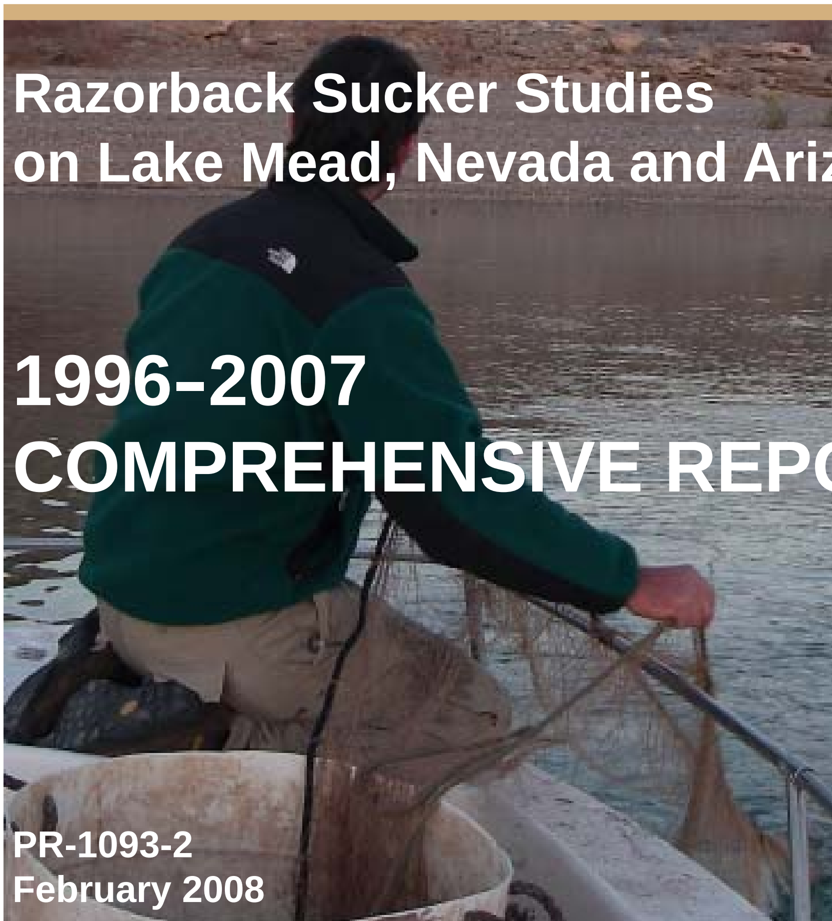
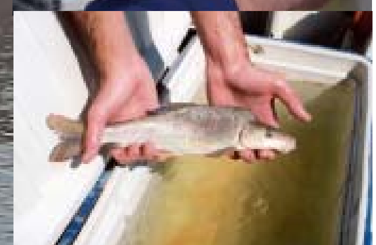
RECLAMATION

Managing Water in the West

Razorback Sucker Studies on Lake Mead, Nevada and Arizona

1996–2007 COMPREHENSIVE REPORT





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Bureau of Reclamation
Lower Colorado Region
P.O. Box 61470
Boulder City, Nevada 89006-1470

and

Southern Nevada Water Authority
P.O. Box 99956
Las Vegas, Nevada 89193-9956

Submitted by:

Brandon Albrecht, Travis Sanderson,
and Paul B. Holden
BIO-WEST, Inc.
1063 West 1400 North
Logan, Utah 84321-2291

EXECUTIVE SUMMARY

The razorback sucker (*Xyrauchen texanus* [Abbott]) is one of four endemic, large-river fish species (Colorado pikeminnow [*Ptychocheilus lucius*], bonytail [*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). Razorback sucker was historically widespread and common throughout the larger rivers of the Colorado River Basin (Minckley et al. 1991). The distribution and abundance of razorback sucker are currently greatly reduced from historic levels, mainly due to 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). Razorback sucker persisted in several of the reservoirs that were constructed in the lower Colorado River Basin; however, these populations were comprised primarily of adult fishes 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). Riverine populations in the Upper Colorado River Basin also have declined as recruitment has not occurred at significant levels since the construction of these mainstem dams. It is thought that predation by bass (*Micropterus* spp.), common carp (*Cyprinus carpio*), channel catfish (*Ictalurus punctatus*), sunfish (*Lepomis* spp.), and other nonnative species is the primary reason for the lack of razorback sucker recruitment throughout its original distribution (Minckley et al. 1991, Marsh et al. 2003).

It was thought that the same trends in razorback sucker decline were occurring in Lake Mead. Razorback sucker numbers, initially high in Lake Mead, became noticeably decreased in the 1970s, and none were collected during the 1980s. However, in the early 1990s, the Nevada Division of Wildlife (NDOW) was informed by local anglers that the species was still present in two localized areas of Lake Mead: Las Vegas Bay and Echo Bay. Limited sampling efforts initiated by NDOW soon confirmed the presence of remnant populations of razorback sucker in Lake Mead.

In 1996 the Southern Nevada Water Authority (SNWA), in cooperation with NDOW, initiated the Lake Mead studies to attempt to identify some of the basic population dynamics of razorback sucker in Lake Mead. BIO-WEST, Inc. (BIO-WEST) was contracted to design and conduct the study with collaboration from the SNWA and NDOW. Other cooperating agencies included the U.S. Bureau of Reclamation (Reclamation), U.S. National Park Service (NPS), Colorado River Commission of Nevada, and the U.S. Fish and Wildlife Service (USFWS).

Since the inception of the Lake Mead studies more than a decade ago, study efforts have included examining all life history stages of the fish: larval, juvenile, and subadult/adult. Larval sampling has included efforts on a lake-wide basis, but the primary focus has been in Las Vegas and Echo bays. Sampling for juvenile fish was conducted for seven consecutive study years (beginning in 1996), but this effort was discontinued due to the failure to capture even a single juvenile razorback sucker. Adult studies have included trammel netting and tracking of sonic-tagged fish. Trammel netting has been conducted primarily in Las Vegas and Echo bays, but also in the Colorado River inflow and the Muddy River/Virgin River inflow areas.

To date, 12,607 larval razorback sucker have been captured. The majority of these captures came from Las Vegas and Echo bays (> 99%); however, larval fish were also captured in the Colorado River inflow area, Overton Arm, Muddy River/Virgin River inflow area, and the Virgin Basin. Larval sampling has also resulted in the documentation of successful shifts in spawning locations in response to fluctuating lake levels.

A total of 446 razorback sucker captures, including more than 30 subadult fish, occurred via trammel netting in Las Vegas Bay (179 fish), Echo Bay (240), the Overton Arm (6), and the Muddy River/Virgin River inflow area (21). Razorback sucker captures stemming from trammel netting efforts have provided valuable information regarding population dynamics, movement patterns, growth rates, recruitment trends, and age structures of the Lake Mead population. Trammel netting has provided the greatest amount of knowledge regarding all aspects of razorback sucker ecology, excluding larval stages.

Razorback sucker movement patterns and habitat use data have been garnered through sonic telemetry. Fifty-five sonic-tagged fish were stocked in the lake (28 in Las Vegas Bay, 24 in Echo Bay, and 3 in the Muddy River/Virgin River inflow area), and these fish have been located a total of 1,524 times. Sonic telemetry has provided insight into the three spawning populations of Lake Mead, leading us to conclude that while the three populations appear to be distinct, metapopulation dynamics occur through the limited movement of fish between Las Vegas Bay, Echo Bay, and the Muddy River/Virgin River inflow area. Additionally, regardless of location within Lake Mead, razorback sucker seek deeper waters in the summer and fall, while shallower waters are more frequently used in the winter and spring.

Through the implementation of these three sampling techniques, we have discovered that employing various sampling techniques simultaneously enhances capture rate and efficiency for all life stages of razorback sucker. Ultimately, the presence of sonic-tagged fish makes it possible to discern locations of razorback sucker use, which increases our ability to pinpoint the locations of adult fish for trammel netting efforts, which in turn leads us to spawning areas and the successful capture of larval razorback sucker.

Through recapture data and the use of hard structures (fin rays) for aging, we have also been able to determine the growth rates, age structure, and recruitment trends of razorback sucker in Lake Mead. The overall growth rate for all razorback sucker in Lake Mead is 11.9 mm per year, which far exceeds the rates observed for other populations in the Colorado River Basin. Additionally, through non-lethal aging techniques, we have shown that the Lake Mead razorback sucker population is fairly young and undergoes natural recruitment on a near yearly basis. To date, we have aged 132 razorback sucker, of which 48 (32%) were spawned in the last 10 years. When the growth and aging data are combined, they illustrate the youth of the population as a result of naturally occurring recruitment — a phenomenon that has not been witnessed to this degree in any other razorback sucker population in the Colorado River Basin.

It is our hypothesis that cover (in the form of vegetation, turbidity, and perhaps additional abiotic factors present in Lake Mead) is allowing this unprecedented recruitment and sustainment of razorback sucker. However, as this document outlines, the exact parameters and causative agents that result in successful recruitment remain unknown. Thus the recommendations section of this document outlines future efforts that may assist in determining conditions that allow for razorback sucker recruitment in Lake Mead, with the ultimate goal of identifying factors allowing recruitment with the hopes of translating future findings into management practices that could facilitate basin-wide species recovery.

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BACKGROUND AND HISTORY

Due to the general decline of razorback sucker (*Xyrauchen texanus* [Abbott]) throughout their natural distribution, fisheries managers have employed numerous recovery methods in hopes of mitigating the loss of localized populations. Methods of recovery have included the chemical and mechanical removal of nonnative fishes in hopes of subjugating predatory interactions (Lentsch et al. 1996, Tyus and Saunders 1996), the collection of naturally produced larvae to be raised in artificial environments for later reintroduction (repatriation)(Mueller 1995, Marsh et al. 2005), and the transferral of razorback sucker into off-channel habitats free of nonnative species (Minckley et al. 2003, Mueller 2005). To date, stocking programs and nonnative fish removal have been the management activities most used in the attempted recovery of the razorback sucker; however, a debate exists as to which method is most technically and politically feasible (Mueller 2005).

Native fish management in the Upper Colorado River Basin (UCRB) has focused primarily on the reduction of nonnative predatory fishes through mechanical removal (electrofishing, netting, and angling)(Mueller 2005). In order to achieve partial/temporary control, research has shown that large proportions of fish populations must be removed (>80%)(Pacey and Marsh 1998), which has been a difficult task in the past (Lentsch et al. 1996). While cooperating agencies have successfully removed >1.5 million nonnative fishes from the UCRB, native fishes have shown little, if any, positive response (McAda 1997, Modde 1997, Brooks et al. 2000, Burdick 2002, Jackson and Badame 2002, Trammel et al. 2002, Davis 2003, Osmundson 2003). In addition, the cost of mechanical removal ($4.4 million since 1994)(USFWS 1988–2003) adds to the problems associated with removing nonnative fishes from open mainstem environments.

In contrast to the management strategy adopted by the UCRB Recovery Implementation Program, the primary management approach used in the lower Colorado River Basin (LCRB) has been capturing larval razorback sucker, rearing them in predator-free environments, and repatriating subadult- to adult-sized fish into open environments (lakes, reservoirs, and rivers). Through 2004, 14.3 million razorback sucker were repatriated throughout the LCRB (Schooley and Marsh 2007). The majority of these repatriated fish were stocked into central Arizona waters (11.2 million) and the lower Colorado River downstream from Lee's Ferry (2.4 million)(Schooley and Marsh 2007). The remaining 700,000 repatriates were stocked into Lake Havasu, Lake Mohave, and Lake Mead (507,123, 121,668, and 146 fish, respectively). This management approach was established on the idea that razorback sucker of a minimum size (8–12 inches) have a higher likelihood of escaping predation and thus increasing their chances of survival to adulthood (Schooley and Marsh 2007). Repatriation has been described as a critical task for the removal of jeopardy to, and eventual recovery of, the species (USFWS 2002). While such stocking efforts maintain current populations and give scientists time to investigate new solutions, current management activities are unable to sustain viable populations (Marsh et al. 2005).

Razorback sucker use of off-channel habitats, or backwaters, is still a relatively new concept that appears to be gaining popularity with management agencies. The concept emerged primarily after a successfully established population of razorback sucker and bonytail (*Gila elegans*) were observed in a 2-ha grow-out pond at Cibola National Wildlife refuge (Mueller 2005). This was the first documentation of successful recruitment in a natural environment by both species in more than 4 decades. This occurrence spurred the concept of using disconnected habitats (such as old oxbows, backwaters, and ponds) to isolate native fish from predators, which would encourage "natural" production. Due to limited implementation of this management practice, the success or shortcomings of the long-term practicality of raising razorback sucker in artificial or off-channel habitats has yet to be documented. However, Mueller et al. (2003) observed that the re-introduction of non-native predators (bullfrog *Rana catesbeiana*, red swamp crayfish *Procambarus clarkii*, sunfish, rainbow trout *Oncorhynchus mykiss*, and largemouth bass *Micropterus salmoides*) had negative impacts on the native fish populations, and the loss of these populations would occur without continued management intervention (Mueller 2005).

In contrast to management strategies employed by various state and federal agencies as described above, the management of razorback sucker in Lake Mead, Nevada and Arizona, has undergone a different approach. Lake Mead is located on a portion of the Colorado River that is not directly encompassed within either the UCRB or LCRB recovery areas (at least not functionally at this time). Therefore, the respective management practices (predator removal and repatriation) have not been employed on any substantial level. Instead, a cooperative effort between the Nevada Department of Wildlife (NDOW), Arizona Game and Fish Department (AZGFD), Southern Nevada Water Authority (SNWA), U.S. Bureau of Reclamation (Reclamation), National Park Service (NPS), U.S. Fish and Wildlife Service (USFWS), and BIO-WEST, Inc (BIO-WEST) initiated razorback sucker studies on Lake Mead, which have been conducted on a yearly basis for the past 11 years. The purpose of the studies was to identify razorback sucker population parameters, life history characteristics, and possible spawning areas in Lake Mead. This passive approach allowed for the study and observation of a razorback sucker population that existed in an open environment, in the presence of nonnative predators, yet still managed to successfully spawn and recruit new individuals on a near yearly basis (Albrecht et al. 2007). It is possible that the continued studies of razorback sucker in Lake Mead will reveal the causative factors leading to the successful spawning and recruitment of a natural population, which may then be applied to enhance other populations throughout the razorback sucker's historic distribution. The overall goal of this report is to assimilate the information and lessons learned from studying Lake Mead's unique population of razorback sucker.

INTRODUCTION

The razorback sucker is one of four endemic, large-river fish species (Colorado pikeminnow [*Ptychocheilus lucius*], bonytail, humpback chub [*Gila cypha*]) of the Colorado River Basin presently considered endangered by the U.S. Department of the Interior (USFWS 1991). It was historically widespread and common throughout the larger rivers of the Colorado River Basin (Minckley et al. 1991). The distribution and abundance of razorback sucker are currently greatly reduced from historic levels, mainly due to 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)(Figure 1). Razorback sucker persisted in several of the reservoirs that were constructed in the lower Colorado River Basin; however, these populations were comprised 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 in the 1980s, occurred in Lake Mohave, Arizona and Nevada, but it had declined to less than 3,000 by 2001 (Marsh et al. 2003). More recently, Mueller (2005, 2006) reported that the wild Lake Mohave razorback sucker population was approaching 500 individuals. Adult razorback sucker are most evident in Lake Mohave from January through April when they congregate in shallow shoreline areas to spawn, and larvae can be numerous soon after hatching. Today, the Lake Mohave population is largely supported by periodic stocking of captive-reared fish (Marsh et al. 2003, Marsh et al. 2005). Most recently, Marsh (2007) reported the estimate of wild Lake Mohave razorback sucker at 218 individuals. Competition and predation from nonnative fishes that are established in the Colorado River and its reservoirs are thought to heavily contribute to declines in native fish populations (Minckley et al. 1991). Predation by bass (*Micropterus* spp.), common carp (*Cyprinus carpio*), channel catfish (*Ictalurus punctatus*), sunfish (*Lepomis* spp.), and other nonnative species appears to be the primary reason for the lack of razorback sucker recruitment throughout the Colorado River (Minckley et al. 1991, Marsh et al. 2003).

An additional razorback sucker population was documented in Lake Mead, Nevada and Arizona. The Lake Mead population appeared to follow the trend of populations in other LCRB reservoirs. Lake Mead was formed in 1935 when Hoover Dam was closed, and razorback sucker were relatively common lake-wide throughout the 1950s and 1960s, because the fish apparently reproduced soon after the lake was formed. Their 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 NDOW nor the AZGFD collected razorback sucker from Lake Mead (Sjoberg 1995). This may be due in part to changes in their lake sampling programs; however, there was a considerable decline in numbers from the more than 30 razorback sucker collected during sportfish surveys in the 1970s. These results are not surprising; they fit well within the pattern of razorback sucker population declines approximately 40–50 years following reservoir development, as was seen in other LCRB reservoirs.

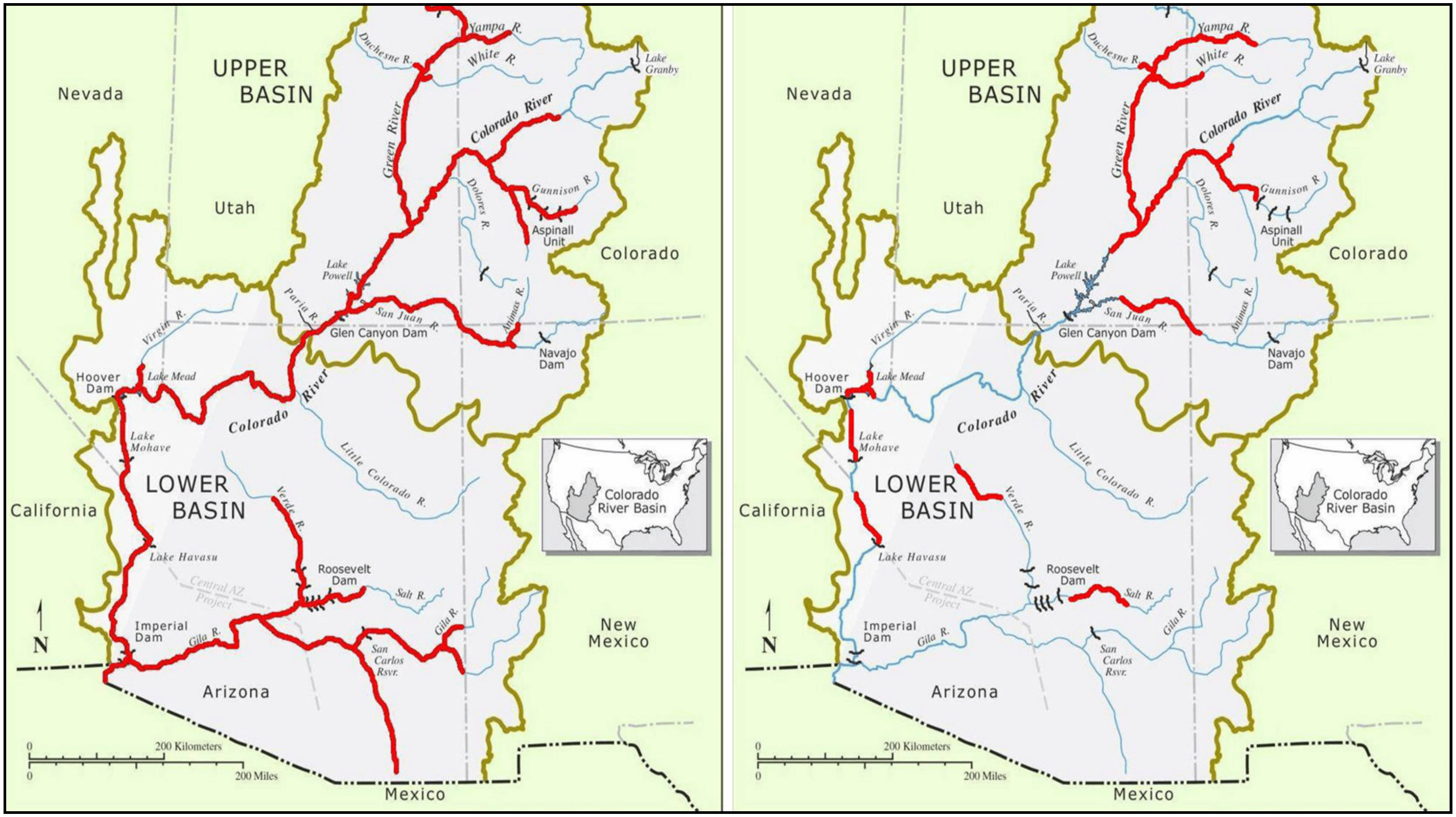

Figure 1. **Historical and recent distribution of razorback sucker in the Colorado River (map altered from the Cartography Lab, Department of Geography, University of Colorado, Boulder).**

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 a limited sampling effort to confirm the reports. From 1990 through 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 sucker larvae were collected by an NDOW biologist in 1995 near Blackbird Point, confirming suspected spawning in this area. In addition to the captures of these wild fish, NDOW also stocked subadult razorback sucker into Lake Mead. Twenty-six razorback sucker were stocked into Las Vegas Bay in 1994, and 14 were stocked into Echo Bay in 1995. All of these stocked fish were tagged with passive integrated transponder (PIT) tags, and all originated from the Dexter National Fish Hatchery 1984 year-class that was reared at Floyd Lamb State Park in Nevada. Collection of razorback sucker in the 1990s raised many questions about the Lake Mead population: 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 two groups different in age structure? In 1996 the SNWA, in cooperation with NDOW, initiated a study to attempt to answer some of these questions. BIO-WEST was contracted to design and conduct the study with collaboration from the SNWA and NDOW. Other cooperating agencies included: the Reclamation, which provided funding, storage facilities, and technical support; the NPS, which provided residence facilities in their campgrounds; the Colorado River Commission of Nevada; and the USFWS.

At the start of the project in October 1996 the following comprised the primary objectives:

- Determine the population size of razorback sucker in Lake Mead.
- Determine habitat use and life history characteristics of the Lake Mead population.
- Determine use and habitat of known spawning locations.

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

If new populations were tentatively 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 funding into 2004. In 2005 a new objective of evaluating the lake for potential stocking options 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 into Lake Mead. Most recently, Reclamation and SNWA decided to complete another cooperative agreement, tentatively extending monitoring efforts for the next several years.

The goal of this cumulative report is to outline and summarize the data collected on Lake Mead during the past 11 years and provide recommendations that may enhance future management practices pertaining to razorback sucker in Lake Mead. The specific objectives of this report are as follows:

- Compare and contrast the management approach and objectives associated with the Lake Mead population of razorback sucker to that of populations found within other systems in the Colorado River Basin.

- Describe the methodologies employed throughout the duration of the study and how protocol has evolved yet still remains comparable across years.

- Describe the 11 years of research findings on razorback sucker in Lake Mead and how the results translate into a greater understanding of razorback sucker ecology/population dynamics not only within the reservoir but within the context of the rest of the Colorado River Basin.

- Provide management and research recommendations that may provide a greater knowledge and ability to understand/enhance current razorback populations in Lake Mead and similar systems in the Colorado River Basin.

METHODS

Throughout the 11 years of razorback sucker studies, the primary foundation of research has been the sampling of larval, juvenile, subadult, and adult fish and sonic-telemetry efforts. Sampling efforts geared towards capturing these different life history stages changed and evolved over the duration of the project; however, the basis of sampling has remained constant to allow for the comparison of data across study years for the purpose of identifying trends. The following sections outline the protocol employed to successfully capture or increase our knowledge of different razorback sucker life history stages.

Lake Elevation

Month-end lake elevations for each of the study years (a study year has been defined as July 1–June 30) were measured in feet above mean sea level (amsl) and obtained from Reclamation's Lower Colorado Regional Office website (Reclamation 2007). The effect of fluctuating lake levels on razorback sucker habitat was documented by written observations and/or photographs during sampling trips to each of the study areas.

Larval Sampling

Sampling methods for larval razorback sucker were initially developed and implemented for research purposes on Lake Mohave (Burke 1995). The procedure uses positive phototactic responses of larval razorback sucker to lure them near the surface, at which time "netters" are able to capture them with long-handled aquarium dip nets. To entice the larval razorback sucker to the surface, the boat was positioned in an area of known or suspected razorback sucker spawning activity after sundown, and two 12-volt "crappie" lights were connected to a battery and placed in the water 4–10 inches deep. Except in rare instances (Holden et al. 2001), the sampling duration at all sites was typically 15 minutes, with approximately 4–12 sites sampled nightly. Sampling efforts were timed so that catch per unit effort (CPUE) could be calculated, which enabled the identification of capture trends through time. Upon capture, larval fish were placed into a holding bucket until sampling at that particular site was completed. Captured larval fish were then returned to their place of capture, or in some instances transported by NDOW personnel to a hatchery for captive rearing and later repatriation. Regardless of sampling location, sampling effort was always timed and the number of razorback sucker larvae were enumerated so that CPUE could be calculated.

Juvenile Sampling

Sampling specifically for juvenile razorback sucker was a study objective during the 1996–2001 study years on Lake Mead. Juvenile razorback sucker sampling was initiated following the capture of relatively large numbers of larval razorback sucker. Since juvenile razorback sucker had generally not been found in reservoirs (Minckley et al. 1991), the appropriate and standard methodologies for capturing this unique life stage had not yet been developed. Several techniques were employed, based on studies of other young native Colorado River fishes, including using minnow traps, seines, fine-mesh gill nets, hoop nets, fyke nets, and electrofishing. This suite of gear types was typically used in areas with emergent vegetation, but sampling was conducted in more open-water habitat types as well. Seining was conducted in the back of Echo Bay where substrate and vegetation permitted. A 30 ft x 6 ft x 0.125 in mesh standard seine was typically used for these efforts. Hoop nets and fyke nets were set in and around emergent vegetation habitats. Several different sizes of hoop and mesh were used on hoop and fyke nets in an effort to find the most effective gear type for sampling this unique life stage (Holden et al. 1997).

Adult and Subadult Sampling

Trammel Netting

Trammel nets were the primary sampling tool used to capture adult razorback sucker throughout the duration of the Lake Mead studies. The majority of nets used were 300 ft long x 6 ft deep, with internal panel sizes of 1-, 1 ½-, or 2-in mesh, and an external panel size of 12-in mesh. However, trammel nets measuring 75 ft x 6 ft with 1-in internal panels and 12-in external panels were used on occasion. Net-setting protocol generally remained constant throughout the studies; one end was set near shore in 5–10 ft of water, with the net stretched out into deeper areas. Each net location was marked with a GPS. Trammel nets were generally set in late afternoon/evening before sunset and pulled the following morning shortly after sunrise.

The number of nets set per night at each location varied upon conditions such as forecasted weather and the total number of fish captured. Conditions — such as high winds — diminished our ability to efficiently pull fish out of the net and resulted in potentially dangerous boating and stressful conditions for fish. Additionally, when numerous species (aside from razorback sucker) were being captured (e.g., during carp spawning activities) the length of time it took to retrieve a net was greatly extended. Thus, under such circumstances, the number of nets set per night varied.

Razorback sucker captured in a trammel net were immediately transferred into large coolers while the remainder of the net catch was processed. Nonnative fishes were placed in a large bucket. Upon completion of retrieving the entire net, nonnative fishes were weighed to the nearest gram and measured to the nearest millimeter (both total length and fork length) before being released. The first five carp were weighed and measured, but the remainder were only counted. Razorback sucker were checked for PIT tags, implanted with PIT tags if they were not recaptured fish, measured (including TL, FL, and SL), weighed to the nearest gram, and returned to the point of capture (unless they were held for sonic tagging or fin-ray removal for aging). Destron/Fearing Model TX1400 (400kHz) PIT tags were used, which was consistent with other fisheries research in the Colorado River System.

While the type, size, and protocol for setting nets remained relatively constant over the years, the factors determining the timing and placement of nets (i.e., what time of year and where nets were set to capture adult fish) evolved over the course of the studies. In the early stages of research, trammel nets were set year-round, specifically targeting areas frequented by sonic-tagged fish and assumed spawning locations. However, capture data suggested that netting razorback sucker in the warmest months (July–September) and adding additional stress to previously captured fish appeared to result in negative effects (tag expulsion or death in the case of sonic-tagged fish). Therefore, from 1998–2002 trammel nets were not set during July–September, or from March–May (warmer portions of the razorback sucker spawning season), and locations near sonic-tagged fish were avoided. Instead, from 1998–2002 net placements were primarily dictated by the presence/absence of larval fish, and more emphasis was placed on locating new spawning grounds as well as sampling juvenile razorback sucker. This practice ended after the

2002 study year due to data provided by the USFWS. Their sampling efforts showed that return rates of fish captured during the spawning season was similar to that of fish captured throughout the rest of the year; thus sampling during the spawning season did not appear to have an affect on adult survival.

Currently, trammel net placement is determined by a combination of factors: nets are set in areas where adult razorback sucker have been successfully captured in the past, in close proximity to locations where sonic-tagged individuals were found, or near supposed/confirmed spawning grounds. By allowing one or more of these parameters to dictate the location of net placements, BIO-WEST has maintained relatively high catch rates of subadult and adult razorback sucker in recent years despite reducing netting to the January–May time period. As a result, sampling is now only conducted during the spawning season. It has been determined that the spawning season is the most efficient time to successfully sample razorback sucker due to the movement and location of fish associated with spawning activity (Albrecht et al. 2006b).

Sonic Telemetry

Sonic tagging was first implemented in the Lake Mead razorback studies during the 1996–1997 study year. It was thought that telemetry would provide valuable biological data regarding movement, habitat use, and spawning locales throughout the lake. Tagging events occurred periodically, usually when a numerous amount of previously tagged individuals were lost or their tags expired.

Three different sonic-tag models were used throughout the duration of the study: (1) Sonotronics Model CT-82-1 with a 60-day battery life, (2) Sonotronics Model CT-82-2 with a 14-month battery life, (3) and Sonotronics Model CT-82-3 with a 48-month battery life. The models used during a particular study year were dependent upon budget, tag availability, and study objectives. During the early study years, multiple tag types were used to compare their effectiveness and efficiency. As the studies continued, models with longer battery lives were found to be the most economically feasible while providing the highest-quality data. In all instances of tag insertion, the transmitter did not exceed 2% of the fish’s body weight (Winter 1996).

Tag implantation followed a combination of protocols developed for humpback chub (Valdez and Nilson 1982, Kaeding et al. 1990, and Valdez and Trinca 1995), Colorado pikeminnow and razorback sucker (Tyus 1982, Valdez and Masslich 1989). Surgical procedures were conducted on shore and involved three individuals: a surgeon, an assistant, and an anesthetist. Fish were placed in an anesthetic bath of Finquel tricaine methanesulfonate (MS-222) at a concentration of 100 mg/l for 2–4 minutes or until the fish lost equilibrium but maintained opercular movement. After sedation fish were placed on a surgical table. A 3–4-cm incision was made on the left side anterior to the pelvic girdle and about 1–2 cm lateral to the midline of the fish. The sonic transmitter was inserted through the incision and pushed back to rest on the pelvic girdle. The incision was closed with 4–6 sutures using 3-0 Maxon absorbable polygluconate monofilament suture with an attached PH 26 curved needle. Throughout the surgical procedure, the fishes’ gills were flushed with either fresh lake water or the anesthetic solution, according to the reaction of the fish. The source of lake water and anesthetic solution being flushed over the gills was two 5-gallon buckets, placed at a level higher than the surgical table, with a 5-foot length of tygon tubing extending from the bottom of the buckets. Typical procedure involved flushing the anesthetic solution over the gills during the first half of the surgery and then finishing with fresh water to expedite post-surgical recovery. Upon completion of the surgery, fish were allowed to recover in a live well until they regained pronounced opercular movement and equilibrium, and exhibited strong escape responses when prompted.

Wild-caught razorback sucker netted in Lake Mead were the sole source of fish for tag implantation during the early studies. However, as the fish database and subsequent data accumulated over time, it became apparent that razorback sucker reared in Floyd Lamb State Park, Nevada, quickly integrated into the natural population upon introduction into the lake (Abate et al. 2002). Therefore, in recent years, the source of fish for telemetry purposes shifted to individuals retrieved from Floyd Lamb State Park with the goal of ameliorating pressures placed on the natural razorback sucker population residing in Lake Mead (Albrecht and Holden 2005, Albrecht et al. 2006a).

The intensity of tracking sonic-tagged fish varied according to time of year, and was primarily dictated by the field schedule. During months in which fish sampling and research were not being conducted, sonic-tagged fish were tracked on a nearly monthly basis. However, during the months when the work schedule placed personnel in the field more frequently, tracking was conducted on a nearly weekly or in some cases a nearly daily basis. The methods employed to locate sonic-tagged fish included initiating the search in the primary study areas (Las Vegas Bay, Echo Bay, and the Overton Arm) and expanding the search area as needed. It was concluded early in the study that sonic-tagged fish did not frequently move great distances from the primary study locations, hence this method of tracking was most effective. In all, tracking efforts were designed to be flexible and were largely dictated by previous locations and habitat use of sonic-tagged fish.

Depth utilization of razorback sucker in Lake Mead was analyzed temporally by defining seasonality (fall, winter, spawning, and summer) and comparing the median depths at which fish were located among seasons. Fall was defined as 1 October–30 November; winter as 1 December–31 January; and summer as 1 June–30 September. Seasonal dates were loosely determined by thermal trends observed in Lake Mead; fall was defined by decreasing water temperatures to near 5° C, winter temperatures remained near 5° C, and summer temperatures reached and remained at/near 20° C. The spawning season was defined as the months in which the greatest amount of spawning activity was observed along the lake shorelines and the months in which the greatest amount of larvae were captured over the course of the Lake Mead studies. Kruskal-Wallis tests and Wilcoxon rank-sum tests were performed to test for differences in seasonal depth utilization. The Kruskal-Wallis test accounted for outlying observation values by their ranks in a single combined sample and applied a one-way analysis of variance *F*-test on the rank transformed data (Ramsey and Schafer 2002). The Wilcoxon rank-sum test is the nonparametric equivalent of a *t*-test, that replaces observations by their ranks in the combined sample to account for outliers (Ramsey and Schafer 2002).

Aerial Surveys

Aerial surveys were an effective method for determining spawning locations on Lake Mohave due to the clear nature of the water column and razorback sucker use of shallow habitats during the spawning season. Therefore, known and likely spawning locations on Lake Mead were aerially observed during the known spawning season from a helicopter flown at an altitude of less than 500 ft above ground level between the study years of 1997–1998, 1998–1999, and during the 2007 spawning season. Flights were made during daylight hours on clear days. The purpose of the survey was to confirm spawning in known locations, to try and identify new spawning aggregations, and to attempt to count the number of razorback sucker observed in spawning habitats.

Video Surveillance and SCUBA

Underwater video surveillance was employed for the purpose of confirming and observing razorback sucker spawning activities. The camera used was manufactured by FISHEYE, Inc., of Everett, Washington, and had a fixed focus, wide-angle lens with an automatic exposure control that immediately corrected for available light levels. The camera was lowered to the benthic zone of the lake, at which point it could be rotated 360 degrees to capture activity in all directions. The images were transmitted to a video monitor/recorder, which also allowed the operator to observe underwater activity. Similarly, Holden et al. (2000a) used SCUBA to reconnoiter the spawning site at Echo Bay in 1999. Both techniques have largely been used at an exploratory level during the course of our studies.

Growth

Growth is one of the most important and reliable indicators of fish health, population production, and habitat quality (Devries and Frie 1996). Due to this, mean annual growth — the difference in TL between captures — has been calculated on recapture data from Lake Mead razorback sucker since the onset of the Lake Mead investigations in 1996–1997. Mean annual growth was only determined for fish that were recaptured with a minimum of 1 year between capture events. Mean annual growth was calculated for all recaptures within a specific portion of Lake Mead when possible (Las Vegas Bay, Echo Bay, and the Muddy River/Virgin River inflow areas) resulting in growth rates for razorback sucker by sampling location.

Population Estimates

Population estimation on Lake Mead began as a USFWS requirement prior to sonic-tagging Lake Mead razorback sucker (Holden et al. 1997). Initially, the number of sonic tags that could be implanted into wild Lake Mead razorback sucker was restricted to 10% of the population estimate. After receiving input from a number of population modelers, it was decided that several population estimates would be made using the program CAPTURE (Otis et al. 1978) as well as the Schnabel estimator (Seber 1982, unbiased estimator). The program CAPTURE uses both true capture/recapture estimators as well as removal-type estimators. It was determined that the Lake Mead data did not fit the removal estimators, thus the results of those estimators were not used for the original population estimate. Confidence intervals as calculated by CAPTURE were also included (Holden et al. 1997).

Age Determination

Development of a non-lethal aging technique to accurately assess recruitment patterns in Lake Mead has been a study focus since 1996. Prior attempts to age razorback sucker using scales were unsuccessful. The lack of clear annular marks, or irregular annuli that did not correspond to annuli found on other structures from the same fish, made reliable aging from razorback sucker scales problematic. This inability to accurately age individual fish using scales was also a problem for other researchers working on wild razorback sucker populations in the Colorado River (McAda and Wydoski 1980, McCarthy and Minckley 1987), and in populations of white sucker (*Catostomus commersoni*)(Beamish 1973, Quinn and Ross 1982).

Morphological structures other than scales can be used for determining fish age, including otoliths, fin rays and spines, opercular bones, branchiostegal bones, and vertebrae. Otoliths have been used to accurately age a wide variety of fish species. However, the fish must be killed to extract these structures. Opercular, branchiostegal, and vertebral bones have all been used to age fish with varying degrees of reliability, but as with otoliths, the fish must be sacrificed. Fin rays have been used to reliably age different species of fish without killing or permanently harming the fish. McCarthy and Minckley (1987) found pectoral fin rays to be a valid structure for use in aging young razorback sucker. Beamish and Harvey (1969) used the first four pectoral fin rays to age white sucker and found this method reliable. Quinn and Ross (1982) reported that pectoral fin rays were accurate for determining ages in younger (age 7 and under) populations of white sucker but that caution should be used in aging older and slower-growing fish. Quist et al. (2007) found that fin rays provided almost the exact age estimates of catostomids in the UCRB.

During the early razorback sucker studies on Lake Mead, we recovered two razorback sucker carcasses and aged both using otoliths and pectoral fin rays to evaluate and develop a non-lethal technique for reliably aging razorback sucker populations. One of the carcasses was a 381 mm TL razorback sucker of unknown sex recovered from Echo Bay, and the other carcass was a 588 mm TL male recovered from Las Vegas Bay. In both instances, ages estimated from pectoral fin rays agreed with those obtained from sectioned otoliths. Both fish proved to be relatively young (ages 5 and 8). We further validated the use of fin rays as a structure for determining age by applying it to multiple, known-age fish originating from Floyd Lamb State Park. In all instances, pectoral fin rays were accurate for determining fish age.

Examination of the pectoral fin rays from the razorback sucker carcasses described above demonstrated that the first 3–4 rays provided readable annuli. Both Beamish and Harvey (1969) and Quinn and Ross (1982) removed the first four fin rays from one pectoral fin of white sucker, aged them, and released them with no reported adverse impacts. Furthermore, we removed fin ray sections from eight anesthetized, age-3 razorback sucker held by the NDOW at the Lake Mead hatchery and observed little to no bleeding and no mortalities.

Our initial attempts at fin ray extraction using bone snips were successful, but this method seemed intrusive (Holden et al. 2001): One recaptured fish on which this method was used had rubbed its pectoral fin raw. Subsequent to the recapture of this fish, we implemented modifications to the fin-ray extraction procedure to allow for quick, efficient, clean, and effective removal of fin-ray sections that was less stressful to captured fish (Holden et al. 2001). Furthermore, Holden et al. (2001) describe what has been perhaps the largest laboratory modification of our aging techniques. Due to large amounts of time spent in preparing and aging the obtained specimens until 2001, replacing the fine-toothed jeweler's saw with a motorized Buhler isomet low-speed saw provided a more efficient preparation of fin-ray segments for reading. This also produced a more efficient way of embedding fin rays using epoxy and molding blocks. The resultant embedded fin ray is set into a mounting bracket and sectioned multiple times, with each cut producing a high-quality, finely cut, thin section that requires little sanding and polishing to achieve acute visual clarity and enhanced readability. Hence, we obtained the ability to quickly and effectively confirm age for nearly all fish aged to date (Holden et al. 2001). In an effort to better describe our current procedures, we included text from our most recent annual report (Albrecht et al. 2007) to highlight the refined method procedures we currently use in comparison with the method used at the onset of our Lake Mead razorback sucker aging studies.

During the 2007 spawning period, select razorback sucker 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 (Figure 2). Fish were anesthetized with a lake water bath containing MS-222, NaCl, and slime coat protectant to reduce surgery-related stress, speed recovery, and avoid accidental injury. During the surgery standard processing was accomplished (weighing, measuring, PIT-tagging), and a sample was surgically collected using custom-made bone snips developed by BIO-WEST. This surgical tool consists of a matched pair of finely sharpened chisels welded to a set of wide-mouth Vise-Grips™ pliers (Figure 3). The connecting membrane between rays was cut using a scalpel, 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 razorback sucker were immediately placed in a recovery bath of fresh lake water containing slime coat protectant, allowed to recover, and released as soon as the fish regained equilibrium and appeared recovered from the anesthesia. Vigilant monitoring of the fish was conducted during all phases of the procedure.

Figure 2. **Removing a fin-ray section in the field.**

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. Oil immersion techniques were also used on occasion to increase clarity and aide in proper specimen age identification. 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, the readers viewed the structure together and assigned an age. For further information regarding the evolution of our fin ray aging technique, please refer to Albrecht and Holden (2005), Albrecht et al. (2006a), as well as other, past annual reports (Albrecht et al. 2007).

Since we have incorporated this new aging methodology, we have found that surgically altered fins regenerate very quickly and that removing sections of two internal fin rays from live razorback sucker appears to have no long-term negative impacts on the fish. The “hole” created in the fin closes almost entirely within 2–3 weeks after segment extraction occurs and is virtually healed within approximately 1 month (based on our observation of recaptured fish, Figures 4 and 5). We have successfully aged over 130 razorback sucker using this technique.

Figure 3. BIO-WEST developed and refined this tool to quickly, cleanly, and easily obtain fin rays.

As previous year's studies of Lake Mead razorback sucker have indicated, fin ray use has proven to be a valid method for obtaining age information and helped elucidate possible recruitment patterns for these fish (Holden et al. 1997, 1999, 2000a, 2000b, 2001; Abate et al. 2002; Welker and Holden 2003; Welker and Holden 2004; Albrecht and Holden 2005; Albrecht et al. 2006a; Albrecht et al. 2006b; Albrecht et al. 2007).

Figure 4. Surgically altered fin in the process of healing (about 1 week post surgery).

Figure 5. A healed fin about 3 weeks after ray-removal surgery.

Other Methods

Water Quality Parameters

A study was initiated in spring 2000 with the goal of identifying water quality parameters that may be contributing to the successful recruitment of razorback sucker in Lake Mead. BIO-WEST was contracted by the SNWA to develop a study design to compare nutrient levels, zooplankton density, and available cover at sites in Lake Mead and Lake Mohave.

Five study locations were established on Lake Mead and Lake Mohave: Las Vegas Bay, Echo Bay, and Trail Rapids Bay in Lake Mead (Figure 6), and Arizona Bay and Tequila Cove in lake Mohave (Figure 7)(Golden and Holden 2001). Within each location, five sampling sites were chosen to capture parameter variability throughout the bay. Each site was defined as an approximate 200 m by 20 m rectangle that encompassed a portion of shoreline.

In Las Vegas Bay, the five sites were distributed from the Las Vegas Wash inflow to the north shore of Las Vegas Bay between Gypsum Cove and Government Cove (Figure 8). The five sites in Echo Bay were located from the back of the bay along the south shore out to the Pumphouse Bay area (Figure 9). In Trail Rapids Bay, sites were located from the back of the bay near the wash to just outside the mouth on the south side (Figure 10). The sites in Arizona Bay were located from the southeast corner of Arizona Bay to the first cove north of Yuma Cove (Figure 11). The sites in Tequila Cove originated on the south shore of Sandy Point Cove and extended north to the second cove north of Tequila Cove (Figure 12).

During both years (2000 and 2001) of the water quality comparison study, sampling occurred during March and May, when larval razorback sucker are generally present. Within each 200 m x 20 m site within the five study locations, water quality and plankton measurements were collected in three locations. Water quality parameters, such as dissolved oxygen, nitrate, ammonium, total dissolved solids, and turbidity (during the 2001 study year), were taken with a HydroLab Datasonde 4a and Surveyor 4. A one-grab sample was also collected, preserved with hydrochloric acid, and stored on ice until it could be delivered to NEL Laboratories in Las Vegas for analysis of phosphorous. Plankton tows were conducted using a 30 x 90 cm plankton net with 153 µm mesh at each of the three locations. Tows were pulled horizontally for approximately 6 m at 0–0.5 m from the surface. Ten percent formalin was used to preserve samples that were later analyzed in a laboratory. Finally, aquatic cover within each 200 m by 20 m site was mapped using one or more of the following methods: visual observation from boat, underwater video camera, and/or snorkeling to assess vegetation in deeper areas.

