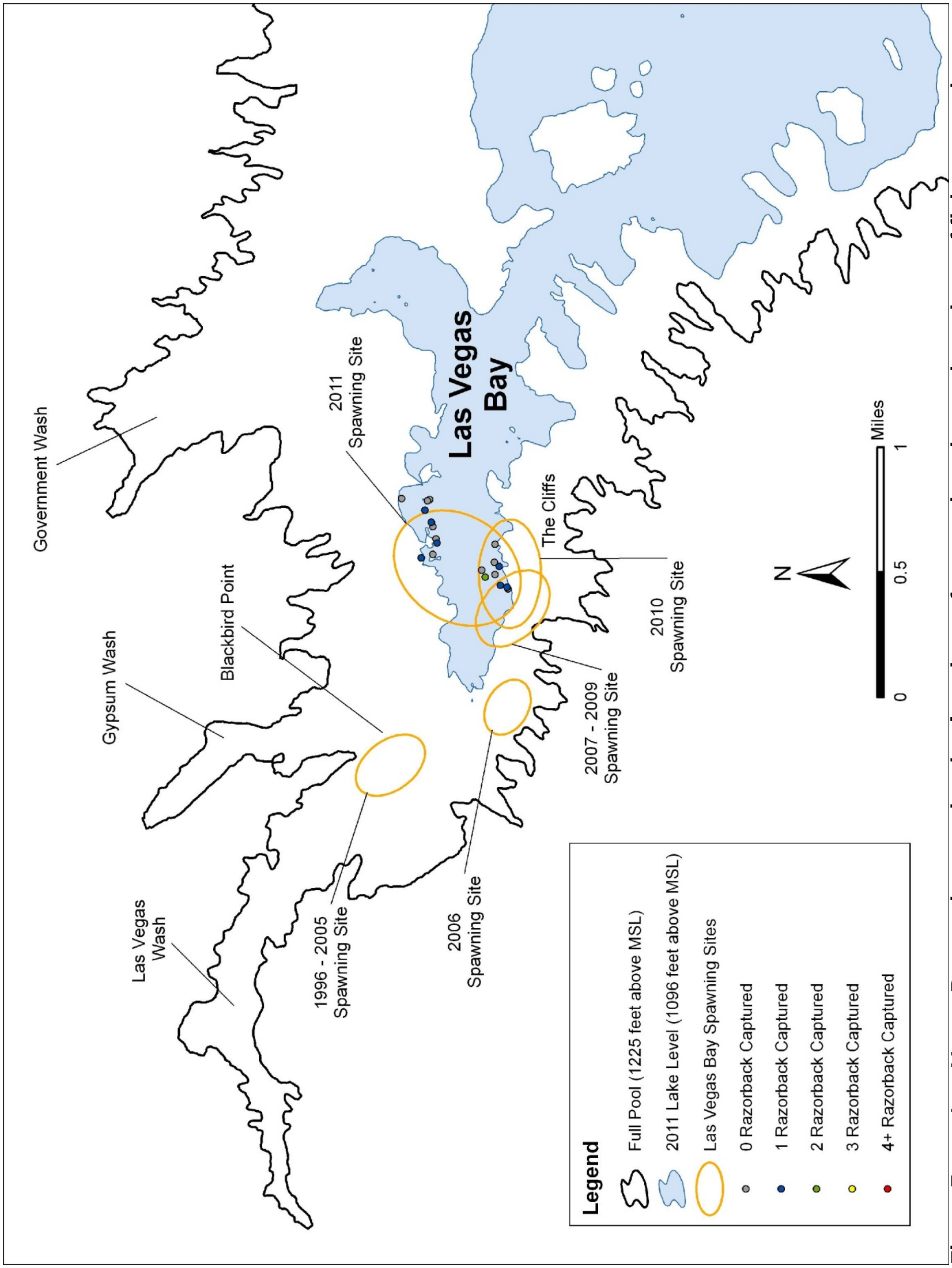

Figure 7. Las Vegas Bay study area showing locations of trammel netting and numbers of fish captured, February 2011–April 2011.

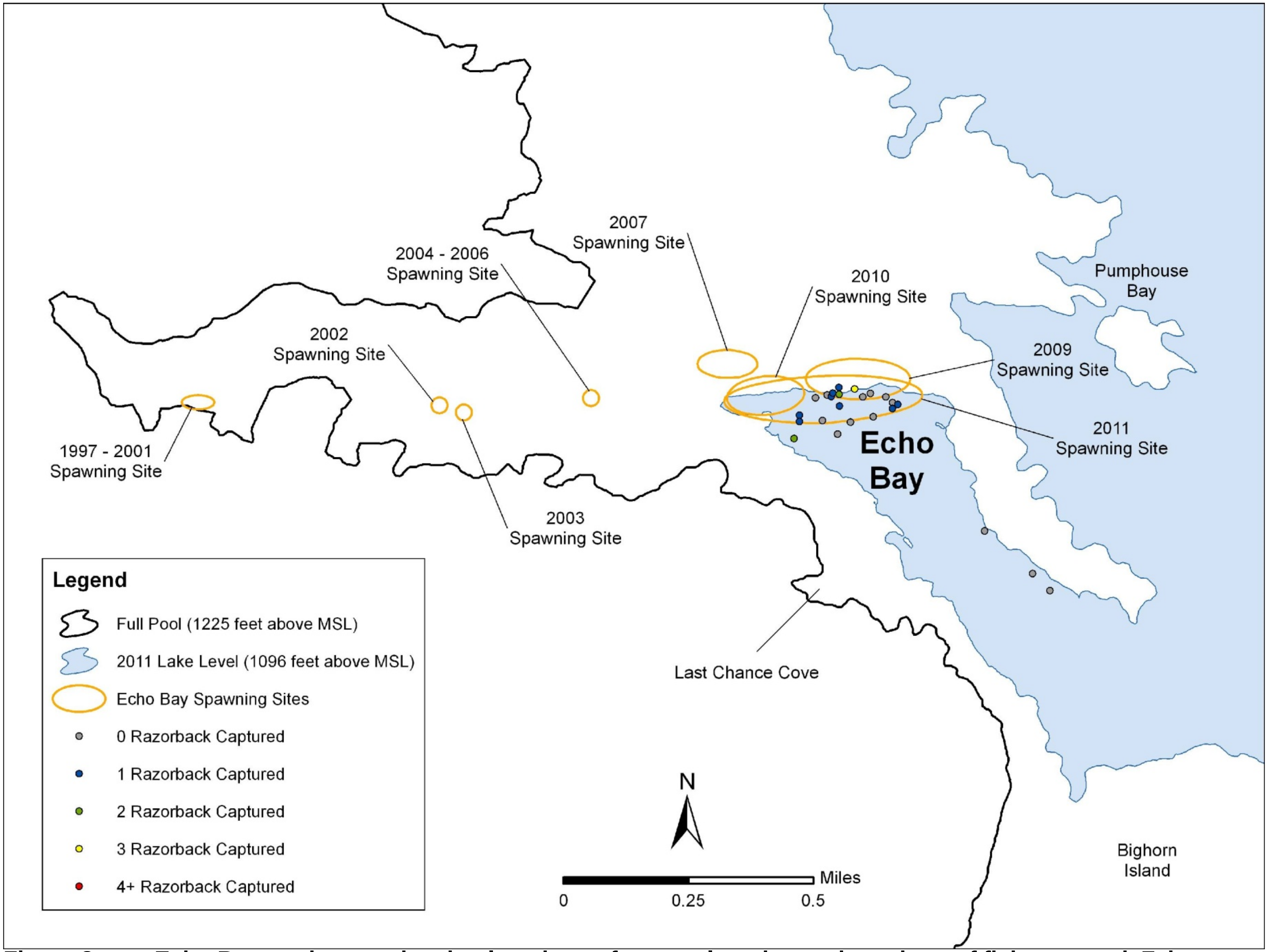

Figure 8. **Echo Bay study area showing locations of trammel netting and numbers of fish captured, February 2011–April 2011.**

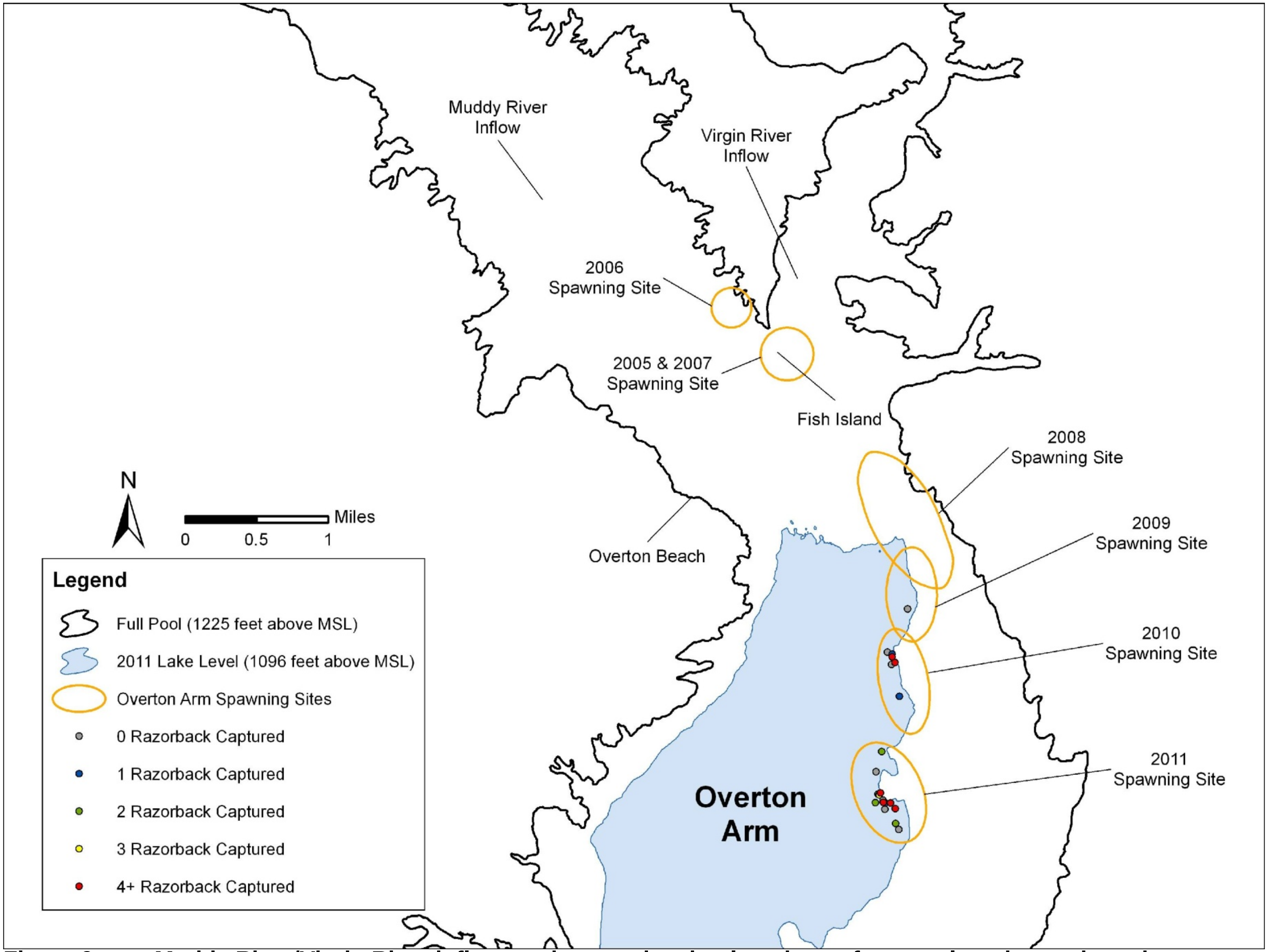

Figure 9. Muddy River/Virgin River inflow study area showing locations of trammel netting and numbers of fish captured, February 2011–April 2011.

Table 3. Location, tagging, and size information for razorback suckers captured in Lake Mead from February 2011–April 2011.

DATE	CAPTURE LOCATION [a]	PIT TAG NUMBER	SONIC TAG	DATE STOCKED [b]	RECAPTURE	TL [c] (mm)	FL [d] (mm)	SL [e] (mm)	WT [f] (g)	SEX [g]
2/1/2011	OA	3D9.257C60E179		2/25/2010	YES	506	462	425	1,690	M
2/1/2011	OA	3D9.1C2C2F86BA		2/1/2011	NO	601	561	518	2,480	F
2/1/2011	OA	3D9.1C2D25D9CD		2/1/2011	NO	556	515	471	1,990	F
2/1/2011	OA	3D9.1C2D27580E		2/1/2011	NO	586	439	492	2,488	F
2/1/2011	OA	3D9.257C608715		2/1/2011	NO	506	461	434	1,448	M
2/1/2011	OA	3D9.257C61BD72		2/1/2011	NO	500	460	429	2,960	M
2/1/2011	OA	3D9.257C60B636		2/1/2011	NO	572	520	486	4,880	F
2/1/2011	OA	3D9.1C2C83E120		2/1/2011	NO	571	529	490	4,602	F
2/8/2011	LB	3D9.1C2D2745D7		2/8/2011	NO	587	555	520	2,532	M
2/9/2011	EB	3D9.1C2D25B898		2/9/2011	NO	529	486	544	1,566	M
2/9/2011	EB	3D9.1C2D27542A		2/9/2011	NO	524	487	450	1,518	M
2/10/2011	LB	451548093E	3355	12/4/2008	YES	574	525	500	2,102	M
2/22/2011	OA	3D9.1C2C83E2AA		2/22/2011	NO	501	460	421	1,630	M
2/22/2011	OA	3D9.257C60C033		2/22/2011	NO	586	544	509	2,008	F
2/22/2011	OA	3D9.257C60E183		2/22/2011	NO	512	470	434	1,690	M
2/22/2011	OA	3D9.257C619794		2/22/2011	NO	585	544	505	2,170	F
2/22/2011	OA	3D9.257C5F4F54		2/22/2011	NO	580	536	502	2,010	F
2/22/2011	OA	3D9.257C60BE38		2/22/2011	NO	509	472	432	1,528	M
2/22/2011	OA	3D9.1C2D26990C		2/22/2011	NO	524	486	455	1,508	M
2/22/2011	OA	3D9.1C2D2633CB		2/22/2011	NO	506	468	434	1,488	M
2/22/2011	OA	3D9.1C2C8412CB		2/22/2011	NO	534	490	454	1,688	M
2/22/2011	OA	3D9.1C2D268EC1		2/22/2011	NO	508	475	443	1,358	M
2/22/2011	OA	3D9.1C2D278BC3		2/22/2011	NO	517	482	441	1,288	M
2/23/2011	OA	3D9.1C2C85776B		2/23/2011	NO	527	487	450	1,789	M
2/23/2011	OA	3D9.1C2C85741F		2/23/2011	NO	500	468	422	1,628	M
2/23/2011	OA	3D9.1C2C841C6D		2/23/2011	NO	545	510	473	1,808	M
2/23/2011	OA	3D9.1C2D268469		2/23/2011	NO	552	509	479	1,888	F
2/24/2011	EB	3D9.1C2D269868		2/24/2011	NO	555	510	457	1,818	F
3/1/2011	OA	3D9.1C2C844E09		3/1/2011	NO	553	521	452	2,058	F
3/1/2011	OA	3D9.1C2C583AE3		3/1/2011	NO	510	470	418	1,562	M
3/1/2011	OA	3D9.1C2D265BAF		3/1/2011	NO	563	523	465	2,176	F
3/1/2011	OA	3D9.1C2C7F47CD		3/1/2011	NO	573	528	477	2,102	F
3/1/2011	OA	3D9.1C2D265DD5		3/1/2011	NO	555	512	461	1,708	F
3/1/2011	OA	3D9.257C629ACA		2/3/2010	YES	500	460	407	1,458	M
3/1/2011	OA	3D9.1C2D279A4D		3/1/2011	NO	560	519	458	2,014	F
3/1/2011	OA	3D9.1C2D266829		3/1/2011	NO	483	439	387	1,021	M
3/1/2011	OA	3D9.1C2C83C193		3/1/2011	NO	538	497	442	1,079	F
3/1/2011	OA	3D9.1C2D262910		3/1/2011	NO	595	553	498	2,360	F

Table 3. (Cont.)

