PERFORMANCE EVALUATION OF A 74 KILOCYCLE/ SECOND TRANSMITTER FOR BEHAVIORAL STUDIES ON RESERVOIR FISHES [1]

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ABSTRACT

Ultrasonic transmitters were commercially purchased. They were cylindrical in shape, 90 mm long by 19 mm in diameter, and they weighed 29.5 g, with battery, in water. They transmitted at a frequency of 74 kilocycles/second.

The number of days of active transmission was related to battery type and impulse rate. Transmitters emitting a greater number of impulses per second, with a range of 2.4 to 5.8, tended to stop transmitting sooner than those emitting fewer impulses per second. The difference in longevity between a 3 and 6 impulse per second transmitter was estimated to be 14 days. The average transmitting life of 11 transmitters was 30.5 days, with a range from 24 to 52 days. Battery capacity was a significant factor affecting longevity; transmitters with a 160 milliamperehour battery had an average longevity of only 18.5 days. None of the tags had a transmitting life equal to the 60 days advertised by the manufacturer. Within a range of 5 to 30 C, temperature was not a significant factor affecting the life span of the transmitter, although there was an indication that higher temperature slightly increased impulse rate which reduced total longevity.

Impulse rate of individual transmitters is used to distinguish different fish in a body of water. The impulse rate of each transmitter increased sharply during the last few days of operation which produced greater overlap in impulse rates than prior to this change. The average deviation of impulse rate was much greater than the 10% tolerance specified by the manufacturer.

Turbidity within a range of 8.7 to 41.2 ppm SiO_2 had little effect on transmission range. Wind, apparently due to its effect on waves, was found to add background noise which interfers with sensing impulses. Transmission range averaged 280 m and varied from 150 to 576 meters. Transmission range of a 74 k transmitter was not less when surgically implanted in the abdomen of a flathead catfish than the range of the same transmitter outside the body of the fish.

INTRODUCTION

Observations on homing, home range, and seasonal movements of fish traditionally have been studied by mark-and-recapture techniques employing multilation (clipping) or application of a tag for recognition of individual fish. These procedures have provided basic knowledge of migration and homing in salmon (Hasler, 1966), and stability of stream populations of warmwater fishes (Gerking, 1953). However, these techniques are too inefficient for describing behavior of reservoir fishes because a very large number of fish must be marked in a short interval in order to provide a sufficient number of recaptures to make generalizations about the behavior of the fish over the interval. Even with an intensive marking program, directional movements during the interval between marking and recapture must be inferred as actual movements from one point to another are unknown. Diel movements cannot be

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ascertained by mark-and-recapture procedures because recaptures over 24-hour intervals are far too infrequent. Although many physico-chemical factors having potential influence on the behavior of reservoir fishes can be monitored, even continuously recorded, the impact of normal changes on fish movements cannot be closely related because mark-and-recapture techniques do not allow measurements of change in activity with changes in environmental variables.

In some cases, very useful information has been obtained on directional movements by attaching bobbers to fish with monofilament line (Hasler and Wisby, 1958). Noting movements by following bobbers, however, is unsatisfactory for most studies because of the drag effect of the bobber, which undoubtedly tires the fish and alters its behavior, and also because the line may snag, either breaking or entangling the fish. When actual movements cannot be observed, the investigator is obviously at a loss to associate movements with specific environmental cues. Sensory cues used in migrating salmon had to be obtained by blocking a specific sensory pathway without affecting the remaining systems (Wisby and Hasler, 1954). A number of innovative, but generally unsatisfactory, devices have been tried for continuous tracking including a balloon-inflating mechanism (Horrall, 1961) and a dye marker (Hasler and Henderson, 1963).

Continuous tracking of a fish can be accomplished by internal or external placement in or on the fish, of a continuously transmitting signal which can be accurately sensed and followed by an observer. Trefethen (1956) described a system employing a sonic oscillator for use on adult pacific salmon. The first application of telemetry to study of fish movements was Johnson's (1960) observations in 1957 of adult salmon movements in the forebay of Bonneville Dam and parts of the Columbia River with the 132 kc/sec transmitter and portable tracking equipment used by Trefethen, Dudley and Smith (1957). Equipment developed for the latter study by a commercial electronics firm was the most sophisticated appartus described to date. It included a self-positioning, directional transducer, automated with a servo system and echo-ranging accessories which displayed on a calibrated cathode ray tube the bearing and range of the sonic transmitter. Novotny and Esterberg (1962) reported on an improved transmitter using a zirconium titanate rather than barium titanate crystal, and an improved battery pack and a hog-ring device for external attachment of the transmitter to the fish. The combination of improved batteries and greater frequency stability improved longevity of the transmission to 10 days. Henderson (1963) experimented with a simple design for a 130 kc/sec transmitter for use on homing experiments with white bass (*Roccus crysops*). Henderson, Hasler and Chipman (1966) reported performance of Henderson's (1963) transmitter attached to white bass over periods of 1 to 13 hours. McKay's (1968) excellent book length review of telemetry should be examined by investigators wishing a broader perspective on problems of sensing and transmitting information. Circuitry is shown of several transmitters for tracking and measuring temperature of fish, iguana, or marine mammals. The author provided a detailed and informative discussion of factors bearing on signal attenuation, encapsulation materials, and related topics.

Use of radio frequencies have received considerable attention for tracking free-ranging terrestrial vertebrates but relatively little use for aquatic vertebrates (Adams, 1965). A radio frequency transmitter (100 mc/sec), described by Lonsdale an Baxter (1968), was field tested on 3 white suckers (*Catostomus commersoni*) and 1 brown trout (*Salmo trutta*). The transmission could be received in the air at a distance of 75 feet from the river when fish were 5-8 feet of water and 100 feet when fish were in 2-3 feet of water. Transmitters functioned for 5 weeks on two of the suckers. Lonsdale and Hepworth (1968) described several additional types of radio frequency (100 mc/sec) transmitters for use on fish.

