Survival of razorback sucker in the lower Colorado River

Final Project Report

January 2006 - April 2008

Jason D. Schooley, Brian R. Kesner, Joshua R. Campbell,

Judith M. Barkstedt and Paul C. Marsh

Native Fish Lab

School of Life Sciences

Arizona State University

Tempe, Arizona 85287-4501

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Summary

Portions of the lower Colorado River between Parker and Laguna dams were surveyed during the period January 2006 to April 2008 as part of a broad program to assess efficacy of the stocking program for razorback sucker *Xyrauchen texanus*. Our findings document that short-term mortality is high and long-term survival is nil because of predation losses to nonnative fishes and to fish-eating birds. The program has not resulted in establishment of persistent populations, and continued stocking is not recommended under current practices. Instead, stocking should be only into habitats that are depleted of nonnative fishes and where control of avian predators can be developed. Natural feed delivery during rearing, pre-release training, and temperature acclimation at the time of stocking also are recommended to enhance post-release survival.

The study area included the main river channel and selected confluent, watercraft-accessible backwaters and side channels of La Paz and Yuma counties in Arizona, and San Bernardino, Riverside, and Imperial counties in California. Primary methods were boat electrofishing and trammel netting that resulted in contact with a total of 24,602 fish representing at least 21 species, including 2,433 razorback sucker contacts (9.9% of the total catch) and 182 bonytail *Gila elegans* contacts (0.7% of total catch).

All razorback sucker are thought to have been stocked and many (1,075) contained PIT tags at capture. Of these 1,075 fish, 959 had been tagged at the time of stocking. Time-at-large ranged from 2 – 913 days, but most fish were encountered within a few months of release. Sex ratios of characterized fish were 468 female, 777 male, 836 juvenile, and 200 unknown. Mean total length (TL) for females was 45.4 cm (range 34.2 – 65.0), for males was 38.8 cm (range 29.0 – 58.5), and for juveniles was 34.9 cm (range 28.3 – 39.9).

All bonytail are thought to have been stocked and 93.9% contained hatchery-implanted wire tags. Only 27, however, contained PIT tags; all of these tags had been implanted at the time of stocking. Sex ratios were almost uniformly “unknown.” One fish was recorded as female, and one as juvenile; however, no secondary sexual characteristics were present to verify these assessments. Mean TL for bonytail was 33.4 cm (range 27.0 – 41.0).

Twelve adult razorback sucker (>50 cm) were affixed with radio tags in an effort to track dispersion of mature fish and locate spawning sites. Tagged fish were released into A-7 and C-

7 backwaters between December 2006 and February 2008, and were subsequently contacted only in A-7 Upper before tags expired and tracking was discontinued in April 2008.

Multifaceted investigations on factors contributing to apparent loss of stocked fish were performed as part of this study. Environmental conditions and fish health are generally of little concern because most fish are captured in good condition, and both spawning and successful reproduce have been observed. Water physico-chemistry in lower Colorado River backwaters appears to be sufficient for sustaining fish communities, at least in most places and at most times. Parasite infection is variable but not of concern.

Primary mortality factors were piscine and avian predation on released fish. Observations indicated that piscine predation was ubiquitous in all stocked sites. Estimated predator abundances, though low in certain localities, are sufficient to impact stocked populations. Overwhelming evidence of avian predation on stocked fish indicates it is a significant threat to survival. Fish were captured with wounds from failed avian predation as early as 2 days post-release. Quantification of fish depth at capture indicated a shift from pelagic to demersal swimming within 100 days post-release, a behavioral change that may reduce avian predation. Smaller size classes of two experimental stocks of razorback sucker were under-represented in the catch, suggesting that vulnerability to avian predation may be related to fish size.

Regardless of release size, estimated annual survivorship was less than 30% for stocked razorback sucker. Evidence of long-term survival was rare, indicating that population augmentation through stocking has failed to replace lost wild populations or establish new ones. Continued stocking to the lower Colorado River is not recommended under current practices because mortality threats are substantial and conditions are not conducive to long-term survival of stocked fish. Instead, population augmentation should occur in habitats devoid of predators. Present and proposed predator free habitats do not mitigate avian predation, and appropriate control measures thus are advocated. If continued stocking to the lower Colorado River is mandated, then recommendations are provided for enhancement of survival of stocked fish, including pre-release training, natural feed delivery, and temperature acclimation.

Introduction

Razorback sucker *Xyrauchen texanus* have been stocked to the lower Colorado River for more than 30 years, but stocking was qualitatively accelerated in the late 1990s to meet requirements of a U.S. Fish and Wildlife Service (USFWS) Biological Opinion of lower river operations (Table 1, Fig.1, USFWS 1997). Prior to 2003, contact with these fish was largely serendipitous and incidental to sport-fish related activities. Since then, the Native Fish Lab at Arizona State University has been contracted by U.S. Bureau of Reclamation (USBR), Boulder City, specifically to assess the post-stocking fate of razorback sucker in the lower Colorado River. An intensive, opportunistic survey was conducted from 2003 to 2005 that targeted razorback sucker in approximately 282 km of river from Parker Dam downstream to Yuma (Schooley et al. 2004, 2006). In that survey, few fish were captured more than a few months post-stocking and a few miles from the stocking site, and it was recommended that alternative stocking sites be sought and that a portion of stocked fish be PIT tagged prior to release to increase recapture rates and enhance opportunities for accrual of other data.

The Native Fish Lab was granted an additional three year contract in 2006 to continue assessing post-stocking fate and focus on potential mortality factors. Monitoring efforts from 2006 to 2008 were concentrated in areas near stocking sites and additional studies were initiated to pinpoint causes of post-stocking mortality. Specifically, studies were conducted to estimate the impact of avian and piscine predation on razorback sucker survival.

This report is the concluding document of monitoring and research conducted for the study period. When appropriate for comparison, data from previous study periods are presented or referenced. A total of 18 interim trip reports and two annual reports were submitted during the current contract period (Table 2), and these are incorporated by reference here.

Study Area

The lower Colorado River survey area included 282 km of main river channel (here, "lower river"), backwaters, side-channels, reservoirs, and floodplain lakes between Parker Dam at river mile (RM)[1] 192 and Laguna Dam at RM 43.5. The primary survey area excluded waters within the boundaries of the Colorado River Indian Tribes (CRIT), approximately located between RM 180 and 122. Backwaters in California were similarly excluded from sampling after April 2007

[1] River miles are measured upstream from the Southerly International Boundary near San Luis, Arizona.

because collecting permits expired and renewal applications were not timely acted upon. Survey dates and locations are summarized in Table 2, and sites are depicted on Maps 1-8.

Sampling focus evolved during 2006 - 2008 to accommodate specific investigations, but primarily included zones where razorback sucker have been stocked and generally reside (Map 1). The first of these sampled zones was the Parker Strip, located in the USBR Havasu Division (Map 2) between Parker and Headgate Rock dams. This section has been stocked with razorback sucker since 1986, most consistently between 1990 and 2000; stocking resumed in December 2006 and continues to present. This 22.5 km reach is predominantly swiftly-flowing, clear discharge from Parker Dam, but includes many eddies, rocky shoals, and a few artificial lagoons. Sampling efforts were increased here as the reach became a more frequent stocking site in 2007 and 2008.

The second sample area (A-7 stocking zone) was centered on A-7 backwater (Maps 3 and 4) within USBR Palo Verde Division. The zone is demarcated by the southern boundary of the CRIT (Arizona shoreline, ca. RM 124) and C-10 backwater (RM 109), a reach of 24.4 km. This zone includes four named backwaters (A-7, C-5, C-7, and C-10[2]), one unnamed California off-channel backwater at RM 124, and the main river channel within Palo Verde Division. Razorback sucker were consistently stocked into A-7 backwater between 2000 and 2005, but no razorback sucker have been released there since 2006. Bonytail *Gila elegans* has been stocked here twice since 2006.

A-7 is divided between upper and lower sections, though they maintain no connectivity to each other and are grouped only by name and proximity. All backwaters in this zone, except C-10, are connected to the main river channel by boat-accessible channels. However, A-7 Lower and C-5 can be inaccessible by boats in low river stages due to siltation and a rock dam respectively. C-10 connects to the main channel by a number of corrugated steel culvert pipes.

The third sampling area, A-10 backwater, is divided approximately equally in surface area between upper and lower sections totaling approximately 10.1 ha total (Map 4). A-10 is also located in USBR Palo Verde Division at RM 114. The two sections of the backwater are connected to each other and the main channel by corrugated culvert pipes, which can restrict exchange of water and biota with the river. This results in seasonal semi-isolation from the main river channel when water level in the backwaters and main channel drop below the culvert

[2] Backwaters in the Palo Verde Division are given an abbreviated name which identifies their location and sequence. Backwater names are prefixed with a state abbreviation (e.g., A = Arizona) and suffixed with a number indicating sequence upstream to downstream (e.g., C-3 is upstream of C-5).

pipes. A-10 has been the primary razorback sucker stocking location in the Palo Verde Division since 2005.

The fourth sampling area (referred to here as the “Other” stocking zone) represents regions of occasional razorback sucker captures downstream of C-10 (RM 109) to Imperial Dam. This zone includes the main channel and three small backwaters: Sandy Cove (Hippie Hole), the Oxbow Recreation Area landing, and an unnamed California backwater (each <1 ha total) located at RM 99-100 (Map 6). These backwaters comprise the only off-channel habitat between C-10 and the Palo Verde Outfall Drain, and the latter location provided numerous contacts with razorback sucker in past surveys (Schooley et al. 2004, Schooley et al. 2006). Quiet water there may be more attractive to razorback sucker than swift currents of the adjacent main channel. Also included in the fourth sampling area are portions of the USFWS Imperial National Wildlife Refuge (NWR). This section includes Martinez Lake, Fisher’s Landing, and the main channel and backwaters within the NWR. Several small stocking events, generally fewer than 100 fish, were conducted by USFWS at the refuge in between 1995 and 2006.

Methods

Post-stocking Monitoring and Assessment

Primary sampling methods were boat electrofishing and trammel netting. Electrofishing (Smith-Root SR-18H package with GPP 7.0 pulsator) was conducted during evening and nighttime. Observations on physical habitat characteristics, including temperature, conductivity, and total dissolved solids (TDS), were recorded for the main channel and backwaters. Navigational notes and information on access were recorded for reference.

Trammel nets (46 m x 1.8 m x 3.8 cm mesh) were generally set in the evening, fished overnight, and retrieved the following day. In areas that were recently stocked or of high known density, nets were set for a few hours in the evening and then retrieved. Net set locations were chosen based on water depth (>1.5 m) and habitat (proximal to cover but free of submerged obstacles or debris). Net sites were generally in backwaters off the main channel, and were intentionally placed in remote, slightly inaccessible locations to avoid watercraft traffic.

All fish were identified to species when possible and counted by method of capture and life stage (0 or 1). Age-0 was used to indicate small-bodied species (such as red shiner, mosquito-fish, and mollies) and young-of-year for large-bodied species, while Age-1 indicated adult, large-bodied fish. Native fish were individually measured (total length [TL], cm), weighed (g), scanned for wire (WT) and a passive integrated transponder (PIT) tags, sexed (male, female, juvenile, and unknown [for fish ≥40 cm for which gender could not be reliably determined]), and examined for general health and condition. Qualitative health condition categories were also recorded using the following rubric: Excellent: Fish shows no obvious signs of injury, disease, parasites, or stress; Good: Fish has few and minor wounds or scars and is vibrant; Fair: Fish looks rough but has energy and will survive; Poor: Fish is in poor condition and listless (belly-up or over-stressed); and MORT: the fish is dead.

A PIT tag was implanted into the abdominal cavity of natives if none was present, and all fish were released near the site of capture. Individual fish captured on more than one occasion may be accounted for more than once in aggregated demographic data. Because these last fish were few, their multiple inclusions likely have no effect on overall averages.

Voucher specimens of up to 20 individuals per nonnative species[3] were fixed in 10% formaldehyde prior to rinsing and preservation in 70% ethanol, and deposited into the Arizona State University [ASU] Collection of Fishes (Table 3). Exceptional individuals and others exhibiting key characteristics or other features were photographed to provide a permanent record.

Von Bertalanffy Growth Curve

Post-stocking growth was assessed by fitting release and capture data for PIT tagged stocks to a Von Bertalanffy Growth (VBG) curve model as described in Marsh et al. (2005). Multiple capture events for individuals were retained and genders were pooled because many fish were recorded as juvenile. The best-fit to the VBG curve,

$$L_t = L_\infty \left[1 - e^{-K(t-t_0)}\right],$$

where e is the base of natural logarithms (approximately 2.71828) and t is age, was determined by adjusting growth parameters L_∞ (asymptotic length of the growth curve), K (growth coefficient describing rate at which asymptotic length is approached), and t_0 (theoretical age at which the fish would have been zero length) to minimize the sum of squares.

[3] This represents the total number of vouchers for the multi-year study period.

Remote Scanning

Two rectangular PIT tag antennae, consisting of copper wire encased in PVC pipe and measuring 0.6 x 2.4 m, were deployed in A-10 in January 2008. Each antenna was independently powered and connected to an FS2001F-ISO portable scanner (Destron Fearing Inc, St. Paul, MN) set to scan continuously. Antennae were designed, constructed, and configured to optimally detect 134 kHz PIT tags, therefore readability of 125 kHz tags[4] was minimal. Antennae were each deployed overnight in A-10 Upper and Lower in areas where razorback sucker had been observed. Deployments were near shore in 1.2 – 1.5 m of water and secured to the substrate with weights for pass-through operation (the 0.6 m dimension was vertical). Catch from trammel nets that were deployed concurrently was retained in live pens to preclude redundant capture.

Larval Sampling

Attempts were made to attract and capture razorback sucker larvae using 12-volt submerged lights and hand-held dip nets, similar to the methods of Mueller (1995), in areas of known razorback sucker abundance. When available, up to 25 razorback sucker larvae were preserved in 95% ethanol for later genetic analysis at ASU; any additional larvae were released at the site of capture.

Piscine Predators

After evidence of piscine predation was noted on captured fish, studies were initiated to gather further information on the status of piscivorous fishes such as flathead catfish *Pylodictis olivaris* and largemouth bass *Micropterus salmoides* (Fig. 2a). Regular monitoring indicated low abundance of flathead catfish in A-10, and relatively higher abundance in A-7. In 2006, an attempt was made to estimate abundances of flathead catfish for each backwater. Gill nets and “jug lines” were deployed in September and October 2006. Large flathead catfish were weighed (kg), measured (TL in cm), scanned for PIT tags and metal objects, and marked. Methods were fully described in Campbell et al. (2007).

[4] Most PIT tagged razorback sucker stocked into the lower river were implanted with Biomark 125 kHz tags. Recent technological advances have necessitated the transition to 134 kHz tags, which results in increased readability. As a result, implantation of razorback sucker with 134 kHz tags was initiated in October 2007.

A mark-recapture census to estimate the population of largemouth bass in A-10 was performed in March and April 2007 (Barkstedt et al. 2008). A single-census, modified Peterson population estimate was calculated (Ricker 1975) and a distribution of largemouth bass TL was examined to estimate predation risk for stocked razorback sucker in A-10.

Avian Predation

Lower Colorado River razorback sucker monitoring 2003 – 2008 amassed qualitative notations for more than 3,000 capture events. These notations often indicated the presence of wounds suggesting avian predation - particularly scratches, punctures, or lacerations from beaks or talons (Figs. 2b – d). These wounds are typically abbreviated "AVP" in the database and were analyzed to investigate seasonal and spatial variation in AVP on razorback sucker. Records were grouped by locality (A-7, A-10 [all], A-10 Upper, A-10 Lower, and Other locations) and month of capture. Months were secondarily pooled into seasons - autumn (September – November), winter (December – February), and spring (March – May). Proportions of total razorback sucker catch with and without AVP were compared across localities, months, and seasons with a log-linear contingency analysis (PROC CATMOD, SAS Inst. 2004). Additionally, proportion of catch with AVP was compared across years to investigate annual fluctuation. A Chi-square Homogeneity Test was used to compare years.

Post -stocking observations of razorback sucker in A-10 indicated surfacing behavior and this was hypothesized as contributory to avian predation vulnerability. Surface feeding in hatchery rearing was identified as a possible cause for this surface orientation. Experimental rearing conditions were employed in attempt to reverse surface habituation. A sub-surface feeding exclosure was constructed and deployed at Arizona Game and Fish Department Bubbling Ponds State Fish Hatchery in October 2006. Construction and deployment details were described in Campbell et al. (2007). Two replications of a controlled rearing comparison of surface- (control) and subsurface-fed (experimental) razorback sucker were ultimately stocked in A-10 in January and October 2007.

An active, temporal monitoring approach was employed to quantify fish depth use at intervals post-stocking. A surface netting methodology was utilized which provided metrics for calculating depth at capture for each fish, and a mathematical model was used to interpret catch data and output a standardized, relative depth for each fish - Depth Index. The surface netting methodology and Depth Index model were thoroughly described in Campbell et al. (2007).

Depth Index was secondarily pooled to represent three depth categories - surface, middle, and substrate. Individual fish were categorized by depth at capture, treatment (surface- or subsurface-fed), and days since stocking, and these data were analyzed with ordinal logistic regression (PROC LOGISTIC, SAS Inst. 2004). Probability of capture within each depth third was modeled over days post-stocking to establish a trend of depth preference over time.

Release data for experimental stocks were compared to capture data in respect to release size (TL in cm). Histograms of slot-lengths were overlaid to investigate differences in distribution of fish size between release and capture.

Post-stocking encounter histories for all individuals from experimental stocks were generated over nine months of pooled capture data. An individual covariate, TL at release, was added and data were analyzed with a recapture model in MARK®. Surface- and subsurface-fed treatments were compared in addition to replicates (Cooch and White, 2008.) The final model chosen was based on numerous model adjustments and parameter reductions, resulting in a streamlined model that estimated seasonal (summer, not-summer) monthly survivorship and recapture rate, where survivorship varies with release size.

Telemetry

Two separate telemetry investigations were conducted in 2006 and 2007 – 2008. The first study investigated comparative movement, dispersal and mortality of razorback sucker stocked into A-7 and A-10. Sonic telemetry tags were used to track 12 fish released in each backwater as described in Campbell et al. (2007). Tracking surveys were conducted daily for the first five days post-release, then monthly thereafter through December 2006. The entire main channel from Palo Verde to Imperial dams was surveyed at least once. Location and habitat were noted for all fish contacts. A SCUBA diver using an underwater diver receiver (UDR) attempted to recover any tags that remained motionless for two survey periods.

The second telemetry survey was an attempt to locate spawning aggregations outside of regularly sampled localities. Twelve large (>50 cm TL), mature fish captured in the course of routine monitoring efforts were externally affixed with radio tags. Tag type and attachment methods were similar to those used by Lee et al. (2006). Seven mature razorback sucker were affixed with tags in January 2007 -- five in A-7 Upper, one in A-7 Lower, and one in C-7. Attempts on subsequent trips were made to contact the fish using ATS Model R2000 portable radio receivers with loop and whip antennae from the levee roads and from boats in A-7, C-5, C-

7, and the main river channel. Five additional fish captured in A-7 Upper were affixed with radio tags in winter of 2007 and monitored until April 2008.

Water Physico-chemistry

Water physico-chemistry measurements were recorded for A-10 and A-7 from August 2006 to September 2007, with increased frequency during summer. Parameters of interest included dissolved oxygen (DO, mg/L) and water temperature (°C). Water physico-chemistry parameters were recorded at a series of established stations within each backwater, the number of which was determined by backwater surface area. A water physico-chemistry profile was created by taking parameter measurements at three depths: at the substrate, in middle of the water column, and just below the surface. Measurements of water temperature, specific conductivity (µS/cm), and TDS (ppm) were also taken in conjunction with electrofishing efforts.

Stocking Site Acclimation

Research has shown that stocked fish become stressed when the transport water and receiving water differ in temperature (Stickney 1979). A tempering demonstration was designed for the September 2007 stocking at River Island / Buckskin Mountain State Park. Of three groups of fish (n = 3,600), two groups were untempered and stocked normally and one group was tempered, and then stocked. Two hundred fish from each treatment were implanted with PIT tags and each treatment was differentially wire tagged as an additional identifying mark. Capture data from subsequent collecting trips to the Parker Strip were queried for these fish to determine if capture rates differed between tempered and untempered PIT tagged fish. During the tempering process, an opportunistic video was taken of the river region where untempered fish were stocked and razorback sucker were seen breeching the water's surface. Video clips were analyzed for count of individual breeching fish and the video was forwarded to regional fisheries professionals for comment.

Results

Post-stocking Monitoring and Assessment

Lower Colorado River sampling yielded 24,602 fish, representing at least 21 species, from January 2006 to April 2008 (Table 4). The species most commonly contacted was bluegill sunfish *Lepomis macrochirus* (21.7% of catch). The dominance of sunfish, common carp *Cyprinus carpio*, and largemouth bass in the total catch was consistent in all sampling sites, except A-10 (Fig. 3).

Sampling effort among the four zones (Parker Strip, A-7, A-10, and Other) was variable across years 2006 – 2008 (Table 5, Fig. 4). The Other zone received extensive effort in 2006, but collections were dispersed over numerous discontinuous localities. Total effort in both A-10 and Other trended down over the study years. In A-10, this was due to increasing CPUE and a desire to limit the number of razorback sucker handled. On the other hand, effort was reduced in the Other zone as a result of previous efforts yielding few captures. Finally, effort in Parker Strip increased when stocking intensity increased for that zone.

Parker Strip zone had the highest electrofishing CPUE with a yield of 74.0 fish per 1,000 sec (seconds) real-time shocking (Fig. 5), while A-10 had the lowest electrofishing CPUE, with 48.9 fish per 1,000 s. CPUE in the A-7 zone was 67.2 fish per 1,000 s. Electrofishing CPUE in the "Other" zone was 71.4 fish per 1,000 s, and the localities with the highest CPUE occurred in this zone, including Walter's Camp (Cibola NWR, CA), where CPUE was 267.9 fish per 1,000 s. All other sampled localities ranged between 45.3 and 90.0 fish per 1,000 s.

A-10 had the highest trammel netting CPUE, with a yield of 5.5 fish per net-hour (Fig. 5), while Parker Strip had the lowest CPUE, with 0.7 fish per net-hour. CPUE in the A-7 zone was 1.5 fish per net-hour. CPUE in the "Other" zone was 2.8 fish per net-hour, however, certain locations within this zone had high CPUEs. For example, Imperial NWR yielded up to 8.2 fish per net-hour (CB-5, in California).