DATE	CAPTURE LOCATION [a]	PIT TAG NUMBER	SONIC TAG	DATE STOCKED [b]	RECAPTURE	TL [c] (mm)	FL [d] (mm)	SL [e] (mm)	WT [f] (g)	SEX [g]
3/1/2011	OA	3D9.1C2C7F4A82		3/1/2011	NO	518	472	420	1,440	M
3/1/2011	OA	3D9.1C2C841878		3/1/2011	NO	532	489	438	1,700	M
3/1/2011	OA	3D9.1C2D2672A1		3/1/2011	NO	599	554	497	2,082	F
3/2/2011	EB	53256C725A		1/11/2007	YES	635	598	562	2,872	F
3/2/2011	EB	3D9.1C2C857F86		3/2/2011	NO	513	476	444	1,818	M
3/3/2011	LB	3D9.1C2D260639		3/3/2011	NO	364	338	301	504	I
3/3/2011	LB	3D9.1C2D2617DD		3/3/2011	NO	434	404	353	782	I
3/9/2011	OA	3D9.1C2C83CAF0		3/9/2011	NO	556	505	465	1,976	F
3/9/2011	OA	3D9.257C6090C5		3/25/2010	YES	531	490	452	1,484	M
3/9/2011	OA	3D9.1C2D260775		3/9/2011	NO	549	500	465	1,730	M
3/9/2011	OA	3D9.1C2D263226		3/9/2011	NO	505	470	433	1,324	M
3/9/2011	OA	3D9.1C2C856F3F		3/9/2011	NO	534	490	448	1,508	M
3/9/2011	OA	3D9.1C2D262E6D		3/9/2011	NO	494	455	415	1,112	M
3/10/2011	EB	53261E2310		3/8/2004	YES	660	615	570	3,826	F
3/15/2011	OA	3D9.257C60C637		3/17/2010	YES	541	493	439	1,440	M
3/15/2011	OA	3D9.1C2C856C17		3/15/2011	NO	551	508	456	1,588	F
3/15/2011	OA	3D9.1C2D2662F9		3/15/2011	NO	542	503	445	1,714	F
3/15/2011	OA	3D9.1C2C84514B		3/15/2011	NO	575	540	487	2,412	F
3/15/2011	OA	3D9.1C2C840759		3/15/2011	NO	575	534	481	2,060	F
3/15/2011	OA	3D9.1C2C841AC6		3/15/2011	NO	572	537	485	2,120	F
3/15/2011	OA	3D9.1C2C841581		3/15/2011	NO	576	530	480	2,326	F
3/15/2011	OA	3D9.1C2D260481		3/15/2011	NO	561	520	471	2,080	F
3/15/2011	OA	3D9.1C2C8413A5		3/15/2011	NO	558	513	464	2,028	F
3/15/2011	OA	3D9.257C6090C5		3/25/2010	YES	525	486	433	1,434	M
3/15/2011	OA	5334521528	488	12/2/2008	YES	601	555	502	2,802	F
3/15/2011	OA	3D9.1C2C8408E1		3/15/2011	NO	551	507	454	1,786	M
3/15/2011	OA	3D9.1C2D260E6F		3/15/2011	NO	566	524	475	2,042	F
3/15/2011	OA	3D9.1C2D269008		3/15/2011	NO	577	532	474	2,354	F
3/15/2011	OA	3D9.1C2C841041		3/15/2011	NO	515	471	420	1,534	M
3/15/2011	OA	3D9.1C2C84159F		3/15/2011	NO	587	542	484	1,994	F
3/23/2011	OA	3D9.1C2D260775		3/9/2011	YES	537	495	434	1,678	M
3/24/2011	LB	3D9.1C2D2675F9		3/24/2011	NO	411	385	347	846	F
3/24/2011	LB	3D9.1C2D269706		3/24/2011	NO	390	355	324	610	F
3/29/2011	LB	3D9.1C2D268153		3/29/2011	NO	376	350	321	588	I
3/29/2011	LB	3D9.1C2D2621D4		3/29/2011	NO	346	321	290	386	I
3/29/2011	LB	3D9.1C2C841591		3/29/2011	NO	379	351	322	530	I
3/30/2011	EB	3D9.257C612FA9		4/22/2010	YES	532	490	461	1,398	M
4/5/2011	OA	3D9.1C2D261224		4/5/2011	NO	521	481	450	1,462	F
4/5/2011	OA	3D9.1C2D264407		4/5/2011	NO	495	458	421	1,298	F

Table 3. (Cont.)

DATE	CAPTURE LOCATION [a]	PIT TAG NUMBER	SONIC TAG	DATE STOCKED [b]	RECAPTURE	TL [c] (mm)	FL [d] (mm)	SL [e] (mm)	WT [f] (g)	SEX [g]
4/6/2011	EB	3D9.1C2C8406B7		2/25/2009	YES	560	520	485	1,878	M
4/7/2011	EB	3D9.1C2C843DBF		4/7/2011	NO	533	490	460	1,538	M
4/7/2011	EB	3D9.1C2D2688F1		4/7/2011	NO	522	489	451	1,298	M
4/7/2011	EB	3D9.1C2D27542A		2/9/2011	YES	514	480	435	1,208	M
4/12/2011	OA	3D9.1C2D2677CC		4/12/2011	NO	572	523	488	2,326	F
4/19/2011	EB	3D9.1C2C840759		3/15/2011	YES	Quick Release [h]				F
4/19/2011	EB	3D9.1C2D26878D		4/19/2011	NO	515	478	439	1,388	M
4/19/2011	EB	3D9.1C2C840860		4/19/2011	NO	540	498	453	1,268	M
4/19/2011	EB	3D9.1C2C7F485C		4/19/2011	NO	537	495	462	1,590	M

[a] OA = Overton Arm (Muddy River/Virgin River inflow area), LB = Las Vegas Bay, EB = Echo Bay.

[b] Date originally stocked or originally captured.

[c] Total Length (millimeters).

[d] Fork Length (millimeters).

[e] Standard Length (millimeters).

[f] Weight (grams).

[g] F = female, M = male, U = unidentified, I = immature (sex not determined).

[h] No measurements taken due to proximity of date of capture to date of recapture, individual was released immediately.

monitoring sites combined were comprised of 48.15% females and 51.85% males. Las Vegas Bay captures were 50.00% females and 50.00% males (excluding the five immature fish), Echo Bay captures were 26.67% females and 73.33% males, and the Muddy River/Virgin River inflow area captures were 53.23% females and 46.77% males.

Four adult and five subadult razorback suckers were captured at Las Vegas Bay during the 2011 spawning period (Table 3). Adult and subadult fish were captured in roughly equal numbers on the north and south shorelines in the western end of Las Vegas Bay (four off the north shore and five off the south shore) (Figure 7). In comparison, 49 razorback suckers were captured in the bay in 2009 and 20 were captured in 2010 (Albrecht et al. 2009, Albrecht et al. 2010c). The razorback sucker catch per unit effort (CPUE) from trammel netting at the Las Vegas Bay area was 0.43 fish/net-night for the 2011 field season. This rate is lower than the past two years (2009 = 1.96 fish/net-night and 2010 = 1.00 fish/net-night); however, it falls within the CPUE values observed throughout the course of this study (Albrecht et al. 2010c) (Figure 10).

Where possible, nets were set toward the west end of Echo Bay near the boat ramp, focusing on areas where sonic-tagged fish were contacted (Figure 8). However, due to the initially shallow water, efforts were constrained in this historically productive area of Echo Bay (Albrecht et al. 2010c). Efforts were focused on the north shore of Echo Bay in an area comprised of larger substrates (e.g., cobble, boulder) and the south shore in an area of recently inundated vegetation. We were unable to sample much of the western end of Echo Bay late in the season because boat-ramp conditions did not permit (i.e., heavy boat traffic and shallow conditions) and trammel

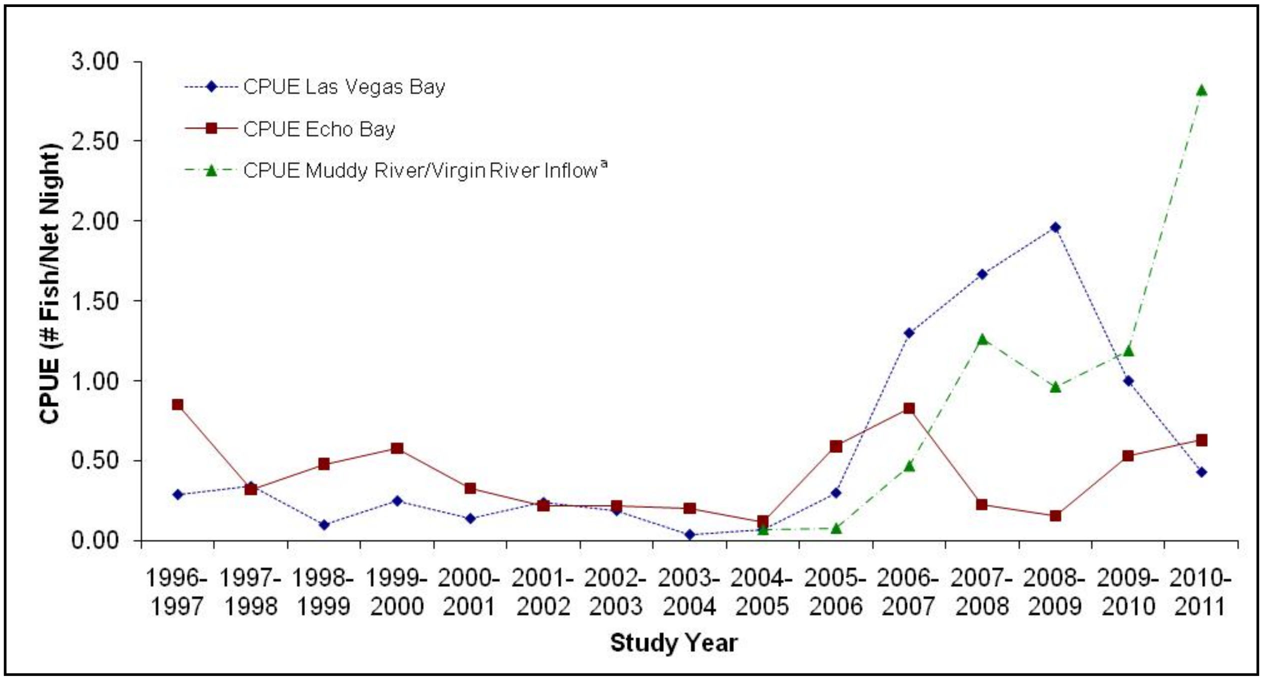

Figure 10. Trammel netting catch per unit effort (CPUE) in number of fish per net-night during studies on Lake Mead razorback sucker, 1996–2011.
[a] Sampling at Muddy River/Virgin River inflow area initiated in 2004–2005.

netting in this area would have interfered with public access to the lake. Despite conditions different from previous field seasons, 15 adult razorback suckers were captured in 24 net-nights (Table 2, Figure 10). In comparison, during the 2009 spawning period only four adult razorback suckers were collected, while 13 razorback suckers were captured during the 2010 spawning period. No subadult fish were captured from Echo Bay during the 2011 spawning period, marking the fourth year this has occurred in the area. The 2011 razorback sucker CPUE for trammel netting at Echo Bay was 0.63 fish/net-night, which is higher than the rate for the previous two field seasons (0.15 fish/net-night in 2009 and 0.53 fish/net-night in 2010) (Figure 10).

The 2011 field season proved successful in capturing razorback suckers at the Muddy River/Virgin River inflow area (Figure 9). In fact, the highest CPUE rates and total number of razorback suckers captured at any location during the 2011 long-term monitoring occurred there. Trammel netting in 2011 resulted in the capture of 62 adult razorback suckers at the Muddy River/Virgin River inflow area. Most of these fish were captured over gravel and small-cobble substrates along the eastern shoreline south of the Virgin River inflow in a small cove near the Meadows area (Figure 9). The razorback sucker CPUE for trammel netting at the Muddy River/Virgin River inflow area was 2.82 fish/net-night, the highest rate for all three long-term monitoring sites on Lake Mead in 2011 and throughout the past 15 years (Figure 10). For the second consecutive year since sampling began at the Muddy River/Virgin River inflow area, CPUE rates exceeded those from both the Las Vegas Bay and Echo Bay study areas (Muddy River/Virgin River inflow area CPUE 2010 = 1.19 fish/net-night) (Figure 10). Despite a lower CPUE in Las Vegas Bay this year compared to 2010 and a generally lower CPUE in Echo Bay for the past 3 years (Figure 10), the overall Lake Mead CPUE for 2011 (1.28 fish/net-night) is higher than the average historical CPUE (0.57 fish/net-night).

Additionally, during the 2011 spawning period two flannelmouth suckers were captured, one new individual in Las Vegas Bay and one recaptured individual in the Muddy River/Virgin River inflow area. The Las Vegas Bay flannelmouth sucker was marked with a PIT tag and a fin ray section was obtained for aging purposes. The recaptured individual was originally captured in 2010 in the Muddy River/Virgin River inflow area. The 2011 CPUE for flannelmouth sucker in Las Vegas Bay was 0.05 fish/net-night; the 2011 CPUE for flannelmouth sucker in the Muddy River/Virgin River inflow area was 0.05 fish/net-night. Although flannelmouth suckers had been captured at the Muddy River/Virgin River inflow area in 2010, this was the first year they have been documented in Las Vegas Bay. This is the second consecutive year that flannelmouth suckers were documented during long-term monitoring efforts.

Another observation from 2011 is the elevated CPUE of razorback suckers in the Muddy River/Virgin River inflow area, marking the second consecutive year CPUE in this study area exceeded CPUE in Las Vegas and Echo bays (Figure 10). Seventy-two percent of the razorback suckers captured in 2011 came from the Muddy River/Virgin River inflow area, while 10% and 17% of the total annual razorback sucker catch came from Las Vegas Bay and Echo Bay, respectively. Perhaps most interesting is that most of the fish captured at the Muddy River/Virgin River inflow area were wild, unmarked individuals. In all, the 2011 spawning period was strong for razorback sucker captures, particularly for captures of wild fish at the Muddy River/Virgin River inflow area (Table 3). This follows trends reported by Albrecht et al. (2007, 2008a) and Kegerries et al. (2009).

In summary, 608 individual razorback suckers have been captured during this 15-year study. At Las Vegas Bay, 276 individual razorback suckers have been PIT tagged; 152 individuals were tagged by BIO-WEST personnel, 117 were tagged by NDOW personnel, and 7 were tagged by USFWS personnel. In Echo Bay, 165 individual razorback suckers have been tagged; 99 of these fish were captured and PIT tagged by BIO-WEST personnel, 62 were PIT tagged by NDOW personnel, and 4 were handled by USFWS personnel during collaborative efforts with BIO-WEST. Of the 137 individual razorback suckers captured in the Muddy River/Virgin River inflow area, 136 were PIT tagged by BIO-WEST personnel and 1 was PIT tagged by NDOW personnel. Two additional individuals were caught and tagged by NDOW personnel in Alkali Bay in the Virgin Basin in 2008. Finally, 36 fish were sonic tagged, PIT tagged, and stocked by BIO-WEST personnel during collaborative research efforts with NDOW. Please note that the 608 fish total does not include razorback suckers found at the CRI in 2011 or newly stocked, sonic-tagged fish used in the CRI this season. Those results are found in the 2011 CRI companion report (Kegerries et al. 2011).

Growth

Although 14 razorback suckers were recaptured during the 2011 field season (1 in Las Vegas Bay, 6 from Echo Bay, and 7 from the Muddy River/Virgin river inflow area), annual growth analyses were only performed using data from 6 of these individuals. All recaptures were not included in the analyses because some individuals were either captured more than once during the 2011 field season or 1 year (365 days) had not passed between the original capture and last date of capture. The difference in TL between capture periods was used to determine mean annual growth (Table 4). Two stocked and four wild fish were used to calculate growth data for 2011. Both stocked fish were captured at Floyd Lamb Park, sonic tagged, and stocked in December 2008. The lake-wide mean annual growth of razorback suckers recaptured from Lake Mead during 2011 was 24.7 mm/year, compared to 58.3 mm/year in 2010 (Albrecht et al. 2010c). Mean annual growth of wild fish captured in Lake Mead in 2011 was 19.3 mm/year, compared to 65.4 mm/year in 2010 (Albrecht et al. 2010c). Mean annual growth of stocked fish was 35.5 mm/year for 2011 and was not calculated in 2010 because only one stocked fish was recaptured.

Table 4. **Lake Mead razorback sucker growth histories for fish recaptured during the February 2011–April 2011 field season.**

PIT TAG NUMBER	DATE STOCKED [a]	TL (mm) [b]	LAST DATE RECAPTURED	TL (mm)	TOTAL GROWTH (mm)	DAYS BETWEEN MEASUREMENTS	GROWTH/ YEAR (mm/365 DAYS)
			LAS VEGAS BAY				
Stocked Fish							
451548093E	12/4/2008	483	2/10/2011	574	91	798	41.6
Mean annual growth							**N/A [c]**
			ECHO BAY				
Wild Fish							
53261E2310	3/8/2004	619	3/8/2011	660	41	2,558	5.9
53256C725A	1/11/2007	535	3/2/2011	635	100	1,511	24.2
3D9.1C2C8406B7	2/25/2009[d]	549	4/6/2011	560	11	770	5.2
Mean annual growth							**11.8**
			MUDDY RIVER/VIRGIN RIVER INFLOW AREA				
Stocked Fish							
5334521528	12/2/2008	534	3/15/2011	601	67	833	29.4
Wild Fish							
3D9.257C629ACA	2/3/2010	455	3/1/2011	500	45	391	42.0
Mean annual growth							**N/A [c]**
Mean annual growth of all wild Las Vegas Bay, Echo Bay, and Overton Arm fish							**19.3**
Mean annual growth of all stocked Las Vegas Bay, Echo Bay, and Overton Arm fish							**35.5**
Mean annual growth of all Las Vegas Bay, Echo Bay, and Overton Arm fish							**24.7**

[a] The date a fish was stocked into Lake Mead, or the date a wild fish was originally captured.

