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Sophisticated electronic devices are providing new data on salmonid biology and migration.

Electronic Tags and Related Tracking Techniques Aid in Study of Migrating Salmon and Steelhead Trout in the Columbia River Basin

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ABSTRACT—Electronic tags for salmon have, since 1956, become more compact, reliable, and versatile. They are facilitating the study of migrating adult Pacific salmon, Oncorhynchus *spp., and steelhead trout,* Salmo gairdneri, *throughout the Columbia River Basin. By using sonic and radio tags and fixed and mobile monitoring devices, NMFS scientists have been able to locate the mainstream spawning areas of the fish, temperature blocks, and migration routes through reservoirs. Sonic and radio tags have also been used to study fish activities at and between dams in relation to modification of fishways, power-peaking operations, modified spillway flows, and passage conditions.*

INTRODUCTION

In 1956, two biologists of the National Marine Fisheries Service (NMFS)[1] released an adult coho salmon, *Oncorhynchus kisutch*, carrying a bulky electronic backpack into the watery backyard of the Northwest Fisheries Center (NWFC), Seattle, Wash. The pack was a 132 kHz, high-frequency sound transmitter (Trefethen, 1956). Homing-in on the transmitted signals with a directional hydrophone and receiver, the biologist planned to follow the movements of the tagged salmon throughout Lake Union. This early attempt at sonic tracking of salmon resulted in a track of slightly over 1 h and covered only a few hundred yards, but the results were encouraging enough that development continued on this technique for electronic surveillance of fish activities.

From 1956 to 1970, the sonic fish tag was refined and improved until an extremely reliable and useful tool was developed for studying problems related to passage of adult fish in the Columbia River Basin. The tags progressed from rather bulky units attached to the fish's back to compact, thumb-size capsules placed in the fish's stomach (Fig. 1). Exact tag specifications vary depending on intended use. Our current standard 50 kHz tag is a cylinder, approximately 2.5 inches long by 0.75 inch in diameter and weighing about 1 oz in water. A schematic diagram of the electronic components that make up the tag is shown in Figure 2. Acoustic output of the tag is 60 db re 1 microbar at 1 yard in fresh water. The tags are pulsed and the pulse rate can be varied to provide a variety of tag codes. This tag configuration provides an effective tracking range of up to 1 mile and battery life of about 10 days. Battery life can be increased by reducing the acoustic output, adding additional batteries, or changing the pulse rate and duration. Battery life up to several weeks is possible within the restraints of a reasonable tag size. In addition to the simple location devices, there are sonic tags that telemeter data about the fish's environment, such as temperature (Fig. 3). Sonic tags work effectively in fresh and salt water as long as the water is not highly turbulent and aerated.

In recent years, a radiofrequency fish tag was developed to be used in areas where attenuation of sonic tag