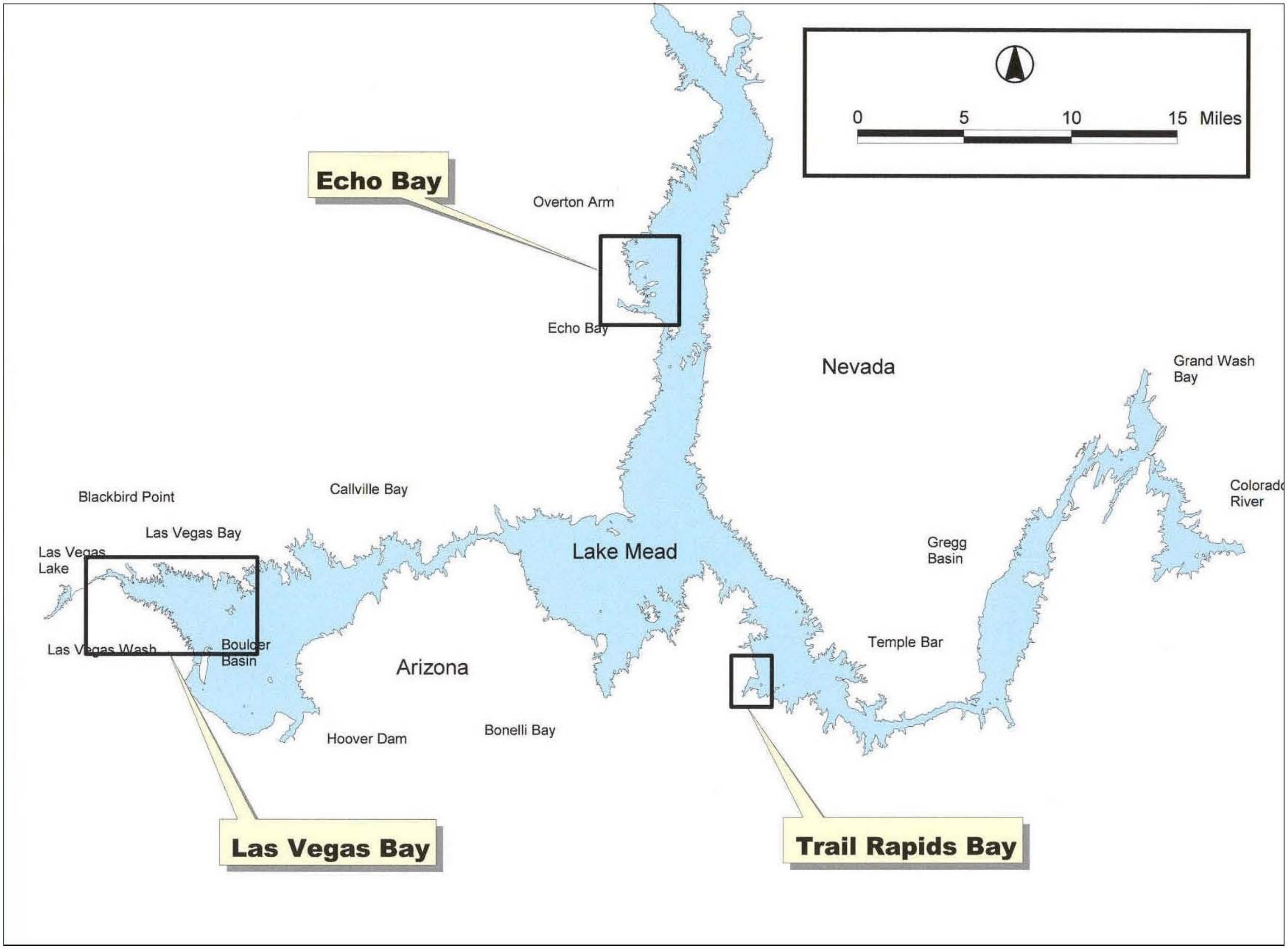

Figure 6. Lake Mead general water quality sampling locations.

Figure 7. Lake Mohave general water quality sampling locations.

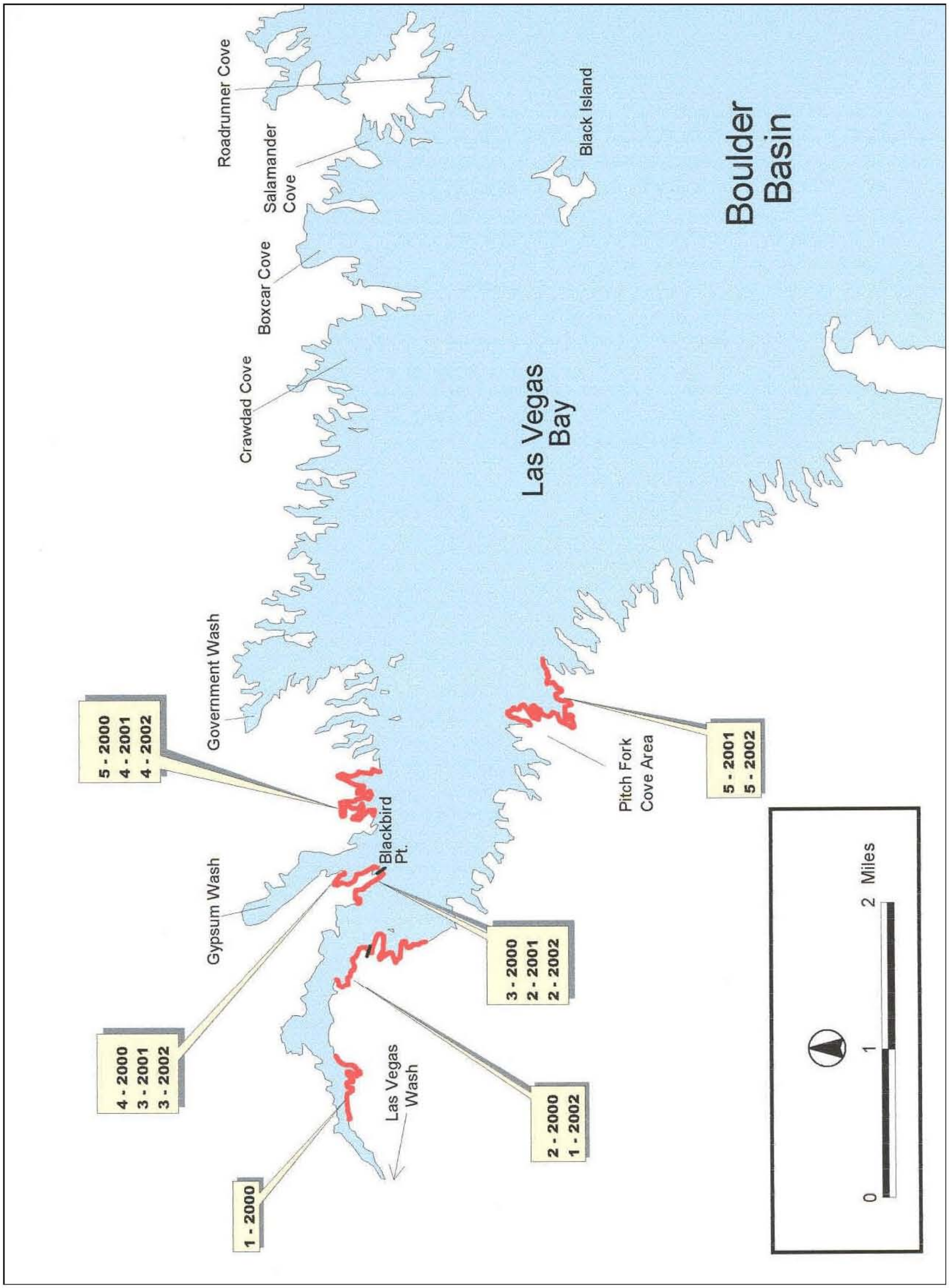

Figure 8. **Las Vegas Bay water quality sampling sites.**

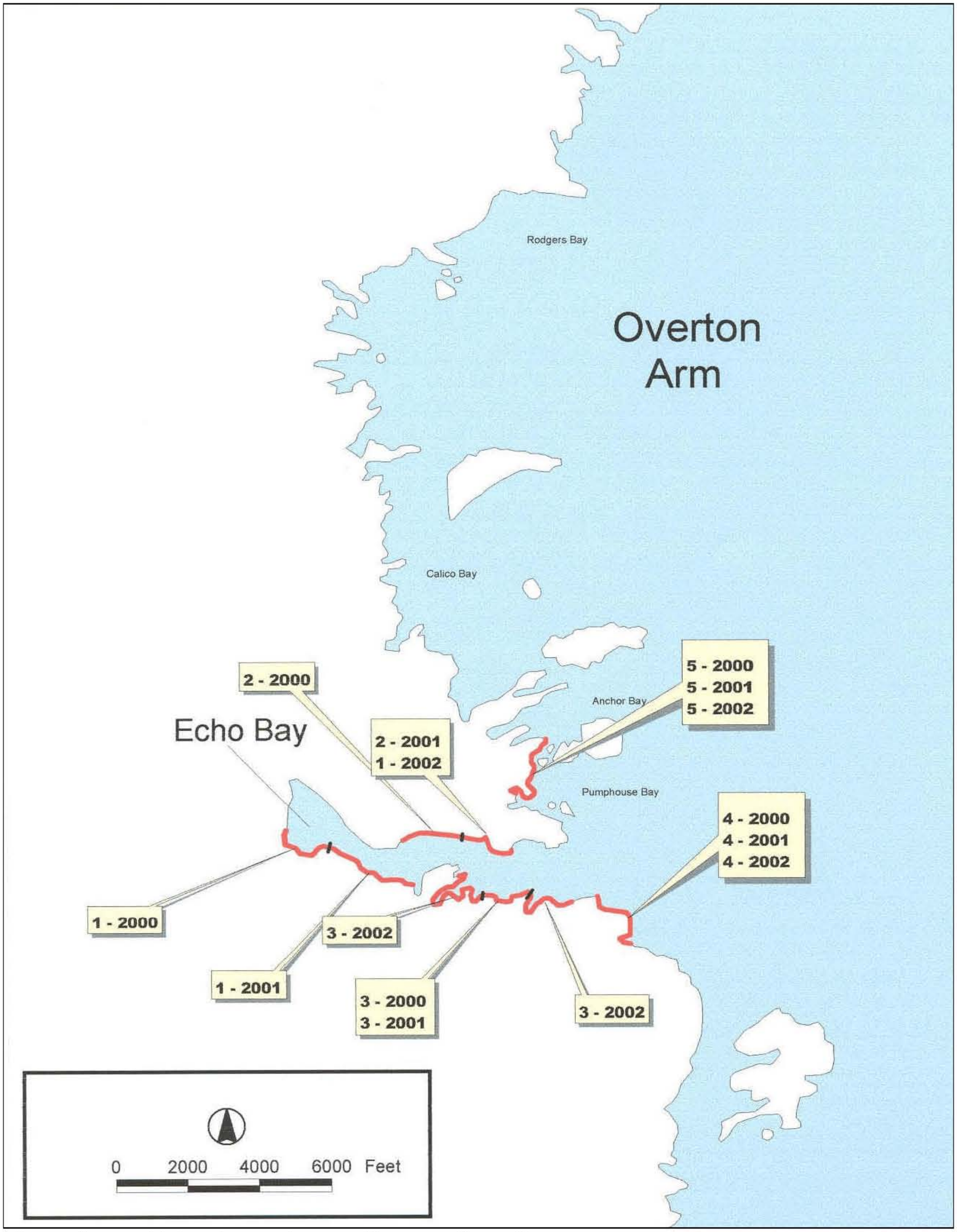

Figure 9. Echo Bay water quality sampling sites.

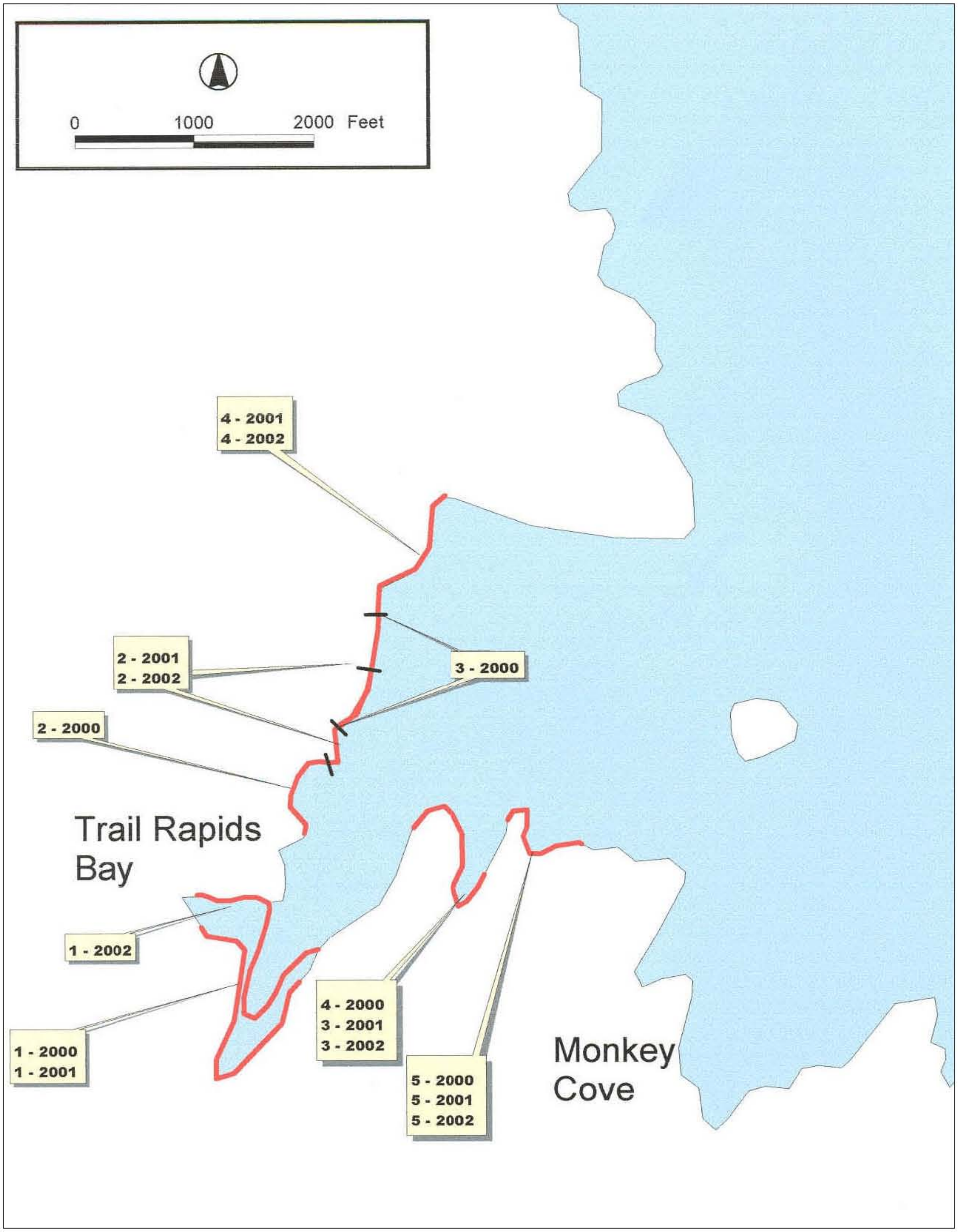

Figure 10. Trail Rapids Bay water quality sampling sites.

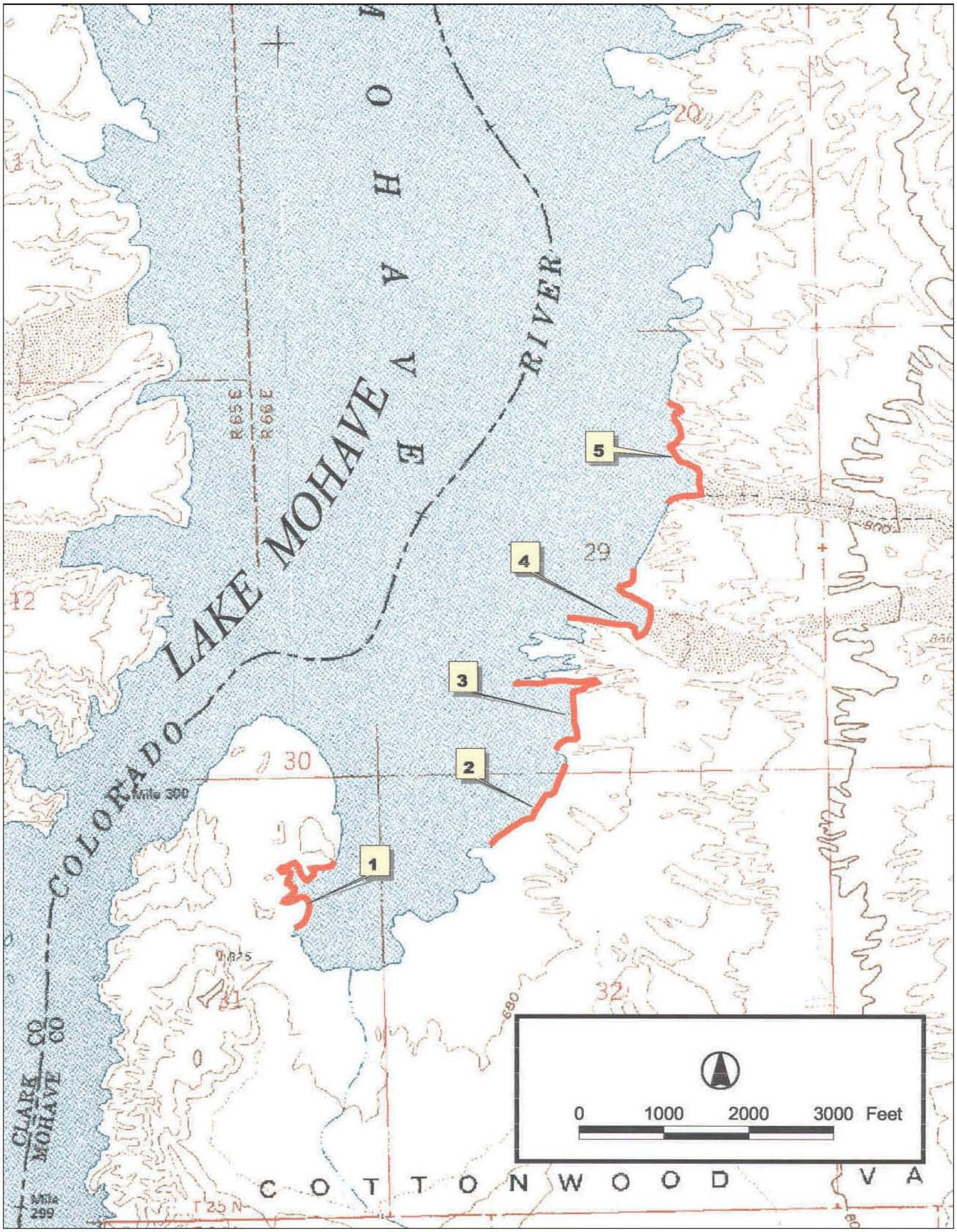

Figure 11. Arizona Bay water quality sampling sites.

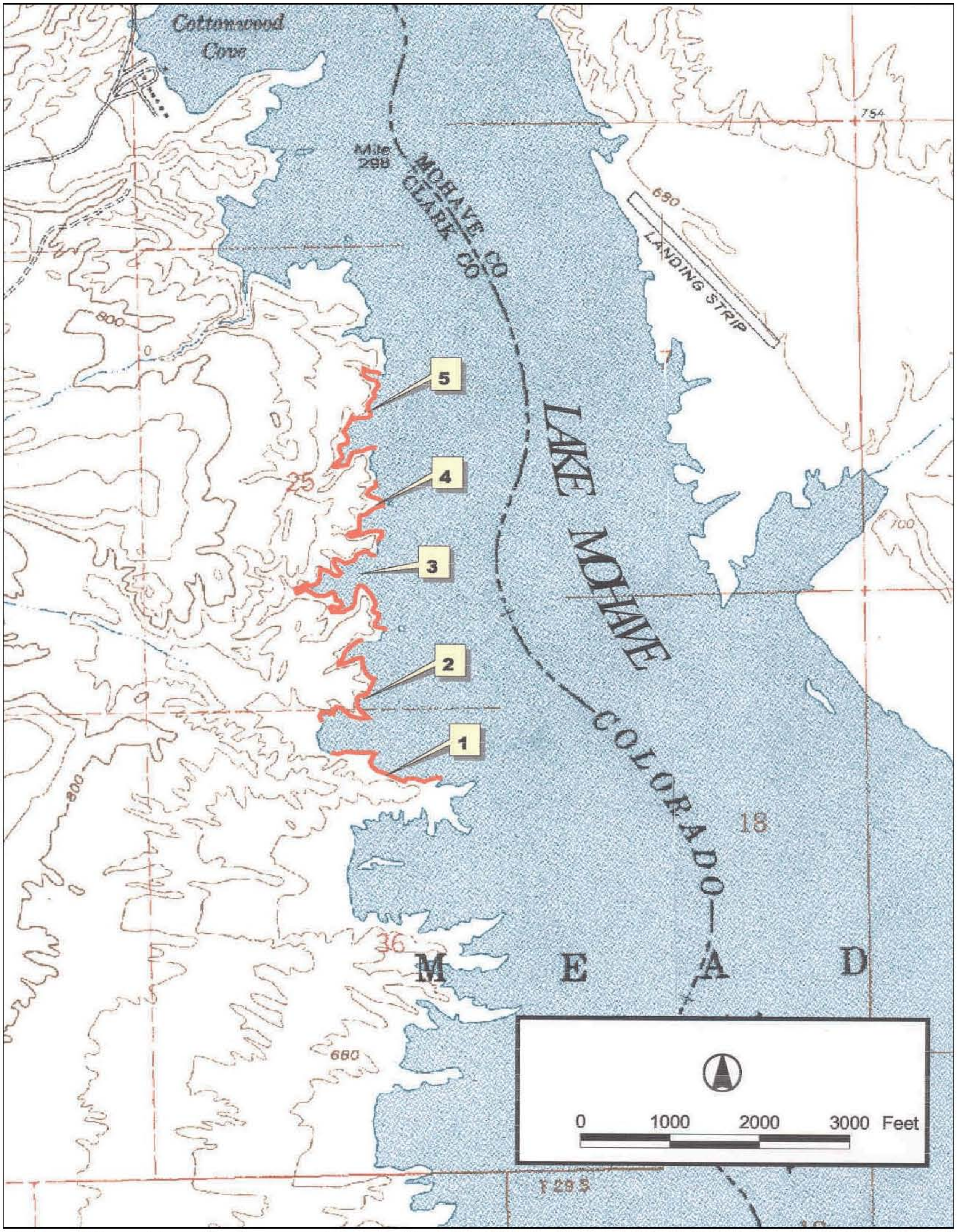

Figure 12. Tequila Cove water quality sampling sites.

Zooplankton samples were examined and enumerated under a 10x to 45x magnification using a Ward Counting wheel. Specimens were identified to order and in some cases family (Cladocera) level. Samples with large numbers of zooplankton were subsampled with a Henson Stemple pipette. Subsamples were taken by suspending the entire sample from a site in 50 ml of water and extracting two 2 ml subsamples with the pipette. The two subsamples were compared to determine the efficiency and accuracy of the subsampling method. After determining that little variation existed between the two subsamples, they were combined for analysis. The goal was to measure a subsample of 30 individuals from each taxonomic group in each sample. Zooplankton density was calculated as number of organisms/l. Further description of these methods can be found in Golden and Holden (2001, 2002, 2003).

STUDY AREAS

Most of Lake Mead has been sampled for at least one life stage of razorback sucker. It should be stressed that during each study year, lake level changes determined sampling areas. The following overview explains where effort was expended searching for razorback sucker during each of the three main life stages: larval, juvenile, and adult fish (Figure 13).

Larval Sampling

Throughout the duration of the Lake Mead studies, the primary locations of larval razorback sucker sampling have been Las Vegas Bay and Echo Bay (Figure 13). These locations have been identified as primary spawning areas and produce larvae on a yearly basis. However, during the early years of the Lake Mead studies (1998–2000) a lake-wide effort was put forth to try and identify possible new spawning aggregates (Holden et al. 2000a). This included sampling at 1-mile intervals along the entire shoreline of the lake during March, April, and May. A Landsat image was prepared using ArcInfo software that established pre-designated sites at 1-mile intervals, and each site was sampled for a 15-minute period. This lake-wide effort continued for two study seasons, during which time the entire shoreline of Lake Mead was successfully sampled twice.

In addition to the lake-wide sampling effort, larval sampling has periodically occurred at various locations within Lake Mead, other than Las Vegas and Echo bays, in an effort to identify new spawning locations. The following locations have been sampled, and the corresponding report explains sampling protocol used in each location: Gregg Basin (Holden et al. 2000b); Colorado River inflow/Grand Wash Basin (Holden et al. 2001); Colorado River inflow (Driftwood Island area and Iceberg Canyon area, Abate et al. 2002, Welker and Holden 2003); and the Colorado River inflow and Muddy River/Virgin River inflow area (Welker and Holden 2004)(Figure 13). Recently (Albrecht and Holden 2004–2005) a spawning aggregate of razorback sucker was identified in the Muddy River/Virgin River inflow area, thus this portion of the lake has been included with Las Vegas Bay and Echo Bay as an area of primary spawning activity. It has since been sampled for larval fish on a weekly basis during the spawning period.

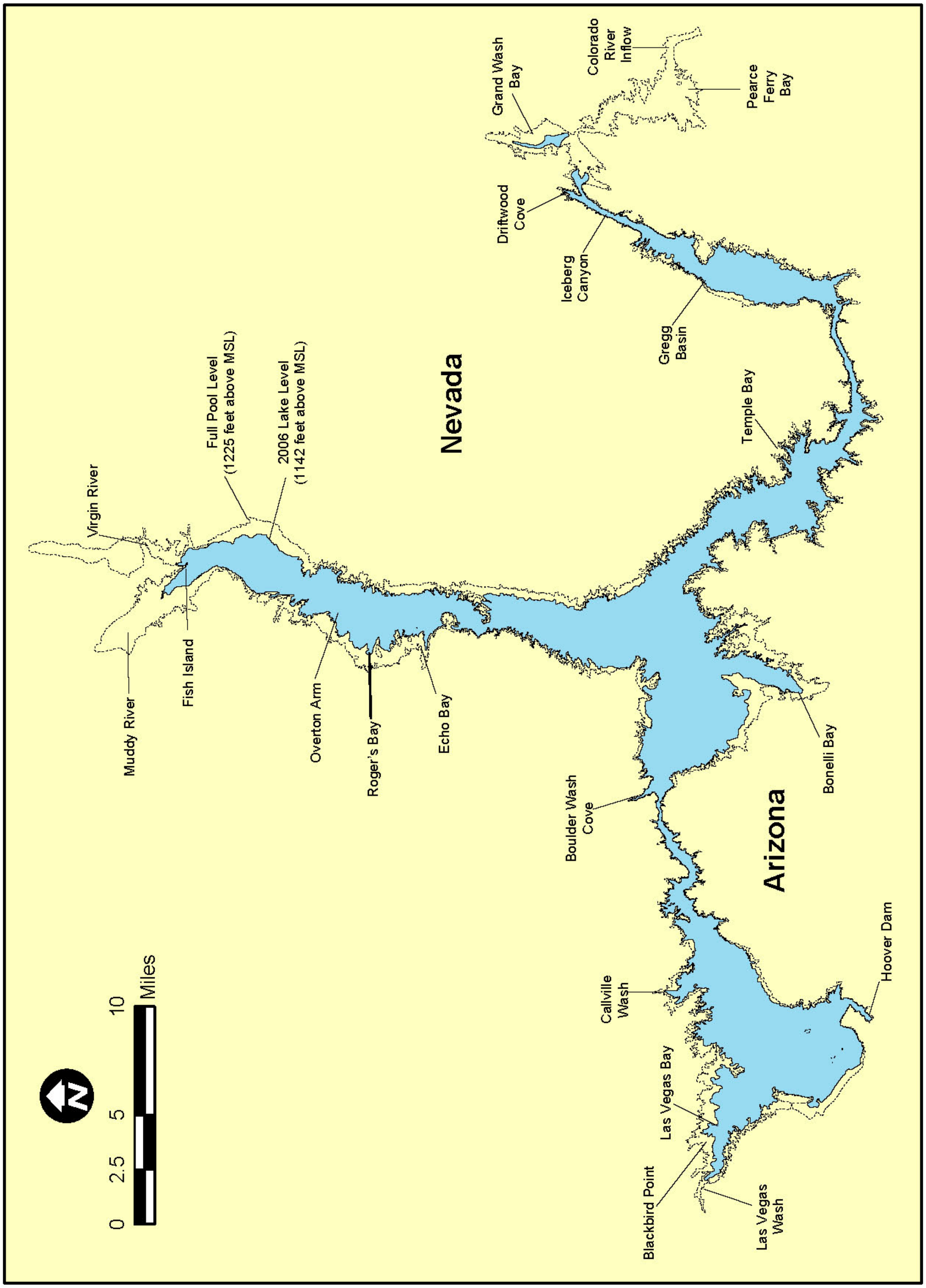

Figure 13. Lake Mead general study locations.

Juvenile Sampling

Sampling for juvenile razorback sucker was initiated at the onset of the Lake Mead razorback sucker studies in an attempt to identify the success of natural razorback spawning/recruitment in the lake, as well as nursery habitats. The sampling areas included Las Vegas Bay and Echo Bay due to historical records identifying them as spawning areas, which was also supported by capture of larvae, subadult, and adult razorback sucker by BIO-WEST personnel (Figure 13). In Las Vegas Bay, juvenile razorback sucker sampling efforts were primarily focused around the Blackbird Point vicinity, and in Echo Bay sampling was conducted in the back part of the bay (Holden et al. 1997).

Adult and Subadult Sampling

Trammel Netting

Trammel netting has been the primary sampling method used to capture adult razorback sucker throughout the duration of the Lake Mead studies. Two locations within Lake Mead — Las Vegas Bay and Echo Bay — have been identified as being primary spawning locations regardless of year or lake level, thus these locations have been sampled regularly each year since the onset of this research. However, other various locations throughout the lake have been sampled in an attempt to broaden the knowledge of razorback ecology and population dynamics lake-wide. The following is a list of areas sampled followed by the corresponding report that details methodology, effort, and years sampled: Colorado River inflow/Grand Wash vicinity (Holden et al. 2000b, Holden et al. 2001); Colorado River inflow/Driftwood Island Bay (Abate et al. 2002); and Pearce Ferry (Welker and Holden 2003)(Figure 13).

In addition to the various sample locations listed previously, the northern portion of the Overton Arm of Lake Mead has also been sampled. During the 2004–2005 study year, the Muddy/Virgin River inflow area of the Overton Arm was identified as a possible spawning location due to the presence of sonic-tagged fish and the capture of ripe, adult razorback sucker. Since that time, the Muddy River/Virgin River inflow portion of Lake Mead has been classified as a primary spawning location, thus sampling has occurred there on a near weekly basis since the 2004–2005 study year.

Sonic Telemetry

The primary locations in which telemetry occurred were Las Vegas Bay and Echo Bay, as these were the locations where fish were released upon tag implantation. One small group of sonic-tagged fish was placed in the Colorado River inflow area. However, most areas of the lake, including the Overton Arm, Boulder Basin, Virgin Basin, and portions of Colorado River inflow areas, were searched using telemetry equipment (Figure 13). Broader searches involving these areas were required when sonic-tagged fish were not located within Las Vegas Bay or Echo Bay; thus a more comprehensive search was required to ascertain fish locations.

Aerial Surveys

Aerial surveys were conducted on a lake-wide basis to observe known spawning locations and to attempt to identify new spawning aggregates. Aerial surveys were conducted lake-wide, with particular emphasis on areas that appeared to offer sufficient razorback sucker habitat (turbid bays, gravel shorelines, cover, etc.). Areas of interest are as follows:

- Las Vegas Bay including Las Vegas Wash,
- Teakettle Bay to East Point,
- Teal Cove to Decision Island,
- east shore of Overton Arm - Walker Bay to Cottonwood Cove,
- all of Echo Bay including the western shoreline north to Overton Beach,
- all of Muddy River and Virgin River arms,
- Grand Wash Cove, and
- Gregg Basin - specifically Devil's Cove to Gold Cross Bay and Crappie Cove to Smith Bay.

Please reference Figure 6 in the 1997–1998 annual report for a detailed map of the listed search areas (Holden et al. 1999).

As this document proceeds, specific descriptive terminology may be used when describing some sampling locations within Lake Mead. Specific definitions for the various portions of the Las Vegas Wash/Bay 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. This section is usually relatively narrow with obvious banks.
- Las Vegas Bay begins where the flooded portion of the channel widens and the velocity is reduced. Las Vegas Bay can have a flowing (lotic) and a non-flowing (lentic) portion. The flowing portion is typically short (200–400 yards) and transitory between Las Vegas Wash proper and Las Vegas Bay. Since 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 the text of 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);
- non-flowing 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, subadult, and larval razorback sucker 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 between the Muddy River confluence and the Virgin River confluence with Lake Mead);
- Fish Island (located between the Muddy River and Virgin River inflows, bounded on its western side by the Muddy River inflow and on its eastern side by the Virgin River inflow. This area may or may not be an actual island depending upon lake elevation); and
- Muddy River and Virgin River proper, the actual flowing, riverine portions that comprise the Muddy and Virgin Rivers.

RESULTS

Lake Elevation

When the Lake Mead razorback sucker studies were initiated in 1996–1997, the lake level was approximately 1,190 ft amsl (Reclamation 2007). The lake level consistently rose until 1998, at which point it reached a maximum level of 1,215 ft amsl (Figure 14). However, since that time there has been an average decrease in the water level of 11.5 ft/year, resulting in the current water level of 1,111 ft amsl. The trend in water level reduction is expected to continue well into the future (Reclamation 2007), with water surface elevations projected below 1,090 ft amsl by August 2009.

Larval Sampling

Table 1 shows the larval razorback sucker sampling effort, expressed as catch per minute (CPM) that occurred between the 1996–1997 and 2006–2007 study years and throughout all portions of Lake Mead that were sampled. We used CPM to be consistent with past annual reports.

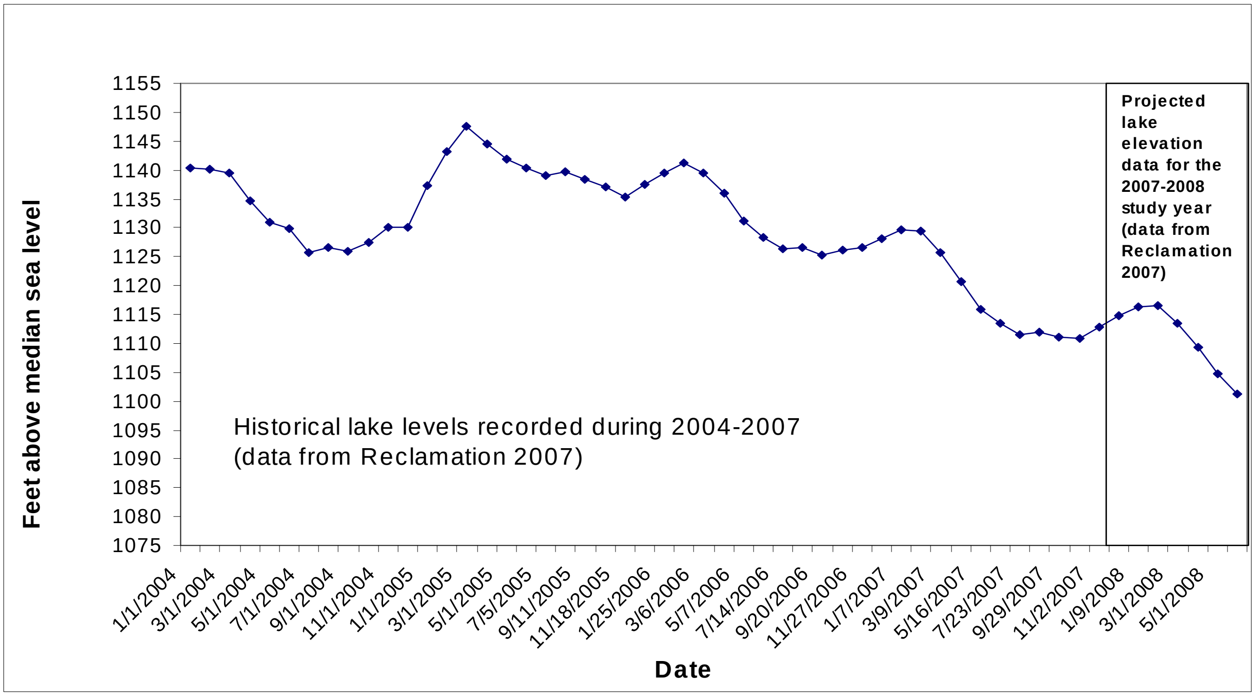

Figure 14. **Lake Mead elevations using a combination of actual, recorded, and historical lake-elevation data, as well as projected lake elevation for the 2007–2008 study period.**

Table 1. **Larval lake-wide overview.**

LOCATION	NO. LARVAE	TIME SPENT (MINUTES)	CPM
Boulder Basin	0	1,110	0.000
Colorado River Inflow	33	20,390	0.002
Echo Bay	10,113	20,267	0.499
Las Vegas Bay	2,410	26,483	0.091
Overton Arm	3	3,220	0.001
Muddy River/Virgin River Inflow	46	6,275	0.007
Temple Basin	0	1,230	0.000
Virgin Basin	2	1,620	0.001
TOTALS	**12,607**	**80,595**	**0.156**

Figure 15 shows the yearly lake-wide larval CPM. Please note that error bars were not constructed because the catch was influenced differentially between years: Standard larval sites were sampled in some cases, and in other years larval sampling sites were dictated primarily by habitat use of sonic-tagged fish as a result of the desiccation of standard sites over time. We have conducted larval fish sampling for a total of 80,595 minutes. The vast majority of those efforts occurred in Las Vegas Bay and Echo Bay, but some effort occurred in nearly every part of Lake Mead during the course of our studies. Figure 16 shows lake-wide larval sampling locations from 1997–2007, while Figure 17 shows larval capture locations from 1997–2007. To date, we have captured a total of 12,607 larval razorback sucker lake-wide. Over the years multiple methodologies have been used to locate and identify spawning sites on an annual basis, but larval sampling results have been used as the primary means to confirm and identify annual spawning sites.

Furthermore, larval sampling efforts are also depicted in (Figures 18, 19, and 20) and larval capture locations and annual spawning site selection are provided in (Figures 21, 22, and 23). The following text describes in detail the location, effort, and results of larval sampling within each general location of Lake Mead.

Las Vegas Bay

Blackbird Point was the primary observed spawning location used by razorback sucker in Las Vegas Bay throughout these studies (Figure 18). However, during the 2005–2006 study year, declining water levels resulted in the eventual desiccation of this well-known spawning habitat and larval sampling efforts were shifted to the southwestern shoreline (Albrecht et al. 2006). Since the 2006 spawning period, the bulk of larval sampling in Las Vegas Bay occurred along the southwestern shoreline, which provided a high capture rate for larval razorback sucker compared with elsewhere in Las Vegas Bay. This high capture rate typically indicates a primary spawning area (Albrecht et al. 2007) (Figure 21). To date, we have captured a total of 2,410 larval fish and dedicated 26,393 minutes of sampling time in that vicinity. The resulting overall CPM at Las Vegas Bay is 0.091 fish/min (Table 1).

Historically, larval capture rates from Las Vegas Bay were lower than those reported for Echo Bay, but that changed in 2006 and 2007. However, larval fish were captured at Las Vegas Bay every year since the onset of larval sampling in 1997. Larval CPM at Las Vegas Bay ranged from a high of 0.123 fish/min in 2006–2007 to a low of 0.001 fish/min in 2004 (Table 2, Figure 24).

Figure 25 depicts mean larval razorback sucker capture rates on a monthly basis combining data collected from 1997–2007. As depicted, February was the month of highest mean larval CPM at Las Vegas Bay during the course of our studies. Figure 26 presents larval fish capture events coupled with temperatures at time and point of capture. Larval fish captures in Las Vegas Bay coincided with surface water temperatures ranging between 55–79 °F, and the bulk of larval captures coincided with surface water temperatures of 56–70 °F. It should be noted that we have

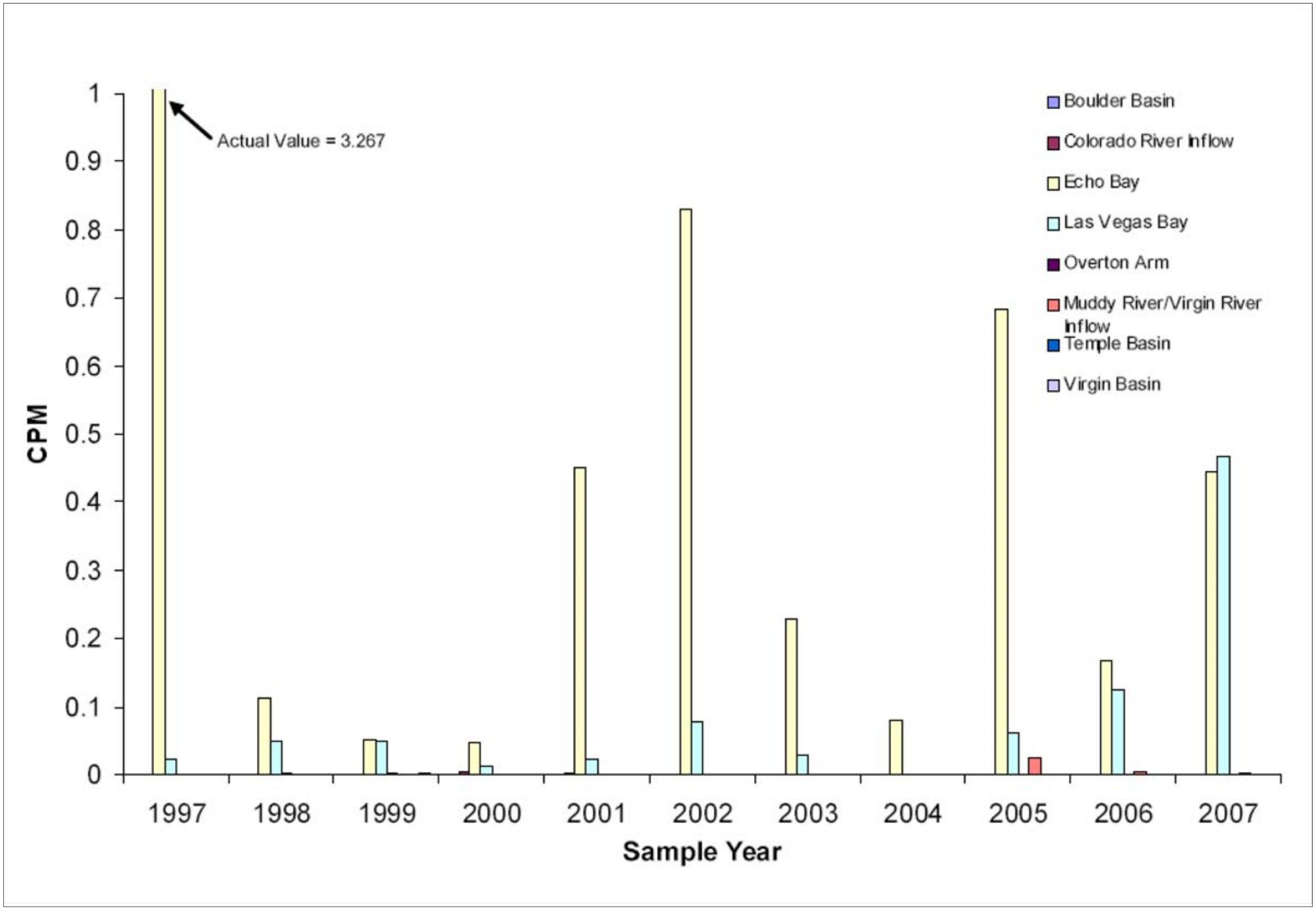

Figure 15. **Lake-wide larval sampling effort (expressed as CPM) 1997–2007. (Please also refer to site-specific larval CPM figures.)**

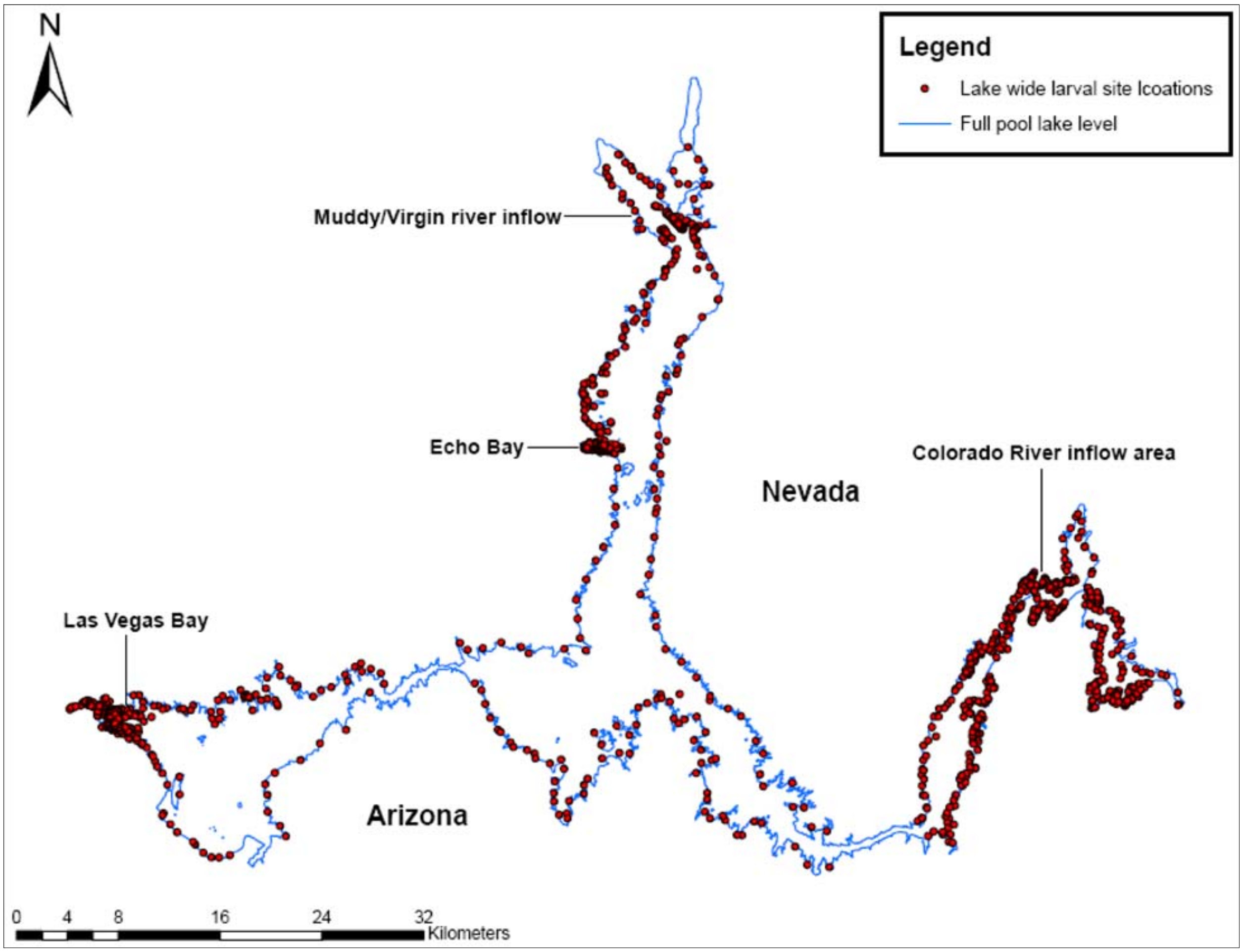

Figure 16. Lake-wide locations of larval razorback sucker efforts.

