

## Striped Bass Dispersion and Effects on Fisheries Management in Lakes Mohave and Pleasant, Colorado River Basin

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*Abstract.*—The striped bass *Morone saxatilis* was introduced into the lower Colorado River in the late 1950s and into Lake Mead, Nevada and Arizona, in the late 1960s. The unintended immigration of striped bass into Lake Mohave, Nevada and Arizona, on the main stem, and Lake Pleasant, a tributary reservoir in central Arizona, has resulted in changing management practices. Striped bass entered Lake Mohave via downstream emigration from Lake Mead through Hoover Dam at various life stages, and the newly established population quickly became the primary sport fish in the reservoir. Predation from the striped bass population in Lake Mohave coincided with elimination of threadfin shad *Dorosoma petenense* and a rapid decline in the survival of stocked rainbow trout *Oncorhynchus mykiss*. Striped bass are also believed to be hindering ongoing efforts to reestablish the native endangered species razorback sucker *Xyrauchen texanus* and bonytail chub *Gila elegans*. Striped bass gained access to Lake Pleasant via Lake Havasu, California and Arizona, by way of the Central Arizona Project (CAP) Canal. Operation of the CAP Canal began in 1985 and the canal was fully connected to Lake Pleasant in 1992. In 1986 and 1989, striped bass population densities in the CAP Canal were estimated at  $70 \pm 37$  fish/ha and  $3 \pm 1$  fish/ha, respectively. Striped bass were first captured in Lake Pleasant in 1998 during a gill-netting survey. Catch per unit effort increased almost yearly from 0.13 fish/net-night in 1998 to 6.74 fish/net-night in 2005. Since their unintended introduction into both reservoirs, striped bass have established viable reproducing populations. Management efforts have emphasized promoting harvest and minimizing the impacts of striped bass on existing fisheries. These experiences provide guidance for evaluating unintended dispersion of striped bass elsewhere.

### Introduction

The discovery of landlocked populations of striped bass *Morone saxatilis* in impounded waters in the Santee and Cooper rivers in the

1950s significantly changed the way reservoirs are managed (Van Horn 2013, this volume). Due to success in the eastern United States, striped bass were introduced into the Colorado River in the late 1950s (Gustaveson and Blommer 2013, this volume). From 1959 to 1972,

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an estimated 93,000 striped bass were planted into the lower Colorado River (Grabowski et al. 1984). Stocking locations included two of the three major reservoirs along the lower Colorado River: Lake Mead and Lake Havasu. At the time, natural reproduction was considered unlikely because literature stated that striped bass eggs and larvae must be suspended by current to prevent settling and death by suffocation (Gustaveson and Blommer 2013). However, self-sustaining populations soon became established creating one of the most popular sport fisheries in the southwest. Lake Mohave, located between Mead and Havasu, was never intentionally stocked with striped bass. Nonetheless, striped bass were soon found in Lake Mohave, having likely passed through Hoover Dam (Lake Mead). Striped bass then found their way to Lake Pleasant, likely through a water storage pumping project on Lake Havasu serving Phoenix and southern Arizona.

Inadvertent dispersion of striped bass through dam and pumping plant intake structures is not uncommon. For example, the A.D. Edmonstom Pumping Plant carries water from Northern California along the western side of the San Joaquin Valley over the Tehachapi Mountains to Southern California. A 2-year study on the movement and survival of fish passing through the California State Water Project's A.D. Edmonstom Pumping Plant in 1972 and 1973 documented several species of fish including striped bass surviving the 587-m lift and 13.5-km-long journey. An estimated 20,500 striped bass ranging from 250 to 410 mm total length (TL) were pumped into Southern California during the 2-year study (Aasen et al. 1982). Additionally, striped bass have immigrated into Gene Wash, Copper Basin, Lake Mathews, Lake Skinner, San Vicente, and El Capitan reservoirs (all in California) through the Colorado River Aqueduct, a diversion canal that provides water from Lake Havasu to Southern California (M. Giusti, California Fish and Game Department, personal communication). This paper addresses the magnitude, impacts, and implications of the inadvertent dispersion

of striped bass on two popular sport fisheries in the southwestern United States: Lake Mohave and Lake Pleasant. It concludes with points to be considered for evaluating the likelihood of striped bass emigration from the intended water body and dispersion to unintended locations where fisheries management may be affected.

## Lake Mohave

### **Striped bass source reservoir (Lake Mead)**

Lake Mead was created in 1935 by the construction of Hoover Dam. Hoover Dam was built by the U.S. Bureau of Reclamation (USBR) in the Black Canyon of the Colorado River near Las Vegas, Nevada (Figure 1). At full pool, Lake Mead is 63,900 ha with a maximum depth of 177 m and maximum length of approximately 184 km. The Colorado River is the primary water source for Lake Mead; additionally there are two secondary inflows: the Virgin-Muddy River system and the Las Vegas Wash. The water resources of Lakes Mead and Mohave are managed by the USBR. Lake Mead and Lake Mohave are part of the Lake Mead National Recreation Area administered by the National Park Service (NPS). The Nevada Department of Wildlife (NDOW), the Arizona Game and Fish Department (AGFD), the NPS, the U.S. Fish and Wildlife Service (USFWS), and the USBR are all involved in managing the aquatic wildlife resources of Lakes Mead and Mohave.

The fish assemblage in Lake Mead is comprised mostly of nonnative fish, including largemouth bass *Micropterus salmoides*, smallmouth bass *M. dolomieu*, striped bass, channel catfish *Ictalurus punctatus*, yellow bullhead *I. natalis*, black bullhead *I. melas*, bluegill *Lepomis macrochirus*, green sunfish *L. cyanellus*, black crappie *Pomoxis nigromaculatus*, gizzard shad *Dorosoma cepedianum*, threadfin shad *D. petenense*, red shiner *Cyprinella lutrensis*, blue tilapia *Oreochromis aureus*, and common carp *Cyprinus carpio* (Allen and Roden 1978; Nevada Department of Wildlife, unpublished report, 2008).