[b] Total length in millimeters.

[c] Mean could not be calculated from growth of one individual.

[d] Fish was originally tagged at the Muddy River/Virgin River inflow area and recaptured in Echo Bay.

Mean annual growth was not calculated for Las Vegas Bay because only one recaptured fish could be included in the analyses. In Echo Bay three wild fish were recaptured and used in growth analyses. One of the fish was originally tagged at the Muddy River/Virgin River inflow area in 2009. Mean annual growth in Echo Bay, including the individual tagged at the Muddy River/Virgin River inflow area, was 11.8 mm/year; mean annual growth for Echo Bay without the individual tagged at the Muddy River/Virgin River inflow area was 15.1 mm/year (Table 4). At the Muddy River/Virgin River inflow area two fish (one wild and one stocked) were recaptured. Growth could not be calculated separately for wild and stocked fish due to an insufficient sample size; however, the mean annual growth rate for wild and stocked fish combined was 35.7 mm/year for the Muddy River/Virgin River inflow area.

Larval Sampling

Razorback sucker larval sampling at the three primary spawning sites (Las Vegas Bay, Echo Bay, and the Muddy River/Virgin River inflow area) was initiated on February 2, 2011. With few exceptions, four to eight monitoring sites were sampled weekly in February, March, and April 2011 for each of the three primary spawning sites. Larvae were first collected on February 14, 2011, at Las Vegas Bay over gravel/cobble and sand/gravel substrates at temperatures 14–15°C (57–59°F) in a small cove on the northern shoreline just outside of Las Vegas Wash (Figure 11). Larvae were collected in this area until we changed locations because of higher larval fish abundances on the southwestern shore outside of the wash. The southwestern side of the wash had an alluvial fan with large amounts of inundated terrestrial vegetation adjacent to a set of cliffs and deeper water. The majority of larvae (n = 302) were collected near this area from February 24–March 28, 2011, at temperatures between 15–21°C (59–70°F). This general area corresponds with primary spawning sites identified by Albrecht et al. (2008a), Kegerries et al. (2009), and Albrecht et al. (2010c). The capture of larval fish from both the north to south shores, in conjunction with sonic-tagged fish locations and trammel netting, helped define the location of the 2011 spawning site (Figures 2 and 11). Las Vegas Bay yielded 449 larval fish captured within 1,590 minutes of sampling, providing a catch per minute (CPM) value of 0.282 (Table 5). The trend of razorback sucker larvae CPM at Las Vegas Bay in 2011 returned to similar levels of recent years after a decline in 2010 (Table 6).

At Echo Bay, the first razorback sucker larvae were captured on March 1, 2011, over sand/gravel substrates at temperatures of 12–13°C (54–55°F) in the northwestern portion of the bay. Collection efforts in Echo Bay returned the highest total number of captures and CPM values for larval razorback sucker in any study area during 2011. The collection of 3,818 larval razorback suckers resulted in a CPM value of 1.482 (Table 5). Larval fish were found on both the northern and southern shorelines; however, collections were most consistent and most abundant with increased proximity to the boat ramp infrastructure on the westernmost end of the bay (Figure 12). The 2011 Echo Bay larval razorback sucker capture rates are much higher than rates in recent years (Table 6), and larval captures confirmed spawning success in Echo Bay during 2011. The primary spawning site was identified along the westernmost northern shoreline (Figure 12).

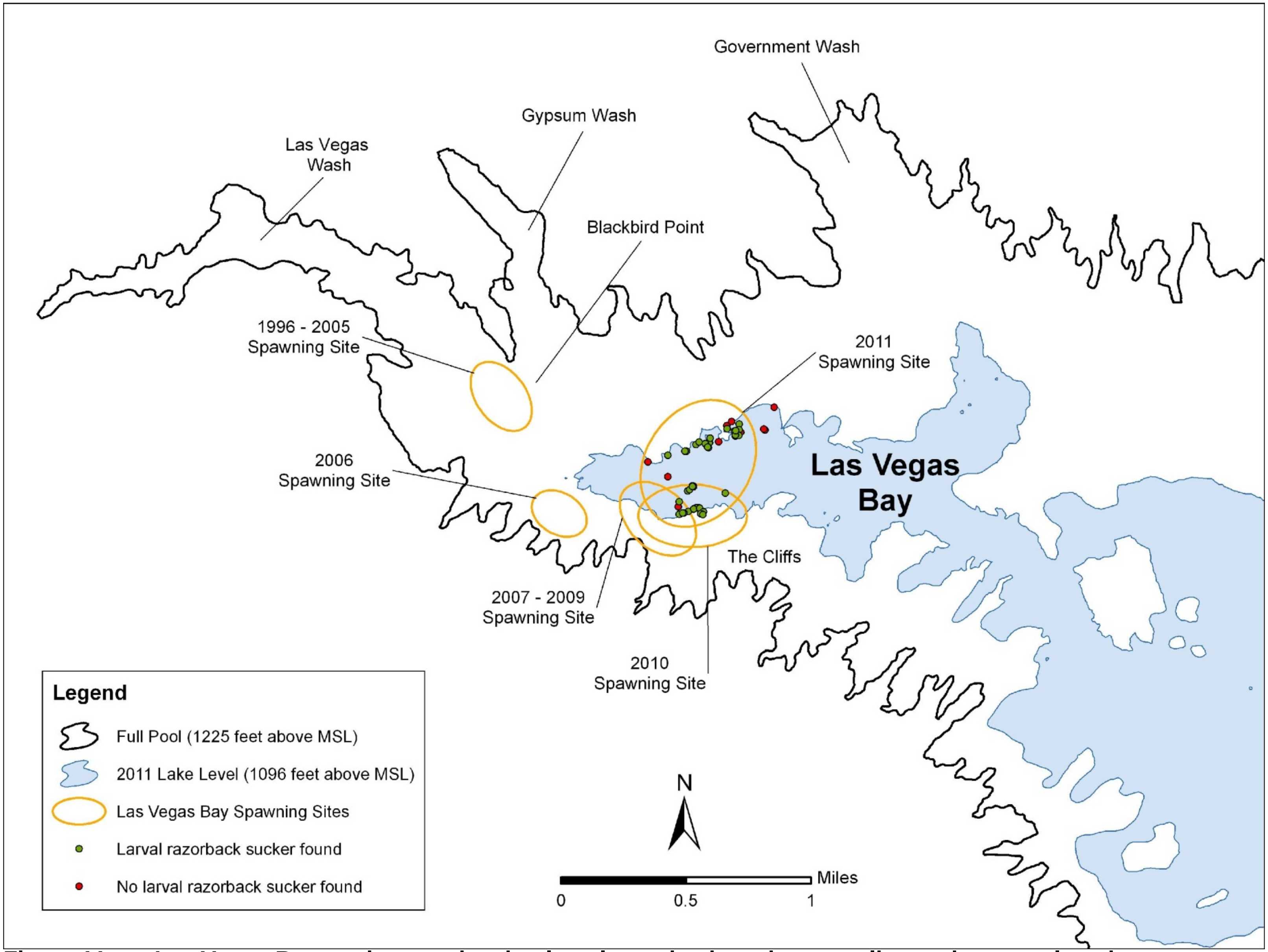

Figure 11. **Las Vegas Bay study area showing larval razorback sucker sampling and capture locations, February 2011–April 2011.**

Table 5. **Number of razorback sucker larvae collected at Las Vegas Bay, Echo Bay, and Muddy River/Virgin River inflow area of Lake Mead during February 2011–April 2011.**

Date	LAS VEGAS BAY SAMPLING SITES			ECHO BAY SAMPLING SITES			MUDDY RIVER/VIRGIN RIVER INFLOW SAMPLING SITES		
	Minutes Sampled	Larvae Captured	CPM [a]	Minutes Sampled	Larvae Captured	CPM [a]	Minutes Sampled	Larvae Captured	CPM [a]
02/02/11				60	0	0.000			
2/3/2011	120	0	0.000						
02/07/11	120	0	0.000						
02/08/11				120	0	0.000			
02/09/11	120	0	0.000						
02/14/11	180	36	0.200						
02/21/11							96	0	0.000
02/23/11				90	0	0.000			
02/24/11	120	99	0.825						
02/28/11							150	0	0.000
03/01/11				210	15	0.071			
03/03/11	180	65	0.361						
03/08/11							180	0	0.000
03/09/11				315	140	0.444			
03/10/11	180	140	0.778						
03/14/11							120	0	0.000
03/15/11				270	1284	4.756			
03/17/11	150	22	0.147						
03/21/11				297	222	0.747			
03/22/11							180	11	0.061
03/28/11	180	35	0.194						
03/29/11							270	0	0.000
03/30/11				225	351	1.560			
04/04/11							180	4	0.022
04/05/11				150	153	1.020			
04/06/11				315	504	1.600			
04/11/11							180	2	0.011
04/12/11	180	49	0.272	150	502	3.347			
04/18/11				225	610	2.711			
04/19/11	60	3	0.050						
04/26/11				150	37	0.247			
04/27/11							240	4	0.017
Totals	**1,590**	**449**	**0.282**	**2,577**	**3818**	**1.482**	**1,596**	**21**	**0.013**

[a] Catch per minute.

Table 6. Larval razorback sucker catch-per-minute (CPM) comparisons by primary study area for 2007–2011.

PRIMARY STUDY AREA	2007	2008	2009	2010	2011
Las Vegas Bay	0.390	0.430	0.342	0.093	0.282
Echo Bay	0.430	0.024	0.021	0.269	1.482
Muddy River/Virgin River inflow	0.001	0.116	0.107	0.011	0.013

At the Muddy River/Virgin River inflow study area, the first razorback sucker larvae of the season were captured on March 22, 2011, over cobble and gravel substrates at temperatures of 14–15°C (57–59°F), approximately 2 mi (3.2 km) south of the Muddy River/Virgin River inflow area along the eastern shoreline of the Overton Arm near the Meadows (Figure 1, Figure 13). Larval captures occurred in the same vicinity as multiple adult razorback sucker captures from trammel-netting collections (Table 5, Figure 13), although in numbers disproportionate to the abundance of adult captures. Thus, although numerous adult razorback suckers were captured and documented as being reproductively ready near sites where larvae were collected, other environmental variables (e.g., high winds in the Overton Arm) may have played a part in the low larval abundance in the Muddy River/Virgin River inflow area, relative to other Lake Mead study areas. In 2011, larval captures in the Muddy River/Virgin River inflow area were comparable with the majority of previous years' captures and occurred at temperature ranges of 14–20°C (57–68°F). A total of 21 larval razorback suckers were captured, resulting in a CPM of 0.013 (Tables 5 and 6).

Spawning Site Identification and Observations

For the past decade, decreasing lake elevations have influenced habitat conditions in all areas where razorback sucker sampling activities have occurred during this 15-year study. However, favorable runoff conditions in 2011 increased lake elevations, and as of June 1, 2011, the lake elevation was approximately 1,102 ft (335.9 m) ASL, compared with 1,094 ft (333.5 m) ASL recorded the previous year on the same date. This marks a noteworthy shift from low and generally declining lake elevations to increasing lake elevations (Figure 14). As a result of variable lake elevations over the last decade, Lake Mead razorback suckers have continually shifted spawning sites over the years to accommodate varying, but generally declining, conditions.

The primary Las Vegas Bay spawning site during the 2005–2006 field season was located 500 m south of the Las Vegas Wash inflow area, along the southwestern shoreline of the bay (Albrecht et al. 2006b). For the past 4 years the razorback suckers' primary spawning site was in the same general vicinity, shifting with receding lake elevations farther southeast of the 2006 spawning site (Figure 11). Larval razorback suckers were captured in surrounding areas; however, the majority of larval captures (over 90%) occurred within the identified primary spawning site (Figure 11). With rising lake elevations in 2011, we observed general use of the entire back portion of Las Vegas Bay. Spawning activity primarily occurred along the northern shoreline early in 2011, but it also occurred along the southern shoreline in latter months (Figure 11). In

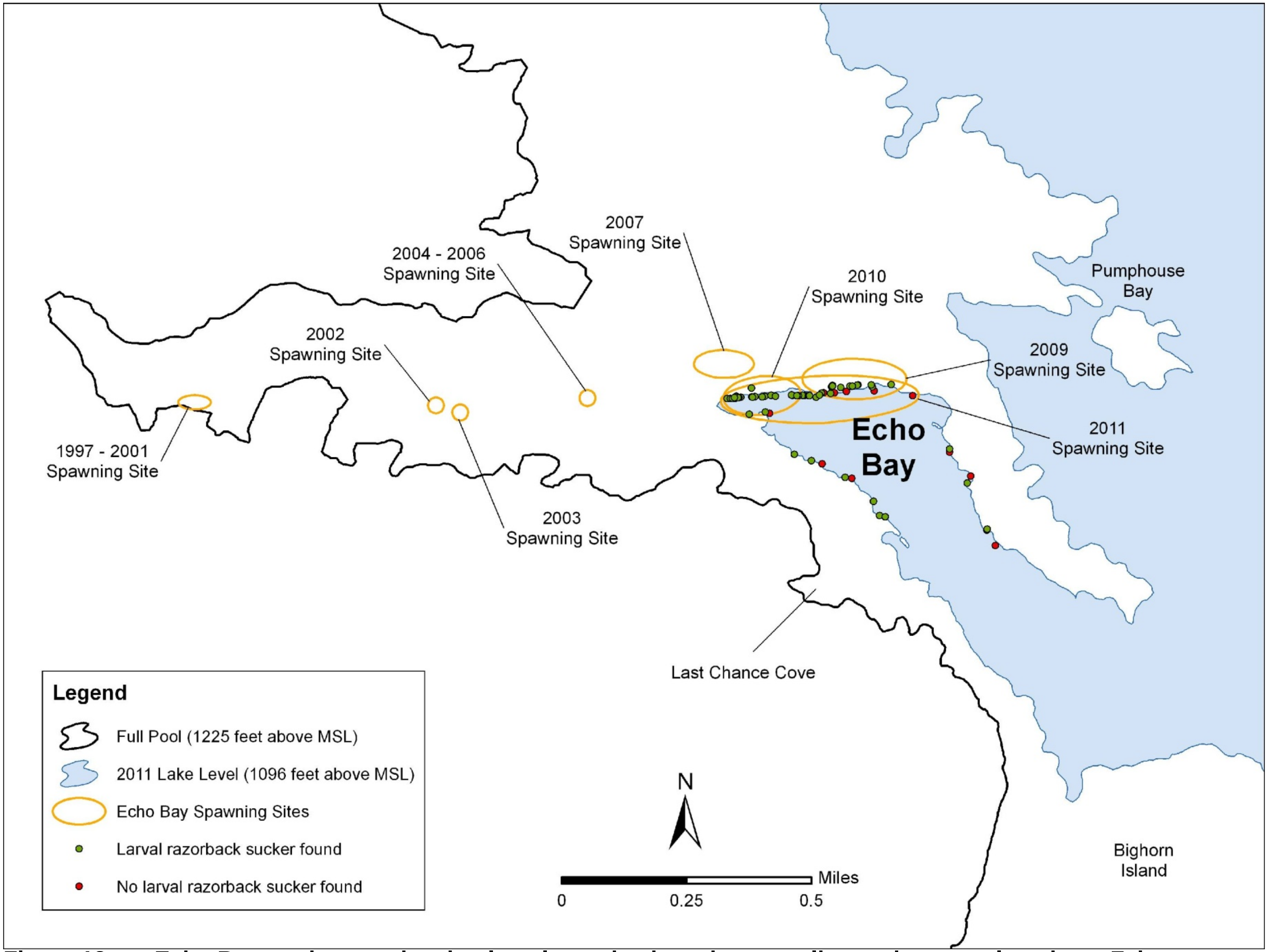

Figure 12. **Echo Bay study area showing larval razorback sucker sampling and capture locations, February 2011–April 2011.**