Relative effectiveness of transmitter tracking systems compared with mark-and-recapture was obtained during studies on movements of flathead catfish in Lake Carl Blackwell. Using gill netting and sphagetti tags, 94 flathead catfish were tagged in 120 gill-net days [3] over 3 months (11 April to 11 July); 64 were first captures, 2 were recaptures of fish marked in the three month interval and 28 were recaptures of fish marked prior to commencing this three month interval. Thus, in spite of a relatively high catch per day, only 2 site locations could be obtained on the fish tagged with traditional devices in three month interval; while by comparison during the same three months, 366 site locations were made on 9 flathead catfish which had an ultrasonic transmitter (74 kc/sec) surgically implanted in the abdominal cavity. With the possibility for automation obtained by installation of an "autotrack" system (Trefethen, *et al.*, 1957), transmitters could be monitored continuously and fish location obtained on small (<200 ha) reservoirs by automatically recording output from two scanning hydrophones. Our observations of transmitter tagged fish indicated that the procedure gave precise locations, directional movements, and home range data not obtainable from mark-and-recapture procedures (manuscript in preparation). Moreover, the procedure allows the investigator to evaluate effects of environmental factors (light, temperature, current, etc.) on behavior. This should provide valuable insight into environmental cues associated with diel and seasonal movements.

Jenkins' (1965) review of previous reservoir research, including fish life histories and vertical distribution of fishes, indicates few studies on home range, diel and seasonal movements, or aggregations of reservoir fishes. Considerable research effort is needed on behavior of reservoir fishes to provide a better basis for rational fisheries management. However, application of telemetry techniques will be severely retarded if it requires conversion of biologists into electronics specialists, or vice versa. Use of off-the-shelf commercial equipment can greatly facilitate immediate application of the technique, but unfortunately, there has been too little information available on the performance of commercial equipment to inform biologists of its utility and to challenge innovative improvements in technology.

The objective of this report is to present findings of performance of a commercial, off-the-shelf transmitter, hydrophone, receiver system; designated the S.R.E. system.[4] This appartus has been applied to the study of homing, home range and diel movements of the flathead catfish, *Pylodictis olivaris* (manuscript in preparation). Evaluation was made of several characteristics which are most important to the problem of tracking: factors affecting longevity of the transmitter, and accuracy, transmission range and specificity of the transmitter, hydrophone, receiver system.

DESCRIPTION OF THE TRANSMITTER-RECEIVER SYSTEM

The S.R.E. system consists of a transmitter, hydrophone and receiver. The transducer (crystal) of the transmitter generates an oscillating acoustic wave from electrical energy derived from a chemical power source (7, 1.4 v, 350 milliamperehour, mercury button cells). The transmitter (i.e., oscillator) frequency coil functions as an antenna and generates an omni-directional acoustic wave of 74 kilocycles per second (kc/sec). Transmitter specificity is obtained by obtaining non-overlapping transmitter pulse repetition rates (impulses per second, or abbreviated ips) or different carrier frequencies. Although the acoustic wave spreads through the water in all directions from the tag, which aids location of the transmitter, the greatest concentration of acoustic

[3] A gill net day was one 91-meter (300 ft.) gill net fished for 24 hours.

[4] The apparatus was purchased from Smith-Root Electronics, Seattle, Washington. This report is not to be construed as an endorsement of Smith-Root products. Their system was chosen for evaluation because when this study commenced, they produced the only transmitting-tracking system known to the authors.

energy is received in the central axis of the beam. Variation in signal strength are used to obtain both range and bearing.

The acoustic wave vibrates the hydrophone crystal (transducer) which generates a current transmitted by a coaxial cable to the receiver which had a tuner to receive over a frequency range of 25 to 80 kc/sec. The receiver had a sensitivity control to adjust for variable signal strength, and a tone control to adjust audio output to form a click ("beep") or "hiss". The receiver, which is quite compact (measuring 102 x 165 x 178 mm), weighs 6.6 kg and has a built-in speaker and jack for earphones. The latter was preferred in the field because wind and other environmental noise inteferred with reception by the speaker. The receiver operates on two, 6 v rechargable (nickle-cadmium) batteries.

Specifications on the S.R.E. model SR69A "standard sonic transmitters" (Figures 1 and 2) as advertised by the manufacturer were: 14 mm to 19 mm diameter at the small (oscillator end) and large (battery end) ends, respectively; 90 mm length; 29.5 g weight in water; 52 decibel power output in freshwater; 1.61 to 4.8 km range[5]; output frequency 74 kc/sec ± 1 kc/sec; 2% duty cycles; pulses were coded from 0.5 to 8 impulses per second (ips) at 10% tolerance; 60-day useful life span (longevity). A smaller (9.1 g) transmitter model number

[5] Manufacturer indicates that range is affected by water conditions.