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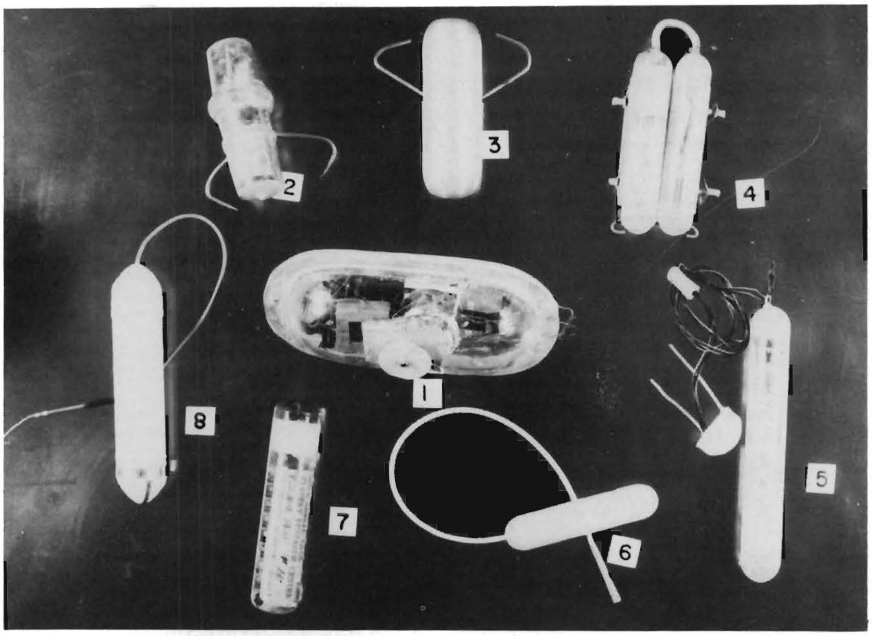
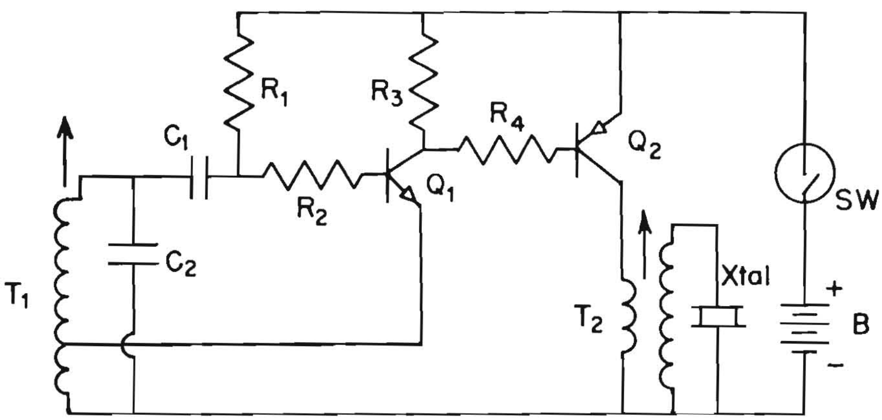


Figure 1.—Electronic tags: (1) first sonic tag; (2, 3) early model external sonic tags; (4) twin backpack sonic tag; (5) sonic tag (crystal fastened on fish's snout); (6) temperature sensitive sonic tag; (7) current model internal sonic tag; (8) radio tag.

[1]Known in 1956 as the Bureau of Commercial Fisheries (BCF), this agency was renamed in 1970 when transferred into the newly established National Oceanic and Atmospheric Administration (NOAA).



C_1 = 0.68 mfd. tantalum capacitor
C_2 = 0.0082 mfd. polyester film capacitor
R_1 = 3.6 Meg ohms, 1/8 watt resistor
R_2 = 1.2k ohms, 1/8 watt resistor
R_3 = 3.3k ohms, 1/8 watt resistor
R_4 = 3.3k ohms, 1/8 watt resistor
Q_1 = 2N2925 transistor
Q_2 = 2N3702 transistor

T_1 = 350 turns # 40 wire, center tapped, wound on a 3/16" form, and tuned with an 8-32 ferrite slug.

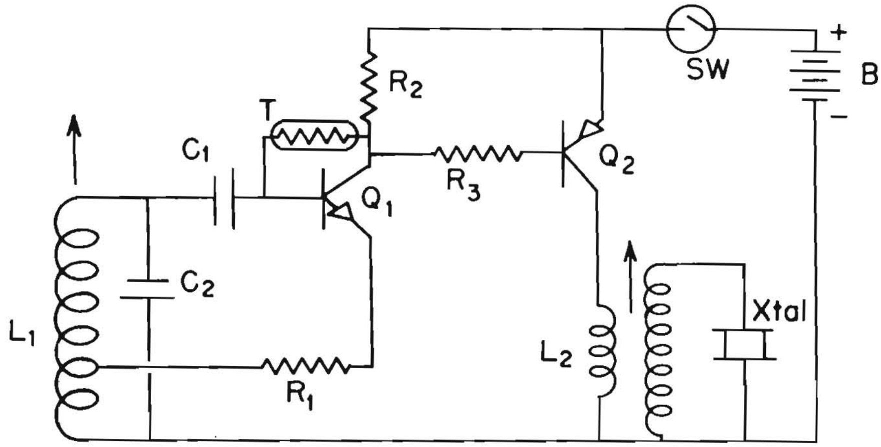
T_2 = Primary - 40 turns # 32 wire, Secondary - 700 turns # 36 wire, wound on a 3/16" form and tuned with an 8-32 ferrite slug.