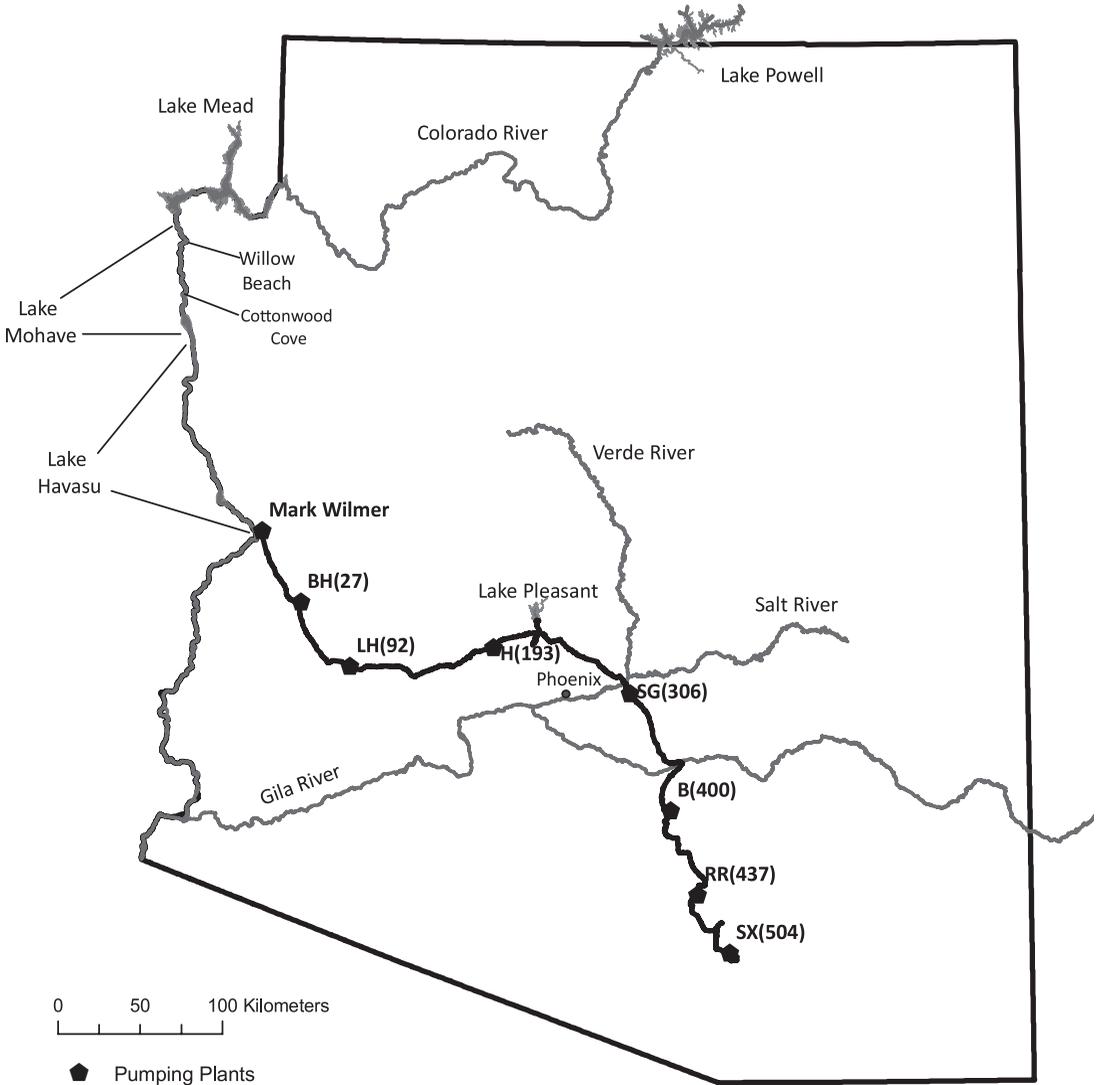


FIGURE 1. Map of lower Colorado River reservoirs, Lake Pleasant, and location of Bouse Hills (BH), Little Harquahala (LH), Hassayampa (H), Salt-Gila (SG), Brady (B), Red Rock (RR), and San Xavier (SX) pumping plants along the Central Arizona Project Canal. Numbers in parentheses represent distance from Lake Havasu in kilometers.

A remnant population of the native razorback sucker *Xyrauchen texanus* can also be found in Lake Mead (Allen and Roden 1978).

Given the success of striped bass in the eastern United States and the belief that they would not reproduce, stocking striped bass in Lake Mead seemed appropriate. Between 1969 and 1972, approximately 64,000 striped bass, ranging from 50 to 150 mm TL, were stocked

into Lake Mead (Allen and Roden 1978). Successful reproduction of striped bass in Lake Mead was first documented in 1973 (Allen and Roden 1978), and by 1976, striped bass comprised 1.4% of the angler catch. Seven years later, in 1983, striped bass harvest increased to 50% of the total angler catch (Allen and Roden 1978; Nevada Department of Wildlife, unpublished report, 1983).

### **Striped bass receiving reservoir (Lake Mohave)**

Located southeast of Las Vegas, Nevada, Lake Mohave was created in 1951 by the USBR. The reservoir was impounded by Davis Dam approximately 103 river km south of Hoover Dam on the Colorado River (Figure 1). At full pool, the north end of Lake Mohave backs into the tailrace of Hoover Dam. Located in the Mohave Desert, the lake forms the common boundary between Clark County, Nevada and Mojave County, Arizona. The 11,396-ha reservoir is 103 km long, with a maximum width of 6.4 km and 322 km of irregular shoreline. The maximum depth is 42 m, with a mean depth of 19 m. The only significant inflow into Lake Mohave is the cold, clear Colorado River passing through Hoover Dam. The upper 23 km of the reservoir is confined within the narrow walls of the Black Canyon. The remainder of the reservoir is comprised of two open basins interspersed with the flooded canyons of the Colorado River channel. Water elevations generally fluctuate between 193 and 196 m above sea level. Lake Mohave water levels are generally on the rise through the winter and peak in the late spring to early summer. Elevations remain high through the summer and are declining by late summer to early fall. Through the winter months, Lake Mohave is isothermal, with water temperatures ranging between 11°C and 13°C. As summer approaches, the temperature regime becomes more complex. The Hoover Dam discharge is taken from the hypolimnion of Lake Mead, which is 11–13°C. Because of this cold inflow, the upper 24–32 km of the reservoir remains cold, 11–13°C, all year. The remainder of the reservoir becomes seasonally stratified with surface temperatures above 26°C (Jones and Sumner 1954).

Prior to the passage of striped bass into Lake Mohave, the reservoir provided both a warm- and coldwater sport fishery. The coldwater fishery was supported by stocked salmonids, primarily rainbow trout *Oncorhynchus mykiss*. The warmwater fishery was supported

by largemouth bass and channel catfish. There was and remains an abundant population of bluegill and green sunfish, and threadfin shad were an abundant forage fish. Common carp were present and abundant both before and after the establishment of striped bass (Allen and Roden 1978; Nevada Department of Wildlife, unpublished report, 1979–1981). Two native cyprinids, the bonytail chub and the razorback sucker, are found in Lake Mohave (Minckley 1973) and are federally endangered species.

Lake Mohave is a popular sport fishery. In 1980, the estimated lake-wide total angler use was 340,000 angler-days. Those anglers were estimated to have caught 380,000 rainbow trout, 130,000 largemouth bass, and 24,000 channel catfish. A creel census in 1980 showed that at Willow Beach, 98% of the anglers were fishing for trout while at Cottonwood Cove, 45% of the anglers were fishing for trout, 47% for largemouth bass, and 4% for channel catfish (Figure 1; Nevada Department of Wildlife, unpublished report, 1980).

Striped bass were never intentionally introduced into Lake Mohave but were first documented there in 1981 (Liles 1991). They likely entered Lake Mohave through Hoover Dam as eggs or larvae. Larger life stages may have passed through the dam, and a few may have survived the pressure change and turbines. Additional introductions probably occurred in 1983–1984, when Lake Mead filled to capacity and flowed over the Hoover Dam spillways. Striped bass eggs were first documented in the reservoir through ichthyoplankton sampling by AGFD in 1986 (Liles 1991). Additional ichthyoplankton sampling by NDOW through the late 1980s found striped bass eggs and larvae from April through September. Spatially, striped bass eggs and larvae were found throughout the entire seasonally warm part of the reservoir (Nevada Department of Wildlife, unpublished reports, 1984–1992). While some of the eggs and larvae may have passed through Hoover Dam, the numbers collected, the widely dispersed samples (64 km of reservoir), and the

rapid increase in the striped bass population indicated that they were spawned in Lake Mohave.