Razorback sucker

Surveys yielded 2,445 razorback sucker capture events including 10 hand collected mortalities and 2 fish incidentally captured in gill nets. One hundred sixteen fish were not PIT tagged or processed in any way due to fish escaping, equipment malfunction, or extremely large catch. Out of the 2,329 captures remaining, 2,213 were individual fish (Tables 6a - e, and 8). Razorback sucker captures made up 9.9% of the total trammel and electrofishing catch. Sex determinations were made for 2,281 fish, of which 777 were male, 468 female, 836 juvenile, and 200 unknown (48 fish were uncharacterized, Table 6d). Average TL was 39.0 cm (range 28.3 – 65.0 cm) and mean weight was 637 g (range 214 - 2,684 g). These values were based on measurements of 93% (TL, n= 2,265) and 74% (weight, n= 1,816) of all captures. Mean TL and weight were calculated separately for each sex: 45.4 cm (range 34.2 – 65.0 cm) and 951 g for females, 38.8 cm (range 29.0 – 58.5 cm) and 617 g for males, 34.9 cm (range 28.3 – 39.9 cm) and 451 g for juveniles (Tables 6b, c). Mean values above are additionally reported by stocking zone (Table 7). Fish size within gender was generally similar across localities, with great overlap in ranges. In contrast, distribution of catch differed among genders, but this may have been due to timing of samples. Growth rates (cm per day and cm per year) and days at large (number of days between stocking and capture determined from PIT codes) were calculated for multiple captures during the study period. As expected, females grew faster than males, but fish of undetermined gender exhibited fastest growth and juveniles grew the slowest (Table 8). Additionally, there were 32 mortalities, 15 of which were salvaged carcasses. Most fish contained hatchery wire tags (77.8%, Table 6e).

The overall CPUE for razorback sucker was 14.8 fish per 1,000 sec and 2.3 fish per net-hour. Electrofishing CPUE was highest in A-10 (22.5 fish per 1,000 sec) and the Parker Strip (19.3 fish per 1,000 sec). Trammel netting CPUE was highest in A-10, with 5.1 fish per net-hour, while all other zones had CPUE <0.2 fish per net-hour (Fig. 6). Throughout the study period, CPUE of razorback sucker in A-10 has increased annually (Fig. 7). Total fish CPUE in A-10 was likely influenced by razorback sucker abundance (Fig. 8).

Long-term trends in cumulative fish stocked and cumulative CPUE provided comparative evidence as to the local accumulation of stocked fish. In A-7, from which fish were known to disperse rapidly, cumulative CPUE remained consistently low for electrofishing and trammel netting (Fig. 9). In contrast, cumulative CPUE in A-10 maintained a positive slope, indicating accumulation of fish (Fig. 10), even though the total number fish stocked was half that in A-7.

PIT Tags and Mark-Recapture

ASU implanted 1,232 fish with PIT tags during the study period 2006-2008. This represents 67.0% of the 1,838 total tags implanted by ASU since 2003. An additional 1,075 razorback sucker captures (1,006 individuals, 5 short-term recaptures) were already PIT tagged; of these, 959 (907 individuals) had been tagged at stocking, 107 (96 individuals) had been tagged previously by ASU, 3 were tagged by Arizona Game & Fish Department, and one fish had an unknown tagging history (Table 6a). One hundred thirty-eight fish did not have PIT tag data: 17 were mortalities and 121 were released without being tagged. Among fish PIT tagged at stocking, 83% were captured in their location of release (Table 9), and time at large ranged from 12 – 913 d (0.03 – 2.5 y for 919 of these fish for which gender at capture was recorded. Most fish were at large <100 d (55.3%), and median days at large was 90 d (Table 8, Figs. 11a - b).

The lower river Native Fish Work Group (NFWG) razorback sucker PIT tag database reports a total 12,405 PIT tagged razorback sucker released into the Colorado River below Parker Dam since 1993 (Table 10). Of these, 1,014 (8%) have been captured after stocking, and only 62 (6%) of these were captured a second time. This number represents razorback sucker stocked with PIT tags and captured prior to the current study period by ASU or other agencies.

Stocking Zones

Parker Strip: Stocking in the Parker Strip resumed in December 2006 after a six year (2001 - 2005) hiatus, which resulted in increased sampling effort and razorback sucker catch after 2006 (Figs. 4, 8). Six monitoring trips yielded 265 razorback sucker captures (11.1% of total contacts in all zones). Of these captures, 237 fish were marked with PIT tags. Twenty-five additional fish contained PIT tags; two of these had been previously captured and tagged by ASU (Table 6a). Sex determinations were 101 males, 45 females, 93 juveniles, and 26 unknown (Table 7). Razorback sucker CPUE for electrofishing on Parker Strip yielded 19.3 fish per 1,000 s, whereas trammel netting CPUE was <1 fish per net-hour (Fig. 6).

Razorback sucker have been consistently captured within the Parker Strip in the lagoons at Castle Rock Shores (RM 190) and La Paz County Park (RM 184). No razorback sucker were encountered downstream of RM 181.5, although that area was sampled and USFWS has occasionally encountered razorback sucker on waters within the CRIT (NFWG online database at http://www.nativefishlab.net/nfwg/).

A-7 Zone: During the 2006-2008 study period, 143 razorback sucker were captured in the A-7 stocking zone (Table 6a). Of these, 102 fish were captured without PIT tags and were subsequently marked. Thirty-six fish (25.2%) contained PIT tags, 22 of which were PIT tagged at the time of stocking, and 13 of which were previously PIT tagged by ASU. Five fish were processed but released without a PIT tag. For all captures, sex determinations were: 43 males, 48 females, 37 juveniles, and 15 unknown (Table 7).

Within the A-7 backwater, 118 razorback sucker were contacted (109 in A-7 Upper, and 9 in A-7 Lower), accounting for 5.0% of the total catch in all zones. CPUE of razorback sucker was low at 0.76 fish per 1,000 sec and 0.19 fish per net-hour. This is consistent with the low CPUE for the preceding years, 2003 - 2005. Razorback sucker have been stocked into A-7 as recently as March 2006, and capture rates have decreased each year since then. During the study period, only 15 fish stocked in A-7 were captured after 150 or more days-at-large representing less than 0.01% of fish released (Figs. 11a, b). Collections in the main channel outside A-7 backwater resulted in three captures during the study period.

Due to collecting permit renewal issues, sampling in California backwaters within the A-7 stocking zone was limited, with the last collection conducted in April 2007. Before January 2006, California backwaters accounted for 21 of the razorback sucker captures in the study period; these were divided between C-5 (three captures) and C-7 (18 captures).

A Peterson population estimate was computed for A-7 using a single marking trip (January 2007) and multiple capture trips (March and April 2007, and February 2008). The estimate was calculated twice: once using captures from only A-7 Upper, and once from all waters in the A-7 zone. The number of recaptures (3) was the same in both estimates, regardless of capture locations. The backwater population was estimated to be 50 razorback sucker based on captures taken only from A-7 Upper, and the population estimate for the A-7 zone was 84 razorback sucker using captures from the entire zone.

A-10: Sampling in A-10 during 2006 – 2008 yielded 2,009 razorback sucker contacts (910 in A-10 Lower, and 1,099 in A-10 Upper) representing 82.2% of total captures in all zones. Of the captured fish, 890 did not contain PIT tags and were subsequently marked, and 990 fish contained PIT tags at the time of capture (13 mortalities and 116 unprocessed fish were untagged). Ninety-two of fish captured with PIT tags had been implanted by ASU. Sex determinations of captures in A-10 were 627 males, 368 females, 691 juveniles, and 159 unknown (including 13 mortalities but excluding 48 captures not processed for gender).

A-10 had the highest trammel netting CPUE for razorback sucker with 4.5 fish per net-hour for A-10 Upper and 5.9 fish per net-hour in A-10 Lower (Figs. 8, 9). All other sites had CPUE of fewer than 0.2 fish per net-hour. A-10 also had the highest razorback sucker CPUE for electrofishing, with 25.3 fish per 1,000 sec in A-10 Upper and 19.7 fish per 1,000 sec in A-10 Lower. Average CPUE has increased in A-10 every year since stocking began. Remote scanning over the course of four nights in A-10 resulted in 759 PIT tag contacts, including 536 individual razorback sucker. Scans per hour ranged from 1 to 86, with an average of 13.3.

Population estimates were calculated for A-10 based on paired sampling events. Only two estimates were calculated using more than two recaptures. Pairing February and March 2007 sampling efforts provided in nine recaptures and a population estimate of 2,719 (95% Confidence Interval [CI] 1,502 – 5,438). A second estimate was 6,054 fish (95 % CI 3,145 – 12,746), based on January and March 2008 samples with seven recaptures in A-10 (Upper and Lower combined).

A third population estimate was based on December 2007 and January 2008 sampling events, using additional data from remote scanning in January. Because of a tag frequency bias and the combination of sampling methods, only fish stocked in October 2007 with 134kHz PIT tags were used in calculating this estimate. Therefore the sub-population estimate for A-10 (representing fish stocked in October 2007 and present in December 2007) was 1,676 fish (95 % CI of 1,039 – 2,852). This confidence interval includes the actual number of fish stocked in October 2007 (1,399).

Other. Outside of the Parker Strip, A-7, and A-10 stocking zones, 28 razorback sucker were captured during 2006 – 2008. Three of these fish did not contain PIT tags, and were subsequently marked by ASU. Twenty-two of the 28 captures were from Imperial Division: Martinez Lake, Fisher's Landing, and Imperial NWR, and the other six were from Cibola Division. The 22 captures occurred in 2006 – 2007, and represented 0.9% of contacts during the 2006 - 2008 study period. No sampling was conducted in Imperial Division in 2008. Fish captured in Martinez Lake were recaptures from fish stocked with PIT tags at the same location in December 2005 and January 2006. The six razorback sucker captures in Cibola Division included two fish captured in the wash fans in the main channel between river miles 106 and 110 (Map 5). Eleven razorback sucker had been encountered at Sandy Cove (Hippy Hole) between 2004 and 2005, but only three were present when the site was sampled in 2006. Finally, one fish was captured in an unnamed California backwater at RM 99 in 2006.

A number of sites were sampled during 2006 which failed to yield razorback sucker contacts. These included Adobe Lake, Taylor Lake, Island Lake, Ferguson Lake, CS-1, CB-2, CB-3, CB-4, CB-5, and CB-6 backwaters, CB-10 Squaw Lake, C-10 backwaters, Oxbow Recreation Area, and Cibola NWR (Walter's Camp) (Maps 7, 8). In 2007 – 2008, fewer ancillary locations were sampled, including Walter's Camp, C-10, and Oxbow Recreation Area, resulting in no razorback sucker contacts.

Von Bertalanffy Growth Curve

A total of 984 paired records were available for the VBG curve. Average TL at release was 35.7 cm (range 30 – 46) and average TL at capture was 38.1 cm (range 29 – 59). All captures were within three years post-release and growth was nearly linear (Fig. 12). Asymptotic length (L_∞) was estimated at 108.2 cm and growth coefficient (K) was estimated at 0.0818. The VBG curve estimates average annual growth of 6 and 5 cm in years 1 and 2 respectively. Generally, fish size was variable within a 15 cm range at any given point within 1 year post-release; possibly due to similar variation in release size. This variation was generally restricted to a 10 cm range after 1.5 years. Extrapolated annual growth from fish measurements (n = 915) reflected a similar range 1.8 – 6.1 cm per year (Table 8).

Health and Parasite Observations

Qualitative razorback sucker data such as health (e.g., physical scars, tattered fins, wounds), characteristics (sexual condition), and presence of external parasites were noted, in addition to the quantitative measurements and tagging process. This information was compiled and compared over the various stocking zones with basic presence or absence of key comments in the database.

From 2006 - 2008, the percentage of tuberculate males was high in all zones, ranging from 74.3% (in Parker Strip) to 100% (in “Other”). The percentage of ripe males varied in each zone, ranging from 38.6% (in Parker Strip) to 100% (in “Other”). However, the overall percentage of ripe females was low in all zones, averaging 8.5%, and two females were tuberculate. These results are consistent with an expectation that a lower percentage of mature adults are in spawning condition (ripe) compared with fish that only exhibit secondary sexual characters.

Most razorback sucker across all zones were characterized as “Excellent” and “Good” for overall qualitative condition. There were a total of 35 mortalities during the 2006 – 2008 study period, 30 of which were salvaged from A-10 (Table 11).

All fish were examined for evidence of avian and piscine predation. The proportion of fish with AVP increased annually 2003 - 2008, with ca. 23% of total captures exhibiting marks (Fig. 13). Evidence of piscine predation was much lower (4.2% of all captures) and most notably higher in the A-7 and the Parker Strip zones (Table 12). Most piscine predation wounds were attributed to failed capture attempts by flathead catfish based on shape and size of bite marks.

A high incidence of external parasites, including anchorworm *Lernaea cyprinacea* and white grubs *Posthodiplostonum* sp., was noted among captured razorback sucker (Table 13). Mean incidence of anchorworm was highest in A-10 at 28% and ranged between 22% and 32% in 2006 – 2008. Fish in the Parker Strip had the second highest mean incidence of anchorworm (16%) and ranging from 10% to 28% over the same period (Figs. 14, 15). White grubs were present on 2.1% of all razorback sucker captured in all zones, and the highest incidence occurred on fish in the Parker Strip (3%, Fig. 14, 16).

Fish vulnerability to illness or parasitism increases with stress (Almeida et al. 2008, Costas et al. 2008, Huntingford et al. 2006). Previous capture, processing, and PIT tag implantation were predicted as stressors for razorback sucker. The possible correlation between handling stress and parasite infestation was investigated with two approaches. First, proportion of catch with and without parasites was analyzed (Chi-square homogeneity) for first captures of fish grouped by tag status (PIT tagged at stocking or not). Results indicated that parasite occurrences (anchorworm, white grub, or both) among fish PIT tagged at stocking were equivalent to that of fish without a PIT tag, suggesting that PIT-tagging at stocking did not influence parasite infection rate (Yates-corrected $X^2 = 45.2$, df = 1, $p < 0.001$, Fig. 17). Second, a similar analysis was performed to compare prevalence of parasitism between first and second captures for fish not PIT tagged at stocking. These fish were PIT tagged at first capture and were presumably stressed as a result. Results indicated that fish captured a second time were not significantly more parasitized than first captures (Yates-corrected $X^2 = 0.02$, df = 1, $p = 0.88$). White grub infestation was more prevalent among dead fish bearing PIT tags than without, but sample sizes precluded significance testing.

Wire Tag Loss

Analysis of hatchery-implanted wire tag retention has indicated that pectoral implantation, used on fish released at A-10 Upper, may result in high rates of tag loss or lack of readability (Barkstedt et al. 2008, Campbell et al. 2007). A release of 2,360 razorback sucker in September 2006 included individuals with both PIT and wire tags. Comparisons of release and capture data indicate that 353 of these fish were recaptured between October 2006 and April 2008. Of these, 91 were recaptured without detectable wire tags (25.8%). This was an insignificant increase of 1.8% when compared to catches up to December 2006, at which time 24.0% of fish from this same cohort were caught without detectable wire tags.

Larval Sampling

Three instances of contact with razorback sucker larvae were recorded during the study period 2006 – 2008, resulting in a total of 40 specimens. On 5 March 2007 over the course of 9 min, 29 razorback sucker larvae were contacted in A-10 Upper. Of these larvae, 25 were retained for genetic analysis and the others released. Local water temperature was 11.4º C. Additional collections were made in A-10 Upper, where 11 larvae were captured over the course of two nights (24 and 25 March 2008); all specimens were delivered to ASU for genetic analysis. Water temperature averaged 17.4º C for these two collections.

Bonytail

Recent bonytail stocking events have been limited to Buckskin State Park on the Parker Strip and A-7, with two stocking events in 2006 and one in 2007 (Table 1b). A total of 5,217 bonytail were stocked into A-7, and 1,208 were stocked into the Parker Strip.

Surveys yielded 183 bonytail capture events representing 177 individual fish (Table 14). Six fish were captured twice on the same collecting trip. Bonytail captures comprised 0.7 % of the total catch. Most fish were fully processed, but only 126 individuals were weighed. Two fish were female, the rest were of undetermined gender. Total length averaged 33.4 cm (27.0 – 41.0) and average weight was 359 g. There was one mortality. All of these fish are thought to be stocked because most contained hatchery wire tags: 26 in the left dorsal, 138 in the right dorsal, 2 in the caudal peduncle. Ten fish did not have detectable wire tags, and one fish was not scanned.

Six individual bonytail were captured at Parker Strip, none of which contained PIT tags. Average TL was 31.2 (range 27.0 – 35.5) and weight was not recorded. In the A-7 zone, 170 individual bonytail were contacted; 152 of these were in A-7 Upper and one in A-7 Lower. Twenty-five of these fish contained PIT tags, all implanted at stocking. Average TL for fish captured in A-7 was 33.5 cm (range 27.2 – 40.2 cm), and the average weight was 365 g. Sixteen individual bonytail were contacted in C-7. Two of these fish contained PIT tags; both were implanted at stocking. Average TL was 33.0 cm (range 27.2 – 35.6 cm) and average weight was 316 g. One bonytail was captured in the main channel in the Palo Verde Division. It was 33.5 cm and 276 g. A wire tag in the left dorsal indicated that the fish was released at A-7 Upper in 2007[5]. One bonytail was captured in Hippie Hole in February 2008. It was not marked with a PIT tag and it was 31.8 cm TL and weighed 263 g. A wire tag in the right dorsal indicated that the fish was released at A-7 Upper in 2007.

[5] Wire tags were implanted into the left dorsal region of bonytail released in A-7 backwater.

Piscine Predators

In A-10 backwater, multiple gill nets were fished for a total of 245.5 hrs in attempt to target large piscivores. These efforts captured only two flathead catfish, one common carp, and one razorback sucker. Jug lines captured only one largemouth bass. One flathead catfish was dead and the other was marked by us with a brass ring through the lip and released. None of the fish contained detectible PIT tags or metal. In A-7, similar gill nets were fished for a total of 160 hrs and captured one flathead catfish, two common carp, and 20 large blue tilapia *Oreochromis aureus*. The flathead catfish contained no detectible PIT tags or metal. Subsequent monitoring in A-10 has not encountered the one marked flathead catfish.

During March 2007, 61 largemouth bass were captured in A-10 (Upper and Lower), measured, and marked with fin clips. Total length of these fish averaged 26.5 cm (12.3 to 59.2 cm). The same sites were sampled in April 2007, resulting in the capture of 40 largemouth bass with an average TL of 25.5 cm. Four of these fish (two at each site) were recaptures from the marking event, allowing for population estimation. A standard modified Peterson single-census population estimate of largemouth bass in A-10 was N = 459 (95% CI 205 – 1,147).

Avian Predation

Proportion of catch with AVP increased from 2003 to 2008 (Fig. 13). Annual variation was significant (i.e., AVP was unequally distributed across years, $X^2 = 261.8$, df = 5, $p < 0.001$). Cumulative proportion of catch with AVP was 23% (675 of 2,970 records). A subset of fish captured with AVP were PIT tagged stocks, therefore of known age. At capture, these 293 fish were at large a mean of 146 d, whereas nearly half of the fish (137) were at large 43 d or less. Also, AVP varied monthly, seasonally, and spatially with one exception. Data indicated that seasonal variation in AVP in A-7 was not significant. In A-10 (all), A-10 Upper, A-10 Lower, and other locations, there was significant seasonal variation in AVP, with peaks generally observed in winter months (>30%, Fig. 18). A-10 was found to have significantly more AVP in the catch than A-7 or other locations ($X^2 = 85.92$, df = 1, $p < 0.001$, Fig. 19). Also, A-10 Upper had significantly more AVP than A-10 Lower ($X^2 = 11.36$, df = 1, $p < 0.001$), in fact, 60% of the January catch in A-10 Upper exhibited evidence of AVP.

A behavioral shift from pelagic to demersal swimming depth was evidenced by Depth Index model output. For up to 44 days post-release, more than 50% of the population is expected to spend time in the upper 2/3 of the water column (Fig. 20). Probability of capture in the upper third of the water column, though minimal, steadily declined to a mere 1.7% at 100 days post-stocking. Conversely, the probability of capture in the lower third of the water column steadily increased more than two-fold, with >75% probability by 100 days post-stocking.

Post-release monitoring of experimental stocks resulted in capture of 24% of fish released. Analysis of comparative size distributions for release and catch indicated that encounter rates for smaller fish were reduced (i.e., more large fish were captured than expected, Fig. 21). This trend was similar across treatments.

Survivorship modeling provided estimates of monthly survival based on release size. From these estimates, a size-based survivorship curve was generated (Fig. 22) in which a 35 cm razorback sucker stocked to A-10 has a monthly survivorship of 83.8% (95% CI 77.7 – 88.4) in non-summer months and a constant summer survivorship of 80.8% (95% CI 73.1 – 86.8). Similar values for larger stocked fish (40 cm) are 96.8% (95% CI 93.2 – 98.4) and 80.8%. Summer monthly survivorship was unrelated to release size, so this estimate is constant for all sizes of fish. Summer and non-summer monthly survivorship were combined to estimate overall monthly survivorship by multiplying the square-roots of each summer and non-summer estimate for a given fish size (Fig. 22). The mark-recapture model was modified to similarly estimate annual survivorship (Fig 23). Again, overall annual survivorship was derived by combining summer and non-summer estimates. For 35 and 40 cm fish, annual survivorship was estimated at 9.4% and 27.7%, respectively. Overall annual survivorship asymptotes at ca. 28% due to the fact that summer survivorship was constant. Unfortunately, treatment had no significant effect on survivorship in the mark-recapture model, therefore it was removed and differences between surface- and subsurface-fed fish were not realized. During one collection event, remote PIT scanning was used in addition to the standard collection methods of boat electrofishing and trammel netting. When only electrofishing and netting were used, recapture rate was estimated at <1% to 9%, while recapture rate increased four-fold to 39% when remote scanning was used.

Telemetry

Final status of 24 sonic-telemetry-tagged razorback sucker released in A-7 and A-10 is summarized in Campbell et al (2007). Briefly, 50% of the 12 fish released into A-7 backwater dispersed out of the backwater within 50 d. Fish that exited A-7 backwater were never contacted in any subsequent sonic survey, despite coverage of the entire main channel and adjacent backwater habitat. The remaining six fish that did not disperse all died within the backwater. These mortalities were confirmed by recovery of telemetry tags via SCUBA. In contrast to A-7, no dispersal was detected from A-10 backwater. All fish released there remained within A-10, and at the end of 200 days, only 2 of the 12 fish released at A-10 were still alive. All 12 fish stocked into A-7 were noted as dead or had disappeared within 70 days of release.

All seven fish that were radio-tagged in January 2007 were detected in February and March that year. Three fish moved between backwaters within the A-7 stocking zone from the release site at A-7 Upper. Results were mixed for fish implanted with radio tags in winter 2007 – 2008. One fish implanted in December 2007 in A-7 Upper was detected in February 2008 in A-7 Upper. Five fish tagged in February 2008 at A-7 Upper were detected immediately after release, but only two were contacted on subsequent trips, and these later contacts indicated the fish remained in A-7 Upper.