Xtal = .50 kHz piezo-ceramic cylinder 0.695"OD x 0.485"ID x 0.5"H, material EC64.

SW = Magnetic reed switch.

B = 11.2V., 350 M.A.H. mercury battery.

Figure 2.—Schematic for a 50 kHz sonic tag.



C_1 = .022 mfd. polyester film capacitor
C_2 = .0047 mfd. polyester film capacitor
R_1 = 220 ohm, 1/8 watt resistor
R_2 = 1 k ohm, 1/8 watt resistor
R_3 = 2.2 k ohms, 1/8 watt resistor
Q_1 = 2N2925 transistor
Q_2 = 2N3702 transistor
T = Fenwal GA615MI thermistor

L_1 = 300 turns # 38 wire, CT, wound on a 3/8" length of soda straw and tuned with an 8-32 x 3/8" threaded slug.

L_2 = Primary - 35 turns # 36 wire, Secondary - 375 turns # 38 wire, wound on a 3/8" length of soda straw and tuned with an 8-32 x 3/8" threaded ferrite slug.

Xtal = 70kHz piezo-ceramic cylinder, 0.512"OD x 0.452"ID x 0.25"H, material EC64.

B = 7V., 160 M.A.H. mercury battery.

Figure 3.—Schematic for a 70 kHz sonic temperature tag (300 pps at 100°F, 50 pps at 32°F. Pulse length, 350 microseconds).

signals by entrained air and turbulence in the water made sonic tracking impossible. This radio tag is a battery powered, high-frequency radio transmitter that operates on a carrier frequency of approximately 30 kHz; with a 167 milliwatt input, it has an effective tracking range of 0.5 mile or more and an operational life of approximately 15 days. The tag is similar in size to a sonic tag and is carried in the stomach of the fish except for a small wire antenna that extends from the tag, through the fish's esophagus, to the roof of its mouth where it is attached with a plastic barb (Fig. 4). A schematic diagram of a typical radio tag is shown in Figure 5. The radio tag transmits efficiently through the turbulent waters below dams and can be tracked with mobile or fixed radio direction finders. Tags weigh about 1 oz in water and can be pulse-rate coded or frequency coded. Currently, the use of the radio tag is restricted to fresh water.

SONIC TRACKING

Sonic tracking is accomplished with a directional hydrophone placed in the water to pick up the signal from the tag. A sonic receiver receives the signal from the hydrophone and converts it to an audible tone. The operator then rotates the hydrophone and determines the direction of the loudest signal which indicates the direction of the tagged fish.

The sonic tracking system was first used in a full-scale biological study in 1957 at Bonneville Dam (Johnson, 1960). A total of 43 salmon and steelhead trout, *Salmo gairdneri*, were tagged and tracked as they exited into the forebay from the Washington-shore fishway. Fish were kept under surveillance with sonic receiving equipment in a small boat for as long as 16.75 h and tracked upstream as far as 10 miles. The study produced the first detailed information on individual fish behavior in the immediate vicinity of a major Columbia River Dam and showed migration patterns of adult salmon and trout exiting from a fishway. It also proved the worth of sonic tags and tracking for surveillance of fish activities. Further studies and improvements in the system followed.

Shore Monitors Used

In 1961-62, adult salmon passage was studied in Brownlee Reservoir (57.5 miles long) on the Snake River (Trefethen and Sutherland, 1968).

Figure 4.—Radio tag insertion into stomach of adult chinook salmon.