As the striped bass population grew, so did its popularity with anglers. By 1990, striped bass had become the largest sport fishery on Lake Mohave when the harvest estimate exceeded 100,000 fish. The harvest estimate peaked in 1994 at more than 400,000 fish (Nevada Department of Wildlife, unpublished reports, 1990–2008). Population growth as measured by annual gill-net sampling accelerated in 1989 and continued upward to peak in 1994. After the 1994 peak, the population began to decline until 2006 when it leveled off at a density similar to the late 1980s (Figure 2). The cessation of a strong year-class entering the population every few years was not anticipated. This change in the population dynamic coincided with the invasion of quagga mussels *Dreissena bugensis* into Lake Mohave (Moore et al. 2009). The direct effect that mussels are having on the striped bass population is unknown at this time.

Until recently, Lake Mohave exhibited excellent recruitment of striped bass. The proportional stock densities (PSD) show that the population was dominated by small fish, at least through 2007 (Figure 3). Following the sharp decline in gill-net catches (Figure 2), a major increase in PSD appeared in 2008 when it more than doubled from 2007. A further increase was noted in 2009 when PSD exceeded 40 for the first time since striped bass arrived in the lake. The reasons for the population decline and subsequent PSD changes are not yet known.

Lake Mohave lacks an abundant, easily available, small to mid-size forage fish (Nevada Department of Wildlife, unpublished reports, 1990–2009). The forage deficit likely inhibits the recruitment of fish into larger size-classes. While the number of fish that recruit past 650 mm TL is small, the fish that do recruit have the potential to grow to exceptional size by foraging on stocked trout, carp, and stocked native fish (the razorback sucker and bonytail chub, both listed as endangered are stocked for

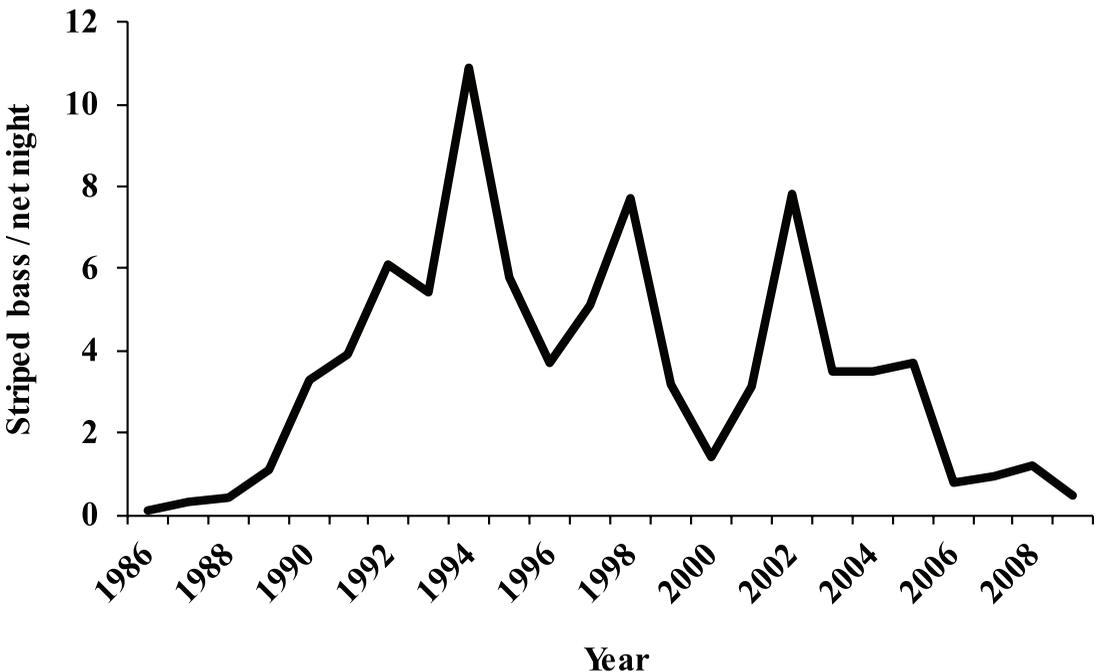


FIGURE 2. Catch per unit effort (CPUE; fish per net-night) of striped bass in gill-net surveys of Lake Mohave, 1986–2009 (Nevada Department of Wildlife, unpublished reports, 1986–2009).

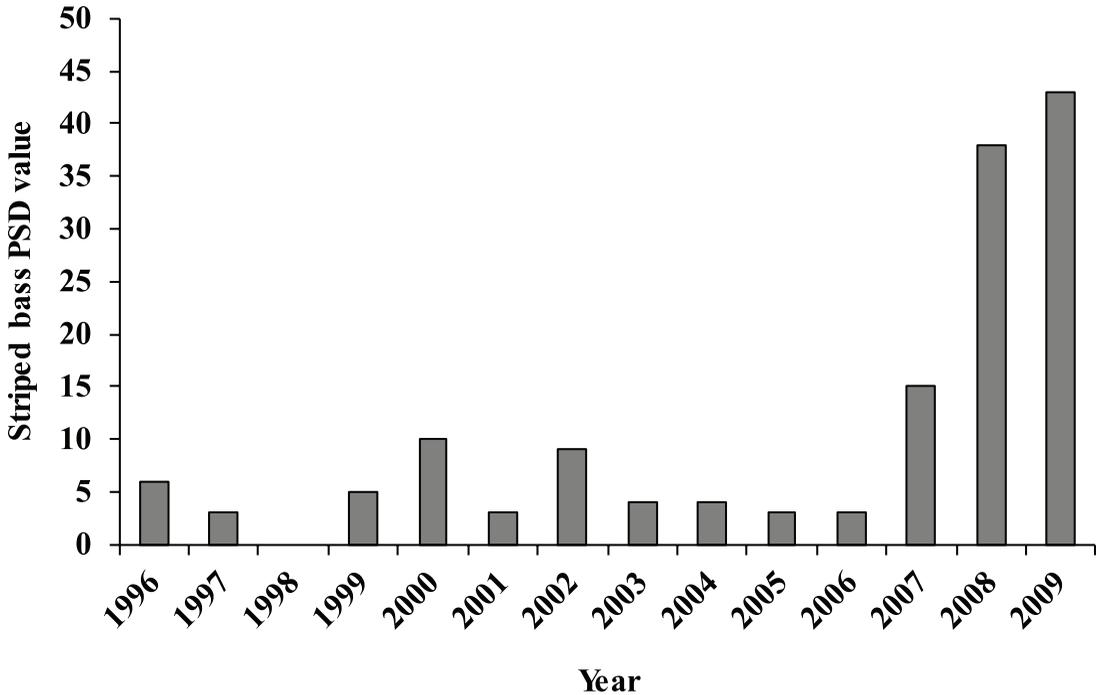


FIGURE 3. Lake Mohave striped bass proportional stock densities (PSD) from gill-netting surveys, 1996–2009. No data from 1998. (Nevada Department of Wildlife, unpublished reports, 1986–2009).

population restoration purposes). Lake Mohave has become known as a reservoir where large striped bass can be found. Individual fish up to 30 kg have been caught by anglers (Nevada Department of Wildlife, unpublished reports, 1990–2009).

