Overview of Telemetry Equipment and Techniques Used with Native Fish in the Upper Colorado River Basin

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ABSTRACT

Radio telemetry has filled major information gaps on distribution, migration and movement, seasonal habitat use, and spawning area delineation for five species of large-river, native fish: the Colorado pikeminnow, humpback chub, bonytail, razorback sucker, and roundtail chub. A digitally encoded telemetry system with data logging capabilities is currently being used to evaluate fish passage by Colorado pikeminnow at two diversion structures in Western Colorado. Telemetry has greatly increased and contributed to the knowledge and assisted in development of conservation strategies for these native fish.

INTRODUCTION

The Colorado River basin was originally occupied by only thirteen native fish species (Behnke and Benson 1983). However, today native fish of the Colorado River basin have been negatively impacted by major environmental changes from human alterations to the ecosystem, including the introduction of non-native fish and modification of mainstem river and tributary habitats. Today, 42 non-native fish compose 76% (42 of 55 species) of the fish community in the upper Colorado River basin (Tyus et al. 1982). As a result of these changes, four of these warm water fish endemic to the Colorado River system – the Colorado pikeminnow (*Ptychocheilus lucius*), humpback chub *(Gila cypha*), bonytail (*G. elegans*), and razorback sucker (*Xyrauchen texanus*) – have declined significantly to the point that they are now listed as endangered by the United States Endangered Species Act; United States Fish and Wildlife Service (USFWS).

The Colorado pikeminnow, a long-lived, formerly abundant, potamodromous species, is the largest minnow in North America, and is reported to have weighed up to 36 kg. This species is now extirpated

downstream of Glen Canyon Dam and only occupies approximately 20% of its historic range. It is only found in mainstem rivers and tributaries in the upper Colorado River basin. Humpback chub populations occupy specific, deepwater habitats in canyon-bound areas. They are found in the Grand Canyon in the lower Colorado River basin and in localized areas in mainstem rivers and tributaries in the upper Colorado River basin. Bonytail disappeared rapidly in the 1960s and are now considered the rarest native fish in the Colorado River. Except for an occasional wild bonytail that is captured, most of the bonytail now in upper basin rivers are those that have been domestically reared and stocked. Bonytail are also found in small numbers in two lacustrine areas in the lower Colorado River basin. Razorback sucker is one of three native catostomid species in the basin that are presently found in both the lower and upper Colorado River basin – the largest population being in Lake Mohave in the lower basin. The current, main restoration effort for this species in the upper Colorado River is producing domestic reared fish and stocking them in previously occupied, historic areas of mainstem rivers and tributaries.

Some of the major factors that are suspected of reducing populations of these four "big river" endangered fish include alteration of the hydrologic regime, reduced water quality, competition and predation from the introduction and proliferation of non-native fish, possible reproductive impairment from both human-produced contaminants, and harmful natural trace elements (Hamilton and Waddell 1994, Waddell and May 1995), reduced or complete recruitment failure due to a loss of available spawning or nursery habitats, reduced food base, and angler-related mortality of adult fish.

The Colorado River and its tributaries flow through six states in the southwestern United States and serve more than 15 million people with water for various uses including municipal use, irrigated agriculture, industry, and mining (Utah Water Research Laboratory 1975) (Figure 1). The demarcation between the lower and upper basin is Glen Canyon Dam. Water development began around the turn of this century, but it did not become extensive until the 1920s when several dams constructed on the lower Colorado River modified and converted a historic warm water riverine environment to one with several reservoirs that released cold water downstream. In the upper basin, transmountain water diversions began in the late 1930s and the Colorado River Storage Project Act of 1956 authorized the construction of four dams and reservoirs on major rivers and tributaries; that construction occurred in the 1960s. Historic data on fish species composition, distribution, and abundance for much of the Colorado River basin are difficult to characterize because of the lack of past quantitative data. The remoteness and lack of technology to access remote riverine areas of the Colorado River precluded early explorers from

conducting thorough ichthyofaunal investigations and surveys. Unfortunately, before investigations could be conducted, some native fish declined with causal factors largely unidentified and undescribed. The listing of some of these native species in the 1970s increased efforts to conduct more intensive investigations and research to test hypotheses and determine the exact casual factors for changes in species composition, distribution, and abundance.