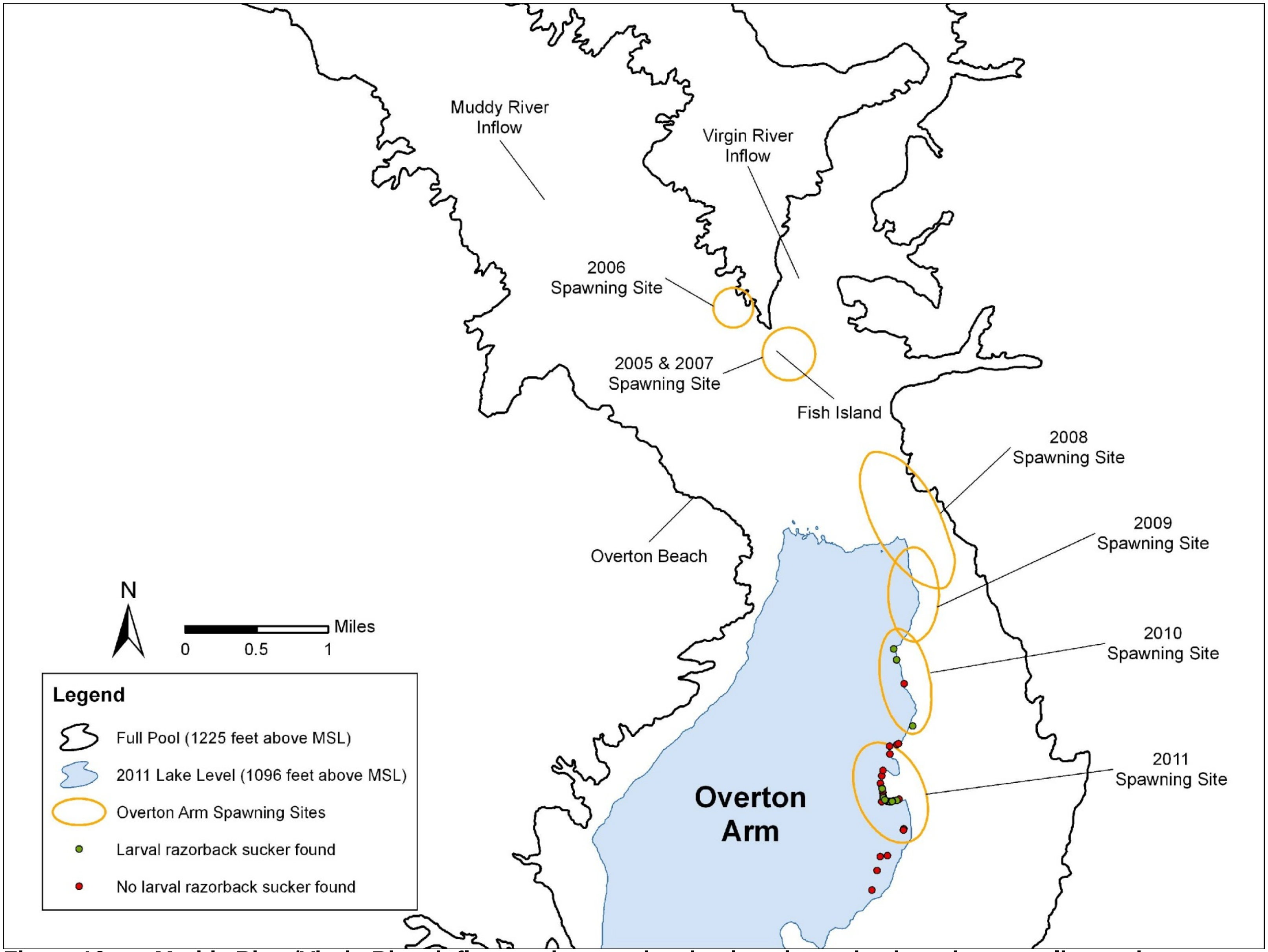

Figure 13. **Muddy River/Virgin River inflow study area showing larval razorback sucker sampling and capture locations, February 2011–April 2011.**

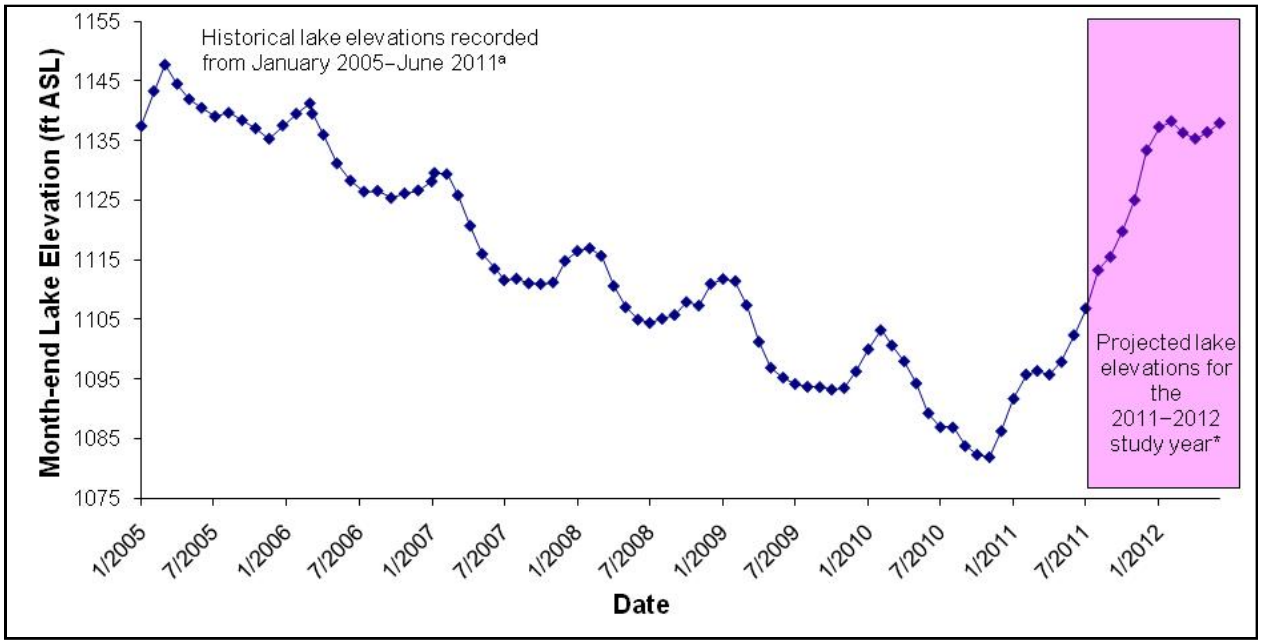

Figure 14. Historical Lake Mead month-end lake elevations in feet above sea level (ft ASL) from January 2005–June 2011, and projected lake elevations for the 2011–2012 study year.
[a]Data from USBR (2011).

either case, successful spawning of razorback suckers was confirmed within the back portions of Las Vegas Bay, and razorback sucker habitat use appeared to be most associated with shoreline habitats near the inflow of Las Vegas Wash.

As described in past annual reports (Welker et al. 2003, 2004, Albrecht et al. 2005, 2006b), receding lake elevations resulted in eastward shifts of the primary Echo Bay spawning site. Data for 2011 appear to be somewhat consistent with these findings; however, with increasing lake elevations in the spring of 2011, spawning was observed to cover a larger area of the back of Echo Bay when compared to 2010 (Figure 12). This broadened habitat use in 2011 is consistent with findings described above for Las Vegas Bay. Although 2011 trammel netting for adult razorback suckers resulted in relatively few captures in Echo Bay, this was mainly an artifact of our inability to set nets in the back portion of the bay because of lake elevation changes and construction on the new boat ramp. The new ramp was not completed, forcing all boats to launch at the old, congested ramp at the back of Echo Bay. The presence of larval fish during the 2011 spawning period, however, suggested there was a fairly widespread spawning site along the northern shoreline (Figure 12). Rising lake elevations have increased the size of Echo Bay, and spawning sites were found near the old Echo Bay boat ramp for the second consecutive year. Adult and subadult captures may appear relatively sparse, but larval sampling data suggests 2011 was a fairly successful year for razorback sucker spawning in Echo Bay. Projected lake elevation increases (Figure 14) will likely create vegetated areas and habitat conditions similar to those present during the early years of this study.

Of the three main study areas on Lake Mead, we know the least about historical razorback sucker habitat use in the Muddy River/Virgin River inflow area. Similar to the 2007–2010 field seasons, the collection of large numbers of ripe, adult razorback suckers in 2011 signified that spawning was likely occurring there. Furthermore, the capture of larval fish confirmed successful spawning in the northern part of the lake. The spawning site in the Muddy River/Virgin River inflow area was approximately 2 mi (3.2 km) south of the Virgin River inflow along the eastern shoreline of the Overton Arm near the Meadows (Figure 1, Figure 13). This site was discovered as a result of collecting adult and larval fish. It differs considerably from spawning sites established near Fish Island during the 2005–2007 field seasons. Future efforts in the Muddy River/Virgin River inflow area will be crucial in determining changes in the size of the spawning aggregate, changes in spawning sites, and the degree to which successful spawning and recruitment is occurring. Due to the gradual sloping nature of the bathymetry of this part of Lake Mead, future lake level increases will result in perhaps the greatest degree of change in spawning/recruitment habitat at this fairly broad and dynamic long-term monitoring site. Continued monitoring of the Muddy River/Virgin River inflow area will undoubtedly shed light on what to expect from razorback sucker population dynamics and habitat use at the other long-term monitoring locations.

Age Determination

A definitive age was obtained for all 73 razorback suckers collected in trammel nets on Lake Mead in 2011 (Appendix 1, Figure 15). Fifty-three of the fish (72.6%) were 7 years old or younger. The remaining 20 fish were from 8–12 years old. Most fish were 5–7 years old. The oldest fish was 12 years old (n = 1) and 574 mm TL. The youngest fish were 3 years old (2008 year class, n = 2) and averaged 383 mm TL. Only in the last five field seasons have we aged fish spawned after 1999, which suggests a continued pattern of recruitment in Lake Mead despite relatively dramatic lake elevation changes (Albrecht et al. 2006b, 2007, 2008a, 2010c).

To date, all of the aged fish were spawned from 1972–2008, with the exception of one fish that was spawned around 1966 (Appendix I). Until the last few field seasons, the majority of aged fish were spawned during high lake elevations between 1978–1989 and 1997–1999 (Figure 15). However, our most recent data show Lake Mead razorback sucker recruitment occurring beyond 1999, which coincides with the steady decline of lake elevations during recent years. Based on data obtained this season, 2001–2006 appears to be one of the better periods for Lake Mead razorback sucker recruitment, despite dropping lake elevations (Figure 15). The best observed recruitment year appears to have been 2005. It also appears that some level of recruitment is possible in Lake Mead regardless of lake elevation, with natural recruitment occurring nearly every year. This year’s aging data validate natural, wild recruitment within the Lake Mead razorback sucker population as recently as 2008. Since nothing suggests the trend in recruitment will cease, we anticipate that fish spawned from 2009–2011 will become susceptible to sampling gear within the next couple of years. To date, age has been determined for 360 Lake Mead razorback suckers captured during long-term monitoring efforts.

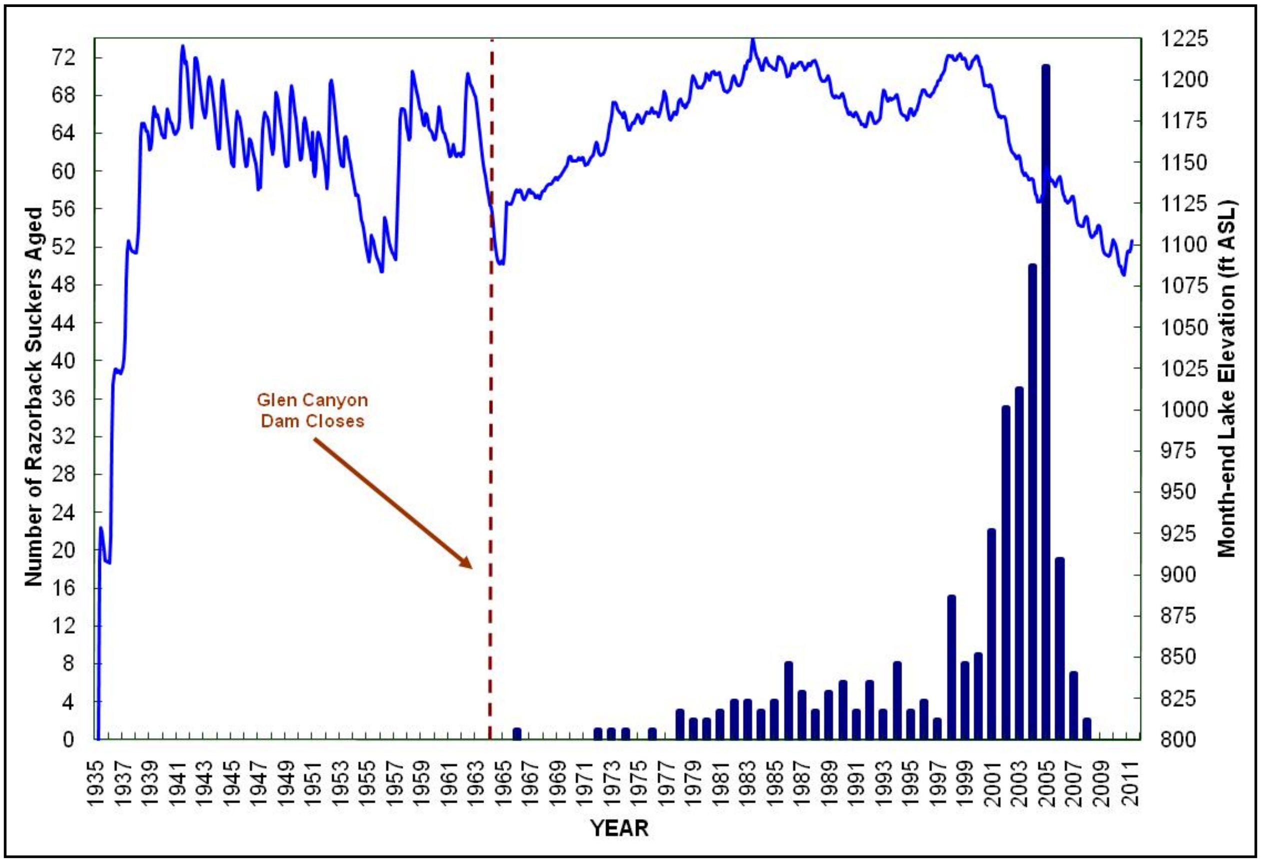

Figure 15. Lake Mead month-end lake elevations in feet above sea level (ft ASL) from January 1935–June 2011, with the number of aged razorback suckers spawned each year.

Age was also determined for one new flannelmouth sucker captured in Las Vegas Bay in 2011. This marks the first time a flannelmouth sucker has been captured in this area of Lake Mead. The fish was 7 years old (year class 2004). Additional flannelmouth suckers were captured in the CRI in 2011 and their ages were also determined. Those results can be found in Kegerries and Albrecht (2011).

Population Estimates

Over the past several years there have been numerous occasions in which fish from Echo Bay have moved into the northernmost portions of Lake Mead and vice versa, as reported in Albrecht et al. (2007, 2008a, 2008b, 2010c) and Kegerries et al. (2009). Hence, we can no longer categorize Echo Bay as a “closed” population or as one separate from the Muddy River/Virgin River inflow area spawning aggregate. For that reason data obtained in 2011 from Echo Bay and the Muddy River/Virgin River inflow area have been combined to provide a single population estimate. Additionally, a lake-wide population estimate that includes fish captured in the CRI is given solely for comparison. Population estimates were generated in the programs CAPTURE and MARK using razorback sucker netting-collection data obtained from 2009–2011. Modeling estimates given in the two programs were nearly identical; however, the program MARK was found to be more efficient in the data analysis process. Due to ease of use and overlapping results, only population estimates from the program MARK are displayed below (Table 7). Because population estimates for Lake Mead razorback sucker based on the program MARK proved valuable in 2011, future studies and reports will continue to use this program. Caution should still be used with any of these estimates for management purposes though, as the data continue to violate assumptions for closed-model population estimates.

Table 7. Population estimates using the program MARK, data from 2009–2011.

ESTIMATOR	2009–2011	95% CONFIDENCE INTERVAL
ECHO BAY AND MUDDY RIVER/VIRGIN RIVER INFLOW AREAS		
Model M_o	1,237	688–2,648
Chao M_h	1,568	760–3,427
Model Selection Procedure		
Jackknife	737	619–885
LAS VEGAS BAY		
Model M_o	107	81–154
Chao M_h	136	90–245
Model Selection Procedure		
Jackknife	167	112–278
LAKE WIDE (Including the Colorado River inflow area)		
Model M_o	733	560–992
Chao M_h	1,038	702–1,604
Model Selection Procedure		
Jackknife	982	825–1,180

The combined Echo Bay and Muddy River/Virgin River inflow area razorback sucker population point estimates ranged from 737–1,568 (95% confidence interval [CI] range 619–3,427) fish during 2009–2011. The Las Vegas Bay population point estimates ranged from 107–167 (95% CI range 81–278) fish. Similar to 2010, the population estimates for 2011 are higher than estimates from most previous years, presumably because of the relatively large number of young, unmarked fish captured during the past few spawning periods. The lake-wide population is closely associated with combined estimates for the northern end of the lake and Las Vegas Bay. Point estimates ranged from 733–982 (95% CI range 560–1,180) fish. Despite variability in the 2009–2011 population estimates, similar results were produced with overlapping confidence intervals; this suggests some level of correlation between the different models. Although results from the lake-wide estimate and the combined Echo Bay and Muddy River/Virgin River inflow area estimate appear higher, they fall within the confidence intervals of all the models from the program MARK.