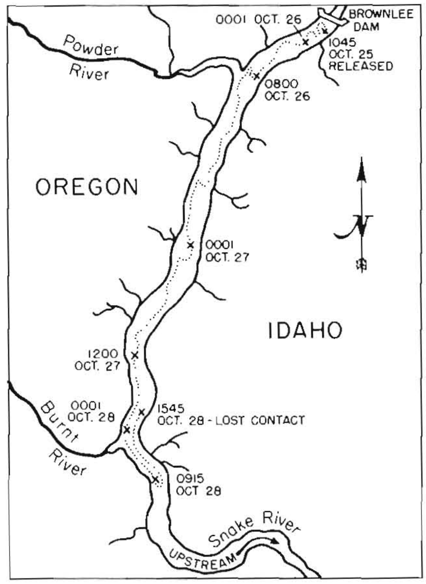
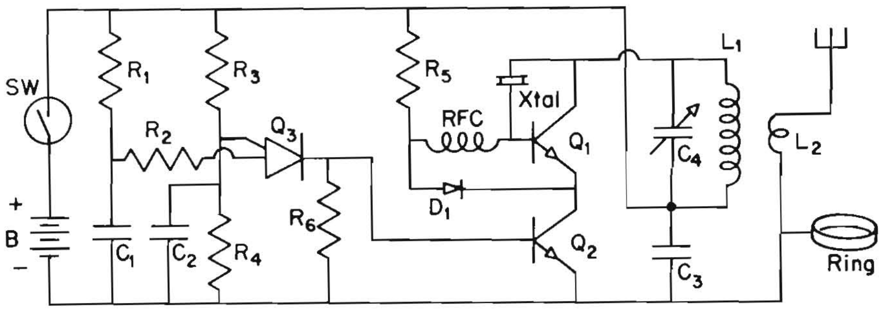


Figure 6.—Course of salmon tracked 77 h in Brownlee Reservoir. Drawing is diagrammatic; width of reservoir is not to scale. Fish traveled approximately 50 miles upstream before turning back.



C_1 = 0.27 mfd. tantalum capacitor
C_2 = 0.001 mfd. polyester film capacitor
C_3 = 0.01 mfd. polyester film capacitor
C_4 = 15-60 mmfd. ceramic trimmer capacitor
R_1 = 1.8 Meg ohms, 1/8 watt resistor
R_2 = 43 k ohms, 1/8 watt resistor
R_3 = 100 k ohms, 1/8 watt resistor
R_4 = 150 k ohms, 1/8 watt resistor
R_5 = 47 k ohms, 1/8 watt resistor
R_6 = 100 k ohms, 1/8 watt resistor
D_1 = 1N457 diode
Q_1 = 2N2222 transistor
Q_2 = 2N2925 transistor
Q_3 = P13T1 transistor

L_1 = 12 turns #24 wire, rectangular air wound 3/16"H x 3/8"W x 9/32"L.
L_2 = 3 turns #32 wire wound on L_1 near middle of the coil.
Xtal = Quartz crystal, 3rd O.T., series, Freq. tol-.0025% at 68°F, ESR-60 ohms max, SM-1 holder.
SW = Magnetic reed switch.
Ring = Stainless steel band 1/8" wide x 0.003" thick, cemented to outside of capsule.
B = 11.2V., 350 M.A.H. mercury battery.
RFC = 75 turns #4 wire wound on a 22 Meg, 1/8 watt resistor.

Figure 5.—Schematic for a 30 Mhz radio tag (pulse rate: 1 pps; pulse length: 25 milliseconds).

Tracking of individual sonic-tagged fish provided detailed information on the movements of fish through this long, deep reservoir where there is little water current to provide orientation (Fig. 6). This study marked the first use of unmanned, fixed monitors placed at specific points along the shoreline to automatically record the date, time, and direction of travel of sonic-tagged fish on time-event charts. Although some fish were delayed, they were able to pass through the reservoir and on upstream to spawning areas.

