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BRIEF COMMUNICATIONS

Acoustic telemetry to assess post-stocking dispersal and mortality of razorback sucker *Xyrauchen texanus*

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Acoustic telemetry and scuba revealed immediate and high post-stocking mortality of razorback sucker *Xyrauchen texanus* in Lake Mohave, U.S.A., a Colorado River impoundment. At the conclusion of this 6 month study, only three of 19 (16%) study fish remained active. Concurrently, 20 *X. texanus* implanted with acoustic transmitters and held in a hatchery raceway remained healthy throughout the experiment and no transmitters were shed. Post-stocking mortality was probably due to predation by striped bass *Morone saxatilis*, a piscivorous non-native fish.

Key words: Colorado River; endangered species; predation; repatriation; surgical mortality; transmitter retention.

Researchers have recently estimated fish mortality using radio or acoustic telemetry (Jepsen *et al.*, 1998, 2006; Aarestrup *et al.*, 2005). Hightower *et al.* (2001) used telemetry to estimate natural and fishing mortality of striped bass *Morone saxatilis* (Walbaum), but their study relied on transmitter returns from fishermen and the assumption that immobile transmitters represented natural mortality events. Jepsen *et al.* (1998, 2000) validated mortality of tagged study fishes by recovering transmitters from piscivorous fishes. This approach was dependent on predators inhabiting shallow waters accessible by electrofishing. Direct observation to determine status (alive or dead) of a fish is considered generally untenable during a telemetry study (Bradford & Gurtin, 2000; Hightower *et al.*, 2001). Advances in telemetry technology, however, have led to the development of a hand-held, waterproof, acoustic receiver, which in cases of suspected mortality, allows for direct underwater observation or recovery of the fish or transmitter.

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Lake Mohave, Arizona and Nevada, U.S.A., a mainstem regulatory reservoir on the Colorado River, is a focal point for current stocking efforts for the endangered razorback sucker *Xyrauchen texanus* (Abbott). Results from collaborative monitoring indicate post-repatriation survival is exceptionally low, *c.* 2–6% (Marsh *et al.*, 2005). These estimates are based on mark-recapture data and have broad confidence intervals due to low recapture rates. In addition, the estimates assume that fish do not disperse out of the system, which may or may not be true.

Lake Mohave also supports a robust sport fishery of non-native species including large (>800 mm total length, L_T) *M. saxatilis*. These visual predators are aided by clear reservoir conditions (Secchi depths typically >5 m and seasonally >10 m) created by hypolimnetic discharges from upstream dams on the Colorado River. Piscivory by non-native fishes, including *M. saxatilis*, is well documented throughout the Colorado River basin (Minckley *et al.*, 1991) and is suspected as a major cause of low survival for stocked razorback suckers in Lake Mohave.

In this study, post-stocking dispersal and fate of *X. texanus* were monitored using active and passive acoustic telemetry techniques, and in cases of immobile transmitters, scuba diving in combination with an underwater diver receiver (UDR; Sonotronics Inc., Tucson, AZ, U.S.A.) was used to determine actual status of tagged individuals. These techniques were used to evaluate: (1) whether *X. texanus* emigrate from the reservoir and are therefore unavailable for recapture, (2) the rate of post-stocking mortality and (3) whether predation is a major component of post-stocking mortality. (4) Finally, a captive tagging experiment was used to estimate transmitter retention and effects of the surgical procedure and transmitter presence on fish survival and growth.

