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FISH DIVISION
Oregon Department of Fish and Wildlife

Using Radio Telemetry in Fisheries Investigations
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INTRODUCTION

We have often been asked for information by fishery workers who are considering use of radio telemetry in fishery research. This report draws upon our field experience and on review papers by Stasko and Pincock (1977), Winter et al. (1978), and Winter (1983) to catalog our knowledge of radio telemetry. In it we describe ways that radio telemetry can be used; discuss factors that should be evaluated when considering use of radio telemetry; describe equipment; and compare methods of attaching the radiotag and of tracking radiotagged fish.

USES OF RADIO TELEMRY

The Oregon Department of Fish and Wildlife has used radio telemetry in the Columbia River basin to study movement and distribution of juvenile and adult chinook salmon Oncorhynchus tshawytscha, steelhead Salmo gairdneri, walleye Stizostedion vitreum, and northern squawfish Ptychocheilus oregonensis (Nigro et al. 1985; Nigro and Ward 1985, 1986; Faler et al. 1988; Ward et al. 1988). We have used radio telemetry in conjunction with mark-and-recapture studies to gather detailed information on movement of individual fish (Faler et al. 1988), and to help verify assumptions inherent to mark-and-recapture methods (Nigro et al. 1985). We found that radio telemetry is the best way to describe fish distribution in areas, such as the tailrace of a large dam, that are not easily sampled by conventional methods.

Data collected in most radio telemetry studies are fish locations at various times, and environmental data such as flow and temperature. The amount of data collected depends on study objectives and effort needed to locate radiotagged fish. Migrating juvenile salmonids may need to be located often (e.g., hourly) to determine migration rates and inshore-offshore distribution patterns. Radiotagged adult salmonids should also be located often (e.g., three times per day) to accurately identify holding sites and determine travel time and passage rate of individual fish. Stream flow, water temperature, and turbidity should also be monitored to evaluate their effects on migration of radiotagged fish. A large number of observations per individual fish are not required to describe seasonal movements and distribution of radiotagged resident fish such as walleye or northern squawfish. Fish may be located daily in small lakes, or as infrequently as once or twice per week in a study area as large as John Day Reservoir.

Location data can be recorded many ways. A Cartesian grid system overlaid upon a map of the study area is often used to assign x,y coordinates to locations of radiotagged fish. Investigators should familiarize themselves with locations of known landmarks shown on the map to more easily estimate the correct location (grid square) of radiotagged fish. Size of grid squares is dependent on the study
area and tracking method. In a small river such as the Umatilla River, locations of fish can be determined within 25 m. In a large reservoir, locations of radiotagged fish can be estimated within 150 m from an airplane. Locations can also be recorded as river mile or distance from known landmarks.

Methods of interpreting radio telemetry data are dependent on the type and amount of data and on study objectives. For migrating fish, plots of fish location against time can be used to determine travel rate and identify holding sites. Migration rate of tagged fish can also be plotted against concurrent environmental readings to identify possible correlations. The number or percent of locations within various areas (grid squares, habitats, etc.) can also be compared statistically.

Radio telemetry can also be used to follow fish movement and generate a large amount of information on home range of individual fish (Winter and Ross 1982). One method is to map locations of a radiotagged fish, then connect the extreme outermost locations so that the smallest possible convex polygon encloses the other locations. If a large number of locations have been determined, the convex polygon often represents the maximum home range size. Another method of determining home range involves using grid squares. The area of the home range can be computed by summing the number of grid squares in which a radiotagged fish has been located.

**FACTORS THAT AFFECT USE OF RADIO TELEMETRY**

Many factors must be considered before beginning a telemetry project. The cost of equipment (APPENDIX A) and labor needed can be prohibitive, and care should be taken to ensure that a radio telemetry study is necessary to obtain the desired information. An important consideration is whether objectives can be met by means other than radio telemetry.

After the decision to use radio telemetry has been made, the investigator should try to foresee and minimize potential problems. Careful thought needs to be given to purchase of equipment, methods of tagging and tracking, collection and analysis of data, and sources of outside interference with radio signals. Working closely with a radio telemetry supplier will help to ensure proper equipment is used, and soliciting input from experienced investigators will help ensure a proper study design.

Certain characteristics of a study area could limit the reliability of radio telemetry. Range of a radiotag decreases almost exponentially as depth increases (Winter 1983). The range of a radiotag also decreases with increasing conductivity of the water. The higher the radio frequency used, the more restraining are the effects of depth and conductivity on signal reception. The most commonly used frequencies for telemetry are between 30 and 60 MHz.
For work on a deep water species, a low frequency (30-40 MHz) should be used.