Water Physico-chemistry

Water temperature varied seasonally, daily, and with depth and ranged from 8.2 – 32.7 ºC. DO readings also varied seasonally: highest in January and lowest in July or August. Within generalized seasonal patterns, variation in readings was also localized. Barkstedt et al. (2008) provided full details on water physico-chemistry activities and results. Although local DO conditions approached theoretical tolerance limits for razorback sucker, such conditions were rare and highly localized. Overall, water physico-chemistry alone was not identified as a mortality factor, but it could have contributed to stressful summer conditions.

Stocking Site Acclimation

Approximately 450 fish (62 of which were PIT tagged) experienced the full stocking site acclimation period; others were released early and thus only partially acclimated. After the 2007 stocking, two sampling trips were conducted on the Parker Strip (Table 2), but only a few PIT tagged fish were recaptured after the acclimation experiment to assess the effect of tempering (6 tempered and 4 or more [6] untempered fish).

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[6] Four untempered fish were subsequently captured and verified by PIT code, but wire tag implant location did not allow differentiation of non-PIT tagged fish from previous stocks.

Also, review of video documenting the stocking event showed 60 individual fish breeching the surface in 103 seconds. This behavior may be partially explained as a stress response to the temperature differential between the transport and stocking waters. This response upon initial stocking is not unusual and has been observed to occur in other fish species as well (J. Millosovich, CADFG; R. Clarkston, USBR Phoenix; G. Mueller, USGS Denver; P. Marsh, ASU; pers. comm.)

Discussion

Razorback sucker have been stocked into the lower Colorado River for nearly three decades, resulting in the release of more than 2.5 M fish. However, less than 1% of these fish have ever been encountered again. In the last 5½ years, ASU has expended 21,703 net-hours and 165 real-time h of electrofishing effort in an attempt to assess razorback sucker populations in the river. Despite these efforts there were few contacts released fish, indicating that stocking has not established local populations. Similar stocking programs in the Gila River basin also have resulted in poor survival of razorback sucker and Colorado squawfish *Ptychocheilus lucius* (Hendrickson 1993, Jahrke and Clark 1999, Hyatt 2004). Variation in fish accumulation at lower river stocking locations has been observed, with only minimal abundances realized in backwaters such as A-7 with open connections to the main river channel. Stockings to A-10 resulted in comparatively greater accumulation of stocked fish, yet long-term survival was not realized. Calculations of time-at-large indicated that while stocked fish were relatively easy to encounter within a few months post-stocking, fish at large for longer than 1½ years are rare.

Rapid post-release dispersal was initially implicated as the reason that few were fish captured in stocking areas, but significant efforts failed to locate more than a few dispersed fish. Only a few individuals stocked into A-7 were encountered more than a few kilometers downstream, and capture data generally supported high site fidelity for captured fish. If in fact, fish did disperse downstream, they were virtually undetectable outside of backwaters proximal to the stocking site. Mortality was the alternative to dispersal from the stocking area. In an attempt to minimize dispersal and investigate post-release fish disappearance, stocking was shifted to a semi-isolated backwater were survival was predicted to be better. Telemetry also was employed to compare dispersal and survival of fish stocked into open vs. semi-isolated backwaters (A-7 and A-10, respectively). Dispersal from A-7 was rapid and from A-10 was nil, but ultimate survival of telemetered fish was uniformly low, indicating that dispersal alone did not necessarily put stocked fish at a higher risk of mortality.

Methodological (stocking practice) or environmental stressors were also predicted as contributors to high short-term mortality. Stocking stress, particularly due to thermal shock imposed by inadequate temperature acclimation, was implicated by observed stress-response behaviors of fish immediately post-release. Investigation of stocking records revealed that, for numerous stocking events during the study period, receiving water temperatures were much warmer than transport temperatures and likely resulted in undue stress at release. The feasibility temperature acclimation at the stocking site was investigated and found fraught with many difficulties. Instead, a policy change in hatchery delivery and stocking practice is required so that fish are adequately acclimated in hatchery trucks prior to release.

Fish health and condition at capture indicated that fish generally are encountered in excellent or good condition. Notable maladies included infection by anchorworm and white grub, but neither of these parasites are regarded as detrimental to overall survival and therefore these may be of minimal concern. It was noted that parasite incidence was not significantly more prevalent among fish which had been captured twice in comparison to first captures. Handling stress alone thus did not increase vulnerability to parasitism.   Spatial differences in parasitism (i.e., A-7 compared to A-10), may simply be due to higher transmission rates associated higher host density. Regardless of any perceived health issues, fish generally exhibited signs of spawning preparation (tuberculate or ripe), some were observed spawning, and larvae were collected. Additionally, fish growth was approximately linear for three years post-stocking. These data may have been weighted by numerous negative growth values, possibly indicating measurement error, but overall growth was positive. The Von Bertalanffy growth coefficient K = 0.16 was much lower than that of Lake Mohave (K = 0.86, unpublished data). However, much of the Lake Mohave data were from fish at large for more than 3 years, and may not be comparable to lower river data.

Water physico-chemistry, particularly low DO and elevated temperature, were hypothesized as contributory to observed declines in population abundance between spring and autumn 2006 (Campbell et al. 2007). Summer measurements of physico-chemical variables in 2007 indicated that although localized conditions for DO approached presumed tolerance limits, in general, backwaters provided hospitable conditions for razorback sucker. That year at least it seems unlikely that poor razorback sucker survival was a result of poor water conditions. It was therefore unlikely that fish condition, parasitism, or water physico-chemistry were consistently to blame for the lack of long-term survival for razorback sucker in the lower river.

The observations of fish condition that were of greatest concern were the presence of wounds suggesting fish or avian predation. While relatively few fish were captured with wounds from piscine predation, this is a known threat to the persistence of the species, especially in cohabitation with flathead catfish, striped bass *Morone saxatilis*, and largemouth bass. Flathead catfish is likely the most perilous predator of the razorback sucker in the lower river. Although flathead catfish is not known as a selective predator (Pine et al. 2005), numerous other researchers have noted the effects of this species on native communities (Guier et al. 1984; Moser and Roberts 1999; Thomas 1995). Slaughter and Jacobson (2008) noted that flathead catfish is not likely gape limited at larger adult sizes; and this probably holds true for razorback sucker as prey. Capture of large flathead catfish in monitoring efforts is uncommon, but even low abundances of this predator are likely of great impact to a razorback sucker population. Mueller et al. (2007) demonstrated that razorback sucker do not initially recognize flathead catfish as a mortality threat and naively approached the predator. A learned response was also demonstrated in that prey fish witnessing an attack learned that flathead catfish were to be avoided. This learning may be diluted in a larger system where prey and predators are dispersed and where water turbidity is high.

Much of the evidence of piscine predation in A-10 and elsewhere implicates flathead catfish as a predator. The shape, size, and positioning of certain bite marks, often on the lateral or ventral surface of the fish, suggests a demersal, ambush predator such as the flathead catfish (Fig. 23). These markings may provide an estimation procedure for predator TL by measuring the width of bite marks on wounded fish. Activities in 2006 attempted to estimate abundance for flathead catfish in A-7 and A-10 (Campbell et al. 2007). Collections resulted in insufficient data, but CPUE for this species has also remained low in both backwaters, indicating low abundance. A few exceptionally large specimens were weighed and measured: mean weight was 13.1 kg (range 4.1 – 22.7, n = 25) and mean TL was 96.0 cm (range 70.5 – 126.0, n = 13). These large specimens are rare in the catch but likely require high food intake. A single flathead catfish in an enclosed backwater like A-10 might make a significant negative impact on the population over time. For this opportunistic predator, a fish community dominated by an endangered species will likely result in a prevalence of razorback sucker in the predator's diet. The isolated observations of a razorback sucker found in the stomach contents of flathead catfish and one large channel catfish *Ictalurus punctatus* indicated that both species are likely of concern.

While striped bass were generally rare in the catch, they should not be excluded as a significant predator of razorback sucker in the lower river. CPUE of striped bass was higher in flowing river collections (e.g., Parker Strip) than in slackwater habitats, particularly backwaters. This voracious predator is implicated as a primary predator of razorback sucker stocked in Lake Mohave (Karam et al. 2008), but its effects on lower river razorback sucker is largely unknown. Fish stocked into semi-isolated backwaters are likely relatively immune to predation by this species, but fish stocked into the river or into open backwaters may be at higher risk.

Some published literature exists on the relationship between prey size and largemouth bass TL. Due to the lack of recruitment and stocking size minimums (30 cm TL), small razorback sucker do not occur in the lower river, therefore it was generally assumed that most stocked fish are outside the range of prey for largemouth bass. Numerous trophy-sized largemouth bass have been encountered in monitoring efforts: mean weight 3.7 kg (range 2.3 – 5.9, n = 31) and mean TL 55.8 cm (range 40.0 – 67.0, n = 19). Even the largest specimens would likely have much difficulty swallowing a 30 cm razorback sucker, but this might not deter a predation attempt, the aftermath of which could be partial digestion (see next) or infection and death. Largemouth bass is generally ubiquitous in all localities along the lower river, though large specimens are often selected through angling. Few fish of such size were encountered in A-10 and it is unlikely that this predator poses a significant threat to razorback sucker simply because of its low abundance.

During 2007 – 2008 collections, several floating razorback sucker mortalities were discovered in A-10 Upper. All appeared to have been swallowed head-first by a piscine predator. The heads were in various states of digestion (some down to the skeleton) while the remainder of the body (post-nuchal) was fully intact (Fig. 24). It was hypothesized that this suggested incomplete digestion by a largemouth bass attempting to consume oversized prey. Kurtenbach (1985) noted that largemouth bass have a tendency to attempt swallowing oversized prey, resulting in the prey becoming lodged in the throat. The author observed that such predation attempts were restricted to sick or injured prey. Later, when possible, the partially digested prey was regurgitated. In spite of this evidence, more questions remain unanswered and may warrant further study: Does the nuchal hump of the razorback sucker represent a hindrance to the predator in swallowing the prey? Does the process of attack, incomplete digestion, and regurgitation result in increased predation or prey mortality because the predator is not satiated?

The most overwhelming evidence implicating a single mortality factor is that of fish bearing wounds from failed avian predation (AVP). Annual increases in AVP were observed from 2003 - 2008, but this may not simply be due to an increase in regional avian predator abundance. In

2005, the primary stocking location was moved from A-7 to A-10, and fish caught in A-10 Upper exhibited elevated AVP in comparison to other sites. A-10 Upper was the initial recipient of stocked fish; therefore the temporal increase in AVP may in part be due to the shift in stocking location. A-10 Upper receives relatively less recreational use due to accessibility (i.e., condition of boat ramp) than A-7 or A-10 Lower, and this may provide a habitat of reduced human disturbance that fosters increased residency by avian piscivores. Seasonal trends in avian predation were expected, as the lower river is a migratory corridor for many of these birds. The fact that more than half of the fish caught in January in A-10 Upper had AVP indicates that this mortality threat is significant.

Nearly half of the fish captured with AVP were at large less than 43 d, which indicates that the threat of avian predation begins immediately upon release. This corresponds with the depth probability curve in which half of captured fish are found in the upper 2/3 of the water column for some time post-stocking. Only after ca. 90 days post-release are stocked fish residing near the substrate almost exclusively (>75%). This substantial delay in changing behavior provides a window of opportunity in which to interact with avian predators.

It might be assumed that smaller fish fell victim to avian predation (either consumed or critically injured) because they were absent from the catch, whereas larger fish escaped (though many showed signs of failed predation). Survivorship of razorback sucker in A-10 was indeed correlated with release size, but it is unknown whether or not this relationship holds through the 2nd or subsequent years because there were few long-term recaptures. Summer survivorship was not significantly influenced by release size, indicating that factors other than avian predation may be dictating survival during summer months. However, since summer monthly survival was derived from few data in comparison to non-summer survivorship, this estimate may later be refined. Overall, estimated annual survivorship is considerably less than that predicted for Lake Mohave.

Stocking of subadult razorback sucker in the lower river is generally failing to establish populations of adult fish. Fish at large for longer than two years are extremely rare in the catch, despite continued stocking of more than 80,000 subadult fish since 2000. Of all sources of post-stocking mortality investigated here, only piscine and avian predation appear to preclude long-term survival. In Parker Strip, there are high abundances of largemouth bass, striped bass, and flathead catfish, three major predators of razorback sucker, and piscine predation continues to be a major concern. The permanent connection between A-7 and the main river channel allows continual immigration of large piscivorous fish, and high AVP incidence in A-10 means that this uncontrolled factor will continue to have a significant negative impact on razorback sucker in that backwater.

Recommendations

We do not advocate continued stocking of razorback sucker into the lower Colorado River below Parker Dam. This will merely result in the maintenance of low abundance levels for newly-released fish, and therefore has little value in light of the purpose of population augmentation. Revised razorback sucker recovery goals call for stable populations of 5,000 individuals (USFWS 2008). Present stocking locations are not hospitable to razorback sucker and alternate locations on the lower river are expected to present similar threats to survival. Parker Strip maintains substantial populations of predatory flathead catfish, striped bass, and largemouth bass, but also maintains low levels of avian predation, a factor that is likely curtailed by recreational boating. A-7 backwater maintains notable, but lower abundances of flathead catfish, striped bass, and largemouth bass and offers ample habitat for avian piscivores. In contrast, A-10 backwater is occupied by few large piscine predators, but this is largely outweighed by the consistent presence of avian piscivores. No location on the lower river is absent of piscine and avian threats, thus the outcome of relocated stocking is going to be the same as what already has been documented.

If stocking must continue because it is mandated, several modifications may enhance survival of stocked fish. Pre-release training in predator avoidance and natural foraging are critical for stockings into backwater. Research has shown that fish learn predator avoidance responses by observation of predation on conspecifics. Although this behavior may be exhibited only briefly, it may pay great dividends in short-term survival. Research outlined here indicated a shift in swimming depth post-stocking, although this shift occurred slowly. Methodological enhancements in hatchery feeding to encourage more natural foraging regimes may result in more rapid transition from hatchery to the wild. If this translates to reduced vulnerability to avian predators, then there may be substantially increased survival. Finally, adequate temperature acclimation is encouraged for backwater stockings. Backwater surface water temperatures are often higher than transport temperature, resulting in temperature shock and undue stress upon release. Implementing this change will also require hatchery protocol and policy changes because temperature acclimation is best performed in the transport tank to minimize additional handling. For river stockings (e.g., Parker Strip), pre-release flow conditioning or rearing in flowing water systems could enhance post-stocking survival. Although fish may be stocked in slackwater areas, they have been observed to immediately leave the area into swifter currents.

The rate of loss of wire tags, and the lack of individual identification, makes them less desirable than PIT tags for long-term monitoring. PIT tags provide individual information that can be used to evaluate fish growth and dispersal, among other factors. If stocking continues, both razorback sucker and bonytail should be PIT tagged before release, if not earlier in the grow-out process. This could make enumerating fish more efficient for hatchery personnel, and ultimately provide more accurate growth data on individual fish. Also, full PIT-tagging of released fish will provide opportunity to use less invasive remote scanning methods to more effectively monitor these populations.

The only solution to appropriately ensure long-term survival of razorback sucker in the lower river is to stock these fish into predator-free habitats. Presently, nonnative fish-free habitats exist or are easily created, but no habitats exist which mitigate the effects of avian predation. Control measures are strongly suggested to discourage residency and use by avian piscivores. Data here have demonstrated that avian piscivores can have a swift and significant impact on survival of fish stocked into a closed habitat.

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Table 1a. Number, year, and location of razorback sucker stocked into the lower Colorado River below Parker Dam [7].

Year	Stocking Location	No. Stocked
1986	1/3 Acre Backwater	9,995
	3 Acre Backwater	400,467
	Agnes Wilson River Crossing	5,000
	Bluewater Lagoon	70,000
	CA Backwater RM 68	466,560
	CRIT, 1 Acre Drain	9,995
	La Paz Lake	25,000
	Parker Strip	254
	River Island, Buckskin Mountain State Park	38,000
	Smoketree Point	20,000
1987	2 RM upstream of Oxbow lake, Isolated pond	20,490
	AZ Backwater RM 167	402,998
	AZ Backwater RM 67	90,736
	C-5 Backwater, Goose Flats	11,617
	CA Backwater 66.5	94,848
	CA Backwater RM 167	604,752
	CA Backwater RM 81.8	59,461
	La Paz Lake	5,129
	PVID Canal-intersection US HWY 95 N of Blythe	5,088
	Senator Wash	82
1988	Senator Wash	1,700
1989	C-5 Backwater, Goose Flats	1,375
1990	Senator Wash	3,039
1993	Cibola NWR, High Levee Pond	14,006
1995	Cibola NWR, High Levee Pond	4,000
	Farm Fish Pond	9,000
	Imperial Reservoir	26
1996	Imperial Reservoir	33
	River Island, Buckskin Mountain State Park	70,000
1997	River Island, Buckskin Mountain State Park	2,000
1998	Imperial Reservoir	62
1999	Imperial Reservoir	38
	River Island, Buckskin Mountain State Park	2,383

[7]Stocking data were compiled from numerous sources that are not listed in this report. Summary information is adapted from Schooley and Marsh 2007, and updated with recent data.

2000	A-7 Upper backwater	2,990
	Imperial Reservoir	37
	Lower River, Unknown location	45
	River Island, Buckskin Mountain State Park	1,308
2001	A-7 Upper Backwater	4,388
	Imperial Reservoir	37
2002	A-7 Upper Backwater	15,548
2003	A-7 Upper Backwater	14,058
	Imperial NWR, Main Channel	12
2004	A-7 Upper Backwater	5,212
2005	A-10 Upper Backwater	2,161
	A-7 Upper Backwater	2,143
2006	A-10 Lower Backwater	4,841
	A-10 Upper Backwater	790
	A-7 Upper Backwater	1,642
	Buckskin Mountain State Park	200
	Main Channel, Imperial Duck Ponds	30
	Martinez Lake	727
	River Island, Buckskin Mountain State Park	200
2007	A-10 Lower Backwater	1,288
	A-10 Upper Backwater	3,765
	Buckskin Mountain State Park	1,051
	River Island, Buckskin Mountain State Park	6,502
2008	A-10 Lower Backwater	2,648
	River Island, Buckskin Mountain State Park	3,024
Total		2,522,781

Table 1b. Number, year, and location of bonytail stocked into the lower Colorado River below Parker Dam.

Year	Stocking Location	No. Stocked
2006	A-7 Upper Backwater	4,007
	River Island, Buckskin Mountain State Park	1,208
2007	A-7 Upper Backwater	1,210
Totals		6,425

Table 2. Razorback sucker survey trip and annual report numbers, dates and locations on the lower Colorado River, January 2006 – April 2008.

Report No.	Trip Dates	Sampling Locations
2-1	06 - 13 Jan 2006	Main Channel (Imperial), Adobe Lake, Taylor Lake, Island Lake
2-2	09 - 17 Feb 2006	Imperial NWR, Martinez Lake, Ferguson Lake, Fisher's Landing, Main Channel (Imperial)
2-3	28 Feb - 9 Mar 2006	C-5, C-7 and C-10 Backwaters, A-10 Upper and Lower Backwaters, A-7 Upper Backwater
2-4	11 - 20 Apr 2006	Main Channel (Imperial), CS-1, CB-2, CB-3, CB-4, CB-5, and CB-6 Backwaters, CB-10 Squaw Lake
2-5	2 - 11 May 2006	C-5 and C-7 Backwaters, A-10 Upper and Lower Backwaters, A-7 Upper Backwater, Sandy Cove, Main Channel (Cibola)
2-6	9 - 13 and 23 - 27 Oct 2006	C-5 and C-7 Backwaters, A-10 Upper and Lower Backwaters, A-7 Upper Backwater, Sandy Cove
2-7	6 - 9 Nov, 28 Nov - 2 Dec 2006	Cibola NWR (Walter's Camp), Oxbow Recreational Area, Bonnie's Kitchen, Squatter Backwater, C-7 and C-10 Backwaters, A-10 Upper and Lower Backwaters, Main Channel (Palo Verde)
2-8	11 - 15 Dec 2006	Main Channel (Parker Strip)
2006	Jan 2006 - Dec 2006	Annual Report on Lower Colorado River downstream of Parker Dam to Laguna Dam
2-9	2 - 6 and 15 - 19 Jan 2007	Main Channel (Cibola), C-5 and C-7 Backwaters, A-7 Upper and Lower Backwaters, Sandy Cove, Oxbow Recreation Area
2-10	5 - 9 and 19 - 23 Feb 2007	Imperial NWR, Martinez Lake, Fisher's Landing, Main Channel (Palo Verde), A-10 Upper and Lower Backwaters, C-5 and C-10 Backwaters
2-11	5 - 8 and 26 - 30 Mar 2007	A-10 Upper and Lower Backwaters, A-7 Lower Backwater, Main Channel (Parker Strip and Palo Verde)
2-12	9 - 13 and 23 - 27 Apr 2007	C-7 Backwater, A-10 Upper Backwater, A-7 Upper and Lower Backwaters, Sandy Cove, Oxbow Recreation Area, Main Channel (Cibola and Palo Verde)

2-13	8 - 12 and 22 - 26 Oct 2007	A-10 Upper and Lower Backwaters, A-7 Upper and Lower Backwaters, Main Channel (Parker Strip)
2-14	5 - 9 Nov 2007	A-10 Upper Backwater, A-7 Upper and Lower Backwaters, Sandy Cove, Main Channel (Cibola and Palo Verde)
2-15	5 - 7 and 17 - 20 Dec 2007	A-10 Upper and Lower backwaters, A-7 Upper section
2007	Jan 2007 - Dec 2007	Annual Report on Lower Colorado River downstream of Parker Dam to Laguna Dam
2-16	15 - 18 and 28 Jan - 1 Feb 2008	Main Channel (Parker Strip), A-10 Upper and Lower Backwaters
2-17	4 - 8 Feb 2008	A-7 Upper and Lower Backwaters, Sandy Cove, Main Channel (Cibola and Palo Verde)
2-18	3 - 7 and 24 - 28 March 2008	Main Channel (Parker Strip), A-10 Upper and Lower Backwaters
2-19	22 - 27 April 2008	A-7 Upper and Lower Backwaters, Main Channel (Parker Strip)

Table 3. Summary of voucher specimens (field-collected, fixed, preserved and deposited into Arizona State University Collections, Tempe) from the lower Colorado River, 2003 – 2008. Not all species were collected every year and "N/A" indicates that the species was not collected in that year. No voucher specimens were collected in 2007 or 2008.