Twenty *X. texanus* (mean L_T = 381 mm, range 355–455 mm) were collected from a hatchery stock of subadult *X. texanus* on 25 September 2006 at U.S. Fish and Wildlife Service Willow Beach National Fish Hatchery, Willow Beach, AZ (Willow Beach NFH). All fish had previously received a 400 kHz passive integrated transponder (PIT) tag for individual identification. Fish were transferred to an indoor raceway (6·1 m long, 0·8 m wide, 0·7 m deep) and acclimated for 30 min prior to surgery. Acoustic transmitters (IBT-96-6-I; Sonotronics Inc., 7·4 g in air) were chosen based on a transmitter to fish mass proportion of ≤2% (Winter, 1996) and precluded the use of a larger transmitter with a longer life span or a mortality signal. Although there are exceptions to this rule (Jepsen *et al.*, 2005), it has served as a reference for previous telemetry studies of *X. texanus* (Burdick, 2000). Each fish was anaesthetized with 125 mg l^{-1} of tricaine methanesulphonate (MS-222), scanned for a PIT tag and measured (L_T). A short (<20 mm) incision was made slightly anterior to the right pelvic fin and an acoustic transmitter sterilized in 70% ethanol was inserted into the abdominal cavity. The incision was sutured with 2–3 knots using USSC 3-0 Monosof black monofilament and a C-14 cutting needle. MS-222 water was continually flushed over each fish's gills to maintain anaesthesia for the duration of the surgery. Following surgery, the wound was swabbed with Betadine and 0·20 ml (23 mg ml^{-1}) of Baytril® (enrofloxacin) was injected into dorsal–lateral musculature to prevent infection (Martinsen & Horsberg, 1995). Fish were placed in an indoor raceway with fresh circulated water and monitored for 2 days to ensure proper health and transmitter retention. The care and use of fish used in this study was approved by Arizona State University's Institutional Animal Care and Use Committee, protocol number 05-767R, and complied with local animal welfare laws.

Submersible ultrasonic receivers (SURs) (SUR-1; Sonotronics Inc.) were used to detect the dispersal of study fish. The SURs were initially deployed in the main channel upstream (3 km) and downstream (8 and 13 km) of the stocking site at Fortune Cove (Fig. 1). When a fish was contacted by an SUR, the respective unit was moved further away from the stocking site to broaden the search area for all telemetry fish (Fig. 1). Data from SURs were downloaded to a laptop computer during each manual tracking survey.

On 27 September 2006, telemetry fish were placed into an 1890 l aerated tank, transported by boat downriver from Willow Beach and released into Fortune Cove on the Nevada side of Lake Mohave (Fig. 1). These fish were released as part of a 2 day event in which a total of 1034 *X. texanus* were repatriated into the reservoir (*c.* 500 fish were released each on 26 and 27 September) at Fortune Cove.

During the first 30 days post-release, intensive surveys were conducted by boat in coves and the main river channel between the upstream- and downstream-most deployed SURs. Signals were detected using a hand-held, directional hydrophone and an acoustic receiver (USR-96; Sonotronics Inc.). Thereafter, bimonthly surveys were conducted by boat using a grid composed of 148 waypoints or listening stations programmed into a global positioning system (GPS) navigational system (Mueller *et al.*, 2000). For any given date, efforts were concentrated between upstream- and downstream-most deployed SURs, and surveys terminated if no fish were contacted by the SUR positioned furthest downstream from Fortune Cove. Periodic surveys of the entire reservoir (all 148 listening stations) were made to ensure no fish had dispersed undetected beyond the downstream-most deployed SUR.

Each transmitter signal was triangulated to its exact location. If feasible, return trips were made within 1–3 days to relocate previously contacted transmitters. When re-contacts were made in the same location, a scuba diver was deployed with a UDR to locate and attempt to recover the transmitter. The diver noted presence or absence of fish remains in the vicinity of a located transmitter. For each manual tracking contact with a fish, transmitter frequency, code, universal transverse mercator (UTM) co-ordinates, date, time and depth were recorded and later entered into a database. SUR data were electronically transferred into the database with location data entered based on SUR position when a transmitter contact was made. If an individual fish was contacted multiple times by an SUR over a short period of time (span of time between contacts <2 h), only one contact event was recorded. A geographic information-system database (ESRI; ArcMap 9.1) was created to illustrate and measure fish dispersal by mapping UTM co-ordinates from manual tracking and SUR contacts.

Post-stocking fate was determined from the contact database and tag recovery data. A live contact with a fish was one in which the subsequent contact was in a different location (*i.e.* the fish was moving). If a transmitter was recovered, all contacts for the corresponding fish in that location were considered dead