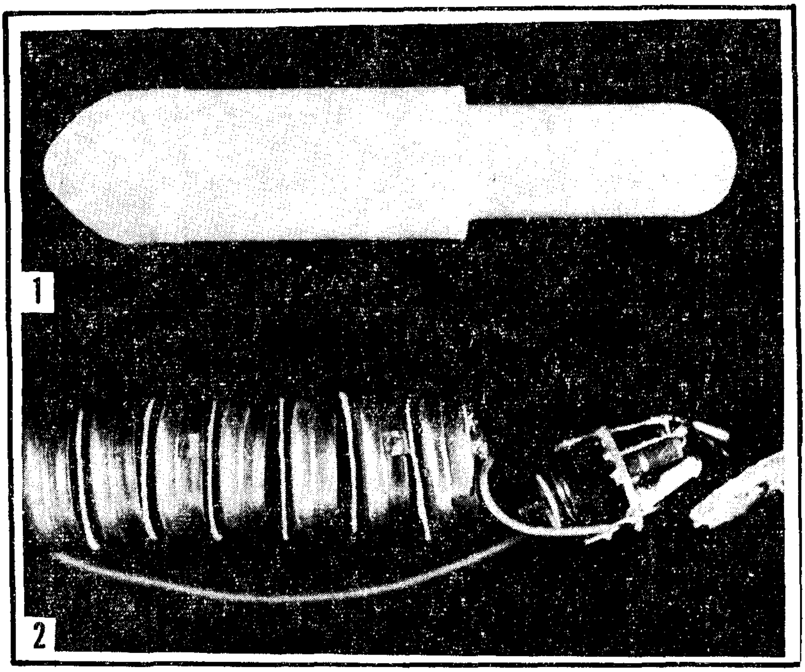

FIGURE 1. "Ultrasonic tag", a 74 kc/sec S.R.E. Model SR69A transmitter encased in standard plastic case, with a coating of paraffin. Small end of case contained transducer and electrical components. The larger left side is the battery compartment.

FIGURE 2. Parts of 74 kc/sec transmitter showing several basic components (left to right): 7, 1.4 v, 350 mah mercury button cells; threaded shaft of frequency tuning coil; pulse rate capacitor; transducer base plate separating frequency and pulse rate capacitors (left) from transducer coil and resistor (right).

SR69, available from the manufacturer, has an advertised life span of 30 days. The transmitters were received ready to use except for twisting and soldering two protruding wires, then closing the orifice for the wires with a special plastic sealer. After sealing, the entire transmitter was dipped in hot paraffin to obtain a coating which would further seal the unit and avoid possible reaction between body fluids of the host fish, the sealer, or the plastic. The paraffin coating added about 3 g to the weight in air but diminished by 7 g the weight in water.

Signals are obtained from the receiver speaker and a signal strength meter, or from earphones plugged to special jack on the receiver. For special measurement of the directional sensitivity of the hydrophone, signal strength was measured with an oscilloscope using current from the earphone jack. Directional location is obtained by rotation of the hydrophone cone, maximum diameter was 14.5 cm, until the opening of the cone was aligned with the central axis of the signal beam. The transducer of the hydrophone is set in the center of the funnel and surrounded by a plastic substance of the same density as water to serve as a support without reflecting the signal. The hydrophone cone apparently serves as a shield so the transducer receives a signal largely through opening of the cone. The hydrophone as supplied by the manufacturer was positioned on the end of a 156 cm submersible shaft with a 14.5 cm rubber handle. In pond application, and for measuring azimuth degree deviation of the signal from the source, a plane table with azimuth was constructed (Figures 3, 4 and 5). This table, supported by detachable legs, had the hydrophone shaft mounted with a bearing in a sleeve on the table top. Above the table top the shaft had a pointer to obtain azimuth and a level control for measuring vertical deviation. The latter was intended for measurement of depth.

FINDINGS

Longevity and Influence of Battery Type

The manufacturer advertised a 60-day lifetime (longevity) for these transmitters which require 9.8 v, derived from 7, 1.4 v, 350 millampere-hour (mah) batteries in series. Using standard off-the-shelf transmitters, and fresh batteries, 8 transmitters were suspended by a string from the end of a pier, between 2 January and 12 March 1971, in ponds near the University until the transmitter signals stopped. The last day of transmission was interpolated in several cases by assuming it was one-half the time between the last day of observation when it was running and the next observation when it was inactive. The average longevity of these 8 transmitters was 32.0 days, the range 21 to 52 days. No transmitter we tested had a longevity equal to the 60 days advertised by the manufacturer.[6]

After use in the pond, the exhausted standard battery pack was replaced with a TR-177[7] battery containing 7, 1.4 v, 160 mah batteries (MR675)[7] in series. This replacement was chosen because the standard batteries were not available in a 9.8 v pack, only as separate 1.4 v, 350 mah cells (MR625).[7] For convenience, and because of possible effects of soldering heat on joining the 7, 1.4 v, 350 mah batteries in series, a single TR-177 was used as a replacement.

The effect of battery type on transmitter longevity was compared by determining longevity of the same transmitters with two battery types. The longevity of transmitters with a standard battery was, as reported above, 32.0, range 21-52 days, compared with 21.8 days, range 10-39 days, for the same transmitters with the replacement TR-177 batteries. The difference, 10.2 days, between the longevity of the same trans-

6 The transmitters obtained in this study had a duty cycle of 2%. The manufacturer, after learning of the less than satisfactory performance, changed the duty cycle to 1% which they believe will increase longevity to the advertised 60 days. We did not evaluate the performance of the newer transmitters.