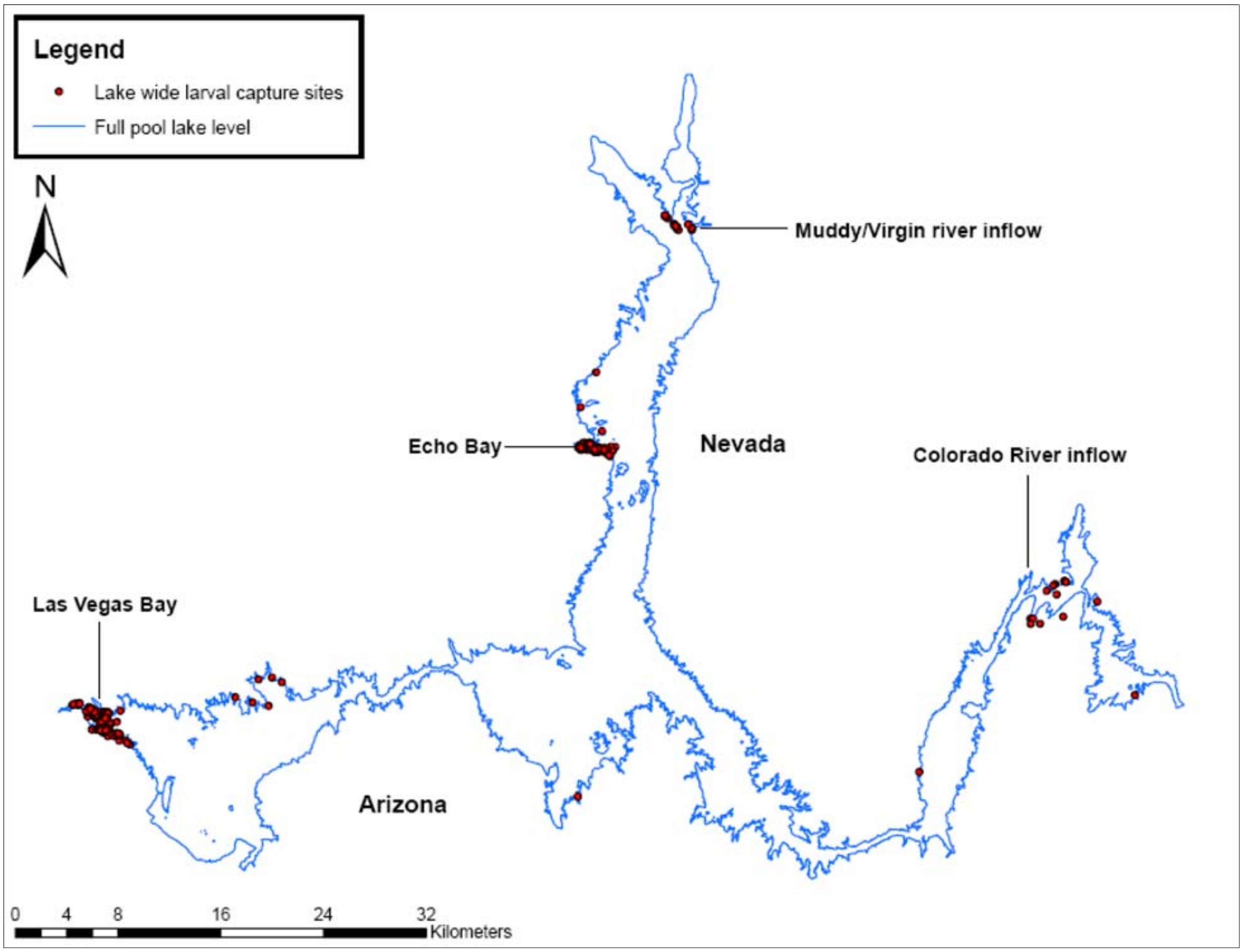

Figure 17. Lake-wide locations of larval razorback sucker captures.

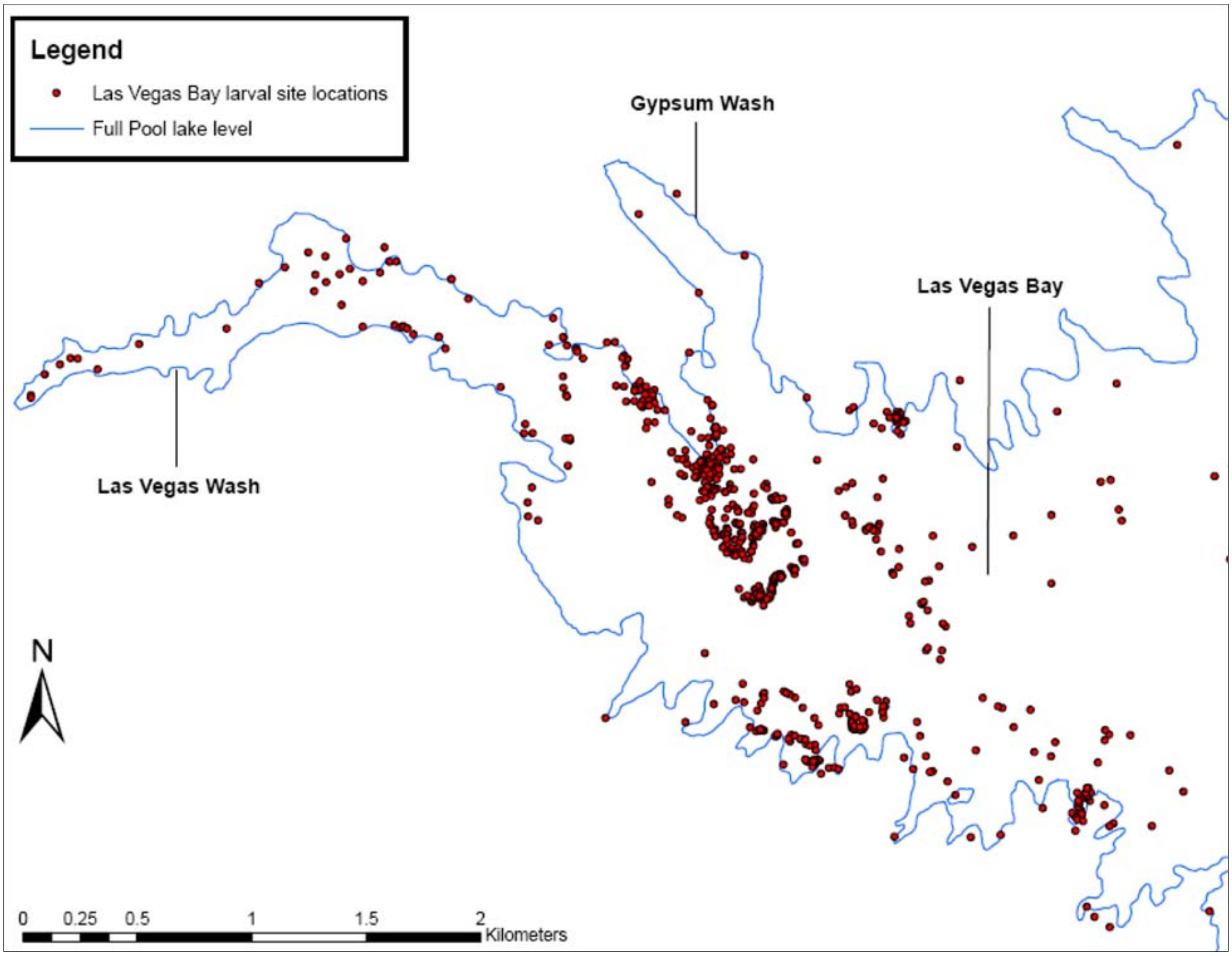

Figure 18. Las Vegas Bay locations of larval razorback sucker efforts.

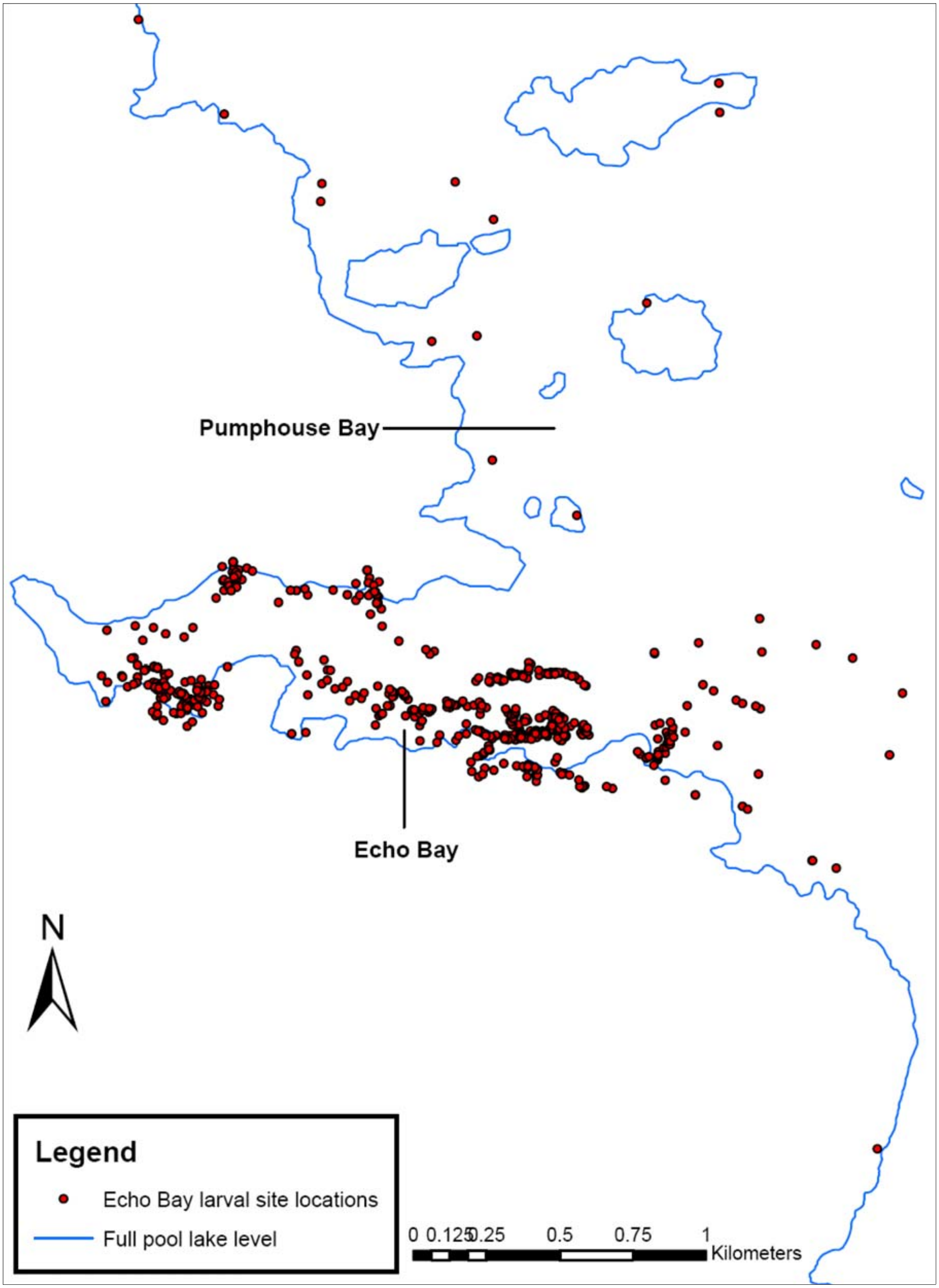

Figure 19. Echo Bay locations of larval razorback sucker efforts.

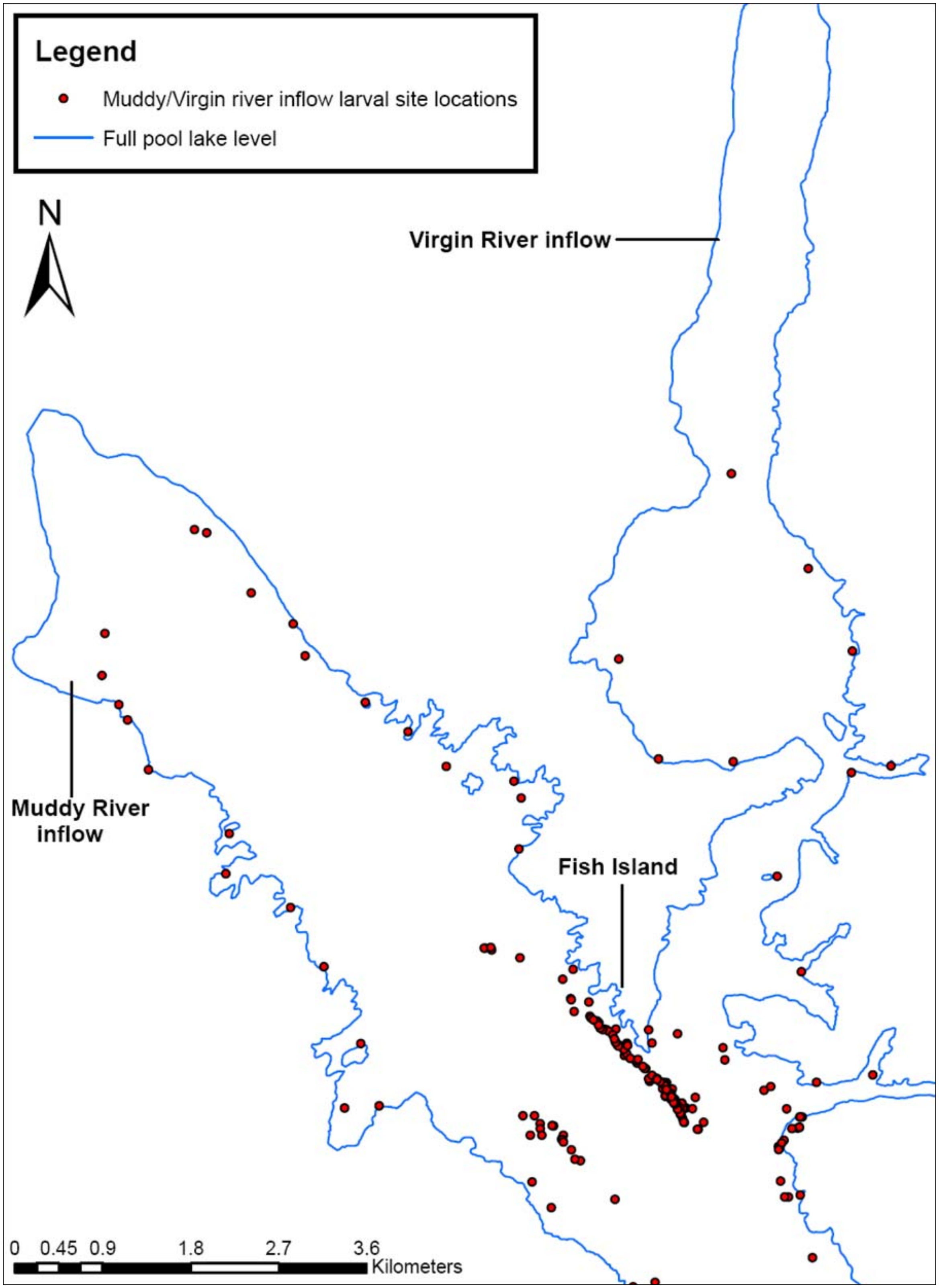

Figure 20. Muddy River/Virgin River inflow area larval razorback sucker efforts.

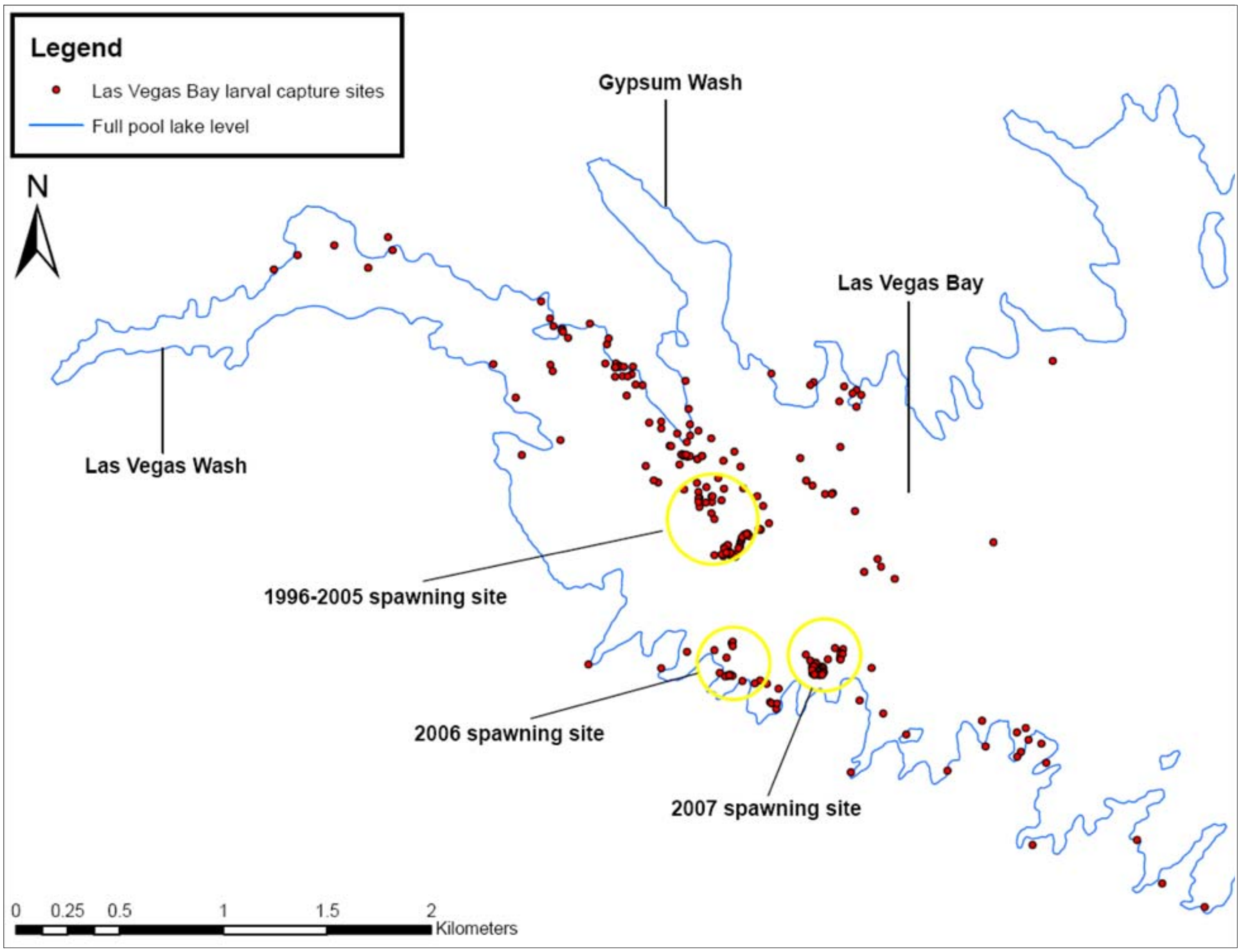

Figure 21. Las Vegas Bay locations of larval razorback sucker captures and yearly spawning-site selections.

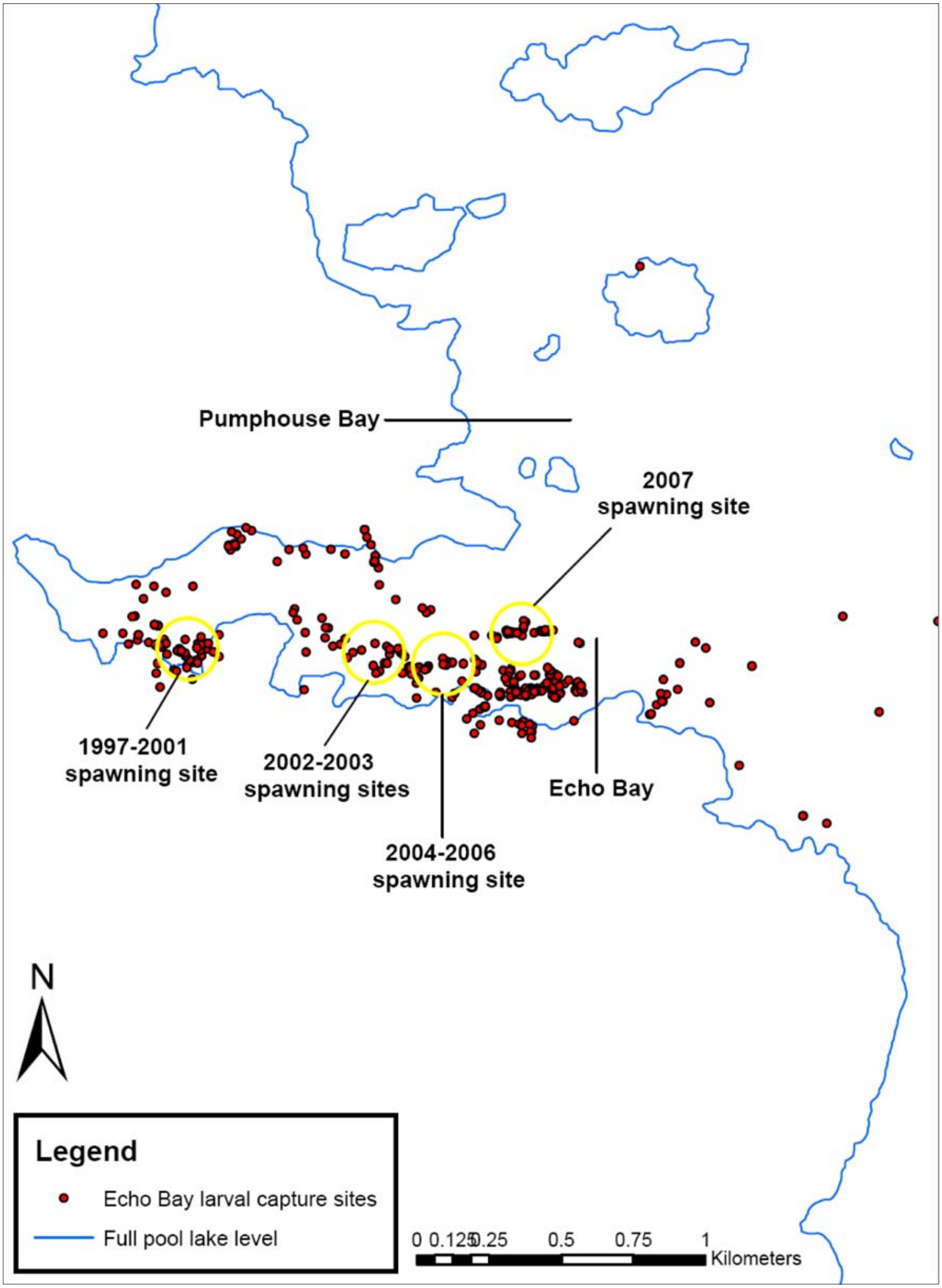

Figure 22. Echo Bay locations of larval razorback sucker captures and yearly spawning-site selections.

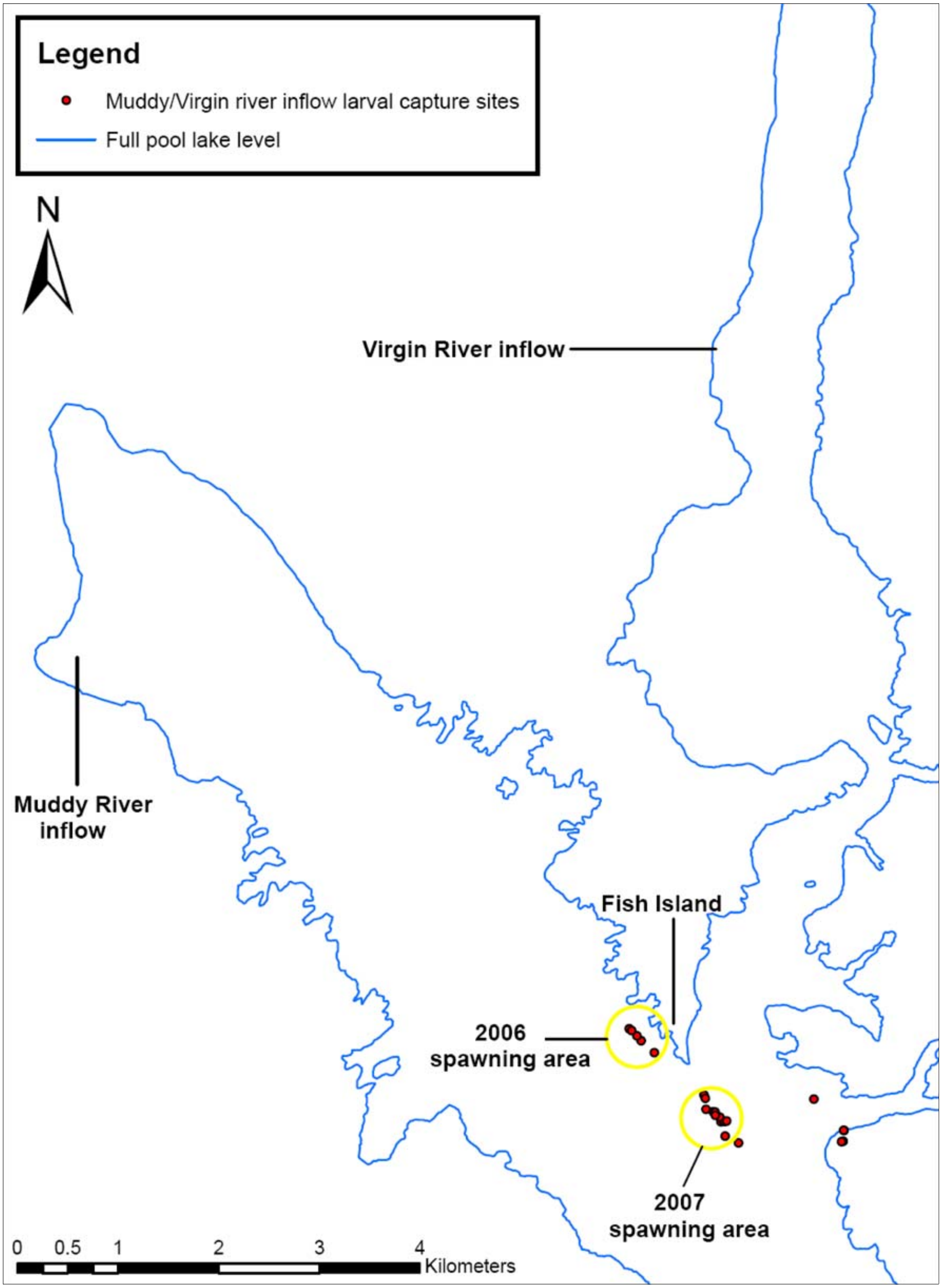

Figure 23. **Muddy River/Virgin River inflow area locations of larval razorback sucker captures and yearly spawning-site selections.**

Table 2. Larval CPM by year sampled at Las Vegas Bay.

YEAR	NO. LARVAE	TIME SPENT (MINUTES)	CPM
1997	25	1,074	0.023
1998	159	3,272	0.049
1999	146	2,979	0.049
2000	48	3,570	0.013
2001	39	1,789	0.022
2002	130	1,680	0.077
2003	73	2,400	0.030
2004	4	2,945	0.001
2005	96	1,530	0.063
2006	259	2,100	0.123
2007	1,431	3,054	0.469
TOTALS	**2,410**	**26,393**	**0.091**

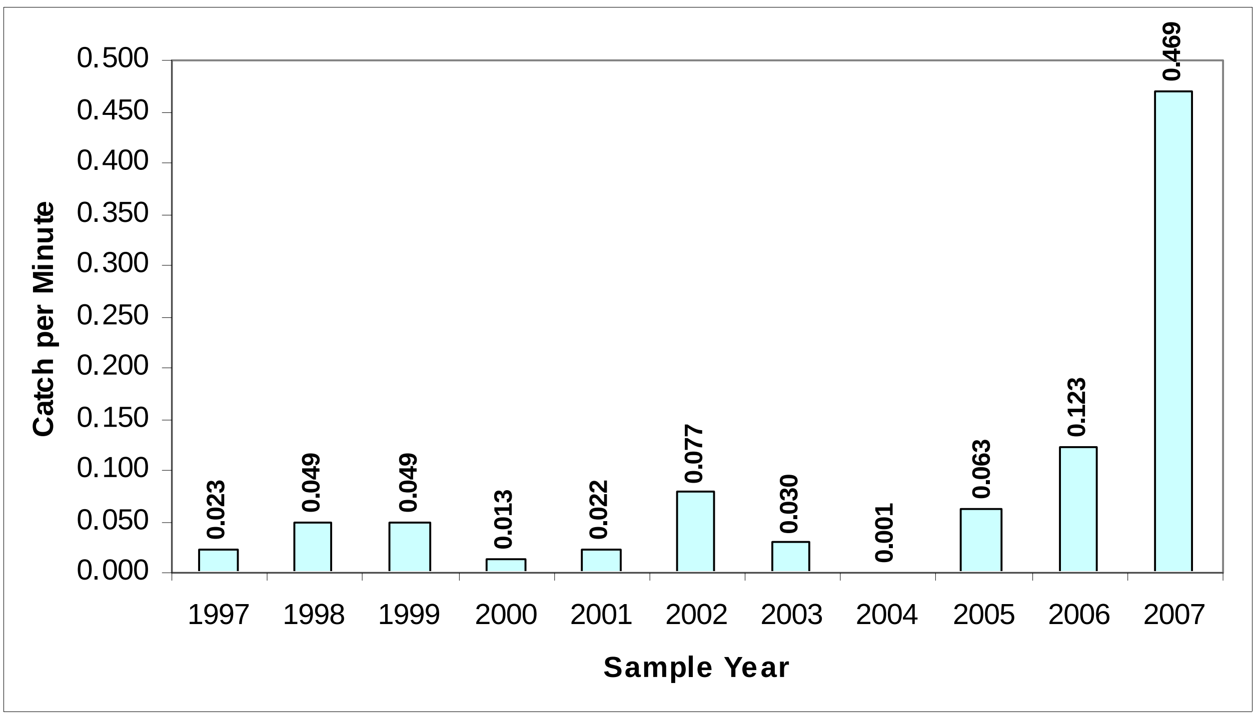

Figure 24. Larval razorback sucker CPM at Las Vegas Bay 1997–2007.

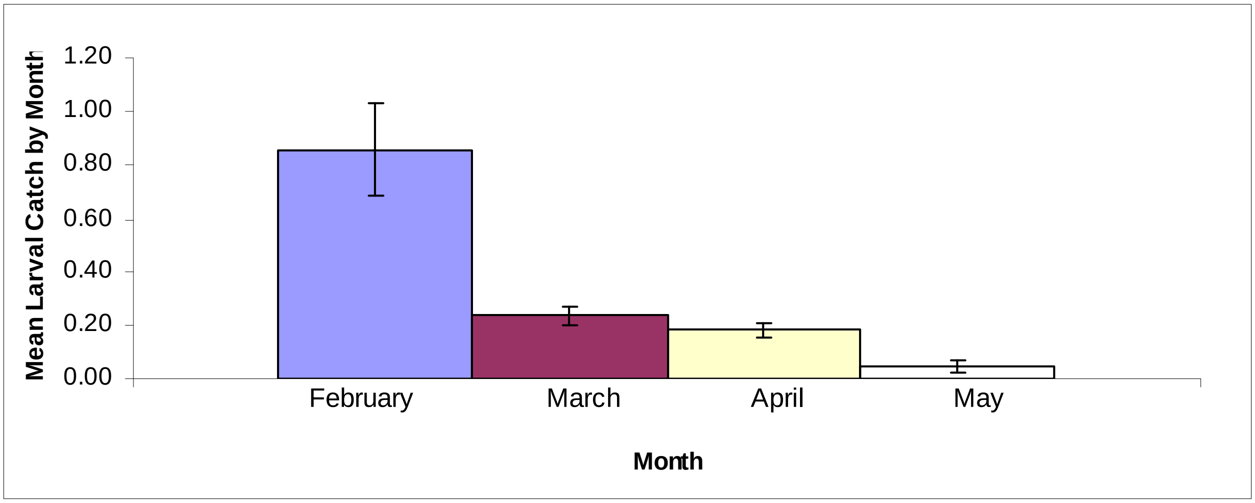

Figure 25. Mean monthly CPM at Las Vegas Bay combining data from 1997–2007. Note error bars indicate 1 standard error.

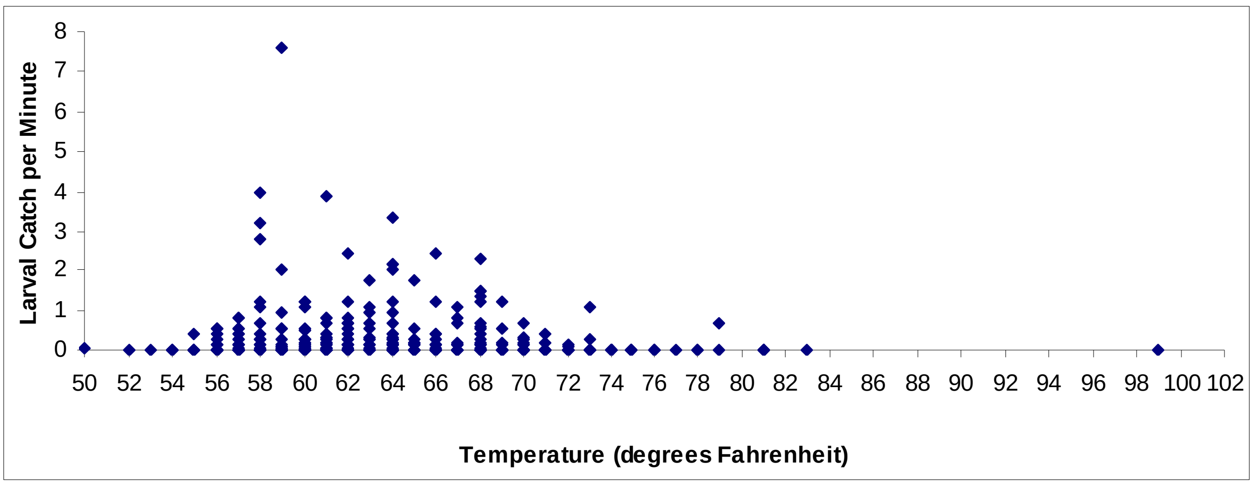

Figure 26. Las Vegas Bay larval fish/temperature relationship.

never captured larval razorback sucker at Las Vegas Bay when surface water temperatures were below 55 °F. Table 3 provides an overview of the first date that larval fish were found in Las Vegas Bay by study year.

Echo Bay

Larval sampling at Echo Bay was primarily conducted towards the back of Echo Bay (Figure 22). Echo Bay consistently boasted the highest collection numbers of razorback sucker in Lake Mead. Since 1997, when larval sampling efforts were initiated, the majority of larval captures were located towards the back of Echo Bay. This same spawning site continued to produce the

Table 3. Date that larval fish were first found in Las Vegas Bay by study year.

YEAR	MONTH/DAY
1997	4/5
1998	3/19
1999	3/4
2000	3/11
2001	3/11
2002	3/25
2003	3/4
2004	3/23
2005	3/3
2006	2/6
2007	2/5

highest densities of larval fish through the 2001 spawning season. As the lake began to recede over the years, the primary spawning site and larval capture locations shifted easterly down the bay with the declining lake (Figure 22). The primary spawning and larval collection site has recently shifted to the northern shoreline, just west of the Echo Bay launch ramp (Albrecht et al. 2007). To date, we have captured a total of 10,113 larval fish and dedicated 20,267 minutes of sampling time in the vicinity. The resulting overall CPM at Echo Bay was 0.499 fish/min (Table 1).

Larval razorback sucker have been captured in Echo Bay since the onset of larval sampling in 1997. Catch rates at Echo Bay have ranged from a high of 3.267 fish/min in 1997 to a low of 0.048 fish/min in 2000 (Table 4, Figure 27) and have typically been higher than at Las Vegas Bay.

Figure 28 depicts mean larval razorback sucker capture rates at Echo Bay on a monthly basis combining data collected from 1997–2007. As depicted, the month of highest mean larval CPM at Echo Bay has been April during the course of our studies. Figure 29 presents larval fish capture events coupled with temperatures at time and point of capture. Larval fish captures in Echo Bay coincided with surface water temperatures ranging between 55–73 °F, and the bulk of larval captures coincided with surface water temperatures of 57–63 °F. We have never captured larval razorback sucker at Echo Bay when surface water temperatures were below 55 °F. As demonstrated above, this is the precise temperature that appears to dictate the presence/absence of larval captures at Las Vegas Bay. Table 5 provides an overview of the first date that larval fish were found in Echo Bay by study year.

Table 4. Larval CPM by year sampled at Echo Bay.

YEAR	NO. LARVAE	TIME SPENT (MINUTES)	CPM
1997	4,777	1,462	3.267
1998	197	1,770	0.111
1999	95	1,821	0.052
2000	70	1,470	0.048
2001	987	2,190	0.451
2002	847	1,020	0.830
2003	552	2,436	0.227
2004	207	2,650	0.078
2005	1,330	1,950	0.682
2006	308	1,830	0.168
2007	743	1,668	0.445
TOTALS	**10,113**	**20,267**	**0.499**

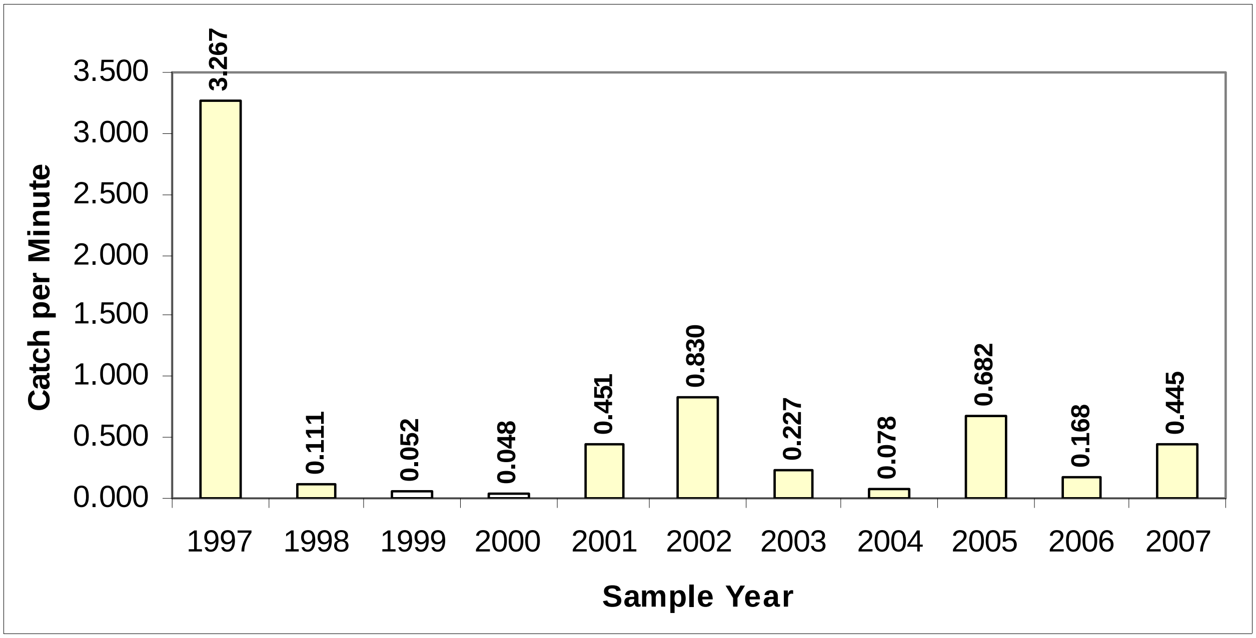

Figure 27. Larval razorback sucker CPM at Echo Bay 1997–2007.

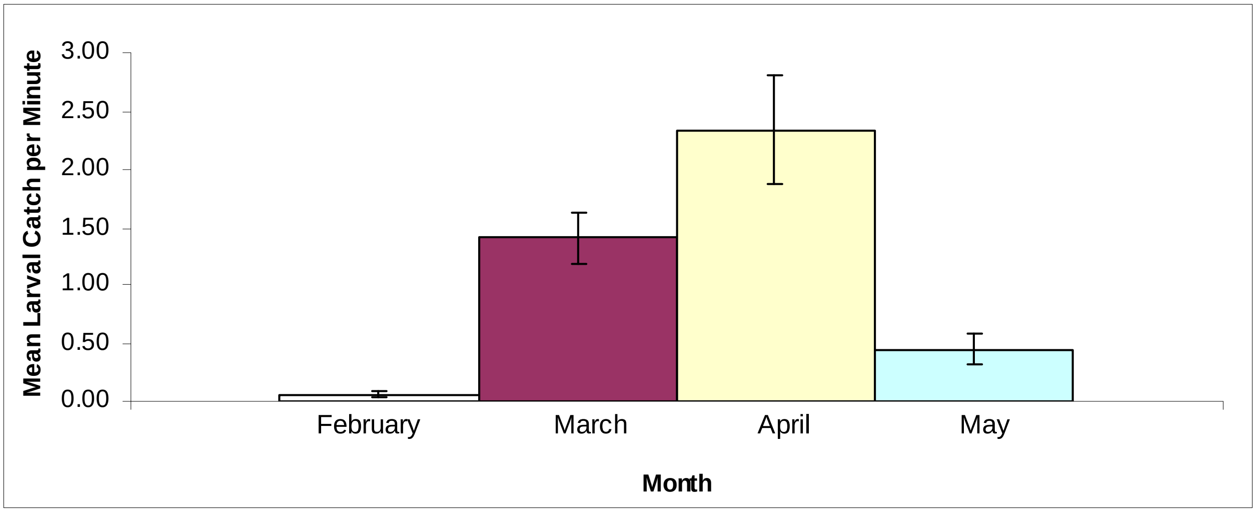

Figure 28. **Mean monthly CPM at Echo Bay combining data from 1997–2007. Note error bars indicate 1 standard error.**

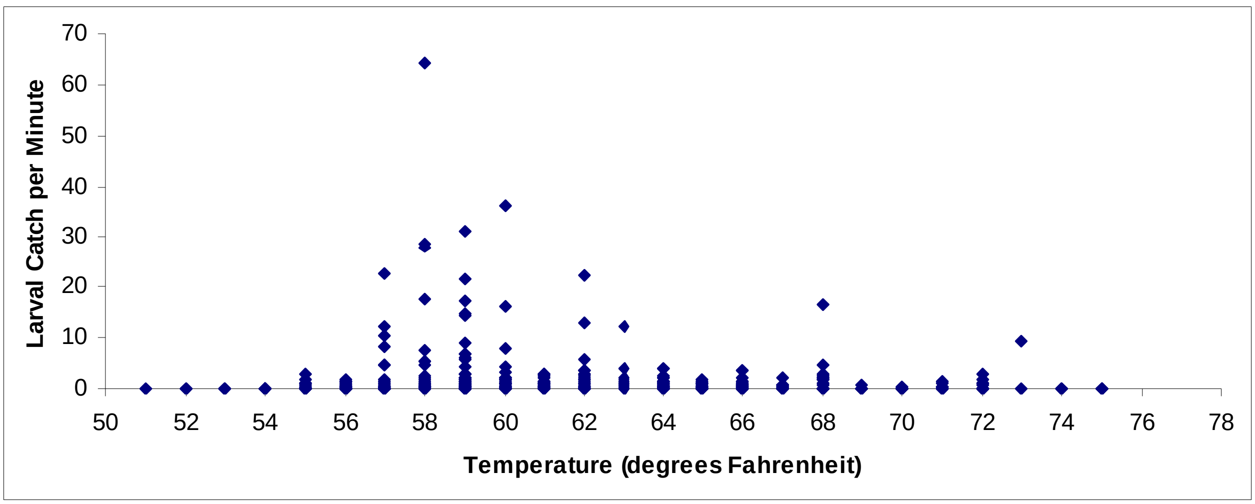

Figure 29. **Echo Bay larval fish/temperature relationship.**

Muddy River/Virgin River Inflow Area

Although we occasionally sampled for larval razorback sucker in the Muddy River/Virgin River inflow area during the earlier years of our studies, they were not captured until the last three spawning periods (Table 6). In fact, relatively little is known regarding larval fish production in this area of Lake Mead due to their overall rarity at this newly discovered spawning location (Albrecht et al. 2007)(Figures 20 and 23). To date, we have captured a total of 47 larval fish and dedicated 6,305 minutes of sampling time in the vicinity. The resulting overall CPM at the Muddy River/Virgin River inflow was 0.007 fish/min (Table 1, Figure 30).

Table 5. Date that larval fish were first found in Echo Bay by study year.

YEAR	MONTH/DAY
1997	3/18
1998	3/11
1999	4/20
2000	2/27
2001	3/12
2002	3/26
2003	3/5
2004	2/24
2005	2/22
2006	3/13
2007	3/5

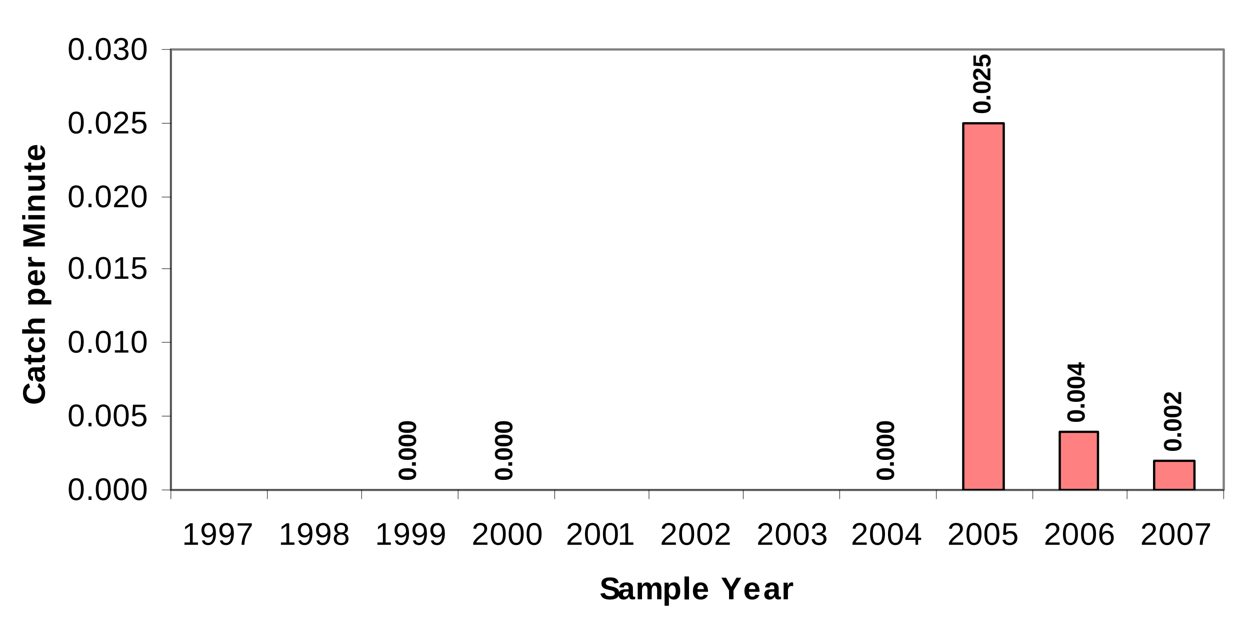

Figure 30. Larval razorback sucker CPM at the Muddy River/Virgin River inflow area 1997–2007.

