Assessment of Radio and Ultrasonic Telemetry Systems in a Polyhaline Reservoir

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Abstract: We tested the performance of low- (40 MHz) and high-frequency (150 MHz) radio and ultrasonic (75 kHz) telemetry transmitters in Robert S. Kerr Reservoir, Oklahoma, a polyhaline body of water. We measured the maximum detection distance of all 3 transmitters at various depths and conductivity levels in lacustrine habitats and the ultrasonic transmitter in riverine habitats. The ultrasonic transmitter had the greatest detection distance (600–1,200 m) in all lacustrine habitats and in clear, deep riverine habitats. Ultrasonic transmitter detection distance decreased by 94% at a shallow riverine site with high velocity and suspended sediment levels compared with a moderately deep, clear riverine site. Maximum detection distance for the low-frequency radio transmitter was 370 m at a depth of 1 m. It was nearly undetectable below 1 m at conductivity levels above 345 μS/cm. The high-frequency radio transmitter had a detection distance of up to 390 m at the surface and was virtually undetectable when in water deeper than 1 m. Considering the performance of the 3 types of transmitters, we recommend using ultrasonic transmitters for telemetry studies of highly mobile fishes in reservoirs that encompass a wide range of conductivities and have depths greater than a few meters. However, for studies of fishes restricted to shallow rivers with high suspended sediment loads, low- or high-frequency radio transmitters may be preferable to ultrasonic transmitters because of their greater detection distance under these conditions.

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Fisheries biologists commonly use telemetry to locate and track fish whose distribution and movements cannot be easily studied by conventional tagging

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methods. Before initiating a telemetry study, a decision must be made about which system, ultrasonic or radio, to use for the fish species and aquatic environment under study. Many rivers and reservoirs in the southern, and particularly southwestern, United States have high levels of naturally-occurring dissolved salts (e.g., chlorides and sulfates) that create polyhaline aquatic environments. Conductivity levels in these environments can vary by an order of magnitude. This variation coupled with high suspended sediment loads and other physical factors (e.g., temperature, depth) affects the detectability of radio and ultrasonic transmitter signals (Stasko and Pincock 1977, Tyus 1982, Winter 1983) and makes the decision of which telemetry system to use difficult.

Ultrasonic transmitter signals travel easily through fresh or salt water, and this type of telemetry system has been the traditional method used to track fish locations. Ultrasonic signal wavelengths (20–300 kHz) can travel long distances in water and are relatively unaffected by conductivity or water depth (Stasko and Pincock 1977, Tyus 1982, Winter 1983). However, they are attenuated, often severely, by physical structures (e.g., sand bars, vegetation, and ice) and certain environmental conditions (e.g., high concentrations of suspended materials, noise, and gas bubbles). Furthermore, aerial tracking is impossible because ultrasonic wavelengths travel only about 1 m in air. This necessitates the use of an underwater receiver or hydrophone to accurately locate tagged fish.

Radio telemetry transmitters have been increasingly used to track fish movements in freshwater environments. Radio waves are longer (27–300 MHz) than ultrasonic waves and travel only short distances in water (Stasko and Pincock 1977, Winter 1983). However, when these signals reach the water surface and enter the air, where little attenuation occurs, they travel long distances. Detection distances up to 10 km have been reported for radio transmitters (Tyus 1982). Furthermore, physical structures and physicochemical conditions (e.g., vegetation, gas bubbles, suspended sediments, or other sounds) do not attenuate radio waves. Disadvantages of radio transmitter signals include severe attenuation in high conductivity water and with increasing water depth (Stasko and Pincock 1977, Tyus 1982, Winter 1983). The attenuation of these signals is inversely proportional to conductivity and depth (Tyus 1982, Winter 1983).

Although relationships between detection distances of telemetry transmitter signals have been theoretically described (Stasko and Pincock 1977, Winter 1983) and individual telemetry systems have been field tested (Stasko and Pincock 1977, Tyus 1982, Jacks 1990), there have been no published empirical evaluations of both ultrasonic and radio telemetry systems under the same field conditions. Our objective was to assess the performance of high- and low-frequency radio and ultrasonic transmitters in a polyhaline system with a wide range of physical and chemical conditions. Our goal was to develop recommendations for the use of these telemetry systems in reservoir systems of the southwest.