7 P.R. Mallory and Co., Inc., Indianapolis, Indiana.

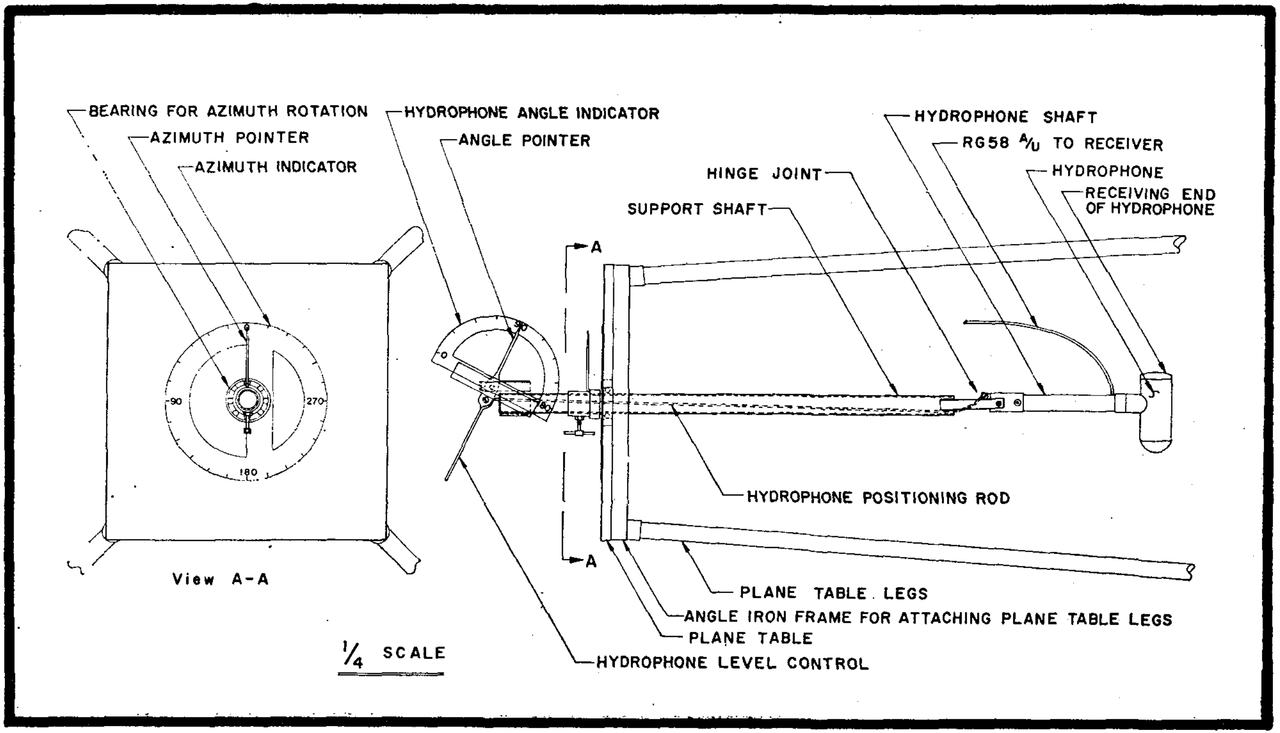

FIGURE 3. Plane table-hydrophone system used in tracking fish in ponds. Directional readings are obtained by revolving the hydrophone positioning shaft in a 360° arc and reading the azimuth when the strongest signal is located. The hydrophone is coupled to the bottom of the positioning rod, which is suspended by a bearing seated in the table top, for obtaining smooth rotation of the hydrophone. Vertical location is obtained by reading vertical deviation from the water surface from a hydrophone angle indicator.

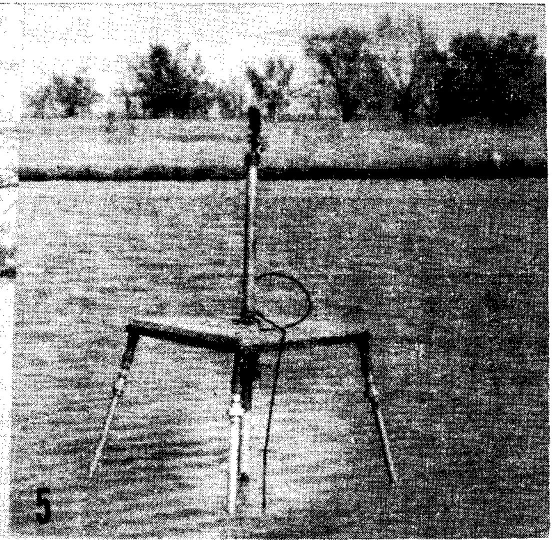

FIGURE 4. Monitoring position of fish in pond with S.R.E. tracking system and plane table with azimuth for directional location. Investigator was turning shaft attached to hydrophone and listening for maximum signal strength.

FIGURE 5. Second hydrophone-plane table with coaxial cable running from this base station to other where signal is received. Location in pond is by intersection of two angles. The arrangement requires two base stations but one receiver.

mitters with two battery types was highly significant ("t" test of two means, P<.01).

The effect of battery type on longevity, as described above, was verified by comparing mean longevity of 15 transmitters (including 9 used in the observations above) with standard batteries (350 mah type) to longevity of 14 transmitters having the replacement battery (160 mah type). Fourteen transmitters with 350 mah batteries functioned 30.5 days (range 12-52 days) compared with 18.5 days (range 10-39 days) for transmitters with 160 mah batteries. Difference in transmitter longevity, 39% less, was highly significant ("t" test, P<.01).

Surgical placement of transmitters in the abdominal cavity of flathead catfish had little influence on longevity, indicating usefulness of the pond and laboratory tests of longevity of transmitters as indicators of expected longevity of transmitters implanted in fish. Seven flathead catfish with transmitters surgically implanted in the abdominal cavity were released into Lake Carl Blackwell, a 810 ha reservoir. They were tracked for an average of 28.8 days, range 11 to 42 days, between release and last signal pickup. The difference between longevity of the transmitters in fish and transmitters suspended in a pond or tank was non-significant ("t" test, P>.05). The slight reduction in longevity which was noted in the transmitters implanted in the fish was attributable to behavior of a few fish which either moved out of the range of search or moved to a position where the signal was not easily monitored. Cover such as logs, or sharp depressions in the basin such as the old river channel, shielded the signal. Observation of a fish in the creek channel was especially difficult, requiring the observer to be almost directly above the fish. Transmission range in a "weedy" pond containing dense growths of *Chara*, *Ceratophyllum*, and *Potamogeton* was very greatly reduced by vegetation. The effects of vegetation needs careful consideration whenever fish movements are studied in clear water.