The CPUE of larval fish in the Muddy River/Virgin River inflow area has been steady but low since the spawning location was identified in 2005 (Albrecht and Holden 2005). Larval razorback sucker captures have ranged from no fish being captured during lake-wide larval sampling efforts (1999, 2000, and 2004) to a high of 0.025 fish/minute during the first season that the area was identified as a spawning location (2005)(Table 6, Figure 30). Although overall larval fish captures were low before the area was identified as a spawning location, the Muddy River/Virgin River inflow area generated substantial interest simply because it is the only other location on Lake Mead where larval fish were found fairly regularly, and it is the only known spawning location outside of Echo and Las Vegas bays. In fact, 2006 was the first time sufficient evidence was gathered to formulate the hypothesis that the Echo Bay spawning aggregate and the Muddy River/Virgin River spawning aggregate share metapopulation dynamics, since several spawning fish were found in both locations over the course of a single spawning season (Albrecht et al. 2007).

Table 6. Larval CPM by year sampled at the Muddy River/Virgin River inflow area.

YEAR	NO. LARVAE	TIME SPENT (MINUTES)	CPM
1999	0	660	0.000
2000	0	630	0.000
2004	0	575	0.000
2005	39	1,545	0.025
2006	6	1,590	0.004
2007	2	1,305	0.002
TOTALS	**47**	**6,305**	**0.007**

Figure 31 depicts mean larval razorback sucker capture rates on a monthly basis using data collected from the 2005–2007 spawning periods. To date, we are hesitant to report which month is the most productive at the Muddy River/Virgin River inflow area. Figure 32 presents larval fish capture events coupled with temperatures at time and point of capture. Larval fish captures from the Muddy River/Virgin River inflow area coincided with surface water temperatures between 59–72 °F, and the bulk of larval captures coincided with surface water temperatures of 61–66 °F. However, we acknowledge that fewer data have been collected at this location, so comparisons with the other known spawning locations should not be made at this time. We have not collected larval razorback sucker from the Muddy River/Virgin River inflow area when surface water temperatures were below 59 °F. Table 7 provides an overview of the first date that larval fish were found in the Muddy River/Virgin River inflow area by study year.

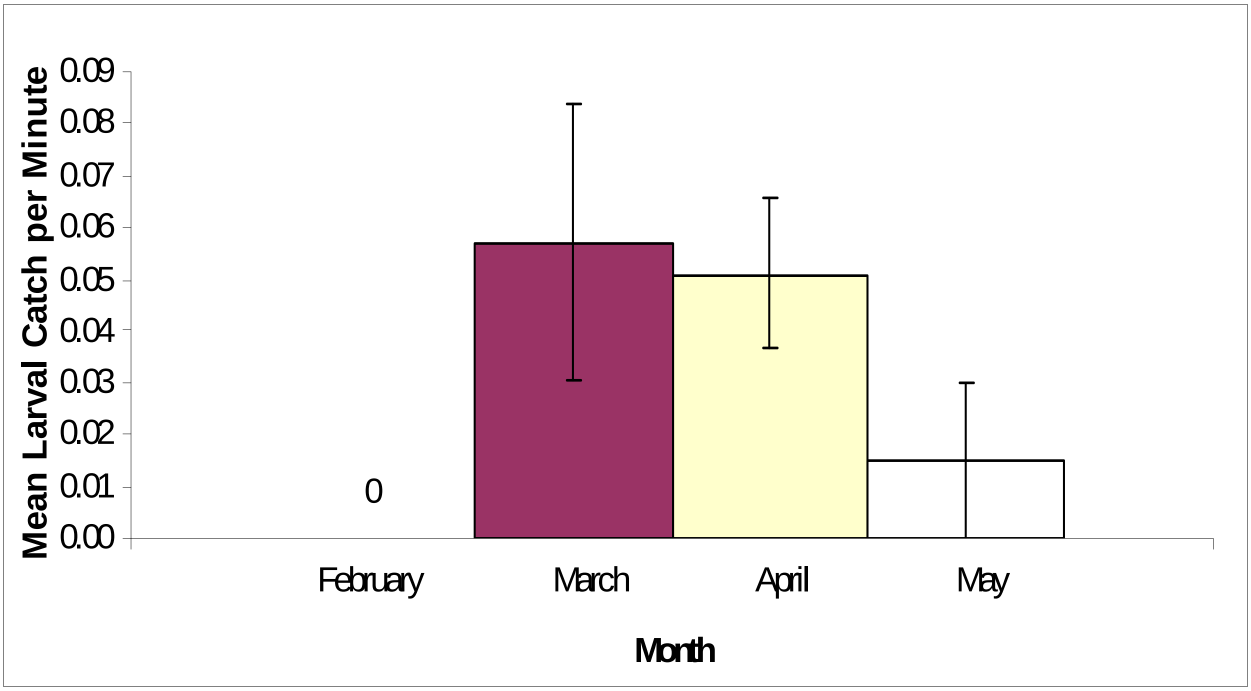

Figure 31. **Mean monthly CPM at the Muddy River/Virgin River inflow area combining data from 2005–2007. Note error bars indicate 1 standard error and sampling efforts in this area commenced in 2005.**

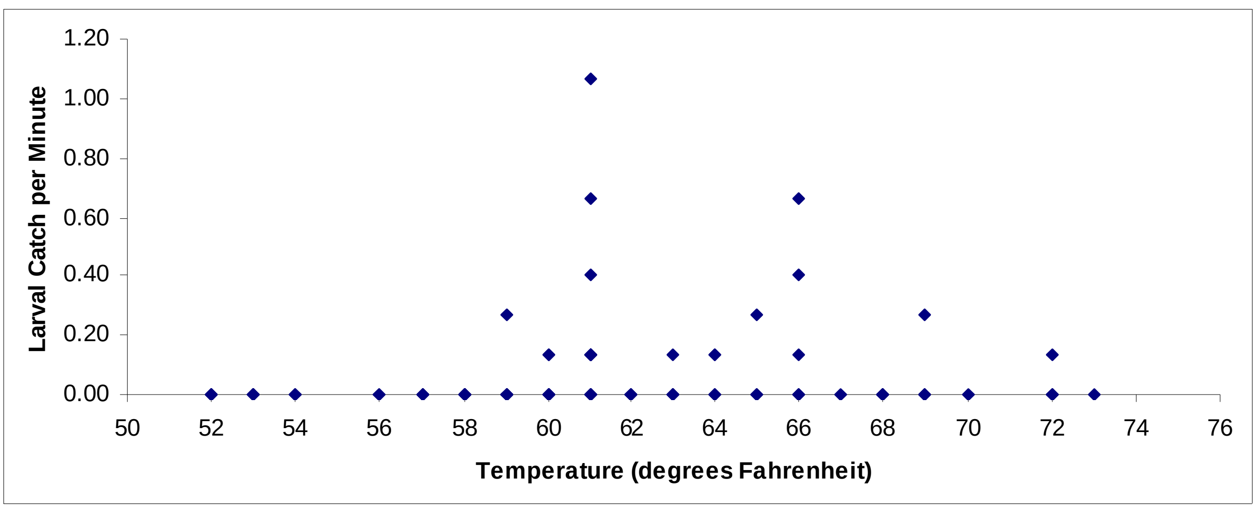

Figure 32. **Muddy River/Virgin River larval fish/temperature relationship.**

Table 7. Date that larval fish were first found in the Muddy River/Virgin River inflow area by study year.

YEAR	MONTH/DAY
1999	n/a
2000	n/a
2004	n/a
2005	3/2
2006	4/12
2007	4/10

Colorado River Inflow Area

In addition to Las Vegas Bay, Echo Bay, and the Muddy River/Virgin River inflow area, the Colorado River inflow area has been one of the areas of Lake Mead sampled for larval fish on a fairly regular basis (Figure 33). Reasons for investigating the Colorado River inflow area were based on the overarching hypothesis that razorback sucker in Lake Mead tend to be found in locations exhibiting a high degree of cover, in terms of both vegetation and turbidity. As will be described further in the results and discussion sections of this report, the concept of cover and recruitment has long been the major working hypothesis driving the majority of our efforts on Lake Mead. Sufficiently for now, cover in the form of both vegetation and turbidity both appear to be highly abundant at the Colorado River inflow, thus this location has been and will continue to be an area of interest for razorback sucker research on Lake Mead. To date, we have captured a total of 33 larval fish and have dedicated 20,390 minutes of sampling time in the vicinity (Figure 34). The resulting overall CPM at the Colorado River inflow area is 0.002 fish/min (Table 1, Figure 35).

Historically, larval capture rates from the Colorado River inflow area have tended to be lower than those reported for the primary spawning locations on Lake Mead. However, larval fish were captured at the Colorado River inflow area in 2000 and 2001 (Table 1, Figure 35). Larval catch rates at the Colorado River inflow area have ranged from a high of 0.004 fish/min in 2001, to 0.002 fish/min in 2000, to no captures during 1998, 1999, and the 2002–2004 spawning periods (larval sampling has not been conducted in this area since 2004)(Table 8).

Dates of annual larval fish first captures in the Colorado River inflow area are presented in Table 9, but the capture and temperature relationship (as shown in previous sections) will not be presented here due to the data limitations. As shown in Table 9, larval fish were captured in the Colorado River inflow area on the exact same date during both 2000 and 2001; thus we felt that the temperature disparity was not sufficient for further analysis.

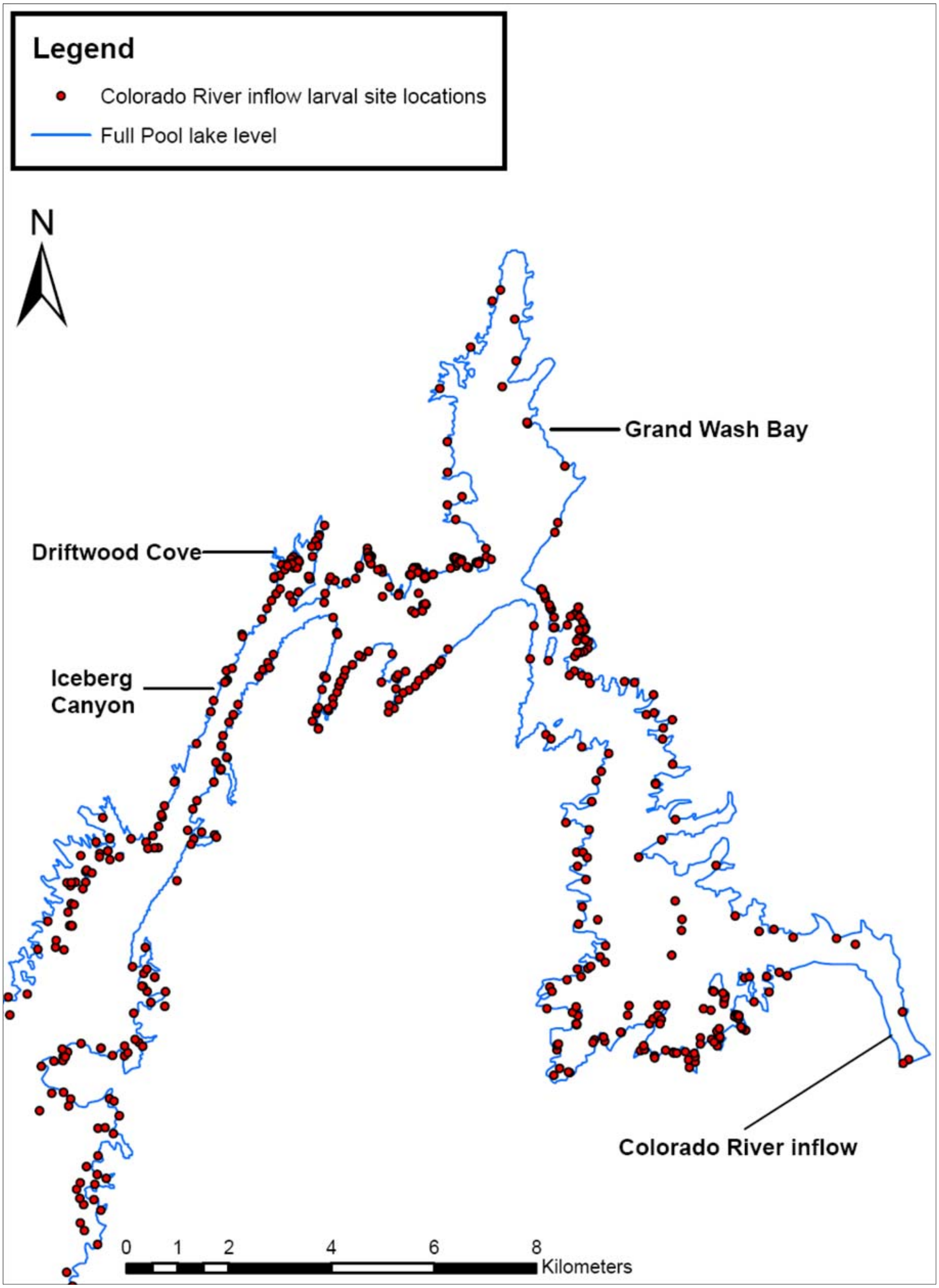

Figure 33. Locations of Colorado River inflow larval razorback sucker efforts.

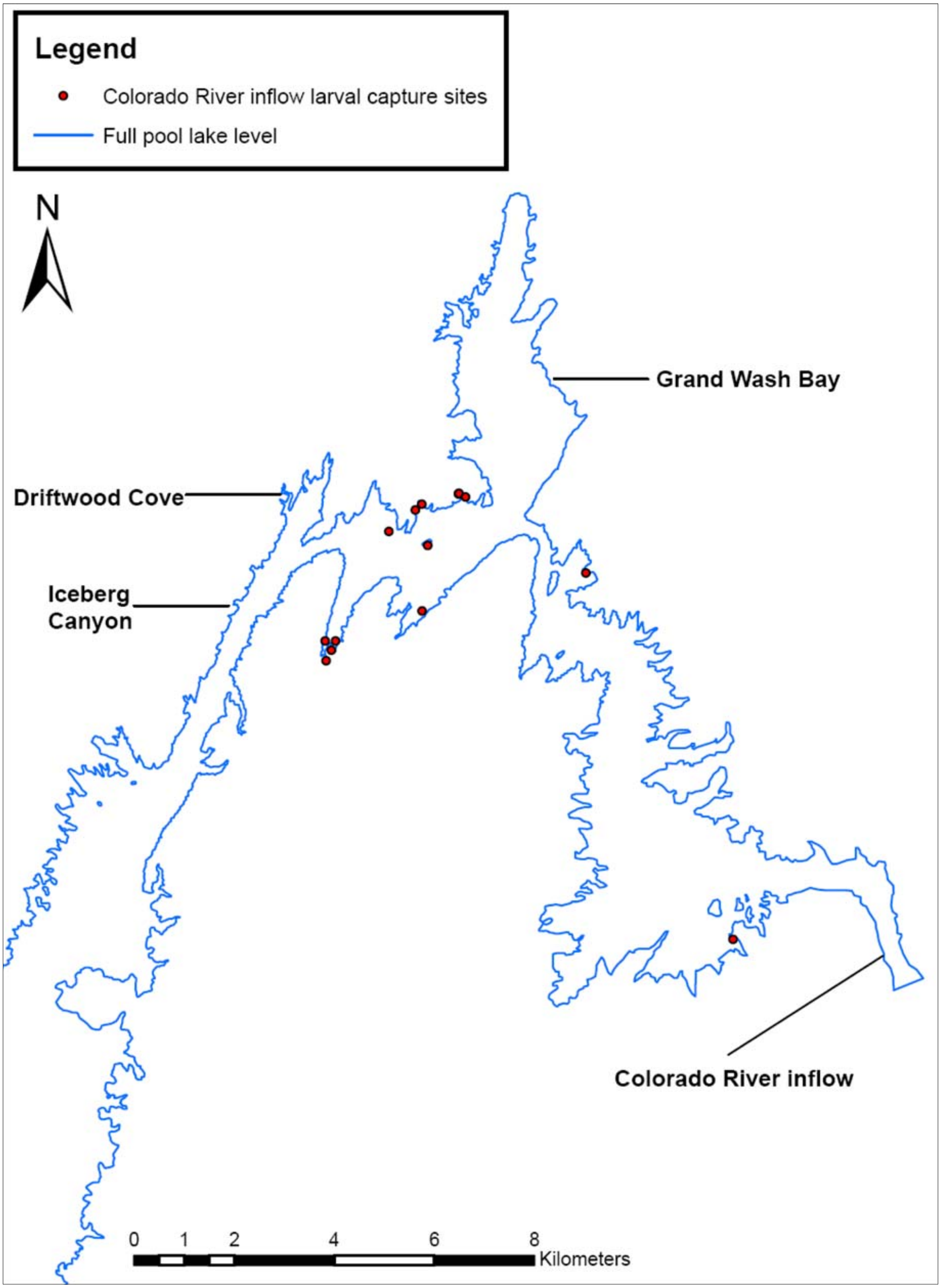

Figure 34. Colorado River inflow locations of larval razorback sucker captures.

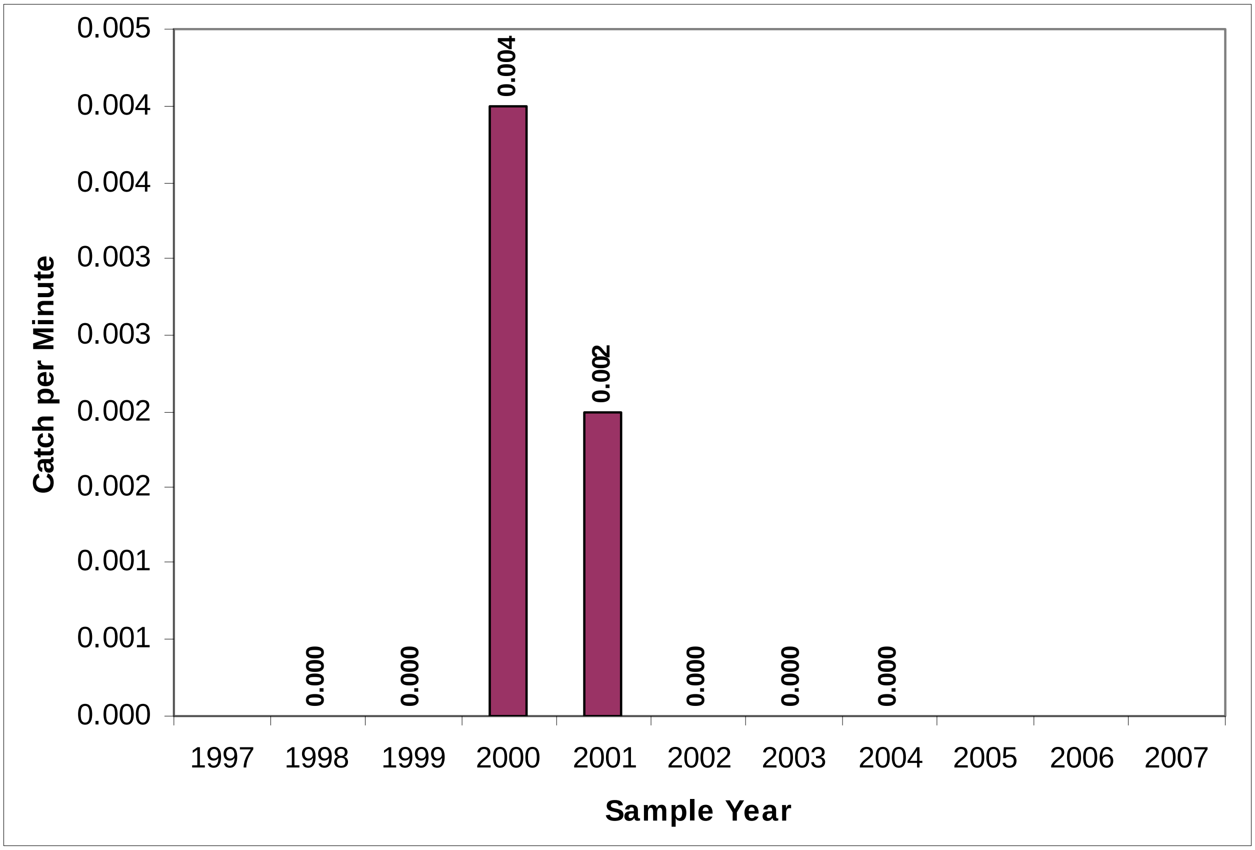

Figure 35. Larval razorback sucker CPM at the Colorado River inflow area 1998–2004.

Table 8. Larval CPM by year sampled at the Colorado River inflow area.

YEAR	NO. LARVAE	TIME SPENT (MINUTES)	CPM
1998	0	1,080	0.000
1999	0	1,500	0.000
2000	11	2,530	0.004
2001	22	8,890	0.002
2002	0	1,980	0.000
2003	0	2,760	0.000
2004	0	1,650	0.000
TOTALS	**33**	**20,390**	**0.002**

Table 9. Date that larval fish were first captured in the Colorado River inflow area by study year.

YEAR	MONTH/DAY
1998	n/a
1999	n/a
2000	4/29
2001	4/29
2002	n/a
2003	n/a
2004	n/a

Other Locations

In addition to larval sampling at Las Vegas Bay, Echo Bay, the Muddy River/Virgin River inflow area, and the Colorado River inflow area, most of the remainder of Lake Mead was sampled at least once according to project goals. The remaining portions of the lake were sampled during lake-wide larval sampling (Holden et al. 2000a, Holden et al. 2000b). In most of these other locations, no razorback sucker larvae were found, although in a few instances a rare, random, individual, larval razorback sucker was identified during collections but additional larvae were either not collected during subsequent sampling or no collection pattern was discernable. Thus, after lake-wide larval sampling was discontinued, these other locations were not investigated further so that time and resources were allocated to studying known razorback sucker spawning aggregates.

For the purposes of this report, the following other locations were sampled, but no new spawning areas were identified: Areas within the Boulder Basin, but not that part of the basin comprising Las Vegas Bay and nearby vicinities; locations within the Overton Arm located to the north of the immediate Echo Bay/Pumphouse Bay area and positioned to the south of the Old Swim Beach area; the Temple Basin area; and the Virgin Basin area. Summary information for these other locations is provided in Table 10.

Juvenile Sampling

Efforts to capture juvenile razorback sucker were initiated between the 1996–1997 and 2002–2003 study years (Table 11). These efforts were de-emphasized and eventually abandoned after the 2002–2003 study year due to the ineffectiveness of the techniques used to capture juvenile razorback sucker. (Holden et al. 1999, Holden et al. 2000a, Holden et al. 2000b, Holden et al. 2001, Abate et al. 2002, Welker and Holden 2003, Welker and Holden 2004, Albrecht and Holden 2005, Albrecht et al. 2006a, Albrecht et al. 2007). No juvenile razorback sucker were captured during these efforts, and all subadult fish that were captured during our studies stemmed from trammel netting efforts directed at capturing adult fish. The use of minnow traps,

Table 10. Larval CPM by year sampled at all other locations sampled during the course of our studies.

LOCATION	YEAR	NO. LARVAE	TIME SPENT (MINUTES)	LARVAE/MINUTE
Virgin Basin	1999	2	870	0.002
Virgin Basin	2000	0	780	0.000
Temple Basin	1999	0	300	0.000
Temple Basin	2000	0	930	0.000
Overton Arm	1997	0	80	0.000
Overton Arm	1998	2	830	0.002
Overton Arm	1999	1	540	0.002
Overton Arm	2000	0	1,530	0.000
Overton Arm	2002	0	150	0.000
Overton Arm	2006	0	90	0.000
Boulder Basin	1999	0	720	0.000
Boulder Basin	2000	0	390	0.000
TOTALS	**ALL**	**5**	**7,210**	**>0.001**

Table 11. Yearly sampling effort for juvenile razorback sucker in Lake Mead at Las Vegas Bay and Echo Bay by gear type and effort expended.

	LAS VEGAS BAY EFFORT					ECHO BAY EFFORT				
Study Year	Gill Net (net hours)	Seines (ft^2)	Hoop/ Fyke Nets (net nights)	Minnow Traps (net nights)	Electro-fishing (minutes)	Gill Net (net hours)	Seines (ft^2)	Hoop/ Fyke Nets (net nights)	Minnow Traps (net nights)	Electro-fishing (minutes)
1996–1997	-	3,410	12	120	-	6.2	33,210	27	414	-
1997–1998	10.5	-	-	18	-	-	-	6	36	130
1998–1999	-	-	16	-	-	13.0	-	44	-	-
1999–2000	12.0	-	32	30	167.5	-	-	25	120	-
2000–2001	-	-	-	-	-	35.0	-	24	30	-
2001–2002	13.0	-	13	72	-	-	-	9	-	-
2002–2003	-	-	-	7	-	-	-	-	6	-
TOTALS	**35.5**	**3,410**	**73**	**240**	**167.5**	**54.2**	**33,210**	**135**	**600**	**130**

seines, hoop nets, and fyke nets for collecting juvenile razorback sucker will not be discussed further in this report. For those interested in the specific results related to the employment of these techniques, please refer to the past annual reports as outlined above.

Adult and Subadult Sampling

Trammel Netting

Table 12 shows trammel netting effort, expressed as net nights, that occurred between the 1996–1997 and 2006–2007 study years in all sampling areas within Lake Mead. To date, 1,706 net nights have occurred, the vast majority in Las Vegas Bay and Echo Bay (Figure 36). Figure 37 displays the CPUE among Las Vegas Bay, Echo Bay, the Overton Arm, and the Muddy River/Virgin River inflow area by month over the duration of the study. It is evident that the lake-wide capture efficiency of adult razorback sucker is greatest during January–April. The following text describes in detail the efforts and results of trammel netting within sampling locations of Lake Mead where razorback sucker were captured.

Table 12. Trammel netting effort (net nights) on Lake Mead throughout the 11-year study period by sampling location.

STUDY YEAR	COLORADO INFLOW	LAS VEGAS BAY	BOULDER BASIN	ECHO BAY	OVERTON ARM	MUDDY RIVER/VIRGIN RIVER INFLOW	YEAR TOTALS
1996–1997		95		39			134
1997–1998		62		71	5		138
1998–1999		43	7	37	5		92
1999–2000	20	57		46			123
2000–2001	98	49		39			186
2001–2002	45	76		67			188
2002–2003	18	113		94			225
2003–2004		107		138			245
2004–2005		54		50		28	132
2005–2006		44		49		40	133
2006–2007		38		40		32	110
TOTALS	**181**	**738**	**7**	**670**	**10**	**100**	**1,706**

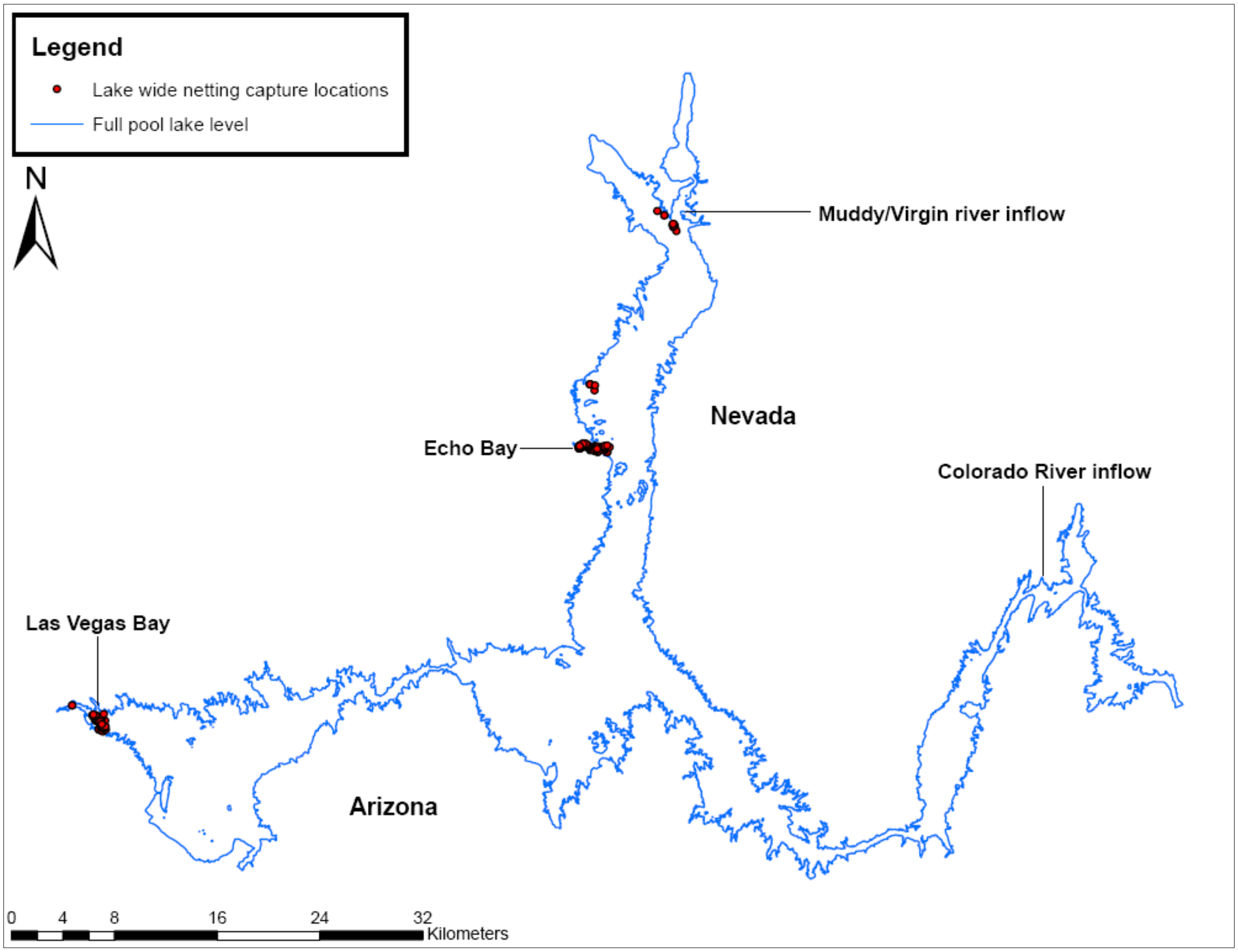

Figure 36. Lake-wide trammel netting captures 1996–2007.

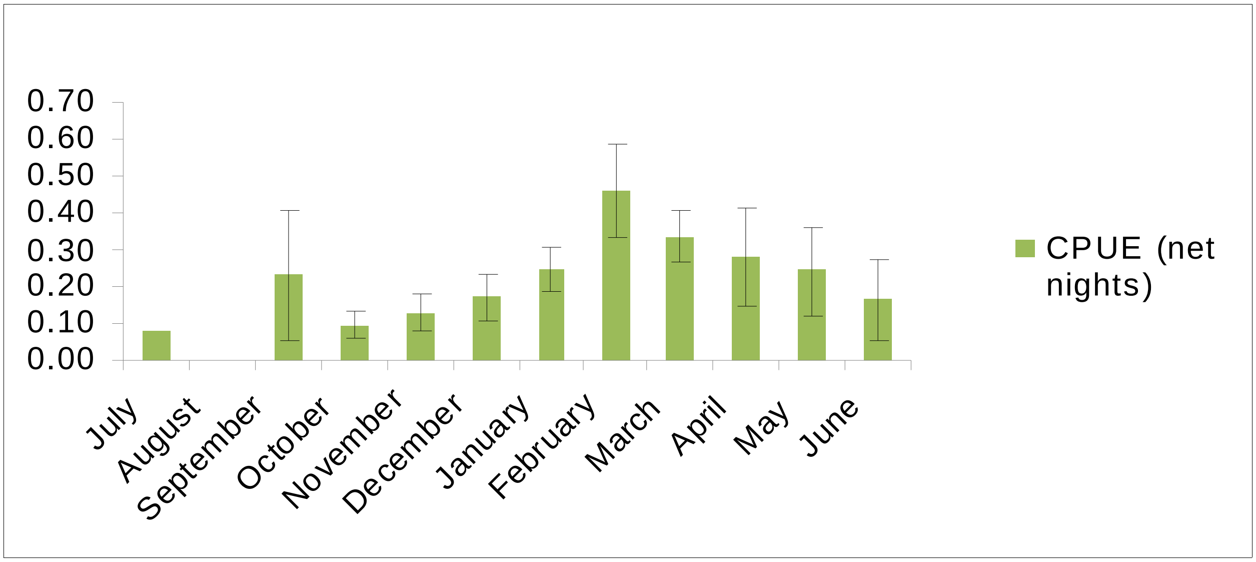

Figure 37. Lake-wide catch per unit effort (fish caught/net night) by month in Lake Mead from 1997–2007.

Las Vegas Bay

Throughout the Lake Mead studies, the primary sampling location in Las Vegas Bay has been on/around the historical razorback sucker spawning location near Blackbird Point (Figure 38). During the 2005–2006 study year, decreasing water levels resulted in the eventual dessication of this spawning habitat, thus netting efforts were shifted to the southwestern shoreline (Albrecht et al. 2006). To date, 178 razorback sucker have been captured in Las Vegas Bay as a result of 738 net nights (Table 13). The cumulative CPUE for all sampling years in Las Vegas Bay is 0.24 fish/net night. The maximum and minimum capture rates occurred during 2006–2007 and 2003–2004 (1.03 and 0.05 fish/net night, respectively). In regards to sampling timing, December–March have the highest capture rates, specifically February, March, and May (0.31, 0.41, and 0.31 fish/net night respectively) (Figures 39 and 40). Las Vegas Bay has the second-highest rate of newly captured fish of any sampling location in Lake Mead. Of the 178 razorback sucker captured in Las Vegas Bay, 97 (55%) were new captures (fish that had not been previously captured or PIT tagged)(Figures 41 and 42).

Trammel netting also provided some idea of spawning area based on the location of ripe fish in the net. At Las Vegas Bay the Blackbird Point spawning area was apparently quite deep, 80–90 ft, when the lake was high as ripe fish were primarily found at the deep end of the net set. As the lake receded, the same area was used but it then became shallower. Once the spawning area became inundated with silt, the fish moved to another spawning location.

Echo Bay

Trammel netting in Echo Bay was primarily conducted towards the back of the bay, close to identified spawning areas (Figures 22 and 43). As the lake level receded, trammel netting locations shifted in a lake-ward direction, compensating for the advancing shoreline. Trammel nets were also set around the mouth of Echo Bay, as well as within the confines of Pumphouse Bay. For the purposes of this report, Pumphouse Bay is considered an extension of Echo Bay, due to their proximity and direct access.

Throughout 11 years of Lake Mead studies, 240 razorback sucker were captured from Echo Bay during 670 total net nights (Table 14), resulting in an overall CPUE of 0.45 fish/net night. The maximum and minimum capture rates occurred during 1996–1997 and 2004–2005 (0.85 and 0.12 fish/net night, respectively). Data suggest that sampling efficiency is highest during January–April (Figures 44 and 45).

The rate at which fish were recaptured was higher in Echo Bay than any other sampling location in Lake Mead. Seventy percent (167 of 240) of the razorback sucker captured were previously PIT-tagged by either NDOW, USFWS, or BIO-WEST personnel (Figures 41 and 42).

Ripe fish in Echo Bay were generally captured at shallower depths than at Las Vegas Bay, suggesting that the actual spawning occurred at shallower depths. Redds were located in 10 ft or less of water in Echo Bay, requiring the fish to move spawning locations nearly annually as the lake receded.

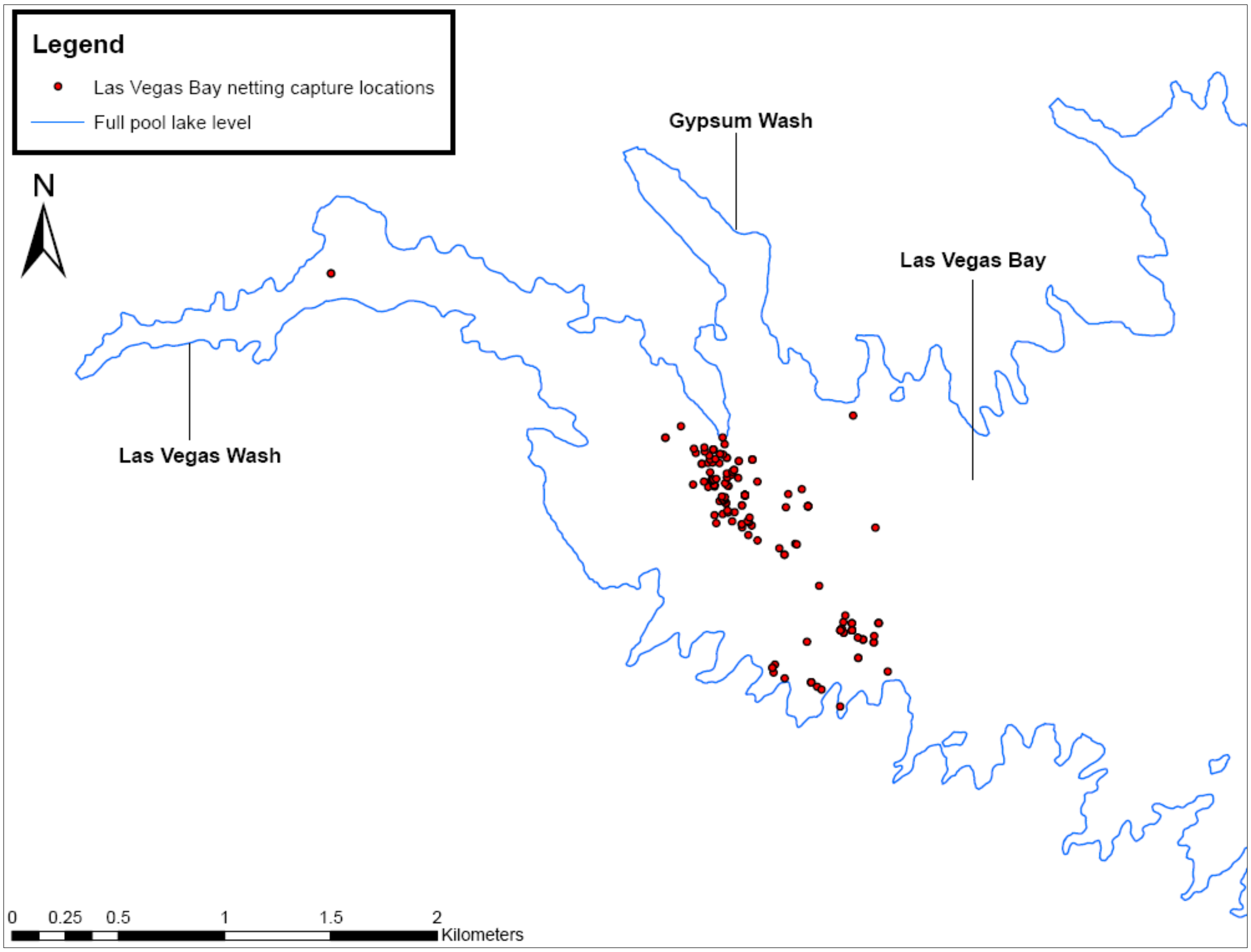

Figure 38. Locations of trammel net captures in Las Vegas Bay from 1997–2007.

Table 13. Trammel netting effort (net nights) in Las Vegas Bay throughout the 11-year study period by sampling location.

YEAR	NUMBER OF RAZORBACK SUCKER	EFFORT (NET NIGHTS)	CPUE (FISH/NET NIGHT)
1996–1997	28	95	0.29
1997–1998	22	62	0.35
1998–1999	5	43	0.12
1999–2000	15	57	0.26
2000–2001	9	49	0.18
2001–2002	18	76	0.24
2002–2003	21	113	0.19
2003–2004	5	107	0.05
2004–2005	4	54	0.07
2005–2006	13	44	0.30
2006–2007	39	38	1.03
TOTALS	**179**	**738**	**0.24**

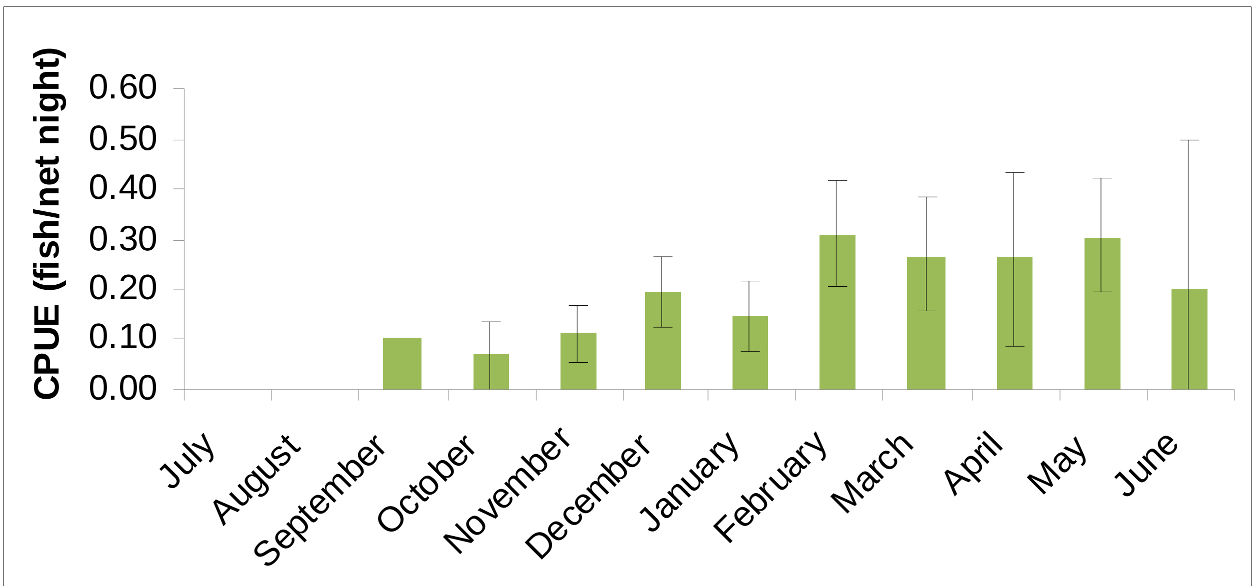

Figure 39. Las Vegas Bay catch per unit effort (fish caught/net night) by month from 1997–2007.