DISCUSSION AND CONCLUSIONS

Information collected during the 2010–2011 field season (15th field season) has expanded our knowledge of spawning behavior, habitat use, recruitment patterns, growth, and age of razorback sucker populations in Lake Mead. Information has also been gained regarding age at sexual maturity, the nature of stocked and wild fish interactions, population abundance, and razorback sucker response to changing lake elevations. Sonic-telemetry, trammel-netting, and larval-collection data reaffirm the importance of Echo Bay, Las Vegas Bay, and the Muddy River/Virgin River inflow area to spawning razorback suckers and subadult fish in Lake Mead. Additional data on annual razorback sucker growth has confirmed rates documented in previous years. Also, aging data from 73 razorback suckers collected in 2011 were added to the 287 fish aged from 1998–2010, bringing the total number of aged fish to 360 during the course of our studies. Our data demonstrate nearly annual recruitment and continued production of new, wild razorback suckers in Lake Mead, processes that have not been documented for the species anywhere else in the Colorado River Basin.

Lake Elevation

Lake elevations at Lake Mead steadily increased through the 2010–2011 field season (Figures 2 and 14), and habitat that had been dry in previous seasons was once again inundated. In the past, changes in Lake Mead lake elevations have resulted in the movement of suspected razorback sucker spawning sites. The 2010–2011 field season saw exceptionally high seasonal input via snowmelt, as well as high-discharge disturbance events that eventually increased the lake volume (Figure 3). The timing and magnitude of the increased lake input (Figure 3), which brought increased amounts of woody debris and higher turbidity levels, may have helped cue reproductively ready razorback suckers to spawn. It is unclear if razorback suckers show specific site fidelity to reproductive habitat; however, it has been widely demonstrated that individuals do migrate to specific areas as they return for reproductive activity (Tyus and Karp 1990, Mueller et al. 2000), a finding supported by the recapture of individuals from previous field seasons at Lake Mead. More on this subject will be included in the Spawning Site Identification discussion section below.

Sonic Telemetry

Sonic telemetry proved valuable during the 2010–2011 field season. We were able to maintain contact with all eight fish from the January 2011 tagging event and six fish from the 2008 tagging event. Considering the amount of time the 2008 sonic tags have been active, it is likely that their batteries will begin to expire and the fish will no longer be contacted, a suspicion confirmed by the capture of two 2008 individuals in trammel nets (codes 488 and 3355) with expired tags (Table 1). Along with habitat and movement data, sonic-tagged fish provided crucial information regarding specific locations of the razorback sucker population, greatly enhancing our ability to catch adults, subadults, and larvae.

Sonic-tagged fish played an essential role in determining trammel-net placement for the capture of razorback suckers in Lake Mead, especially at the Muddy River/Virgin River inflow area. Fish caught and tagged in this area in 2011 may have cued in on proximal reproductive activity and congregated at the northern point of the cove west of the Meadows area of the Overton Arm. Nets placed above contact points for sonic-tagged fish consistently captured reproductively ready razorback suckers (Figures 6 and 9). We rarely captured the sonic-tagged fish, but unmarked fish were captured nearly every time we set the trammel nets, possibly indicating there are more razorback suckers than we think. Additionally, razorback suckers stocked in this area helped demonstrate the connectivity between spawning sites throughout the Overton Arm by using both the Muddy River/Virgin River inflow area and Echo Bay (Figures 5 and 6). The movement of two fish (codes 555 and 3354) in particular showed a pattern of habitat use also seen in the recapture and movement of wild fish tagged. Low lake elevations at the beginning of the 2010–2011 field season made areas such as Echo Bay difficult to sample for sonic-tagged fish. The initial lack of sonic-tagged fish, or inability to detect them, in Echo Bay provided a bit of uncertainty as to the best location for trammel nets; however, the eventual presence of one individual (code 555) helped in net placement and assisted in defining the 2011 spawning site. Although sonic-tagged fish aided our netting efforts in Echo Bay and the Muddy River/Virgin River inflow area, this was not the case in Las Vegas Bay (Figure 4). As Lake Mead lake elevations changed at the beginning of the 2011 field season (Figures 2 and 14), sonic-tagged fish stocked into Las Vegas Bay are thought to have moved into Las Vegas Wash and efforts to contact them were unsuccessful. Because of this, some of our netting locations were chosen based on past experience in Las Vegas Bay and our efforts perhaps weren't as productive as they would have been with the help of sonic-tagged fish.

Inflow areas may provide refuge and recruitment habitat for Lake Mead razorback suckers. Unfortunately, it is difficult to track sonic-tagged fish in inflow areas using the current sonic-telemetry protocol. Thus, it is plausible that some of the "unknown" sonic-tagged fish (Table 1) avoided detection in these shallow areas of the lake. Data from tracking sonic-tagged fish helped determine the 2011 spawning sites; however, changing lake elevations hindered efforts in some areas where the water was too shallow to navigate by boat. As lake elevations increased, many sonic-tagged fish followed the rising water. Several fish from the 2011 tagging event were found in the shallow, flowing water of inflow areas such as Las Vegas Wash and the Muddy River/Virgin River. This observation may support the idea that inflow areas are important to Lake Mead razorback sucker. It may also support the hypothesis that increased turbidity provides cover for razorback suckers in inflow areas, which typically lack inundated vegetation. Sonic-tagged fish will continue to provide invaluable data on changes in razorback sucker movement patterns, habitat use, and selected spawning sites.

In 2010 two sonic-tagged fish were found in the CRI that had not been tagged there; one fish (code 3354) had been caught in the Muddy River/Virgin River inflow area, and one had been caught in Las Vegas Bay (codes 465) (Albrecht et al. 2010b). Tagged in 2008, these individuals suggest that stocked razorback suckers move throughout Lake Mead and can leave their original stocking location to join other spawning aggregates. Similar behavior was observed in 2010–2011 with increased monitoring efforts in areas of Lake Mead not normally sampled. One fish (code 678) stocked into Echo Bay in 2008 had been contacted in the area until it disappeared; it then showed up in Las Vegas Bay in late 2010. This individual helped guide netting efforts, define a 2011 spawning site in Las Vegas Bay, and provided support for the idea that razorback suckers may use multiple spawning sites throughout their life. It also helped confirm the use of Bonelli Bay as a productive postspawn foraging area. (Bonelli Bay might also be a spawning site, although this has not been confirmed.) The collection of long-term movement data is important in assessing temporal changes in Lake Mead razorback sucker habitat use. These data may also be helpful in evaluating seasonal movement to and from reproductive habitat.

The first year use of SURs in long-term monitoring was a relatively novel concept (for Lake Mead long-term monitoring) in 2011. The ability to monitor areas unfrequented by regular sonic surveillance might help us learn where razorback suckers go outside of the spawning period. Passive telemetry might also prove useful should wild fish be sonic-tagged in the future, as they may have different seasonal habitat-use patterns than hatchery fish. We may have only begun to understand the potential of SURs, and we expect that data gathered with this technology in the 2011–2012 field season will more completely show seasonal-movement patterns of Lake Mead razorback sucker.

A remote PIT-tag reader may also prove useful in attaining razorback sucker seasonal-movement data. The technology has been used successfully on Lake Mohave (Marsh and Associates 2011), and it may find purpose in future applications on Lake Mead. One particular application could include exploring potential spawning sites without the elevated effort of netting. Additionally, a remote PIT-tag reader could validate our netting method or detect the rates at which razorback suckers escape capture. Although PIT-tag readers have been used on Lake Mohave, there are limitations and challenges to using them in Lake Mead. A smaller proportion of the razorback sucker population in Lake Mead is tagged with the necessary 134 kHz PIT tags, there are relatively large numbers of unmarked wild fish in Lake Mead, and the relatively large expanses of water in Lake Mead decrease the probability of chance detection.

Finally, we do not know if sonic-tagged and wild razorback suckers behave similarly in Lake Mead. This could be investigated by sonic-tagging wild razorback suckers, similar to the efforts of Holden et al. (1997) during the earlier years of the study. Such an investigation could also help determine the behaviors and habitat use of juvenile/subadult wild fish, which may be the key to recruitment success in Lake Mead. A sonic-telemetry study that utilizes wild fish of various size classes may help us ascertain whether the wild population engages in the large-scale movements observed in stocked, pond-reared, sonic-tagged razorback suckers. If sufficient numbers of wild juvenile/subadult fish could be captured and tagged, such a study could provide valuable insights into the recruitment success and abilities of Lake Mead razorback sucker. It could also be used to test the thesis that smaller, wild juvenile/subadult fish are able to escape predation by using some unknown feature or area of Lake Mead.

Adult Sampling and Spawning Site Observations

Trammel netting results in 2011 documented the continued presence of wild adult and subadult razorback suckers. Five wild subadult individuals were captured in Las Vegas Bay and 55 new wild adults were captured in the Muddy River/Virgin River inflow area, following the trend in Albrecht et al. (2008) and Kegerries et al. (2009), who reported high numbers of young fish present in Lake Mead. These capture events demonstrate the following:

1. Subadult fish are present on or near spawning habitat during the spawning period and may aggregate or school with conspecifics. Monitoring results from 2008–2011 demonstrate a relatively high abundance of young razorback suckers in Lake Mead.

2. Data from the last several years indicate that our ability to capture wild, subadult fish is rather stochastic and sporadic. The likelihood of capturing young, wild razorback suckers in Lake Mead was also discussed by Albrecht et al. (2006a), who indicated potential difficulties in sampling this younger portion of the Lake Mead razorback sucker population. Further efforts directed specifically at this life stage may be worth investigating in order to understand where recruitment is occurring in Lake Mead.

3. Natural recruitment of razorback suckers continues at Lake Mead, despite changing lake elevations. However, it is not understood why catching subadults has proven difficult. As our research continues, we anticipate uncovering the factors behind continued razorback sucker recruitment (a topic discussed in greater depth by Albrecht et al. [2008b] during their comprehensive review of Lake Mead razorback sucker research).

Despite continued changes in lake elevations and the subsequent changes in associated habitat, successful razorback sucker spawning is still occurring in Lake Mead. The 2011 primary spawning sites shifted little from previous years and are similar to the spawning sites identified in 2010 (Albrecht et al. 2006b, 2007, 2008a, 2010c; Kegerries et al. 2009). Spawning sites shifted only slightly relative to lake elevation, strengthening the idea that many razorback suckers return to the same spawn site year after year (Tyus and Karp 1990).

The 2011 spawning site in Las Vegas Bay was more difficult to define than in years previous. Although the 2011 sonic-tagged individuals frequented the suspected spawning site briefly, few sexually mature adults were collected. In past field seasons we have suspected that the north shore of Las Vegas Bay might be used as a spawning site. This remains a possibility, as abundant larval fish and reproductively active adults were captured here; however, changing lake elevations may have disrupted spawning activity in this area. Because many larval collections were made on the south shore and adult razorback suckers were collected on the north shore, it was more accurate to include the entire western end of Las Vegas Bay in the 2011 suspected spawning site. The disparity in locations of larval and adult fish could be due to larval drift caused by high winds or water currents from Las Vegas Wash, a point discussed further in the Larval Sampling section below. Although fewer adults were collected in Las Vegas Bay in 2011 than in previous field seasons, numerous subadults were captured in the inundated alluvial fan area of the Las Vegas Wash delta. The use of this habitat by young fish may be due to the area's highly productive environment coupled with the increase in available habitat seen with rising lake elevations in 2011. In general, the occurrence of subadult razorback suckers has been somewhat scant in our netting collections, which have focused on areas where adult fish are congregating to spawn. Perhaps because of this subadult habitat use is poorly understood in Lake Mead, and it is a topic for future investigations (Albrecht 2008a, 2010c). The 2011 field season saw record catches for adults in Lake Mead, although very few subadults were captured outside of Las Vegas Bay. The Lake Mead population appears to be relatively young, as nearly three-quarters of the individuals collected this field season were 7 years old or younger (Appendix I); thus, there appears to be a difference in the seasonal habitat use of adults and subadults.

We were able to identify a spawning site in Echo Bay, primarily based on larval fish collection data and sonic-tagged fish locations. In recent years Echo Bay spawning sites have been on the north side of the bay and appear to have followed receding lake elevations. Although we anticipated the spawning site would significantly move because of declining lake elevations and diminishing spawning habitat, this was not the case in 2010. In 2011 the Echo Bay spawning site covered a larger area than in previous years (Figure 12). Late increases in lake elevations made it possible to sample previously inaccessible portions of Echo Bay. Had conditions been less dynamic, the 2011 sampling efforts may have been greatly improved. Trammel-netting catch rates in Echo Bay may have been artificially low in 2011 due to difficulties of sampling the northwestern extent near the boat ramp.

Similar to Echo and Las Vegas bays, we located the 2011 spawning site in the Muddy River/Virgin River inflow area based on a combination of larval collection data, adult collections, and sonic-tagged fish locations. Sonic-tagged fish were contacted frequently in the Meadows area at the Muddy River/Virgin River inflow (Figures 1 and 6), and the placement of trammel nets near these sonic-tagged fish yielded high densities of adult razorback suckers exhibiting reproductive readiness (e.g., colored and tuberculated individuals freely giving milt or eggs). Although larval-collection data was included in the determination of the 2011 spawning site, the area had low larval abundances. One possible reason for low larval abundances is that high winds and the associated wave action could have pushed the larva out of the spawning site, a point discussed further in the Larval Sampling section.

A number of adults, from both sonic surveillance and trammel netting, used the Muddy River/Virgin River inflow and Echo Bay during the spawning period. Past monitoring efforts in the northernmost portions of Lake Mead, near the Muddy River/Virgin River inflow area, have provided fairly sound evidence that this spawning aggregate is an extension of the Echo Bay spawning population (Albrecht et al. 2008b). Based on data collected since 2005, it appears that the northern Lake Mead razorback sucker population's use of spawning habitat is broader and more diverse than previously thought. The size of this population also appears larger than previously reported, and the number of new recruits in this area of the lake makes continued investigation of this population and area worthwhile. Data from 2011 suggest that the Muddy River/Virgin River inflow area spawning aggregate is one of the largest in Lake Mead, as evidenced by the relative numbers and catch rates of subadult and adult fish captured in that area.

Furthermore, elevated trammel-netting capture rates occurred in this area, aided in part by sonic-tagged fish. The broad use of spawning habitats throughout the northern portion of Lake Mead is extremely important in terms of the overall status of Lake Mead razorback sucker, suggesting that the total numbers of fish inhabiting the lake may be higher than previously thought.

Additionally, nine razorback sucker year-classes were identified in 2011. It also appears a strong year-class from the 2004–2005 field season has recruited to the population, a finding made in past reports (Kegerries et al. 2009, Albrecht et al. 2010a, 2010b, 2010c) and one that is discussed further in sections below. Continued monitoring of razorback suckers in all three long-term study areas of Lake Mead through sonic telemetry, trammel netting, and larval sampling will be invaluable in describing habitat use, determining spawning sites, and understanding recruitment patterns. It will be important to find other predictors of spawning-site preference and recruitment success, perhaps through investigations of water quality or littoral zone predator-abundance data.

Physically, the three primary study areas have changed dramatically over the last 15 field seasons. Biologically, the relatively new influx of gizzard shad and quagga mussels at the known spawning sites may be important factors to track and understand in terms of their potential impacts to future razorback sucker recruitment success. It is essential to track physical, chemical, and biological changes over time to better understand and document razorback sucker recruitment success. Although recent study of water-quality changes 2 years after the introduction of quagga mussels in the Boulder Basin found no significant impacts, this species may still be in the primary stages of establishment and is cause for concern (Wong et al. 2010). Quagga mussels prefer a hard substrate for attachment, and approximately 49% of Lake Mead's subsurface is comprised of this preferred substrate. Areas already greatly affected by quagga mussels, such as the Hudson River, have approximately 7% hard substrate (Strayer et al. 1996, Wong et al. 2010). Additionally, although no significant impacts were found in water quality (Wong et al. 2010), Turner et al. (2011) stated that quagga mussels may degrade razorback sucker foraging and spawning habitat.

Larval Sampling

Larval razorback suckers were captured at each of the previously documented spawning sites in Lake Mead (i.e., Las Vegas Bay, Echo Bay, and the Muddy River/Virgin River inflow area) during the 2011 spawning period. Overall, the 2010–2011 field season was an excellent year for larval fish when compared with larval captures from past years (Albrecht et al. 2008a, 2010c, Kegerries et al. 2009). The increase in the number of larval fish in Lake Mead may be correlated with the large 2005 year-class of razorback sucker, a group of individuals now 6–7 years old and likely recruiting to the spawning population (Figure 15). Lake conditions in 2004–2005 may have provided habitat and environmental settings essential for larval and juvenile razorback sucker survival. With that, and similar conditions seen in 2010–2011, there is cause for excitement because the Lake Mead razorback sucker population has the potential to substantially increase. Increased lake elevations in 2011 may have helped alleviate environmental conditions that hindered larval fish production in past years. Increases in turbidity, woody debris, and nutrients from high-flow events are hypothesized to promote or allow for recruitment because of the cover they provide to young razorback suckers. These factors are thought to have favored the 2005 year-class, and we predict a similar outcome for the 2011 year-class.