Influence of Environmental Temperature on Longevity

Tests of standard and replacement batteries described above for identical transmitters were made at average temperatures of 15.6 and 19.0 C, respectively. Thus, it seemed that the temperature difference might have influenced the observations, but the difference in average temperatures during the observation period was not significant ("t" test, P>.05). Moreover, observations on the relationship between longevity and temperature (4 to 30 C) of 16 transmitters, the same 8 transmitters used above plus 8 others, indicated a non-significant (P<.05) correlation, correlation coefficient = –.05, between average temperature and longevity of transmitters. Average impulse rate was determined by averaging three counts made on 5 to 28 days of transmitter service. When it was not possible to determine the last day of operation of a tag by direct observation, the final day of operation was assumed to be one-half the time between the last observation when the transmitter was still functioning and the next observation when the transmitter had stopped.

Maximum variation in longevity of 16 transmitters used in the temperature tests was 24 to 52 days. However, total number of impulses emitted by the two transmitters having the 24 and 52 days longevity were nearly identical, 11.9×10^6 and 12.67×10^6 impulses, respectively. Also, two other transmitters with identical longevity had vastly different total impulses. Thus, total impulses generated by a transmitter was independent of longevity. Transmitters with a faster impulse rate, however, generally exhausted faster than those with a slower rate. Apparently, the battery capacity allows transmitters a specific number of impulses which determines longevity.

Although longevity was not related to temperature, because the transmitters had different impulse rates, total impulses could be a function of temperature. However, under pond conditions, where temperatures ranged from 4 to 30 C, and total dissolved solids 350 ppm, correlation coefficient (0.08) was non-significant ($P>.05$) between temperature and total impulses for 14 transmitters with the standard batteries. Number of impulses did increase on the average by 47,000 per degree C increase in temperature between 5 and 30 C, but the increase was trivial relative to total impulses which averaged 12.35 x 10^6.

Effects of Impulse Rate on Longevity

Generation of an impulse by a transducer uses battery current. During the pulse, the drain on the battery can be a few tenths of an ampere. Battery capacity is finite as defined by its milliamperehour rating. Thus, longevity of the transmitter should be inversely proportional to impulse rate. Impulse rates can be obtained in the range 0.5 to 8.0 from manufacturer, but use of transmitters with a shorter impulse rate should lengthen the observation interval. We endeavored to test the hypothesis that transmitter pulse rate affects longevity.

Eleven transmitters with initial impulse rates of 2.4 to 5.8 were observed to determine variation in average ips during the entire life span. The ips were determined with a stop watch and rates converted to daily outputs which were summed for the entire life span. Average rate was computed from the sum of the total impulses observed in the life span.

Average ips of 11 transmitters operative 21 to 52 days ranged from 2.8 to 6.6. Longevity was, as hypothesized, inversely related to average impulse rate (Figure 6). The correlation coefficient was −0.63, significant at the 5% level. This finding is of considerable practical importance for tracking a fish since the investigator usually desires the maximum longevity obtainable. A transmitter with an average impulse rate of

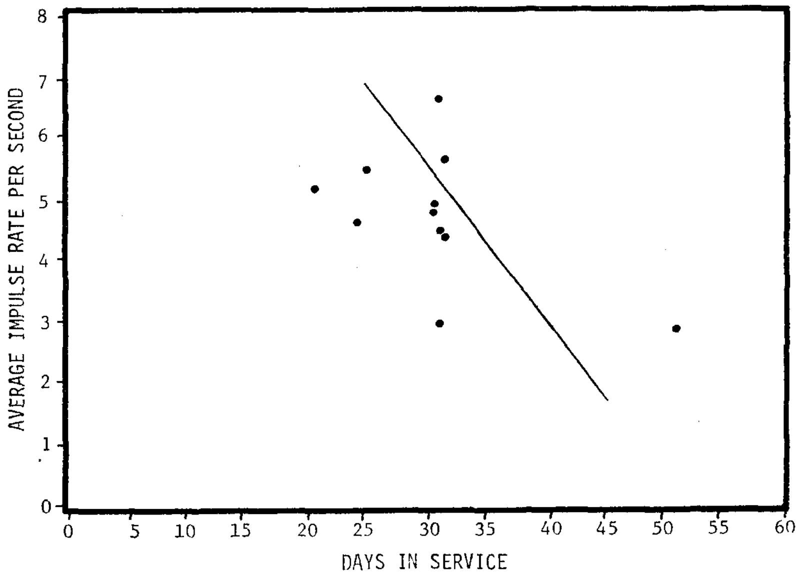

FIGURE 6. Relationship between average pulse rate and longevity (days in service) of eleven 74 kc/sec transmitters containing the standard batteries. Correlation coefficient was 0.68 ($P<.05$).

6 would have a longevity of only 26 days compared with 40 days for one having an average ips of 3.

Average pulse rate was computed for a group of transmitters which had an overall average (mean of means) of 1.8, range of means of individual transmitters of 1.0 to 2.9. Longevity ranged from 12 to 42 days, and the correlation coefficient between pulse rate and longevity was not significant at even the 20% level (i.e., P>.20). This group with an average pulse rate of 1.8 had an average longevity of 29. Thus, interpolation of the relationship between average pulse rate and transmitter longevity from the regression was not applicable for this group. The correlation was also non-significant when the lower code levels were combined in an analysis with the higher pulse rates. This problem needs further evaluation.