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Methods

Robert S. Kerr Reservoir is an 18,000-ha mainstream reservoir on the Arkansas River located in east-central Oklahoma. It is bounded by lock and dam structures with hydroelectric generators at its upper riverine (Arkansas River) and lower lacustrine (Main Lake) portions and hydroelectric dams at the headwaters of its major tributaries, the Illinois River and Canadian River (Fig. 1). The Illinois River arm is a shallow, clear Ozarkian river 15 km long with cobble, gravel, and mud substrates and low conductivity (Table 1). The Canadian River is a shallow, turbid Plains river 25 km long with a shifting sand substrate and intermediate conductivity levels (Table 1). The Arkansas River has a relatively narrow, deep channel upriver (the channel is maintained for navigation) that widens below the confluence of the Illinois and Canadian rivers as it enters the Main Lake. It has low water clarity and high conductivity levels (Table 1). The Main Lake of Kerr Reservoir is a moderately shallow lacustrine habitat with

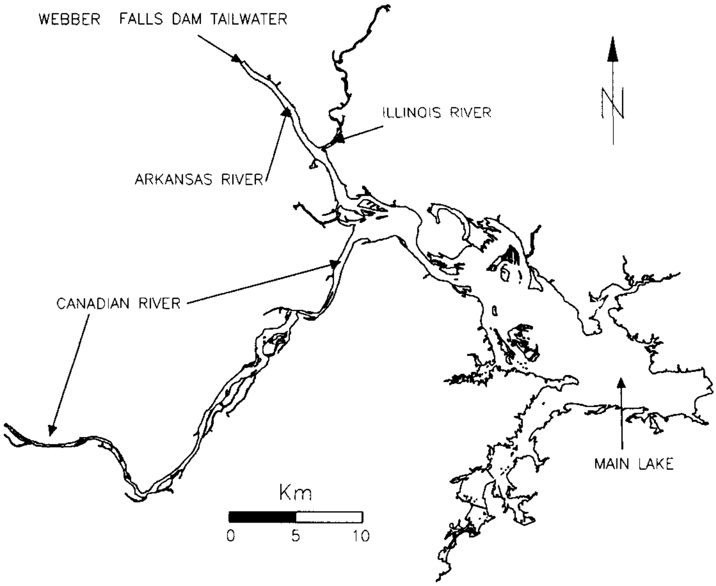

Figure 1. Location of telemetry transmitter test sites in Robert S. Kerr Reservoir, Oklahoma.

Table 1. Mean and range of physical and chemical characteristics of riverine and lacustrine habitats in Robert S. Kerr Reservoir, Oklahoma.

	Water depth (m)		Secchi depth (cm)		Conductivity (μS/cm)	
Location	Mean	Range	Mean	Range	Mean	Range
Arkansas River	3.2	0.3–5.5	33	5–122	596	245–1,144
Illinois River	1.5	0.3–3.0	107	10–290	195	103–391
Canadian River	1.4	0.3–3.5	53	15–155	408	171–563
Main Lake	2.4	0.3–6.5	36	8–104	455	54–859

low water clarity, high but variable conductivity levels, and a large proportion of shallow muddy areas with submerged tree stumps. Discharge in these areas of the reservoir varies with seasonal flows and hydroelectric generation.

Detection distances of low- (40 MHz) and high- (150 MHz) frequency radio and ultrasonic (75 kHz) transmitters were measured under a range of conditions in different habitats of Kerr Reservoir. From 19 May to 8 June 1992, we measured the maximum detection distance of all 3 transmitters in lacustrine habitats of the Arkansas River below the Webber Falls lock and dam, Arkansas River main channel, and Main Lake. On 16 September 1993, we evaluated maximum detection distance of the 75-kHz ultrasonic transmitter in 4 riverine habitats of the reservoir. Testing locations were in the upper Canadian River, lower Canadian River, Arkansas River below Webber Falls lock and dam, and Illinois River near the mouth (Fig. 1).