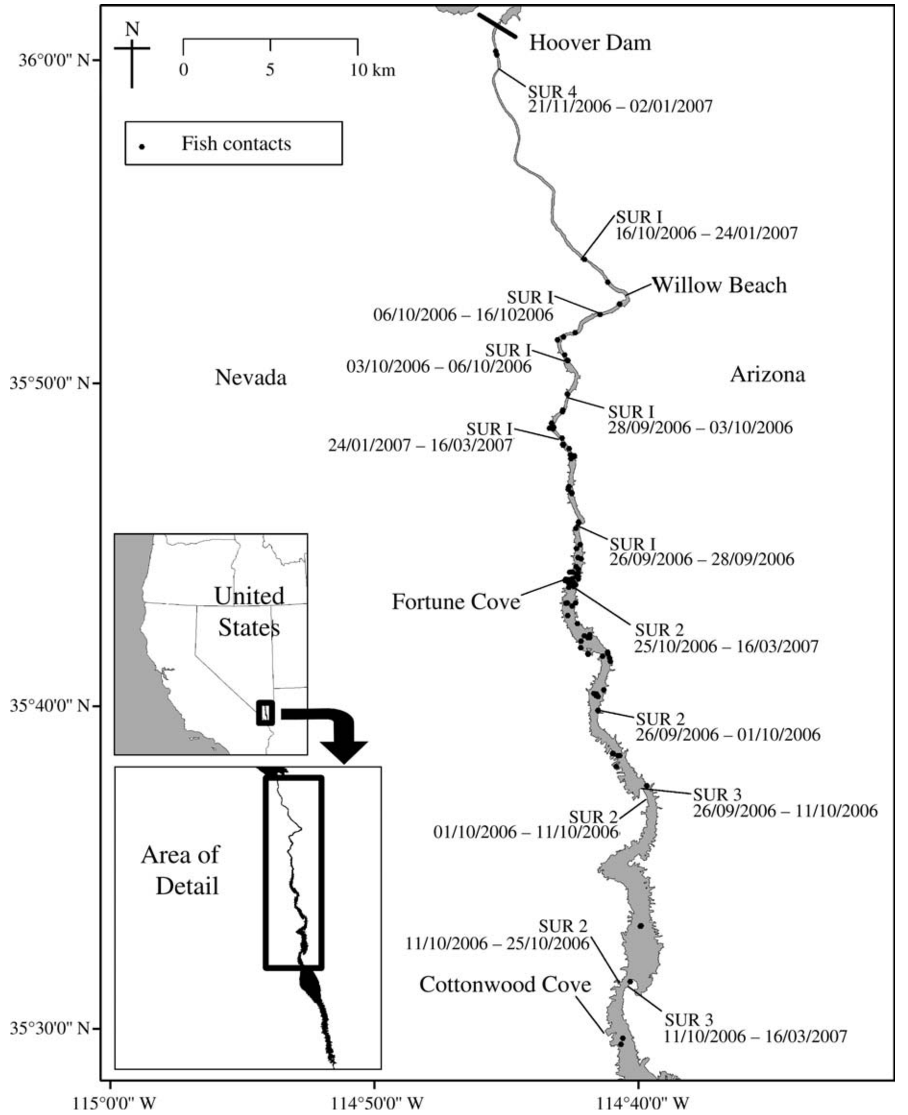

FIG. 1. Map of Lake Mohave, Arizona and Nevada, U.S.A., showing (1) locations and dates in which four individual submersible ultrasonic receivers (SURs) were deployed and relocated throughout the study area and (2) geographic distribution of all acoustic telemetry contacts of *Xyrauchen texanus* recorded between 27 September 2006 and 16 March 2007.

contacts. If a transmitter was never recovered, but never moved from a location where it was contacted multiple times for a time period spanning more than a month, all contacts at that location were considered dead contacts.

Post-surgical transmitter retention and mortality were two additional factors that could bias results compared to normally stocked fish. To estimate their impact, a captive fish study was implemented. A total of 43 *X. texanus* were randomly selected from a hatchery stock of subadults on 10 January 2007 and placed in an indoor raceway at Willow Beach NFH. All fish were measured (L_T) and received a 400 kHz PIT tag. Twenty individuals (mean L_T = 377 mm, range 365–395 mm) were selected from the group to approximate the size of fish used in the telemetry study and implanted with a transmitter following the procedures previously outlined. Mean L_T of individuals used in the captive fish and telemetry studies were not significantly different (*t*-test, d.f. = 23, $P > 0{\cdot}05$). The remaining 23 fish (mean L_T = 354 mm, range 326–403 mm) were controls. All 43 fish recovered in an indoor raceway for 3 days, after which they were transferred to an outdoor raceway (27·4 m long, 2·4 m wide, 1·5 m deep). The flow-through raceway was fed by Lake Mohave and temperature was within 1° C of the reservoir. Metal screens (5 mm mesh) located at both ends of the raceway prevented transmitters and dead fish from leaving.