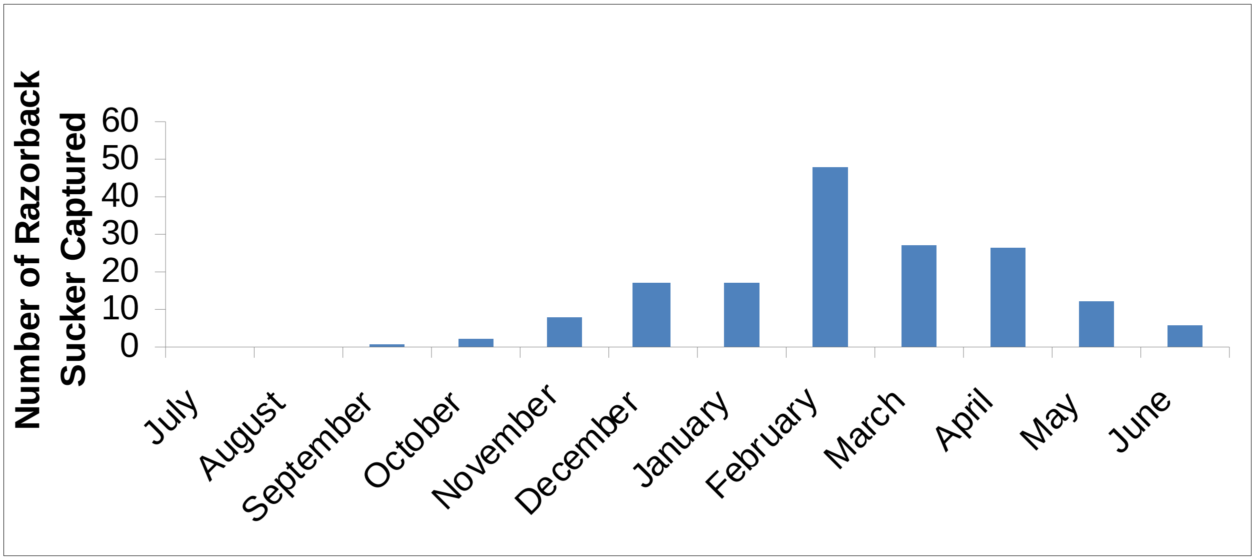

Figure 40. **Total number of trammel net captures in Las Vegas Bay by month from 1997–2007.**

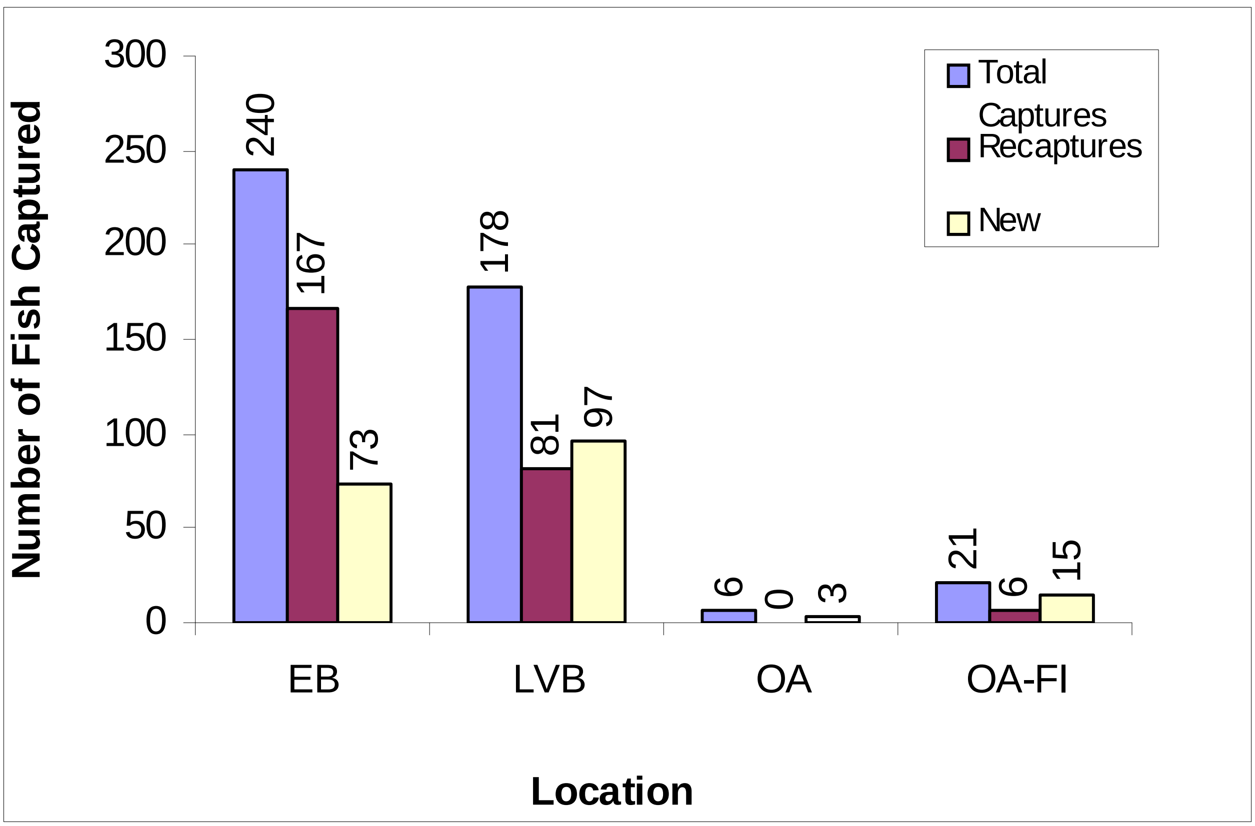

Figure 41. **Number of total captures, recaptures, and newly captured fish by sampling location in Lake Mead from 1997–2007.**

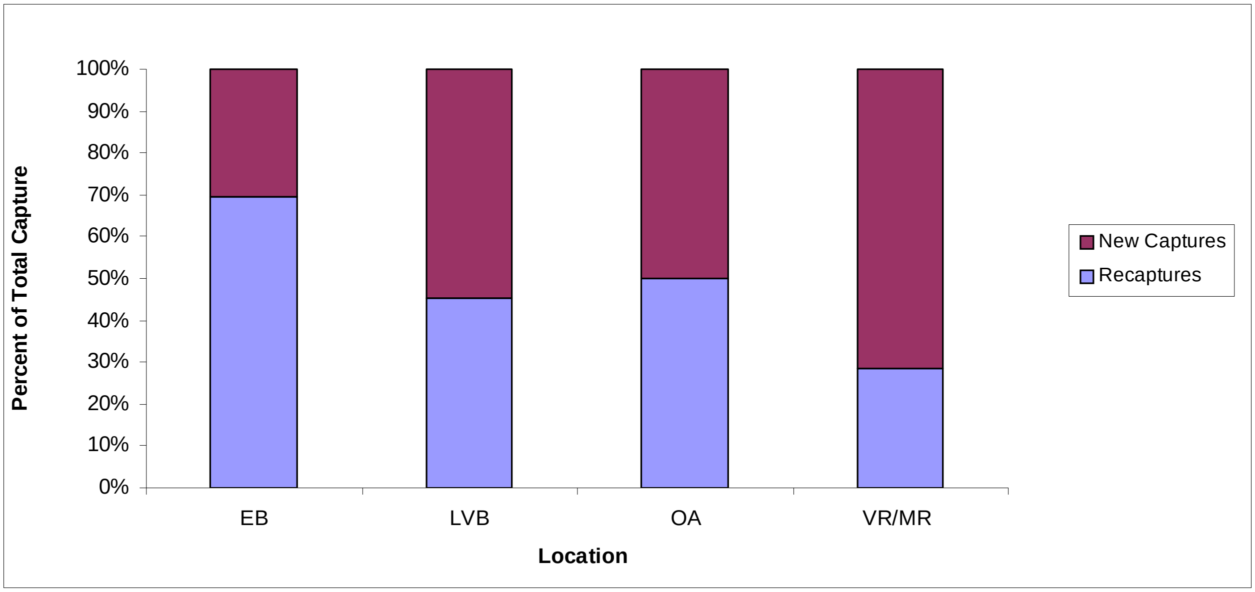

Figure 42. Proportions of recaptured and newly captured fish by sampling location in Lake Mead from 1997–2007.

Muddy River/Virgin River Inflow

Trammel netting was first initiated in the Muddy River/Virgin River inflow area during the 2004–2005 study season. Since that time, 21 razorback sucker have been netted from this portion of the lake, during 100 total net nights (Table 15, Figure 46). The cumulative CPUE for the Muddy River/Virgin River inflow area is 0.21 fish/net night. Throughout the three sampling seasons in which the Muddy River/Virgin River inflow area was sampled, the maximum and minimum capture rates were 0.50 and 0 fish/net night (during 2006–2007 and 2004–2005, respectively). Sampling efficiency was greatest during February–April (Figures 47 and 48).

The Muddy River/Virgin River inflow area has produced the fewest recaptured razorback sucker as compared to other sampling locations on the lake (Figures 41 and 42). To date, 21 razorback sucker have been captured, of which only 6 (29%) were recaptured fish.

Colorado River Inflow Area

The Colorado River inflow area was sampled arduously between 1999–2000 and 2002–2003. During this time, trammel nets were set a total of 181 net nights. Nonetheless, not a single razorback sucker was captured. As a result, yearly and monthly capture data were not calculated for this portion of Lake Mead.

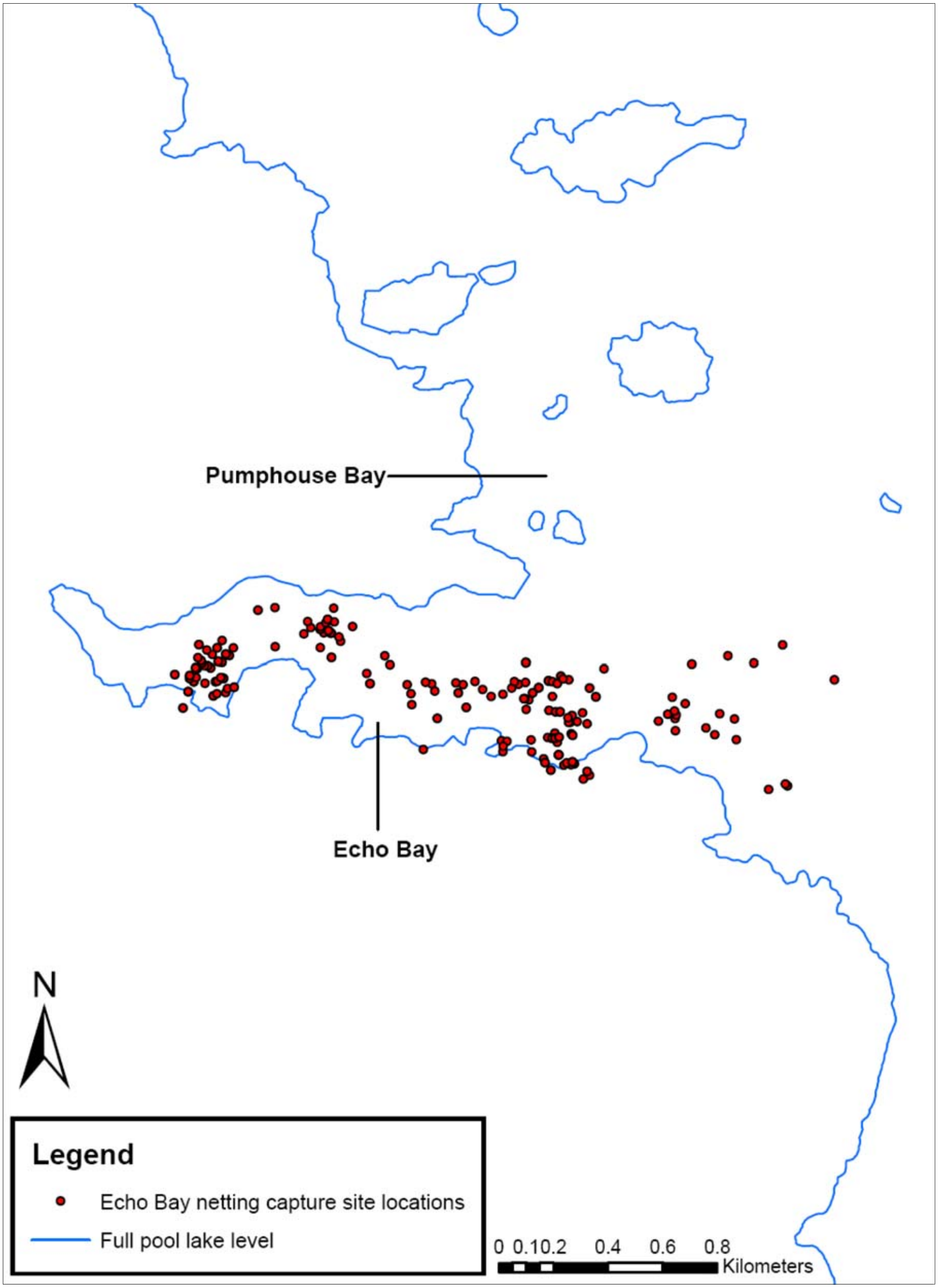

Figure 43. Locations of trammel net captures in Echo Bay from 1997–2007.

Table 14. **Trammel netting effort (net nights) in Echo Bay throughout the 11-year study period by sampling location.**

YEAR	NUMBER OF RAZORBACK SUCKER	EFFORT (NET NIGHTS)	CPUE (FISH/NET NIGHT)
1996–1997	33	39	0.85
1997–1998	45	71	0.63
1998–1999	20	37	0.54
1999–2000	24	46	0.52
2000–2001	13	39	0.33
2001–2002	14	67	0.21
2002–2003	20	94	0.21
2003–2004	29	138	0.21
2004–2005	6	50	0.12
2005–2006	27	49	0.55
2006–2007	33	40	0.83
TOTALS	**264**	**670**	**0.45**

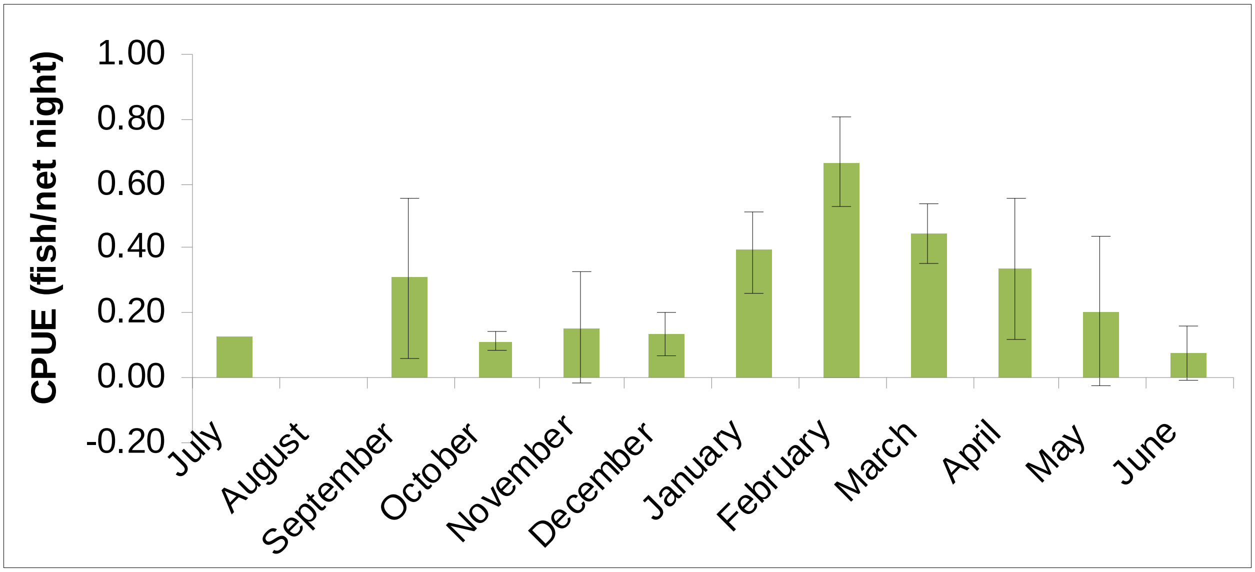

Figure 44. **Echo Bay catch per unit effort (fish caught/net night) by month from 1997–2007.**

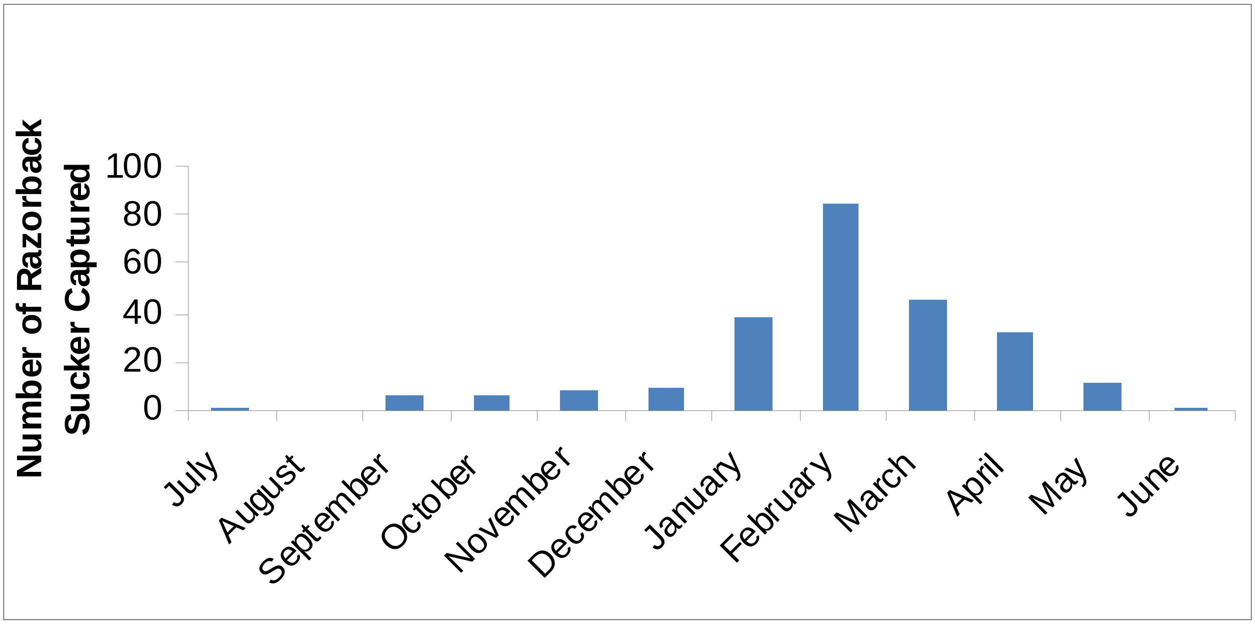

Figure 45. **Total number of trammel net captures in Echo Bay by month from 1997–2007.**

Table 15. **Trammel netting effort (net nights) in the Muddy River/Virgin River inflow area throughout the 11-year study period by sampling location.**

YEAR	NUMBER OF RAZORBACK SUCKER	EFFORT (NET NIGHTS)	CPUE (FISH/NET NIGHT)
2004–2005	2	28	0.07
2005–2006	3	40	0.08
2006–2007	16	32	0.50
TOTALS	**21**	**100**	**0.21**

Overton Arm

For purposes of this report, the Overton Arm is considered any portion of Lake Mead extending north from the Virgin Bowl to Old Swim Beach (just south of Overton Beach), excluding Echo Bay. The Overton Arm has not been systematically sampled; however, random trammel netting was conducted mostly in the region between Anchor Cove and Blue Point Bay.

Sampling within the Overton Arm portion of Lake Mead was not as rigorously conducted as in areas such as Las Vegas Bay, Echo Bay, and the Muddy River/Virgin River inflow area. In total, six new razorback sucker were captured during 13 net nights. The majority of these captures were the result of setting nets near the locations of sonic-tagged fish. Due to the limited amount of sampling that occurred, CPUE by year and month were not calculated. However, the associated cumulative CPUE is 0.46 fish/net night.

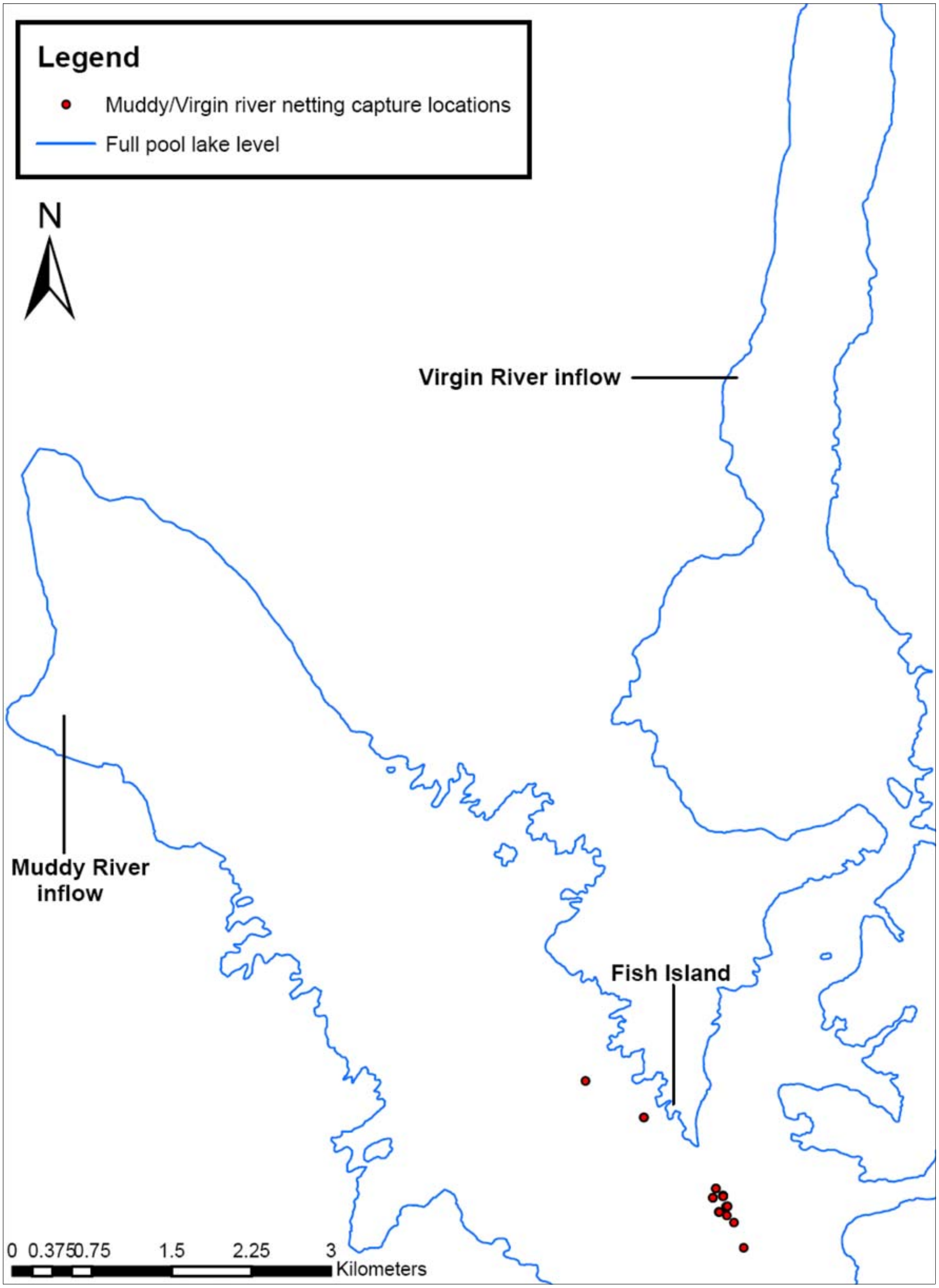

Figure 46. Locations of trammel net captures in the Muddy River/Virgin River inflow area from 1997–2007.

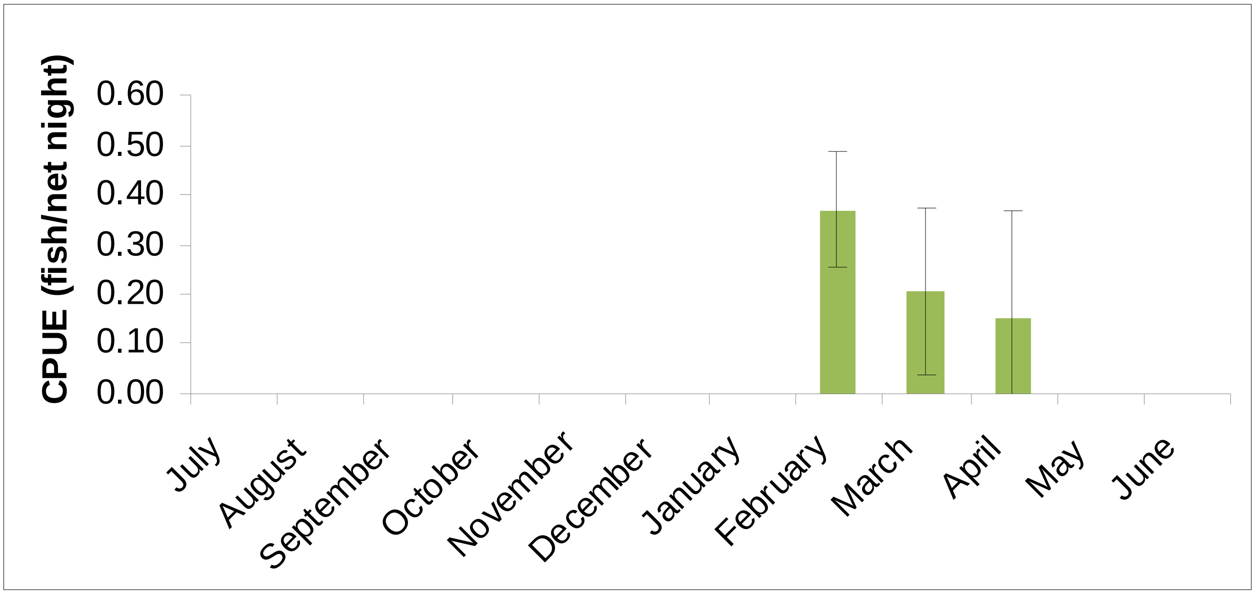

Figure 47. **Muddy River/Virgin River inflow area catch per unit effort (fish caught/net night) by month from 1997–2007.**

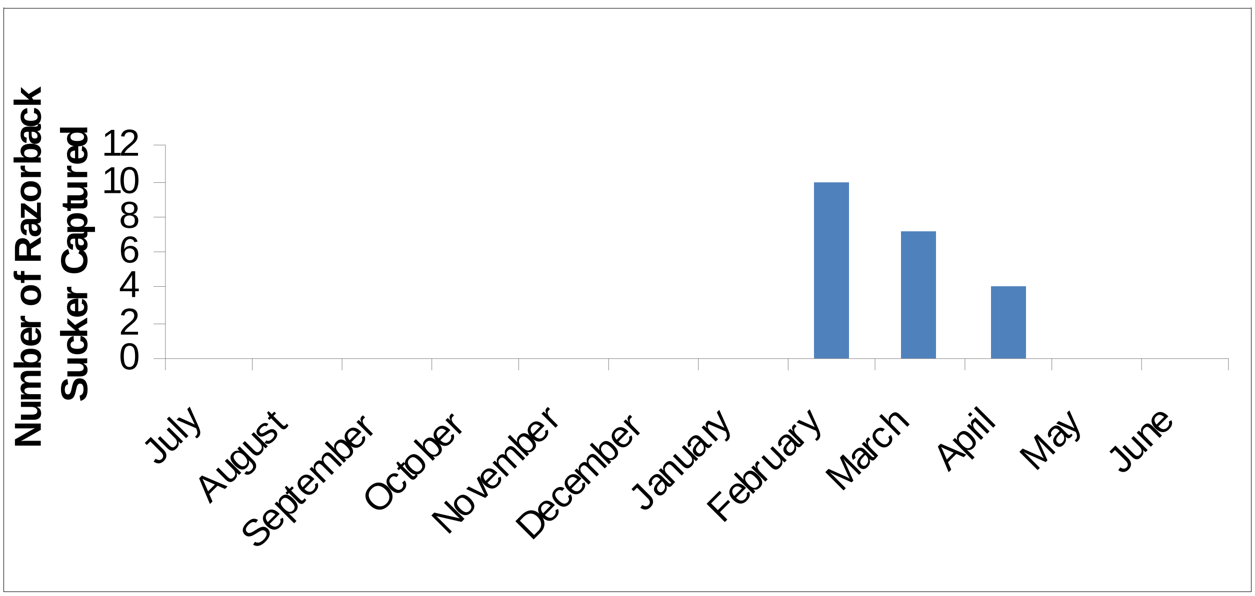

Figure 48. **Total number of trammel net captures in the Muddy River/Virgin River inflow area by month from 1997–2007.**

The proportion of razorback sucker that were either new captures or recaptures is unknown for this portion of the lake because a PIT-tag reader malfunctioned when three of the individuals were captured. However, we know that three of the six razorback sucker from the Overton Arm were new captures, so at the very least 50% of these fish were new captures (Figures 41 and 42).

Sonic Telemetry

During the 11 study seasons on Lake Mead, 59 sonic tags were implanted into razorback sucker to monitor their movements and habitat use (Table 16). In total, 28 sonic-tagged fish were implanted in Las Vegas Bay, 24 in Echo Bay, 3 in the Muddy River/Virgin River inflow, and 4 in the Colorado River inflow. The sonic-tag implantations resulted in contacting razorback sucker at 1,524 separate locations, which has provided insight into razorback sucker movements and ecology (Figure 49). The following sections describe the locations at which sonic-tagged fish were observed within specific portions of Lake Mead, as well as depths at which fish were located during specific seasons.

Las Vegas Bay

Sonic tags were first inserted into razorback sucker for the purpose of tracking movements and habitat use in Las Vegas Bay during the first year (1996–1997) of the Lake Mead razorback sucker investigations. Since that time, 28 sonic tags have been implanted into fish that have been stocked into Las Vegas Bay (Table 16), resulting in 846 fish locations (Figure 50). The numerous locations provided by sonic-tagged fish assisted with determining general movement patterns, habitat use, spawning locations, and changes in spawning locations due to the receding lake.

We observed that general movement patterns displayed by sonic-tagged razorback sucker in Las Vegas Bay throughout these studies were seasonally dependent. During non-spawning months, razorback sucker were generally located in the middle of Las Vegas Bay, residing in depths near 30–40 ft. However, at the onset of the spawning season (January and February) these fish underwent diel migrations toward the general direction of Las Vegas Wash inflow and were found in shallower waters (5–20 ft). Typically it is in these shallower locations of Lake Mead that spawning activities are carried out.

The specific locales of spawning activities shifted in response to receding lake levels during the 11 years of Lake Mead studies. Blackbird Point served as the primary razorback sucker spawning area during the early years of investigation (Holden et al. 1997); however, due to receding lake levels and the eventual desiccation of Blackbird Point, a new spawning site was identified along the southwestern shoreline of Las Vegas Bay during the 2005–2006 study year (Figure 21)(Albrecht et al. 2006).

Table 16. Capture date, location, length (mm), weight (gm), sonic-tagging information, and current status of fish implanted with sonic-telemetry tags in Lake Mead from 1997–2007.

CAPTURE DATE	CAPTURE LOCATION	TL (MM)	FL (MM)	SL (MM)	WT (GM)	SEX	SONIC CODE	PIT NO.	STOCKING LOCATION	NUMBER OF RELO-CATIONS	STATUS
11/18/1996	Las Vegas Bay	576	530	485	2,130	F	249	1F483F0D4D	Las Vegas Bay	10	unknown
11/20/1996	Echo Bay	591	550	489	2,710	F	357	7F7B012325	Echo Bay	71	expired tag
11/20/1996	Echo Bay	569	533	471	2,270	M	348	7F7D152A5D	Echo Bay	8	unknown
11/20/1996	Echo Bay	585	540	479	2,871	F	258	7F7D515B6E	Echo Bay	3	unknown
11/20/1996	Echo Bay	588	545	485	2,235	M	267	7F7D2B330C	Echo Bay	13	unknown
11/20/1996	Echo Bay	606	564	502	2,604	M	285	7F7D165D68	Echo Bay	9	tag expelled
12/18/1996	Las Vegas Bay	713	664	605	4,508	F	276	7F7D3B6539	Las Vegas Bay	33	inactive
12/18/1996	Las Vegas Bay	492	459	410	1,637	M	339	7F7D4B7052	Las Vegas Bay	7	tag malfun-ction
1/27/1997	Echo Bay	585	545		2,475	M	2255	7F7D4D6F34	Echo Bay	19	unknown
1/27/1997	Echo Bay	695	645		4,245	F	2228	7F7D22351B	Echo Bay	0	unknown
1/27/1997	Echo Bay	590	550		2,610	M	2246	7F7D4D7777	Echo Bay	19	unknown
1/28/1997	Las Vegas Bay	512	383		1,603	F	384	7F7D4A7E47	Las Vegas Bay	33	unknown
1/29/1997	Las Vegas Bay	735	695	640	4,736	F	2237	7F7D28296B	Las Vegas Bay	8	unknown
1/29/1997	Las Vegas Bay	560	520	465	2,222	M	2264	7F7D4B7C2E	Las Vegas Bay	56	tag expulsion
2/10/1997	Las Vegas Bay	617	578	525	2,375	M	294	7F7D4B7A54	Las Vegas Bay	55	expired tag
4/5/1997	Las Vegas Bay	581	529	475	2,438	M	2264	201D5B1751	Las Vegas Bay	56	mortality/ tag expulsion
4/17/1997	Las Vegas Bay	662	605	545	3,150	M	2525	201D61560C	Las Vegas Bay	29	tag expulsion
4/20/1997	Echo Bay	573	484	334	1,989	M	3344	1F7B477827	Echo Bay	76	unknown
4/20/1997	Echo Bay	559	516	464	2,006	M	2273	1F7B0D2345	Echo Bay	8	unknown
4/20/1997	Echo Bay	632	586	536	3,011	F	2336	201D5B6107	Echo Bay	6	unknown
4/21/1997	Las Vegas Bay	508	465	419	1,330	M	2444	7F7D4D6275	Las Vegas Bay	61	unknown
12/9/1997	Las Vegas Bay	692	645	588	4,479	F	238	7F7D516462	Las Vegas Bay	9	tag expulsion
12/10/1997	Echo Bay	595	550	495	2,362	M	365	7F7D2F320A	Echo Bay	61	mortality
12/10/1997	Echo Bay	318	296	258	305	I	88	7F7D516F6E	Echo Bay	4	tag expulsion
1/5/1998	Las Vegas Bay	604	555	500	3,047	M	464	7F7D4A0478	Las Vegas Bay	68	unknown
1/5/1998	Las Vegas Bay	595	550	495	2,559	M	347	7F7D467310	Las Vegas Bay	5	unknown

Table 16. (Cont.)

CAPTURE DATE	CAPTURE LOCATION	TL (MM)	FL (MM)	SL (MM)	WT (GM)	SEX	SONIC CODE	PIT #	STOCKING LOCATION	NUMBER OF RELO-CATIONS	STATUS
1/15/1998	Echo Bay	630	588	525	2,985	M	79	F7FD481E44	Echo Bay	106	expired tag
1/15/1998	Echo Bay	381	353	310	575	I	555	7F7D302048	Echo Bay	40	tagging mortality
5/7/1998	Las Vegas Bay	532	480	430	1,620	M	247	1F4A40391E	Las Vegas Bay	75	expired tag
5/7/1998	Las Vegas Bay	562	515	475	1,844	M	283	7F7D483714	Las Vegas Bay	28	mortality
5/7/1998	Las Vegas Bay	588	541	498	1,940	M	374	1F7B5E3553	Las Vegas Bay	3	tagging mortality
5/20/1998	Echo Bay	553	513	460	1,833	F	455	7F7D4D5405	Echo Bay	13	mortality
5/20/1998	Echo Bay	564	510	462	1,876	M	274	7F7D222A48	Echo Bay	16	mortality/ tag expulsion
6/3/1998	Echo Bay	597	556	510	2,175	F	2543	1F78205673	Echo Bay	8	unknown
6/14/2000	Las Vegas Bay	687	634	583	3,742	F	3434	2037205732	Las Vegas Bay	11	expired tag
11/29/2001	Floyd Lamb State Park pond	621	565	510	3,154	F	242	1F78047138	Bradley Bay	11	unknown
11/29/2001	Floyd Lamb State Park pond	615	580	515	3,033	F	253	1F78241A2B	Bradley Bay	16	mortality
11/29/2001	Floyd Lamb State Park pond	593	547	490	2,474	F	349	1F780A6B74	Bradley Bay	6	unknown
11/29/2001	Floyd Lamb State Park pond	636	594	540	3,384	F	2345	1F7777541F	Bradley Bay	21	mortality/ tag expulsion
1/7/2003	Las Vegas Bay	650	610	545	3,958	F	445	1F484B0648	Las Vegas Bay	87	unknown
1/7/2003	Las Vegas Bay	665	619	578	4,040	F	256	5325637C1A	Las Vegas Bay	19	mortality
1/7/2003	Echo Bay	596	561	495	2,369	M	355	53263D264D	Echo Bay	44	unknown
1/21/2003	Echo Bay	691	571	505	2,326	M	456	531F0A6332	Echo Bay	0	unknown
11/30/2004	Floyd Lamb State Park pond	525		425	1,903	M	234	5326241877	Las Vegas Bay	9	unknown
11/30/2004	Floyd Lamb State Park pond	527		435	1,664	M	244	53245E6862 E	Las Vegas Bay	3	unknown
11/30/2004	Floyd Lamb State Park pond	551		465	2,270	M	333	5325505B1C	Las Vegas Bay	2	48-month tag, inactive
11/30/2004	Floyd Lamb State Park pond	575		450	1,938	M	334	53260E3D6A	Las Vegas Bay	1	49-month tag, inactive
12/1/2004	Floyd Lamb State Park pond	524		420	1,694	M	222	532624527C	Echo Bay	66	active

Table 16. (Cont.)

CAPTURE DATE	CAPTURE LOCATION	TL (MM)	FL (MM)	SL (MM)	WT (GM)	SEX	SONIC CODE	PIT #	STOCKING LOCATION	NUMBER OF RELO-CATIONS	STATUS
12/1/2004	Floyd Lamb State Park pond	556		465	2,266	M	344	53244B0648	Echo Bay	13	unknown
11/30/2005	Floyd Lamb State Park pond	528	487	452	2,092	M	445	5325661D5B	Las Vegas Bay	87	active
11/30/2005	Floyd Lamb State Park pond	616	576	535	2,998	F	446	5324051E2D	Las Vegas Bay	50	active
11/30/2005	Floyd Lamb State Park pond	515	480	440	1,940	M	448	5326182909	Las Vegas Bay	46	active
11/30/2005	Floyd Lamb State Park pond	555	511	475	2,134	M	554	5326104578	Las Vegas Bay	30	mortality
11/30/2005	Floyd Lamb State Park pond	604	553	520	2,528	F	555	532575245C	Las Vegas Bay	40	active
11/29/2005	Floyd Lamb State Park pond	635	595	543	4,000	F	447	5326000260	Echo Bay	57	active
11/29/2005	Floyd Lamb State Park pond	632	592	540	4,000	F	556	53256F4C3C	Echo Bay	1	tag failure
11/29/2005	Floyd Lamb State Park pond	610	561	512	2,700	F	444	5324632D5A	Muddy River/Virgin River inflow	46	mortality
11/29/2005	Floyd Lamb State Park pond	545	503	456	2,290	M	557	5324641B76	Muddy River/Virgin River inflow	26	unknown
11/29/2005	Floyd Lamb State Park pond	662	612	565	3,500	F	558	53257F4D73	Muddy River/Virgin River inflow	42	unknown

Echo Bay

The use of sonic-tagged fish was first employed in Echo Bay during the initial study season on Lake Mead. To date, 24 sonic tags have been implanted into fish that have been stocked into Echo Bay (Table 16), resulting in a total of 495 separate fish locations (Figure 51). The locale of sonic-tagged fish in Echo Bay assisted with determining the general movement patterns, habitat use, and seasonal spawning locations of razorback sucker, along with the occasional shifts in locations used for spawning purposes (Figure 22).

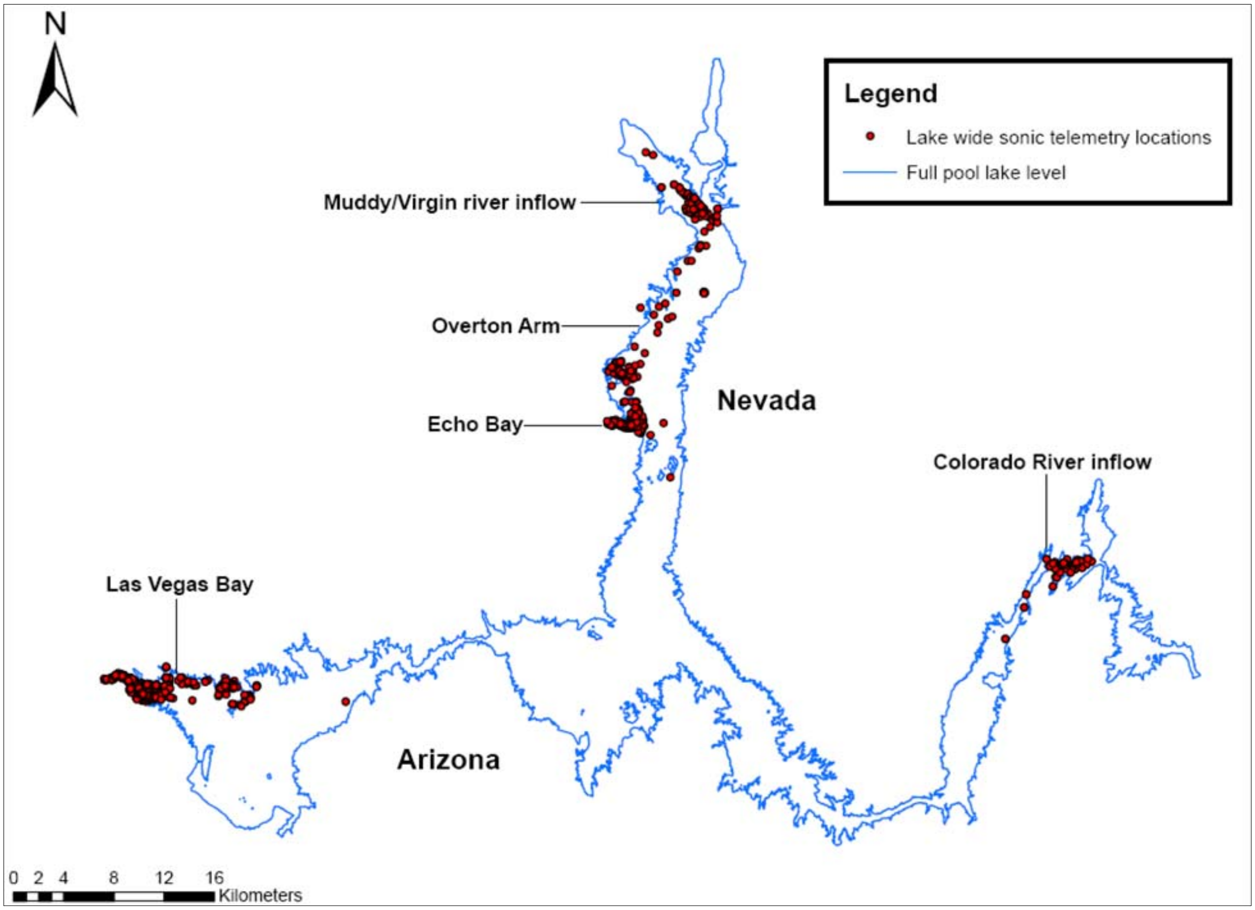

Figure 49. Lake-wide locations of sonic-tagged fish in Lake Mead from 1997–2007.

Similar to razorback sucker residing in Las Vegas Bay, our observations suggest that razorback sucker in Echo Bay show different movement patterns during the non-spawning months compared with the spawning season. During non-spawning months razorback sucker tend to be located in bays north of Echo Bay, including Pumphouse Bay, Roger's Bay, and Anchor Cove (Figure 51), residing in depths from 40–60 ft. Virtually no observations of sonic-tagged fish have occurred in Echo Bay outside the spawning season. However, during January–April, sonic-tagged fish were typically observed during diel migrations from the deep bays surrounding Echo Bay into the head of Echo Bay, where they were observed in depths greater than 20 ft. In addition to the described movement patterns, razorback sucker migrated between Echo Bay and the Muddy River/Virgin River inflow area both within and outside the spawning season. While such observations occurred in a few instances, this movement behavior is not considered to be a relatively common part of the general movement patterns displayed by Echo Bay fish.

As with Las Vegas Bay, the primary spawning locations in Echo Bay shifted throughout the years in response to receding lake levels. Shifts in spawning site localities occurred after the 2001, 2002, 2003, and 2006 spawning seasons (Figure 22)(Albrecht et al. 2007).

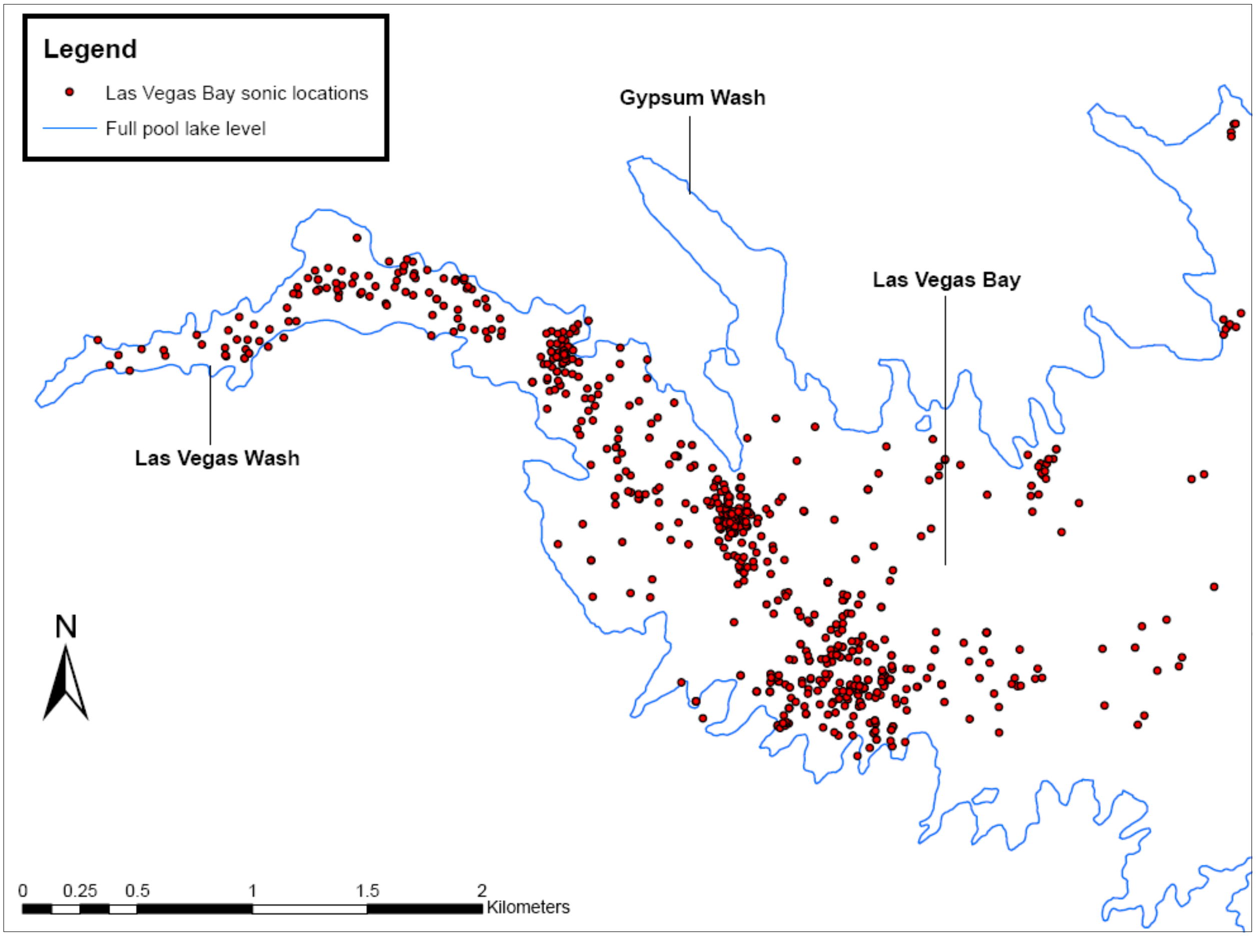

Figure 50. Las Vegas Bay locations of sonic-tagged fish in Lake Mead from 1997–2007.

Muddy River/Virgin River Inflow Area

The use of sonic-tagged fish was first employed in the Muddy River/Virgin River inflow area during the 2005–2006 study year. Three fish were captured from Floyd Lamb State Park, tagged with abdominal sonic transmitters, and ultimately stocked into the Muddy River/Virgin River inflow area near Fish Island (Albrecht et al. 2006). This effort was largely due to the movement of an additional sonic-tagged razorback sucker that was stocked into Echo Bay the previous field season and observed frequently moving between Echo Bay and the Muddy River/Virgin River inflow. Sonic-tagged razorback sucker have been observed a total of 128 times in the Muddy River/Virgin River inflow (Figure 52), providing valuable data in respect to general movement patterns, habitat use, spawning locations, and shifts in spawning locations.