Reflection of radio signals off dams, buildings, and terrain, and interference from electrical systems and outside radio transmissions can cause reduced signal strength and errors in determining signal direction. Noise from power lines, two-way radios, ignition systems, irrigation pumps, and hydropower facilities also interfere with signal direction. From an airplane we could not detect radiotagged fish directly under high tension power lines, and from boats or shore we had difficulty detecting them.

We encountered ignition interference from our boat engine at speeds greater than a slow cruise. Depth finders, windshield wipers, and bilge pumps also caused noise interference on our boat. We encountered ignition interference to varying degrees during aerial tracking depending on the aircraft used. Interference level was highest when tracking from a helicopter. Newer airplanes caused less ignition interference than older ones, but interference could be reduced in all airplanes by using a filter on the ignition system. Other sources of noise encountered while aerial tracking were caused by wind and the aircraft engine. The effect of nonelectrical noise can be reduced by using tight-fitting, light, comfortable, and sound-insulated headphones.

Most of the problems related to signal bounce or noise can be avoided. However, interference from outside sources can often be a serious problem if tracking is done within a major metropolitan area. At times signals may be completely blocked out by electrical or radio interference. A preliminary survey of the study area could be used to determine which frequencies are subject to the most interference.

A problem encountered on the Columbia River was duplicate signal frequencies. Other fisheries agencies involved in radio telemetry studies on the Columbia River used the same frequencies that we did. Fortunately, their signal pulse rate was different from ours. Before ordering radiotags, check with other research agencies to avoid the problem of duplicated frequencies.

An assumption of radio telemetry is that radiotagging does not affect fish behavior. Actually, not much is known about the effects of radiotagging on fish behavior. When possible, behavior of radiotagged fish should be compared with that of fish conventionally marked during a concurrent mark-and-recapture study, or to that of unmarked fish held under controlled conditions. Knowing the effect of radiotagging on fish behavior may be critical in studies where fish cannot be given time to acclimate to the radiotag (e.g., salmonid migration studies). The method used to radiotag a fish can reduce the effect of radiotagging on fish behavior.
EQUIPMENT

A radio telemetry study involves attaching a radiotag to a fish and monitoring the location of the radiotagged fish over time with a receiving system. Radiotags, antennas, receivers, and headphones come in a variety of types and sizes. Winter (1983) describes most of the equipment necessary to conduct a radio telemetry study and many of the recent advances in radio telemetry equipment. A list of suppliers most commonly cited in recent literature (1983-88), and approximate costs of equipment (1988) are given in APPENDIX A.

Radiotags

A radiotag is a transmitter that emits a signal (usually pulsing) that a receiver converts to an audible sound. Many different types and sizes are available. Pulse rates may vary among individual radiotags. When ordering radiotags, size of the fish to be tagged and the study duration must be considered. A fish generally should not be radiotagged with a unit that weighs more than 2% of the fish's weight out of water (Winter 1983). Size and weight of the radiotag vary depending on battery size. As battery size increases so does the distance that a signal travels (range) and the period of time that a signal is transmitted (life). Radiotags we used to study yearling spring chinook salmon weighed approximately 2.3 grams and had an expected life of 10 days; radiotags we attached to adult salmonids weighed 23 grams and had an expected life of 90 days; and radiotags we attached to adult walleye weighed 35.5 grams and had an expected life of 300 days. Range of the smaller radiotags was less than one-half the range of the larger ones. However, technical advances are continually increasing the efficiency of radiotags. A good telemetry equipment supplier can prescribe a radiotag suited to project needs.

Frequencies of signals from radiotags we used ranged from 48 to 50 MHz. Other frequencies are available, and may be preferable depending on water depth, conductivity, and possible electrical and radio interference. The effects of depth and conductivity are greater for higher frequencies than for those in the 30–60 MHz range. Radiotags we used were cylindrical to aid placement within a fish, and were encased in epoxy for protection. Most suppliers can also provide radiotags especially designed for external attachment.