In contrast to Las Vegas Bay in 2010, where the lowest larval catch rates were observed since 2006, catch rates appeared to recover in 2011, resulting in CPM values near those of the past 5-years (Table 6). Reasons for the higher CPM values are likely related to the increase in lake elevation at Lake Mead and the inundation of the Las Vegas Wash delta area. The inundation of shallow, productive delta habitats may have attracted adults to spawn and aided young fish by providing increased cover and forage. However, the highest numbers of razorback sucker larvae found in 2011 were located near the interface of Las Vegas Wash and the lake proper, suggesting that spawning may have occurred within the inaccessible areas of the wash. The relative absence of reproductively ready adult razorback suckers in trammel netting also suggests that although successful spawning occurred, larval captures could have been even higher with a more specific spawning site to key in on. As in 2010, our larval captures suggest that some of the Las Vegas Bay spawning aggregate may have successfully reproduced along the northern and southern shorelines.

Larval sampling in Echo Bay resulted in the highest CPM (1.482 fish/minute) among long-term monitoring sites in 2011 and among long-term monitoring sites for the past 5 years (Table 6). Las Vegas Bay and the Muddy River/Virgin River inflow area also continued to be successful spawning sites in 2011, with larval fish captured in both areas. The high larval razorback sucker yield at Echo Bay can be considered a success story, and it demonstrates the long-term resiliency of razorback sucker as a species. During the 2006–2007 and 2007–2008 field seasons, larval captures appeared to suffer greatly from a number of environmental and anthropogenic disturbances, such as declining lake elevations, reduction of spawning habitat, and high levels of marina development and maintenance in Echo Bay (Albrecht et al. 2008a, 2010c). Despite similar disturbances in 2011, the Echo Bay razorback sucker population spawned successfully and was able to capitalize on freshly inundated habitats and increased lake elevations. Similarly high CPM values for larval razorback suckers were also observed in the other long-term monitoring study areas of Lake Mead.

Although 2011 larval catch rates in the Muddy River/Virgin River inflow area were higher than in 2010, larval razorback sucker catch rates at this location were the lowest for the long-term monitoring areas in 2011 (Albrecht et al. 2010c). The Muddy River/Virgin River inflow area has typically seen low capture rates for larval razorback suckers. This is perplexing, particularly given the high number of adult and subadult razorback sucker captures at the Muddy River/Virgin River inflow area over the past several seasons. One potential explanation for the low CPM (0.013 fish/minute) at the Muddy River/Virgin River inflow area is high winds and the fact that the spawning site is located at the far end of an extreme fetch. Movement of larvae by wind has been suggested as an issue for larval locations in Lake Mead in previous reports (Albrecht et al. 2010c). Additionally, it has been postulated that high winds and the associated wave action could be a cause of mortality in larval razorback suckers in nearby Lake Mohave (Bozek et al. 1989) and a source of movement for larvae (M. Urban 2011, pers. comm.). Similarly, in Upper Klamath Lake, Oregon, high winds are likely the cause of mortality and dispersal from rearing grounds in larval catostomids (Cooperman et al. 2010). Spring 2011 was quite windy, often affecting our ability to sample for larvae. Movement of larval fish due to wind currents is likely, although larval sampling north and south of the suspected spawning site produced very few individuals. Further research in the Muddy River/Virgin River inflow area is warranted to determine the factors that may be limiting observed larval production.

As in past field seasons, BIO-WEST teamed with biologists from NDOW and Reclamation to collect additional larval razorback suckers for future repatriation efforts. These fish are being held and reared by NDOW, and BIO-WEST continues to work with NDOW and Reclamation to design experimental stocking procedures and monitoring strategies for these valuable fish. Finally, future collection of detailed physiochemical and limnological data could help in understanding differences in larval fish production, which in turn will provide important data on Lake Mead razorback sucker recruitment.

Aspects of Lake Mead Recruitment

The increase in razorback sucker captures at all sampling locations in recent years—specifically the continued pulses of new, young individuals—supports our hypothesis of why and how Lake Mead continues to support the only known, sustainable, growing, and largely wild population of razorback sucker (Albrecht et al. 2006b). We have attributed the initiation of recruitment of Lake Mead razorback sucker to a change in the management of Lake Mead. From the 1930s to1963, Lake Mead was either filling (a time when initial recruitment likely occurred and created the original lake population of razorback sucker) or it was operated with a sizable annual fluctuation. The lake was drawn down approximately 100 ft (30.5 m) in the mid-1960s as Lake Powell filled, and since that time it has been operated with relatively small annual fluctuations but relatively large multiyear fluctuations. It has been suspected that the drawdown of Lake Mead (for filling of Lake Powell and a subsequent drawdown in the 1990s) allowed terrestrial vegetation to become well established around the lake shoreline. The vegetation was then inundated as the lake rose, but (with small annual fluctuations) the vegetation remained intact for many years and provided cover in coves and other habitat that young razorback suckers may inhabit. Furthermore, vegetation and turbidity (an additional form of cover) near the inflows have resulted in recruitment. Before 1970 vegetation was unlikely to establish because of the relatively large, annual reservoir fluctuations. The presence of individual razorback suckers older than 30 years indicates that limited recruitment may have occurred from 1966–1978, a time when lake elevations slowly rose. Lake elevations reached their highest levels from 1978–1987, and the maximum amount of intact inundated vegetation probably existed in the lake.

Golden and Holden (2003) showed that cover, in terms of turbidity and vegetation, is more abundant in Echo Bay and Las Vegas Bay than in other Lake Mead or Lake Mohave coves. Furthermore, it has been accepted for years that turbidity plays a role in the susceptibility of young razorback suckers to predation (Johnson and Hines 1999). This information led to the hypothesis that low, annual fluctuations and large, multiyear lake elevation changes that promote the growth of vegetation around the lake, the inundation of that vegetation, and turbid conditions (compared with other locations Lower Colorado River Basin) are likely major reasons for continued razorback sucker recruitment in Lake Mead. Data collected during recent spawning periods suggest that turbidity may be much more important for razorback sucker recruitment in Lake Mead than previously thought, at least under conditions imposed by low lake elevations

(Albrecht et al. 2008). In the last four field seasons we have noticed a pulse of recruitment that coincides with lake condition and water year. Figure 15 best exemplifies the pulses in razorback sucker recruitment in relation to lake elevation and lake input, and Figure 3 illustrates the similarity between 2005 and 2011 with regard to input via the Virgin River. The data show that, along with the strong recruitment in 2002 and 2003, very substantial recruitment continued from 2004–2006. Since lake elevations declined during this period, turbidity may be much more important for razorback sucker recruitment than once thought. Additionally, large high-flow events that bring woody debris and fine sediments into Lake Mead may play a large role in providing cover and nutrients. Both turbidity and vegetative cover are likely important recruitment factors and should be considered for future investigation and monitoring. Although we have not measured vegetative cover or turbidity during the past few years, our field observations suggest there is less inundated vegetation or rooted aquatic vegetation than there has been in the past (Albrecht et al. 2010a). These parameters need to be measured consistently so comparisons between years or lake elevations can be made in the future.

Albrecht et al. (2007, 2008a, 2008b) identified items to evaluate in terms of turbidity and its effects on razorback sucker recruitment, with questions ranging from fairly simple to complex. For example, have turbidity levels increased in recent years (e.g., years since 1999 when the lake was at/near full pool)? Has there been a recent increase in the productivity of Lake Mead, especially near the known spawning sites? What impacts have low lake elevations had on the recruitment and status of littoral predatory fishes? With rising lake elevations, will these relationships change? Is it possible that fluctuating lake elevations have also impacted nonnative fish populations (such as green sunfish [*Lepomis cyanellus*], bluegill [*Lepomis macrochirus*], and other littoral fishes), and are these data even available for evaluation? Is it possible that larger deltas near the inflows, with their increased sediment loads and turbidity levels, could in fact provide habitat essential for recruitment of subadult razorback suckers? Are there other water-quality parameters that may have changed recently in Lake Mead, parameters that might impact early life-stage fishes and particularly affect young razorback sucker survival?

We hypothesize that turbidity is an important factor allowing for continued razorback sucker recruitment under low lake elevations on Lake Mead; however, turbidity appears to be equally important in the transitional increase of lake elevation currently seen. It seems logical that deltas associated with Lake Mead inflows begin to expand during low-water years, and riverine and wave action on the exposed sediment of the deltas and barren shorelines could contribute to increased cover in the form of turbidity, either directly (by deposition of smaller, suspended particles) or indirectly (through increased nutrient loading). Additionally, high-flow disturbances that provide large influxes of sediment and woody debris would too, in turn, provide increased cover in the form of turbidity in an increasing lake level scenario. In fact, we have observed this during the course of our studies. As the deltas expand because of dropping lake elevations and hydrological forces of flowing water at the inflows, more and more sediment could be eroded. As stated previously, this may in turn increase the amount of sediment (turbidity) that enters Lake Mead at the inflows and provide cover for early life stages of razorback sucker. Hence cover in the form of turbidity increases, ultimately leading to increased recruitment. Because data obtained from 2007–2011 show that pulses in razorback sucker recruitment are possible at both low (e.g., 2002–2006) and high lake elevations (e.g., 1978–1985 and 1998–1999), cover in the form of turbidity and/or vegetation, similar to that found in Lake Mead, is a potential key to understanding and perhaps enhancing the sustainability of the species through the Colorado River Basin.

Growth and Aging

Growth rates of recaptured Lake Mead razorback sucker continue to surpass those recorded for other wild razorback sucker populations. Mean annual growth for Lake Mead fish recaptured in 2011 was 24.7 mm/year, compared with very low growth (< 2.0 mm/year) for razorback sucker in Lake Mohave (Pacey and Marsh 1998) and the Green River (McAda and Wydoski 1980, Tyus 1987). It should be noted that the calculated growth rate for Lake Mead razorback sucker in 2011was based on four wild fish and two stocked fish recaptures. It is assumed that these growth rates of young wild fish would be greater than growth rates of older stocked fish. In general younger fish grow at a faster rate than older fish. As previously discussed in annual reports (e.g., Albrecht et al. 2006b, 2007, 2008a, 2008b, 2010c, Kegerries et al. 2009), higher growth rates for Lake Mead razorback sucker suggests the overall youthfulness of the population (Modde et al. 1996, Pacey and Marsh 1998, Mueller 2006).

Of the fish aged in 2011, most were from the 2005 year-class (age 6 in 2011). The strength of the 2005 year-class is also documented in Kegerries et al. (2009) and Albrecht et al. (2010c). These data are indicative of a healthy recruiting population, and the elevated numbers of young, quick-growing fish are likely driving the relatively high growth rates. As an increasing amount of young fish (< 7 years old) are captured and tagged, we expect that the additional data provided will enable us to understand and promote this relatively unknown life stage of razorback sucker in other locations.

Ages of the 73 fish evaluated during the 2011 field season and the 287 previously aged fish helped us conclude that recruitment has occurred regularly from 1978–2008. The greatest recruitment occurred from 2001–2006; 234 razorback suckers have been aged from those spawning periods alone. Forty-four percent of the fish aged in 2011 were less than 7 years old, indicating a strong recruitment trend in recent years. This pulse of young fish indicates that successful spawning and recruitment are indeed occurring at low lake elevations and that razorback sucker recruitment has occurred in Lake Mead nearly every year since the 1970s.

In 2005, flooding of the Muddy River and Virgin River increased lake elevations during the razorback sucker spawning period. A similar scenario occurred in 2011. Future investigation may show that pulses of recruitment are correlated with sudden lake elevation increases due to flooding events. However, unknown variables are still sustaining, if not increasing, recruitment of razorback sucker on Lake Mead.

Population Estimates

Estimates of razorback sucker populations in Lake Mead generated from data collected during the 2009–2011 field seasons are higher than estimates from past field seasons. This increase is also apparent in the recent trammel-netting CPUE values at the Muddy River/Virgin River inflow area, which appear to be partially driving the estimates for that area (Figure 7). Similarly, lake-wide estimates include the CRI, where a low CPUE is likely influencing these results. However, the most interesting results are the identical Las Vegas Bay population estimates given by program MARK and program CAPTURE. These estimates for Las Vegas Bay show how a smaller population could eliminate more variability in the model, resulting in similar population estimates. Based on findings from this season, future Lake Mead razorback sucker population estimates will likely be calculated only using program MARK. Again, we caution against basing management decisions and actions solely on these estimates, which likely underestimate the Lake Mead razorback sucker population.

Unfortunately, it is still too soon to tell what has caused the increase in captured razorback suckers during the past 4 years. Our results are a positive indication of the unique ability of Lake Mead razorback sucker to maintain what appears to be a sustainable, perhaps growing, population. Lake Mead razorback sucker appear to be capable of sustaining a population despite pressures imposed by nonnative fishes and ever-changing lake conditions. Future monitoring and research efforts on Lake Mead should help us understand the increase in new and young fish captured in 2011. Albrecht et al. (2008b) provide a more exhaustive discussion of the factors that potentially influence the annual population estimates of Lake Mead razorback sucker. Although population estimation in general may be somewhat subjective, the analysis allows for annual comparisons of the overall status of the razorback sucker in Lake Mead. Continuing this study will undoubtedly reveal more information regarding population dynamics and trends of razorback sucker in Lake Mead, specifically in respect to the parameters currently driving the recent increased recruitment trend.

Conclusions

The 2010–2011 field season was exceptional in that we met all of our objectives. Record numbers of razorback suckers were captured, sampled, and surveyed across all gear types in a fluctuating environment. Although it is unclear how changing lake elevations will affect future recruitment and population size, it appears that similar environmental conditions that proved favorable for the 2005 year-class may have occurred once again in 2010–2011. The 2011 year-class of razorback sucker may be one to follow in future studies, should it recruit as successfully as that of the 2005 year-class in Lake Mead. As a result of high catch rates and the capture of an abundance of larval fish at spawning sites, we remain optimistic about the status of the Lake Mead razorback sucker. When information on growth, age structure, and population estimates are considered together, the population appears generally young, self-sustaining, and perhaps growing. This alone demonstrates the uniqueness of the Lake Mead razorback sucker population and provides a positive outlook for an endangered species. Lake Mead provides an unequaled opportunity to discover how to promote this unique trend in other locations throughout the Colorado River Basin; hence, we reiterate the need for future research to understand how and why razorback suckers are able to naturally maintain a population despite fluctuating habitat conditions.

2011–2012 WORK PLAN

Specific Objectives for the 16th Field Season

1. Continue historical data collection, including tracking the remaining active, sonic-tagged Floyd Lamb Park razorback suckers in hopes of (1) continuing to document natural, wild, razorback sucker recruitment in Lake Mead, (2) following spawning populations to evaluate whether any further shifts in spawning-site selection occur, (3) continuing investigation of the Muddy River/Virgin River inflow area spawning site to evaluate and understand razorback sucker use of this area, and (4) potentially identifying new spawning sites as dictated by tracking sonic-tagged fish.

2. Continued monitoring efforts will include larval sampling, trammel netting, and fin ray collection and aging techniques, with particular emphasis on PIT-tagging and aging subadult and adult razorback suckers. Data stemming from continued monitoring will further assist with understanding the size and habitat use of the populations of razorback sucker in Lake Mead, help document the exchange of fish between sites, identify problems or habitat shifts associated with the known spawning aggregates (e.g., Echo Bay), and elucidate recruitment patterns in Lake Mead. Methods will follow those outlined in Albrecht et al. (2006a), updated in Albrecht et al. (2007, 2008a), and reviewed by Albrecht et al. (2008b). Following past field seasons, all data will be incorporated into the long-term Lake Mead razorback sucker database maintained by BIO-WEST.

3. Continue to lend support to the newly formed Lake Mead Interagency Work Group. In short, this effort will also help the Lower Colorado River Multi-Species Conservation Program more easily achieve its overall goals and objectives related to razorback sucker. We will present ideas for sonic-tagging wild fish, perhaps even juvenile/subadult fish, in an effort to gain a more robust understanding of the wild population and the habitats used by this unique population of razorback sucker.

4. Continue to coordinate and work jointly with the newly initiated razorback sucker investigations in the CRI. In 2010, efforts were undertaken to document the presence or absence of razorback sucker at the CRI. Through the capture of wild, ripe adult and larval razorback suckers, these efforts have resulted in the documentation of a razorback sucker spawning aggregate near the Colorado River/Lake Mead interface. Not only were wild fish documented using this new study area, but sonic-telemetry efforts in this portion of Lake Mead have located sonic-tagged fish originating from the long-term monitoring study areas. Thus, the potential exists for continued, perhaps increased, exchange of sonic-tagged razorback suckers between different areas of Lake Mead. Furthermore, it will be important to ascertain whether any of the PIT-tagged fish captured during long-term monitoring trammel-netting efforts are recaptured at the CRI (or vice versa). Coordination and collaboration between field crews will continue in 2012 to achieve the best possible research system for understanding Lake Mead razorback sucker.