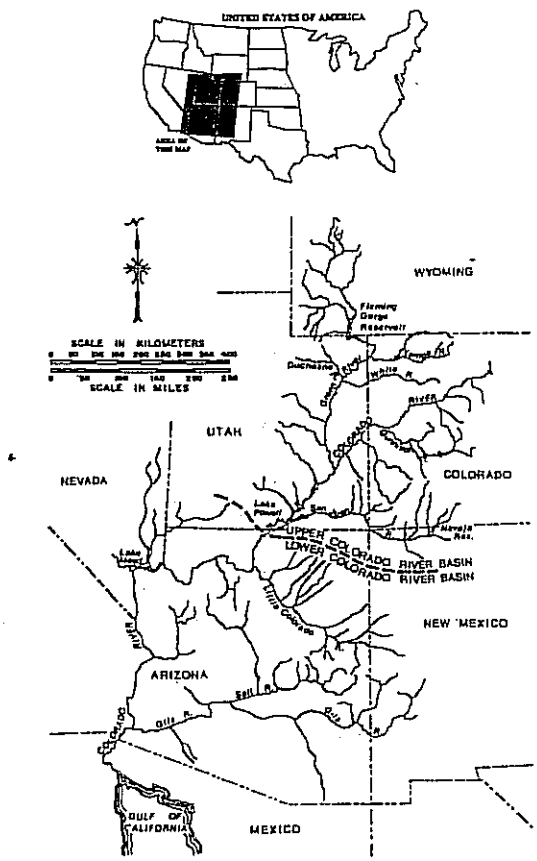

Figure 1. Map of the Colorado River basin located in the southwestern United States.

Radio telemetry has been a pivotal research tool in filling major information gaps on life history aspects including distribution, migration and movement, seasonal habitat use, and spawning area delineation for these large-river, native, endangered fish as well as other more common and abundant, non-listed native fish. Radio telemetry has been a relatively useful tool for monitoring the behavior and movement of Colorado River native fish and has been particularly useful in freshwater, riverine settings

where visual observations are impossible because of turbidity and other types of telemetry (e.g., ultrasonic) that have proven less suitable. The paper discusses the various telemetry equipment and techniques that have been used with native fish in the upper Colorado River basin with emphasis on those used by the USFWS Colorado River Fishery Project.

METHODS

Surgical Procedures

Surgical protocol was established from procedures developed for Colorado pikeminnow and razorback sucker in 1980 from Tyus (1982), for humpback chub (Valdez and Nilson 1982, Archer et al. 1985) and roundtail chub (*G. robusta*) in the early- and mid-1980s (Archer et al. 1985). Fish were selected for transmitter implantation on the basis of weight and condition. Female Colorado pikeminnow were not implanted during late spring and early summer, the period immediately prior to and during spawning, to avoid stress and eliminate risk of transmitter expulsion from enlarging egg masses in gravid fish (Bidgood 1980, Marty and Summerfelt 1986).

For wild fish, surgery occurred in a riverside setting. Fish were anesthetized with Finquel, a brand of tricaine methanesulfonate (MS222), at a concentration of about 100-200 mg/l for about 2-4 min, or until the fish lost equilibrium. Fish were then transferred to an operating table where either fresh water or anesthetized water was continually passed over the fish's gills to provide oxygen and to keep the body moist. Gill opercular rate was maintained at about one per five seconds. Fish were oriented ventral-side up so that the internal organs would gravitate dorsally to reduce the likelihood of severing internal organs with surgical instruments upon entering the peritoneal cavity. A 30-40 mm long incision was made about 15-25 mm lateral to the mid-line (linea alba), and slightly anterior to the pelvic fin. If a transmitter had a trailing, external antenna, a second incision, 5-8 mm long, was made ventral, about 5-10 mm posterior from the pelvic fin and about 10 mm lateral to the midline to provide an exit for the antenna. A stainless steel scalpel and toothed forceps aided in making the incisions through the ventral musculature.

Once initial entry to the peritoneal cavity had been gained for the primary incision, a grooved director was inserted in the incision opening that aided in protecting the internal organs from accidentally being damaged or cut by the scalpel. A curved avian feeding tube facilitated positioning the external antenna. The feeding tube (17 cm long), hollow with a blunt, bulbous end, was first inserted through the secondary incision under (dorsal to) the pelvic girdle and then pushed anterior where it exited