Antennas

We have used loop, yagi, and omnidirectional (whip) receiving antennas (Figure 1). Loop and yagi antennas are directional. Pointing a loop or yagi antenna directly at a radiotag will result in peak signal strength, whereas pointing the antenna at a 90° angle to a radiotag will result in a weak or null signal. Our loop antennas were small and diamond-shaped. Each had a handle and could be
Figure 1. Two-dimensional representations of radio telemetry antennas. (A) Hand-held loop antenna, (B) telescoping omnidirectional antenna, and (C) yagi antenna without a mounting mast.

carried or mounted to vehicles, boats, or airplanes. They could detect signals up to 1/4 mile away. We used loop antennas to locate radiotagged fish from shore and from a helicopter in the Umatilla River, from a boat in the Willamette River, and from shore and an airplane in the Columbia River. Yagi antennas consist of a series of small metal elements attached perpendicular to a long metal rod (similar to a television antenna). The length of the rod of a yagi antenna increases as the frequency of signals it is tuned to receive decreases (a yagi tuned to receive 53 MHz signals is 3.7 m long, whereas a yagi tuned to receive 48 MHz signals is 4 m long). Yagi antennas have greater sensitivity than other antennas, but their size, especially when designed to detect low frequency (30-40 MHz) signals, can prohibit mobile tracking. We used a yagi antenna to locate radiotagged fish within 1/4-3/4 miles of our boat on the Columbia River. We used an omnidirectional antenna with a fixed-station receiving system (see METHODS OF TAGGING, page 6) to monitor the time of appearance of radiotagged fish near Three Mile Dam on the Umatilla River. An omnidirectional antenna should be used where radiotagged fish are expected to pass or gather at a given location.
The receiving system at a fixed station is often unattended.

Receivers

Several factors must be considered when choosing a receiver. Portable receivers should be small and light, use rechargeable batteries, and be moisture resistant. We used programmable scanning receivers designed and constructed by Advanced Telemetry Systems Inc., of Isanti, Minnesota (mention of commercial equipment does not constitute endorsement by the state of Oregon). These receivers were easily carried with one hand, and with an antenna and headphone were the only equipment necessary to track a radiotagged fish. Each receiver had a 2 MHz bandwidth (48-50 Mhz), which enabled us (theoretically) to program 2,000 possible frequencies at 1-KHz intervals. Practically, no more than 200 frequencies spaced at 10-KHz intervals could be programmed. We monitored frequencies from no more than 40 radiotags because that was the most we could monitor at any one time using one receiver. We found that to closely monitor movement of a highly and variably migratory species such as yearling chinook salmon we could track no more than three radiotagged fish at one time from a boat.

The receivers we used included many features necessary for efficient tracking (Figure 2). We could program the receivers to monitor given frequencies at various scan rates. Frequencies could be instantly added to or deleted from the scanning program. We could adjust the RF gain (which controls sensitivity, i.e., the maximum distance from which we could detect a signal from a given radiotag) and the audio (which controls the level of background noise) to maximize the sensitivity of the receiver and minimize the noise level. A signal meter indicated relative signal strength of a radiotag. When we used a directional antenna we could determine direction of the radiotag by comparing relative signal strengths. Other features included fast forward or backward scan, stop scan, and delta tuning. Delta tuning allowed us to monitor frequencies within 1-4 KHz of each programmed frequency to detect signals from radiotags whose frequencies may have drifted, a common occurrence in radiotags near the end of their life. Features should be weighed against cost when choosing a receiving system. Receiver features and costs vary significantly among suppliers.

Headphones

Headphones, which are connected to the receiver and are often worn to limit distractions from outside noise, must be worn in airplanes. Inexpensive headphones (about $40) do not filter noise from electrical interference and should only be worn for short periods of time, or when receiver volume is low. We often used headphones specially designed to reduce engine and electrical noise from airplanes.
Figure 2. Top view of Advanced Telemetry Systems, Inc. "Challenger 200" programmable receiver.

METHODS OF TAGGING

The most common methods of attaching a radiotag to a fish are stomach insertion, external attachment, and surgical implantation. Winter (1983) reviewed these methods and the criteria used to choose a method. The type and condition of the fish to be radiotagged, data needs, and study objectives should be considered when deciding on an attachment method. Extreme care should be practiced while anesthetizing and radiotagging fish to prevent injury caused by the procedure. A fish should be well anesthetized while being radiotagged to reduce stress in the fish and prevent the fish from moving, especially if a radiotag is surgically implanted in the body cavity. Before radiotagging a fish, the tagger should practice the technique (possibly on a carcass or on a fish that can be held and observed after being radiotagged), or at least observe the procedure being done by someone with experience.

Stomach Insertion

We inserted radiotags into the stomachs of adult chinook salmon and steelhead, and yearling chinook salmon (Figure 3). We used a plastic tube to push the radiotag through the esophagus and into the
anterior portion of the stomach. Before the tag was inserted we coated it and the tube with glycerin to lubricate passage. We anchored the radiotag antenna to the roof of the mouth of adult salmon with stainless steel hooks. We cut excess length off of antennas on radiotags placed in yearling chinook salmon, but we did not anchor the antennas. Radiotags are now available with a stiff whip antenna that does not need to be anchored. We inserted the radiotag while the fish was upside down to relieve pressure on the fish's internal organs.