For the lacustrine evaluations, we suspended the 3 transmitters from a buoy apparatus and measured their maximum detection distance at 1-m increments down to a depth of 5 m. In the riverine evaluations, we measured the maximum detection distance of the ultrasonic transmitter suspended 1 m below the water surface. The boat was equipped with 2 TRX-1000 radio receivers (Wildl. Materials, Inc., Carbondale, Ill.), one with a 3-element, hand-held Yagi antenna, and the other with a 3-element, boat-mounted Yagi antenna and a USR-5B digital ultrasonic receiver (Sonotronics, Tucson, Ariz.) with a directional hydrophone (model DH-2). The receivers were moved away from the transmitters until the signals were no longer detectable. This distance was recorded as the maximum detection distance.

Water depth and conductivity were measured adjacent to the buoy with a Surveyor II multiparameter meter (Hydrolab, Corp., Austin, Texas). Mean water velocity was measured near the buoy with a Teledyne Gurley current meter (model 211 AA) at 0.6 of the total depth. Water transparency was measured with a Secchi disk. A water sample was taken at each test location and analyzed in the lab for total suspended solids (TSS). Underwater sound was measured at each riverine test site with a tape recorder connected to the hydrophone. We digitized these recordings with a computer program to measure the amplitude (expressed as the coefficient of variation, CV) of the ambient underwater sounds.

We tested for differences in detection distance among transmitters with analysis of variance (ANOVA). Differences in detection distance with depth and conductivity by transmitter type were determined with 2-factor ANOVA without replication (Zar 1984). The Duncan multiple range test was used to compare differences among means. We used correlation analysis (Pearson's test) to examine the relationship between maximum detection distance and water depth and conductivity from each transmitter. Correlation analysis was also used to identify relationships between detection distance of the ultrasonic transmitter and water depth, Secchi depth, water velocity, and underwater ambient sound.

Results

In lacustrine habitats, detection distance of the ultrasonic transmitter was greater than that of the 2 radio transmitters at all depths and conductivity levels (Fig. 2). Mean maximum detection distance of the 75-kHz ultrasonic transmitter ($\bar{x}$ = 873 m, SD = 216.4 m, N = 14) exceeded the range of the 40-MHz ($\bar{x}$ = 95 m, SD = 113.4 m, N = 14) and 150-MHz ($\bar{x}$ = 66 m, SD = 108.8 m, N = 14) radio transmitters. For the 40-MHz radio transmitter, detection distance was greater ($P < 0.05$) at 1 m than at all other depths (ANOVA, $P = 0.016$, $F = 6.61$, df = 4); however, detection distance did not differ among conductivity levels ($P = 0.063$). For the 150-MHz radio transmitter, detection distance declined considerably ($P = 0.075$) below 1 m, but did not differ among conductivity levels ($P = 0.572$). For the 75-kHz ultrasonic transmitter, detection distance was greatest ($P < 0.05$) at the highest (969 µS/cm) conductivity level (ANOVA, $P = 0.006$, $F = 11.84$, df = 2), but did not differ among depths ($P = 0.776$).

Detection distance in lacustrine habitats decreased with increasing water depth for the 2 radio transmitters but not for the ultrasonic transmitter (Fig. 2). Detection distance was negatively correlated with depth for the 40-MHz ($r = -0.703$, $P = 0.005$) and 150-MHz ($r = -0.636$, $P = 0.014$) radio transmitters. Below 1 m, detection distance of the 40-MHz radio transmitter signal decreased to 111 m in low conductivity water (345 µS/cm) and 0 m in high conductivity water (969 µS/cm). At 5 m, the signal was detectable 19 m from the transmitter only in low conductivity water. Detection distance of the 150-MHz radio transmitter signal dropped to 37 m at 3 m depth and 19 m at 5 m depth in low conductivity water. The high frequency transmitter was undetectable at 3 m depth in high conductivity water. Detection distance of the ultrasonic transmitter signal ranged from 574 m at 3 m depth to 1,202 m at 3 m and 5 m depths and was not correlated with water depth ($P = 0.875$). Detection distance increased with increasing conductivity for the ultrasonic transmitter ($r = 0.801$, $P < 0.001$), but was not correlated with conductivity for either of the 2 radio transmitters ($P > 0.01$).