#### ***Impacts of striped bass on Lake Mohave***

Establishment of striped bass likely contributed, to some extent, to a decline in the rainbow trout population and fishery. However, rainbow trout harvest was in decline prior to the striped bass population expansion (Figure 4). The decline was attributed to several other factors, including a decrease in angler effort for trout, temporary trout hatchery shut downs, and reduction in stocking. When the striped bass harvest began to accelerate in 1990, the estimated trout harvest had begun to level off between 50,000 and 100,000 fish, which was down significantly from an estimated annual harvest of 500,000 in the early 1980s (Figure 4). In response to de-

clining trout harvest, the AGFD initiated a study in the early 1990s to investigate the trout fishery decline in Lake Mohave's Hoover Dam tailwater (Walters et al. 1996). In that study, Walters et al. concluded that stocked trout were the main prey item of striped bass in Lake Mohave and that striped bass predation could quickly deplete the stocked trout population.

As the striped bass population continued to increase rapidly, there was a major shift in angler interest. In 1987, at Cottonwood Cove, 72% of anglers were fishing for trout and 2.5% were fishing for striped bass. By 1991, the ratio had reversed to 3% of anglers fishing for trout and 76% angling for striped bass (Nevada Department of Wildlife, unpublished reports, 1987–1991). At Willow Beach changes also occurred but to a lesser degree. In 1987, 96% of anglers were fishing for trout and only 1.5% for striped bass. By 1991, that ratio had changed to 27% trout anglers and 30% striped bass anglers (Figure 5).

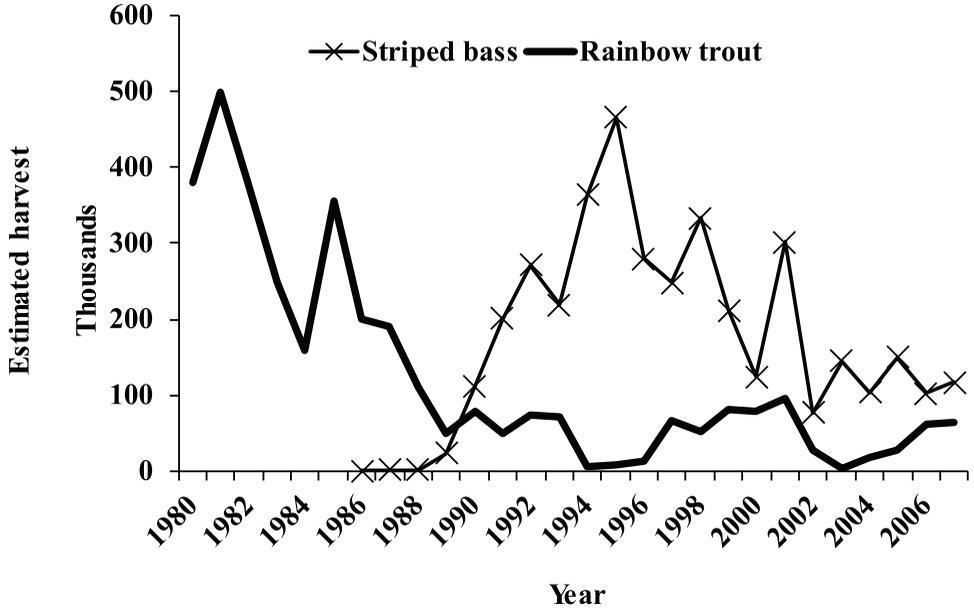


FIGURE 4. Estimated rainbow trout and striped bass harvest in Lake Mohave from 1980 to 2007 (Nevada Department of Wildlife, unpublished reports, 1986–2009). Trout hatcheries were shut down in 1984, 1994, and 2003.

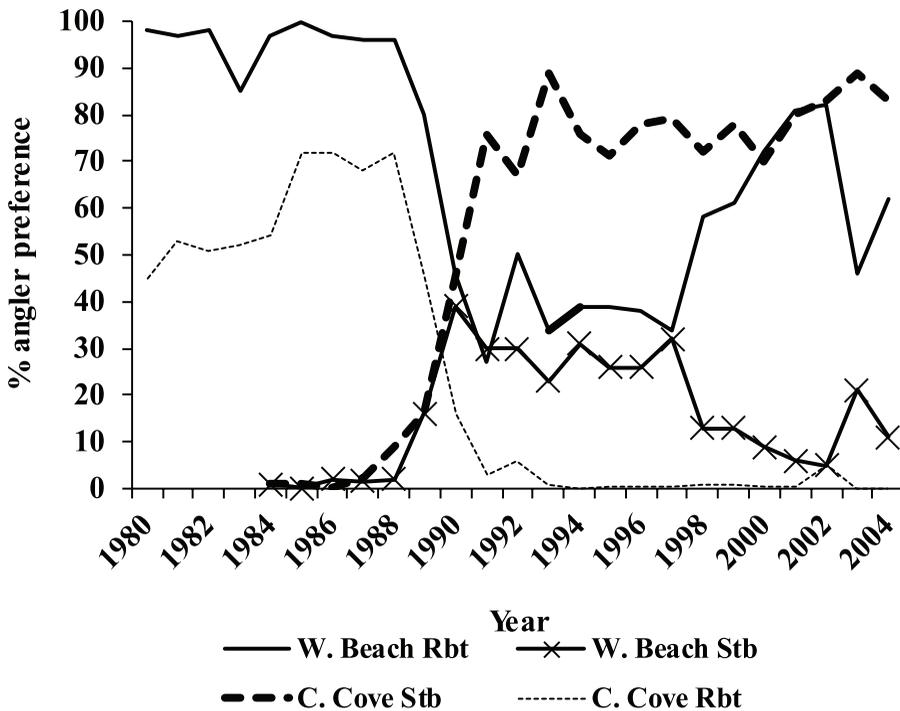


FIGURE 5. Lake Mohave percent angler preference for rainbow trout (Rbt) and striped bass (Stb), Cottonwood Cove (C. Cove) and Willow Beach (W. Beach; Nevada Department of Wildlife, unpublished reports, 2006–2009).

Because of constant, coldwater temperatures and continued trout stocking, Willow Beach remained the center of trout angling on Lake Mohave and retained a significant amount of trout angler interest. The trout fishery, however, has become primarily a put-and-take fishery. Very few striped bass less than or equal to 500 mm TL are present in the upper reaches of Lake Mohave, presumably because of the cold water temperatures. The continued stocking of trout, however, does attract striped bass greater than 500 mm TL. The Willow Beach area is known by anglers as an area where large striped bass can be caught year-round (Nevada Department of Wildlife, unpublished reports, 1980–2009). Between 2006 and 2009, the mean length of striped bass measured by creel census at Willow Beach was 635 mm TL ( $n = 116$ ). By contrast, between 2007 and 2008 (no data available for 2006 and 2009), striped bass caught at Cottonwood Cove, located in the seasonally warm part of the lake, had a mean length of

353 mm TL ( $n = 916$ ) (Nevada Department of Wildlife, unpublished reports, 2006–2009).