A radiotag can be quickly inserted into a stomach, and fish need little time to recover. The stomach insertion method is best for spawning salmon. Disadvantages of stomach insertion include possible regurgitation of the radiotag and possible damage to the esophagus or stomach. We held yearling chinook salmon 24-48 hours after placement of the radiotag in the stomach to monitor regurgitation rate and to ensure that fish regained bouyancy and swimming ability. Fish regurgitated approximately 5% of the radiotags during this holding period, all within 24 hours. We feel that fish did not regurgitate radiotags after they were released, although data on long term regurgitation rate are not available. We held adult salmon and steelhead long enough to ensure that they had recovered from the anesthetic and handling before we transported them to the release site. One of 10 steelhead released in 1984 was known to have
regurgitated its radiotag.

Another concern with stomach insertion is that the fish must be large enough to pass a radiotag through its esophagus. Yearling chinook salmon had to be at least 170 mm fork length before they could pass a radiotag that weighed 2.3 grams. Adult salmonids had to be at least 650 mm fork length before they could pass a radiotag that weighed 23 grams.

External Attachment

We attached radiotags externally to steelhead just below the anterior portion of the dorsal fin, with the antenna directed back (Figure 4). In general, externally attached radiotags are placed on one side of the fish and held in place by wire passed through the dorsal musculature and secured on the opposite side of the fish. Detailed attachment technique has been described by Winter (1983) and Migro and Ward (1985). Most telemetry suppliers now offer radiotags especially designed for external attachment.

External attachment can be done quickly and can be used for spawning and for feeding fish. It also allows fish to recover quickly. However, externally attached radiotags may cause balance problems and increase drag on fish. They may also snag, cause abrasions, or lead to disease or infection, especially if attached improperly. Tissue deterioration may cause loss of tags attached externally to adult salmon.

Surgical Implantation

Recovery from surgery and resumption of normal behavior require time. Therefore, surgically implanting a radiotag into the body cavity of a fish is best suited to long-term studies where immediate collection of data is not important. We do not recommend it for gravid females because ripe eggs often fill the body cavity. Surgery should not be performed on fish that are in poor condition at capture (e.g., spawning salmon).

We surgically implanted radiotags into the body cavities of walleye and northern squawfish (Figure 5). After anesthetizing a fish, we placed it upside down into a V-shaped radiotagging trough. We then passed anesthetic or fresh water over the gills as needed with a squeeze bottle. We made an incision on the belly slightly to one side of the midventral line, large enough to insert the radiotag into the body cavity (all materials were previously sterilized by soaking them in antiseptic). The incision was made away from vital organs. We passed the whip antenna out of the body cavity through a second, smaller incision made posterior to the first incision. We then sutured the incisions with nylon thread and applied antibiotics to both incisions.
Figure 4. External attachment of radiotag on adult steelhead. (A) Dorsal view of steelhead pierced through the back with two hollow needles. (B) Wire attached to the radiotag threaded through each needle. (C) Needles removed. (D) Radiotag pulled snug against the fish and wires threaded through clamps attached to a soft rubber template. (E) Template pulled snug against the fish, radiotag secured by crushing the clamps around wires, and excess wire removed.
Figure 5. Surgical implantation of radiotag. (A) Ventral view of fish with two incisions on belly. (B) Radiotag partially inserted into anterior incision and antenna passed out of posterior incision. (C) Radiotag fully inserted into body cavity and both incisions closed.

Retention of surgically implanted radiotags may depend on water temperature and the species involved. We inspected sutures in radiotagged walleye and northern squawfish we recaptured and found walleye retained sutures and healed incisions better than northern squawfish. Walleye may have done better because we radiotagged them during November when water temperature was low (40°-45° F), whereas we radiotagged northern squawfish in April and May when increasing water temperature (45°-60° F) increased potential for bacterial infection. Also, the abdominal wall of northern squawfish is thinner and the musculature is softer than that of walleye. Care should be taken to pass the suturing needle completely through the muscle so that the skin completely covers the incision.