the primary incision. The external antenna was then threaded into the bulbous end and completely through to the female luer hub of the tube. The tube and antenna were then both pulled posteriorly through the exit incision. The tube provided a rigid frame in which the flaccid external antenna could be threaded underneath the pelvic girdle from the primary to secondary incision within seconds, expediting this portion of the surgery and minimizing tissue trauma. Finally, the transmitter was inserted and positioned dorsal to the primary incision. The incisions were closed with either Ethicon absorbable or non-absorbable sutures (3-0, FS-1 cutting needle) that were triple-tied, individual surgical knots. Usually, five to seven sutures were needed to close the primary incision depending on the length of transmitter implanted; two to three were used to close the secondary incision. Sterile saline was used to wash the fish's ventral musculature in the immediate area of the primary and secondary incisions. In the 1990s, Colorado River Fishery Project biologists began injecting Gentamicin sulfate (100 mg/ml), a wide-spectrum antibiotic, interperitoneally in radio-tagged fish immediately following surgery at 0.5 ml/kg of fish body weight. Surgical tools were immersed in 100% alcohol in the field. Wetted cotton toweling was used to surround the fish to keep the fish's skin moist and aid in supporting the fish's body. The surgical process required approximately 7-10 minutes. Following surgery, fish were allowed to recover in fresh water from the anesthetic. Fish were released when they regained their motor skills.

Telemetry Equipment

Transmitters. A wide variety of transmitters have been used that have ranged in size, frequency, pulse rate, and operational life (i.e., battery type and voltage) according to the size and species of fish and study objectives. AVM Model SM-1 transmitters (40.600-40.699 MHz) have been implanted in humpback chub and roundtail chub (9 g air weight, 90 day life expectancy) and in Colorado pikeminnow and razorback sucker (4.6 g air weight, 6.5 month battery life expectancy). Smith-Root transmitters (about 28-30 g air weight, 360 day battery life expectancy) with internal antenna have also been used in adult Colorado pikeminnow in the upper Colorado River (McAda and Kaeding 1991).

Most manufactured tags were oblong, capsule-shaped, and encased in acrylic resin. Internal antenna were either the "padlock" style (Smith-Root, AVM, and Advanced Telemetry Systems [ATS]) or were wrapped within the tag. The AVM tag used with humpback chub was circular-shaped with a padlock antenna. Smith-Root models were the largest used, 95 mm length and 17 mm diameter. ATS external antennas were 30 cm long and 1 mm diameter. Lotek Engineering, Inc. external antennas were 40 cm long. Both external antennas were plastic-coated.

When the 40 MHz band was used, individual fish were distinguished and identified by different frequencies, separated by at least .010-Hz, and a combination of pulse-rates between 30 pulses/min and 60 pulses/min. A particular combination of frequency and pulses was reused following expiration of a transmitter. When 149.760 MHz was used, each transmitter had a unique identity code (e.g., Code 82) which was the fish's specific transmitter signature.

Receivers. Various makes and models of receivers have been used. Smith-Root Model RF-40, Model SR-40, and ATS Model R2000 receivers (40-41 MHz) were used extensively from 1980 to the present. The ATS Model R2000 was a programmable, sequential-scanning receiver used to monitor radio frequencies in omni-directional searching and directional triangulation. The Smith-Root Model SR-40 was a programmable, simultaneous-scanning receiver used exclusively for omni-directional searching.

Two types of Lotek Model SRX-400 receivers were used. One was a field datalogger that was deployed with a remote land-based telemetry station to constantly monitor the presence and movement of tagged fish within predetermined receiving zones. This surveillance technique provided an automatic means of constantly and simultaneously monitoring and storing unique codes of tagged fish. This reduced scan delay time, which minimized the likelihood of missing several tagged fish that might simultaneously occupy a location for a short time. One remote data logging station was deployed in June 1996 at the newly constructed fish passageway at the Redlands Diversion Dam on the Gunnison River in western Colorado. This station consisted of seven different antenna-receiving sites, four aerial and three underwater within the fish passageway that provided fish position relative to a particular antenna. Two other SRX-400 data logging receivers were used concurrently at two other riverside locations on the Gunnison River in conjunction with two three-filament directional antennas. These stations were easily dismantled and redeployed. One station was redeployed in 1998 to evaluate passage of fish through a series of pools and riffles and a newly constructed notch on an existing, low-head diversion structure on the Colorado River in western Colorado. An SRX-400 receiver, not programmed for data logging, has also been used to search from boats for radio-tagged fish outside the range of the remote, land-based stations.

Antennas. Larsen-Kulrod omni-directional whip antennas, Smith-Root loop antennas, and Cushcraft and Telex low-band VHF Yagi antennas were used for omni-directional searching, and directional locating of tagged fish in the 40-41 MHz frequency range. The Cushcraft 4-element Yagi and Telex Yagi antennas were the largest (boom length 3.7 m, element length 3.2 m) antennas used. These two large Yagi antennas were

mounted in a 5-m long aluminium boat, rotated 90° to obtain vertical polarization, and used for active directional searching. While these Yagi antennas increased the gain and horizontal range, and therefore the likelihood of signal reception, they were cumbersome and difficult to maneuver and transport. Nine- and four-element aerial directional antennas (148-152 MHz) were used for surveillance at remote stations; three-element antennas (AF Antronics, Inc.) were used from boats. Stationary underwater antenna used in the Redlands fishway consisted of an 8 cm end portion of the inner solid copper wire of a coaxial cable (58 W) exposed and positioned 15 cm above the floor of the fishway. Smaller-sized, multi-element antennas used with the high-band frequency did not compromise signal reception or gain.