5. Continue to search for avenues to investigate the physicochemical and biological factors that allow continued Lake Mead razorback sucker recruitment. This research item was originally posed by Albrecht et al. (2008b) and is now contained within the current Lake Mead razorback sucker Management Plan (Albrecht et al. 2009). Ultimately, we believe it is important to investigate and try to understand why Lake Mead razorback sucker are continuing to recruit despite the nonnative fish pressures and habitat modifications that are common throughout the historical range of this species.

6. Razorback suckers from Floyd Lamb Park or, better yet, wild-caught razorback suckers from Lake Mead should be sonic tagged if we lose contact with the majority of the currently sonic-tagged fish. Maintaining a sonic-tagged fish presence will serve to locate and sample existing populations and help identify other, new spawning sites. Data stemming from sonic-tagged fish are important in understanding the size and habitat use of razorback sucker populations at the long-term monitoring sites. Sonic-tagged razorback suckers also help document exchanges of sonic-tagged fish between sites, and they serve as beacons to identify potential problems or unexpected habitat shifts associated with the known spawning aggregates. For these reasons and others, it is important to maintain their continued presence at the long-term monitoring locations.

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REFERENCES

Abate, P.D., T.L. Welker, and P.B. Holden. 2002. Razorback sucker studies on Lake Mead, Nevada. 2001–2002 Annual Report. Prepared for the Department of Resources, Southern Nevada Water Authority, by BIO-WEST, Inc., Logan, UT. PR-578-6.

Albrecht, B., and P.B. Holden. 2005. Razorback sucker studies on Lake Mead, Nevada. 2004–2005 Annual Report. Prepared for the Department of Resources, Southern Nevada Water Authority, by BIO-WEST, Inc., Logan, UT. PR-960-1.

Albrecht, B., P.B. Holden, and M. Golden. 2006a. Lake Mead razorback sucker monitoring recommendations. 2005–2006 Report. Prepared for the Department of Resources, Southern Nevada Water Authority, by BIO-WEST, Inc., Logan, UT. PR-977-1.

Albrecht, B., P.B. Holden, and M. Golden. 2006b. Razorback sucker studies on Lake Mead, Nevada. 2005–2006 Annual Report. Prepared for the Department of Resources, Southern Nevada Water Authority, by BIO-WEST, Inc., Logan, UT. PR-977-1.

Albrecht, B., T. Sanderson, and P.B. Holden. 2007. Razorback sucker studies on Lake Mead, Nevada. 2006–2007 Annual Report. Prepared for the U.S. Bureau of Reclamation and the Department of Resources, Southern Nevada Water Authority, by BIO-WEST, Inc., Logan, UT. PR-1093-1.

Albrecht, B., R.B. Kegerries, and P.B. Holden. 2008a. Razorback sucker studies on Lake Mead, Nevada and Arizona. 2007–2008 Annual Report. Prepared for the U.S. Bureau of Reclamation and the Department of Resources, Southern Nevada Water Authority, by BIO-WEST, Inc., Logan, UT. PR-1161-1.

Albrecht, B., T. Sanderson, and P.B. Holden. 2008b. Razorback sucker studies on Lake Mead, Nevada and Arizona. 1996–2007 Comprehensive Report. Prepared for the U.S. Bureau of Reclamation and the Department of Resources, Southern Nevada Water Authority, by BIO-WEST, Inc., Logan, UT. PR-1093-2.

Albrecht, B., P.B. Holden, and R. Kegerries. 2009. Long-term management plan for the conservation of razorback sucker in Lake Mead, Nevada and Arizona. Prepared for the U.S. Bureau of Reclamation, by BIO-WEST, Inc., Logan, UT. PR-1161-03.

Albrecht, B., P.B. Holden, R. Kegerries, and M.E. Golden. 2010a. Razorback sucker recruitment in Lake Mead, Nevada–Arizona, why here? Lake and Reservoir Management 26(4):336–344.

Albrecht, B., R. Kegerries, R. Rogers, and P.B. Holden. 2010b. Razorback sucker investigations at the Colorado River inflow area of Lake Mead, Nevada and Arizona. Prepared for the U.S. Bureau of Reclamation, by BIO-WEST, Inc., Logan, UT. PR-1310-01.

Albrecht, B., R. Rogers, R. Kegerries, and P.B. Holden. 2010c. Razorback sucker studies on Lake Mead, Nevada and Arizona. 2009–2010 Annual Report. Prepared for the U.S. Bureau of Reclamation, Southern Nevada Water Authority, by BIO-WEST, Inc., Logan, UT. PR-1303-01.

Anderson, W.G., R.S. McKinley, and M. Colavecchia. 1997. The use of clove oil as an anesthetic for rainbow trout and its effects on swimming performance. North American Journal of Fisheries Management 17:301–307.

Baker, J.R., and L.J. Paulson. 1980. Influence of Las Vegas Wash density current on nutrient availability and phytoplankton growth in Lake Mead. Pages 1638–1646 *in* H.G. Stefan, editor. Symposium on surface water impoundments. Minneapolis, Minnesota.

Bidgood, B.F. 1980. Field surgical procedure for implantation of radio tags in fish. Fisheries Research Report No. 20. Alberta Fish and Wildlife Division, Department of Energy and Natural Resources. 10 p.

Bozek, M.A., L.J. Paulson, and G.R. Wilde. 1990. Effect of ambient Lake Mohave temperatures on development, oxygen consumption, and hatching success of the razorback sucker. Environmental Biology of Fishes 27:255–263.

Bunt, C.M., S.J. Cooke, C. Katopodis, and R.S. McKinley. 1999. Movement and summer habitat of brown trout (*Salmo trutta*) below a pulsed discharge hydroelectric generating station. Regulated Rivers: Research and Management 15:395–403.

Burke, T. 1995. Rearing wild razorback sucker larvae in lake-side backwaters, Lake Mohave, Arizona/Nevada. Proceeding of the Desert Fishes Council 26:35 (abstract only).

Carpenter, J. and G.A. Mueller. 2008. Small nonnative fishes as predators of larval razorback suckers. Southwestern Naturalist 53(2):236–242.

Chao, A. 1989. Estimating population size for sparse data in capture-recapture experiments. Biometrics 45:427–438.

Cooch, E. and G. White, editors. 2010. Program MARK: a gentle introduction, 9th edition. Cornell University, Ithaca, New York. Available: http://www.phidot.org/software/mark/docs/book/. (August 2011).

Cooperman, M.S., D.F. Markle, M. Terwilliger, and D.C. Simon. 2010. A production estimate approach to analyze habitat and weather effects on recruitment of two endangered freshwater fish. Canadian Journal of Fisheries and Aquatic Sciences 67(1):28–41.

Golden, M.E., and P.B. Holden. 2003. Determining conditions that promote razorback sucker recruitment in Lake Mead: a summary of the 2000–2002 pilot study. Prepared for the Department of Resources, Southern Nevada Water Authority, by BIO-WEST, Inc., Logan, UT. PR-784-2.

Holden, P.B., and C.B. Stalnaker. 1975. Distribution of fishes in the Dolores and Yampa River systems of the upper Colorado Basin. Southwestern Naturalist 19:403–412.

Holden, P.B. 1994. Razorback sucker investigations in Lake Mead, 1994. Prepared for the Department of Resources, Southern Nevada Water Authority, by BIO-WEST, Inc., Logan, UT. Final Report, PR-470-1.

Holden, P.B., P.D. Abate, and J.B. Ruppert. 1997. Razorback sucker studies on Lake Mead, Nevada. 1996–1997 Annual Report. Prepared for the Department of Resources, Southern Nevada Water Authority, by BIO-WEST, Inc., Logan, UT. PR-578-1.

Holden, P.B., P.D. Abate, and J.B. Ruppert. 1999. Razorback sucker studies on Lake Mead, Nevada. 1997–1998 Annual Report. Prepared for the Department of Resources, Southern Nevada Water Authority, by BIO-WEST, Inc., Logan, UT. PR-578-2.

Holden, P.B., P.D. Abate, and J.B. Ruppert. 2000a. Razorback sucker studies on Lake Mead, Nevada. 1998–1999 Annual Report. Prepared for the Department of Resources, Southern Nevada Water Authority, by BIO-WEST, Inc., Logan, UT. PR-578-3.

Holden, P.B., P.D. Abate, and J.B. Ruppert. 2000b. Razorback sucker studies on Lake Mead, Nevada. 1999–2000 Annual Report. Prepared for the Department of Resources, Southern Nevada Water Authority, by BIO-WEST, Inc., Logan, UT. PR-578-4.

Holden, P.B., P.D. Abate, and T.L. Welker. 2001. Razorback sucker studies on Lake Mead, Nevada. 2000–2001 Annual Report. Prepared for the Department of Resources, Southern Nevada Water Authority, by BIO-WEST, Inc., Logan, UT. PR-578-5.

Johnson, J.E., and R.T. Hines. 1999. Effect of suspended sediment on vulnerability of young razorback suckers to predation. Transactions of the American Fisheries Society 128:648–655.

Joseph, T.W., J.A. Sinning, R.J. Behnke, and P.B. Holden. 1977. An evaluation of the status, life history, and habitat requirements of endangered and threatened fishes of the upper Colorado River system. U.S. Fish and Wildlife Service, Office of Biological Services, Fort Collins, CO. FWS/OBS Rep. 24, part 2. 183 p.

Kaeding, L.R., B.D. Burdick, P.A. Schrader, and C.W. McAda. 1990. Temporal and spatial relations between the spawning of humpback chub and roundtail chub in the Upper Colorado River. Transactions of the American Fisheries Society 119:135–144.

Kegerries, R., B. Albrecht, and P.B. Holden. 2009. Razorback sucker studies on Lake Mead, Nevada and Arizona. 2008–2009 Annual Report. Prepared for the U.S. Bureau of Reclamation and the Department of Resources, Southern Nevada Water Authority, by BIO-WEST, Inc., Logan, UT. PR-1161-02.

Kegerries, R., and B. Albrecht. 2011. Razorback sucker investigations at the Colorado River inflow area of Lake Mead, Nevada and Arizona. Prepared for the U.S. Bureau of Reclamation, by BIO-WEST, Inc., Logan, UT. PR-1310-02.

Marsh and Associates. 2010. March 2010 razorback sucker summary, Lake Mohave, AZ-NV. Marsh and Associates LLC, Tempe, AZ.

Marsh and Associates. 2011. Update on remote sensing and population estimates for razorback sucker in Lake Mohave. Marsh and Associates LLC, Tempe, AZ.

Marsh, P.C., C.A. Pacey, and B.R. Kesner. 2003. Decline of razorback sucker in Lake Mohave, Colorado River, Arizona and Nevada. Transactions of the American Fisheries Society 132:1251–1256.

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

Marty, G.D., and R.C. Summerfelt. 1990. Wound healing in channel catfish by epithelialization and contraction of granulation tissue. Transactions of the American Fisheries Society 115:577–589.

McAda, C.W. and R.S. Wydoski. 1980. The razorback sucker, *Xyrauchen texanus*, in the upper Colorado River basin. U.S. Fish and Wildlife Service Technical Paper 99:1–15.

McCall, T. (Arizona Game and Fish Department). 1980. Fishery investigation of Lake Mead, Arizona-Nevada, from Separation Rapids to Boulder Canyon, 1978–79. Water and Power Resources Service, Boulder City, NV. Final Report. Contract Number 8-07-30-X0025. 197 p.

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

Minckley, W.L. 1983. Status of the razorback sucker, *Xyrauchen texanus* (Abbott), in the Lower Colorado River Basin. Southwestern Naturalist 28:165–187.

Minckley, W.L., P.C. Marsh, J.E. Brooks, J.E. Johnson, and B.L. Jensen. 1991. Management toward recovery of razorback sucker. *In:* W.L. Minckley and J.E. Deacon, editors. Battle against extinction: native fish management in the American West. Tucson: University of Arizona Press. pp. 303–357.

Modde, T., K.P. Burnham, and E.J. Wick. 1996. Population status of the razorback sucker in the middle Green River (U.S.A.). Conservation Biology 10(1):110–119.

Modde, T., Z.H. Bowen, and D.C. Kitcheyan. 2005. Spatial and temporal use of a spawning site in the middle Green River by wild and hatchery-reared razorback suckers. Transactions of the American Fisheries Society 134:937–944.

Mueller, G.A., P.C. Marsh, G. Knowles, and T. Wolters. 2000. Distribution, movements, and habitat use of razorback sucker (*Xyrauchen texanus*) in a lower Colorado River reservoir, Arizona-Nevada. Western North American Naturalist 60(2), 180–187.

Mueller, G.A. 2005. Predatory fish removal and native fish recovery in the Colorado River mainstem: what have we learned? Fisheries 30(9):10–19.

Mueller, G.A. 2006. Ecology of bonytail and razorback sucker and the role of off-channel habitats to their recovery. Scientific Investigations Report 2006–5065. U.S. Department of the Interior, U.S. Geological Survey. 64 p.

Otis, D.L., K.P. Burnham, G.C. White, and D.R. Anderson. 1978. Statistical inference from capture data on closed animal populations. Wildlife Monographs 62:1–135.

Pacey, C.A. and P.C. Marsh. 1998. Growth of wild adult razorback sucker in Lake Mohave, Arizona-Nevada. Presented at 30th Annual Meeting, Desert Fishes Council, Page, AZ. November 14, 1998.

Rexstad, E. and K. Burnham. 1992. User's guide for interactive program CAPTURE. Colorado Cooperative Fish and Wildlife Research Unit, Colorado State University, Fort Collins, CO.

Ryel, R. 2001. Consultant, personal communication with Tim L. Welker of BIO-WEST, Inc., Logan, Utah, regarding population abundance estimates. 09/14/2001.

Schooley, J.D., A.P. Karam, B.R. Kesner, P.C. Marsh, C.A. Pacey, and D.J. Thornbrugh. 2008a. Detection of larval remains after consumption by fishes. Transactions of the American Fisheries Society 137:1044–1049.

Schooley, J.D., B.R. Kesner, J.R. Campbell, J.M. Barkstedt, and P.C. Marsh. 2008b. Survival of razorback sucker in the lower Colorado River: Final project report January 2006–April 2008. Prepared for the Bureau of Reclamation by Arizona State University Native Fish Lab. Tempe, AZ.

Sjoberg, J.C. 1995. Historic distribution and current status of the razorback sucker in Lake Mead, Nevada-Arizona. Proceedings of the Desert Fishes Council 26:24–27.

Strayer D.L, J. Powell, P. Ambrose, L.C. Smith, and M.L. Pace. 1996. Arrival, spread, and early dynamics of a zebra mussel (*Dreissena polymorpha*) population in the Hudson River estuary. Canadian Journal of Fisheries and Aquatic Sciences 53:1143–1149.

Tyus, H.M. 1982. Fish radiotelemetry: theory and application for high conductivity rivers. FWS/OBS-82/38. U.S. Department of the Interior, Fish and Wildlife Service, Washington, D.C.

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

Tyus, H.M., and C.A. Karp. 1990. Spawning and Movements of Razorback Sucker, *Xyrauchen texanus*, in the Green River Basin of Colorado and Utah. Southwestern Naturalist 35(4):427–433.

Turner, K., W.H. Wong, S.L. Gerstenberger, and J.M. Miller. 2011. Interagency Monitoring Action Plan (I-MAP) for quagga mussels in Nevada-Arizona, USA. Aquatic Invasions 6(2):195–204.

(USBR) U.S. Bureau of Reclamation. 2011. Historical Lake Mead reservoir levels. Location: http://www.usbr.gov/lc/. Numerous links utilized.

(USFWS) U.S. Fish and Wildlife Service. 1991. Endangered and threatened wildlife and plants; the razorback sucker (*Xyrauchen texanus*) determined to be an endangered species; Final rule. Federal Register 56 (23 October 1991): 54957–54967.

(USFWS) U.S. Fish and Wildlife Service. 1997. Final biological and conference opinion on Lower Colorado River operations and maintenance-Lake Mead to southerly international boundary. U.S. Fish and Wildlife Service, Phoenix, AZ.

Valdez, R.A., and B.C. Nilson. 1982. Radiotelemetry as a means of assessing movement and habitat selection of humpback chub. Transactions of the Bonneville Chapter of the American Fisheries Society 182:29–39.

Valdez, R.A., and W.J. Masslich (BIO-WEST, Inc.). 1989. Winter habitat study of endangered fish - Green River: wintertime movement and habitat of adult Colorado squawfish and razorback suckers. BIO-WEST Report No. 136-2. Contract No. 6-CS-40-04490. U.S. Department of the Interior, Bureau of Reclamation, Salt Lake City, Utah. 184 p.