Distinctive Coding

Transmitters were available with pulse rates from 0.5 to 8.0. Pulse rates can serve to "code" the transmitter, and of course a fish which has a transmitter placed in its abdominal cavity. The manufacturer advertised a variability "within 10% tolerance of the specified code". Variability of a transmitter code must be known to avoid overlap in range of impulse rates of other transmitters if they are to be distinguishable. Variation in ips of 11 trnsmitters with initial impulse rates varying from 1.0 to 5.8 were recorded over 24 to 52 days of service.

For this evaluation, variability of ips of 8 transmitters containing the standard battery pack (350 mah) were compared with variability of ips of the same transmitters with the replacement battery (160 mah). An example of the type of variability is illustrated (Figure 7). Pulse rate increased during the life span of the battery, generally, the increase was very abrupt within the final 2-5 days prior to total cessation of function. Variation in pulse rate was not related to fluctuation in

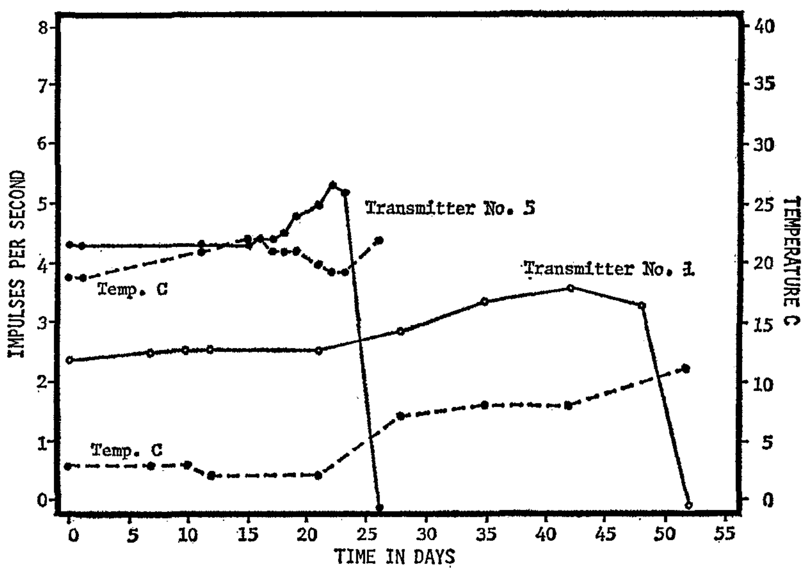

FIGURE 7. Changes in impulse rates of two transmitters over the lifetime of the battery. Impulse rates characteristically increase to a maximum amount in the last day or two before an abrupt cessation at the end of battery life. There was no relationship between longevity and environmental temperature.

environmental temperature as seen in Figure 7. Mercury batteries maintain a constant voltage over their lifetimes, implying that variability may be a problem with a capacitor or other functioning of the code determining circuit of the transmitter.

Mean ips for transmitters with standard 350 mah batteries averaged 0.5 ips more than the ips when started, and an average deviation from the mean rate (4.6) was 1.2 or 25% of the average pulse rate. Greatest variation observed was a transmitter with an initial rate of 3.8 ips, but an average of 4.9 ips, and a maximum which was 2.5 ips larger than the initial rate. Performance of the group with the replacement batteries was similar, i.e., ips increased continuously, rarely going down from one day to the next, showing a sharp increase 2-5 days prior to cessation. Average initial ips for the 8 transmitters with 160 mah batteries was 4.0 compared to the 4.2 average ips during the 21.8 average number of days operative. The maximum increase from the initial rate was 2.0 ips in a transmitter with an initial rate of 3.4.

Because of the wide range of variability in pulse rates, ranging up to 65% of the initial rate not 10% as advertised by the manufacturer, the range of ips for individual tags available from the manufacturer, 0.5 to 8.0, provides relatively few classes (*ca.* 4-5) of non-overlapping codes. If transmitters with fast pulse rates, i.e., above 3 or 4, are avoided because of their short life span, then specific codes would be limited to about 3. Electronics people could make a significant contribution to tracking and studying fish movements by greatly improving the code tolerance to allow "marking" a larger number of fish with transmitters with non-overlapping pulse rates.

Transmission Range

Maximum distance through which a signal can be perceived, also called the limiting range, is a major transmitter performance parameter. Signal strength is said to vary inversely to the square of the distance from the transmitter (MacKay, 1968). Transmission range, however, is influenced by water depth, bottom type, salinity, and other factors contributing to absorption or dispersion of the signal (MacKay, 1968; Novotny and Esterberg, 1962). Absorption and scattering decrease signal level, and reflections from the bottom and surface causes large fluctuations in signal level which affect transmission range. Empirical observations of transmission range would be of practical value as mathematical computation of signal strength as a function of scatter and absorption in a reservoir would be difficult. In the present study, transmission range was the distance attainable along a cord when moving the hydrophone away from the transmitter to a point where signal strength was imperceptible and blended with receiver background noise. These observations were made in Lake Carl Blackwell, a turbid reservoir with 350 ppm total dissolved solids. Consideration was given to water depth of the transmitter, turbidity and wind speed as variables affecting transmission range. Turbidity of lake water was measured in the laboratory with a turbidimeter calibrated with SiO_2 standards and wind speed was measured with a hand-held anemometer about 1.2 m above lake surface.

Twenty-seven measurements of transmission range were made of five 74 kc/sec transmitters. A grand average of all observations indicated transmission range, irrespective of wind, turbidity, and temperature was 280 m (918 ft.). Minimum and maximum transmission range was 150 m (492 ft.) and 576 m (1889 ft.), respectively. The manufacturer advertised a range of 1610 to 4800 m which was not attainable.