RESULTS AND DISCUSSION

Biologists with the Colorado River Fishery Project have implanted radio transmitters in sub-adult and adult wild Colorado pikeminnow, razorback sucker, humpback chub, and roundtail chub. Radio transmitters have also been implanted in captive-reared Colorado pikeminnow, razorback sucker, and bonytail that were subsequently stocked in mainstem and tributary rivers to repatriate these species to former historical stream reaches.

Ultrasonic tags, surgically implanted in the body cavity in Colorado pikeminnow (Seethaler 1978) and razorback sucker (McAda 1977), were the first transmitters to be used in the mid-1970s to collect data on riverine movement, spawning, and habitat use. Ultrasonic tags were surgically implanted in the early 1980s in Colorado pikeminnow in the Colorado River arm of Lake Powell, Utah, and have been attached externally and surgically implanted internally in juvenile razorback sucker that were stocked in the San Juan River arm of Lake Powell (Mueller and Marsh 1998) and adult razorback sucker in Lake Mohave (Mueller et al. 1998). In the riverine studies, researchers reported limited success monitoring fish tagged with ultrasonic tags. Signal range was limited and signal reception retarded by turbulence and by solid objects such as boulders. In the Lake Powell studies, fish could be monitored successfully if they remained in small bays. But tagged fish were lost if they moved into the main body of the lake because wave action affected signal strength and range, combined with the logistics of tracking such large, open expanses of open water reduced the likelihood of detection. Radio transmitters were first implanted in Colorado pikeminnow in the Green River, Utah, in the upper basin in the mid-1970s (Holden and Selby 1978).

The Colorado River Fishery Project first began using radio telemetry in 1980 to implant radio tags in adult Colorado pikeminnow and adult razorback sucker in the Green River, Utah (Tyus and McAda 1984; Tyus et al. 1984). Adult humpback chub and roundtail chub, a native, non-listed fish common to abundant in mainstem rivers and tributaries of the upper Colorado River basin, were first implanted with AVM Model SM-1 radio tags (HG-675 mercury battery; 4-month life expectancy) at Black Rocks on the Colorado River, Colorado, in the early-1980s (Valdez and Nilson 1982). The first bonytail implanted with radio tags were domestic-reared fish that were stocked in the Green River, Utah, in the late-1980s by the State of Utah, Division of Wildlife Resources (Chart and Cranney 1990). A subsample of captive-reared bonytail stocked in the Colorado River near Moab, Utah, in 1998 were implanted with ATS radio tags. Information obtained from these studies included habitat use, spatial and temporal spawning areas and spawning requirements, and general movement and seasonal migration of tagged fish.

ATS model transmitters with external antenna were first used with humpback chub at Black Rocks in 1985 (Kaeding et al. 1990). Later in the 1990s, transmitters equipped with external antenna (ATS Model 6, 40-41 MHz, life expectancy 48 months) and a microprocessor chip to emit a signal for 12 h and be "asleep" or off for 12 h were implanted in pond-reared razorback sucker that were stocked in the upper Colorado and Gunnison Rivers (Burdick and Bonar 1997). High-band encoded transmitters (Lotek Model MCFT-7A, 149.760 MHz) with external antenna were first implanted in wild adult Colorado pikeminnow in 1996-1998 from the upper Colorado and Gunnison Rivers (Burdick and Pfeifer 1998).

ATS transmitters (Model 10, 30 g air weight) and AVM models (40-41 MHz) with internal antenna (battery life 9, 12, or 24 months) have been implanted in wild adult Colorado pikeminnow (Ryden and Ahlm 1996) and captive-reared and stocked razorback sucker, respectively, in the San Juan River, New Mexico, Colorado, and Utah (Ryden and Pfeifer 1996). ATS transmitters (Model 6, 40.600-40.699 MHz) with external antenna) have been implanted in wild adult humpback chub and captive-reared adult Colorado pikeminnow, sub-adult and adult razorback sucker, and sub-adult and adult bonytail that were later stocked in upper basin rivers and tributaries. ATS transmitters with external antennas (40.600-40.740 MHz) have also been used for studying life history aspects of the humpback chub in the Grand Canyon reach of the Colorado River, Arizona (Valdez and Ryel 1995).