Valdez, R.A., and L. Trinca. 1995. Data collection plan, supplement no. I., life history and ecology of the humpback chub (*Gila cypha*) in the Colorado River, Grand Canyon, Arizona. U.S. Bureau of Reclamation, Upper Colorado River Region, Salt Lake City, Utah.

Welker, T.L. and P.B. Holden. 2003. Razorback sucker studies on Lake Mead, Nevada. 2002–2003 Annual Report. Prepared for the Department of Resources, Southern Nevada Water Authority, by BIO-WEST, Inc., Logan, UT. PR-578-7.

Welker, T.L. and P.B. Holden. 2004. Razorback sucker studies on Lake Mead, Nevada. 2002–2003 Annual Report. Prepared for the Department of Resources, Southern Nevada Water Authority, by BIO-WEST, Inc., Logan, UT. PR-578-8.

Wick, E.J., C.W. McAda, and R.V. Bulkley. 1982. Life history and prospects for recovery of the razorback sucker. *In:* W.H. Miller, H.M. Tyus, and C.A. Carlson, editors. Fishes of the upper Colorado River System: present and future. American Fisheries Society, Western Division, Bethesda, MD. pp. 120–126.

Wong, W.H., T. Tietjen, S. Gerstenberger, G.C. Holdren, S. Mueting, E. Loomis, P. Roefer, B. Moore, K. Turner, and I. Hannoun. 2010. Potential ecological consequences of invasion of the quagga mussel (*Dreissena bugensis*) into Lake Mead, Nevada-Arizona. Lake and Reservoir Management 26: 4, 306–315.

APPENDIX I: RAZORBACK SUCKER AGING DATA

Table A-1. Ages determined from razorback sucker pectoral fin ray sections collected from Lake Mead.

DATE COLLECTED	TOTAL LENGTH (mm) [a]	AGE	PRESUMPTIVE YEAR SPAWNED
	LAS VEGAS BAY		
5/10/1998	588	10 [b]	1987
12/14/1999	539	13	1986
12/14/1999	606	17+	1979–1982
12/14/1999	705	19+	1977–1980
1/8/2000	650	18+	1978–1981
2/27/2000	628	17+	1979–1982
1/9/2001	378	6	1994
2/7/2001	543	11	1989
2/22/2001	585	13	1987
12/1/2001	576	8–10	1991–1993
12/1/2001	694	22	1979
12/1/2001	553	10	1991
2/2/2002	639	16	1985
3/25/2002	650	22	1979
3/25/2002	578	10–11	1990–1991
3/25/2002	583	22–24	1977–1979
3/25/2002	545	20 [b]	1982
3/25/2002	576	20	1982
5/7/2002	641	15	1986
6/7/2002	407	6	1995
6/7/2002	619	20 [b]	1982
6/7/2002	642	20 [b]	1982
12/3/2002	354	4	1998
12/6/2002	400	4	1998
12/6/2002	376	4	1998
12/19/2002	395	4	1998
1/7/2003	665	16	1986
1/22/2003	494	4	1998
2/5/2003	385	4	1998
2/18/2003	443	5	1997
3/4/2003	635	19	1983
3/20/2003	420	4	1998
4/8/2003	638	21 [b]	1982
4/17/2003	618	10	1992

Table A-1. (Cont.)

DATE COLLECTED	TOTAL LENGTH (mm) [a]	AGE	PRESUMPTIVE YEAR SPAWNED
4/22/2003	650	20–22	1980–1982
5/4/2003	415	3+ [c]	1999
3/3/2004	370	5	1998
2/22/2005	529	6	1998
2/22/2005	546	6	1998
3/29/2005	656	16	1989
1/26/2006	740	15	1991
2/21/2006	621	23	1983
3/23/2006	461	5	2001
3/23/2006	718	16	1990
3/31/2006	635	7	1999
3/31/2006	605	6	2000
4/4/2006	629	6	2000
4/25/2006	452	4	2002
4/25/2006	463	4	2002
1/30/2007	514	5	2002
2/6/2007	519	5	2002
2/6/2007	574	8	1999
2/13/2007	526	5	2002
2/16/2007	530	5	2002
2/20/2007	534	6	2001
2/21/2007	358	3	2004
2/21/2007	511	5	2002
2/27/2007	645	13	1994
2/27/2007	586	15	1992
2/27/2007	603	13	1994
2/27/2007	650	17	1990
3/6/2007	515	4	2003
3/6/2007	611	13	1994
3/6/2007	565	6	2001
3/13/2007	586	7	2000
3/13/2007	636	25	1982
3/13/2007	524	5	2002
4/2/2007	704	9	1998
4/9/2007	644	11	1996
2/12/2008	425	5	2003

Table A-1. (Cont.)

DATE COLLECTED	TOTAL LENGTH (mm) [a]	AGE	PRESUMPTIVE YEAR SPAWNED
2/12/2008	390	3	2005
2/12/2008	490	3	2005
2/12/2008	430	4	2004
2/12/2008	379	4	2004
2/12/2008	399	4	2004
2/12/2008	430	4	2004
2/12/2008	413	4	2004
2/12/2008	554	9	1999
2/12/2008	426	9	1999
2/18/2008	385	3	2005
2/25/2008	605	6	2002
2/25/2008	655	36	1972
4/3/2008	468	4	2004
4/3/2008	619	7	2001
4/3/2008	640	10	1998
4/3/2008	560	11	1997
4/8/2008	423	3	2005
4/8/2008	535	6	2002
4/10/2008	422	3	2005
4/10/2008	375	3	2005
4/10/2008	452	4	2004
4/10/2008	472	4	2004
4/10/2008	467	4	2004
4/10/2008	429	5	2003
4/23/2008	430	4	2004
2/12/2009	536	7	2002
2/12/2009	510	7	2002
2/20/2009	377	3	2006
2/24/2009	458	4	2005
2/24/2009	421	4	2005
2/26/2009	369	3	2006
3/3/2009	376	4	2005
3/3/2009	411	4	2005
3/3/2009	438	5	2004
3/3/2009	451	4	2005
3/3/2009	395	5	2004

Table A-1. (Cont.)

DATE COLLECTED	TOTAL LENGTH (mm) [a]	AGE	PRESUMPTIVE YEAR SPAWNED
3/3/2009	416	4	2005
3/13/2009	427	4	2005
3/11/2009	565	8	2001
3/11/2009	510	8	2001
3/17/2009	440	5	2004
3/17/2009	420	5	2004
3/17/2009	431	5	2004
3/17/2009	340	5	2004
3/17/2009	44	5	2004
3/24/2009	546	8	2001
3/24/2009	539	8	2001
4/8/2009	521	8	2001
4/13/2009	419	6	2003
4/13/2009	403	6	2003
4/13/2009	446	6	2003
4/13/2009	535	6	2003
4/15/2009	578	13	1996
4/15/2009	748	17	1992
4/15/2009	528	11	1998
4/15/2009	630	15	1994
2/2/2010	531	5	2005
2/2/2010	391	5	2005
2/2/2010	342	5	2005
2/11/2010	351	3	2007
3/3/2010	485	5	2005
3/3/2010	553	6	2004
3/3/2010	621	9	2001
3/23/2010	395	3	2007
3/23/2010	500	5	2005
3/23/2010	514	6	2004
4/20/2010	560	7	2003
2/8/2011	587	8	2003
2/10/2011	574	12 [d]	1999
3/3/2011	364	7	2004
3/3/2011	434	4	2007
3/24/2011	411	4	2007

Table A-1. (Cont.)

DATE COLLECTED	TOTAL LENGTH (mm) [a]	AGE	PRESUMPTIVE YEAR SPAWNED
3/24/2011	390	3	2008
3/29/2011	379	6	2005
3/29/2011	346	4	2007
3/29/2011	376	3	2008
		ECHO BAY	
1/22/1998	381	5	1993
1/9/2000	527	13	1987
1/9/2000	550	13	1987
1/9/2000	553	13	1987
1/9/2000	599	12–14	1986–1988
1/27/2000	557	13	1986
1/27/2000	710	19+	1979–1981
2/9/2001	641	13	1988
2/24/2001	577	18+	1980–1982
2/24/2001	570	8	1992
2/24/2001	576	15	1986
2/24/2001	553	18	1983
12/18/2001	672	13	1988
2/27/2002	610	18–20	1982–1984
3/26/2002	623	16	1986
4/2/2002	617	35+	1966–1968
4/17/2002	583	20 [b]	1982
5/2/2002	568	18–19	1983–1984
11/18/2002	551	13	1989
12/4/2002	705	26	1976
1/21/2003	591	16	1986
2/3/2003	655	27–29	1974
2/3/2003	580	13	1989
4/2/2003	639	19–20	1982
4/2/2003	580	23–25	1978
4/23/2003	584	10	1992
5/6/2003	507	9+	1993
5/6/2003	594	20	1982
12/18/2003	522	20	1982
1/14/2004	683	14	1989
2/18/2004	613	10	1993

Table A-1. (Cont.)

DATE COLLECTED	TOTAL LENGTH (mm) [a]	AGE	PRESUMPTIVE YEAR SPAWNED
3/17/2004	616	19	1983
3/17/2004	666	17	1985
3/17/2004	618	9	1994
4/6/2004	755	17	1985
3/2/2005	608	15	1990
3/2/2005	624	8	1996
1/10/2006	630	12	1994
2/1/2006	705	16	1990
2/16/2006	601	22	1984
1/11/2007	535	5	2002
1/11/2007	493	5	2002
2/1/2007	637	7	2000
2/8/2007	609	12	1995
2/14/2007	501	4	2003
3/2/2007	590	11	1996
3/9/2007	660	12	1995
3/16/2007	691	21	1986
3/28/2007	564	13	1994
2/28/2008	640	25	1983
2/29/2008	635	8	2000
3/5/2008	653	24	1984
3/19/2008	532	6	2002
3/19/2008	510	7	2001
2/19/2009	602	7	2002
4/15/2009	662	16	1993
2/18/2010	520	7	2003
2/25/2010	465	5	2005
3/10/2010	535	7	2003
3/10/2010	530	9 [e]	2001
3/24/2010	451	4	2006
3/24/2010	465	5	2005
3/24/2010	466	5	2005
4/8/2010	470	5	2005
4/8/2010	540	8	2002
4/22/2010	538	7	2003
4/22/2010	489	8	2002

Table A-1. (Cont.)

DATE COLLECTED	TOTAL LENGTH (mm) [a]	AGE	PRESUMPTIVE YEAR SPAWNED
4/22/2010	460	9	2001
2/9/2011	529	7	2004
2/9/2011	524	7	2004
2/24/2011	555	7	2004
3/2/2011	513	6	2005
4/7/2011	533	7	2004
4/7/2011	522	7	2004
4/19/2011	537	6	2005
4/19/2011	540	7	2004
4/19/2011	515	6	2005
MUDDY RIVER/VIRGIN RIVER INFLOW AREA			
2/23/2005	608	6	1998
2/22/2006	687	33 [f]	1973
2/22/2007	452	4	2003
2/22/2007	542	5	2002
2/22/2007	476	5	2002
2/22/2007	459	4	2003
2/22/2007	494	5	2002
3/1/2007	477	5	2002
3/1/2007	512	4	2003
3/8/2007	463	5	2002
3/8/2007	455	4	2003
3/15/2007	516	4	2003
4/3/2007	508	4	2003
4/11/2007	498	7	2000
2/27/2008	465	4	2004
2/27/2008	670	20	1988
3/25/2008	530	6	2002
3/25/2008	271	2 [g]	2006
3/26/2008	345	3	2005
3/26/2008	541	7	2001
3/26/2008	521	7	2001
3/26/2008	665	18	1990
4/1/2008	229	2	2006
4/1/2008	370	3	2005
4/1/2008	360	3	2005

Table A-1. (Cont.)

DATE COLLECTED	TOTAL LENGTH (mm) [a]	AGE	PRESUMPTIVE YEAR SPAWNED
4/1/2008	385	4	2004
4/1/2008	514	5	2003
4/1/2008	536	5	2003
4/1/2008	514	6	2002
4/1/2008	548	6	2002
4/1/2008	518	7	2001
4/1/2008	530	7	2001
4/1/2008	494	8	2000
4/1/2008	535	9	1999
4/1/2008	559	10	1998
4/22/2008	533	6	2002
4/22/2008	504	6	2002
2/4/2009	549	7	2002
2/13/2009	348	3	2006
2/13/2009	374	3	2006
2/13/2009	372	3	2006
2/17/2009	390	3	2006
2/17/2009	365	3	2006
2/17/2009	375	3	2006
2/18/2009	399	3	2006
2/18/2009	291	3	2006
2/18/2009	366	3	2006
2/24/2009	362	3	2006
2/25/2009	585	8	2001
3/3/2009	386	4	2005
3/3/2009	390	4	2005
4/6/2009	464	5	2004
4/8/2009	552	8	2001
4/15/2009	496	9	2000
4/15/2009	553	10	1999
4/15/2009	572	9	2000
4/15/2009	505	8	2001
2/3/2010	455	3	2007
2/3/2010	475	5	2005
2/3/2010	441	5	2005
2/3/2010	495	7	2003

Table A-1. (Cont.)

DATE COLLECTED	TOTAL LENGTH (mm) [a]	AGE	PRESUMPTIVE YEAR SPAWNED
2/3/2010	532	8	2002
2/9/2010	491	5	2005
2/9/2010	444	5	2005
2/9/2010	500	5	2005
2/9/2010	464	6	2004
2/9/2010	471	6	2004
2/17/2010	494	6	2004
2/17/2010	470	7	2003
2/17/2010	479	7	2003
2/17/2010	425	7	2003
2/17/2010	483	7	2003
2/24/2010	234	4	2006
3/17/2010	477	4	2006
3/17/2010	465	5	2005
3/17/2010	485	5	2005
3/17/2010	499	6	2004
3/17/2010	491	6	2004
3/17/2010	600	9	2001
3/18/2010	452	5	2005
3/18/2010	473	5	2005
3/24/2010	485	5	2005
2/1/2011	601	7	2004
2/1/2011	571	6	2005
2/1/2011	556	7	2004
2/1/2011	586	6	2005
2/1/2011	506	8	2003
2/1/2011	572	8	2003
2/1/2011	500	6	2005
2/22/2011	501	7	2004
2/22/2011	534	6	2005
2/22/2011	506	6	2005
2/22/2011	508	6	2005
2/22/2011	524	7	2004
2/22/2011	517	8	2003
2/22/2011	580	5	2006
2/22/2011	509	8	2003

Table A-1. (Cont.)

DATE COLLECTED	TOTAL LENGTH (mm) [a]	AGE	PRESUMPTIVE YEAR SPAWNED
2/22/2011	586	6	2005
2/22/2011	512	7	2004
2/22/2011	585	6	2005
2/23/2011	545	6	2005
2/23/2011	500	6	2005
2/23/2011	527	7	2004
2/23/2011	552	5	2006
3/1/2011	510	10	2001
3/1/2011	573	9	2002
3/1/2011	518	8	2003
3/1/2011	538	6	2005
3/1/2011	532	9	2002
3/1/2011	553	6	2005
3/1/2011	595	6	2005
3/1/2011	563	6	2005
3/1/2011	555	6	2005
3/1/2011	483	7	2004
3/1/2011	599	9	2002
3/1/2011	560	5	2006
3/9/2011	556	7	2004
3/9/2011	534	6	2005
3/9/2011	549	7	2004
3/9/2011	494	4	2007
3/9/2011	505	6	2005
3/15/2011	575	8	2003
3/15/2011	551	8	2003
3/15/2011	515	7	2004
3/15/2011	558	8	2003
3/15/2011	576	8	2003
3/15/2011	587	8	2003
3/15/2011	572	7	2004
3/15/2011	575	10	2001
3/15/2011	551	7	2004
3/15/2011	561	7	2004
3/15/2011	566	9	2002
3/15/2011	542	6	2005

Table A-1. (Cont.)

DATE COLLECTED	TOTAL LENGTH (mm) [a]	AGE	PRESUMPTIVE YEAR SPAWNED
3/15/2011	577	8	2003
4/5/2011	521	7	2004
4/5/2011	495	6	2005
4/12/2011	572	8	2003

[a] mm = millimeters.

[b] Fish stocked from Echo Bay larval fish captured in 1999 and raised at Nevada Department of Wildlife Lake Mead Fish Hatchery.

[c] Fish stocked from Floyd Lamb Park ponds (1982 Dexter National Fish Hatchery cohort placed in Floyd Lamb Park ponds in 1984).

[d] Fish stocked from Floyd Lamb Park ponds, sonic tagged in 2008 (code 3355).

[e] Fish stocked from Floyd Lamb Park ponds (from an unknown 2001-2003 cohort stocking event).

[f] Fish was aged at 33 years of age, +/- 2 years.

[g] Fish was a mortality. Found dead in net, obvious net predation/wounds. Fin ray aging results validated using otoliths.