Between 10 January and 12 April 2007, study fish were fed weekly. No antibiotics or prophylactics were administered. In-depth monitoring of experimental fish was conducted on a bimonthly basis throughout the study. During each visit, the raceway was swept and inspected for dropped transmitters and mortalities. On 12 April 2007, all captive fish were measured (L_T) and scanned for a PIT tag. PIT tag number, L_T and sexual condition were recorded for each fish. Fish growth (ΔL_T) was calculated as the difference in L_T from initial measurements on 10 January 2007 to measurements made on 12 April 2007. Due to differences in initial L_T between control and experimental fish, growth between groups was compared by regressing fish growth with initial L_T following the methods used for tagging data (Fabens, 1965; Haddon, 2001). This linear regression approach provided intrinsic, size independent, growth rate estimates for each group. Seven experimental fish (five males and two females) were randomly selected and sacrificed to locate and retrieve the implanted transmitters. All others were returned to the hatchery raceway.

All 20 *X. texanus* implanted with acoustic transmitters and released into Lake Mohave were contacted over the course of the 6 month telemetry study for a total of 247 individual contacts. Of the 247 total contacts, 82 were made remotely with SURs and 63 (77%) of these were made after dark. SURs were relocated on 10 occasions, which reflected the outward-most dispersal of study fish away from the stocking site. Fish dispersal was confined to the northern half of the reservoir (Fig. 1). Two surveys of the entire reservoir confirmed that no fish moved past the downstream-most positioned SUR. One individual was contacted in Fortune Cove immediately following its release but thereafter was never located again. Consequently, this fish was excluded from further analysis.

Sixteen of 19 (84%) fish stopped moving after exhibiting extended periods of activity, as documented by manual and SUR tracking (Fig. 2). Thirteen transmitters were located and recovered from the bottom of the reservoir by a scuba diver. No fish remains were observed near any of the transmitters. Median number of days between first contact at recovery location and transmitter recovery was 8 days (range 2–48 days). Scuba observations were not made for three fish that stopped moving, but transmitters remained motionless for the remainder of the study and those individuals were presumed to be dead. Of the 16 sessile transmitters, 14 were located in the main channel [mean distance was 10 km from the release site (range 2–30 km), mean depth was 10 m (range 3–21 m)] and two transmitters were found in shallow coves [mean

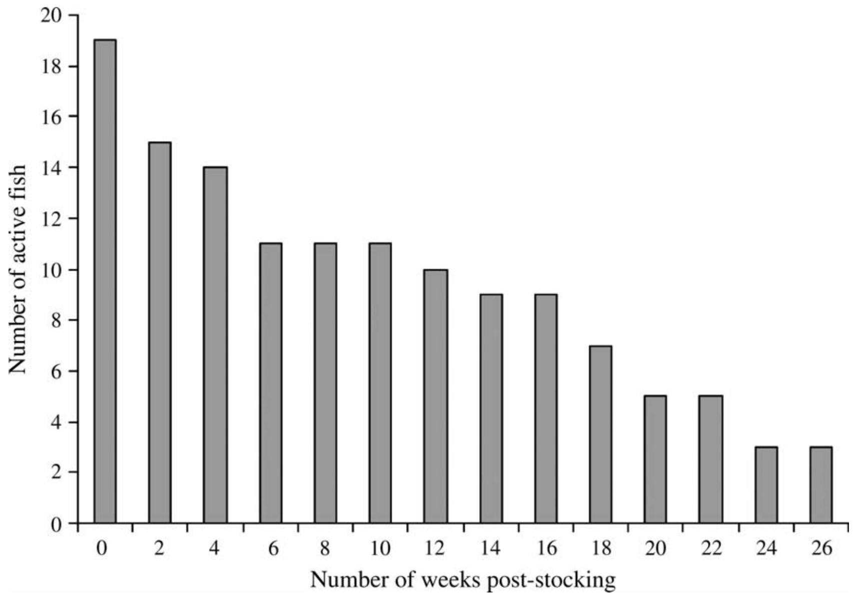

FIG. 2. Summary of active tagged *Xyrauchen texanus* contacted over the 6 month study. Number of active fish is the total number of *X. texanus* without a documented dead contact for a given bimonthly survey.

distance was 7 km from the release site (range 4–10 km), mean depth was 4 m (range 2–5 m)].