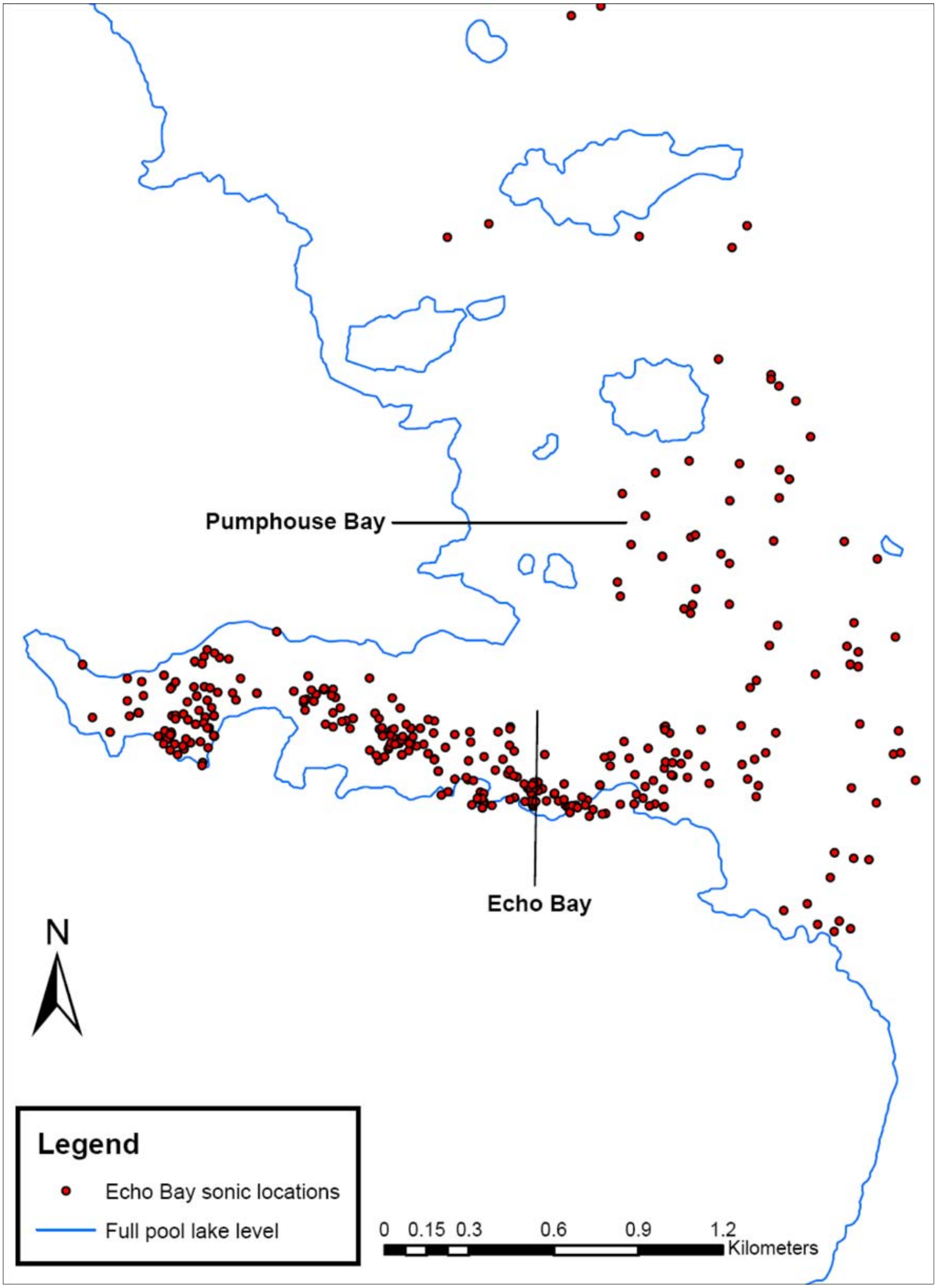

Figure 51. **Echo Bay locations of sonic-tagged fish in Lake Mead from 1997–2007.**

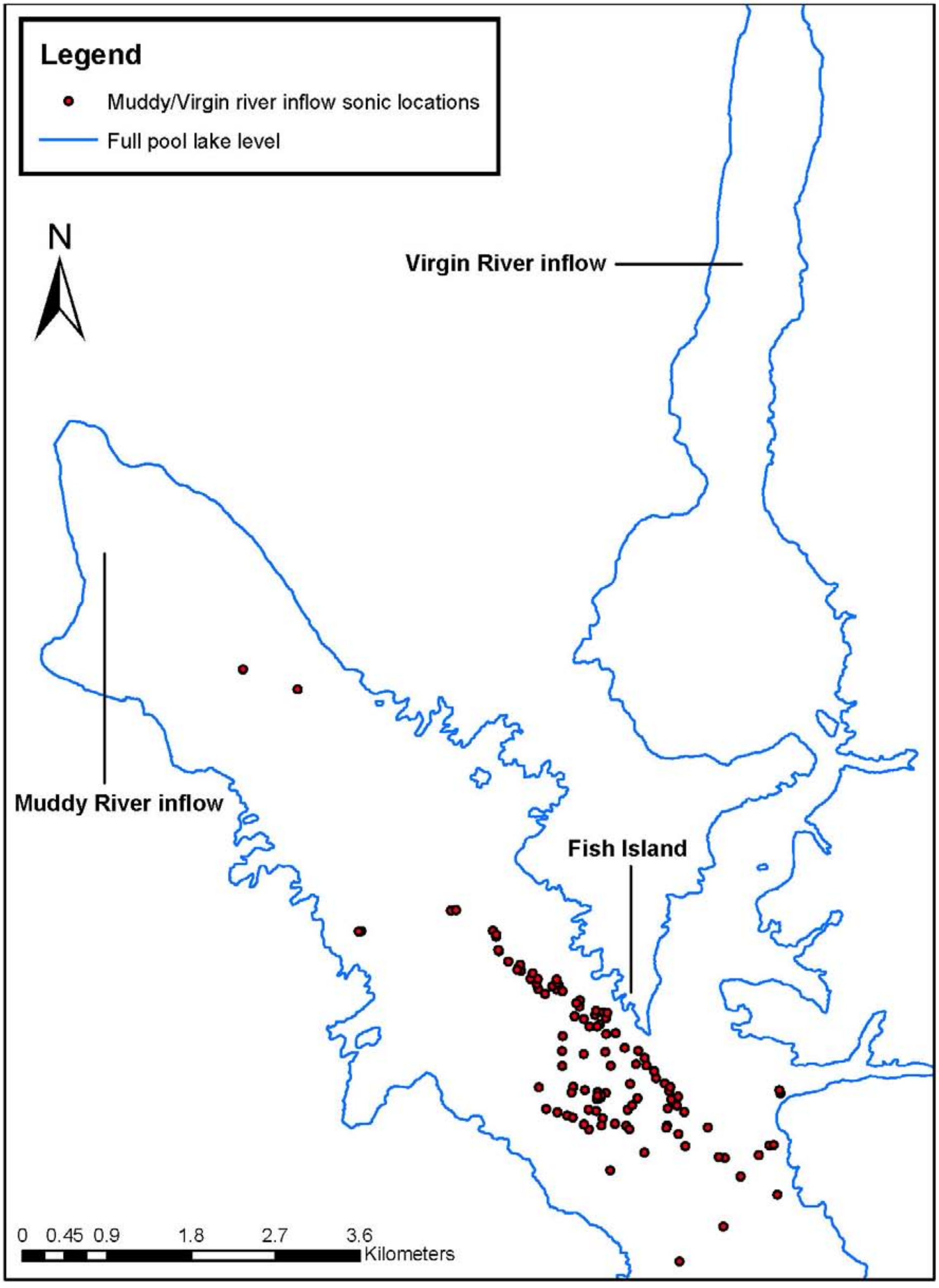

Figure 52. Muddy River/Virgin River inflow area locations of sonic-tagged fish in Lake Mead from 1997–2007.

Observations of sonic-tagged fish movement in the Muddy River/Virgin River inflow area have shown that tagged fish do not generally occupy this portion of the lake during the non-spawning months (May–December). A minimal amount of observations occurred between May–December during the earlier study years (Albrecht and Holden 2005); however, since the lake receded and rendered the Muddy River/Virgin River inflow area shallow and relatively featureless, no observations of sonic-tagged fish have occurred in this portion of the lake outside of the spawning season. Unfortunately, we can not describe the general movement patterns of razorback sucker during the non-spawning season in the Muddy River/Virgin River inflow area because we have been unable to locate them consistently throughout this time period. However, we hypothesize that the sonic-tagged fish use the surrounding deeper bays, which makes tracking difficult due to the vastness of habitat and complex topology between the Muddy River/Virgin River inflow and Echo Bay.

During the spawning season, we observed that sonic-tagged fish in the Muddy River/Virgin River inflow area reside in the center of the bay in depths between 15–25 ft and move into more shallow water (>10 ft) at night to spawn. Interestingly, we observed a number of sonic-tagged fish using the flowing portions of the Muddy River proper during spawning months, typically during daylight hours. While we observed fish occupying the Muddy River/Virgin River inflow area for an entire spawning season, it is not rare for fish to move between this portion of the lake and Echo Bay. However, as described in the Echo Bay section, this movement is not considered to be the typical movement pattern displayed by razorback sucker in the Muddy River/Virgin River inflow area.

As with the other spawning locations within Lake Mead, razorback sucker have displayed plasticity in response to varying lake levels in the Muddy River/Virgin River inflow area. Shifts in spawning site localities has occurred after the 2005 and 2006 spawning seasons (Figure 23)(Albrecht et al. 2007).

Colorado River Inflow Area

During the sixth study year, four adult fish from Floyd Lamb State Park were implanted with sonic tags with an expected 4-year battery life and stocked into the Colorado River inflow area (Abate et al. 2002). The objective of this stocking event was to identify possible spawning aggregates of wild razorback sucker in the Colorado River inflow area. The four sonic-tagged fish provided a total of 88 locations during the first 1.5–2.5 months; however, they were lost after that time period (Figure 53)(Abate et al. 2002). While the exact cause of our inability to relocate the sonic-tagged fish is unknown, we believed that the tags failed. This effort did not result in the capture of adult or larvae razorback sucker, and possible new spawning aggregates were not identified. No further telemetry efforts were conducted in the Colorado River inflow area.

Lake-wide Seasonal Depths Used by Telemetered Razorback Sucker

In addition to information regarding movements and spawning locations of razorback sucker, sonic telemetry rendered valuable data pertaining to the depths at which razorback sucker were found by season on a lake-wide basis. Sonic-tagged fish were found in greater depths during the

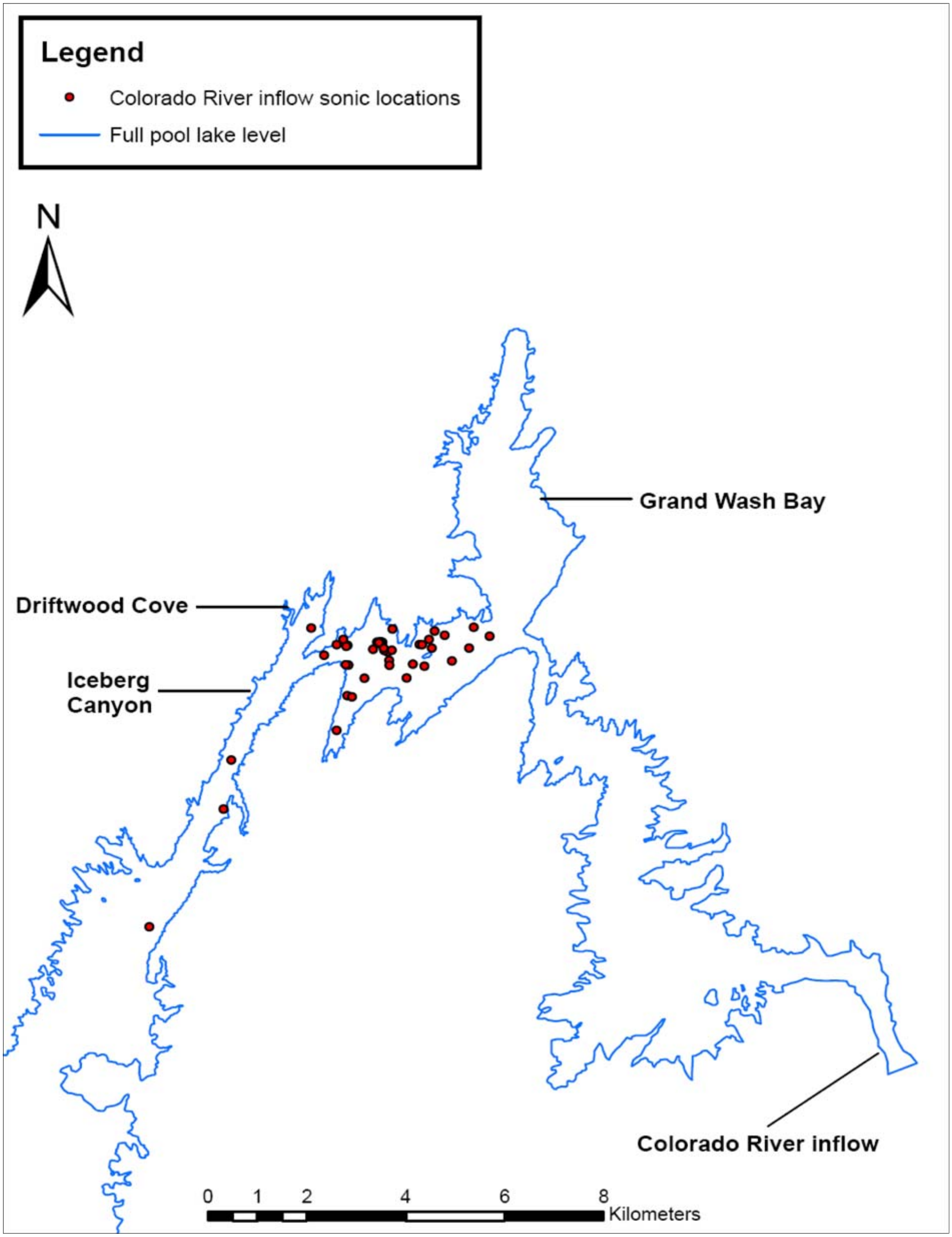

Figure 53. Colorado River inflow area locations of sonic-tagged fish in Lake Mead from 1997–2007.

fall and summer than during the winter and spawning season (Wilcoxon rank sum test; $P < 0.01$ in all instances). The median depth at which fish were located in fall, summer, winter, and the spawning season were 46, 45, 24, and 22 ft, respectively. Depths used did not vary among fall and summer ($P = 0.52$); however, depths did vary slightly among spring and winter ($P = 0.03$).

Aerial Surveys

While aerial surveys were useful in other locations, such as Lake Mohave, we observed that Lake Mead is typically too turbid, particularly at the inflow and known spawning areas, to effectively locate spawning razorback sucker aggregates by visual means alone and, to our knowledge, no new razorback sucker were observed during past flights. Therefore, this technique will not be discussed further in the following sections of this report. It should be noted however, that aerial surveys (if/when available) do provide a unique and useful perspective of lake conditions, inflow changes, and changes in shoreline habitat, which is a perspective that is unlikely to be captured by standard on-the-lake sampling.

Video Surveillance and SCUBA

Both video surveillance and SCUBA were used on an opportunistic basis for the purpose of confirming and observing razorback sucker spawning activities. Underwater videography was used periodically, when lake conditions and field scheduling allowed, at Las Vegas Bay and Echo Bay during the course of our studies. Holden et al. (2000a) also report the use of SCUBA to reconnoiter the spawning site at Echo Bay in 1999. This technique helped confirm the size and condition of the spawning site, as well as the composition of the substrate. From a long-term project perspective, underwater videography and SCUBA (to the degree that we have used these techniques on Lake Mead) should likely be used only on an opportunistic basis to further understand razorback sucker spawning locations and activities, and add to our overall understanding of Lake Mead razorback sucker and how they interact with their environment. In summary, both techniques played a minimal role during the course of our research; hence those interested in further details of these two techniques are encouraged to refer to past annual reports.

Growth

Information on growth of Lake Mead razorback sucker was examined in several ways. As in past annual reports, Table 17 provides growth histories for razorback sucker recaptured since the onset of our studies in 1996. Based on recapture data, Table 17 provides mean annual growth at a lake-wide, site-specific level of detail, as well as in terms of wild and stocked fish. Table 17 was constructed based on data from 108 individually recaptured fish. It should be noted that, while more fish were recaptured during the course of our studies on Lake Mead, many of these fish were excluded from analysis because they were recaptured multiple times within a short time frame or because a full year had not passed between the date of original capture (or stocking event) and the subsequent recapture event.

Table 17. Razorback sucker growth histories monitored since 1996.

LOCATION	ORIGIN	PIT TAG NUMBER	INITIAL CAPTURE DATE	TOTAL LENGTH (mm)	LATEST RECAPTURE DATE	TOTAL LENGTH (mm)	TOTAL GROWTH (mm)	DAYS BETWEEN MEASUREMENTS	GROWTH PER YEAR (mm)
Echo Bay	Stocked	1F476B7936	7/25/1995	541	1/30/2007	674	133	4,207	11.5
Echo Bay	Stocked	1F4A457C62	7/25/1995	488	1/11/2007	556	68	4,188	5.9
Echo Bay	Stocked	1F4A217303	11/24/1998	614	3/19/2001	645	31	846	13.4
Echo Bay	Stocked	1F4A017E18	1/22/2002	560	4/2/2003	563	3	435	2.5
Echo Bay	Stocked	1F4A16047D	1/22/2002	595	3/3/2006	611	16	1,501	3.9
Echo Bay	Stocked	1F4A1A5429	1/22/2002	512	4/9/2003	519	7	442	5.8
Echo Bay	Stocked	1F4A3C6972	1/22/2002	554	4/27/2006	566	12	1,556	2.8
Echo Bay	Stocked	1F4B224430	1/22/2002	536	5/15/2003	540	4	478	3.1
Echo Bay	Stocked	1F500E4043	1/22/2002	628	2/9/2006	638	10	1,479	2.5
Echo Bay	Stocked	1F4A2B5418	12/2/2003	580	4/27/2006	584	4	877	1.7
Echo Bay	Stocked	1F4A300F58	12/2/2003	637	2/8/2006	631	-6	799	-2.7
Echo Bay	Stocked	1F50024946	12/2/2003	658	2/10/2006	669	11	793	5.1
Echo Bay	Stocked	1F5003414D	12/2/2003	619	2/14/2007	636	17	1,170	5.3
Echo Bay	Stocked	1F500A3156	12/2/2003	557	4/4/2007	560	3	1,219	0.9
Echo Bay	Stocked	1F7D5D6225	12/2/2003	520	2/22/2005	522	2	448	1.6
Echo Bay	Stocked	53244B0648	12/1/2004	556	1/11/2007	567	11	771	5.2
Echo Bay	Stocked	532624527C	12/1/2004	524	3/2/2007	537	13	821	5.8
Echo Bay	Wild	7F7D133272	3/18/1992	546	3/11/1998	604	58	2,184	9.7
Echo Bay	Wild	7F7D152A5D	3/18/1992	523	11/20/1996	569	46	1,708	9.8
Echo Bay	Wild	7F7D163E40	3/18/1992	536	4/2/1993	548	12	380	11.5
Echo Bay	Wild	7F7D16534B	3/18/1992	549	2/8/2007	619	70	5,440	4.7
Echo Bay	Wild	7F7D165D68	3/18/1992	531	11/20/1996	606	75	1,708	16.0
Echo Bay	Wild	7F7D1A2E1A	3/18/1992	536	3/12/1997	584	48	1,820	9.6
Echo Bay	Wild	7F7D1A366E	3/18/1992	556	2/25/2000	602	46	2,900	5.8
Echo Bay	Wild	7F7D22242B	3/18/1992	554	10/24/1996	595	41	1,681	8.9
Echo Bay	Wild	7F7D22341E	3/18/1992	574	10/23/1997	625	51	2,045	9.1
Echo Bay	Wild	7F7D164F08	3/19/1992	572	2/9/2000	601	29	2,883	3.7
Echo Bay	Wild	7F7D15463D	3/20/1992	594	3/19/2001	668	74	3,286	8.2
Echo Bay	Wild	7F7D16411F	3/20/1992	577	3/15/2005	658	81	4,743	6.2
Echo Bay	Wild	7F7D222A48	2/26/1993	519	5/20/1998	564	45	1,909	8.6
Echo Bay	Wild	7F7D22351B	2/26/1993	620	1/27/1997	695	75	1,431	19.1
Echo Bay	Wild	7F7B012325	4/2/1993	555	3/12/1998	606	51	1,805	10.3
Echo Bay	Wild	7F7D2B2D5F	4/2/1993	574	1/11/2007	606	32	5,032	2.3
Echo Bay	Wild	1F4A157B07	2/15/1996	560	2/10/1998	585	25	726	12.6
Echo Bay	Wild	1F4A592D11	2/15/1996	680	2/24/2001	703	23	1,836	4.6
Echo Bay	Wild	1F7A39743A	3/12/1997	590	2/25/2000	579	-11	1,080	-3.7
Echo Bay	Wild	201D5F2A3A	3/12/1997	645	2/9/2000	649	4	1,064	1.4
Echo Bay	Wild	1F7A721C59	4/20/1997	582	3/19/2001	608	26	1,429	6.6
Echo Bay	Wild	1F7B477827	4/20/1997	573	2/10/2006	614	41	3,218	4.7
Echo Bay	Wild	7F7D3B3240	5/19/1997	667	2/9/2000	694	27	996	9.9
Echo Bay	Wild	7F7D51650E	12/10/1997	318	2/10/2000	619	301	792	138.7
Echo Bay	Wild	7F7D482104	2/10/1998	675	2/24/2004	682	7	2,205	1.2
Echo Bay	Wild	7F7D4C302B	2/10/1998	347	2/10/2006	610	263	2,922	32.9
Echo Bay	Wild	2037096F31	9/14/1998	600	2/9/2000	633	33	513	23.5
Echo Bay	Wild	201D576408	1/28/1999	519	12/17/2003	584	65	1,784	13.3
Echo Bay	Wild	2037175B37	2/9/1999	625	4/2/2003	639	14	1,513	3.4
Echo Bay	Wild	203718652C	2/9/1999	703	2/24/2001	713	10	746	4.9
Echo Bay	Wild	201D697169	12/13/1999	705	2/7/2001	707	2	422	1.7
Echo Bay	Wild	1F7A252D15	1/27/2000	557	2/24/2001	583	26	394	24.1
Echo Bay	Wild	20371A3B54	1/27/2000	544	4/17/2002	567	23	811	10.4
Echo Bay	Wild	2037260E75	2/25/2000	621	2/23/2006	640	19	2,190	3.2
Echo Bay	Wild	1F78417335	2/25/2000	704	3/21/2006	660	-44	2,216	-7.2

Table 17. (Cont.)

LOCATION	ORIGIN	PIT TAG NUMBER	INITIAL CAPTURE DATE	TOTAL LENGTH (mm)	LATEST RECAPTURE DATE	TOTAL LENGTH (mm)	TOTAL GROWTH (mm)	DAYS BETWEEN MEASUREMENTS	GROWTH PER YEAR (mm)
Echo Bay	Wild	1F7B083727	2/25/2000	521	4/18/2006	578	57	2,244	9.3
Echo Bay	Wild	7F7D24083F	2/25/2000	604	10/23/2001	613	9	606	5.4
Echo Bay	Wild	1F7818430E	2/24/2001	577	4/5/2006	607	30	1,866	5.9
Echo Bay	Wild	1F7B106D69	2/24/2001	553	2/23/2006	586	33	1,825	6.6
Echo Bay	Wild	1F777A3B35	12/18/2001	672	3/8/2004	684	12	811	5.4
Echo Bay	Wild	201D653628	3/26/2002	623	3/28/2006	671	48	1,463	12.0
Echo Bay	Wild	531F0A6332	1/21/2003	612	3/19/2007	631	19	1,518	4.6
Echo Bay	Wild	53263D264D	1/21/2003	596	2/23/2007	617	21	1,494	5.1
Echo Bay	Wild	53257C0232	4/2/2003	580	2/23/2007	586	6	1,423	1.5
Echo Bay	Wild	5324580E11	3/17/2004	666	2/16/2006	681	15	701	7.8
Echo Bay	Wild	53255E6C50	3/17/2004	616	3/21/2006	606	-10	734	-5.0
Echo Bay	Wild	5325515754	2/1/2006	705	3/2/2007	706	1	395	0.9
Las Vegas Bay	Stocked	1F483F0D4D	5/26/1995	525	11/18/1996	576	51	542	34.3
Las Vegas Bay	Stocked	1F4A1B7E7E	5/26/1995	527	5/17/2003	629	102	2,913	12.8
Las Vegas Bay	Stocked	1F4A46272A	5/26/1995	510	3/9/1998	575	65	1,018	23.3
Las Vegas Bay	Stocked	1F4A59231B	5/26/1995	517	1/8/2000	553	36	1,688	7.8
Las Vegas Bay	Stocked	1F7D66324C	11/25/1998	560	2/22/2000	574	14	454	11.3
Las Vegas Bay	Stocked	1F7D790D5E	11/25/1998	574	4/10/2007	656	82	3,058	9.8
Las Vegas Bay	Stocked	1F7E530010	11/25/1998	538	2/25/2004	581	43	1,918	8.2
Las Vegas Bay	Stocked	2037194749	12/10/1999	204	2/23/2006	660	456	2,267	73.4
Las Vegas Bay	Stocked	1F476C5856	1/17/2001	542	2/13/2007	580	38	2,218	6.3
Las Vegas Bay	Stocked	1F484B0648	1/17/2001	620	11/12/2003	650	30	1,029	10.6
Las Vegas Bay	Stocked	1F4A1E0D6C	1/17/2001	606	6/7/2002	619	13	506	9.4
Las Vegas Bay	Stocked	1F5007206A	1/17/2001	623	5/22/2003	640	17	855	7.3
Las Vegas Bay	Stocked	1F4A1E2356	3/19/2001	651	2/19/2004	678	27	1,067	9.2
Las Vegas Bay	Stocked	1F48452C28	1/22/2002	631	2/8/2007	649	18	1,843	3.6
Las Vegas Bay	Stocked	1F482B046A	9/30/2002	245	2/21/2005	529	284	875	118.5
Las Vegas Bay	Stocked	1F4A1C4A31	9/30/2002	269	4/20/2006	537	268	1,298	75.4
Las Vegas Bay	Stocked	5326000260	11/29/2005	635	1/30/2007	650	15	398	13.8
Las Vegas Bay	Stocked	5324051E2D	11/30/2005	616	3/6/2007	611	-5	461	-4.0
Las Vegas Bay	Stocked	5325661D5B	11/30/2005	528	2/27/2007	538	10	454	8.0
Las Vegas Bay	Stocked	532575245C	11/30/2005	604	4/10/2007	632	28	496	20.6
Las Vegas Bay	Wild	7F7D140A46	3/10/1992	548	2/21/2006	621	73	5,096	5.2
Las Vegas Bay	Wild	7F7D16550D	3/10/1992	671	4/2/1993	655	-16	388	-15.1
Las Vegas Bay	Wild	7F7D31366D	4/2/1993	621	4/2/2002	617	-4	3,287	-0.4
Las Vegas Bay	Wild	7F7D770148	4/2/1993	635	3/9/1998	668	33	1,802	6.7
Las Vegas Bay	Wild	7F7D7D492C	3/22/1994	633	11/11/1997	684	51	1,330	14.0
Las Vegas Bay	Wild	7F7D3B6539	12/18/1996	713	11/30/1999	730	17	1,077	5.8
Las Vegas Bay	Wild	7F7D4A7E47	1/28/1997	512	3/9/1998	555	43	405	38.8
Las Vegas Bay	Wild	7F7D4B7A54	2/10/1997	617	3/9/1998	630	13	392	12.1
Las Vegas Bay	Wild	7F7D4D6275	2/25/1997	502	2/22/2000	584	82	1,092	27.4
Las Vegas Bay	Wild	7F7D4A0478	3/10/1997	600	12/13/1999	606	6	1,008	2.2
Las Vegas Bay	Wild	7F7D483714	4/21/1997	515	5/7/1998	562	47	381	45.0
Las Vegas Bay	Wild	7F7D4C0651	4/21/1997	605	4/22/2003	650	45	2,192	7.5
Las Vegas Bay	Wild	1F4A40391E	5/7/1998	532	3/25/2002	576	44	1,540	10.4
Las Vegas Bay	Wild	1F7815490B	11/19/1998	642	2/22/2000	641	-1	460	-0.8
Las Vegas Bay	Wild	201D5B2345	11/19/1998	645	2/27/2007	645	0	3,022	0.0
Las Vegas Bay	Wild	1F7A217F47	12/13/1999	539	4/17/2003	596	57	1,222	17.0
Las Vegas Bay	Wild	1F780E2239	1/7/2000	650	4/12/2005	668	18	1,922	3.4
Las Vegas Bay	Wild	7F7D78472F	2/7/2000	628	4/9/2001	616	-12	427	-10.3
Las Vegas Bay	Wild	7F7D7B2741	2/23/2000	591	6/7/2002	607	16	835	7.0
Las Vegas Bay	Wild	20370C7F1E	3/25/2002	578	1/12/2004	586	8	658	4.4

Table 17. (Cont.)

LOCATION	ORIGIN	PIT TAG NUMBER	INITIAL CAPTURE DATE	TOTAL LENGTH (mm)	LATEST RECAPTURE DATE	TOTAL LENGTH (mm)	TOTAL GROWTH (mm)	DAYS BETWEEN MEASUREMENTS	GROWTH PER YEAR (mm)
Las Vegas Bay	Wild	5326063458	3/4/2003	635	3/31/2006	625	-10	1,123	-3.3
Las Vegas Bay	Wild	53256C6224	4/17/2003	618	3/31/2006	687	69	1,079	23.3
Las Vegas Bay	Wild	532603134E	5/22/2003	471	2/6/2007	584	113	1,356	30.4
Las Vegas Bay	Wild	7F7D312A1B	3/20/2004	562	4/10/2007	644	82	1,116	26.8
Mean annual growth of Echo Bay stocked fish									**4.4**
Mean annual growth of Echo Bay wild fish									**10.4**
Mean annual growth of all Echo Bay fish combined									**8.8**
Mean annual growth of Las Vegas Bay stocked fish									**23.0**
Mean annual growth of Las Vegas Bay wild fish									**10.7**
Mean annual growth of all Las Vegas Bay fish combined									**16.3**
Mean annual growth of all stocked fish combined lake-wide									**14.2**
Mean annual growth of all wild fish combined lake-wide									**10.5**
Mean annual growth of all stocked and wild fish combined lake-wide									**11.9**

The combined, lake-wide mean annual growth of all razorback sucker recaptured to date is 11.9 mm. The combined lake-wide mean annual growth of all stocked, recaptured fish is 14.2 mm. The combined lake-wide mean annual growth of all wild, recaptured fish is 10.5 mm. The combined mean annual growth of both stocked and wild fish recaptured in Las Vegas Bay is 16.3 mm, with wild fish from Las Vegas Bay averaging 10.7 mm of growth per year and stocked fish recaptured at Las Vegas Bay averaging 23.0 mm of growth per year. At Echo Bay the combined mean annual growth of both stocked and wild recaptured fish is 8.8 mm, while Echo Bay wild recaptured fish averaged 10.4 mm of growth per year and Echo Bay stocked recaptured fish averaged 4.4 mm of growth per year. Muddy River/Virgin River razorback sucker growth information, based on recapture data, will not be presented at this time due to a lack of recaptures (Table 17).

As Table 17 shows and as reported in Albrecht et al. (2007) and other past annual reports, negative growth values are thought to reflect measurement error between values recorded during the initial capture occasion and those values observed during subsequent recapture events; this may also be a function of old and/or slow-growing individuals. Alternatively, negative growth values could also reflect netting-induced stress, stress associated with sonic tagging, or other unknown, naturally imparted stressors (Holden et al. 2000b). In all, and as alluded to in past annual reports (e.g., Albrecht et al. 2007), growth rates for Lake Mead razorback sucker continued to be higher than those of other razorback sucker populations, suggesting the overall youthfulness of Lake Mead razorback sucker populations (Modde et al. 1996, Pacey and Marsh 1998, Mueller 2006).

A length histogram (presented in mm TL) portraying Lake Mead razorback sucker data is provided as Figure 54. As presented, no captures of razorback sucker smaller than 300 mm occurred during the course of our studies (with the exception of larval fish captures as presented above). However, a substantial number of smaller fish were captured in the size classes from 300–500 mm. As shown, the bulk of our captures tended to fall within the 500–700 mm size

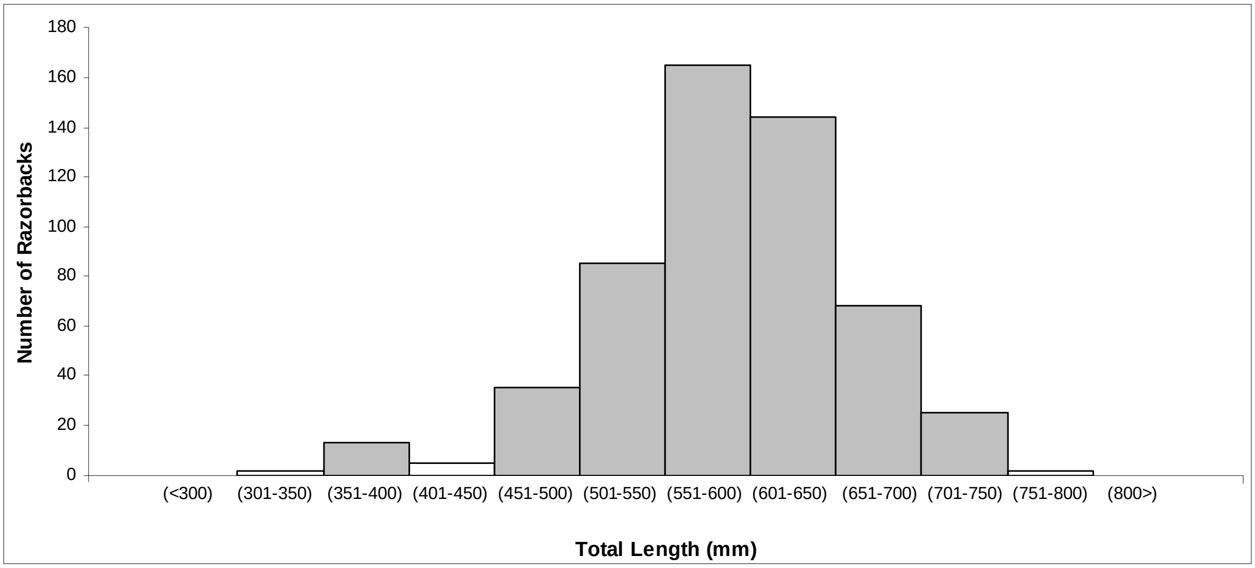

Figure 54. Length histogram of Lake Mead razorback sucker 1996–2007 data.

range, with the remainder of captures comprising individuals larger than 700 mm. In all, captures of Lake Mead razorback sucker ranged from a minimum of 318 mm to maximum of 765 mm, and captures were comprised of both immature and mature razorback sucker. The majority of fish collected were between the upper and lower size extremes typical of a healthy, sustainable population.

Further insight pertaining to growth information is also provided in terms of length-weight relationships (Figures 55, 56, 57, and 58). Figure 55 provides the length-weight relationship for all fish captured from Lake Mead during the course of our studies. Figure 56 provides the length-weight relationship for female fish only, Figure 57 provides the same information for male fish only, and Figure 58 provides the length-weight relationship for immature subadult fish only. In all cases, length is expressed as millimeters total length and weight is presented in grams. As is evident, R^2 values are quite strong (based on power function), indicating that a fairly tight relationship between length and weight of Lake Mead razorback sucker exists. Furthermore, these figures provide some indication of the condition factor (K) of Lake Mead razorback sucker. In all cases with adult fish (sexually mature and of both sexes) K-values approach 3.0, indicating fairly well-conditioned fish and near-proportional growth. For immature fish K-values are a bit higher than 3.0 (a value indicative of isometric growth); thus, young Lake Mead razorback sucker typically tend to be a bit heavier in proportion to their length.

Coupling results from our aging techniques (as will be discussed in the subsequent section) with corresponding length information of aged fish, a length-age relationship graph was prepared based on the length-age data obtained during the course of our studies (Figure 59). To our knowledge, this may be the first time that such a relationship has been attempted or even

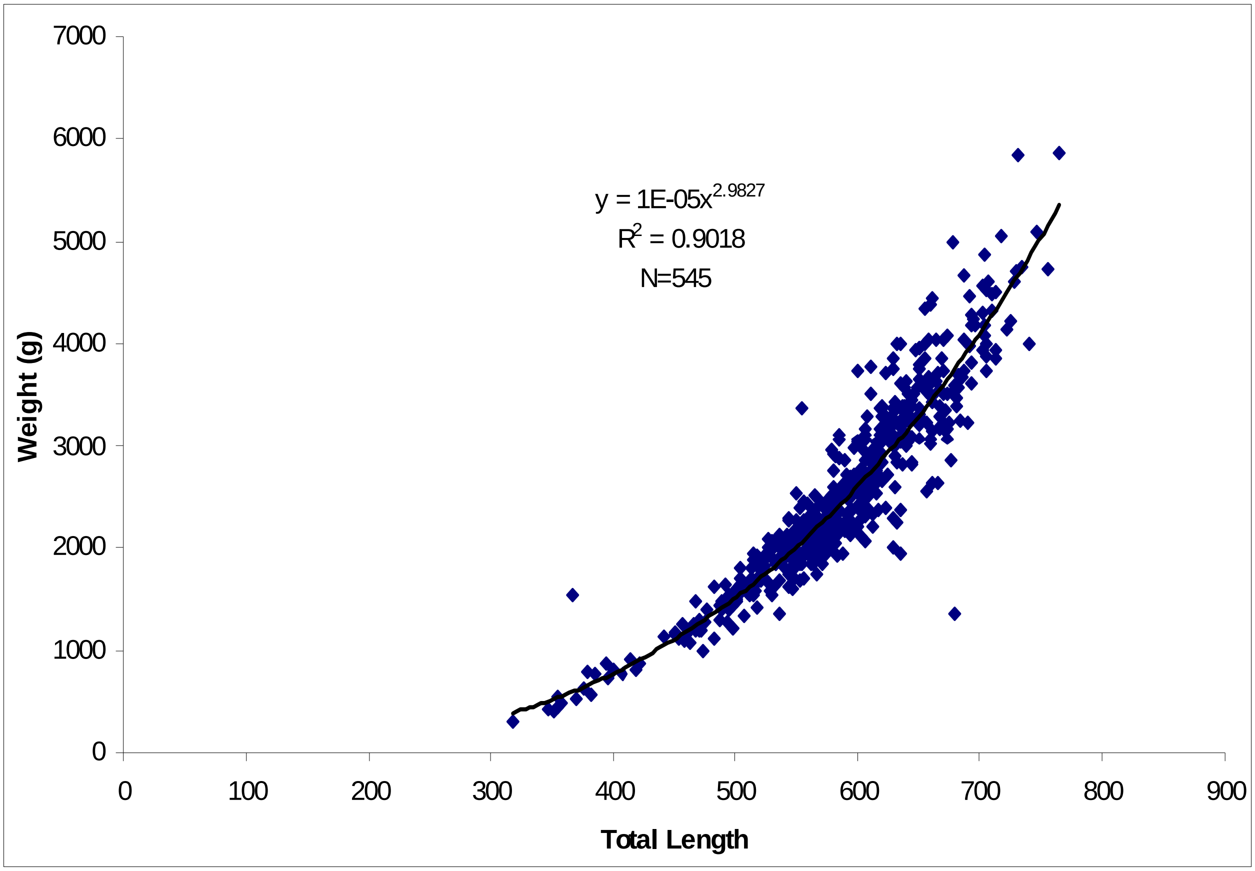

Figure 55. **Length-weight relationship for all Lake Mead razorback sucker captured to date (1996–2007 data).**

possible for razorback sucker captured from a "natural" setting and using data from largely wild, non-repatriated fish. Although the data do not group as nicely as the length-weight data presented above (which was expected), there is some positive correlation between total length (mm) and age (R^2 = 0.56). However, as displayed in Figure 59, it should be stressed that it is often impossible to correctly predict the age of an individual Lake Mead razorback sucker (especially fish greater than about 500 mm TL).

Razorback Sucker Aging

Table 18 shows the results of aging 132 wild fish through 2007. Figure 60 shows the number of razorback sucker recruits per year plotted against Lake Mead elevations from January 1935–June 2007. All of the aged fish were spawned between 1974–2004, with the exception of one fish that was spawned around 1966.

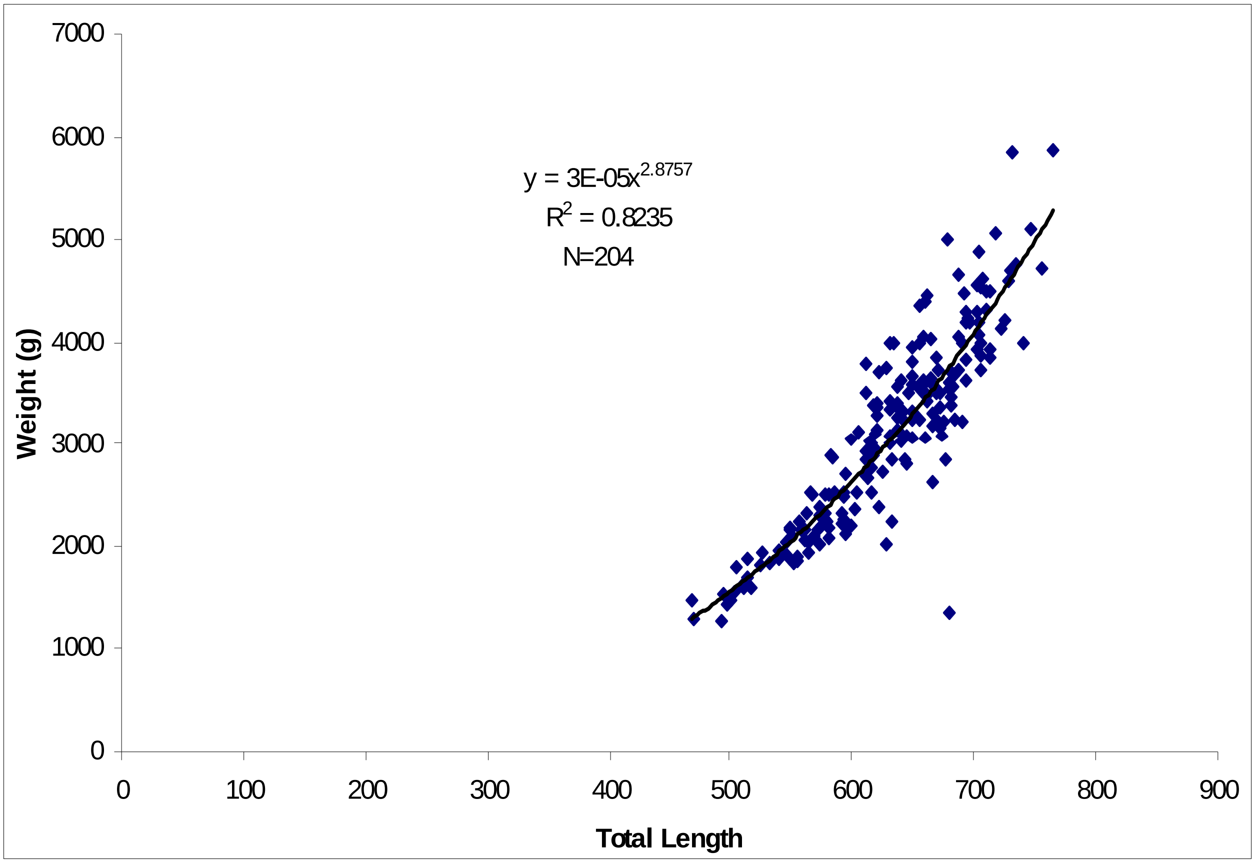

Figure 56. Length-weight relationship for female razorback sucker from Lake Mead (1996–2007 data).

As Figure 60 indicates, evidence of recruitment occurs nearly every year based on back-calculation techniques. For clarity, the back-calculation techniques referred to in this report consist of obtaining a fin-ray sample from a Lake Mead razorback sucker, determining the age of that specimen, and then determining the year (or in some cases range of years) that the fish was spawned. Until 2007, pulses in recruitment were observed to coincide with high-water years (e.g., 1978–1989 time period and 1997–1999 time period). However, data collected during 2007 indicate that recruitment pulses can and do occur during low and/or declining lake elevations (e.g., 2002). In fact, it appears that some level of recruitment is possible in Lake Mead regardless of lake level (Figure 60)(Albrecht et al. 2007).

Albrecht et al. (2006b) indicate that aging efforts are important for understanding patterns of recruitment on Lake Mead. Furthermore, it appears that there is a lag time between the year that a given fish is spawned and the susceptibility of that fish to sampling techniques. Albrecht et al. (2006b) indicate that juvenile fish younger than 4 years of age were unsusceptible to capture gear (i.e., trammel netting). As such, future monitoring will be conducted to sample 4-year-old fish or older, thereby resulting in a 4-year delay (minimum) until we have any realistic ability to ascertain how strong a particular year class might have been. Hence, continued monitoring

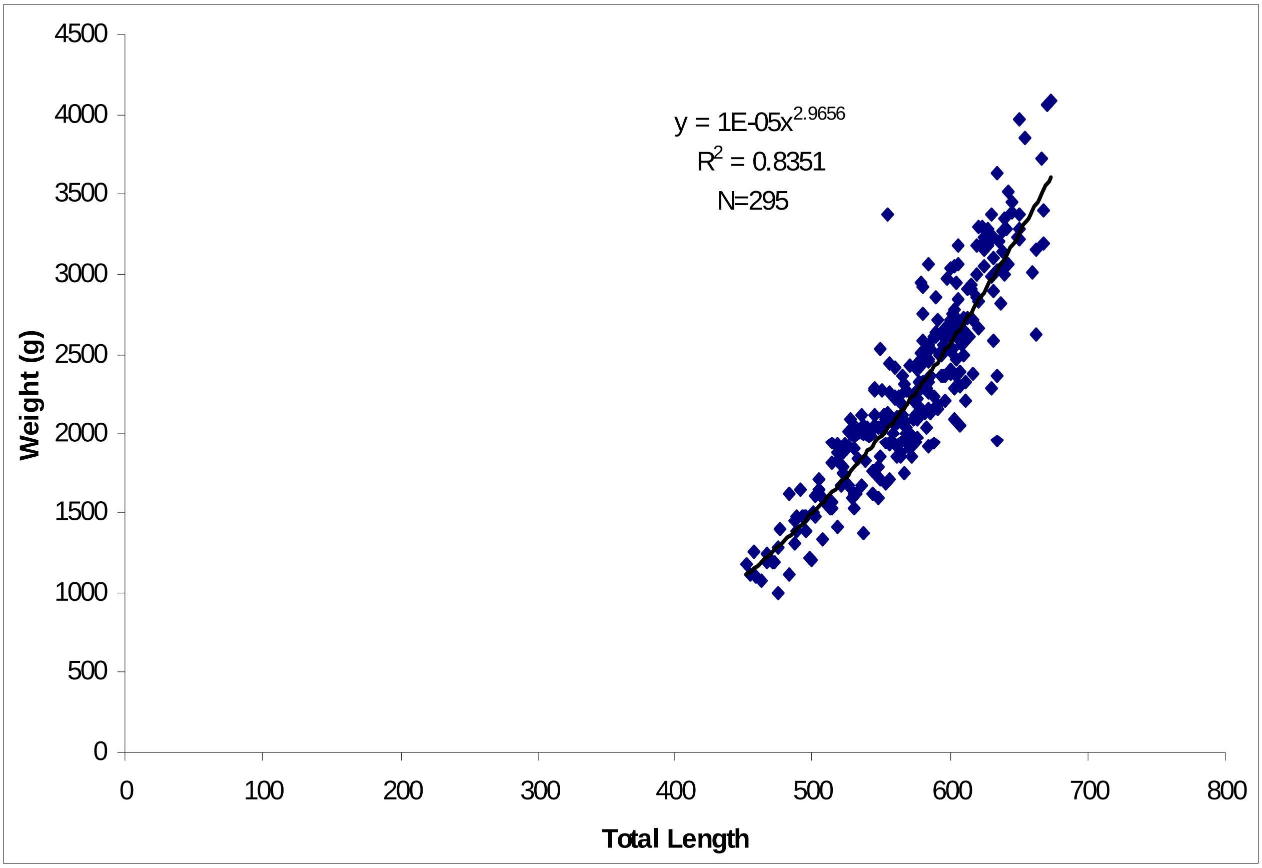

Figure 57. Length-weight relationship for male razorback sucker from Lake Mead (1996–2007 data).

efforts incorporating aging techniques are highly important for understanding the status of razorback sucker in Lake Mead. It should be noted that questions about the relationship of current sampling year and recruitment will not be answered until 4 years or more post-spawn. This same trend is evident in Table 18, as very few fish less than 4 years of age were collected. In fact, only twice (2003, 2007) have razorback sucker less than 4 years of age been collected, and both of these fish were determined to be 3-year-old individuals.