Sonic-tagged fish and fixed monitors were used in 1963 at Ice Harbor Dam on the Snake River to determine the proportion of adult migrants that fall back downstream over the spillway after they exit from the fishways (Fig. 7). Hydrophones placed near the spillgates detected sonic signals and fed them to receiver-amplifiers; the amplified tag signals were automatically recorded on multichannel recorders to provide a record of fish that fell back through the spillway gates. Data from 223 tagged salmon indicated that 6.3 percent of the spring[2] chinook salmon, *O. tshawytscha*, migrating past Ice Harbor Dam fell back over the spillway during the study period. About 50 percent of the sonic tagged fish that fell back survived the experience and reascended the dam.

Spawning activity of fall chinook salmon in the area to be flooded by John Day Dam on the Columbia River was surveyed by a sonic tracking team in 1965 as part of a joint study with the Fish Commission of Oregon. In this study, 213 fall chinook salmon —judged by skin color to be at different stages of maturation—were tagged with coded sonic tags and released at The Dalles Dam, 24 miles downstream from the John Day Dam site. Fixed monitors located on the river banks recorded turnoff of tagged fish into two main tributaries—the Deschutes and John Day Rivers. To identify mainstem spawning areas,

[2]Seasonal races of chinook salmon in the Columbia River system are classified as spring, summer, or fall chinook depending on the time of year that the adults enter the river to spawn.

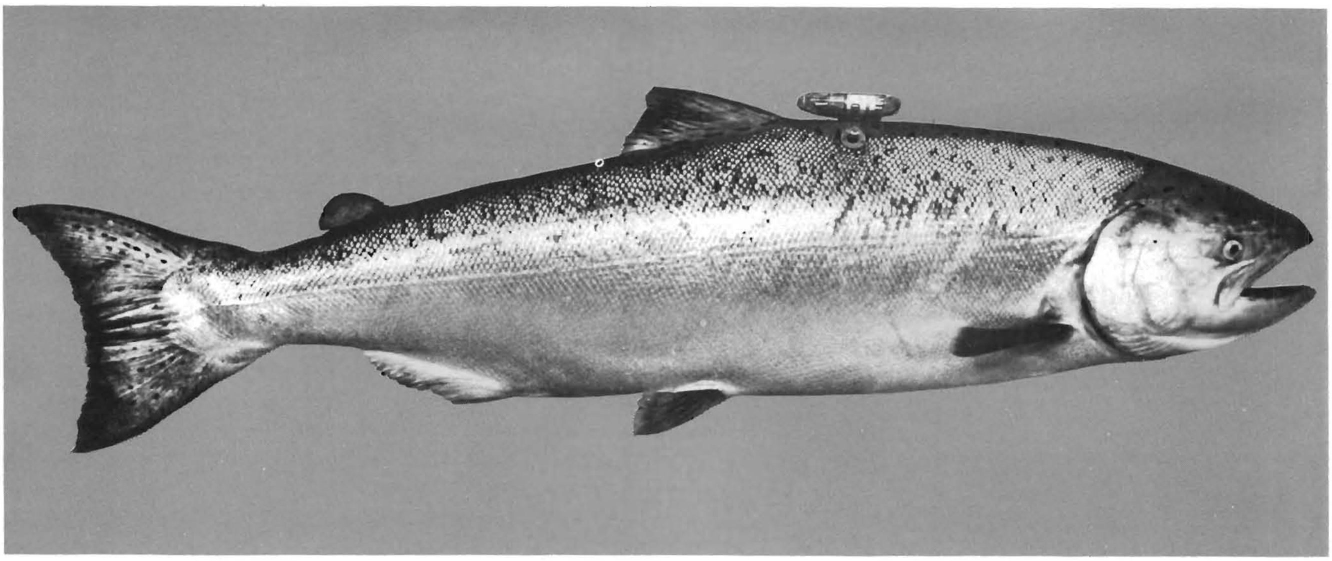


Figure 7.—Chinook salmon tagged with early model sonic tag.

Figure 8.—Sonic tracking crew in action.