Species	2003	2004	2005	2006	Total
Ameiurus natalis	5	2	0	0	7
Carassius auratus	1	0	0	0	1
Cyprinus carpio	0	0	0	0	0
Cyprinella lutrensis	3	0	5	N/A	8
Dorosoma petenense	10	0	0	0	10
Gambusia affinis	0	0	0	N/A	0
Gila elegans	N/A	N/A	N/A	N/A	0
Ictalurus punctatus	2	3	5	1	11
Lepomis cyanellus	9	1	0	0	10
Lepomis gulosus	12	1	0	2	15
Lepomis macrochirus	15	0	0	2	17
Lepomis microlophus	8	0	0	0	8
Lepomis sp.	19	0	0	0	19
Micropterus dolomieu	8	4	0	0	12
Micropterus salmoides	12	3	0	3	18
Morone saxatilis	2	1	7	8	18
Mugil cephalus	0	0	0	0	0
Notemigonus crysoleucas	N/A	N/A	1	N/A	1
Oreochromis aureus	N/A	N/A	N/A	0	0
Pimephales promelas	N/A	1	N/A	N/A	1
Poecilia latipinna	N/A	2	3	N/A	5
Pomoxis annularis	1	N/A	N/A	N/A	1
Pomoxis nigromaculatus	9	5	3	3	20
Pomoxis sp.	1	N/A	N/A	N/A	1
Pylodictis olivaris	5	4	3	0	12
Tilapia sp.	19	0	0	1	20
Tilapia zilli	N/A	N/A	0	1	1
Unknown larval fish	N/A	1	N/A	N/A	1
Xyrauchen texanus	2	10	6	0	18

Table 4. Number of each species captured and percentage of catch by electrofishing (EF) and trammel netting (TN), lower Colorado River, January 2006 – April 2008.

Species	EF	%	TN	%	Sum	Total %
Ameiurus natalis	-	-	15	0.13 %	15	<0.1 %
Carassius auratus	12	0.09 %	3	<0.1 %	15	<0.1 %
Cyprinella lutrensis	1	<0.1 %	-	-	1	<0.1 %
Cyprinus carpio	1,546	11.65 %	1,366	12.05 %	2,912	11.84 %
Dorosoma petenense	908	6.84 %	2	<0.1 %	910	3.70 %
Gila elegans	21	0.16 %	161	1.42 %	182	0.74 %
Ictalurus punctatus	248	1.87 %	469	4.14 %	717	2.91 %
Lepomis cyanellus	114	0.86 %	1	<0.1 %	115	0.47 %
Lepomis gulosus	183	1.38 %	108	0.95 %	291	1.18 %
Lepomis macrochirus	2,087	15.73 %	3,242	28.61 %	5,329	21.66 %
Lepomis microlophus	1,240	9.34 %	2,117	18.68 %	3,357	13.65 %
Lepomis sp.	1,330	10.02 %	-	-	1,330	5.41 %
Micropterus dolomieu	563	4.24 %	154	1.36 %	717	2.91 %
Micropterus salmoides	3,775	28.45 %	1,015	8.96 %	4,790	19.47 %
Morone saxatilis	244	1.84 %	267	2.36 %	511	2.08 %
Mugil cephalus	-	-	1	<0.1 %	1	<0.1 %
Oreochromis aureus	43	0.32 %	214	1.89 %	257	1.04 %
Pomoxis annularis	-	-	1	<0.1 %	1	<0.1 %
Pomoxis nigromaculatus	43	0.32 %	45	0.40 %	88	0.36 %
Pylodictis olivaris	131	0.99 %	252	2.22 %	383	1.56 %
Tilapia sp.	4	<0.1 %	14	0.12 %	18	<0.1 %
Tilapia zillii	70	0.53 %	159	1.40 %	229	0.93 %
Xyrauchen texanus	707	5.33 %	1,726	15.23 %	2,433	9.89 %
Total	13,270		11,332		24,602	

Table 5. Summary of effort and catch by stocking zone, lower Colorado River, January 2006 – April 2008.

	Electrofishing			Trammel Netting	
Stocking Zone	Seconds	Hours	Catch	Net Hours	Catch
Parker Strip	31,250	8.7	2,046	1,366.90	849
A-7	85,019	23.6	5,698	3,461.10	4,452
A-10	30,458	8.4	1,290	549.1	1,835
Other	61,506	17.1	4,236	2,482.40	4,196
Total	208,233	58	13,270	7,860	11,332

Tables 6a - e. Razorback sucker capture data summary, lower Colorado River, January 2006 – April 2008.

6a. Capture Status by Stocking Zone, 2006 – 2008.

	Parker	A-7	A-10	Other	Total
Total capture events:	265	143	2,009	28	2,445
Fish marked with PIT tag:	237	102	890	3	1,232
Fish captured with PIT tag[8]:	25	36	990	24	1,075
Marked at release:	22	22	891	24	959
Mortalities:	1	0	17	0	18
ASU Recaptures:	2	13	92	0	107
Mortalities:	0	0	0	0	0
AZGFD Recaptures:	0	0	3	0	3
Unknown Marking Status:	0	0	1	0	1
Same-Trip Recaptures:	1	1	3	0	5
Mortalities:	0	0	0	0	0
Unmarked Fish:	3	5	129	1	138
Mortalities:	3	0	13	1	17
Released without PIT tag[9]:	0	5	116	0	121

6b. Length Data (cm) – 2,281 records, 2006 – 2008.

	Mean TL (range)	Number of Records
Overall	39.0 (28.3 – 65.0)	2,281
Male	38.8 (29.0 – 58.5)	777
Female	45.4 (34.2 – 65.0)	468
Juvenile	34.9 (28.3 – 39.9)	836
Unknown[10]	42.6 (40.0 – 53.5)	200

[8] Five fish were tagged by other agencies, two fish recaptured have unknown tagging histories.
[9] Includes five razorback sucker processed but released without a PIT tag in A-7.
[10] Razorback sucker classified as "unknown gender" are ≥40.0 cm TL and display no diagnostic secondary sexual characteristics. Fish <40.0 cm displaying no diagnostic secondary sexual characteristics are classified as "juvenile."

6c. Weight Data (g) – 1,816 records, 2006 – 2008.		
	Mean Weight (range)	Number of Records
Overall	647 (214 – 2,684)	1,815
Male	617 (235 – 1,828)	628
Female	951 (400 – 2,684)	400
Juvenile	451 (214 – 731)	629
Unknown	776 (485 – 1663)	159

6d. Gender Ratios – 2,281 records, 2006 – 2008.[11]

	Count	%
Male	777	34.1%
Female	468	20.5%
Juvenile	836	36.6%
Unknown	200	8.8%

6e. Hatchery Wire Tags – 2,221 records, 2006 – 2008.

	Count	%		
Detectable wire tags	1,729	77.8 %		
- Left Caudal Peduncle			11	0.5%
- Left Dorsal			138	6.2%
- Left Pectoral			287	12.9%
- Right Caudal Peduncle			1,025	46.2%
- Right Dorsal			4	0.2%
- Right Nuchal			136	6.1%
- Right Pectoral			128	5.7%
None Detected[12]	492	22.2%		

[11] 48 fish captures were uncharacterized.
[12] Multiple stocking events included fish that were PIT tagged and not wire tagged. Therefore this sum includes those fish as well as fish which presumably lost their wire tags.

Table 7. Summary statistics for razorback sucker captured in the lower Colorado River, January 2006 – April 2008. Numbers of fish (No.), mean total length (TL) and range, and mean weight (WT) are presented by gender. Counts exclude captures that were not processed for gender (2,281 capture records, excludes 48 fish).

	Parker Strip		A-7		A-10		Other	
	No.	TL (cm) WT (g)	No.	TL (cm) WT (g)	No.	TL (cm) WT (g)	No.	TL (cm) WT (g)
Male	101	38.9 (30.9 - 52.3) 652 g	43	44.6 (33.3 - 58.5) 1,005 g	627	38.4 (29.0 – 58.5) 580 g	6	36.5 (32.9 – 47.4) 735 g
Female	45	45.6 (39.0 - 65.0) 995 g	48	51.8 (39.9 – 62.0) 1,534 g	368	44.4 (34.2 - 56.4) 865 g	7	50.6 (38.4 – 61.0) 1,536 g
Juvenile	93	35.9 (30.9 - 39.8) 507 g	37	35.6 (32.0 - 39.7) 487 g	691	34.8 (29.0 - 39.9) 440 g	15	33.5 (28.3 - 38.1) 399 g
Unknown	26	42.0 (40.5 - 45.2) 802 g	15	46.2 (40.0 - 53.5) 1,052 g	159	42.3 (40.0 - 49.9) 745 g	0	- -
Total	265		143		1,845		28	

Table 8. Observed (daily) and extrapolated (annual) growth statistics and days at large by sex of recaptured razorback sucker from the lower Colorado River, January 2006 – April 2008. Table includes all captures of razorback sucker PIT tagged prior to release with capture gender characterization (919 records, excludes 40 fish).

	n	Median days at large (range)	Mean daily growth (cm)	Extrapolated annual growth (cm)
Male	277	147 (12-747)	0.0055	2.0
Female	149	315 (12-913)	0.0161	5.9
Juvenile	420	41 (12-560)	0.0049	1.8
Unknown	73	153 (28-795)	0.0175	6.4

Table 9. Site fidelity of razorback sucker, comparing marking and (re)capture locations in the lower Colorado River, January 2006 – April 2008. Note that this table only includes fish stocked with a PIT tag and recaptured by ASU (959 records).

		Stocking Location					
		Parker Strip	A-7 U	A-10 U	A-10 L	Oxbow Rec. Area	Martinez Lake
Recapture Location	Parker Strip	22	-	-	-	-	-
	A-7 U	-	13	-	-	-	-
	A-7 L	-	2	-	-	-	-
	C-7	-	4	-	-	-	-
	MC, Palo Verde	-	1	-	1	1	-
	A-10 U	-	-	315	109	-	-
	A-10 L	-	-	46	421	-	-
	Unnamed Backwater, RM 99	-	-	-	1	-	-
	Hippie Hole	-	-	-	1	1	-
	Martinez Lake	-	-	-	-	-	21

Table 10. Number of razorback sucker PIT tagged and measured (total length) prior to stocking into the lower Colorado River, 1993 - 2008 (Adapted from C. Pacey, ASU, unpublished data)[13].

Year	Number of Tagged Fish	Avg. TL (cm)	SD	Min	Max
1993	53	42.1	4.86	36.3	61.5
1994	80	28.2	2.35	25.0	37.8
1995	513	31.7	5.84	25.0	59.2
1996	199	39.8	9.71	25.0	66.0
1998	99	44.1	5.94	36.0	55.3
1999	46	45.3	4.67	37.7	54.8
2000	7	28.6	1.20	27.2	30.2
2001	221	37.4	2.68	29.2	46.4
2002	10	41.7	11.48	26.4	56.0
2003	18	42.5	6.46	28.5	53.5
2004	811	40.0	7.26	26.5	57.5
2005	861	37.0	5.45	27.6	60.0
2006	4,265	35.7	4.86	30.5	62.0
2007	4,428	35.5	3.50	29.5	57.5
2008	794	37.7	4.71	29.0	59.3
Totals:	12,405	37.8		25.0	66.0

[13] No PIT-tagged razorback sucker were stocked in the lower Colorado River in 1997.

Table 11. Number of razorback sucker in each of the five condition categories categorized by location (stocking zone), lower Colorado River, January 2006 – April 2008. Table includes all captures that were at least partially processed (2,329 records, excludes 116 unprocessed captures).

Stocking Zone	Excellent	Good	Fair	Poor	Mortality	Uncategorized
Parker Strip	104	83	47	26	4	1
A-7	56	62	24	1	0	0
A-10	742	735	286	36	30	64
Other	2	15	8	0	1	2
Total	904	895	365	63	35	67

Table 12. Number of razorback sucker and percentage of the total catch showing evidence of piscine predation by location (stocking zone), lower Colorado River, January 2006 – April 2008.

Stocking Zone	No.	% of Catch
Parker Strip	42	15.8
A-7	18	12.6
A-10	40	2.1
Other	0	0
Total	100	4.2

Table 13. Number of razorback sucker and percentage of total catch showing evidence of parasites (anchorworm and white grub) by location (stocking zone), lower Colorado River, January 2006 – April 2008.

	Anchorworm		White Grub	
Stocking Zone	No.	% of Catch	No.	% of Catch
Parker Strip	44	16.6	10	3.8
A-7	10	7.0	1	0.7
A-10	548	28.3	40	2.1
Other	1	3.6	0	0
Total	603	25.4	51	2.1

Table 14. Bonytail collection data of gender ratios, number of individuals captured in stocking zones, PIT tag status at time of capture, and wire tag location on individuals, lower Colorado River, January 2006 – April 2008.

	No. Captures	No. Individuals
	183	177
Gender Ratios		
Female	-	2
Unknown	-	175
Capture Zone		
Parker Strip	-	6
A-7	-	153
Other	-	18
Capture Status		
Fish marked with PIT tag	149	-
Fish captured with PIT tag	27	-
ASU Recaptures	0	-
Marked at Release	27	-
Mortality	1	-
Same-Trip Recaptures	6	-
Wire Tag Location		
Left Dorsal	-	26
Left Caudal Peduncle	-	2
Right Dorsal	-	138
None Detected	-	10
Not Scanned	-	1

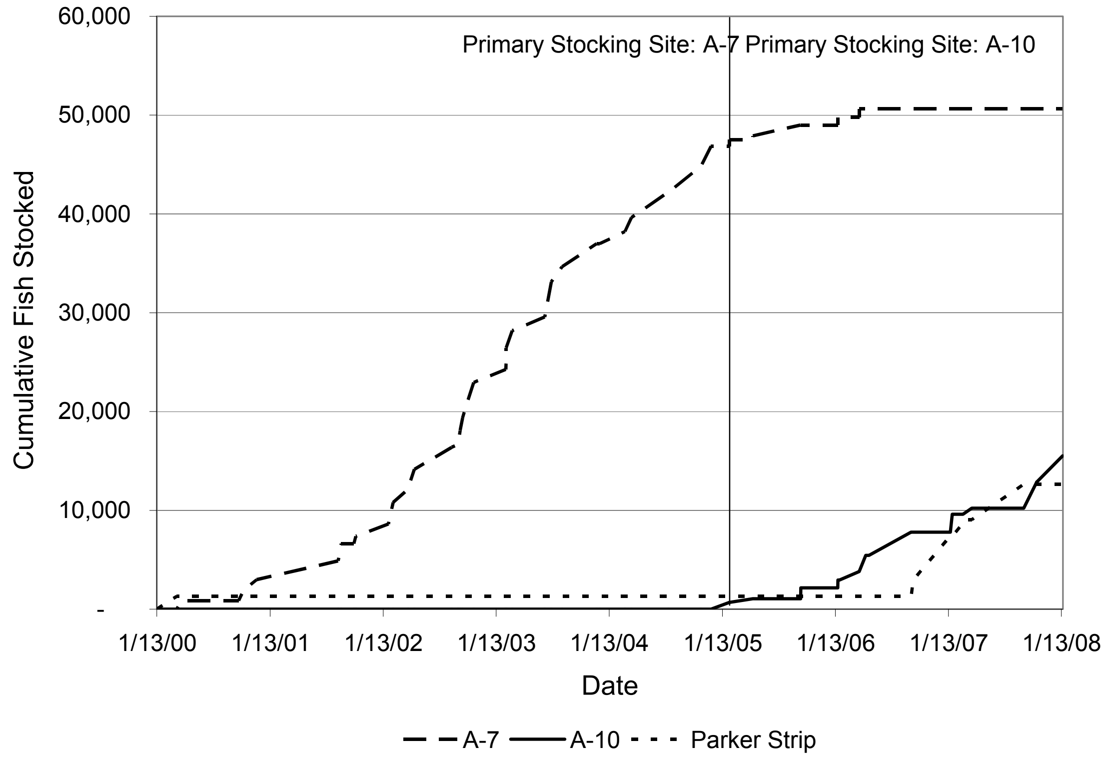

Figure 1. Summary of razorback sucker stocked to the lower Colorado River below Parker Dam 2000 – 2008. Primary stocking site was moved from A-7 backwater to A-10 backwater in February 2005. Stocking to other locations were few and are not depicted here.

Figure 2a. Example of evidence of putative attack on razorback sucker by a piscine predator. Matching wounds on both sides of the fish and the shape of the bite mark implicate a large flathead catfish. Often, such wounds are found on the ventral surface of the prey.

Figure 2b. Example of wounds indicating avian predation. Scratches are generally oriented dorso-ventrally and often are paired on either side of the fish.

Figure 2c. Example of puncture wound indicating avian predation. Such punctures are generally located on the dorsal surface of the fish, implicating an attack from above.

Figure 2d. Example of a laceration indicating avian predation- possibly from the talons of an osprey. Survivors of such attacks may later succumb to injuries or secondary infection.

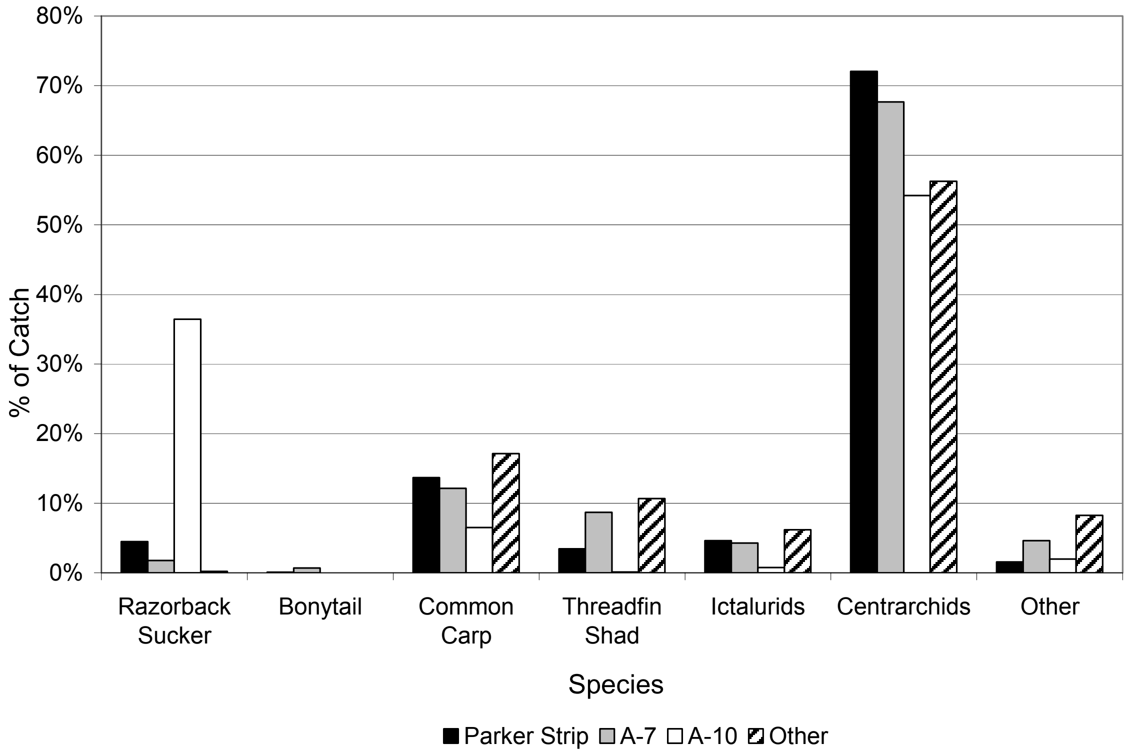

Figure 3. Spatial distribution of fish taxa captured by combined electrofishing and trammel netting for the four stocking zones in the lower Colorado River, January 2006 – April 2008. The "other" species category is predominated by Cichlids (2.8% of overall catch) and striped bass (1.6% of overall catch).

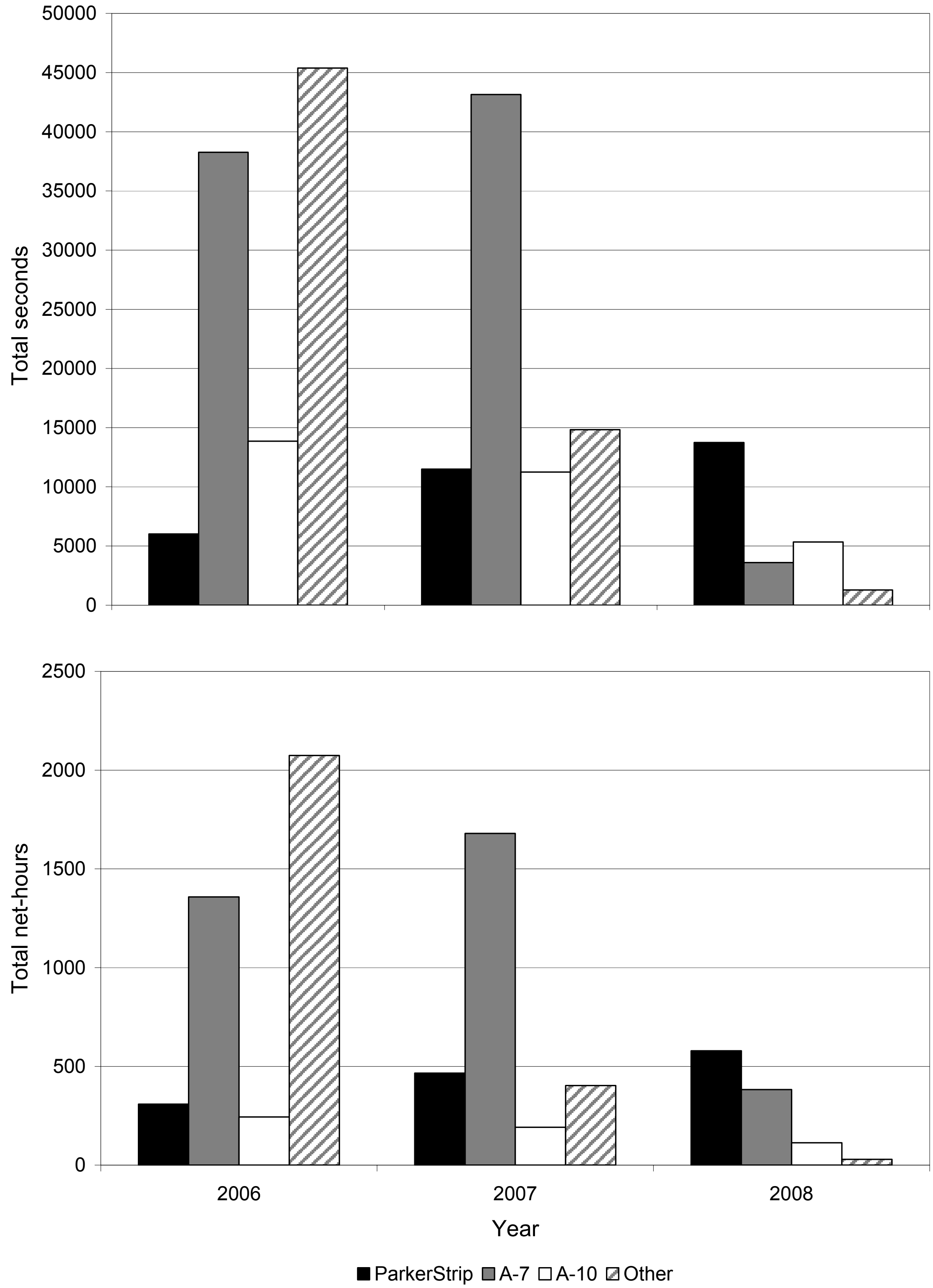

Figure 4. Total sampling effort by stocking zone in the lower Colorado River, January 2006 – April 2008. Figure shows electrofishing (top) and trammel netting (bottom).