Radio transmitter-to-fish weight ratios have averaged no more than 2.0% in Colorado pikeminnow and razorback sucker and no more than 2.5% in humpback chub. Tyus (1988) found that growth rates and

mortality of adult Colorado pikeminnow surgically implanted with radio transmitters did not differ from non-implanted fish. Radio transmitters coated with beeswax appeared not to be rejected by the fish's tissue and caused only mild tissue irritation when implanted internally in adult Colorado pikeminnow. In recaptured fish, he reported that no implants were free in the body cavity; implants were surrounded by connective tissue and bound by adhesions. He concluded that encapsulation and fibrous tissue fixation of transmitters was a normal body response to foreign objects because the body is attempting to isolate them. Regardless of the brand, type, or model of radio tag, retention for implants coated with beeswax were high and expulsion rates low for Colorado pikeminnow that were recaptured several months and years later in the Green River sub-basin (Tyus 1988).

Retention rates for Colorado pikeminnow implanted with radio tags coated only with acrylic resin (ATS and Lotek) in the 1990s in the upper Colorado and Gunnison Rivers provided similar retention rates as those formerly coated with beeswax. Long-term monitoring is particularly important for studying rare fish, especially for the four native endangered fish of the Colorado River basin that are long-lived. Mortality of a few Colorado pikeminnow and roundtail chub has occurred following transmitter implantation and subsequent release in the upper Colorado River. It is uncertain whether this mortality was directly related to handling and surgery or to some other unrelated factor following release since roundtail chub and Colorado pikeminnow died 1 month and 4 months, respectively, following surgery and release. Mortality was high (greater than 90%) for domestic-reared bonytail implanted with radio tags in the Green River, Utah. Modde and Meyer (1991) believed that the high mortality of captive-reared bonytail stocked in the upper Green River, Utah, in 1988 and 1989 (Chart and Cranney 1990) was the result of the failure of individuals to adapt to natural conditions rather than the inability of the species to survive in a natural environment. Similar speculations were hypothesized for the low survival of adult razorback sucker reared in a pond, implanted with radio tags, and stocked in the upper Colorado and Gunnison Rivers (Burdick and Bonar 1997).

The efficiency of radio telemetry is severely limited in deep water, and high conductivity (up to 1,200 µS/cm) in southwestern rivers of the upper Colorado River basin severely attenuates radio tag signal reception and detection. Controlled field experiments showed that radio contact cannot be made with transmitters that are deeper than about 5 m. In the Colorado and Gunnison Rivers of western Colorado, radio-tagged fish equipped with external antenna (ATS Model 6, 40-41 MHz) maximized signal strength and reception and were detected at greater horizontal distances and water depths than those equipped with internal antenna. Transmitters with

external antenna appeared to have stronger signals, which increased the horizontal range of detection. In high-conductivity waters, differences were noted between transmitters emitting low- and high-band frequencies and between those with different battery voltage outputs. Maximum horizontal reception for an ATS transmitter with an external antenna (Model 6, 3.6-V lithium cell, 40-41 MHz) at 4 m depth was about 100 m (825 µS/cm, 25°C); a Lotek transmitter with external antenna (Model MCFT-7A, 7-V lithium battery, 149.760 MHz) at 4-m depth was about 500 m (840 µS/cm, 25° C).

One biological drawback to transmitter models with external antenna is that they remain attached to fish long after radio tags have expired and can cause an open wound to persist at the exit location in the body wall. External antennas are removed from fish recaptured with expired transmitters by cutting the cable near the body wall.

The combination of a high-band frequency, a transmitter model with an external antenna, and a high-voltage lithium battery (7 V) has increased reception efficiency and greatly improved locating radio-tagged fish in deep (up to 4-5 m), high conductivity waters (up to 1,200 µS/cm) of the upper Colorado River basin.

Plans in 1999 are to continue implanting Lotek Model MCFT-7A transmitters in adult Colorado pikeminnow (550 mm and larger) and implanting a lighter (10.3 g) and smaller (11 mm x 59 mm) tag with an external antenna (Lotek Model MCFT-3FM, 3-V lithium battery, 149.760 MHz; average life 550 days) in smaller, sub-adult Colorado pikeminnow (400-550 mm) that use the Redlands fish passageway. Preliminary in situ field tests in the Gunnison River (826 µS/cm, 25° C) in early 1999 revealed that this 3-V tag was easily detected in 4 m depth of water at a horizontal distance of about 250 m; reception power levels were 25% less than a comparable Lotek model with a 7-V lithium battery.

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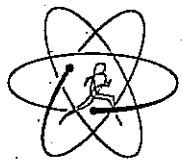

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