In riverine habitats, maximum detection distance of the ultrasonic transmitter was greatest in the lower Illinois River and least in the upper Canadian River (Table 2). Although detection distance was not correlated ($P > 0.1$) with

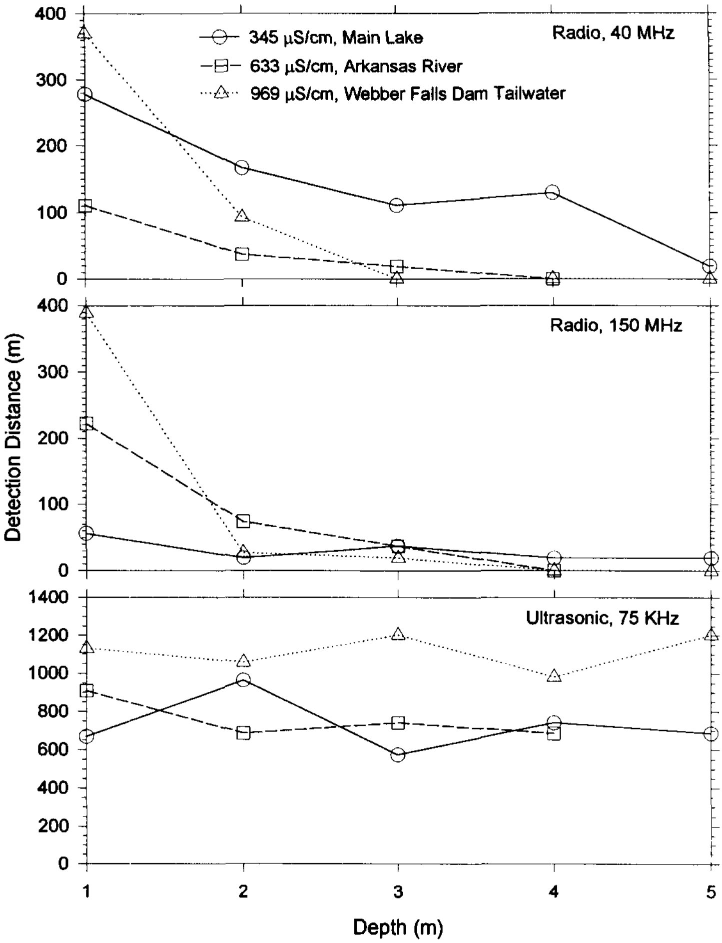

Figure 2. Detection distance of 40-MHz and 150-MHz radio transmitters and a 75-kHz ultrasonic transmitter with increasing water depth and conductivity in Robert S. Kerr Reservoir, Oklahoma, May–June 1992.

water depth, water velocity, Secchi depth, total suspended solids, and the amplitude of ambient underwater sound, there were associations among several of these factors. The shortest detection distance (63 m, upper Canadian River) occurred in relatively shallow, high-velocity water which had high levels of suspended sediments resulting in considerable ambient background noise. The longest detection distance (988 m, Illinois River) occurred in moderately deep, slow-moving water with low levels of suspended sediments and little ambient background noise. Detection distances were intermediate in the lower Canadian River (248 m) and Webber Falls dam tailwaters of the Arkansas River (376 m). Both sites had relatively high water velocity, low levels of ambient background

Table 2. Maximum detection distance of a 75-kHz ultrasonic transmitter and associated habitat variables for 4 riverine locations in Robert S. Kerr Reservoir, Oklahoma, 16 September 1993.

Location	Maximum detection distance (m)	Maximum water depth (m)	Current velocity (m/sec)	Secchi depth (cm)	Total suspended solids (mg/liter)	Ambient sound (CV %)
Upper Canadian River	63	2.8	0.777	96	14.2	6,747
Lower Canadian River	248	3.3	0.875	41	11.2	1,782
Arkansas River, Webber Falls Dam	376	9.0	0.924	13	34.4	1,902
Illinois River	988	3.8	0.436	108	8.2	1,838

noise, and high (Arkansas River) to intermediate (lower Canadian River) suspended sediment levels.