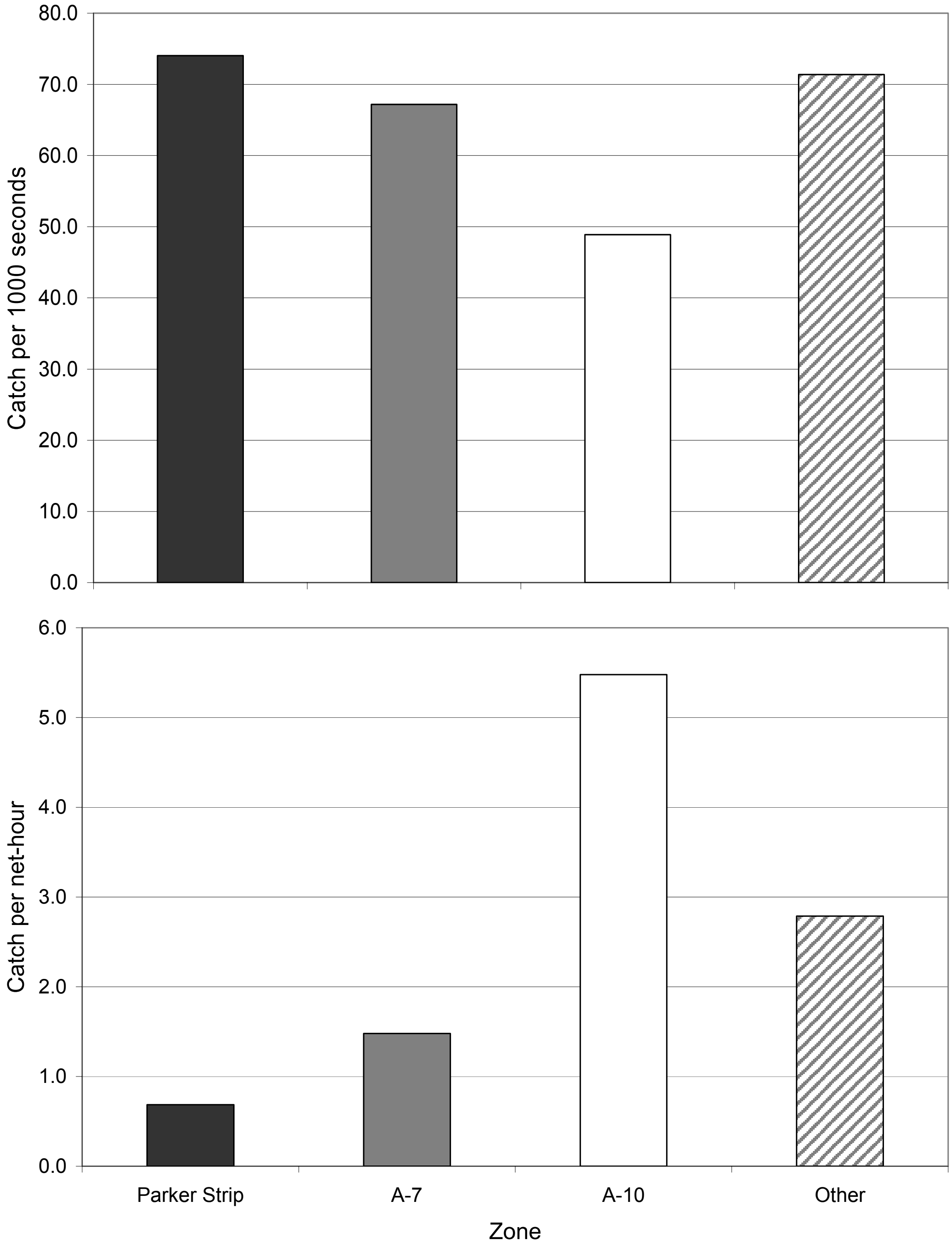

Figure 5. Catch per unit effort for all species using electrofishing (top) and trammel netting (bottom), by stocking zone, lower Colorado River, January 2006 – April 2008.

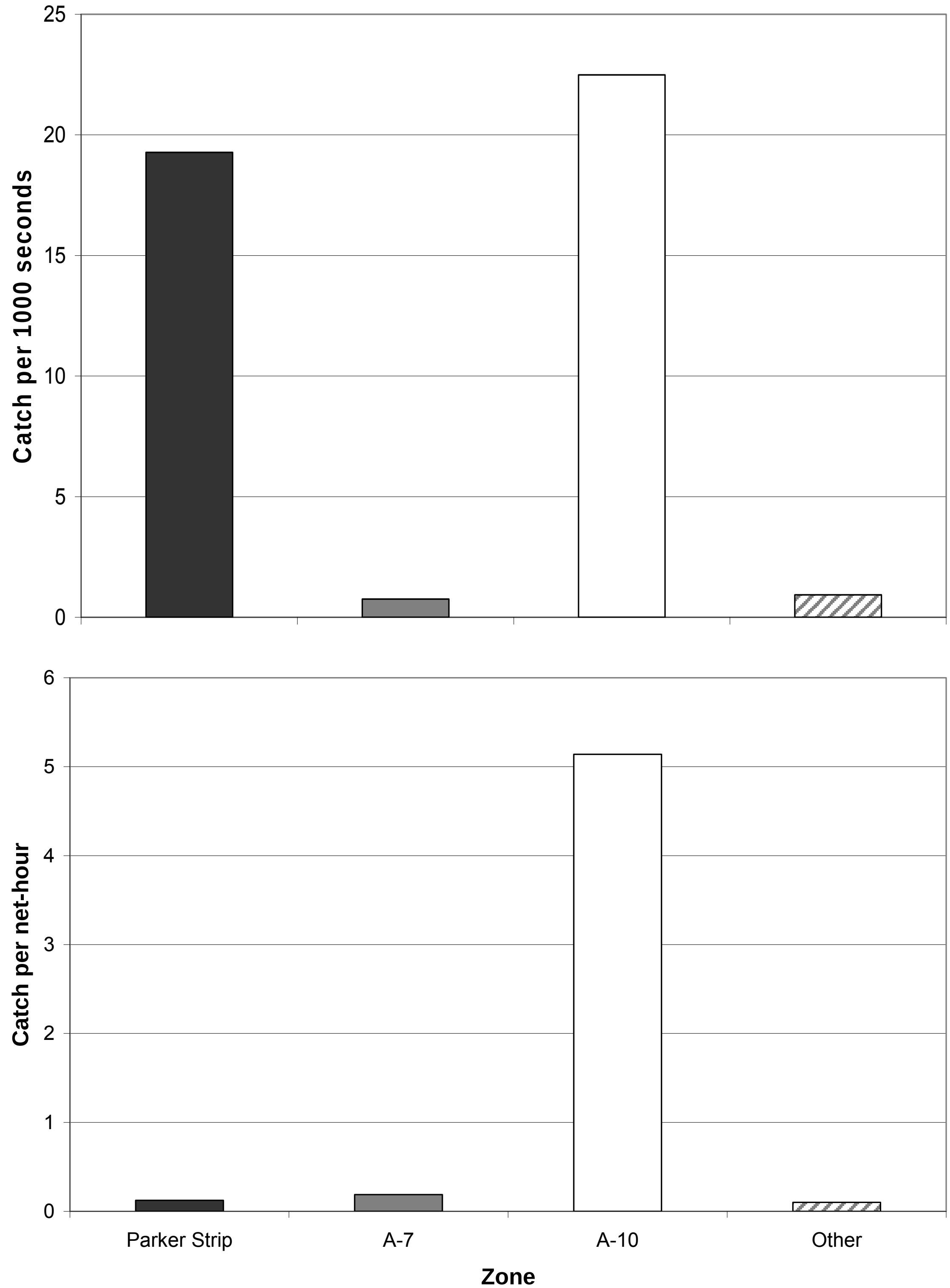

Figure 6. CPUE by stocking zone for razorback sucker captured in the lower Colorado River, January 2006 – April 2008. Figures show CPUE for electrofishing (top) and trammel netting (bottom).

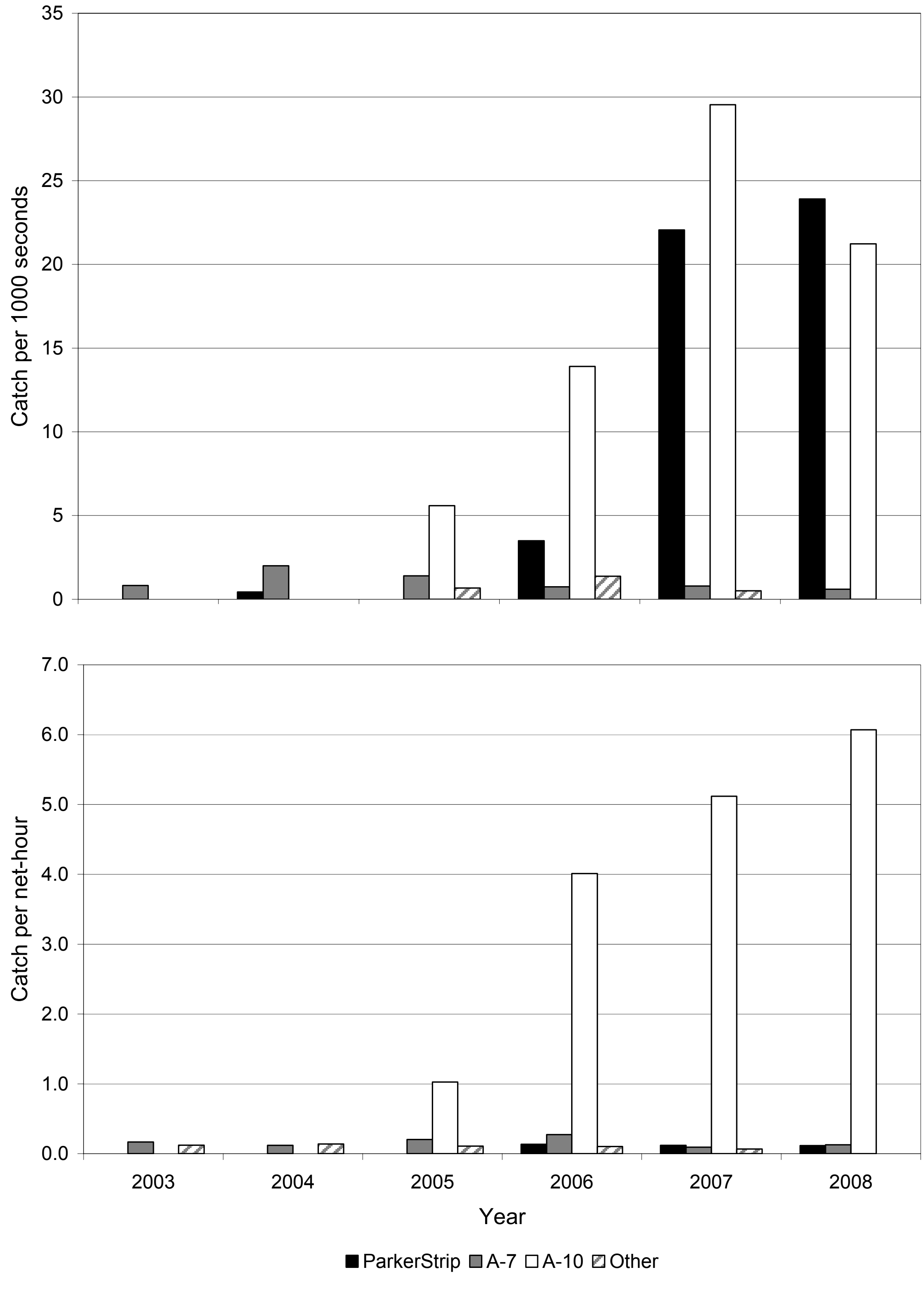

Figure 7. Catch of razorback sucker per unit effort (CPUE) for captures between January 2003 and April 2008 on the lower Colorado River. Figure shows CPUE for electrofishing (top) and netting (bottom).

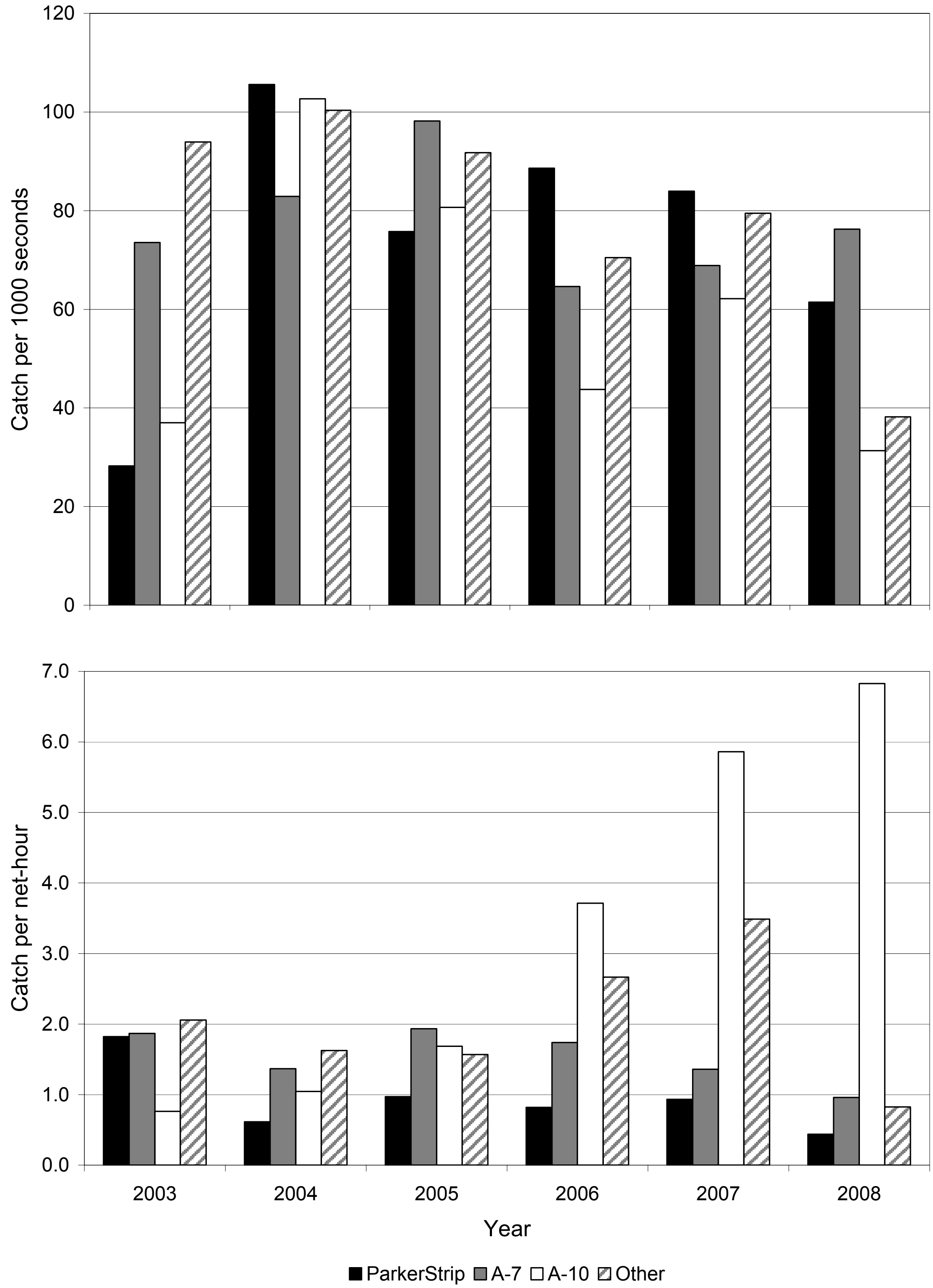

Figure 8. Catch per unit effort for all species using electrofishing (top) and trammel netting (bottom), differentiated by stocking zone, lower Colorado River, 2003 – 2008.

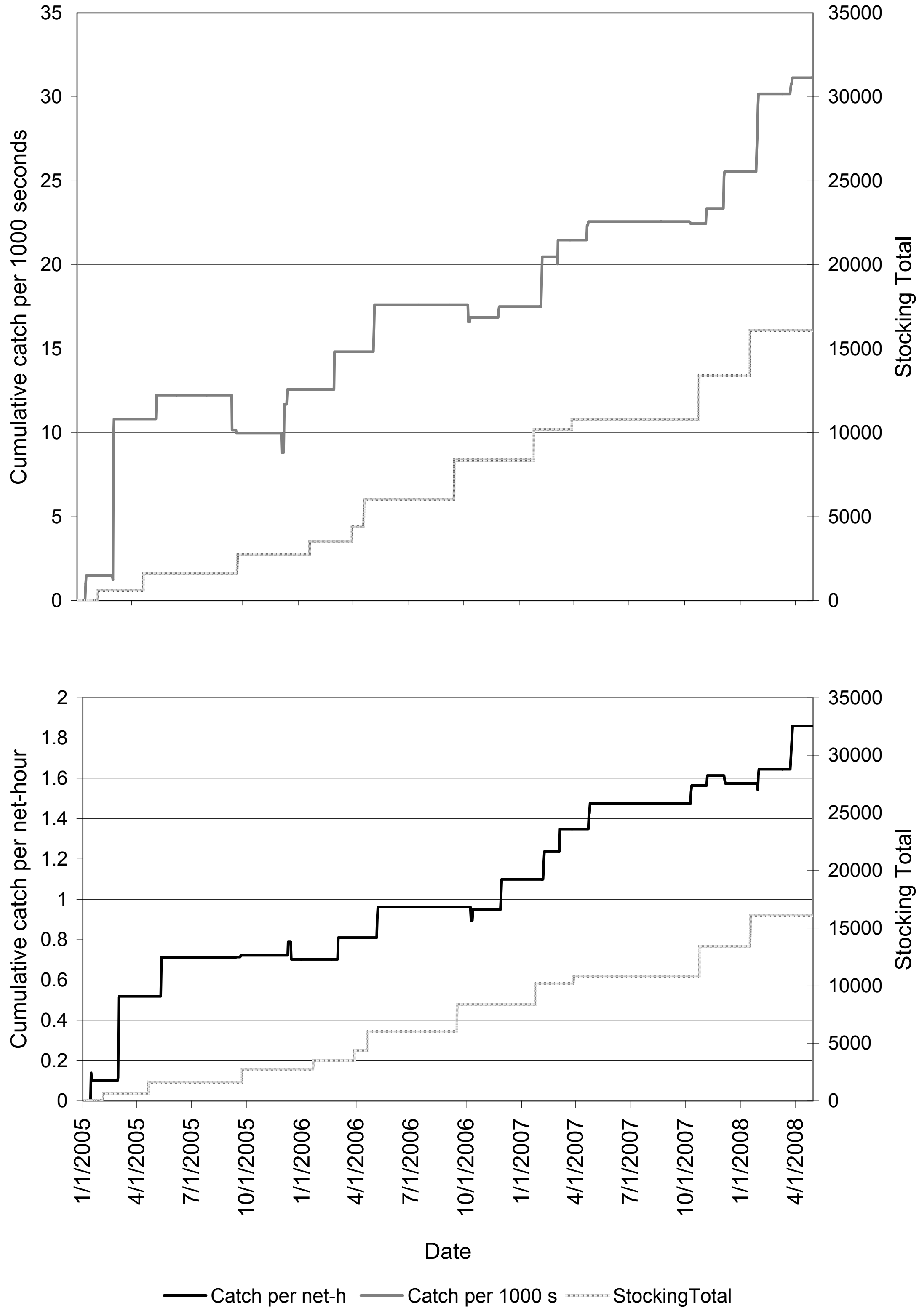

Figure 9. Cumulative number of razorback sucker stocked and catch per unit effort in A-10 by electrofishing (top) and trammel netting (bottom), lower Colorado River, January 2005 – 2008.

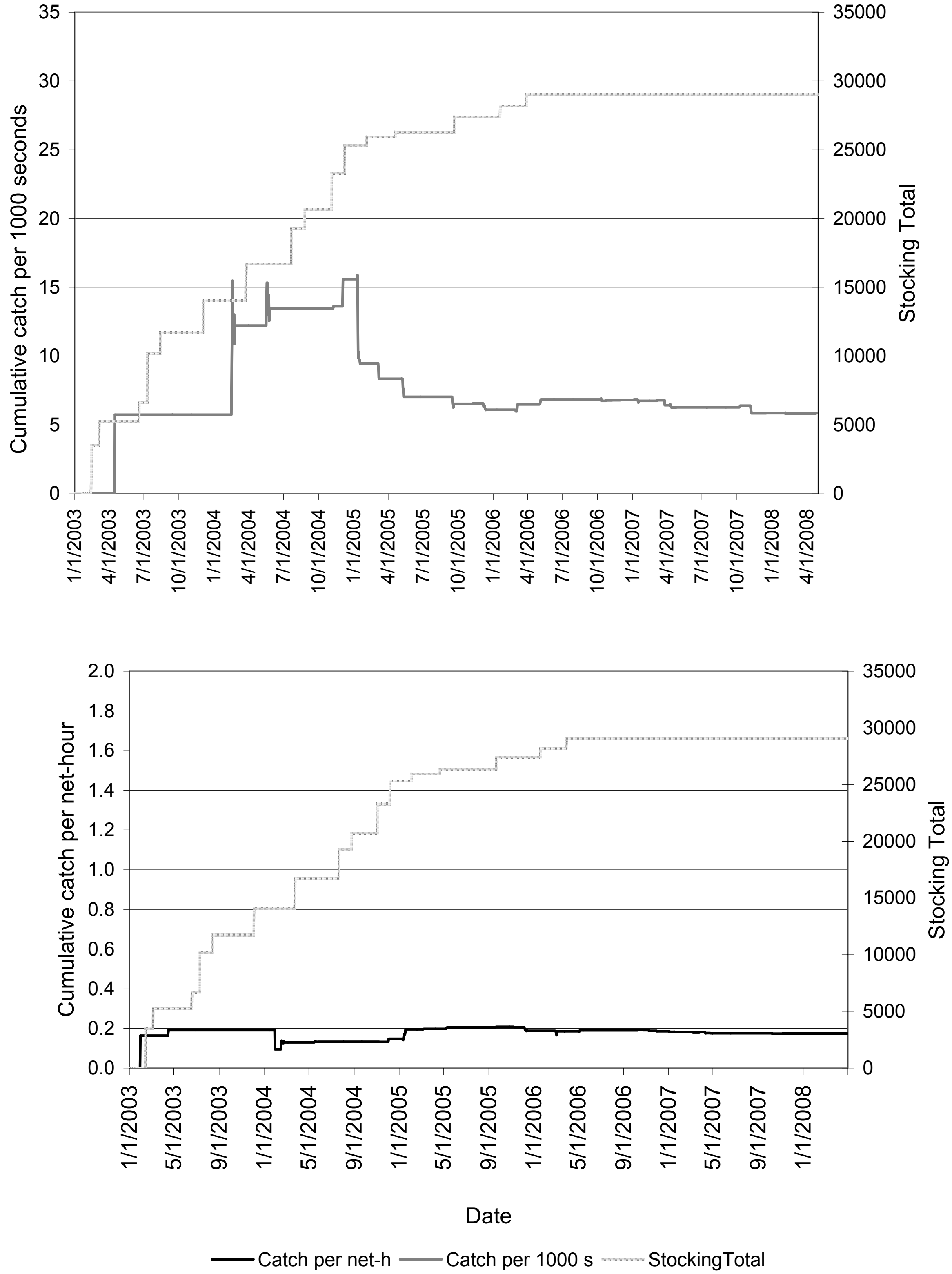

Figure 10. Cumulative number of razorback sucker stocked and catch per unit effort in A-7 zone by electrofishing (top) and trammel netting (bottom), 2003 – 2008.