Angler catch rates on Lake Mohave were also significantly affected by striped bass population growth. At Cottonwood Cove, the combined catch rate for all species more than doubled from a pre-striped-bass average of 0.23 fish per angler-hour (f/h) (1970–1990) to a post-striped-bass average of 0.57 f/h (1991–2004) (Figure 6). The increase in catch rate was largely the result of increasing numbers of striped bass in the catch (Nevada Department of Wildlife, unpublished reports, 1990–2004). At Willow Beach, the angler catch rates actually declined. The combined catch rate for all species dropped from a pre-striped-bass average of 0.37 f/h (1970–1990) to a post-striped-bass average of 0.26 f/h (1991–2008) (Figure 6; Nevada Department of Wildlife, unpublished reports, 1970–2004). This drop can be attributed to decreased trout stocking and, as described by Walters et al. (1996), striped

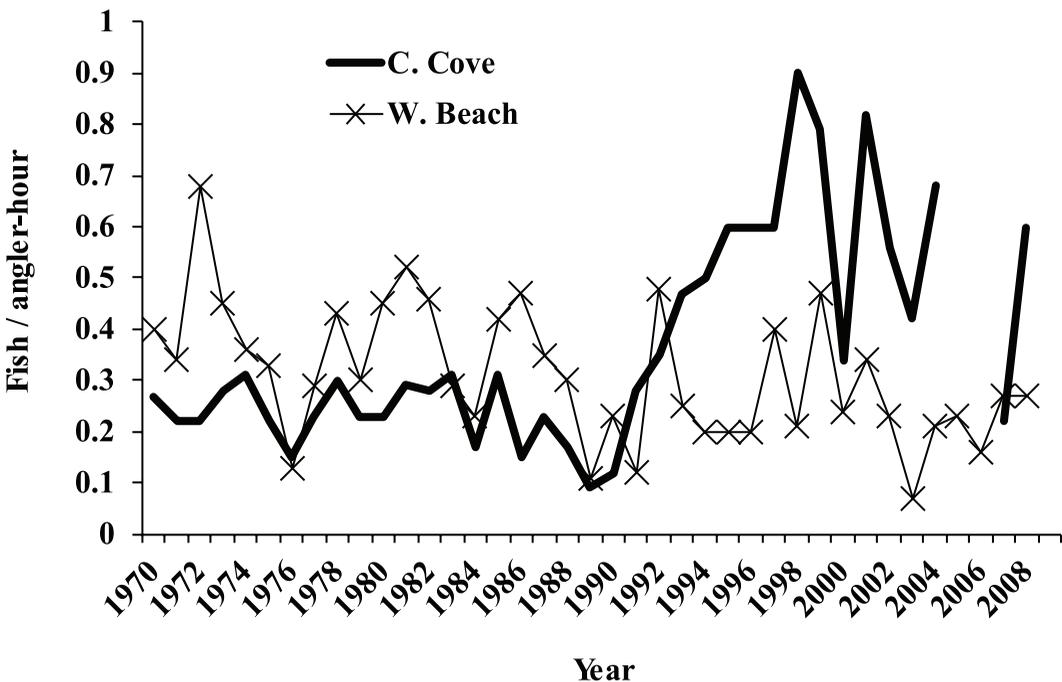


FIGURE 6. Lake Mohave catch rates at Cottonwood Cove (C. Cove) and Willow Beach (W. Beach) from 1970 to 2008. No data were collected at Cottonwood Cove in 2005 and 2006 (Nevada Department of Wildlife, unpublished reports, 1986–2009).

bass predation on stocked trout in the Hoover Dam tailwater.

In Lake Mohave, threadfin shad abundance declined as the striped bass population expanded. Threadfin shad production in Lake Mohave was monitored by open-water trawls, which began in 1987 when striped bass numbers were still fairly low. By 1991, striped bass numbers had increased significantly (Figure 2) and shad production became undetectable (Figure 7). In 1995, after several years of no production, larval shad were again noted in the reservoir and shad production continued through 1997. After 1997, no threadfin shad were observed in Lake Mohave by any method until 2007 (Nevada Department of Wildlife, unpublished reports, 1997–2007). In that year, a number of separate shad schools were noted visually in dispersed locations by agency personnel (NDOW, AGFD, USBR) and by the general public. However, in 2008 and 2009, threadfin shad were again undetectable, with no visual observations or col-

lections in annual gill netting or electrofishing surveys. We hypothesize that because of low water levels in Lake Mead, a pulse or pulses of shad larvae passed through the upper intakes of Hoover Dam and into Lake Mohave in 2007 without continuing survival and recruitment.

Predation by nonnative species is negatively affecting the recruitment of native fish in Lake Mohave, particularly the razorback sucker. There were an estimated 44,000 razorback suckers in Lake Mohave in 1991; by 2001, the estimate was fewer than 3,000 (Marsh et al. 2003). Spawning and the production of razorback sucker larvae continue. Predation by nonnative species has eliminated recruitment (Marsh and Langhorst 1988; Minckley and Deacon 1991; Marsh and Pacey 2005). The Native Fish Work Group (NFWG) was formed in the early 1990s to address the razorback recruitment problem. The NFWG consists of state, federal, academic, and private biologists actively involved in the Lake Mohave fisheries

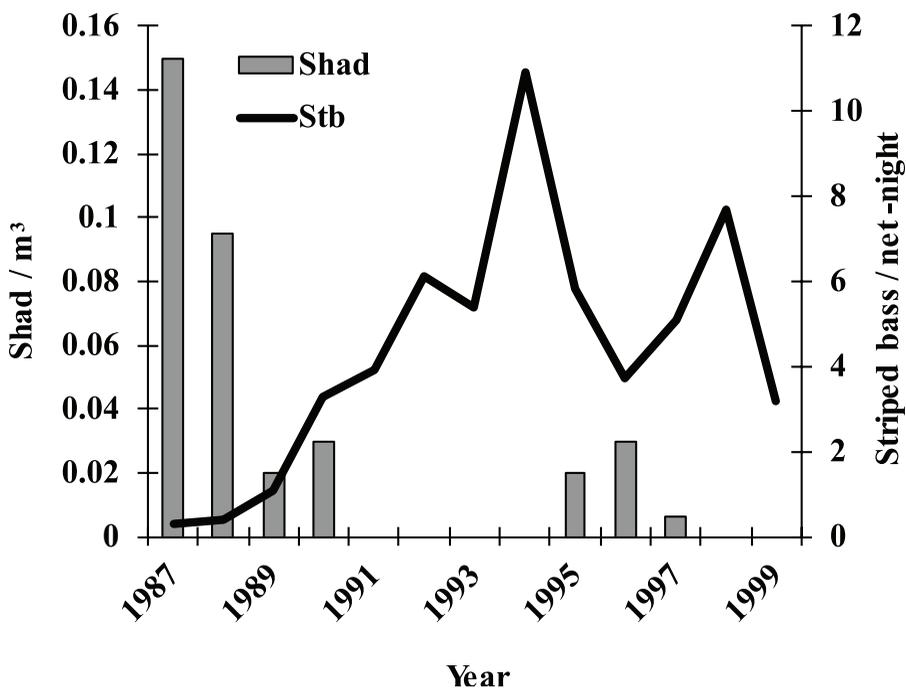


FIGURE 7. Lake Mohave threadfin shad trawl summary from 1987 to 1999. In 1993 and 1994, a light was used to determine presence or absence; no shad were found and no trawls attempted in those years (Nevada Department of Wildlife, unpublished reports, 1986–2009). Stb = striped bass.