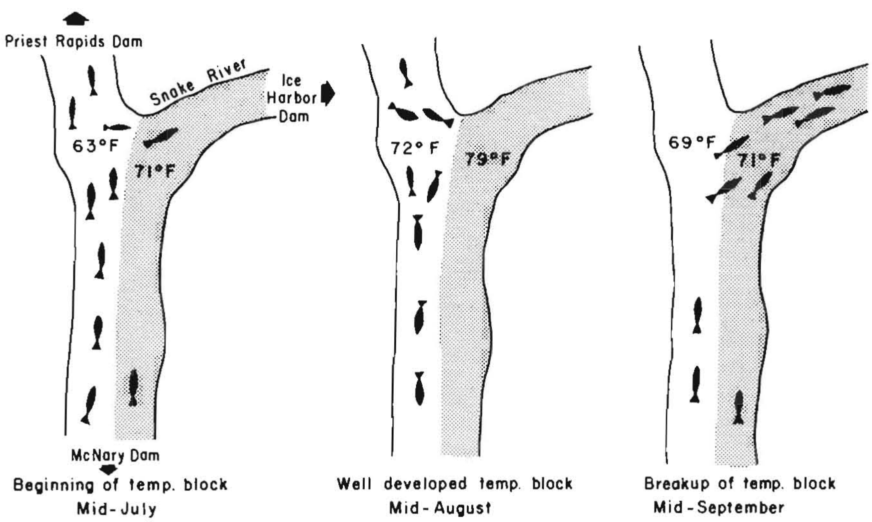


Figure 9.—Temperature block in the Snake River.

weekly surveys of the study area were made and the locations and codes of sonic-tagged fish charted (Fig. 8).

Temperature Block Located

Dramatic evidence of a severe temperature block at the mouth of the Snake River was obtained in 1967 from tracking 251 adult steelhead trout in McNary Reservoir (Snyder and Blahm, 1971) during their upstream migration (Fig. 9). In late July when river temperatures in the Snake River were near 75°F and the Columbia River was 9 degrees cooler, sonic-tagged fish began to concentrate at the confluence of the two rivers. During the temperature block, sonic-tagged fish remained in the cooler Columbia River water. In mid-September, when Snake and Columbia River water temperatures were near 70°F, large numbers of fish began moving up the Snake River. At the time of the temperature block, it was obvious from comparing fish counts at McNary, Ice Harbor, and Priest Rapids Dams that a holdup in fish passage was occurring, but through the use of sonic tags, biologists were able to pinpoint its location.

Scientific Assist To Angling

In 1969, sonic tracking provided a scientific assist to recreational fisheries in Ice Harbor Reservoir where steelhead fishermen were concerned over flooding of their accustomed fishing areas by the large impoundments behind the dams in the Snake River[3]. A cooperative program was developed by the U.S. Army Corps of Engineers and NMFS. Adult steelhead trout were trapped at Ice Harbor Dam, tagged with sonic tags, released into the reservoir, and tracked as they moved upstream. Data indicated the fish followed specific migration routes through the reservoir and used certain areas for milling and resting. Information obtained by NMFS scientists was given to the Corps, which published maps showing migration and milling areas. Tri-State Steelheaders, Inc. (TSI) and the Washington Department of Game (WDG) organized "Operation Slackwater"—a mass fishing effort to develop fishing techniques to catch steelhead in the large reservoir. Based upon the angling success of fishermen armed with data from the tracking study, it was concluded that a sport fishery for steelhead in slackwater reservoirs is possible. The study is a good example of how cooperation of Federal, State, and private organizations can work toward resolution of a problem.

Telemetry Tag Developed

Temperature-sensitive sonic tags, developed by NWFC staff members, were used in a field study for the first time in 1970. In a study made jointly with Battelle Northwest, eight fall chinook salmon tagged with temperature-sensitive sonic tags were tracked in the Columbia River near the nuclear reactors of the Atomic Energy Commission at Hanford, Wash. The study demonstrated the usefulness of the tag, but not enough fish were observed moving past a reactor outfall to provide significant data.