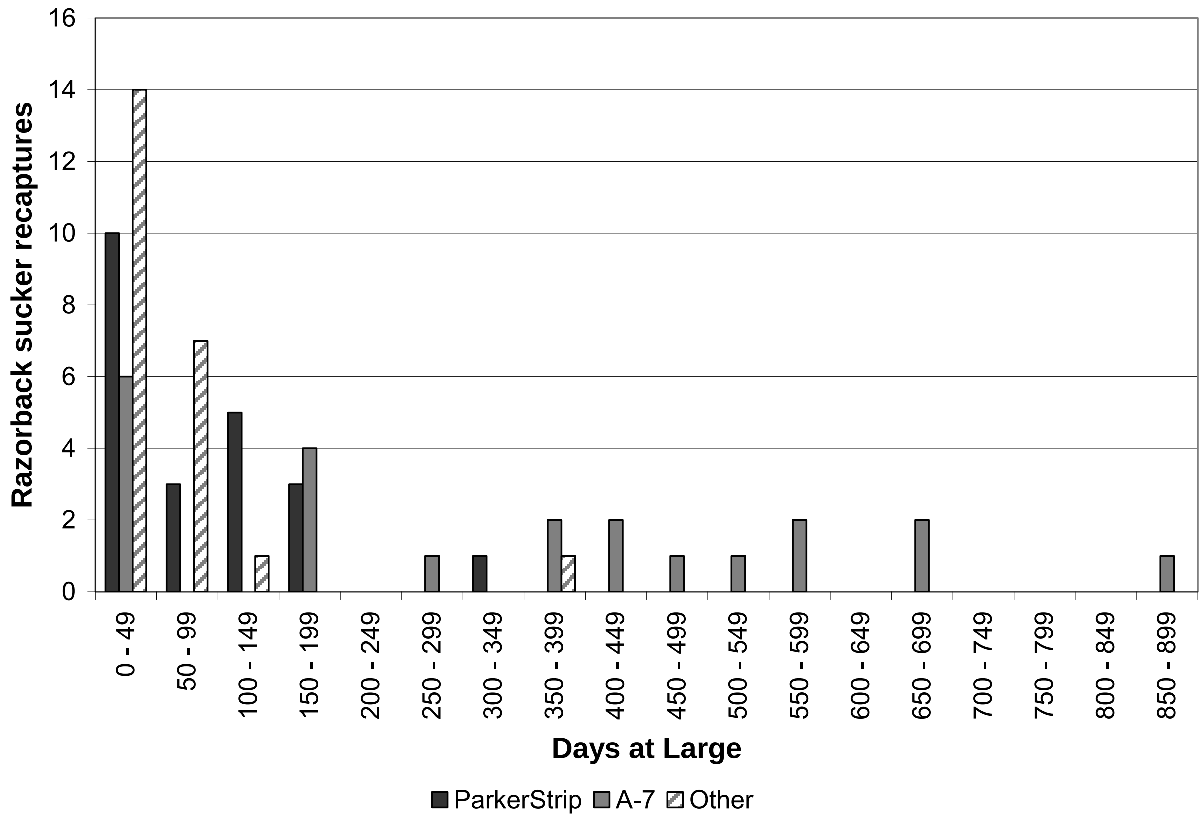

Figure 11a. Days at large for razorback sucker outside the A-10 stocking zone in the lower Colorado River, January 2006 – April 2008. Capture counts are based on PIT-tag data from the stocking date to the recapture (by ASU) date.

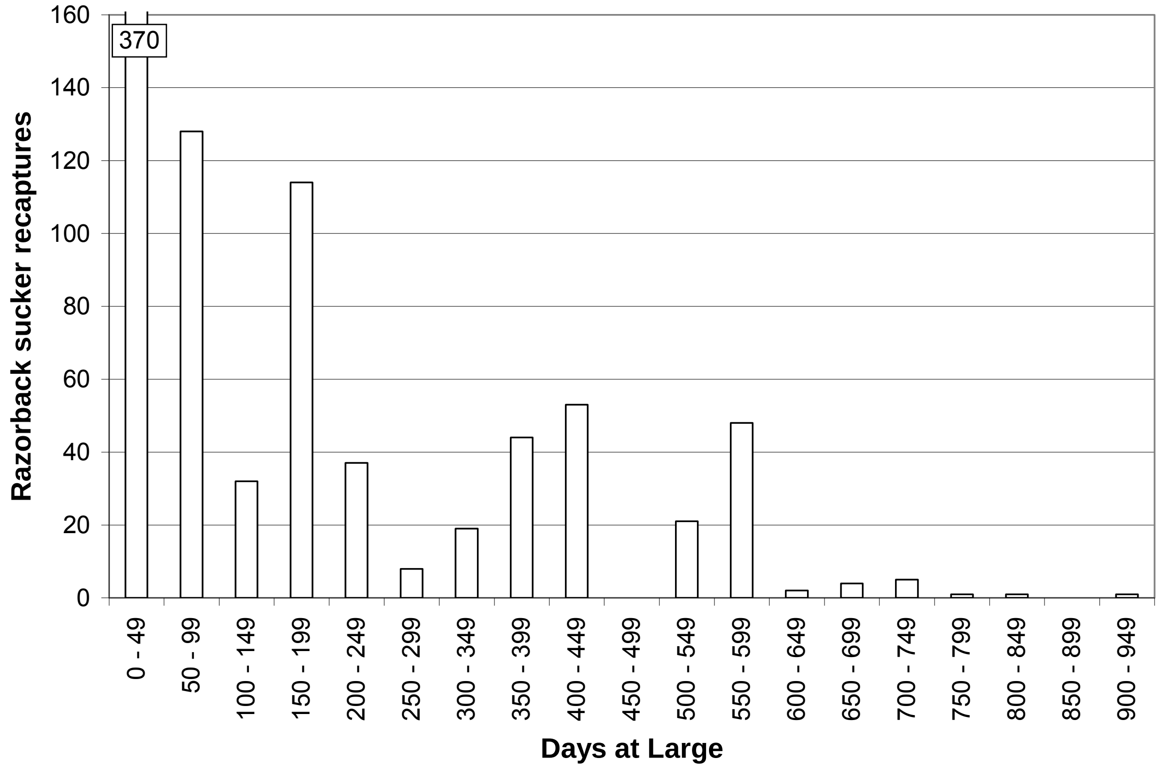

Figure 11b. Days at large for razorback sucker in A-10, lower Colorado River, January 2006 - April 2008. Capture counts are based on PIT-tag data from the stocking date to the recapture (by ASU) date. Maximum days at large was 913.

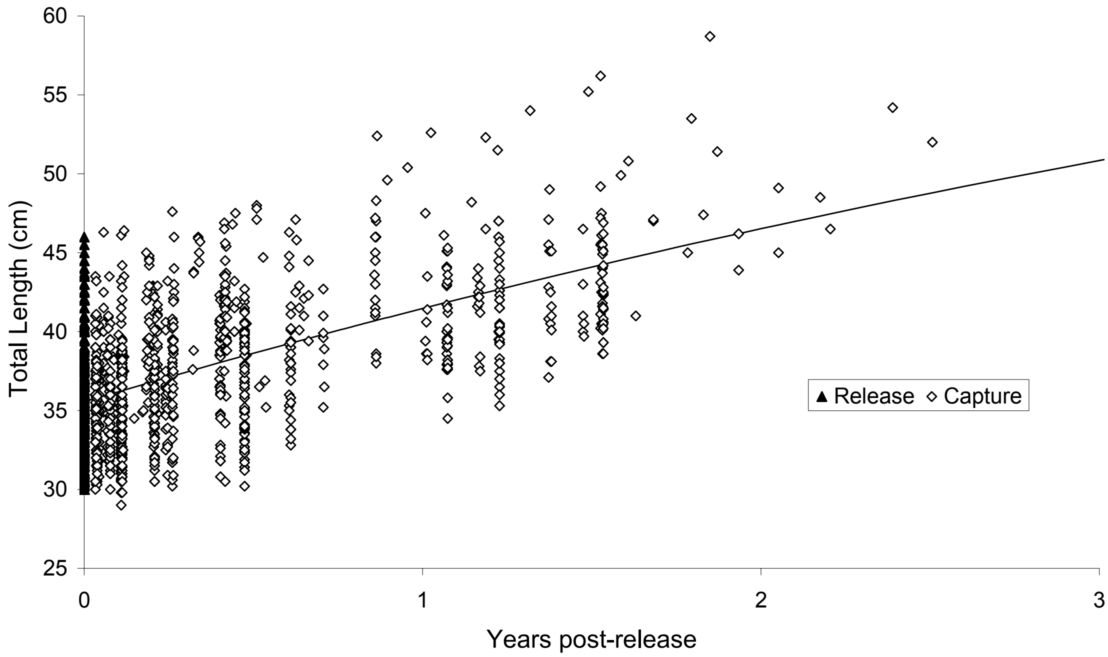

Figure 12. Von Bertalanffy growth curve for combined genders of razorback sucker stocked and subsequently recaptured in the lower Colorado River 2004 – 2008 (n = 984).

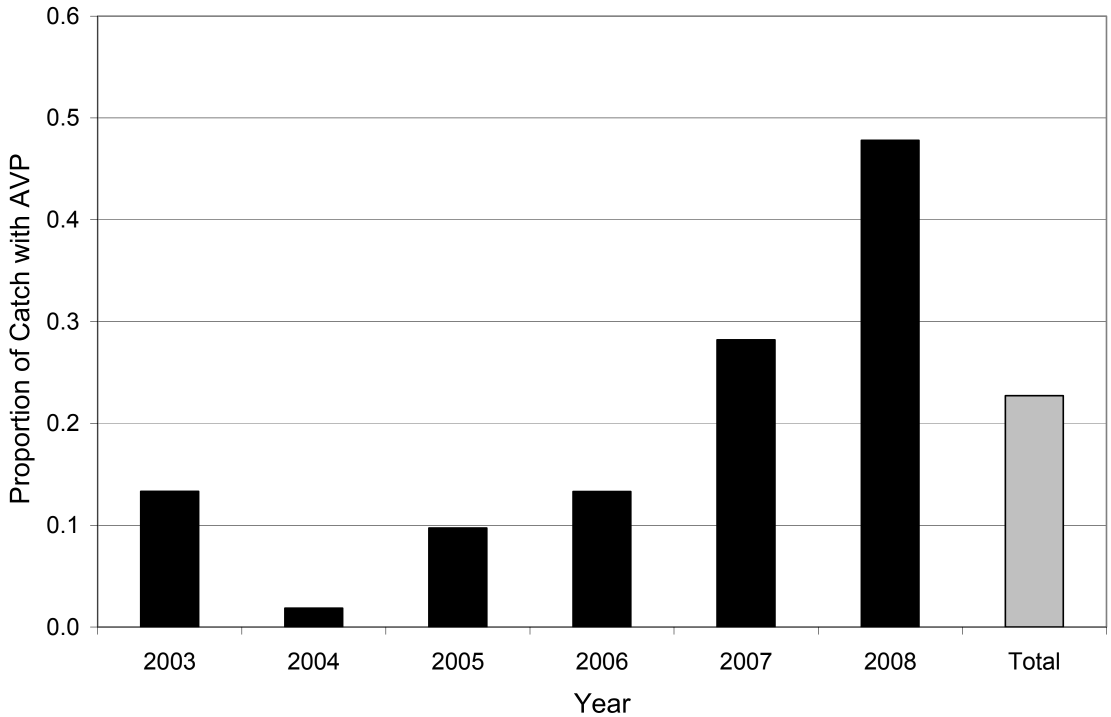

Figure 13. Annual proportion of razorback sucker catch with evidence of avian predation (AVP), lower Colorado River, 2003 – 2008. The total for 2008 includes only data from January collections.

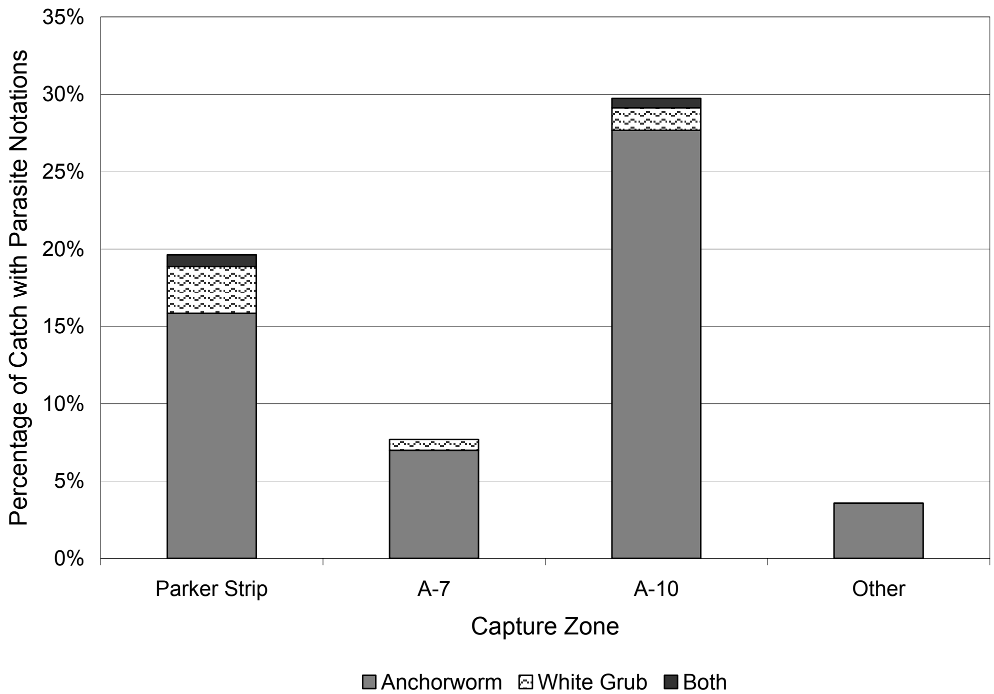

Figure 14. Proportion of razorback sucker catch with external parasites differentiated by stocking zone, lower Colorado River, January 2006 – April 2008.

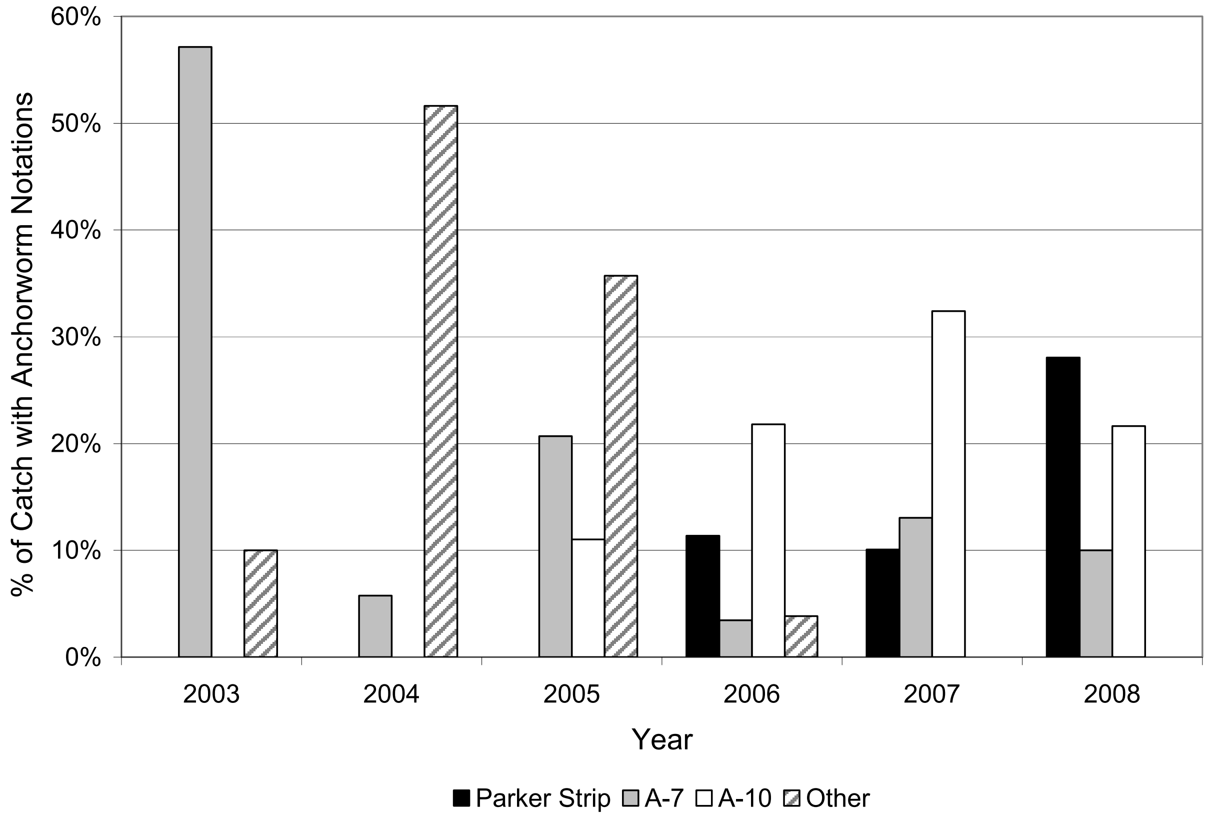

Figure 15. Annual percentage of razorback sucker catch with anchorworm infestation, lower Colorado River, 2003 – 2008.

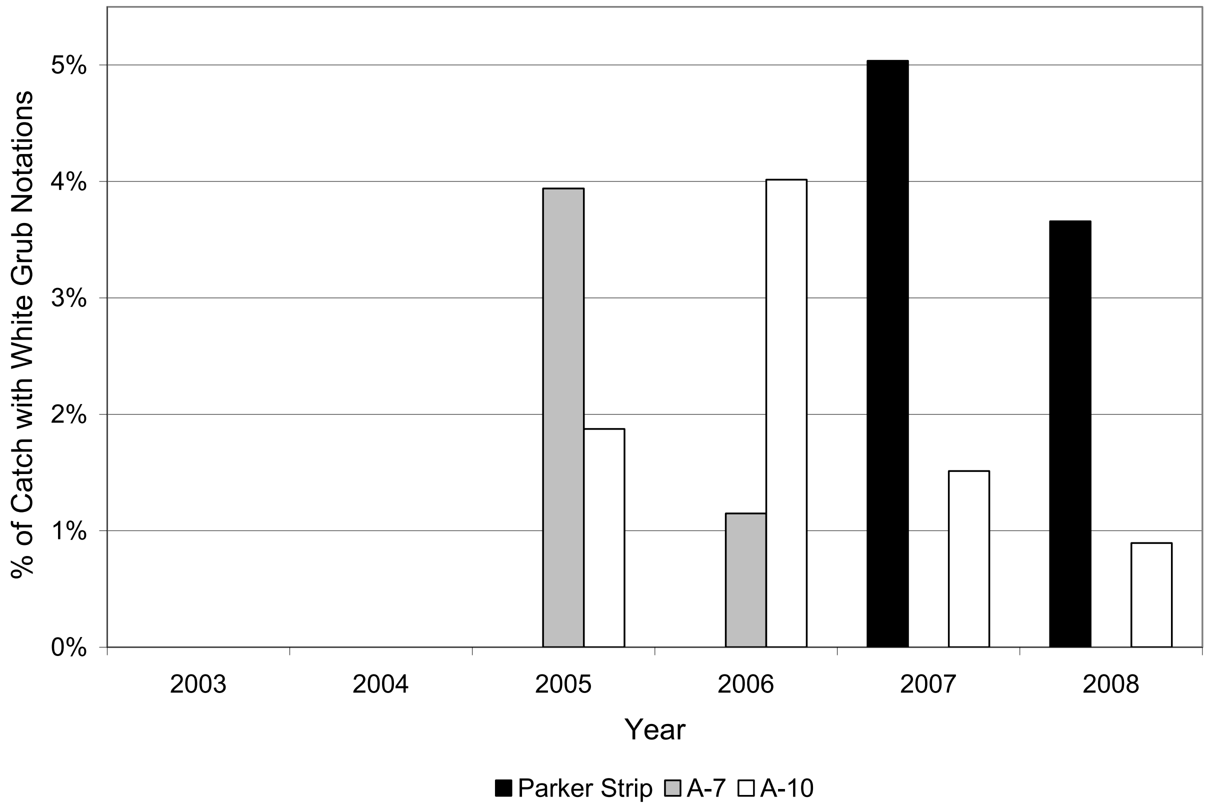

Figure 16. Annual percentage of razorback sucker catch with white grub infestation, lower Colorado River, 2003 – 2008.