program. The goals of the program are to maintain a population of 50,000 razorback suckers in the reservoir and to maintain the genetic diversity of the original wild population. A program of collecting wild razorback sucker larvae, rearing them in a predator-free environment, and repatriating them back into the lake began in the early 1990s and continues with modifications today. The survival rate of stocked fish has been disappointing, less than 3%. While the program has been unable to maintain the desired population size of 50,000, it has been successful in maintaining the genetic diversity of the original population (Dowling et al. 2005).

In summary, the dispersion of striped bass into Lake Mohave has had unintended consequences for fisheries management. Striped bass were never stocked into Lake Mohave because managers and the public preferred to maintain the stocked trout fishery. There was less concern for native fish at the time striped bass dispersed from Lake Mead, but concern has increased over the past 20 years. To compensate, management efforts have been directed at promoting striped bass harvest to minimize the predation impact of striped bass on the existing fishes. From the beginning, striped bass daily harvest limits have been liberal, 20 fish, and by 2001 the limit was totally removed for fish less than or equal to 500 mm TL (NDOW 2001). The ability of Lake Mohave to produce young fish and the desire to control those numbers precipitated the limit removal. The 20-fish limit on fish greater than 500 mm TL was kept.

The trout stocking program has been modified to optimize returns to anglers. The number of trout stocked has been cut by 70%. Trout stocking has been limited to only areas with concentrated angler use. Stocking trout in high-use areas also serves to increase the harvest of striped bass, as large striped bass also concentrate in these areas because of the trout stocking. As recommended by Walters et al. (1996), the sizes of the stocked trout were increased to 300 mm TL. It was thought by Walters et al. that the larger trout would be more adept at escaping predation. The native fish stocking

size has also gradually increased over time, up to 500 mm TL. When possible, native fish are stocked in areas of the lake where trout are not stocked to avoid concentrations of striped bass and other predators and in areas likely to provide escape cover for those fish.

## Lake Pleasant

### *Striped bass source reservoir (Lake Havasu)*

Lake Havasu is located downstream from Lake Mohave between Arizona and California on the lower Colorado River (Figure 1). Formed behind Parker Dam in 1938, the 8,470-ha lake is a storage reservoir from which water is pumped into two major aqueducts, one feeding California and the other feeding Arizona. Lake Havasu extends 40 km north from Parker Dam where it receives water from the Colorado River. The river extends another 81 km to the base of Davis Dam, which forms Lake Mohave.

Striped bass were first stocked into Lake Havasu in 1962. At the time of the introduction, it was generally accepted that striped bass would not be able to reproduce sufficiently to sustain a self-maintaining population (Gustavson and Blommer 2013). Evidence of reproduction in Lake Havasu was found in the late 1960s and a self-maintaining population was established (Edwards 1974) that continues to persist.

During the period of initial striped bass stocking, plans were being developed for the Central Arizona Project (CAP) Canal to divert water to central and southern Arizona. Authorized in 1968 and completed in 1993, the CAP Canal diverts water from the Colorado River at Lake Havasu to central Arizona (Mueller 1990). The concrete-lined canal system is fairly extensive, extending 521 km across the state (Figure 1). Water from the Colorado River at the south end of Lake Havasu is lifted 251 m by the Mark Wilmer Pumping Plant and runs through 11.3 km of tunnel under the Buckskin Mountains before entering the CAP Canal. The pumping plant has six pumps producing a

maximum discharge of 85 m<sup>3</sup>/s. The canal has three sequential aqueducts: Hayden-Rhodes, Fannin-McFarland, and Tucson. Water in the Hayden-Rose Aqueduct is pumped 306 km from the outlet portal at the Buckskin Mountains through three pumping stations (Bouse Hills, Little Harquahala, and Hassayampa) to the city of Phoenix. At kilometer 239, the Waddell Canal diverts water 7.9 km from the Hayden-Rhodes Aqueduct and passes through the Waddell Pumping Plant before entering Lake Pleasant.

The development of the canal system provided striped bass the opportunity to disperse downstream to Lake Pleasant and into central and southern Arizona. The potential effects of the CAP Canal project on Lake Pleasant fisheries were assessed during the construction period. Despite the challenges to fish passage presented by the series of aqueducts and pumping plants, concern over the impacts of striped bass from Lake Havasu on the existing ichthyofauna in Lake Pleasant prompted Grabowski et al. (1984) to assess potential impacts before the canal was filled. They concluded that despite predation, pump intake stresses, and temperatures exceeding 30°C, juvenile striped bass would likely move down the canal and enter Lake Pleasant. They also predicted that if striped bass did survive to maturity in Lake Pleasant, reproductive success would likely be low (Grabowski et al. 1984).

Striped bass were found in the CAP Canal almost immediately after it began to fill. Initial water diversions into the CAP Canal occurred in 1985. Fish sampling from 1986 to 1989 indicated that striped bass were widely distributed throughout the canal, but the majority of them remained in the first 27 km of the canal to the Bouse Hills pumping station, the first main impediment to further passage. As the canal system reached operational capacity, abundance of all fish species declined. Mark-recapture population density estimates of striped bass in 1986 were 70 ± 37 fish/ha and in 1989 were 3 ± 1 fish/ha (Mueller 1990). The decline in striped bass and other species in the canal was attrib-

uted to higher operational velocities and associated scour. From 1986 to 1989, striped bass represented up to 14% of the fish community. However, no striped bass larvae and only five eggs were collected in the canal, suggesting that striped bass populations within the canal are dependent upon entrainment rather than in-canal reproduction (Mueller 1996).

Further analysis and observations showed larger fish were capable of dispersing through the canal and that they did so. Grabowski et al. (1984) showed that striped bass less than or equal to 25 mm TL would not be able to avoid intake velocities at the Mark Wilmer Pumping Plant and likely would be entrained. They also calculated that a striped bass up to 305 mm TL could be pumped and transported down the canal based on minimum clearance of water passage through impellers. However, in 1986, 18 months after the canal began filling, a 500-mm-TL striped bass was collected in the first reach, suggesting that larger fish were entering the canal. From 1986 to 1989, sizes of striped bass ranged from 115 to 613 mm TL. Fish greater than 305 mm TL may have swum through the turbines when pumps were inactive and flushed downstream once operations resumed (Mueller 1990).