RADIO TRACKING

When a radio-tagged fish comes into the study area, its position is usually monitored by two or more trackers. The direction-finder receivers used by the trackers are self-contained, battery-operated units that receive the radio signal from the antenna, amplify it, and convert it to an audible tone. The primary tracking antenna that receives the signal from the tag is a directional loop 18 inches in diameter. Tracking is usually done from fixed tracking stations located throughout the study area. By listening to the tag signal, rotating the loop antenna until a null point is reached, and then sighting along the geometric axis of the loop, the tracker can establish a bearing from the station to the tagged fish. If a second tracker is taking same action simultaneously, the two bearings can be plotted and the location of the fish established by triangulation.

In 1971, radio tags and tracking equipment were used in the first field test of our system to study behavior of adult spring chinook salmon as they approached Bonneville Dam. Radio-tagged fish were released approximately 5 miles downstream, and tracking teams stationed along the shoreline monitored the activities of the fish approaching the dam. The results showed that: (1) tracking radio-tagged fish in turbulent areas below a dam is a workable and useful approach to studying fish behavior—this solved the previously mentioned problem that we had with sonic tags in aerated water; (2) during periods of high river flow, fallback of salmon can contribute to inflation of fish counts at Bonneville Dam—32 percent fallback was estimated in spring of 1974; (3) closure of counting station gates causes excessive delay and should be kept to an absolute minimum; and (4) river flows in excess of 325,000 cfs impede upstream migration.

Mobile Tracking Unit Used

In 1972 a mobile radio-tracking vehicle was developed for a study in which observations were made on fish behavior at Bonneville and The Dalles Dams to compare behavior patterns of spring chinook salmon at the two dams and to determine problem areas relating to loss of spring chinook salmon between the two dams[4]. Radio tags were placed on 40 adult spring chinook salmon which were released at various locations above and below Bonneville Dam. Tracking teams located at each dam monitored fish behavior in the immediate vicinity of the dam and for the first time used the mobile tracking vehicle equipped with two-way radio communications and a radio direction finding unit along the highway between the dams to monitor the progress of tagged fish up the river (Fig. 10). The mobile unit also traveled along tributary streams to record the presence of tagged fish. Based on data from this study, it was concluded that: (1) spring chinook salmon spend more time passing over Bonneville than The Dalles Dam; (2) during certain river flows, fallback

Figure 10.—Mobile tracking unit.

[3]Monan, G. E., K. L. Liscom, and J. R. Smith. 1970. Final report—sonic tracking of adult steelhead in Ice Harbor Reservoir, 1969. Biological Laboratory, Bureau of Commercial Fisheries, USFWS, Seattle, Wash. 12 p. (Processed.)

[4]Monan, G. E. and K. L. Liscom. 1973. Final report—radio tracking of adult spring chinook salmon below Bonneville and The Dalles Dams, 1972. Northwest Fisheries Center, National Marine Fisheries Service, NOAA, Seattle, Wash. 37 p. (Processed.)

can be more of a problem at Bonneville than at The Dalles Dam; (3) a substantial percentage (95 percent) of spring chinook salmon that reach The Dalles area successfully pass over the dam; (4) unaccountable losses between dams (11 percent) were more likely to be associated with events at Bonneville Dam and in the river between dams than with events at The Dalles Dam; and (5) mortalities from dropouts from gill nets fished between the dams are a possible causative factor in the unaccountable losses.