The mercury batteries are reported to maintain a constant voltage over their lifetimes, but show a sharp voltage drop at the end of their capacity (Mackay, 1968). Since voltage greatly affects power of the transducer signal, transmission range would be affected when battery capacity is exhausted. Figure 8 shows transmission of 160 kc/sec transmitter (not a S.R.E. transmitter) over 45 days. Transmission of this transmitter between 1 and 31 days was 150 to 312 m, but when the battery was exhausted, transmission dropped to a negligible amount on

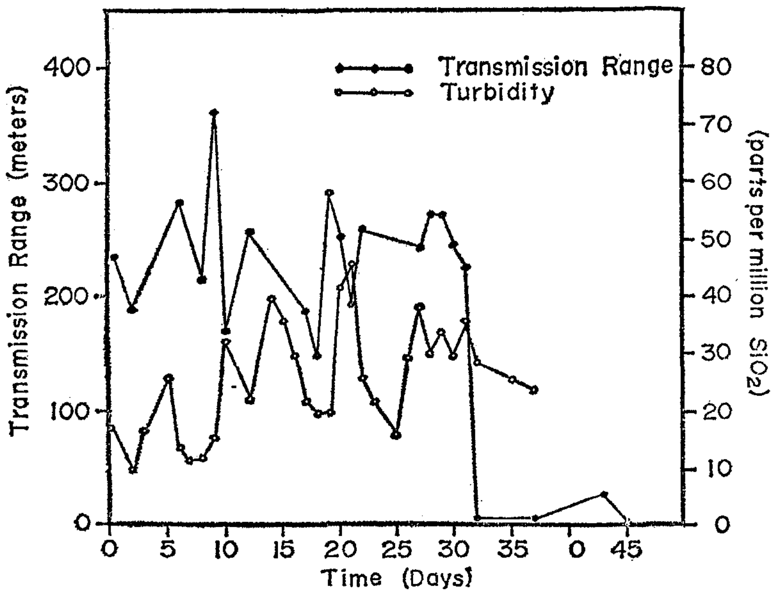

FIGURE 8. Transmission range of a 160 kc/sec transmitter suspended in a lake showing drastic reduction of transmission range at the end of battery life. Also, variation in transmission are shown in relationship to variations in water turbidity but the correlation coefficient ($r = .01$) was non-significant.

day 32; after a small surge on day 43, total cessation of operation occurred on day 45.

Highly aerated surface waters and surface reflections are known to greatly interfere with reception (MacKay, 1968). When we suspended a transmitter at 3 cm from the surface, the transmission range was 150 m, when suspended 1 m from the surface range was 214 m, when suspended 2 m range was 255 m, and when suspended 3 m range was 265 m. Thus, transmitters placed in an epipelagic fish, such as white bass, or in fish migrating near the surface in shallow ponds or rivers would have a shorter transmission range and more interference than with other circumstances.

Turbidity was 8.7 to 41.2 ppm SiO_2 when transmission range varied from 181 to 576 m. A correlation coefficient between turbidity and transmission range was non-significant ($P>.05$). A negative correlation ($r = .30$) between wind speed and transmission range was non-significant at the 5% level but significant at the 20% level suggesting a potentially important factor when transmitters are near the surface. Wind agitation of the surface aerates the water and produces an irregular surface which blocks and scatters signal transmission.

Accuracy of transmission was measured as the azimuth deviation from transmitter location in a pond using the plane table-hydrophone mount (Figures 3, 4 and 5) to measure change in signal strength as the hydrophone was rotated. The hydrophone was located 64 m from the transmitter. Signal strength was relative, measured from a scale on an oscilloscope display screen. The distribution of signal strength (Figure 9) was somewhat skewed to the right, presumbaly due to the influence of a pond levee. Beam width was relatively narrow allowing fairly precise interpolation of transmitter position. Rapid attenuation of relative signal strength between ± 5 and 10° allows fairly accurate interpolation of the

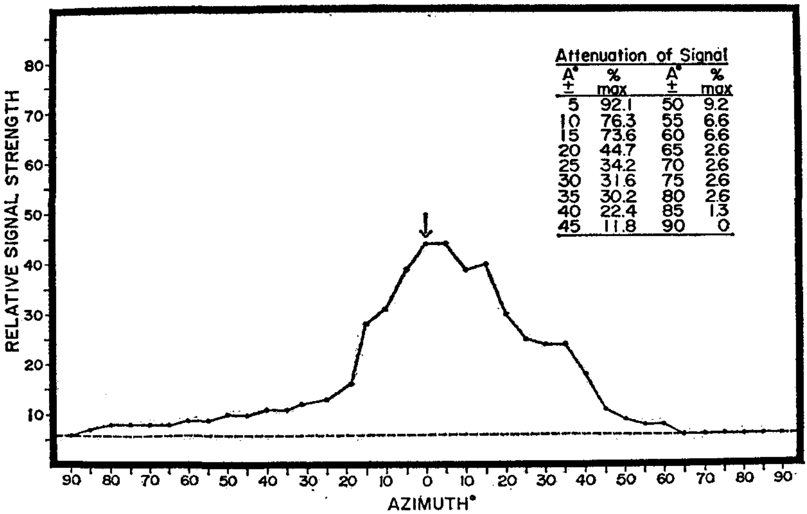

FIGURE 9. Measurement of relative signal strength as a function of hydrophone orientation to the transmitter in a pond where the transmitter was 64 m from the hydrophone. Attenuation of signal strength was tabulated as a percentage of the maximum signal strength, in 5 degree increments.

point of maximum signal strength. Total beam width was extinguished beyond ± 90°.