One of the more insightful comparisons we have made regarding Lake Mead razorback sucker recruitment has linked back-calculated age data with lake-level data. During most study years, aging data indicated some degree of correlation between high lake elevations and relatively high numbers of razorback sucker recruits. This trend continued through 2006; however, data obtained in 2007 suggested that low and/or declining lake elevations may not necessarily indicate years of poor recruitment. The year of highest recruitment coincides with the 2002 spawning period, when at least 16 individuals were successfully integrated into the general population. In light of data collected in 2007, razorback sucker are known to be able to recruit in Lake Mead under declining lake conditions. Figure 61 presents the correlation between mean

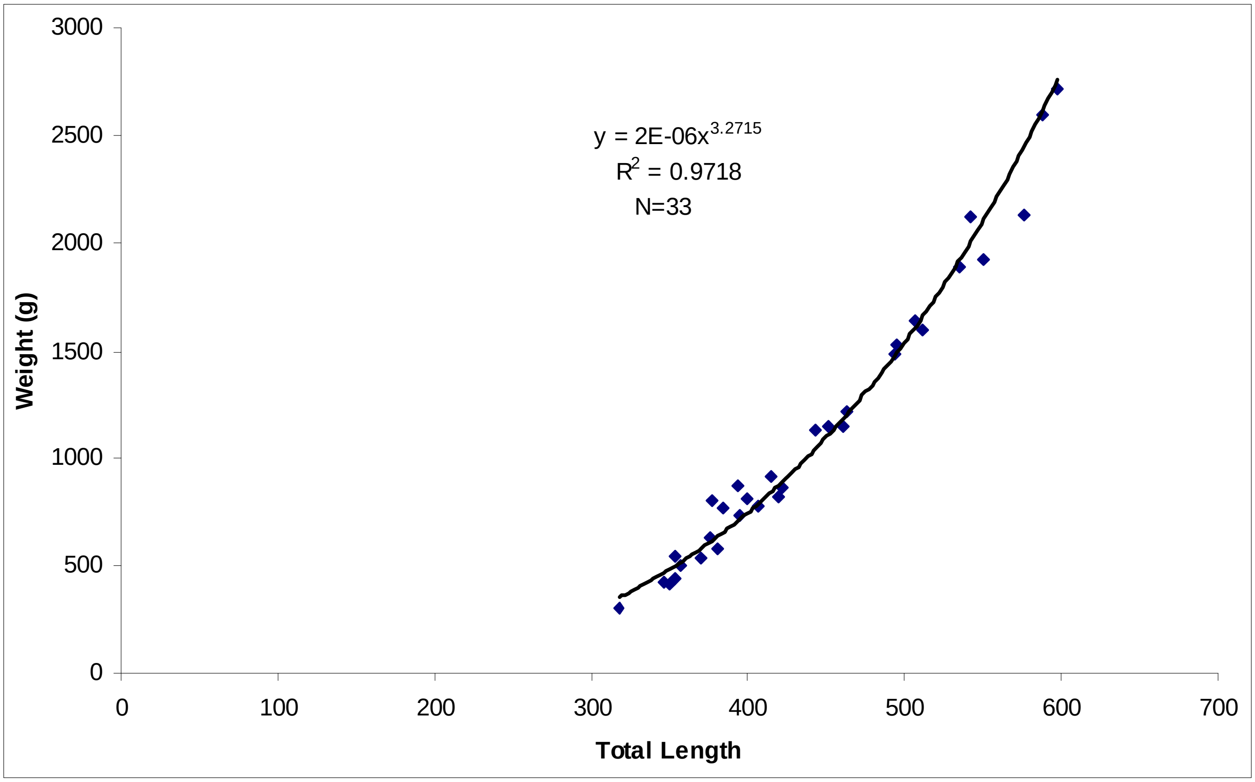

Figure 58. **Length-weight relationship for immature razorback sucker from Lake Mead (1996–2007 data).**

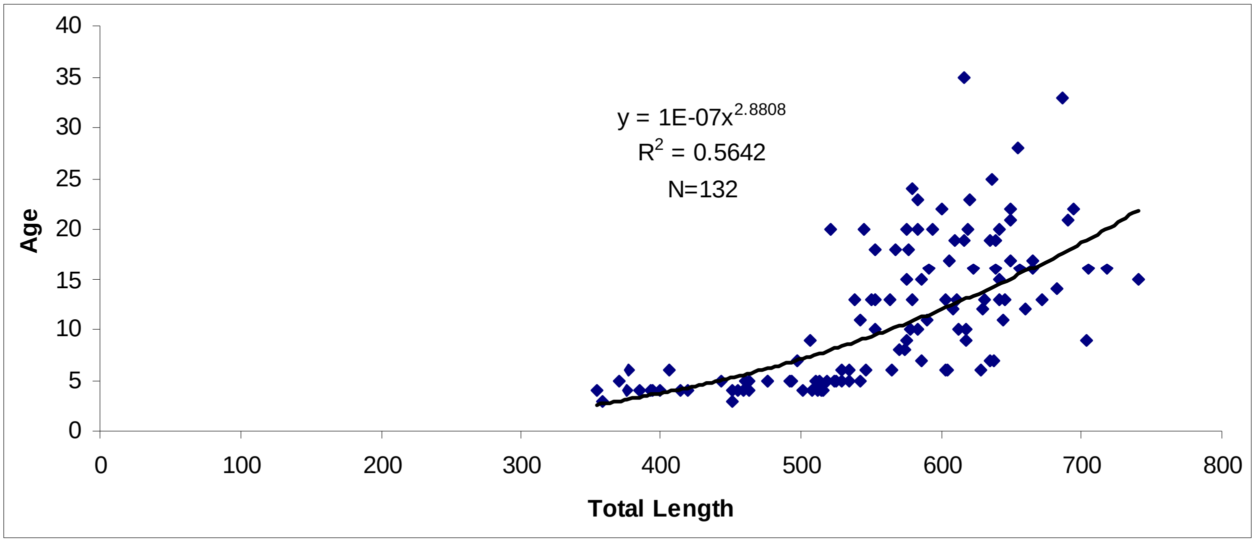

Figure 59. **Length-age relationship for Lake Mead razorback sucker based on all fish aged to date.**

Table 18. Ages determined from wild Lake Mead razorback sucker pectoral fin ray sections (all data through 2007).

DATE COLLECTED	TOTAL LENGTH (mm)	AGE	PRESUMPTIVE YEAR SPAWNED
	LAS VEGAS BAY		
05/10/1998	588	10	1987
12/14/1999	539	13	1986
12/14/1999	606	17+	1979–1982
12/14/1999	705	19+	1977–1980
01/08/2000	650	18+	1978–1981
02/27/2000	628	17+	1979–1982
01/09/2001	378	6	1994
02/07/2001	543	11	1989
02/22/2001	585	13	1987
12/01/2001	576	8–10	1991–1993
12/01/2001	694	22	1979
12/01/2001	553	10	1991
02/02/2002	639	16	1985
03/25/2002	650	22	1979
03/25/2002	578	10–11	1990–1991
03/25/2002	583	22–24	1977–1979
03/25/2002	545	20	1982
03/25/2002	576	20	1982
05/07/2002	641	15	1986
06/07/2002	407	6	1995
06/07/2002	619	20	1982
06/07/2002	642	20	1982
12/03/2002	354	4	1998
12/06/2002	400	4	1998
12/06/2002	376	4	1998
12/19/2002	395	4	1998
01/07/2003	665	16	1986
01/22/2003	494	4	1998
02/05/2003	385	4	1998
02/18/2003	443	5	1997
03/04/2003	635	19	1983
03/20/2003	420	4	1998
04/08/2003	638	21	1982
04/17/2003	618	10	1992
04/22/2003	650	20–22	1980–1982
05/04/2003	415	3+	1999

Table 18. (Cont.)

DATE COLLECTED	TOTAL LENGTH (mm)	AGE	PRESUMPTIVE YEAR SPAWNED
	LAS VEGAS BAY		
03/03/2004	370	5	1998
02/22/2005	529	6	1998
02/22/2005	546	6	1998
03/29/2005	656	16	1989
01/26/2006	740	15	1991
02/21/2006	621	23	1983
03/23/2006	461	5	2001
03/23/2006	718	16	1990
03/31/2006	635	7	1999
03/31/2006	605	6	2000
04/04/2006	629	6	2000
04/25/2006	452	4	2002
04/25/2006	463	4	2002
01/30/2007	514	5	2002
02/06/2007	519	5	2002
02/06/2007	574	8	1999
02/13/2007	526	5	2002
02/16/2007	530	5	2002
02/20/2007	534	6	2001
02/21/2007	358	3	2004
02/21/2007	511	5	2002
02/27/2007	645	13	1994
02/27/2007	586	15	1992
02/27/2007	603	13	1994
02/27/2007	650	17	1990
03/06/2007	515	4	2003
03/06/2007	611	13	1994
03/06/2007	565	6	2001
03/13/2007	586	7	2000
03/13/2007	636	25	1982
03/13/2007	524	5	2002
04/02/2007	704	9	1998
04/09/2007	644	11	1996
01/22/1998	381	5	1993
01/09/2000	527	13	1987
01/09/2000	550	13	1987
01/09/2000	553	13	1987

Table 18. (Cont.)

DATE COLLECTED	TOTAL LENGTH (mm)	AGE	PRESUMPTIVE YEAR SPAWNED
	ECHO BAY		
01/09/2000	599	12–14	1986–1988
01/27/2000	557	13	1986
01/27/2000	710	19+	1979–1981
02/09/2001	641	13	1988
02/24/2001	577	18+	1980–1982
02/24/2001	570	8	1992
02/24/2001	576	15	1986
02/24/2001	553	18	1983
12/18/2001	672	13	1988
02/27/2002	610	18–20	1982–1984
03/26/2002	623	16	1986
04/02/2002	617	35+	1966–1968
04/17/2002	583	20	1982
05/02/2002	568	18–19	1983–1984
11/18/2002	551	13	1989
12/04/2002	705	26	1976
01/21/2003	591	16	1986
02/03/2003	655	27–29	1974
02/03/2003	580	13	1989
04/02/2003	639	19–20	1982
04/02/2003	580	23–25	1978
04/23/2003	584	10	1992
05/06/2003	507	9+	1993
05/06/2003	594	20	1982
12/18/2003	522	20	1982
01/14/2004	683	14	1989
02/18/2004	613	10	1993
03/17/2004	616	19	1983
03/17/2004	666	17	1985
03/17/2004	618	9	1994
04/06/2004	755	17	1985
03/02/2005	608	15	1990
03/02/2005	624	8	1996
01/10/2006	630	12	1994
02/01/2006	705	16	1990
02/16/2006	601	22	1984
01/11/2007	535	5	2002
01/11/2007	493	5	2002

Table 18. (Cont.)

DATE COLLECTED	TOTAL LENGTH (mm)	AGE	PRESUMPTIVE YEAR SPAWNED
	ECHO BAY		
02/01/2007	637	7	2000
02/08/2007	609	12	1995
02/14/2007	501	4	2003
03/02/2007	590	11	1996
03/09/2007	660	12	1995
03/16/2007	691	21	1986
03/28/2007	564	13	1994
	FISH ISLAND		
02/23/2005	608	6	1998
02/22/2006	687	33	1973
02/22/2007	452	4	2003
02/22/2007	542	5	2002
02/22/2007	476	5	2002
02/22/2007	459	4	2003
02/22/2007	494	5	2002
03/01/2007	477	5	2002
03/01/2007	512	4	2003
03/08/2007	463	5	2002
03/08/2007	455	4	2003
03/15/2007	516	4	2003
04/03/2007	508	4	2003
04/11/2007	498	7	2000

lake level during spawning months (for the purposes of this report, January–April) and the number of razorback sucker captured and aged by year, which provides an R^2 of 0.096 indicating very little to no relationship between the number of fish caught (based on aging and back-calculation techniques) and lake elevation. This information warrants further investigations in order to understand the causal mechanism(s) responsible for continued recruitment events of razorback sucker in Lake Mead.

Population Estimates

Confidence intervals were quite large for all estimators, which is thought to reflect the nature of the data used for the estimates. The Jackknife estimator may represent an underestimation of the mean, as this estimator is known to underestimate with sparse data sets (Chao 1987, 1989). The result of these initial efforts was an agreed upon, conservative population estimate of 200 adults lake-wide, and we were granted a permit to sonic-tag 20 individuals.

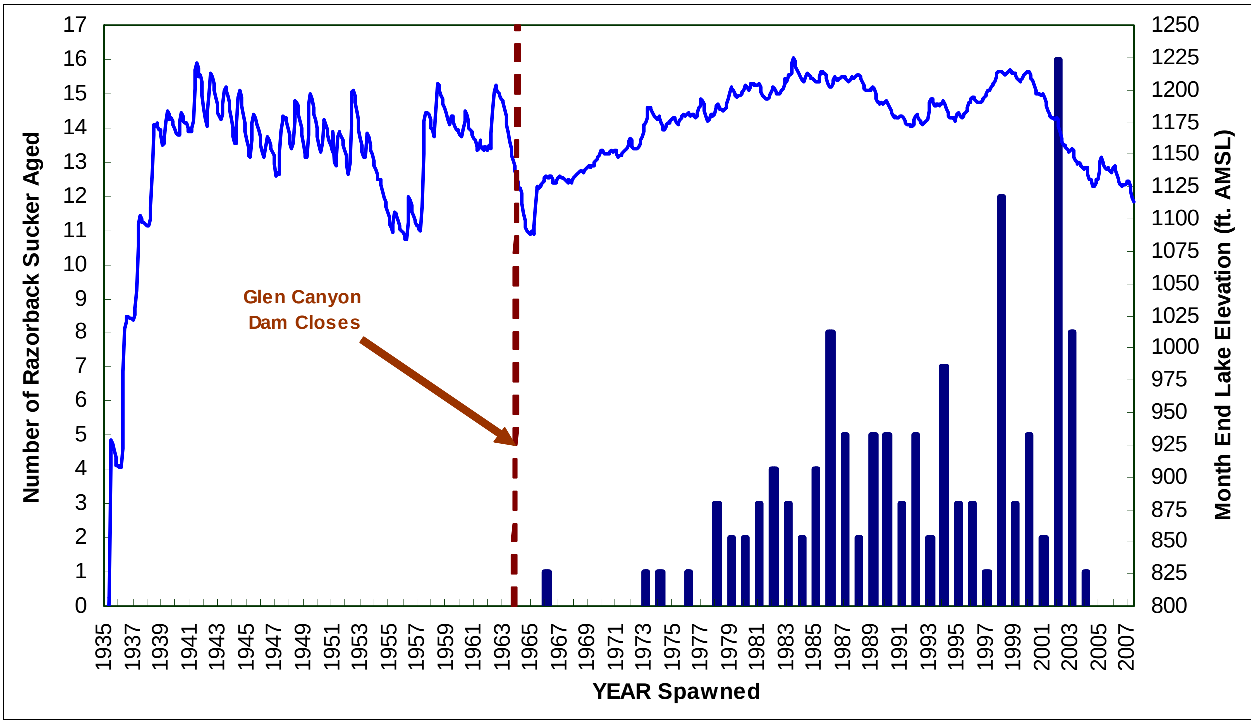

Figure 60. **Lake Mead hydrograph from January 1935–June 2007 with the number of aged razorback sucker that were spawned each year (includes all data obtained through 2007).**

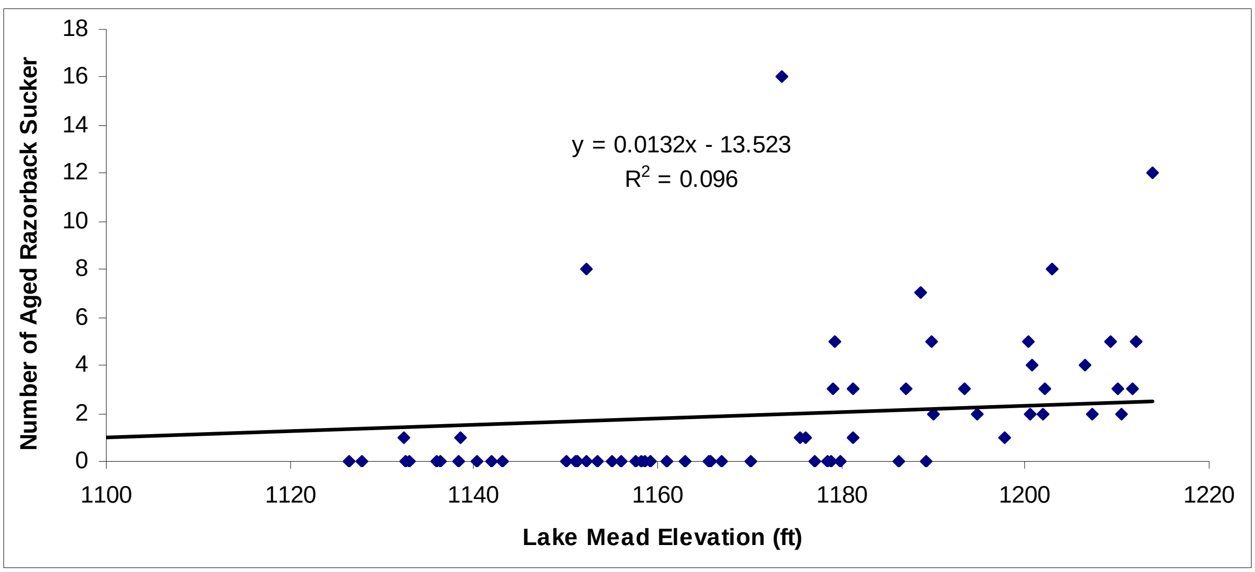

Figure 61. **Relationship between mean lake level during the spawning months (January–April) and the number of razorback sucker aged by year.**

Since 1996–1997, population estimates continued to be made using the program CAPTURE (Holden et al. 1999). Population estimation was not a focus of the study in 2000, but it was revisited by Holden et al. (2001) at which time BIO-WEST's capture data collected from 1996–2001 were used to calculate abundance estimates for razorback sucker populations at Echo and Las Vegas bays. Estimates of both populations were conducted for each consecutive 3-year period (1996–1998, 1997–1999, 1998–2000, and 1999–2001) to investigate abundance trends and examine the consistency of estimates. For each 3-year period, close agreement between the two models (Chao's M_h and Model M_o) indicated a fairly reliable estimate. While patterns of agreement between the models were difficult to discern, the number of individuals during this time period fluctuated between 75–90 fish within each population (Holden et al. 2001).

From 2002 through 2004, populations were estimated as described above, with population abundance estimates remaining highly variable and any patterns of abundance being difficult to distinguish due to the high variability in confidence intervals (Abate et al. 2002, Welker and Holden 2003, Welker and Holden 2004, Albrecht and Holden 2005). However, Albrecht and Holden (2005) point out that population estimates for the 2003–2005 time period were likely influenced by the time devoted to investigating a new spawning aggregate in the Overton Arm, as well as reduced catch and effort in Echo and Las Vegas bays. Therefore, that confounded population estimate comparisons between that study year and others.

Albrecht et al. (2006a) indicate that population estimates on Lake Mead should be cautiously interpreted and compared with past findings. They further indicate that population estimates should not be viewed as trend data, given the violation of many of the assumptions involved with closed population estimation techniques on Lake Mead, in particular the dramatic differences in effort that was expended both within and between years. Furthermore, Albrecht et al. (2006a) reiterate that population estimation on Lake Mead was originally designed to ascertain whether sonic telemetry was actually plausible or whether tag implantation might jeopardize wild Lake Mead razorback sucker populations. Since that initial effort, population estimation has remained an "artifact" in annual reports. Albrecht et al. (2006a) recommend, that due to the violation of many of the assumptions involved with closed population estimation techniques, a more complex, open model may be a better option for understanding population trends over time (Albrecht et al. 2006a).

Albrecht et al. (2007) provide evidence that the population of Lake Mead razorback sucker may actually be larger than previously thought, but again caution against making decisions based solely on population estimates provided. However, this statement seems to be verified by a notable increase in trammel netting CPUE and the overall abundance of newly captured individuals collected in 2007, particularly in the northern portions of Lake Mead. At minimum this information suggests that either recent population estimates were fairly conservative or the Lake Mead razorback sucker population has undergone a recent pulse in recruitment. In either case, this information bodes well for the status of razorback sucker in Lake Mead.

Finally, Table 19 summarizes population estimates of Lake Mead razorback sucker using data collected from 1996–2007. Data are presented in 3-year intervals (as in past annual reports) and delineated by study location and estimator/model used. Population estimates at Las Vegas Bay ranged from a minimum estimated mean of 27 fish to a maximum estimated mean of 310 fish, with 95% confidence intervals ranging from a low of 15 fish to a high of 1,104 fish. The Echo Bay population estimated means ranged from a minimum of 33 fish to a maximum of 142 fish, while the 95% confidence intervals ranged from a low of 25 fish to a high of 242 fish.

Table 19. Lake Mead razorback sucker population estimate summary using 1996–2007 data collections. Estimates are presented in 3-year intervals.

YEARS OF DATA	ESTIMATOR	MEAN	95% CONFIDENCE INTERVAL
	LAS VEGAS BAY		
1990–1996	Chao M_h	273	93–981
1996–1998	Chao M_h	96	58–199
1997–1999	Chao M_h	98	61–201
1998–2000	Chao M_h	148	72–382
1999–2001	Chao M_h	55	39–104
2000–2002	Chao M_h	95	50–244
2001–2003	Chao M_h	97	58–209
2002–2004	Chao M_h	310	108–1,104
2003–2005	Chao M_h	52	18–272
2004–2006	Chao M_h	91	43–267
2005–2007	Chao M_h	271	113–793
1990–1996	Model M_o	191	78–578
1996–1998	Model M_o	97	60–189
1997–1999	Model M_o	87	60–148
1998–2000	Model M_o	118	68–247
1999–2001	Model M_o	55	41–91
2000–2002	Model M_o	68	45–128
2001–2003	Model M_o	76	54–126
2002–2004	Model M_o	112	70–211
2003–2005	Model M_o	27	15–93
2004–2006	Model M_o	70	40–156
2005–2007	Model M_o	97	69–158
	ECHO BAY		
1990–1996	Chao M_h	74	38–192
1996–1998	Chao M_h	94	63–171
1997–1999	Chao M_h	98	68–175
1998–2000	Chao M_h	66	52–105
1999–2001	Chao M_h	107	66–126
2000–2002	Chao M_h	45	31–90

Table 19. (Cont.)

YEARS OF DATA	ESTIMATOR	MEAN	95% CONFIDENCE INTERVAL
	ECHO BAY		
2001–2003	Chao M_h	73	49–144
2002–2004	Chao M_h	52	39–92
2003–2005	Chao M_h	39	25–89
2004–2006	Chao M_h	46	38–74
2005–2007	Chao M_h	142	97–242
1990–1996	Model M_o	69	38–165
1996–1998	Model M_o	92	65–151
1997–1999	Model M_o	84	66–123
1998–2000	Model M_o	65	53–92
1999–2001	Model M_o	58	50–77
2000–2002	Model M_o	54	35–105
2001–2003	Model M_o	57	48–83
2002–2004	Model M_o	50	38–72
2003–2005	Model M_o	33	25–69
2004–2006	Model M_o	47	39–66
2005–2007	Model M_o	107	84–145

Other Results

Water Quality Parameters

Water quality, nutrient levels, zooplankton abundance, and cover availability data were collected at three locations within Lake Mead and at two locations in Lake Mohave during 2000, 2001, and 2002 in an attempt to compare some of the suspected limnological factors that might allow for razorback sucker recruitment in Lake Mead (Golden and Holden 2001, Golden and Holden 2002, Golden and Holden 2003). These studies were conducted in support of, and concurrently with, the overall Lake Mead razorback sucker studies. The main focus of these additional studies was to identify what (if anything) was different about Echo and Las Vegas bays (locations that are known to produce razorback sucker recruits) compared with other Lake Mead and Lake Mohave coves (locations that may or may not produce larval razorback sucker, but where no recruitment was observed). The general locations where sampling activities occurred within Lakes Mead and Mohave are provided in Figures 62 and 63 (Golden and Holden 2001, 2002, and 2003).

In summary, Golden and Holden (2003) highlight two factors that appear to separate Echo Bay and Las Vegas Bay from the other coves sampled within Lake Mead and Lake Mohave, vegetative cover and turbidity. Although zooplankton, temperature, dissolved oxygen, nitrates, ammonium, total phosphorus, and total dissolved solids were all measured, little to no discernable differences, or noteworthy trends were discovered for any of these parameters

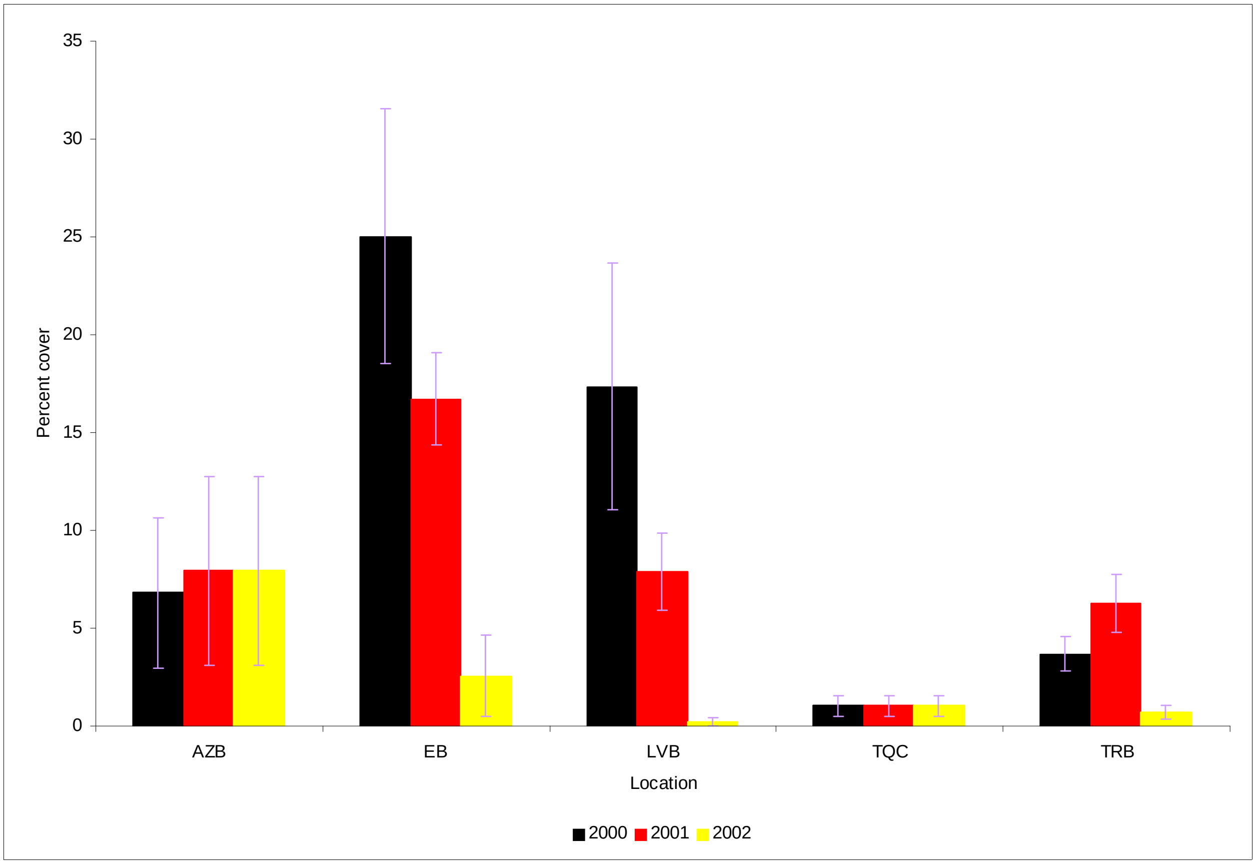

Figure 62. Mean percent cover at locations sampled and as presented in Golden and Holden (2003).

despite rigorous data collection and analytical efforts. One interesting result was that zooplankton were found in variable, yet similar abundances across sites, and it was concluded that young razorback sucker were likely not food limited at the sites evaluated. Therefore, the working hypothesis became such that depredation of young razorback sucker, not food resource production, was most likely the limiting factor for razorback sucker recruitment within and between the areas evaluated (Golden and Holden 2001, Golden and Holden 2002, Golden and Holden 2003).

Vegetative cover was one of two items that appeared to differentiate locations where natural recruitment occurred, compared with locations where no recent recruitment was observed. Comparing data collected during March sampling from all years and locations sampled Golden and Holden (2003) found that mean percent cover was significantly higher at Echo Bay than at Arizona Bay, Las Vegas Bay, Tequila Cove, and Trail Rapids Bay in 2001 (ANOVA, $p < 0.04$) and higher than all locations in 2002 (ANOVA, $p < 0.04$). Additionally, the mean percent cover at Las Vegas Bay in 2000 was significantly higher than the mean percent cover at Las Vegas Bay and Trail Rapids Bay in 2002 (ANOVA, $p < 0.05$). In May 2000 Echo Bay had significantly higher mean percent cover than Las Vegas Bay, Tequila Cove, and Trail Rapids Bay in 2001

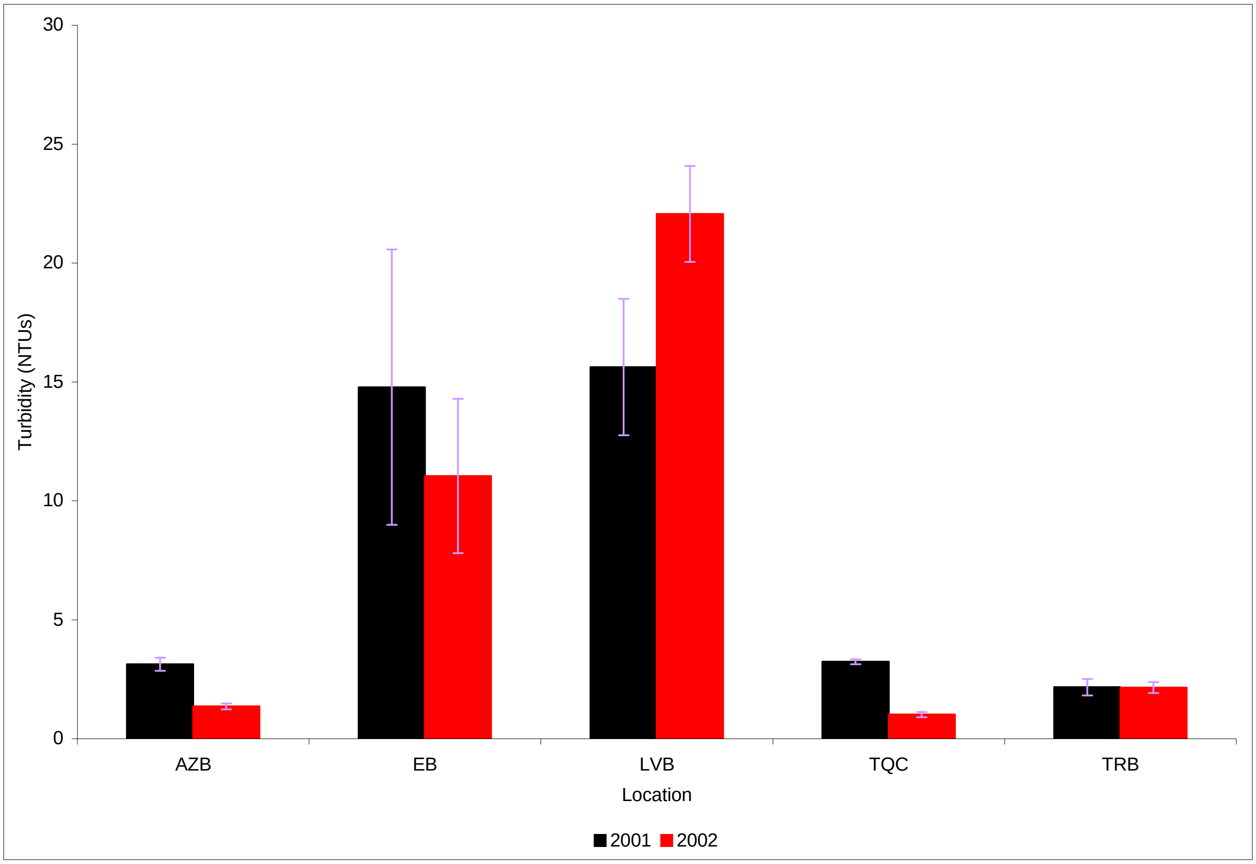

Figure 63. Mean turbidity levels at locations sampled and as presented in Golden and Holden (2003).

(ANOVA, $p < 0.02$), and Echo Bay, Las Vegas Bay, and Trail Rapids Bay in 2002 (ANOVA, $p < 0.004$). Furthermore, as was expected, mean percent cover at locations in Lake Mead known to produce young razorback sucker was found to decline from 2000–2002 in response to lowering lake elevations during the course of those years. As a result, the idea of long-term, climate-driven, lake-elevation changes being an important factor in the establishment of vegetative cover and ultimately the interaction between vegetative cover, diminished predation, and the roles of these factors leading to pulses of razorback sucker recruitment was conceived (Figure 62).

Additionally, Golden and Holden (2003) found that turbidity levels (another form of cover) separated Echo Bay and Las Vegas Bay from the other locations evaluated within Lake Mead and Lake Mohave. Turbidity levels at Las Vegas Bay and Echo Bay were higher than at the other locations sampled (Figure 63). When data for both years were combined, Golden and Holden (2003) found that Las Vegas Bay had significantly higher turbidity levels than all other locations in March (ANOVA, $p < 0.001$) and all locations but Echo Bay in May (ANOVA, $p < 0.001$). While Echo Bay had higher turbidity levels than all locations except for Las Vegas Bay in March and May, the difference was only significant in May (ANOVA, $p < 0.001$) (Figure 63).

However, in hindsight and as shown in Figure 63, turbidity did not appear to be influenced by declining lake levels, at least to the extent that vegetative cover appeared to be. Likewise, Golden and Holden (2003) found that Secchi disk depth data also showed increased turbidity levels at Echo Bay and Las Vegas Bay during their studies. Las Vegas Bay had the lowest clarity with secchi depths ranging from 0.9 m–8 m in March and 0.85 m–3.5 m in May. Echo Bay had secchi measurements of 1.3 m–6.8 m in March and similar readings in May. Conversely, the lowest secchi reading at the other sites was 6.7 m at Arizona Bay in March and 9.1 m at Arizona Bay in May. The highest secchi readings were 13.3 m at Trail Rapids Bay in March and 12.4 m at Arizona Bay in May. For those interested in specific, detailed findings related to water quality parameters, zooplankton, and/or further sampling and associated analytical techniques, please refer to Golden and Holden (2001), Golden and Holden (2002), and Golden and Holden (2003).

DISCUSSION AND CONCLUSIONS

Information collected from 1996–2007 (11 study years) on Lake Mead expanded our knowledge of spawning behavior, habitat use, recruitment patterns, growth, and age structure of razorback sucker populations in Lake Mead. Additionally, multiple methods were developed and refined, all of which helped clarify and obtain insight pertaining to Lake Mead razorback sucker responses to fluctuating lake elevations, the ecology of Lake Mead razorback sucker, the nature of stocked and wild fish interactions, and population abundance.

Lake Elevation

Fluctuating lake levels in Lake Mead desiccated spawning areas, resulting in the near-constant shifting of spawning locations. As lake levels are projected to further decline in the future, razorback sucker will be forced to continually search and locate suitable habitats for spawning. The ramifications of this are largely unknown, particularly in regards to the specific conditions required to ensure successful spawning and recruitment. Currently, it is hypothesized that cover (in the form of vegetation, turbidity, or an unknown form) plays an important role in allowing the successful recruitment of razorback sucker in Lake Mead. As the lake level continues to decrease, it is possible that the combination of factors allowing for successful spawning and recruitment of razorback sucker (i.e., spawning substrate and cover) will no longer exist. The Echo Bay spawning site is an example of this: Echo Bay has been shown to contain higher turbidity levels (Holden 2003) compared with the rest of the reservoir. However, if Echo Bay dries, will the source of turbidity cease to exist, thus terminating the conditions that allow for successful razorback sucker recruitment in this particular locale? Las Vegas Bay, Echo Bay, and the Muddy River/Virgin River inflow area are all distinguished from the rest of the lake because they provide conditions conducive to the razorback sucker spawning and recruitment. Continued monitoring is needed to determine if these areas will continue to be important for razorback sucker population sustainability as lake levels diminish.

Larval Sampling

Sampling for larval razorback sucker was an important aspect of the sampling methodology throughout all years of the Lake Mead studies. To date, larval razorback sucker sampling efforts were primarily focused on Echo Bay and Las Vegas Bay, but substantial effort was also expended throughout Lake Mead during lake-wide larval sampling. Although lake-wide larval sampling did not result in the capture of larval fish from most of the lake, multiple larval fish were captured from within the Colorado River inflow area, which prompted further investigation of that locale and supported the overarching hypothesis that razorback sucker are able to persist in locations containing relatively high amounts of cover despite the presence of nonnative fishes. Lake-wide larval sampling did, however, facilitate a greater understanding of the available habitat throughout Lake Mead, and it became apparent that the various inflows, as well as Echo Bay, were unique compared with the remainder of the lake. As such, subsequent efforts focused on further sampling at the inflow locations outside of Las Vegas Bay and Echo Bay. As a result, the presence of razorback sucker was documented in both the Colorado River and Muddy River/Virgin River inflow areas. It should be noted that we deem lake-wide larval sampling efforts highly important to the successes of the project thus far, as this work allowed us to ascertain locations of razorback sucker spawning activities. Although little in terms of “new” locations was found, by eliminating large portions of Lake Mead as potential spawning habitat we were able to focus subsequent efforts on gaining detailed information at locations identified as primary spawning areas. While we are not able to say that spawning activities do not take place outside of these known areas, time and resources are now allocated consistently at the primary spawning locations until further evidence dictates sampling should be conducted elsewhere.

While much of the larval sampling protocol has remained consistent throughout the studies, the locations sampled within each study area changed over time. During the initial years of our research, standard larval sites were established to provide consistency and comparability over time. From 1998–1999 through 2001–2002, standard locations within both Echo Bay and Las Vegas Bay were sampled (Holden et al. 1999, Abate et al. 2002). However, starting in 2002–2003 (due to the declining lake), many of these standard sites were dry and had to be abandoned. By 2004–2005 standard larval site sampling efforts had to be discontinued (Albrecht and Holden 2005). In response to the loss of the standard larval sampling sites, larval sampling efforts were based on the habitat use patterns of sonic-tagged fish, prior knowledge of spawning areas, trammel netting results, and all prior knowledge of larval abundance from sampling within a given location (Albrecht and Holden 2005). Thus, more recent larval sampling employed a much more fluid, adaptable protocol (Albrecht et al. 2006).

Larval sampling occurred throughout the Gregg Basin, upstream towards Driftwood Cove, Grand Wash Bay, and throughout most of the Colorado River inflow area as dictated by lake elevation and accessibility at time of sampling. Although larval fish were collected from the Colorado River inflow area on occasion during the course of our studies, subsequent trammel netting and sonic-telemetry efforts failed to result in the capture of subadult, or adult razorback sucker. As such, we were unable to rule out the possibility that the source of larval fish captured in the Colorado River inflow was not the result of upstream spawning within the Grand Canyon area or immediate riverine portions of the Colorado River. As such, this interesting area of Lake Mead was never fully identified as a primary spawning location. Furthermore, since the 2005 spawning season, efforts were curtailed in this portion of Lake Mead in an effort to allocate resources to study the new Muddy River/Virgin River inflow spawning area. Although efforts in the Colorado River inflow area subsided prior to writing this report, this area remains a likely location for a spawning population of razorback sucker, based on the presence of larval razorback sucker and the abundance of cover associated with the inflow area.

Overall, Las Vegas Bay has supplied and continues to supply relatively robust numbers of larval fish to the Lake Mead razorback sucker population, and we have seen evidence of larval survival at Las Vegas Bay in the form of sexually immature, subadult fish captures. As such, we feel that some of the larvae produced at Las Vegas Bay help ensure recruitment and the sustainability of the Lake Mead razorback sucker population. Interestingly, from the 1997–2005 spawning seasons, the majority of larval captures from within Las Vegas Bay stemmed from Blackbird Point. As lake levels receded and the delta from Las Vegas Wash expanded, larval captures and spawning activities of razorback sucker shifted from Blackbird Point to the southwestern shoreline. Although there was speculation that the Las Vegas Bay population may not spawn in a new location, or that if spawning did occur that larval fish may not have been produced, it is now apparent that the Las Vegas Bay razorback sucker population was able to successfully shift spawning locations and produce large numbers of larval fish, as evidenced by larval CPM results from 2006 and 2007 (Albrecht et al. 2006, Albrecht et al. 2007). However, it remains unknown at this time if/how larval fish production from these "new" spawning locations within Las Vegas Bay will affect future recruitment. The impacts of the shift in spawning site selection by the Las Vegas Bay razorback sucker population away from Blackbird Point will likely not be manifested until 2009, 2010, or later, due to the 3–4 year lag time it takes for young fish to become susceptible to trammel netting techniques, and because fish of a given recruitment year are generally captured over several years.

Echo Bay also served as an important sampling location and high numbers of larval fish were captured here throughout the Lake Mead study. This was the location of numerous larval captures each year, and some of the highest larval capture rates of any of the Lake Mead spawning sites occurred here. Echo Bay is geologically constricted due to its location at the base of a steep mountain and, although it is more turbid than the rest of the lake (Golden and Holden 2002), its water is much clearer than in Las Vegas Bay and the river inflow areas. It is not known whether the combination of these abiotic factors lends to higher larval capture rates or if there are greater numbers of larval razorback sucker present. Nonetheless, we captured and documented subadult fish in Echo Bay on a number of occasions, supporting the idea that some of the larval razorback sucker produced in Echo Bay likely survive and are recruited into the adult population.

Differences in larval catch rate between Las Vegas Bay and Echo Bay are likely not reflective of more or less fish spawning at either location. Based on information largely from intensive larval collection at Lake Mohave, larvae appear to rise up from spawning areas to the surface and are distributed by wind currents (T. Burke, Reclamation, personal communication). It is our hypothesis that up until 2006, larval fish moving out of spawning areas at Blackbird Point, which were very deep initially, and reached the surface in a fairly wide bay that is susceptible to winds. The wind moved the larvae around and created fewer larvae at any one site. At Echo Bay, which has shallower spawning sites, is more confined, and less susceptible to wind, the larvae were more concentrated. This set of geographical and wind conditions has changed recently, as spawning sites at Las Vegas Bay have become more confined, whereas those at Echo Bay have extended further into the main lake and have become less confined. This may explain why Las Vegas Bay has produced higher larval catch rates in 2006 and 2007, and Echo Bay catches have declined.

Unlike the larval capture of razorback sucker in Las Vegas and Echo bays, we were unable to capture larval fish in numerous amounts or on a frequent basis in the Muddy River/Virgin River inflow area. The explanation for this is unknown, but we speculated that the geographical positioning of the Fish Island shoreline may provide an explanation (Albrecht et al. 2007). The susceptibility of this area to wind and wave action make this location one of the more difficult places to sample on Lake Mead, and sampling efforts can be easily hindered by limited visibility. Furthermore, the combined influxes of sediment and nutrients from the Muddy River and Virgin River make this location exceptionally turbid, often resulting in only a few inches of visibility into the water column. These combined factors result in overall poor sampling conditions that may reduce the sampling abilities of field crews. In addition, and as noted above, wind may also move larvae further from the spawning site, thus reducing catch rate. Since it also appears that there are fewer adults at this site than at the other two sites, we cannot rule out the possibility that, while the Muddy River/Virgin River inflow area is successfully used as a spawning area by razorback sucker, the degree of sampling success and amount of larvae hatched may be small relative to that of the Las Vegas Bay and Echo Bay populations.

Adult Sampling

Trammel netting was probably the most important method for obtaining data regarding razorback sucker ecology throughout the Lake Mead studies. Through the capture and processing of razorback sucker, we were able to obtain information regarding population dynamics, movement patterns, growth rates, recruitment trends, and age structures of the Lake Mead population. This sampling method provided the greatest amount of knowledge regarding all aspects of razorback sucker ecology, excluding larval stages.

Las Vegas Bay and Echo Bay provided the greatest numbers of subadult and adult razorback sucker, as these two locales were the primary study locations within Lake Mead since the inception of the research. Although sampling in Las Vegas Bay and Echo Bay produced large amounts of razorback sucker each year, sampling efforts were employed in varying areas of Lake

Mead in an attempt to further our knowledge of the distribution and spawning locales of razorback sucker. A great amount of sampling effort was expended in the Colorado River inflow. It was hypothesized that the physical characteristics at the Colorado River inflow (presence of cover in the form of turbidity and vegetation) were conducive to the successful spawning and recruitment of razorback sucker. However, after intensive sampling did not result in the capture of a subadult or adult razorback sucker, sampling ceased in the Colorado River inflow and efforts were again re-directed to Las Vegas Bay and Echo Bay.