We held fish in a recovery tank after surgery for only as long as it took them to regain equilibrium and begin swimming. We believed this to be less stressful than holding fish for a day after surgery. Although only one fish died from postoperative trauma, holding fish for a day after surgery to check the sutures and apply additional antibiotics to the incisions may be a good idea.
METHODS OF TRACKING

Watercraft

We monitored movement of radiotagged yearling chinook salmon on the lower Willamette River primarily from a boat. We found migration rate and behavior varied widely among individual fish, and during a 12-hour period one boat crew could only monitor the movements of a few fish at a time. The most efficient way to locate a radiotagged fish was to (1) search its last known position, (2) if the fish was not there, search a short distance upstream, and (3) if the fish was still not found, search downstream. Because of the limited range of the small radiotags we used we either steered a zig-zag course or searched alternate sides of the river. We always set the RF gain of the receiver to maximum when searching for a radiotagged fish. After we located a radiotagged fish we turned down the RF gain and used a loop antenna to determine the direction of peak and null signal strengths and obtain a more specific location. We repeated this process until we were confident that we were directly over the radiotagged fish.

The more that radiotagged fish migrated the harder they were to locate from a boat. Use of larger radiotags and a yagi antenna made it easier to locate radiotagged fish from a boat. If study objectives require less detailed information (e.g., daily location of adult walleye instead of hourly location of yearling salmon), then more fish can be monitored from a boat.

Aircraft

Locating radiotagged fish from an airplane or helicopter is the most efficient method for tracking highly mobile fish in a large system. It is also a good technique for locating a large number of radiotagged fish in a relatively short time period. Generally, locating radiotagged fish from aircraft before trying to locate them from a boat will make obtaining specific locations easier. We used this method to help locate walleye and northern squawfish in the Columbia River. Monitoring frequencies from an airplane was the only way possible for us to locate over 40 radiotagged walleye and northern squawfish. However, renting a pilot and airplane costs $100-$200 per hour, and it is difficult to accurately determine location of radiotagged fish.

We used an airplane to locate radiotagged walleye and northern squawfish on the Columbia River, and a helicopter to locate radiotagged adult salmon and steelhead on the Umatilla River. We attached a loop antenna to the wing of the airplane and to the undercarriage of the helicopter. We preferred high-winged to low-
winged aircraft because the antenna was easily attached, our view of
the river was unobstructed, and the chance for damage to the antenna
on take-offs and landings was reduced. Airplanes are less expensive
and can be used to survey an area faster than helicopters, but
helicopters are more easily maneuvered and can remain stationary long
enough so that many frequencies can be scanned. This was important
on the narrow, twisting Umatilla River.

We flew directly over the center of the Umatilla River while
searching for radiotagged fish. However, we searched one side and
then the other side of the Columbia River because it is wide.
Aircraft were usually flown 400–800 ft above the water surface. The
RF gain of the receiver was usually set at maximum. We assumed we
were above a radiotagged fish when its signal was strongest.

Mobile Shore Station

Determining location of radiotagged fish from shore can be the
most efficient tracking method on a small river with good access. We
either walked or drove slowly near the edge of the river and used a
hand-held loop antenna to locate radiotagged steelhead and salmon.
We determined general and specific locations of radiotagged fish from
shore in a manner similar to that we used from a boat. We searched
for a radiotagged fish in its last known location, then proceeded
upstream or downstream until we located the fish. The RF gain of the
receiver was always at maximum while we searched. After we
determined the general location of a radiotagged fish we continually
turned down the RF gain and determined the direction of peak and null
signal strengths until we found the specific location. We were
usually able to determine the location of a radiotagged fish within
25 m.

Fixed Shore Station

Receiving systems and data recorders can be placed at convenient
fixed locations to monitor presence or absence of radiotagged fish.
On the Umatilla River we placed a recording system with an
omnidirectional antenna at Three Mile Dam to determine arrival times
and holding periods of salmon. The system consisted of a
programmable scanning receiver, a chart recorder, an interface
component to convert radio signals to a form used by the chart
recorder, and an external 12-V battery for power. When a radiotagged
fish was within range of the system the chart recorder would record
the presence of the fish each time the receiver scanned its
frequency. The recorder had an internal clock to record the time a
radiotagged fish was detected.

A recording system may reduce time spent trying to locate
radiotagged fish by constantly monitoring a given location, but
additional factors must be considered. Chart recorders are a
significant extra expense. A radiotag should always be placed in a known location within range of the receiver to act as a standard and to verify that the receiving system is working correctly. The system should be checked daily, and the external battery should be changed weekly. The system will be left unattended for hours at a time; therefore, it must be located in a secure area. Finally, only presence or absence data are collected. Specific information on detailed behavior will not be available.

REFERENCES


### APPENDIX A

**Suppliers and Costs of Radio Telemetry Equipment**

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<th>Supplier</th>
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