Discussion

Among the various advantages of radio telemetry systems is their extensive aerial detection distance when used in freshwater environments (Winter 1983) which makes them well suited for tracking highly mobile fish in rivers and reservoirs. However, because radio transmitter signals are greatly attenuated in high-conductivity, saline waters, their use in these environments has been only marginally successful. Jacks (1990) found the detection distance of a 40-MHz transmitter in the Arkansas River below Keystone Dam to be completely attenuated at depths >1.7 m in water with a conductivity of 2,550 μS/cm, and up to about 50 m at depths <2 m in water with a conductivity of 550 μS/cm. He concluded useful detection distances (e.g., >250 m) in this river occurred only at depths <0.3 m. Tyus (1982) reported a detection distance of 150 m for an implanted low-frequency (40 MHz) radio transmitter in water with a conductivity of 812 μS/cm. He estimated the signal would be undetectable below 3 m. We found the detection distance of the 40-MHz transmitter dropped off significantly below 1 m at all conductivities except 345 μS/cm where it was detectable up to 130 m at 4 m depth. Attenuation of the 150-MHz radio transmitter at all 3 conductivity levels was even more dramatic below 1 m. Both high- and low-frequency radio transmitters were essentially undetectable below 5 m at all conductivity levels. These findings concur with those of Winter (1983) and Jacks (1990), indicating detection distances of fishes with radio transmitters in high-conductivity waters is limited to the first 1–2 m of water.

Although maximum detection distance of the high- and low-frequency radio transmitters occurred mostly within the first 1 m of water, the specific ranges we measured at different conductivity levels were not expected. Theoretically, radio transmitter signals decrease as conductivity and water depth increase (Stasko and Pincock 1977, Winter 1983). Our measurements exhibited an opposite pattern for conductivity (i.e., detection distance increased with increasing conductivity; Fig. 2) at 1 m, but were consistent with theoretical predictions below 1 m. Jacks (1990) also observed this relationship. We suspect variation in the physical and chemical conditions under which we performed the measurements was the main cause of this incongruity. Radio signals are reflected by various features, including the water-air interface and terrain (Stasko and Pincock 1977, Winter 1983); variations in depth, bottom morphometry, and conductivity at the test sites in Kerr Reservoir may have affected our ability to accurately receive the radio signals. Further investigations of the effects of local physical and chemical conditions on radio transmitter signal transmission are needed.

The detection distance of the ultrasonic transmitter far exceeded that of the radio transmitters in lacustrine habitats. However, detection of the ultrasonic signal was quite variable, perhaps because of differences in sound absorption and reflection from varying amounts of suspended materials (Stasko and Pincock 1977) and temperature variations (Winter 1983) in the reservoir (Wilkerson and Fisher 1995). Attenuation of the ultrasonic transmitter signal in riverine habitats with high concentrations of suspended sediments and associated underwater noise (i.e., Upper Canadian River, Arkansas River tailwaters) limits the utility of this transmitter in turbulent rivers with fine sediments and below dams where gas bubbles occur (Stasko and Pincock 1977, Winter 1983).

Based on the performance we observed for each telemetry system and transmitter and the previously discussed findings of Stasko and Pincock (1977), Tyus (1982), Winter (1983), and Jacks (1990), we recommend using ultrasonic transmitters for telemetry studies of highly mobile fishes (e.g., striped bass (*Morone saxatilis*), paddlefish (*Polyodon spathula*)) in waters with wide-ranging conductivity and depths greater than a few meters. Although we did not test the performance of either radio transmitter type in riverine habitats, the moderate detection distance we measured in shallow-water lacustrine habitats indicates they would be suitable for use in riverine environments. For riverine telemetry studies, particularly those with shallow, turbulent water and high suspended sediment loads (e.g., Canadian River), we recommend using radio over ultrasonic telemetry because of the limited detection distance of the latter.

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