An effort tantamount to that expended in the Colorado River inflow area occurred at the Muddy River/Virgin River inflow area during the 2004–2005 field season. Similar to the Colorado River inflow, the Muddy River/Virgin River inflow area had physical characteristics that might allow razorback sucker spawning and recruitment. However, unlike the experience in the Colorado River inflow area, the result was the identification of another spawning area within Lake Mead similar to those found in Las Vegas Bay and Echo Bay. Thus far the Muddy River/Virgin River area contains the lowest proportion of recaptured fish, leading us to believe that we are netting a population that has yet to be studied within Lake Mead.

While the population dynamics of the razorback sucker population in the northern portions of Lake Mead are still unknown, we know that Echo Bay and Muddy River/Virgin River inflow area fish intermingle. We currently have two working hypotheses regarding the fish located in the Muddy River/Virgin River inflow area: (1) the Muddy River/Virgin River inflow area is an extension of the Echo Bay spawning area, and fish frequently move between the two locations to find suitable spawning habitat; and (2) the Muddy River/Virgin River inflow area is a separate spawning location used by a newly identified population of razorback sucker in Lake Mead that shares metapopulation dynamics with the Echo Bay razorback sucker population. We are optimistic that future sampling efforts will allow us to determine the degree of separation that exists among the Echo Bay and Muddy River/Virgin River razorback sucker populations.

Recent study seasons produced higher rates of razorback sucker captures via trammel netting, compared with earlier years (Albrecht et al. 2007). It is not known whether this trend is the result of increased populations in Lake Mead or simply an artifact of lowered lake conditions resulting in the higher concentration of razorback sucker populations in the spawning locations. The composition of recaptured fish remains relatively similar to that of previous study years, thus we theorize that the increased capture rate is due to changing lake conditions that concentrate razorback sucker in smaller areas, thus making them more susceptible to our sampling techniques. Future sampling efforts will provide more data in this regard as the lake is projected to drastically recede.

Sonic telemetry was also a valuable tool for determining razorback sucker movements, spawning locations, and depth use. Specifically, sonic telemetry was crucial in assisting with the determination of larval and trammel netting efforts. By following their movements and pinpointing sonic-tagged fish locations, field personnel were able to precisely identify movement corridors and high-density spawning locations, thereby enabling the successful capture of larval, subadult, and adult razorback sucker. Without the ability to track the movements and locations of sonic-tagged fish, we would be forced to rely on past capture data to determine the locations of our sampling efforts or sample “blindly” in new locations. Due to varying conditions resulting from fluctuating lake levels, the movements and spawning locations of razorback sucker are stochastic. Thus, we strongly believe that our capture efficiency and total numbers of fish sampled would drastically decrease if we relied on past capture data to dictate sampling locations. Ultimately, the sampling time needed to gain valuable information regarding razorback sucker ecology would increase, resulting in less efficient field seasons and decreased ability to obtain general knowledge of razorback sucker dynamics.

In addition to increasing sampling efficiency, sonic telemetry also provides valuable information about population dynamics throughout Lake Mead. The majority of our trammel netting capture/recapture data suggest that the three primary spawning locations in Lake Mead (Las Vegas Bay, Echo Bay, and the Muddy River/Virgin River inflow area) are home to three relatively separate, distinct razorback sucker populations. While we have recaptured PIT-tagged fish that have moved amongst the spawning locations, our capture data alone suggest that the populations are primarily sedentary. However, data provided via sonic telemetry show that movement among the three spawning locales does occur (Albrecht and Holden 2005; Albrecht et al. 2006, Albrecht et al. 2007). For instance, we documented a sonic-tagged fish moving between Echo Bay, Las Vegas Bay, and the Overton Arm multiple times; in fact, this fish migrated between Echo Bay and Las Vegas Bay in less than 23 days (Albrecht et al. 2007). Such behavior has been observed in other reservoirs (Mueller and Marsh 1998); however, it was not observed in Lake Mead until recently. When the movement data from sonic-tagged fish are combined with PIT-tag data, we can state that metapopulation dynamics exist to a small degree between Las Vegas Bay, Echo Bay, and the Muddy River/Virgin River inflow area.

Using all three methods of investigation — larval sampling, trammel netting, and sonic telemetry — conjunctively was an invaluable tool for providing sampling locations for all life stages of razorback sucker in Lake Mead. The events leading to the finding of the Muddy River/Virgin River inflow area spawning aggregate exemplify the effectiveness of using multiple methodologies to locate and research relatively small, elusive native fish populations. Initially, a single sonic-tagged fish that was stocked into Echo Bay was located near Fish Island in the northern portions of Lake Mead. For several weeks this sonic-tagged fish remained near the Muddy River and Virgin River inflow areas, and telemetry efforts indicated near-shore habitat usage indicative of spawning activities. Netting efforts were initiated to determine whether the sonic-tagged fish was solitary or other razorback sucker were present. The result was the capture of multiple wild, ripe, adult razorback sucker and several stocked fish. Subsequently, and based on findings from our sonic-telemetry and trammel-netting efforts, larval sampling was conducted at the capture locations as well as throughout the general vicinity. The result was the documentation of larval razorback sucker, which confirmed that spawning activities had successfully occurred. This example emphasizes the importance of employing multiple methodologies in the investigation of Lake Mead razorback sucker. The presence of sonic-tagged fish in Lake Mead made it possible to discern locations of razorback sucker use and, in turn, trammel-netting and larval-sampling efforts became much more efficient and focused.

Sonic-telemetry, trammel-netting, and larval-collection efforts continued to reaffirm the importance of Las Vegas Bay, Echo Bay, and the Muddy River/Virgin River inflow area as highly important to the continued persistence of Lake Mead razorback sucker. This combination of multiple methodologies was effective during past studies and should continue to be useful for gaining further knowledge regarding Lake Mead razorback sucker; we may even answer questions regarding why and how Lake Mead razorback sucker continue to demonstrate recruitment. As more information is obtained from aging individual razorback sucker with non-lethal techniques, recruitment trends will hopefully be identified. As this process unfolds, year-class strengths could be compared with physical and limnological data (stemming from other investigators) in an effort to understand the physical conditions that are driving recruitment events on Lake Mead. Ultimately, the relationship between recruitment and the physical environment will become better understood and more valuable in terms of promoting and developing similar conditions in other systems. Hence, continued efforts on Lake Mead are warranted, particularly efforts directed at collecting, compiling, and establishing the relationship between age-based recruitment and the abiotic conditions that exist over time.

Growth and Aging

Growth rates of recaptured Lake Mead razorback sucker exceeded rates recorded for other wild razorback sucker populations. The combined lake-wide mean annual growth for all Lake Mead fish recaptured during the course of our studies is 11.9 mm, compared with relatively low growth rates (less than 2.0 mm per year) of razorback sucker in Lake Mohave (Pacey and Marsh 1998) and the Green River (McAda and Wydoski 1980, Tyus 1987). As indicated by Mueller (2006) razorback sucker grow at higher rates when they are young. These elevated growth rates suggest that the razorback sucker population within Lake Mead is fairly young compared with other razorback populations in the Colorado River Basin and has experienced recent natural recruitment events (Albrecht et al. 2006, 2007).

In addition to growth rates, this report also presents length-weight relationships for Lake Mead razorback sucker. This is the first time (to our knowledge) that such a relationship has been attempted based largely on data from Lake Mead wild fish. In summary, the relationships suggest that Lake Mead razorback sucker are healthy, well-conditioned fish, with K-values near, at, or above a value of 3.0, which is indicative of isometric growth (DeVries and Frie 1996). This suggests that the habitat conditions in Lake Mead are suitable to the physiological requirements of razorback sucker.

Similarly, and perhaps even more interesting in ecological terms, a length-age relationship for Lake Mead razorback sucker is presented in this report. According to our knowledge, this is also the first time that such a relationship has been presented for Lake Mead razorback sucker (and may be the first ever relationship of this type for wild razorback sucker in the Colorado River Basin). This relationship between length and age is not as strong as the length-weight relationship: the analysis demonstrates that beyond 500 mm TL, it is nearly impossible to determine the age of razorback sucker based solely on its length data. As such, this stresses the need to continue non-lethal aging of Lake Mead razorback sucker in order to further understand the conditions and determine particular years that result in pulses of razorback sucker recruitment for past and future recruitment events. Furthermore, these results stress the value and applicability of non-lethal aging techniques as a useful, necessary, and highly applicable tool for understanding razorback sucker (and other sucker species) recruitment patterns in other locations.

Fin-ray extraction and aging techniques resulted in some of the most insightful information we have collected on Lake Mead to date. These efforts resulted in aging 132 fish and, when coupled with back-calculation efforts, provided information on years of relatively strong razorback sucker recruitment and indicated years when recruitment was minimal. Calculated ages ranged from 3- to 35-years old, and 37% of the 132 fish were 7-years old or younger at time of capture. During the 2006–2007 study year alone, 41 fish were aged, and 21 of the 41 fish (51%) were 7-years old or younger, which documents recruitment occurring as recently as the 2004 spawning period (Albrecht et al. 2007). This information bodes well for the status of Lake Mead razorback sucker and exemplifies the overall youthfulness of this unique population. As monitoring efforts continue on Lake Mead, we expect to begin capturing fish that were spawned in 2005, 2006, and 2007 as they reach sizes susceptible to capture gear in 3 or 4 more years. Furthermore, we expect to find evidence of continued recruitment as long as aging efforts continue. Lastly, this non-lethal aging technique has been and will continue to be invaluable in understanding year-class strength trends, evaluating the health of Lake Mead razorback sucker over time, and investigating the factors that allow recruitment to occur. Furthermore, aging will continue to be an important method for assessing any stressors to the Lake Mead razorback sucker population, and this technique in particular could be invaluable in investigating future human-caused, exotic species-imposed, disease-related, or other potential impacts on Lake Mead razorback sucker.

Non-lethal aging techniques also provided insight into interacting abiotic and biotic factors that allow the unique natural recruitment of razorback sucker in Lake Mead. When lake water levels were compared with known recruitment years (as defined through back-calculations of known-aged fish), it appeared that there was a strong correlation between high water levels and successful recruitment events. This led Golden and Holden (2001, 2002, 2003) to investigate the presence of cover under varying lake levels, from which they concluded that submerged vegetation was more abundant when lake levels were elevated. Therefore, it was hypothesized that during years of high water elevations, submerged terrestrial vegetation provided cover and reduced the predatory interactions of native and nonnative fishes, resulting in higher levels of recruitment coinciding with higher lake elevations (Figure 64)(Welker and Holden 2004). However, 2007 data suggest that this hypothesis may not fully explain the mechanisms resulting in recruitment pulses. Data collected in 2007 show that the years of highest recruitment, based on known-aged fish, occurred when the lake elevation was low and declining (Figure 60) (Albrecht et al. 2007). This suggests that our hypotheses did not include all of the variables influencing recruitment in Lake Mead and has led us to believe that investigation of other abiotic factors that may influence successful recruitment of razorback sucker is needed.

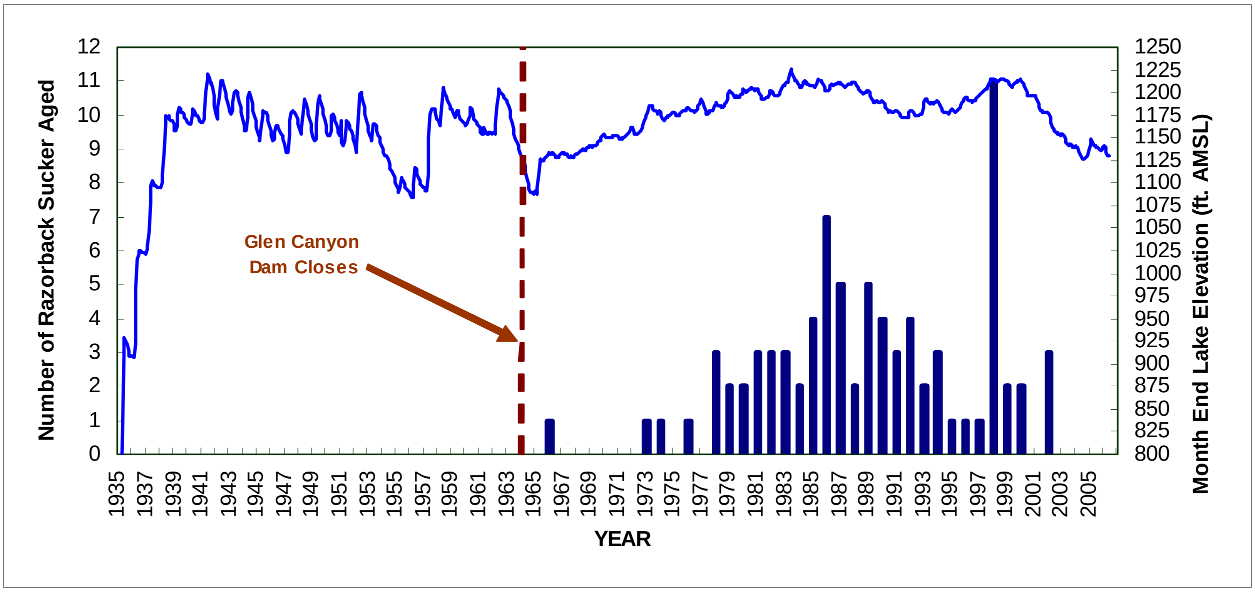

Figure 64. **Lake Mead hydrograph from January 1935–June 2006 with the number of aged razorback sucker that were spawned each year. Note that only data through 2006 are included.**

Aspects of Cover

Data from the 2006–2007 study year suggest that turbidity may play a more important role in the recruitment of razorback sucker in Lake Mead than previously thought (Albrecht et al. 2007). Golden and Holden (2001, 2002, 2003) concluded that the primary spawning areas in Lake Mead (Las Vegas Bay and Echo Bay) significantly differed from other locations in Lake Mead, as well as Lake Mohave, in regards to both cover and turbidity. However, when this observation was examined in conjunction with the known ages of fish at that particular time, the importance of vegetation was emphasized. Since then, we determined the ages and recruitment years of many more razorback sucker, which provided a more general picture of when recruitment occurred and under what lake conditions. Since some of the strongest recruitment events occurred during low and receding lake levels (Albrecht et al. 2007). We modified our working hypothesis: Vegetation, turbidity, and perhaps other unknown parameters provide suitable conditions that allow the unparalleled recruitment that has been documented in Lake Mead.

It has long been acknowledged that turbidity plays an important role in the susceptibility of young razorback sucker to predation (Johnson and Hines 1999). Turbid conditions provide a form of cover that reduces the feeding efficiency of sight-based predators, thus allowing for higher survival rates of young fishes. It is believed that such conditions are a factor that is driving recruitment in Lake Mead, particularly when the lake elevation is low and receding. As the lake level dropped, the inflow deltas (Las Vegas Wash, Muddy River/Virgin River inflows, and the Colorado River inflow) expanded, which likely resulted in a greater amount of interaction between sedimentation and hydrologic processes. The resulting turbid conditions likely provide cover for larval and juvenile razorback sucker, ultimately leading to increased recruitment.

Another potential explanation for the recruitment pulses observed in 2002 and 2003 could be related to the extensive green algae blooms observed in Las Vegas Bay during that same time frame (NPS website access date 10/15/2007, www.nps.gov/archive/lame/algaebloom.html). It is thought that the algal blooms function similar to influxes in sediment: They increase turbidity but as the result of increased levels of productivity. While the nutrient concentrations in most areas of Lake Mead were relatively low, anthropogenic waste water discharges into Las Vegas Bay via Las Vegas Wash caused an increase in the level of nutrients and primary productivity (i.e., aquatic plant and algal production) that could be visually identified by turbid conditions and, at times, algal blooms (LaBounty and Horn, 1997, Rosen et al. 2007). It is plausible that algal blooms during the 2002–2003 time period resulted in a highly turbid, food-rich environment in Las Vegas Bay, which could explain the pulses in recruitment observed during 2002 and 2003. Possible ecological mechanisms that could explain increased razorback sucker recruitment during periods of high algal growth include (1) a reduction in the proficiency of visually-oriented predatory fish species, (2) an increase in other food items for nonnative predators and a resultant decrease in the numbers of razorback sucker larvae consumed during periods of high algal growth and/or turbid conditions and, (3) a possible increase in the abundance of food for larval razorback sucker resulting in the diminished need to search widely for food items and thereby diminishing threat of predation. At any rate, the occurrence of algal blooms and a concurrent increase in razorback sucker recruitment do coincide, thus water quality parameters and their effects on razorback sucker population dynamics require further investigation.

Since aging data provided information that recruitment occurred in Lake Mead regardless of lake level, we hypothesize that cover, in the forms of vegetation and turbidity, and possibly other abiotic factors not yet recognized, are important variables that may contribute to successful recruitment of razorback sucker in Lake Mead. Additionally, we hope that when these factors are better understood, the scientific principles underlying them can be applied in other systems of the Colorado River Basin to assist with the recovery of the species throughout its historical distribution.

Population Estimates

Population estimates were initially required to ensure that inserting sonic tags into a small number of razorback sucker would not significantly impact the population. Since then, population estimates have continued in the same fashion, primarily because the data were available and the procedure to obtain an estimate was relatively simple. Albrecht et al. (2006, 2007) caution against making management decisions and actions based solely on population estimates of Lake Mead razorback sucker due to the multiple violations of many assumptions required for closed population estimation techniques. While the results provided are interesting, informative, and represent the best that could be efficiently achieved without incorporating an open, more complex model, we again caution against making conclusions based solely on the population results presented in this comprehensive report and past annual reports. The population estimates provided in these documents most likely under represent the numbers of fish in Lake Mead. Hence they should be considered minium population estimates because of the wide confidence intervals associated with these data, as well as the observations by Albrecht et al. (2007) that razorback sucker capture numbers may be greatly influenced by factors such as lake level conditions and the presence/absence of sonic-tagged fish. This disparity in capture efficiency may vary within and between years. It may also be exacerbated by the location of spawning aggregates during a given year based on spawning site morphology and the resulting effectiveness of our sampling methods.

To exemplify the speculative nature of population estimates, recently collected data suggest that the razorback sucker population in the Muddy River/Virgin River inflow area is closely associated with the Echo Bay spawning population. As described earlier, fish movement between the two areas is common, and at the very least the two populations share metapopulation dynamics. Hence, it appears that the Echo Bay population is more diverse and broader in use of spawning habitats than previously thought. At the very least, this information suggests that habitat use in the northern portions of Lake Mead is dynamic and interactive and that greater numbers of razorback sucker exist than previously estimated. This concept is supported by the increase in young razorback sucker collected in 2006 and 2007, as well as the large numbers of adult fish captured, which seem to corroborate the increased population estimates. Thus, while population estimates may or may not be representative of the real world number of razorback sucker in Lake Mead, the overall trends depicted by population estimates may represent the status of razorback sucker in Lake Mead, particularly when viewed in light of annual CPUE trends.

Conclusion

When the cumulative data from growth, age structure, and population estimates are considered, we are optimistic about razorback sucker in Lake Mead. All three parameters show a generally young, naturally reproducing, and self-sustaining population that seems to be increasing. This is a unique razorback sucker population whose dynamics remain unparalleled throughout the natural distribution of the species. Hence this situation provides an unequaled opportunity to study razorback sucker ecology to recover populations throughout the Colorado River Basin.

RECOMMENDATIONS FOR FUTURE RESEARCH

To compile this comprehensive report, we have evaluated accomplishments and, more importantly, identified research that would further our knowledge and understanding of Lake Mead razorback sucker ecology. While much has been learned since the onset of studies in 1996, there are questions that remain unanswered and/or understudied. These items, as well as other avenues of research that we feel could/should be explored in more detail, are discussed below. We fully acknowledge that this list below is not exhaustive: It is highly likely additional research and monitoring efforts will produce new questions for investigation.

Item 1. Ensure the continued existence of sonic-tagged fish in the three primary study spawning areas - Las Vegas Bay, Echo Bay, and the Muddy River/Virgin River inflow area.

This report outlined the usefulness and importance of the presence of sonic-tagged fish in regards to the successful sampling of all life stages of razorback sucker. Not only does sonic telemetry provide data regarding movement patterns, habitat use, and metapopulation dynamics, but it is also imperative in determining the locations of trammel net sets and larval sampling. Furthermore, we strongly believe that the presence of sonic-tagged fish increases adult, subadult, and larval razorback sucker capture efficiency.

When the 2006–2007 annual report (Albrecht et al. 2007) was prepared, six sonic-tagged fish were classified as "active," or still present and providing data. Of these active fish, five were implanted with 48-month tags on 30 November 2005, and one was implanted with a 48-month tag on 1 December 2004. Therefore, barring the mortality or the inability to relocate a fish, we anticipate the presence of five tags through the end of the 2008–2009 study year.

The remaining sonic-tagged fish, which is the only one outside of Las Vegas Bay, is only projected to provide data through the 2007–2008 study year. Hence no sonic-tagged fish will be present in Echo Bay and the Muddy River/Virgin River inflow area. This is a cause of concern due to the lowering lake conditions and constant shifts in spawning site selection. At the present rate of surface elevation decline, it is foreseeable that drastic shifts in spawning site selection within both Echo Bay and the Muddy River/Virgin River inflow area will occur, and without a sonic-tagged "guide," we will be unable to document spawning site shifts, which will also result in sampling difficulties. Therefore, we recommend stocking at least three sonic-tagged fish into both Echo Bay and the Muddy River/Virgin River inflow area at the beginning of the 2008–2009 study year. We also suggest making preparations to replace the sonic-tagged fish in Las Vegas Bay to ensure that sonic-tagged fish are present on a yearly basis.

Item 2. Initiate annual vegetative cover quantification efforts at the primary study locations in Lake Mead.

As discussed above, aquatic vegetative cover is thought to serve as predatory protection for early life stage razorback sucker in Lake Mead. While recruitment pulses occurred during elevated lake level conditions, quantification of such vegetative cover types was not a focus of past study years, with the exception of the efforts made by Golden and Holden (2001, 2002, and 2003). Although intuitively the most vegetative cover would be inundated during high water years, little investigation of this apparently important razorback sucker recruitment factor has been conducted. Golden and Holden (2001, 2002, and 2003) demonstrate that vegetative cover in Las

Vegas and Echo bays tends to decline with diminishing lake level conditions, but information regarding annual changes in vegetative cover remain largely unknown. Therefore, it is impossible at this time to correlate the percent vegetative cover with years of strong razorback sucker recruitment. Although we can say that vegetative cover appears to be linked to lake levels, and we know that recruitment tends to occur at the highest lake levels, we cannot now identify whether a certain degree of vegetative cover results in razorback sucker recruitment. By initiating an annual quantification of vegetative cover abundance and type, we may clarify the types and amounts of vegetative cover necessary for recruitment despite nonnative fish presence. Once this relationship is clarified, the information could be used for other restoration and habitat construction activities and in other locations designated for the establishment, maintenance, and sustainability of the species. Hence annual quantification of vegetative cover components in the successful recruitment areas of Lake Mead would help us understand why razorback sucker are able to sustain themselves in Lake Mead despite nonnative fish predation. The results of this investigation could be applied to other locations throughout the Colorado River Basin.

Item 3. Weekly water quality and turbidity monitoring at each of the primary study locations in Lake Mead.

Another physical data collection effort is likely warranted to understand how the physical environment of the primary study areas in Lake Mead facilitates recruitment of razorback sucker. We propose monitoring standard water quality parameters, including turbidity, at each of the primary sampling locations (Echo Bay, Las Vegas Bay, and the Muddy River/Virgin River inflow area) to begin to understand why and how recruitment occurs. Water quality sampling could easily be incorporated with existing monitoring protocols, as depicted in Albrecht et al. (2006a), and would provide another data set to help us understand how physical changes in the lake impact and affect razorback sucker recruitment. Furthermore, this information could be combined with vegetative cover data to understand the dynamics of and potential interactions between vegetative cover and cover in the form of turbidity. Likewise, comparisons of relationships between standard water quality parameters and recruitment could possibly become identified. Similarly, impacts of anthropogentic-related, management-driven, and biologically imposed changes, as related to razorback sucker recruitment may become evident though several of the standard water quality measures. With this information we may be able to proactively assess the potential for a given year or set of management actions to either positively or negatively impact razorback sucker recruitment on Lake Mead. Similar to the vegetative cover monitoring recommendation outlined above, standard parameter water quality monitoring at the spawning locations within Lake Mead may help us understand cut-off values for recruitment, which in turn may be useful to create suitable habitat for razorback sucker recruitment in other systems. The U.S. Geological Survey and other agencies have monitored and continue to monitor water quality at several locations within Lake Mead, and these data would be of aide in understanding the relationship between age-based recruitment data collected during the past decade and changes in historical Lake Mead water quality parameters. The continued collection of water quality data by other groups could be combined with future spawning site-specific water quality data to establish trends, place those trends in context with past collections, and establish potential links between future spawning site water quality data and data collected by other groups from different locations within Lake Mead. The ultimate goal of this research would be to establish and solidify an understanding of how physical components influence the ecology of Lake Mead razorback sucker to gain insight regarding what factors must be present, and in what quantities, to maintain healthy levels of recruitment in Lake Mead. Once these relationships are understood, it may be possible to simulate the necessary physical conditions for recruitment in other systems based on lessons learned from Lake Mead.

Item 4. Investigate the impacts of fluctuating lake levels on littoral zone nonnative fish populations in Lake Mead.

In addition to the physical parameters identified above, we recommend initiating a monitoring regime directed at sampling nonnative littoral zone fishes [e.g., green sunfish (*Lepomis cyanellus*), young bluegill (*Lepomis macrochirus*)] in Lake Mead. Based on our experience, littoral zone fishes are often not captured representatively during typical fisheries surveys and these fishes may be a very important, if not the most important, suite of potential predators and/or competitors for young razorback sucker. We feel that, similar to the physical components outlined above, littoral zone nonnative fish populations within Lake Mead should be closely monitored. Ideally, monitoring should occur weekly during the spawning season and be conducted in association with Lake Mead razorback sucker monitoring efforts. However, realistically we feel that any monitoring plan for littoral zone fishes using a repeatable approach would be money well spent in terms of evaluating why Lake Mead razorback sucker are able to demonstrate continued recruitment. One of the questions that often arises during our discussions of Lake Mead razorback sucker and evidence of continued, recent recruitment, is the status of nonnative fish predator density/abundance compared with other locations where razorback sucker are apparently not able to recruit. While NDOW tracks trends of nonnative fish species in a variety of locations, including Lake Mead, the focus of this sampling is primarily on striped bass (*Morone saxatilis*) and threadfin shad (*Dorosoma petenense*) populations, which typically excludes trends in littoral and non-game fish populations (to our knowledge). Thus we feel that, in order to fully understand how and why recruitment events continue to occur on Lake Mead, littoral zone fishes must be monitored. It is possible that populations of littoral zone fishes differ within Lake Mead, which may favor razorback sucker recruitment. It is even more likely that changes in littoral zone fish populations may be pronounced at higher versus lower lake elevations, which in turn may facilitate continued recruitment. At any rate, we feel that the relationship between predators, lake elevations, and some of the physical components of Lake Mead need to be evaluated together in order to begin understanding the mechanism(s) for razorback sucker recruitment and maintenance of relatively young populations of razorback sucker in Lake Mead.

In summary, investigating and tracking littoral zone fishes in Lake Mead would help us understand more about the ecology of Lake Mead as a whole. It is possible that the driving factor of razorback sucker recruitment is more biologically than physically related. In other words, predation of young razorback sucker in Lake Mead may be the direct result of a different composition, abundance, or density of nonnative fish predators, particularly during certain years, rather than a relation of recruitment to vast differences in limnological- and physical habitat-related measures. If such a scenario is indeed true, we would be unlikely to understand the cause of razorback sucker recruitment trends without monitoring nonnative fish species in combination with physical parameters. Inclusion of littoral zone nonnative fish monitoring would bridge the gap between NDOW's sampling of more pelagic species and past, present, and future water quality and physical data collection efforts combined with continued collections of razorback sucker recruitment data in Lake Mead. Combining these data collection efforts should allow us to investigate cause and effect relationships and provide the basis for understanding the unique recruitment of razorback sucker that has been documented in Lake Mead. We acknowledge that no "silver bullet" data can be quickly examined in order to understand the anomalous recruitment observed on Lake Mead at this time. Rather, we recommend that multiple aspects of the physical and biological environment be explored, perhaps in greater detail than we have attempted to date. Lastly, we stress that Lake Mead provides a real-world example that razorback sucker recruitment in a natural setting (with nonnative fish predators and competitors) can and does occur and, therefore, Lake Mead could, and in our opinion should, be a key location in which to focus efforts and resources with the ultimate goal understanding how and why razorback sucker persist despite abundant nonnative fishes. Ultimately, the knowledge gained could result in less dependance upon hatcheries, nonnative fish removal efforts, and other high-cost management activities for long-term recovery of the species.

Item 5. Renew efforts directed at investigating the Colorado River inflow area as potential habitat for an additional spawning population of razorback sucker in Lake Mead.

Our working hypothesis has been that since areas of high vegetative cover and turbidity are important for razorback sucker recruitment, it is likely that a spawning population is located in this type of habitat. This prerequisite nutrient-rich, vegetated, and highly turbid location occurs at the Colorado River inflow area. We have suggested during several conferences and in symposia papers that razorback sucker were once wide-spread and common throughout Lake Mead, but that the only locations that allow for continued razorback sucker presence are those few areas with abundant vegetation and turbidity. Although sampled during past Lake Mead efforts, we continue to think that the Colorado River inflow area could likely harbor a spawning population of razorback sucker. As mentioned previously in this report, larval razorback sucker were found in the Colorado River inflow, but despite netting efforts no adult razorback sucker were captured. Sonic-tagged fish were also released into the Colorado River inflow area, but all of these fish were lost within a very short time frame. However, as discussed elsewhere in this report, our recent sonic telemetry efforts have benefitted from better, more dependable, and greatly improved tag technology. In fact, since Sonotronics redesigned their products, we have had a vast increase in the number and duration of sonic-tagged fish contacts, which have resulted in an increase in success and movement and habitat use data from fish implanted with updated tags. In light of these improvements, we believe that renewed efforts in the Colorado River inflow would allow us to better assess potential spawning habitat here and could result in the confirmation of a spawning aggregate in that area of Lake Mead. Such information could be exceptionally important in the future, particularly if repatriation efforts or future stocking events occur. In addition to the potential to provide greater understanding of habitat use and movement patterns in Lake Mead, if another population of spawning fish exists, sampling that location could provide additional information regarding recruitment patterns of Lake Mead razorback sucker and the conditions that are conducive to them. The worst case scenario for sonic-tagging and releasing additional fish into the Colorado River inflow would be that the stocked, sonic-tagged fish simply leave the area, thereby providing an indication that the Colorado River inflow is not used as a spawning location. Since this information would be highly useful in and of itself, it is our opinion that investing resources for stocking sonic-tagged fish in the Colorado River inflow area is a worthwhile effort that we highly recommend. Furthermore, we recommend that the sonic-tagging effort be conducted in conjunction with trammel netting and larval sampling, thereby capitalizing on the same suite of methodologies that allowed us to identify the Muddy River/Virgin River inflow area spawning aggregate. These efforts could be combined with the experimental establishment of a new spawning aggregate in the Colorado River inflow area using Driftwood Cove as an opportunity to imprint razorback sucker to this area of Lake Mead. As described in detail by Albrecht et al. (2006a), Driftwood Cove provides an opportunity to “jumpstart” a spawning aggregate in the Colorado River inflow area, particularly if it is found that a current and existing population of razorback sucker in this area of Lake Mead currently does not exist.

In summary, we recommend releasing captive, pond-reared, sonic-tagged razorback sucker into the Colorado River inflow, following a protocol similar to Albrecht et al. 2006. Although we were unsuccessful in the Colorado River inflow area in the past, we feel that with the new tag technology the Colorado River inflow will either be identified as an important spawning location or the sonic-tagged fish will leave the area and incorporate themselves into other spawning populations of razorback sucker in Lake Mead, thereby providing evidence that razorback sucker do not use this area of the lake. This will, in turn, resolve whether the area is an important location for Lake Mead razorback sucker. While the risks are negligible, the potential benefits are substantial, particularly in terms of validating our overall working hypothesis and providing additional information regarding how and why Lake Mead razorback sucker are able to recruit. Likewise, information on habitat use and movement patterns of Lake Mead razorback sucker will become better understood, and the effort could provide potential information for researchers studying the native fishes of the Grand Canyon. This could help establish a link (if any) between the role of Lake Mead and the role of the Colorado River proper in the maintenance and sustainability of Lake Mead razorback sucker populations.

Item 6. Investigate various models that will better estimate the current lake-wide razorback sucker population in Lake Mead.

Our current population estimates are constrained by the nature of “closed” population models, resulting in wide confidence intervals and limiting our ability to apply the model on a lake-wide basis. Due to our current implementation of sampling methodologies and the restrictions of closed population models we violate model assumptions, which greatly reduces the validity of the population estimates. Hence, we are only able to calculate population estimates assuming that distinct populations of razorback sucker exist in Lake Mead (Las Vegas Bay, Echo Bay, and the Muddy River/Virgin River inflow area) and they do not interact. However, as explained in this report, the movement of fishes between these spawning areas has been observed, and metapopulation dynamics among the three primary spawning locations most likely occurs. The models we currently employ do not take these factors into account.

In summary, we recommend pursuing alternative models that will take into account the dynamic nature of razorback sucker movements and allow for a lake-wide population estimate. We believe that this will result in more accurate population estimates and trends, which will be useful in determining and implementing management objectives and actions. However, future sampling will need to meet the assumptions of whichever model is chosen; thus this process may be more complicated than simply inserting current data into a new model. A few examples of changes in sampling protocol that may be required include increased net sets on a wider distribution and the ability to determine recruitment and mortality rates. Ultimately, we believe that the more accurate estimates will be crucial in monitoring numbers and trends through time, particularly in regards to new threats that razorback sucker are facing such as quagga mussels (*Dreissena bugensis*), newly documented gizzard shad (*Dorosoma cepedianum*), ever-decreasing lake levels, and additional potentially harmful anthropogenic activities.

Item 7. Investigate the possibility of incorporating otolith michrochemistry analysis to assist in reconstructing life history characteristics such as stock identification and the determination of elemental trajectories (habitats utilized during specific age ranges).

Fish otoliths were identified as providing metabolically inert environmental data regarding the conditions to which fish have been exposed throughout their lives (Campana 1999). Through the microanalysis of compounds absorbed by the otolith, features — such as stock identification, determination of migration pathways, and detailed chronological records of the fish's environment can — be determined. Such analyses can be performed throughout the life of the fish, or specific ranges of ages or dates can be targeted. Ultimately, otolith analysis has the potential to determine life history specifics that are not currently possible using other approaches (Campana 1999).

One specific otolith use that would benefit Lake Mead razorback sucker research is defining portions of the lake or particular habitats that are used by juvenile razorback sucker. A gap currently exists in our data collection between larval and age-4 razorback sucker. As this document outlines, a great amount of effort has been expended to capture juvenile razorback sucker but to no avail. Currently, only two razorback sucker have been sampled that were less than 400 mm (the smallest being 316 mm). Virtually nothing is known about the specific habitats that are needed/used by wild razorback sucker that successfully recruit in an open system. Past (and possibly future) efforts have been made to identify abiotic factors that were present during years in which strong recruitment events occurred. However, this only allowed for the correlation of habitat conditions that were present at the time of successful recruitment events, and we could only speculate about the causative agents of recruitment. The combination of otolith microchemistry analysis and the identification of abiotic factors associated with years of successful recruitment has the potential to definitively identify the required habitats and conditions that allow successful razorback sucker recruitment in Lake Mead.

Though fish otoliths have the potential to reveal much needed specifics regarding razorback sucker life history requirements, two major drawbacks exist to their use. First, fish must be killed in order to retrieve otoliths. Razorback sucker in Lake Mead are not only endangered, but they are highly unique in their ability to display natural recruitment - a trait not readily observed any where else in their natural distribution. Thus, how would the population respond to the removal of even a few individuals? Second, in order to determine much of the life history traits, specific elements must be present in the environment to distinguish between various locations in a system (Sr - strontium, Ba - barium, Mn - manganese, Fe - iron, and Pb - lead). The number of samples (individual fish otoliths) needed for proper analysis is directly dependent on the number and concentration of these elements in the natural environment.

Ultimately, we recommend that if Lake Mead razorback sucker mortalities occur, the possibility of fish otolith analysis be considered. Should we find deceased fish through efforts on Lake Mead or experience a mortality during handling, these otoliths could be used to determine specific life history data regarding habitat usage and needs. The first step would be to determine whether elemental signatures exist in Lake Mead that would allow for the identification of "defined" portions of the lake, which would provide the means to determine detailed locales of fish during specific age ranges. If such signatures exist, we could consider the feasibility of future otolith microchemistry analysis.

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, Utah. 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, Utah. PR-960-1.

Albrecht, B., P. B. Holden, and M. Golden. 2006a. 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, Utah. PR-977-1.

Albrecht, B., P. B. Holden, and M. Golden. 2006b. Lake Mead razorback sucker monitoring recommendations. 2005–2006 Report. Prepared for the Department of Resources, Southern Nevada Water Authority, by BIO-WEST, Inc., Logan, Utah. 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. Department of the Interior, Bureau of Reclamation, by BIO-WEST, Inc., Logan, Utah. PR-1093-1.

Beamish, R. J. 1973. Determination of age and growth of populations of the white sucker (*Catostomus commersoni*) exhibiting a wide range in size at maturity. Journal of the Fisheries Research Board of Canada 30: 607–616.

Beamish, R. J., and H. H. Harvey. 1969. Age determination in the white sucker. Journal of the Fisheries Research Board of Canada 26:633–638.

Brooks, J. E., M. J. Buntjer, and J. R. Smith. 2000. Non-native species interactions: management implications to aid in recovery of the Colorado pikeminnow *Ptychocheilus lucius* and razorback sucker *Xyrauchen texanus* in the San Juan River, CO-NM-UT. San Juan River Basin Recovery Implementation Program, U.S. Fish and Wildlife Service, Albuquerque, New Mexico.

Burdick, B. D. 2002. Evaluating the use of sloped gravel-pit ponds by listed and non-listed native fishes and removal of non-native fishes from sloped gravel-pit ponds in the upper Colorado River near Grand Junction, Colorado. Recovery Program Report Project C-6-G, Colorado River Fishery Project, U.S. Fish and Wildlife Service, Grand Junction.

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).

Campana, S. E. 1999. Chemistry and composition of fish otoliths: pathways, mechanisms and applications. Marine Ecology Progress Series. 188:263–297.

Chao, A. 1987. Estimating the population size for capture-recapture data with unequal catchability. Biometrics 43:783-791.

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

Davis, J. E. 2003. Non-native species monitoring and control, San Juan River 1999–2001. Progress report for the San Juan River Recovery Implementation Program. U.S. Fish and Wildlife Service, Albuquerque, New Mexico.

Devries, D. R., and R. V. Frie. 1996. Determination of Age and Growth. Pages 483–512 *in* B. R. Murphy and D. W. Willis, editors. Fisheries techniques, 2nd edition. American Fisheries Society, Bethesda, Maryland.

Golden, M. E., and P. B. Holden. 2001. Comparison of water quality, zooplankton density, and cover in razorback sucker (*Xyrauchen texanus* [Abbott]) spawning areas of Lake Mead and Lake Mohave. Prepared for the Department of Resources, Southern Nevada Water Authority, by BIO-WEST, Inc., Logan, Utah. PR-749-1.

Golden, M. E., and P. B. Holden. 2002. Comparison of water quality, zooplankton density, and cover in razorback sucker (*Xyrauchen texanus* [Abbott]) spawning areas of Lake Mead and Lake Mohave: 2001 Annual Report. Prepared for the Department of Resources, Southern Nevada Water Authority, by BIO-WEST, Inc., Logan, Utah. PR-784-1.

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, Utah. PR-784-2.

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, Utah. 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, Utah. 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, Utah. 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, Utah. 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, Utah. 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, Utah. PR-578-5.

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.

Jackson, J. A., and P. V. Badame. 2002. Centrarchid and channel catfish control in the middle and lower Green River; 1997 and 1998. Upper Colorado River Endangered Fish Recovery Program Project 59, Utah Division of Wildlife Resources, Moab.

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, Colorado. 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.

LaBounty, J. F., and M. J. Horn. 1997. The influence of drainage from the Las Vegas Valley on the limnology of Boulder Basin, Lake Mead, Arizona-Nevada. Lake and Reservoir Management 13(2):95-108.

Lentsch, D. L., T. L. Muth, P. D. Thompson, B. G. Hoskins, and T. A. Crowl. 1996. Options for selective control of nonnative fishes in the upper Colorado River basin. Utah Division of Wildlife Resources Colorado River Fishery Project, Salt Lake City. Final Report. Project Number 93-FG(18)-8.

Marsh, P. C. 2007. Update regarding the March 2007 Lake Mohave round-up to the Native Fish Workgroup via email on 4/20/2007. Native Fish Lab, Arizona State University, Tempe.

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.

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.

McAda, C. W. 1997. Mechanical removal of northern pike from the Gunnison River, 1995–1996. Colorado River Recovery Implementation Program, Project 58. U.S. Fish and Wildlife Service, Grand Junction, Colorado.

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, Nevada. Final Report. Contract Number 8-07-30-X0025. 197 p.

McCarthy, M. S., and W. L. Minckley. 1987. Age estimation for razorback sucker (Pisces: Catostomidae) from Lake Mohave, Arizona and Nevada. Journal of the Arizona-Nevada Academy of Sciences 21: 87–97.

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

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. Pages 303–357 *in* W. L. Minckley and J. E. Deacon, editors. Battle against extinction: native fish management in the American West. Tucson: University of Arizona Press.

Minckley, W. L., P. C. Marsh, J. E. Deacon, T. E. Dowling, P. W. Hedrick, W. J. Matthews, and G. Mueller. 2003. A conservation plan for native fishes of the lower Colorado River. BioScience 53:219–234.

Modde, T. 1997. Fish use of Old Charley Wash: an assessment of floodplain wetland importance to razorback sucker management and recovery. Recovery Program Project CAP-6. U.S. Fish and Wildlife Service, Vernal, Utah.

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.

Mueller, G. A. 1995. A program for maintaining the razorback sucker in Lake Mohave. American Fisheries Symposium 15:127–135.

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.

Mueller, G. A., and P. Marsh. 1998. Post-Stocking dispersal, Habitat Use, and Behavioral Acclimation of Juvenile Razorback Suckers (*Xyrauchen texanus*) in two Colorado River Reservoirs. Open-File Report 98-301. Denver, Colorado: U.S. Geological Survey. 24 p.

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 60:180–187.

Osmundson, D. B. 2003. Removal of non-native centrarchids from Upper Colorado Backwaters, 1999–2001: Summary of results. Recovery Implementation Program Project 89. Colorado River Fishery Project, U.S. Fish and Wildlife Service, Grand Junction, Colorado.

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, Arizona. November 14, 1998.

Pacey, C. A., and P. C. Marsh. 1998. Resource use by native and non-native fishes of the lower Colorado River: literature review, summary and assessment of roles of biotic and abiotic factors in management of an imperiled indigenous ichthyofauna. Final Report to the U.S. Bureau of Reclamation, Boulder City, Nevada.

Quinn, S. P., and M. R. Ross. 1982. Annulus formation by white suckers and the reliability of pectoral fin rays for aging them. North American Journal of Fisheries Management 2: 204–208.

Quist, M. C., Z. J. Jackson, M. R. Bower, and W. A. Hubert. 2007. Precision of hard structures used to estimate age of riverine catostomids and cyprinids in the upper Colorado River Basin. North American Journal of Fisheries Management 27:643–649.

Ramsey, F. L., and D. W. Schafer. 2002. The statistical sleuth. Second edition. Duxbury Press, Pacific Grove, California.

[Reclamation] U.S. Bureau of Reclamation. 2007. Historical Lake Mead Reservoir levels. Location: http://www.lc.usbr.gov/. Numerous links utilized.

[Reclamation] U. S. Bureau of Reclamation. 2007. Historical Lake Mead Reservoir levels. Location: http://www.usbr.gov/lc/riverops.html. Numerous links utilized.

Rosen, M. R., S. L. Goodbred, R. Patiño, T. J. Leiker, and E. Orsak. 2007. Investigations of the effects of synthetic chemicals on the endocrine system of common carp in Lake Mead, Nevada and Arizona. U.S. Geological Survey Fact Sheet 2006-3131.

Schooley, J. D., and P. C. Marsh. 2007. Stocking of endangered razorback suckers in the lower Colorado River basin over three decades: 1974–2004. North American Journal of Fisheries Management 27:43–51.

Seber, G. A. F. 1982. The estimation of animal abundance. New York: Macmillan Publishing Co. 654 p.

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.

Trammel, M., R. Valdez, H. Johnstone, and L. Jonas. 2002. Non-native fish control in backwater habitats in the Colorado River. Final Report, Recovery Implementation Program Project 87b. SWCA, Inc. Environmental Consultants, Flagstaff, Arizona.

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

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 J. F. Saunders. 1996. Nonnative fishes in the upper Colorado River basin and a strategic plan for their control. Upper Colorado River Endangered Fish Recovery Program, Denver. Final Report.

[USFWS] U.S. Fish and Wildlife Service. 1988–2003. Fiscal year work plan. Recovery implementation Program for endangered fish species in the Upper Colorado River Basin. USFWS Region 6, Denver.

[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, Arizona.

[USFWS] U.S. Fish and Wildlife Service. 2002. Razorback sucker (*Xyrauchen texanus)* recovery goals: amendment and supplement to the razorback sucker recovery plan. U.S. Fish and Wildlife Service, Denver.

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. Salt Lake City: United States Department of Interior - Bureau of Reclamation. BIO-WEST Report No. 136-2. Contract No. 6-CS-40-04490. 184 p.

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 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. Salt Lake City: Bureau of Reclamation, Upper Colorado River Region.

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, Utah. 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, Utah. PR-578-8.

Wick, E. J., C. W. McAda, and R. V. Bulkley. 1982. Life history and prospects for recovery of the razorback sucker. Pages 120–126 *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, Maryland.

Winter, J. D. 1996. Advances in underwater biotelemetry. Pages 550–590 *in* B. R. Murphy and D. W. Willis, editors. Fisheries Techniques. American Fisheries Society, Bethesda, Maryland.