Effects of Spillway Deflectors Studied

In 1973, radio tracking was used to study fish behavior in relation to flow from experimental flow deflectors at dams[5]. The flow deflectors were installed by the Corps of Engineers to control the levels of dissolved atmospheric gas below spillways by changing the direction of spill from plunging to horizontal. Studies were centered at Lower Monumental Dam on the Snake River, where two of the eight spillbays were modified with deflectors. Here 20 separately identifiable radio-tagged spring chinook salmon were released below the dam and their behavior monitored as they approached and passed over the dam (Fig. 11). To assure that a maximum number of tagged fish frequented the critical areas below the deflectors, spilling was restricted, as much as possible, to the bays containing the flow deflectors. Approximately 50 percent of the tagged fish were tracked into the areas of concern and none showed any signs of abnormal behavior after their experience. All tagged fish passing over the dam were observed at the viewing windows of the counting stations and no serious injuries were apparent. It was concluded that spring chinook salmon, swimming of their own volition into the area immediately below a spillway discharging water over a spillway deflector, do not suffer debilitating injuries when discharges through the bay are in the range of 2,800-9,800 cfs. Results of this study were instrumental in the planning for additional installation of spillway deflectors at Lower Monumental Dam and other dams within the Columbia River Basin.

Peaking Studies

The year 1973 marked the first full-scale use of a Fish Tracking Control Center where the activities of nine separately identifiable radio-tagged fish were monitored at one time. Real-time plots were maintained on each fish based on bearings radioed in from trackers located at stations throughout the study area. The positions of the fish are recorded on large charts much as aircraft positions are plotted by air traffic controllers at an airport (Fig. 12).

Radio tracking studies, begun in 1973, entail examination of the effects of daily fluctuations in river flow on migration of adult salmonids. Changes in the production pattern of electrical energy in the Pacific Northwest will accelerate power peaking operations at mainstem dams on the Columbia and Snake Rivers; this will require higher river discharges to produce large amounts of electrical energy at dams when the demand for power is high (normally in the morning and early evening) and lower flows and storing of water when the demand is low. Fishery agencies are concerned that resulting fluctuations in river flow could adversely affect the migration and survival of adult salmon and trout in the Columbia River System. In the initial tracking study, 51 adult fall chinook salmon were tagged with radio tags and their behavior was ob-

Figure 11.—Manned radio tracking station at Lower Monumental Dam.

Figure 12.—Fish Tracking Control Center in operation at Lower Monumental Dam.

[5]Monan, G. E. and K. L. Liscom. 1974. Final report—radio tracking of spring chinook salmon to determine effect of spillway deflectors on passage at Lower Monumental Dam, 1973. Northwest Fisheries Center, National Marine Fisheries Service, NOAA, Seattle, Wash. 20 p. (Processed.)

served in the vicinity of Bonneville Dam in August and September 1973. At the time, record low river flows resulted in a critical power shortage, which forced some departure from our original test plan of controlled peaking operations. Nevertheless, baseline data were obtained on fall chinook behavior under varying flow conditions.

WHAT ABOUT THE FUTURE?

Electronic surveillance of fish activities will continue to be an important means for studying upstream migrations in the Columbia River Basin and elsewhere. Tracking of sonic and radio tagged adult Pacific salmon and steelhead trout has already provided considerable insight into problems associated with passage conditions at and between dams, increased river water temperatures, and loss of fish and fishing due to dam construction throughout the Columbia River Basin. As additional demands are placed on use of our water resources (e.g., irrigation withdrawals and pumping of water for storage and use when needed at hydroelectric plants), further control of river flow and temperature regimes with corresponding new problems for anadromous fish may be expected. The effects of these manipulations on anadromous and resident fish will need to be determined in the very near future.

Equipment and techniques for sonic and radio tracking of adult salmon and steelhead have improved markedly since their inception in 1956. However, today's technology cannot be relied upon to answer all of tomorrow's questions, and scientists are alert to take advantage of all ways to improve tools and techniques that can provide many needed answers. On the horizon is a pressure sensitive tag to provide eagerly awaited information about migration depths for salmon and trout. Also under investigation is the possibility of automating the tracking process to obtain more and better data with less manpower. A major advance in battery design is needed to further miniaturize the tags to make them suitable for smaller species of fish and perhaps even juvenile salmonids. Fortunately, the field of bioelectronics is racing ahead and breakthroughs are frequent.

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