Throughout the 3 month duration of the captive fish study, all 43 individuals (20 experimental and 23 control) remained active and healthy. No dropped transmitters were observed. All incisions in experimental fish had healed, and there were no signs of infection. Minor irritation was observed at the site of some sutures. At the conclusion of the study, both male and female fish were ripe (showed visible signs of milt or egg production). Transmitters of sacrificed fish were located near the incision site, either between the ventral abdominal wall and gut lumen or between folds of the intestine. There was no evidence of transmitter encapsulation by connective tissue or intestinal loops. Growth regression for control and experimental fish were not significant (linear regression, $r^2 = 0{\cdot}09$, $P > 0{\cdot}05$ and $r^2 = 0{\cdot}03$, $P > 0{\cdot}05$, respectively), therefore growth rates could not be compared. Experimental fish grew 2–9 mm (mean $\Delta L_T = 6$ mm), while control fish grew 0–11 mm (mean $\Delta L_T = 5$ mm).

The movement of telemetered fish in this study does not support a hypothesis that stocked *X. texanus* emigrate from the reservoir, either through Davis Dam (the structure that impounds Lake Mohave) or by any other means. The loss of contact with one fish early in the study could represent undocumented emigration, bird predation (Jepsen *et al.*, 1998) or tag failure. This accounts for a small amount (*c.* 5%) of the total loss of stocked fish for this study.

Acoustic telemetry data and captive fish experiment results indicate that subadult *X. texanus* released during this experiment faced almost certain mortality in a relatively short time following repatriation into Lake Mohave. While recovered transmitters alone are not definitive indicators, 100% tag retention in captive fish suggests that recovered transmitters represented fish mortality. The captive fish study also demonstrated that surgical procedures in no way compromised fish health or behaviour. In fact, at the conclusion of the experiment, fish showed obvious reproductive signs in both sexes suggesting sexual development was not disturbed by the implanted transmitters. Similar observations were made in *X. texanus* implanted with acoustic transmitters on the Green River, Utah, U.S.A. (Tyus & Karp, 1990; Modde & Irving, 1998).

Based on data acquired at the time of transmitter recovery and previous studies of *X. texanus*, rapid loss of telemetered fish from this study was most likely due to consumption by predacious fishes. Piscivory has been reported as a cause of mortality for adult and subadult *X. texanus* elsewhere in the Colorado River Basin (Marsh & Brooks, 1989; Tyus & Nikirk, 1990). Absence of fish remains even when tags were recovered a relatively short time after cessation of movement suggests predation and is consistent with other studies of this population (Marsh *et al.*, 2005).

Although piscivory has been considered a threat to this population for some time (Minckley *et al.*, 2003), the high rate of loss (16 of 19 fish) is troublesome considering that this study accounts for a trivial amount of time (6 months) in the life span of fish that can exceed 40 years (McCarthy & Minckley, 1987). In addition, the size of fish being consumed is alarming. *Xyrauchen texanus* >400 mm L_T were readily consumed in this study. *Morone saxatilis* are the only piscivores in Lake Mohave that have a gape size large enough to ingest fish of this size (Dennerline & Van Den Avyle, 2000). First year survival for a 381 mm *X. texanus* (the average size of fish released in this study) has previously been estimated at 40% (Marsh *et al.*, 2005). This is markedly higher than the experienced 16% survivorship of fish in this study in only 6 months.

This study provides a methodological approach that builds on previous studies employing acoustic telemetry to estimate mortality in fishes (Hightower *et al.*, 2001) and tests several assumptions made in these studies. For non-sport fish species that are rare and endangered, acoustic telemetry is an effective technique to estimate mortality using a small number of fish. Low recapture rates and broad confidence intervals of survivorship from mark–recapture data even after years of labour intensive netting operations is the result of the species being rare (Marsh *et al.*, 2005). This study provides an alternative approach that can be used to narrow confidence intervals using comparatively less effort. Both methods require an additional assumption that handling, capturing and tagging do not negatively affect the individuals if the estimates of mortality are inferred for all stocked fishes. At least for *X. texanus*, this assumption appears valid.

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