Comparative Performance

Characteristics and performance of several transmitters observed by other investigators were summarized (Table 1). Comparatively, the average transmission range of the 74 kc/sec S.R.E. transmitter-hydrophone system was about average. Longevity of the S.R.E. transmitter was better than all but the radio (100 megacycles/sec) transmitters described by Lonsdale and Baxter (1968); however, their longevity was estimated, not empirically derived from field observations. Compared only with the kc/sec range frequency transmitters, the S.R.E. transmitter had the greatest longevity. Mackay (1968) reported that transmission range decreases when going from 50 to 180 kc/sec. We found a 160 kc/sec transmitter had a maximum transmission range of 400 m compared with 576 m for a 74 kc/sec transmitter. Power requirements of a kilocycle transmitter are greater than for a megacycle transmitter, but transmission range of the former should be greater in water.

CONCLUSIONS

1. Maximum longevity of 74 kc/sec transmitters was 52 days with the standard battery pack (7, 1.4 v, 350 mah). Average life of 14 transmitters with the standard batteries was only 30.5 days.

2. Battery capacity was an important factor affecting transmitter longevity. Transmitters with the standard 350 mah batteries functioned for 10.2 days longer than the same transmitters with a replacement battery with 160 mah rating.

3. Environmental temperature within the range of 4 and 30 C was not an important factor affecting transmitter life. Total impulses increased about 47,000 per degree increase in temperature, but this was a relatively small increase relative to total impulses which averaged 12.35×10^6.

TABLE 1. Characteristics of various radio and ultrasonic transmitters used in the study of aquatic organisms

Investigators	Dimensions mm	Weight g	Frequency of tag	Transmission range (meters)	Battery type and voltage (v)	Active life of tag
Trefethen (1956)	23 by 63	2 (w) [3]	132 kc	detected to 610 (fw)	15 v	avg. 7 hrs., Max. 16.7 hrs.
Trefethen, Dudley and Smith (1957)	23 by 63	2 (w)	132 kc	tracked to 800 (fw)	15 v	8 hrs.
Johnson (1960)	23 by 63	2 (w)	132 kc	250 (m) or 244 (fw)	15 v	8 hrs.
Novotny and Esterberg (1962)	20 by 46	7 (w)	132 kc	over 152–450 (fw) over 122 (sw)	NiCd or Hg	3–60 hrs. 3–10 days
Henderson, Hasler and Chipman (1966)	7 by 40	2 (w)	50–75 kc	detected to 1000 (fw); effective range 200–500 ft. (fw)	Hg or Ag	14–20 hrs.
Baldwin (1965)	?	0.86 (w)	45–55 kc	21–30 ft. (fw)	Hg 14 v	8 hrs.
Lonsdale and Baxter (1968)	irregular shape	17 (w)	100 mc	23–30 ft. (fw)	Hg, 4-1.4 v in series	estimated 4 weeks
Lonsdale and Hepworth (1968)	variable	16.0-38.5 (a)	100 mc	75– 150 ppm– 46–229 200– 550 ppm– 91–183 1000 ppm– 12– 46 2500 ppm– 9– 46 over 5000 ppm– 0	?	?
Henderson (1963)	ca 15 by 35	?	130 kc	50–150 (fw)	Hg, 1.4 v	8 hrs.
Horrell, *et al.* (1965)	9 by 40		65 kc	1000 (fw)	Hg, 1.4 v	?

1 In freshwater (fw), or salt water (sw).
2 Range from the deepest to shallowest depth tested for the ppm of total dissolved solids indicated.
3 In water (w), or air (a).

4. Transmitter longevity was inversely correlated with average impulse rate for transmitters with impulse rates from 2.4 to 5.8. From a regression equation, it can be shown that a transmitter with an impulse rate of 3 would function 14 days longer than a transmitter having an impulse rate of 6. However, the regression was not applicable to a second lot of transmitters with impulse rates averaging 1.8. This problem deserves more research as it may greatly limit choice of transmitter codes, or the observation interval.

5. Recognition of individual fish requires transmitter coding which can be accomplished by variation in carrier frequency, transmitters are available from 50 to 165 kc/sec, or by variation in pulse rates (ips). Variability in pulse rates were much greater than the "10% tolerance" advertised by the manufacturer. The average deviation from initial rate for one group of 11 transmitters was 32%. Pulse rates can be distinctive if a wide range of pulse rates are used but the longevity of transmitters with the fastest ips may be greatly reduced.

6. Transmission range averaged 280 m (918 ft.) with 74 kc/sec transmitters. The maximum transmission distance was 576 meters (1789 ft.). Several observations made with 160-165 kc/sec transmitters from the same and from a different manufacturer, indicated maximum range about 400 meters and averaging less than 250.

7. Accuracy of the S.R.E. system was considered good. Signal strength was 92.1% of maximum at $\pm$ 5° azimuth deviation of the true location, and 76.3% of maximum at 10%. Rapid attenuation between 5 and 10% deviation allows fairly precise interpolation of the fish's position.

8. Signal strength was greatly affected by the depth of the transmitter between 3 cm and 3 m. Turbidity within the range of 8.7 to 41.2 ppm SiO_2 was not correlated with daily variations observed in transmission range. Wind agitation of surface waters was suggested as a factor reducing transmission range.

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HANDPICKING MACROINVERTEBRATES; THREE METHODS COMPARED

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ABSTRACT

Benthic samples were sorted by three methods: electrical stimulus applied to living organisms, preserved in rose bengal formalin solution, and preserved natural-colored. The rose bengal stained samples were picked most accurately and rapidly except in very low invertebrate concentrations where the electrical stimulus was more efficient. Natural-colored samples had the least accurate retrieval and were picked at a rate intermediate to the other two methods.

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