In 1995, the USBR developed and implemented a long-term monitoring program to determine the presence and distribution of non-native fish in the CAP Canal (Clarkson 1996). Seven sampling stations located at the Bouse Hills, Little Harquahala, Hassayampa, Salt-Gila, Brady, Red Rock, and San Xavier pumping plants were selected throughout the canal (Figure 1). With the exception of 2004, fewer than 50 striped bass were collected in any one annual survey. In 2004, more than 1,200 striped bass were observed at the Bouse Hills station during a dewatering event in the first reach of the canal. Nearly 80% of the captured fish that year were young of year. Striped bass have been captured at all of the sampling stations, with the exception of the farthest downstream station, San Xavier (Table 1). Most of the striped bass captured during the annual surveys are at

TABLE 1. Presence (+) or absence (–) of striped bass from 1995 to 2008 at each of seven sampling stations along the Central Arizona Project canal (USBR 1995–2008), in order from Lake Havasu downstream: Bouse Hills (BH), Little Harquahala (LH), Hassayampa (H), Salt-Gila (SG), Brady (B), Red Rock (RR), and San Xavier (SX). Blank cells indicate no sampling conducted.

Year	Location						
	BH	LH	H	SG	B	RR	SX
1995	+	+	–	+	+	–	–
1996	–	–	–	–	–	–	–
1997	+	+	+	+	+	+	–
1998	+	+	+	+	+	+	–
1999	+	–	–	+	+	–	–
2000	–	+	–	–	–	+	–
2001	+		–	–	–	–	–
2002	+		–	+	+	+	–
2003	+	+	+		+	+	–
2004	+	+	+	+	+		–
2005				+	–	+	–
2006	+	+	+				
2007	+	–	–	+	–	+	–
2008				+	–	–	–

the first station, Bourse Hill Pumping Plant (USBR 1995–2008). This was also true during Mueller's (1990) study, where only 2% of the striped bass taken from the canal were collected downstream of the first reach. Nonetheless, striped bass dispersal has been extensive in the CAP Canal system.

### **Striped bass receiving reservoir (Lake Pleasant)**

Originally formed by the Waddell Dam in 1927, Lake Pleasant was a 1,497-ha irrigation water storage facility located 48 km northwest of the city of Phoenix (Figure 1). At the time, the lake was primarily fed by the Agua Fria River, an intermittent stream, and several smaller ephemeral streams on the north end of the reservoir. Over the years, Arizona Game and Fish stocked large-mouth bass, bluegill, channel catfish, white crappie *Pomoxis annularis*, black crappie, white bass *Morone chrysops*, and threadfin shad. Threadfin shad has been the primary forage base that supports the only self-sustaining white bass fishery in Arizona (Morgensen 1990).

In 1992, the New Waddell Dam was constructed 800 m downstream from the Waddell Dam to increase water storage at Lake Pleasant. Following the completion of the New Waddell Dam, water from the CAP Canal was pumped into Lake Pleasant and nearly tripled its size to 4,168 ha. Lake Pleasant is now filled primarily by CAP water at the south end of the reservoir. The pattern of water level fluctuation changed drastically. Prior to CAP water, the lake fluctuated less than 4 m throughout the year and was considered a mesotrophic reservoir. Since CAP water has been entering the lake, water levels fluctuate seasonally up to 23 m, based on water needs, and the lake has become meso-oligotrophic (Bryan 2005). As demand for water increases during the summer, water is released through the pump-generation plant back into the canal. In the winter, when water demand is low, Colorado River water is pumped from the CAP Canal into the lake. The Waddell Pumping Station lifts water 58 m into the lake and has a capacity to pump water at 85 m<sup>3</sup>/s.

In December 1992, the old dam was breached and, for the first time, water from the CAP Canal was pumped into the original reservoir. No striped bass were collected during the first gill-netting survey conducted 2 years after CAP water began entering the reservoir (Arizona Game and Fish Department, unpublished data). The first striped bass were detected during a 1998 gill-netting survey and ranged from 395 to 451 mm TL (Arizona Game and Fish Department, unpublished data). Striped bass density gradually increased until a substantial population expansion in 2005 (Table 2; Bryan 2005; Stewart et al. 2007). During early spring, striped bass use the intermittent Agua Fria River located on the north end of the reservoir for reproduction, but successful spawning appears to occur only during years of high inflow (Stewart et al. 2007). Discharge during spring 2005 in the Agua Fria River was nearly three and a half times the average discharge since striped bass were introduced into the lake, and 2005 was the first year that substantial recruitment was detected in the reservoir. Stewart et al. (2007) showed that striped bass reproductive success is highly dependent upon the infrequent flows in the Agua Fria River. The upper reaches of the Agua Fria River run dry most of the year, and the lower reach becomes inundated when the reservoir is at full pool.

Hydroacoustic surveys along with gill-netting surveys were conducted in 2005 and 2006 to obtain density estimates. The estimated striped bass population was  $40,535 \pm 2,980$  and  $27,229 \pm 2,112$  in 2005 and 2006, respectively (Stewart et al. 2007).

### **Impacts of striped bass on Lake Pleasant**

Striped bass introduction has impacted Lake Pleasant fish populations and angler attitudes towards available fish. According to a 2001 state-wide survey, Lake Pleasant was the highest-use lake in Arizona with more than 520,000 user days per year (Pringle 2004). It was a premier largemouth bass fishery holding approximately 150 tournaments per year. A creel survey conducted from 2000 to 2004 showed that less than 1% of anglers were targeting striped bass (Bryan 2005). Since the population expansion in 2005, however, that number has likely increased.

Anglers' concern over competition with largemouth bass, and to a lesser degree white bass, for food (primarily threadfin shad) made striped bass an unpopular sport fish. Most studies, however, have reported little to no predation on other game fish (Miranda and Raborn 2013, this volume). Studies at Lake Pleasant found relatively low diet overlap between largemouth bass and striped bass (Stewart et al. 2007). For white bass, anglers' concerns about competition

TABLE 2. Catch per unit effort (CPUE) with SE, number caught (*N*), and mean total length (TL) and range (mm) of striped bass during gill-netting surveys at Lake Pleasant from 1994 to 2006. Catch per unit effort was calculated as the number of fish caught per net per 12 h (Bryan 2005; Stewart et al. 2007; Arizona Game and Fish Department, unpublished data)

Year	CPUE	SE	<i>N</i>	Mean TL	Range
1994	0.00	0	0		
1998	0.13	0.06	5	419	395–451
2000	0.48	0.22	14	455	220–622
2001	0.47	0.17	27	414	215–722
2002	0.72	0.17	36	443	238–686
2003	1.25	0.17	68	314	210–735
2004	1.14	0.37	53	492	214–762
2005	6.74	2.03	230	323	215–678
2006	3.85	1.01	192	366	236–597

have been supported. From the time striped bass immigrated into Lake Pleasant, white bass relative abundance decreased (Bryan 2005; Stewart et al. 2007). This was especially evident in 2006, the year following the striped bass population expansion, when relative abundance of white bass decreased from 7.62 to 0.52 fish/net-night and relative weights decreased from 93 to 80 (Stewart et al. 2007). Unlike Lake Mohave, threadfin shad do not appear to be declining in Lake Pleasant as indicated by gill-netting surveys (Stewart et al. 2007). Lake Pleasant is composed of numerous embayments and coves that provide refuge for threadfin shad. Lake Pleasant provides the only self-sustaining white bass fishery in the state.