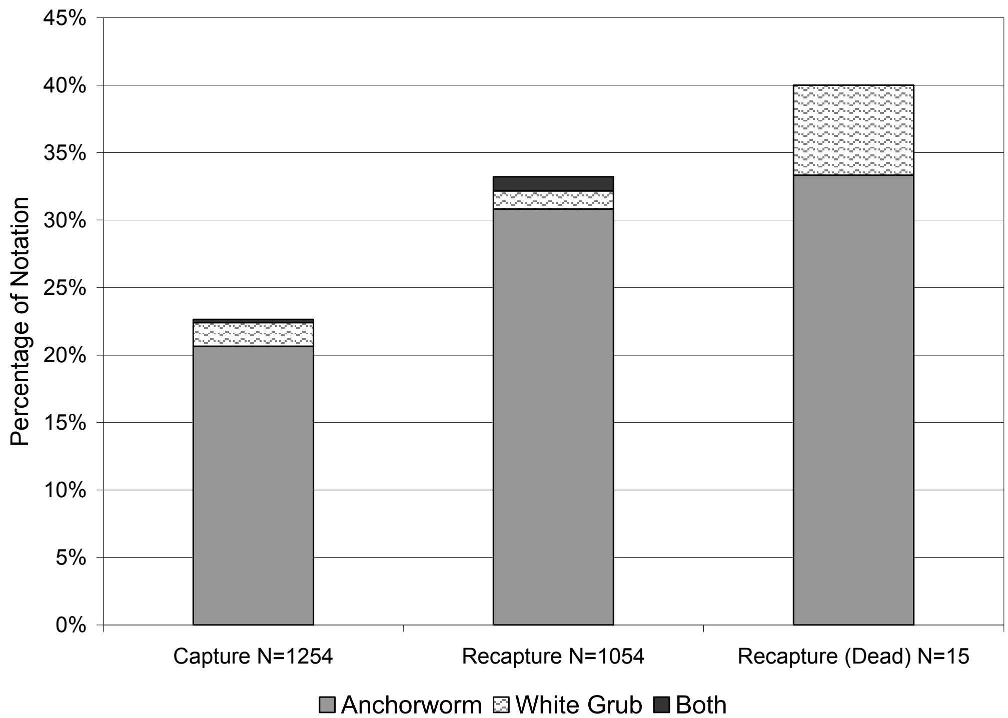

Figure 17. Proportion of razorback sucker catch with parasite infestation, differentiated by PIT tag status (Capture contains no PIT tag, Recapture contains a PIT tag), lower Colorado River, January 2006 – April 2008.

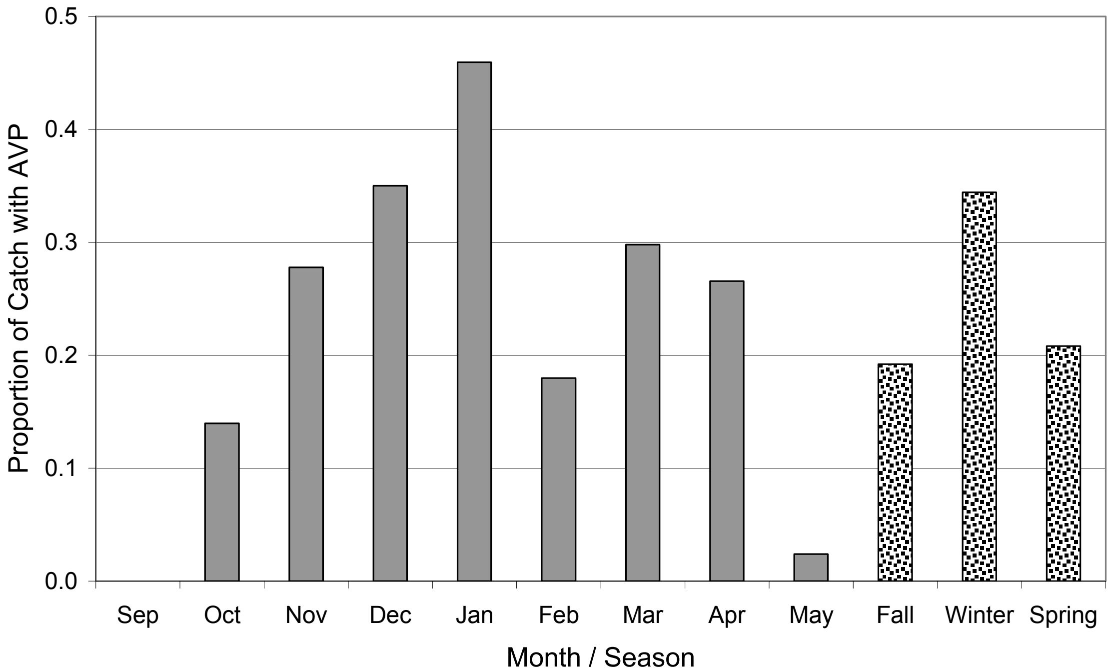

Figure 18. Monthly and seasonal proportions of razorback sucker catch (n = 2,319) in A-10 backwater (Upper and Lower combined) with evidence of wounds from avian predation (AVP), lower Colorado River, January 2006 – April 2008. No surveys were conducted June – Aug.

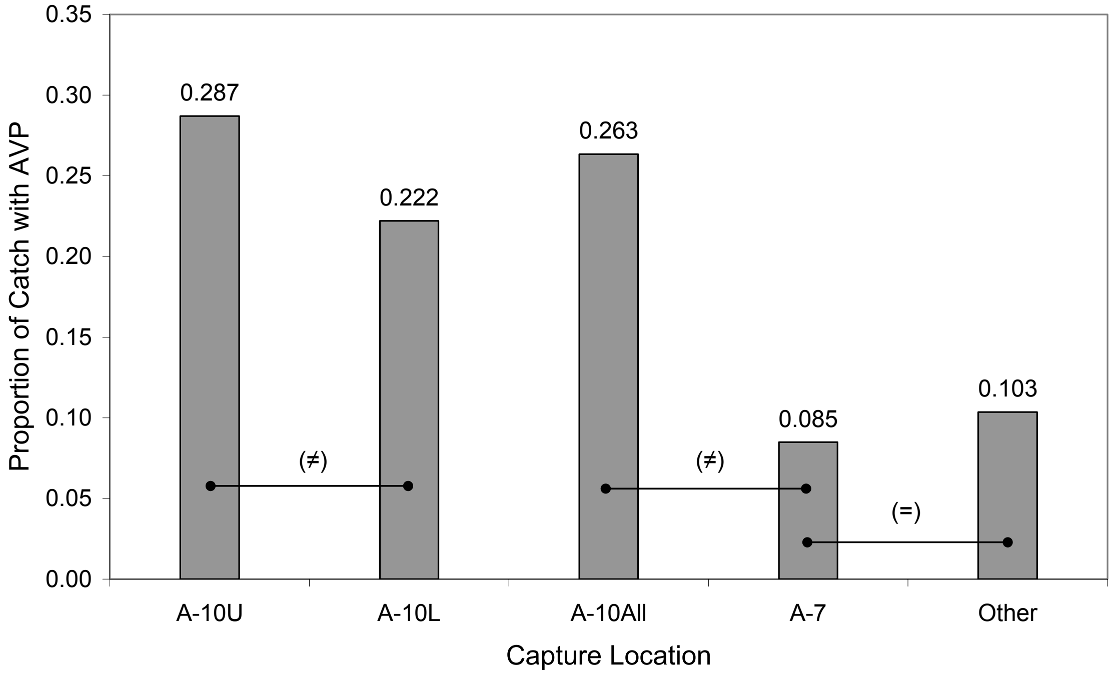

Figure 19. Comparison of proportion of razorback sucker catch (n = 3,024) with avian predation wounds (AVP) between backwaters, lower Colorado River, January 2006 – April 2008. Results of Yates-corrected Chi Square homogeneity tests are indicated as homogeneous (=) or heterogeneous (≠, significant at $p \leq 0.05$).

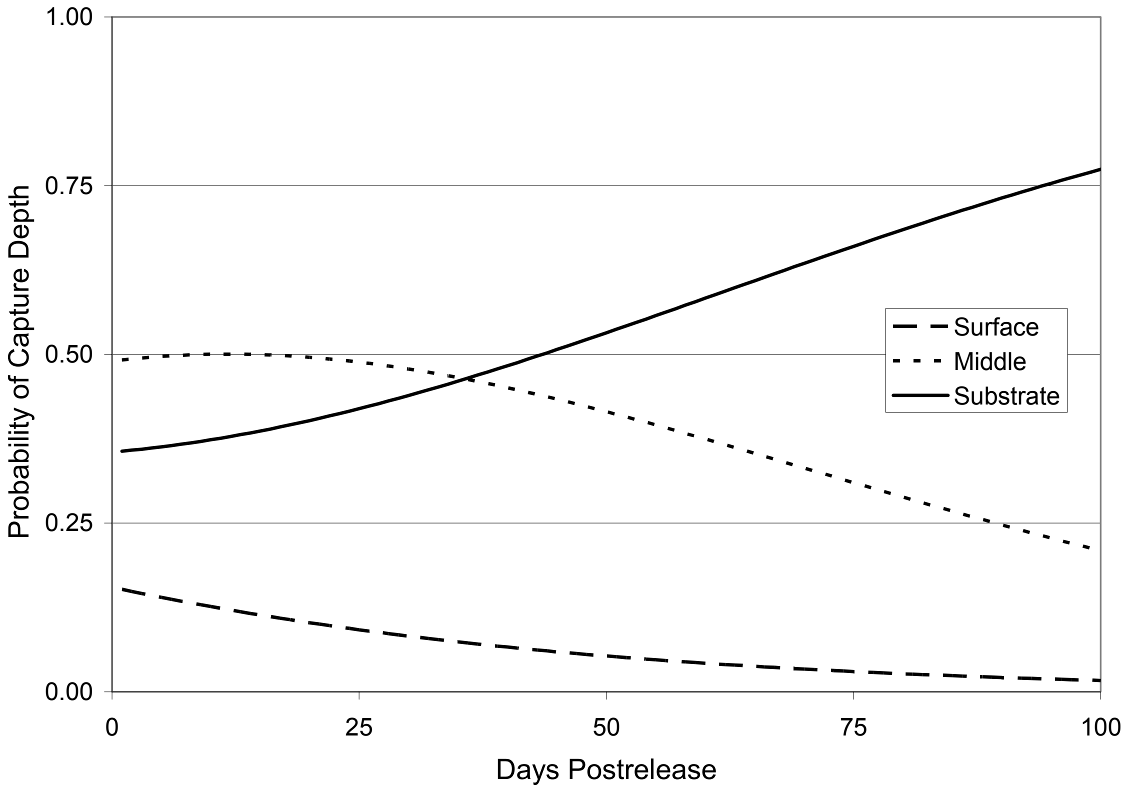

Figure 20. Probability curves generated by logistic regression for razorback sucker captured in A-10 backwater, lower Colorado River, 2007. Curves represent probability of capture within the water column, which is divided into thirds -- surface, middle, and substrate. Data indicate a post-release shift in behavior from pelagic to demersal.

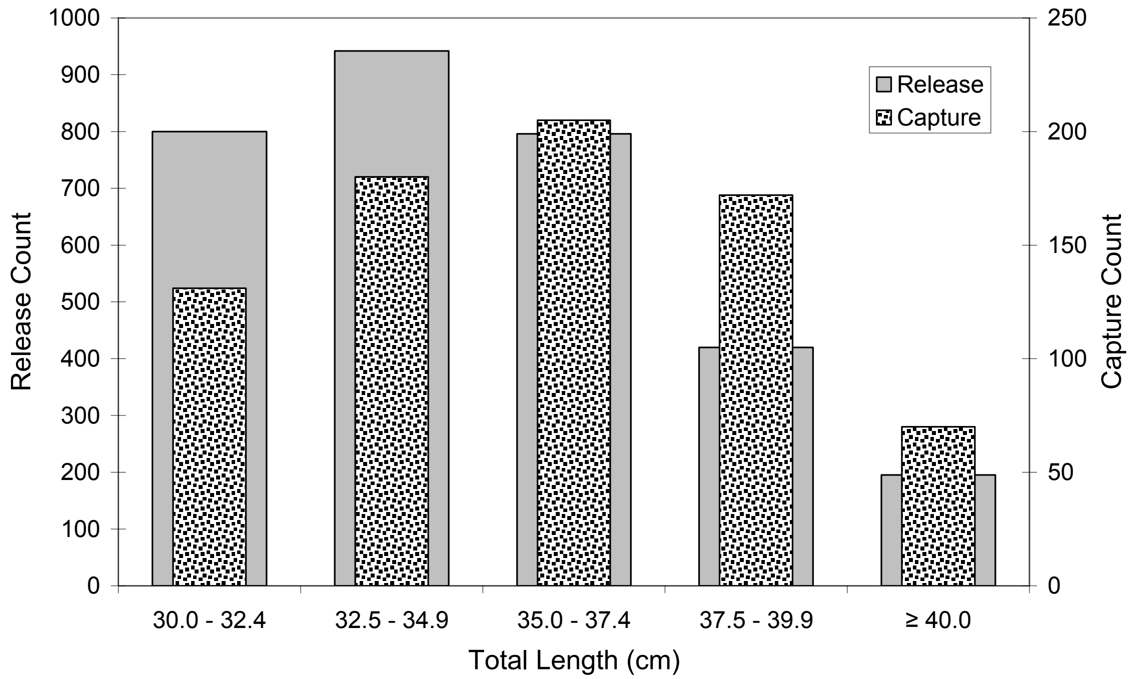

Figure 21. Frequency histogram for counts of release and capture for all surface- and subsurface-fed razorback sucker released to A-10, lower Colorado River, 2007.

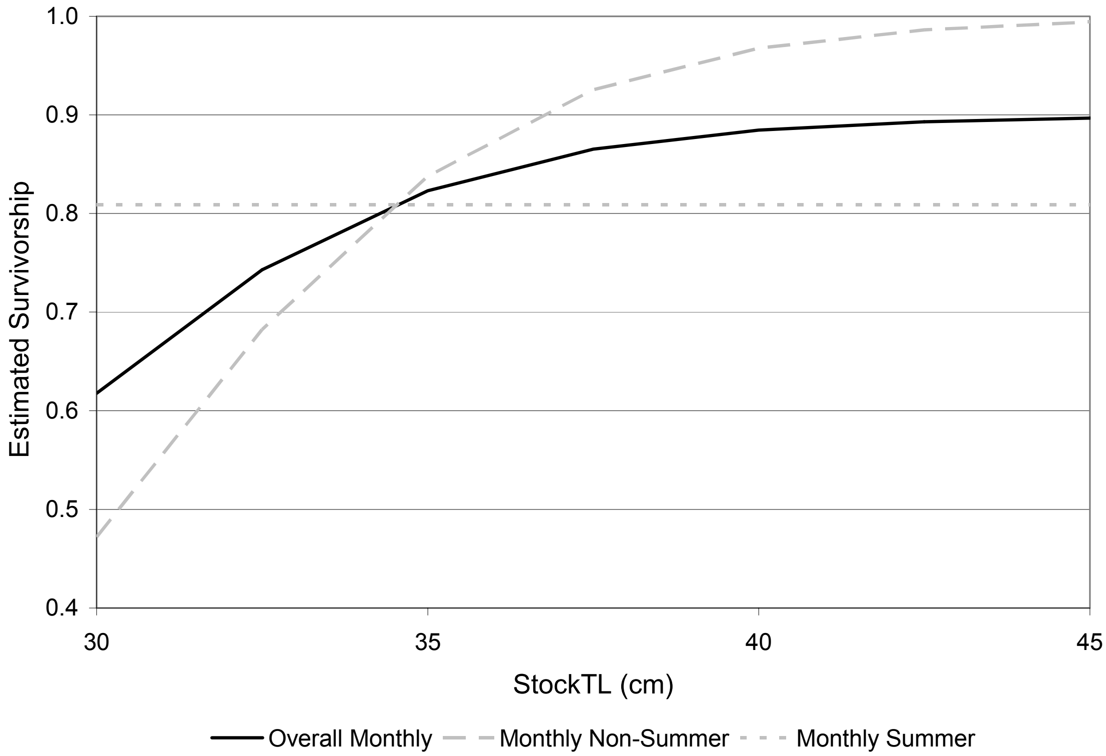

Figure 22. Release size-based survivorship curve for razorback sucker in A-10 backwater, lower Colorado River. Non-summer monthly survival includes November – April. Summer monthly survivorship is estimated at 80.8% (95% CI 73.1 – 86.8%) and is not relative to release size. Overall monthly survivorship is the resultant combination of summer and non-summer survivorship curves.

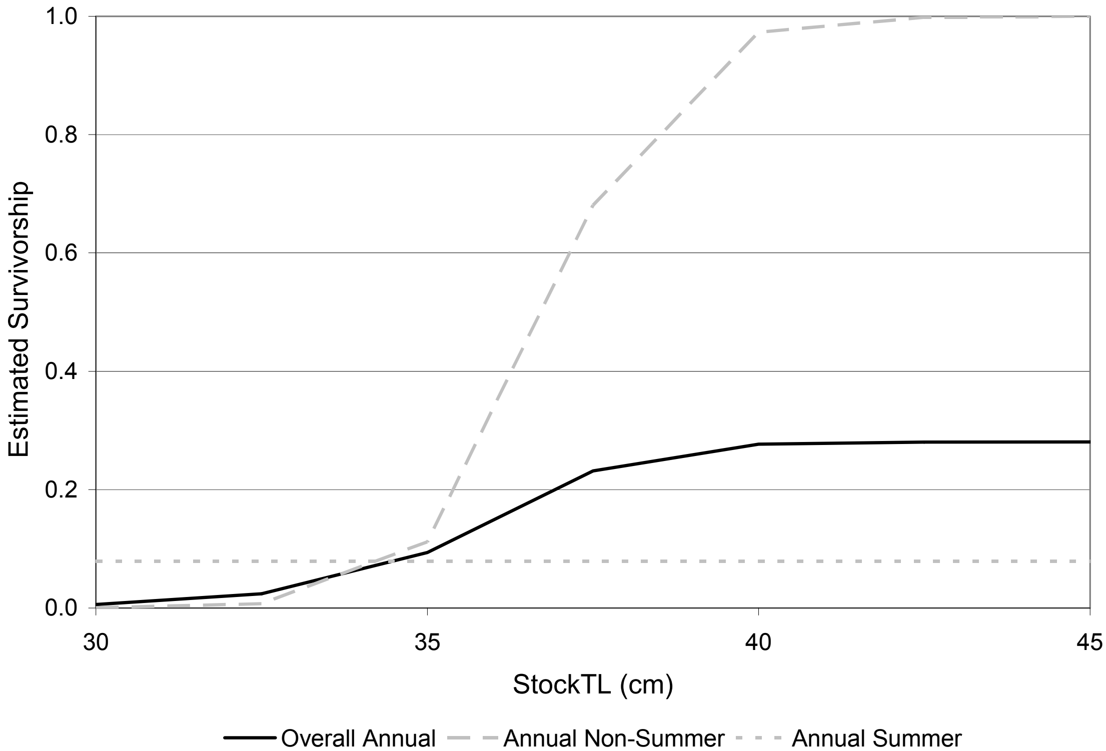

Figure 23. Release size-based annual survivorship curve for razorback sucker in A-10 backwater, lower Colorado River. Non-summer annual survival includes November – April. Annual summer survivorship is estimated at 7.9% (95% CI 2.8 – 20.4%) and is not relative to release size. Overall annual survivorship is the resultant combination of summer and non-summer survivorship curves.

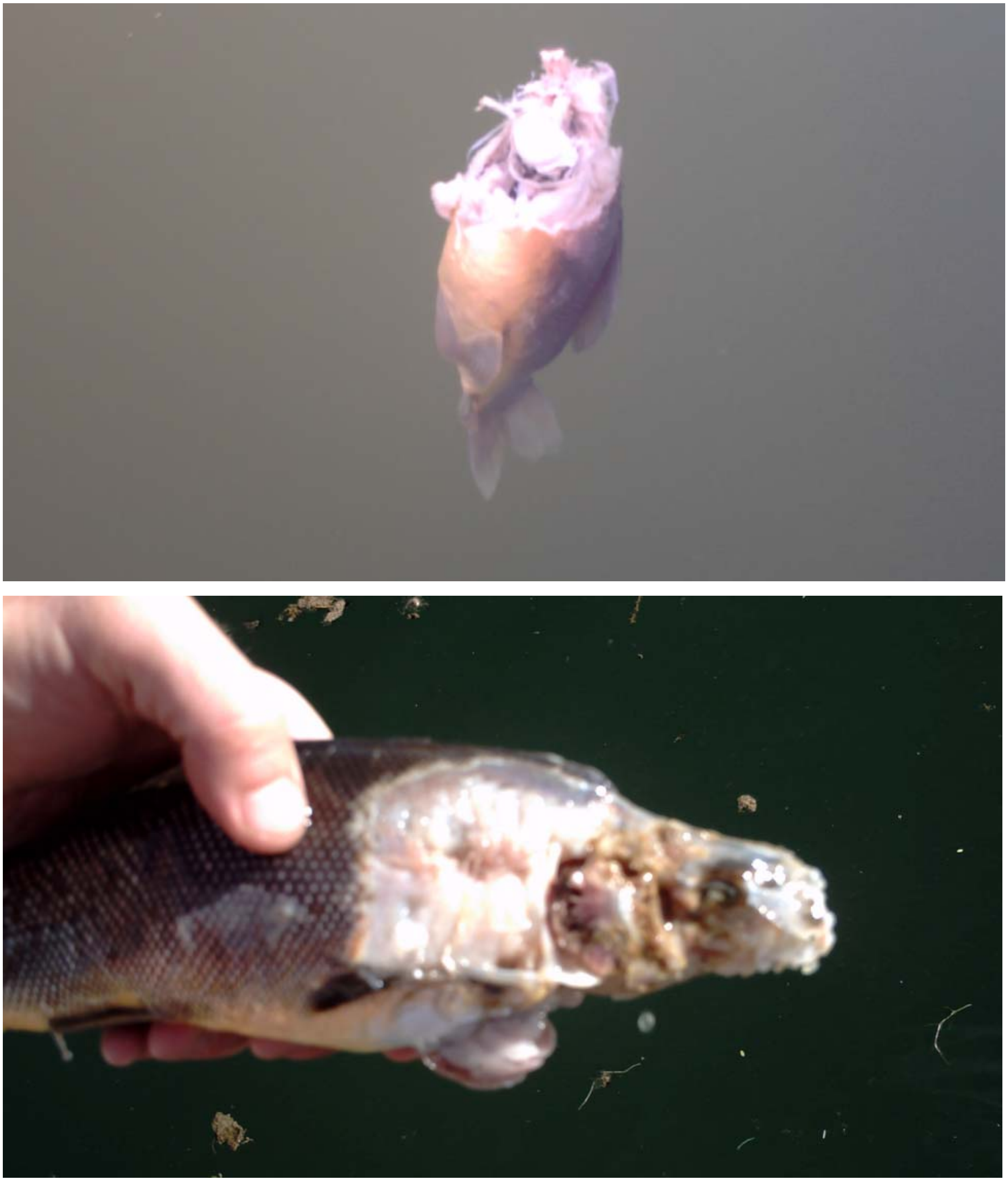

Figure 24. Two examples of dead razorback sucker found in A-10, lower Colorado River, 2007. In each example, only anterior portions of the fish have been digested, while the post-nuchal body is intact.