Management of striped bass in Lake Pleasant and CAP Canal has focused on minimizing unwanted impacts. In 1994, the AGFD implemented a special regulation to allow unlimited take of striped bass to control the striped bass population, to reduce competition with the existing fish populations, and to preserve the only white bass fishery in Arizona. However, the impacts of angling pressure on the striped bass population are unknown.

### **CAP Canal Downstream of Lake Pleasant**

Downstream from Lake Pleasant, the Hayden-Rose Aqueduct continues to carry water though Phoenix before reaching the Fannin-McFarland Aqueduct. Prior to reaching the Fannin-McFarland Aqueduct, water must pass through the Granite Reef Diversion Dam, which is an interconnect between the CAP Canal and the Salt River Project (SRP) canals, which connects water in the Salt and Verde rivers. Striped bass escapement out of the CAP into these river drainages could adversely affect native fish. To control the spread of striped bass and other nonnative fishes from the CAP Canal to other river systems, electrical barriers were constructed as a control strategy to prevent nonnative species from moving upstream once outside the CAP. The electrical barriers were not entirely effective (Clarkson

2004), but striped bass have not been detected above the barriers.

The Fannin-McFarland Aqueduct has only one pumping station, Salt-Gila Pumping Plant, and extends 93 km before reaching the Tucson Aqueduct. The Tucson Aqueduct has nine pumping plants and extends 140 km to the end of the system. In total, the CAP Canal extends 521 km from Lake Havasu to Tucson, Arizona. Striped bass have dispersed almost entirely throughout the canal system and have been detected as far downstream as the Red Rock Pumping Plant (km 437).

### **Discussion**

Unintended dispersal of striped bass from Colorado River reservoirs where they were stocked has had major impacts on fishery management in Lake Mohave and bodies of water connected to the CAP Canal, including Lake Pleasant. When initial stocking of striped bass took place in the 1960s, managers viewed the introduction of nonindigenous species much differently than they do today. At that time, striped bass, along with other limnetic predators, were stocked in Lake Mead to utilize the large population of threadfin shad. It was assumed that striped bass would not successfully reproduce in the reservoirs in the lower Colorado River and that populations and fisheries could be controlled by stocking. The thought at the time was that despite potential spawning runs into tributaries, the reach of river that runs from Davis Dam down to Lake Havasu would not allow adequate time for eggs to hatch before reaching the lake, and they would die. This turned out not to be the case. In addition, spill of striped bass from Lake Mead into Lake Mohave was not anticipated. Thus, the dispersal began.

Striped bass populations in Lake Mohave and Lake Pleasant have been able to succeed largely because of their ability to reproduce locally. Due to the low numbers of striped bass successfully passing Hoover Dam and found in the CAP Canal, numbers entering from the source reservoirs are inadequate to support striped bass populations large enough to impact

other sport fish species by direct predation and competition for common prey items. Striped bass were never intended for these reservoirs, and management strategy has been to reduce the numbers with liberal catch limits to lessen the impact on other species. It is difficult to determine how effective the liberal harvest has been at controlling striped bass numbers. Certainly, many striped bass have been removed by anglers, but the ability of these reservoirs to produce striped bass may outstrip the ability of anglers to remove them.

In Lake Mohave, a new and popular fishery developed for striped bass. Angler effort and harvest estimates for striped bass have declined over time, but catch per unit effort has remained high. The population density as measured by the annual gill-net surveys has declined. How much of this decline is the result of angler harvest as opposed to other factors is unclear and may warrant further studies. There has been no recovery of the threadfin shad population, which might be expected with declining striped bass densities. The result has been an excellent fishery for small striped bass and development of a limited trophy fishery, which has become extremely popular with the angling public.

Despite the lack of in-canal reproduction, dispersion of striped bass throughout the CAP Canal system was extensive and rapid, likely because fish are exposed to higher degrees of downstream drift compared with naturally flowing system. The potential impacts of striped bass dispersing in the CAP Canal and into Lake Pleasant were anticipated and evaluated. Predictions were made that striped bass would enter the CAP Canal and inevitably make their way to Lake Pleasant. It was unknown at the time whether they would establish in the lake, but they certainly did. As a proactive strategy, managers set unlimited bag limits at Lake Pleasant even before the first striped bass was captured. Not knowing whether they would become established in the lake, managers took a wait-and-see approach. Gradually striped bass numbers increased until a very successful

recruitment occurred in 2005. As striped bass popularity increased managers continued to promote and encourage harvest even amending regulations to allow for spear fishing (a rather unique liberalization of harvest for a game fish). Natural hybridization of striped bass and white bass has been recorded in several reservoirs across the United States (Harrell 2013, this volume). As the only self-sustaining white bass fishery in Arizona, the introduction of striped bass has provided opportunity for natural hybridization to occur but is of little concern to managers as white bass are not a highly prized sport fish in Arizona.

The well-being of native fishes is of much greater concern today than it was when striped bass were introduced to the Southwest in the 1960s. After recognition that introduced striped bass disperse well beyond stocked waters and impact existing fish populations, efforts were made to protect and restore native fishes. Native fish have been propagated, but survival of stocked fish has been poor (Mueller and Burke 2005). The degree to which poor survival can be attributed to striped bass is under evaluation. The USFWS in the 1990s anticipated striped bass escaping through the CAP Canal and initiated installation of electrical barriers to prevent them from entering the Salt and Gila rivers. With dispersion of striped bass through the CAP Canal system recognized as inevitable, a "recovery in lieu of threat removal" concept was developed that encompassed several aspects: fish barriers on high-value native fish streams, native fish recovery where striped bass have invaded, and direct control of nonnatives such as striped bass (R. Clarkson, U.S. Bureau of Reclamation, personal communication).

The future of the striped bass and other fisheries in Lakes Mohave and Pleasant after the inadvertent dispersal of striped bass to these lakes is unclear. Recent dispersal of quagga mussels into Lake Mohave and Lake Pleasant will likely be a significant agent of ecological change, possibly affecting striped bass and other fish species being managed. Additionally, the recent and undesired establishment of gizzard

shad and blue tilapia in Lake Mead (Nevada Department of Wildlife, unpublished report, 2008) will further complicate management of Colorado River fisheries, as these species may disperse through the system like striped bass did.

### **Management recommendations**

The lower Colorado River was initially stocked with striped bass more than 50 years ago. Prior to their introduction in the lower Colorado River and during the construction of the CAP Canal, varying degrees of risk analysis were conducted that evaluated the impacts of striped bass and their potential to disperse. While some predictions came true (dispersal to Lake Pleasant), others did not (reproduction would not occur in Lake Mead). Managers wanting to stock striped bass or develop water diversion projects must consider the ability of striped bass to reproduce in both intended and unintended water bodies. Dispersion of striped bass from Lakes Mead and Havasu can largely be attributed to successful reproduction in those reservoirs and a bountiful source for downstream dispersal of striped bass at all life stages. Furthermore establishment of striped bass in unintended waters would not be possible in the absence of reproduction and an adequate prey source such as threadfin shad. It is also evident that dams and pumping plants do not act as barriers to dispersal and managers wanting to prevent dispersal should consider additional measures, which likely depend on the status and importance of fish resources in waters that might be invaded.

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