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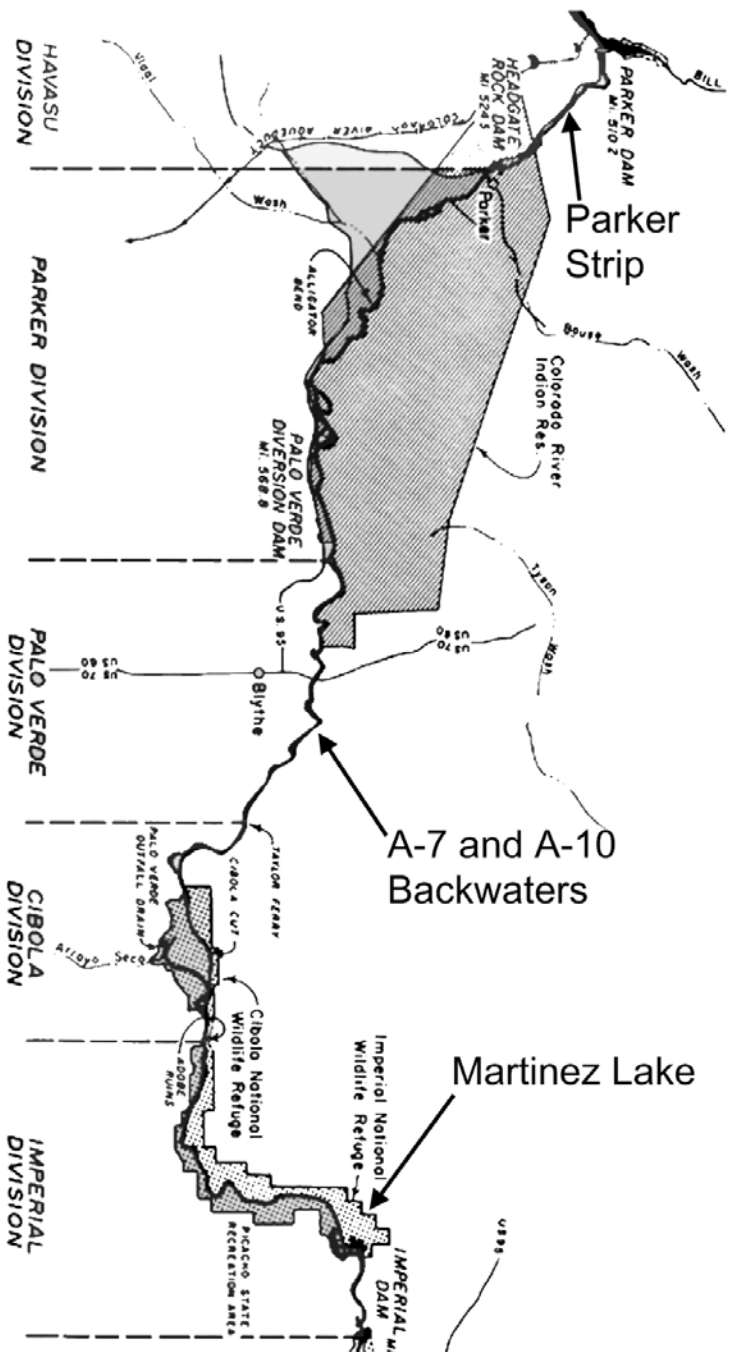
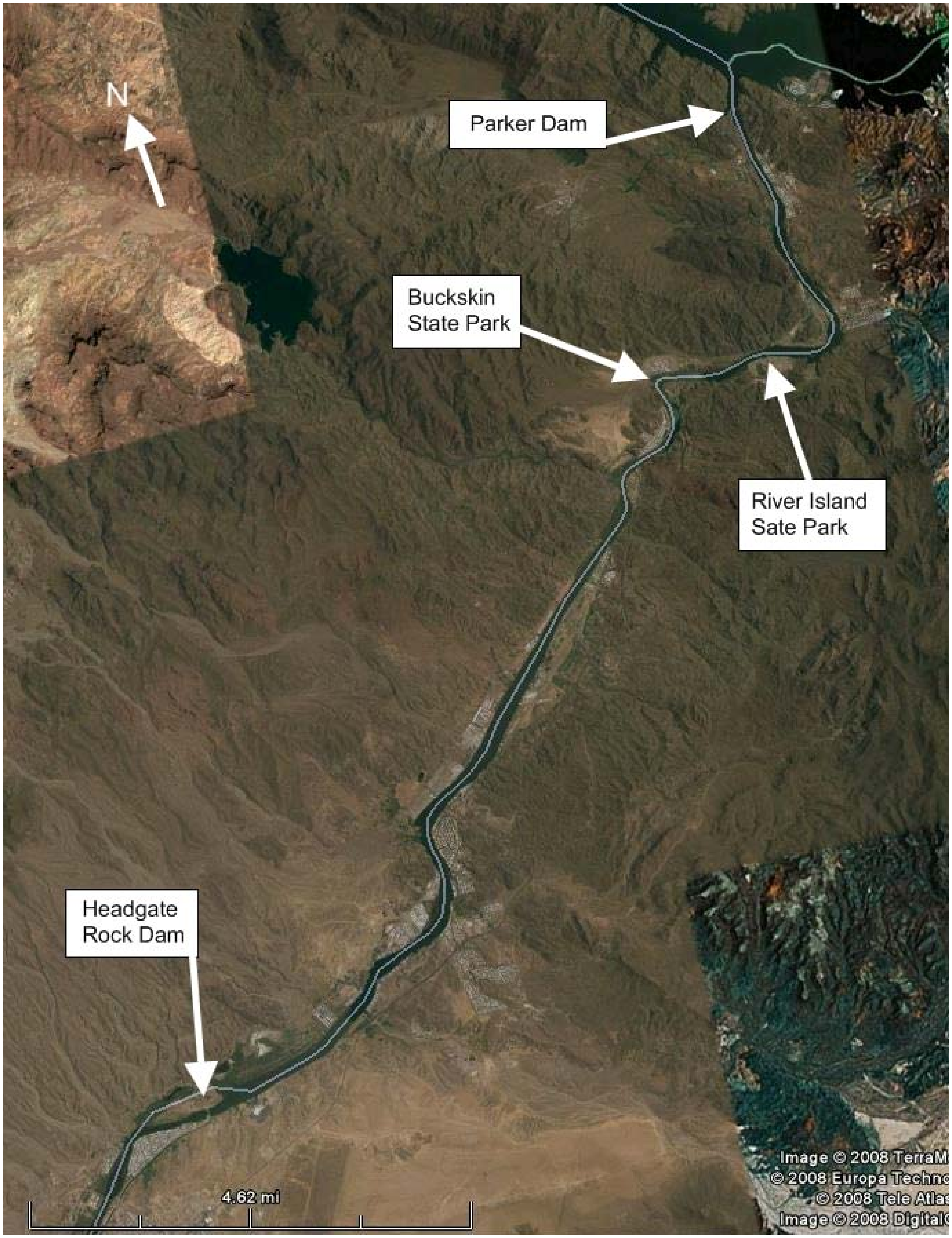
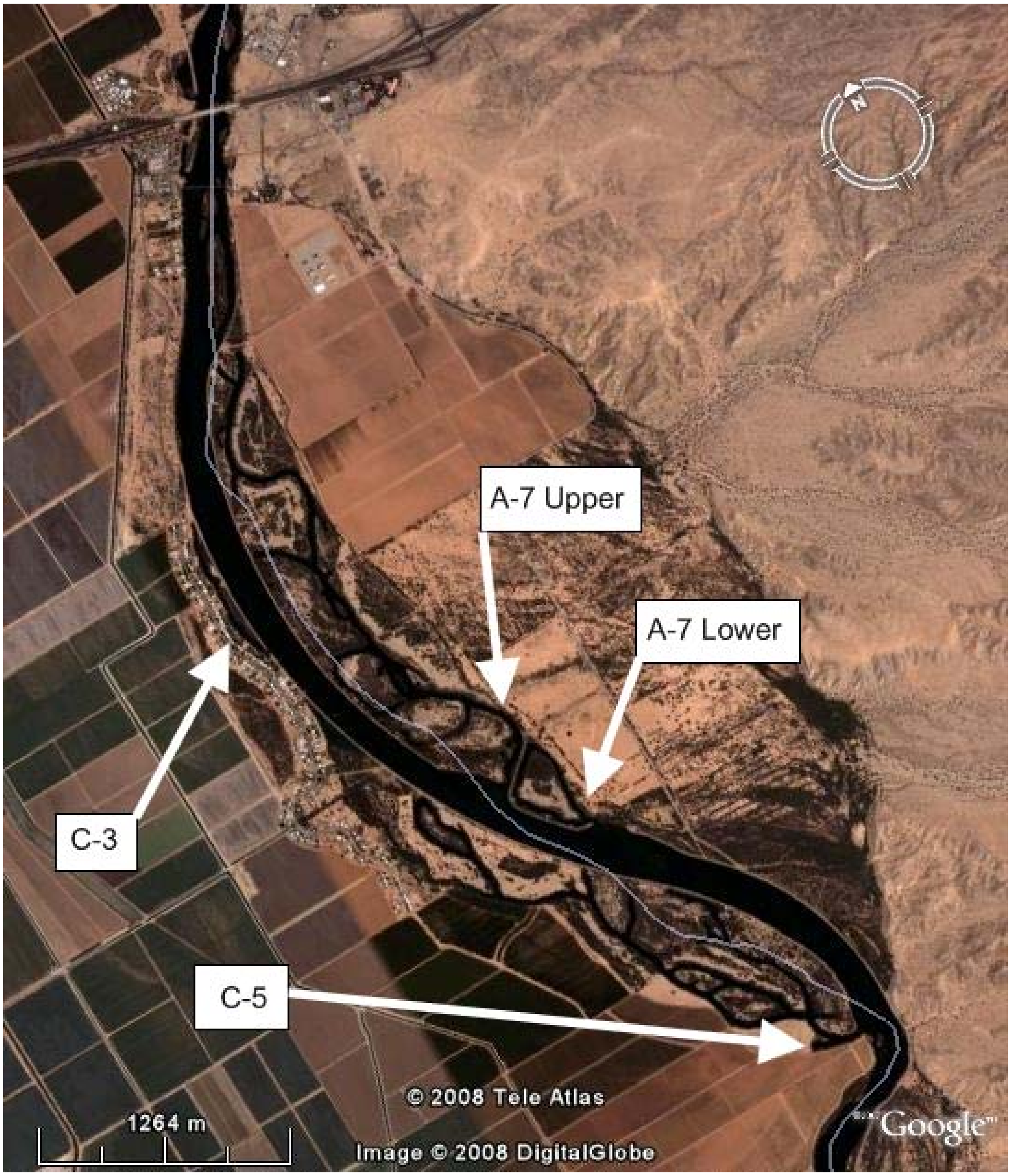
Appendix A. Study Area Maps, lower Colorado River.



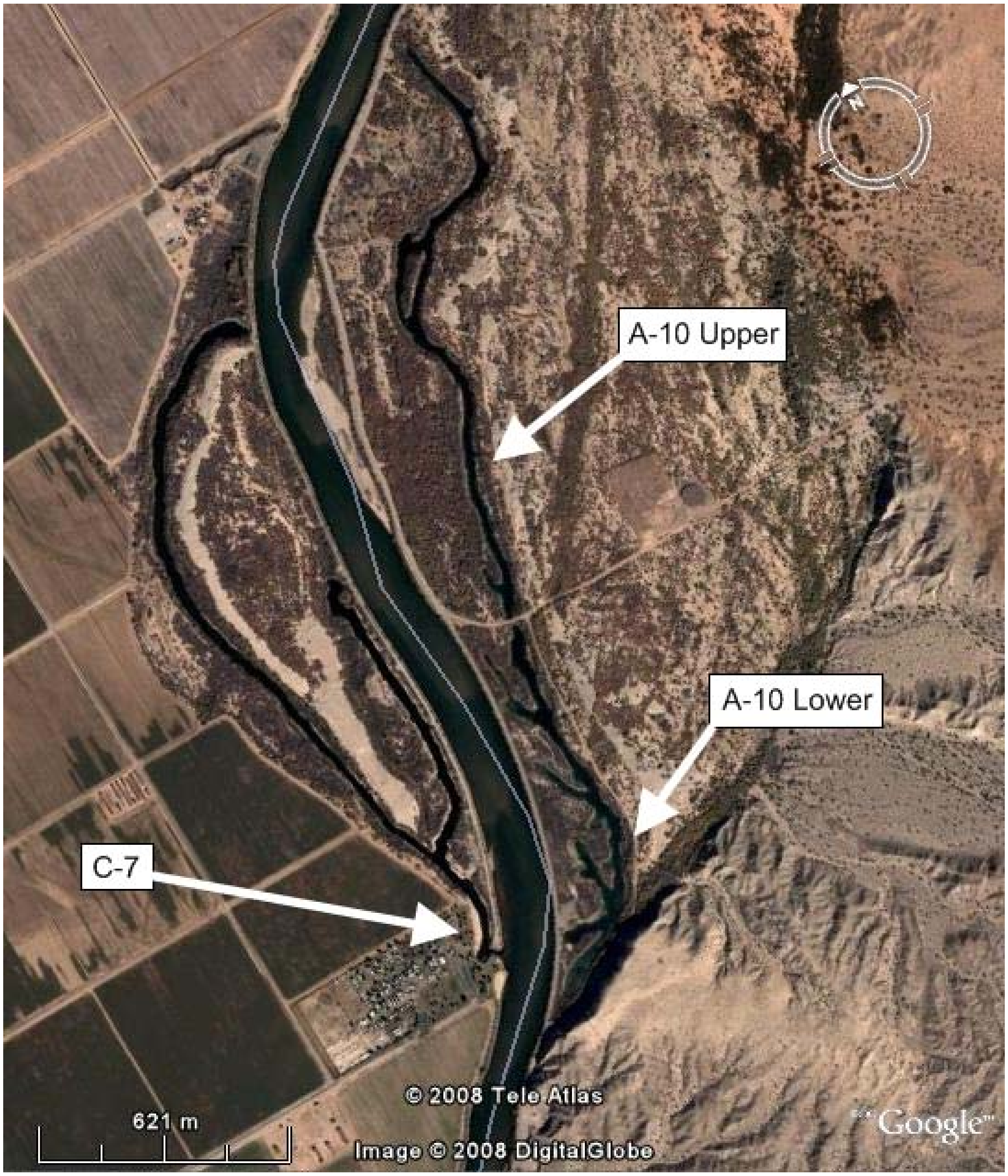
Map 1. Lower Colorado River, below Parker Dam, depicting stocking locations. (Adapted from USBR 1976.)



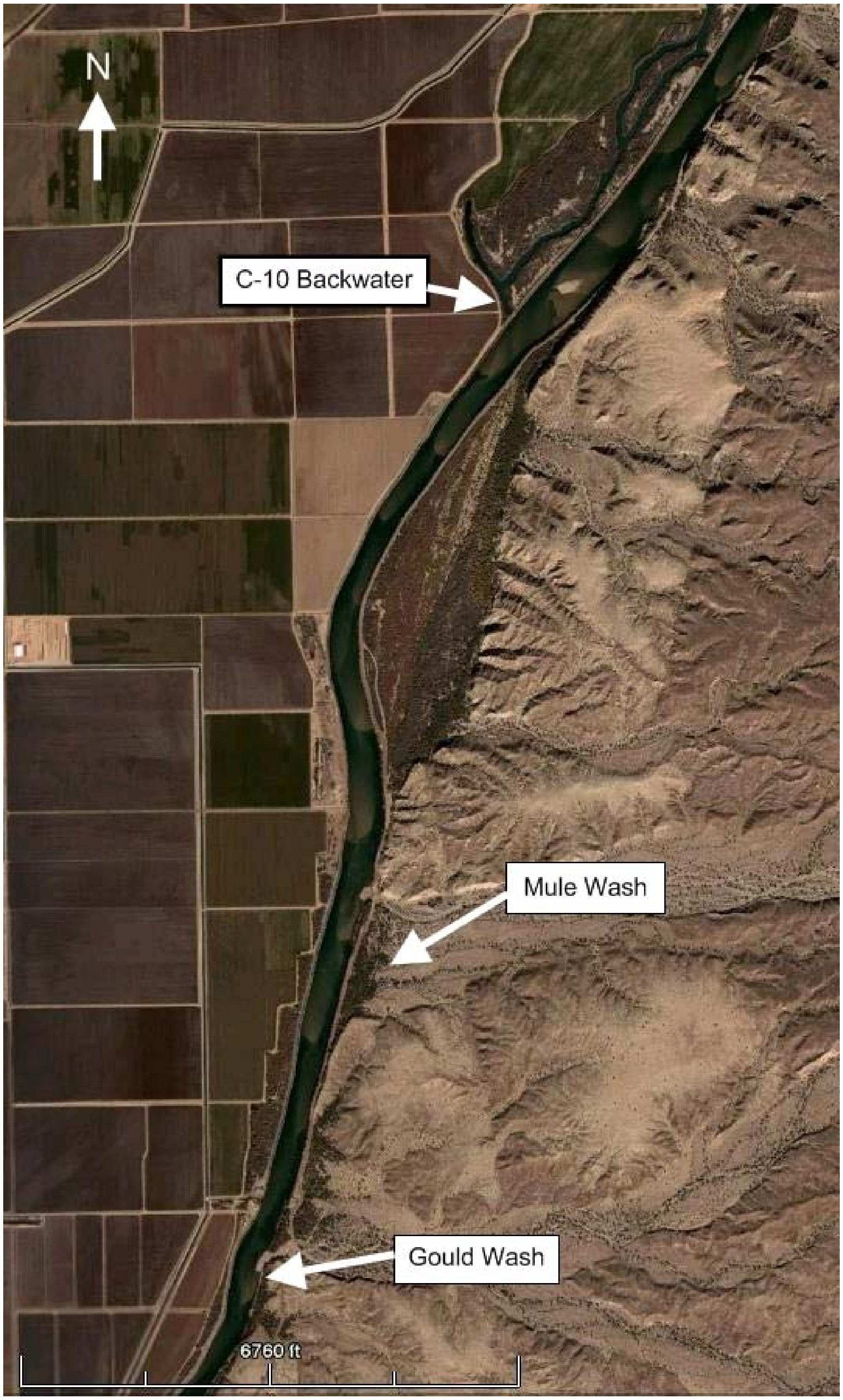
Map 2. Portion of the lower Colorado River, USBR Havasu Division (depicting the Parker Strip), La Paz Co., Arizona and San Bernardino Co., California.



Map 3. Portion of lower Colorado River, USBR Palo Verde Division (depicting A-7 and C-5 backwaters), Riverside Co., California and La Paz Co., Arizona.



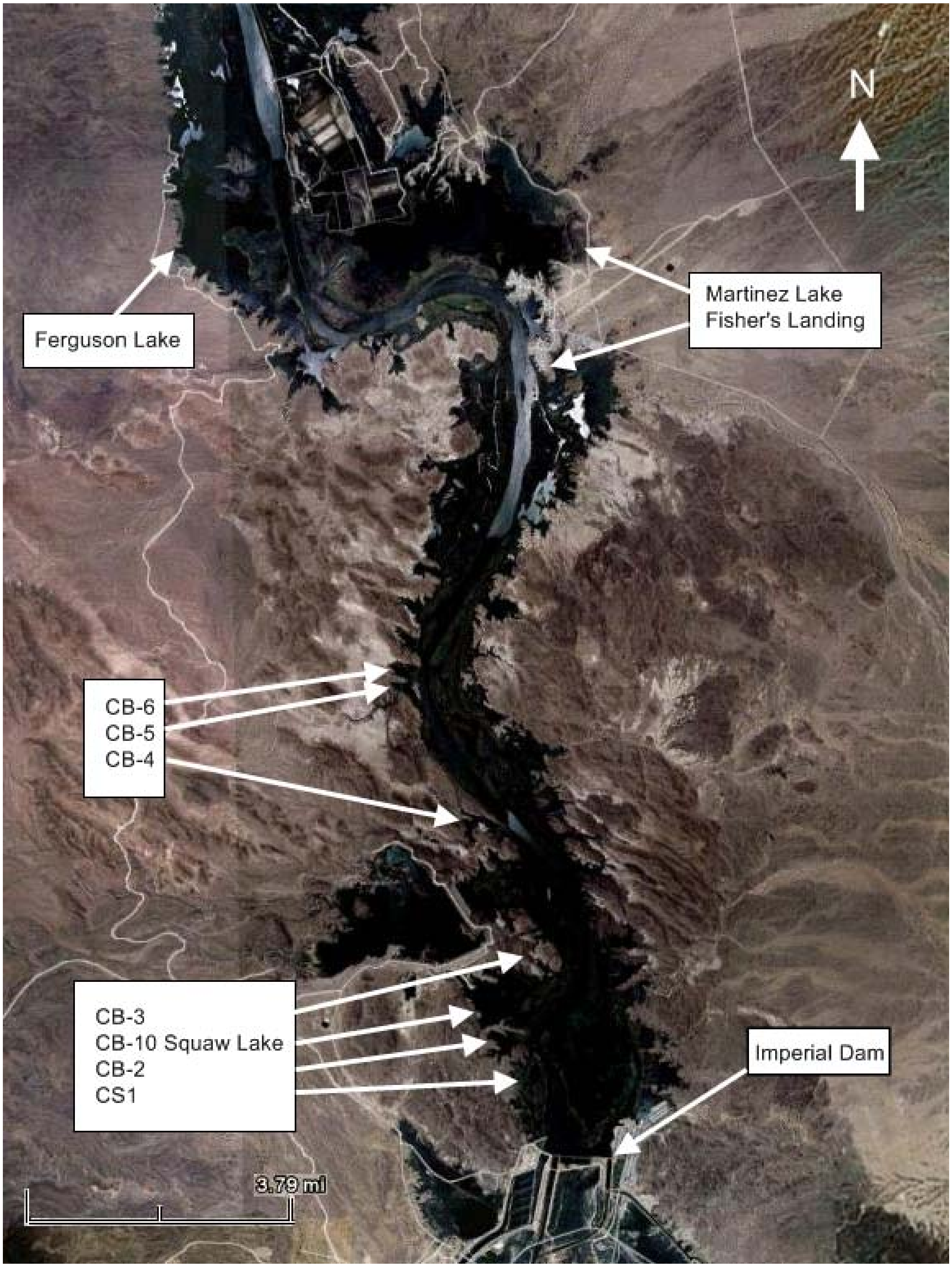
Map 4. Portion of lower Colorado River, USBR Palo Verde Division (depicting A-10 and C-7 backwaters), Riverside Co., California and La Paz Co., Arizona.



Map 5. Portion of lower Colorado River, USBR Palo Verde and Cibola Divisions (depicting wash fans and C-10), Riverside Co., California and La Paz Co., Arizona.

Map 6. Portion of lower Colorado River, USBR Cibola Division (depicting Oxbow Recreation Area, Sandy Cove, and an unnamed backwater), Imperial Co., California and La Paz Co., Arizona.

Map 7. Portion of lower Colorado River, USBR Imperial Division (depicting Adobe, Taylor, and Island Lakes), Imperial Co., California and La Paz Co., Arizona.



Map 8. Portion of lower Colorado River, USBR Imperial Division (depicting Ferguson and Martinez Lakes, and named California backwaters), Imperial Co., California and Yuma Co., Arizona.