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# A Remote Satellite-Linked Tracking System for Studying Pacific Salmon with Radio Telemetry

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*Abstract.*—A remote tracking system with a satellite uplink was used to study the movements of adult chinook salmon *Oncorhynchus tshawytscha* and coho salmon *O. kisutch* in the large, isolated Taku River in Alaska and British Columbia. Salmon were tagged with pulse-coded radio transmitters; 10 codes identified individual fish on each of 52 frequencies. Remote tracking stations automatically collected, processed, and transferred telemetry data via a computer-controlled receiver. A satellite uplink was used to retrieve the data for within-season analysis. Three hundred six chinook salmon were tracked upriver in 1990 and 351 coho salmon in 1992. Coho salmon could not have been tracked with conventional methods due to the inclement fall weather and mountainous terrain typical of this area. The stations recorded 98–100% of the radio-tagged fish that moved past. Tracking success was much higher than in previous studies in which fish were tracked exclusively from aircraft. The remote tracking system is an effective method for precisely tracking large numbers of salmon in large, inaccessible rivers, and it has numerous applications to fisheries research.

Various aquatic animals have been tracked with radio telemetry since the 1960s (Winter 1983). Most studies were limited to small numbers of tagged individuals, usually fewer than 40, and to relatively small areas. Recent advances in telemetry have made it possible to track wider-ranging species and larger numbers of individuals (Eiler et al. 1992; Bendock and Alexandersdottir 1993).

Increasingly, telemetry is being used to obtain quantitative information on large aggregates of fish, such as Pacific salmon *Oncorhynchus* spp. Because of the economic value of salmon, information on run characteristics (numbers of fish returning, timing, spawning distribution, movement patterns) and habitat use is needed to manage salmon returns.

Many glacial rivers in Alaska and northwestern British Columbia are important producers of salmon. Because turbidity in these rivers often precludes visual observations, telemetry is necessary to obtain detailed information on returning salmon. However, telemetry studies of large salmon returns can be difficult because hundreds of these highly mobile fish must be tagged to obtain meaningful results. Conventional tracking methods—locating radio-tagged individuals on foot or from vehicles, boats, or aircraft—are inadequate under these conditions. For example, aerial tracking provides the greatest reception range (Winter 1983) and covers vast areas in relatively short periods. However, when many individuals are tracked, the speed of the aircraft and the time required to scan all frequencies may result in some fish being undetected and subsequently lost. Although coded transmitters can reduce the number of frequencies and improve tracking success (Eiler et al. 1991), aerial surveys over large, remote drainages are still time-consuming, labor-intensive, and costly. Inclement weather and mountainous terrain, typical of many coastal drainages, make aerial tracking hazardous.

Alternative approaches have been used to collect telemetry information when conventional methods were inadequate. In studies requiring intensive tracking at localized sites, receivers interfaced with data loggers have been used to collect telemetry data for birds (Howey et al. 1989; Wilson et al. 1993), mammals (Jansen et al. 1991; Sasaki et al. 1991), and freshwater fish (Prepejchal et al. 1980; Rogers et al. 1984; Turner et al. 1984; Steuhrenberg et al. 1990). Most fishery applications of data loggers have been for monitoring physiological responses under controlled conditions or for tracking movements in confined areas, such as at fish passage structures near hydroelectric dams.

Since the early 1970s, satellites have been used to track radio-tagged animals in isolated areas or migrating over vast distances (Craighead et al. 1972). With the advent of smaller and more reliable transmitters, satellites have collected telemetry data on polar bears *Ursus maritimus* (Harris et al. 1990), loggerhead turtles *Caretta caretta* (Stoneburner 1982), wandering albatross *Diome-*

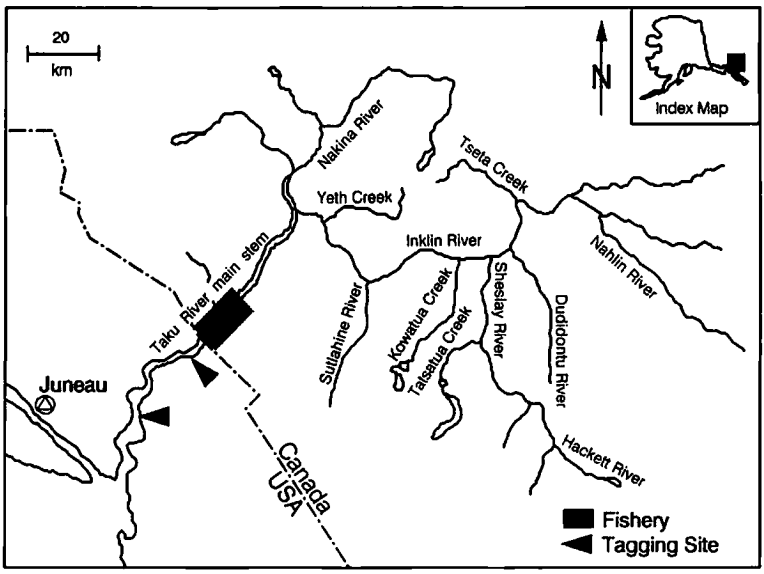


FIGURE 1.—Taku River drainage in southeastern Alaska and northwestern British Columbia.

*dea exulans* (Jouventin and Weimerskirch 1990), and other animals. However, satellite-linked transmitters are currently too large for most small animals, including freshwater fish, and have a high frequency range (400 MHz) that is unsuitable for submerged animals.

During 1990 and 1992, a satellite-linked tracking system was used to study adult chinook salmon *O. tshawytscha* and coho salmon *O. kisutch* in the Taku River near Juneau, Alaska. Telemetry data were collected by fixed, remote tracking stations, and the information was then accessed via satellite. The system remotely tracked, over large, isolated areas, aquatic animals too small to be tagged with satellite transmitters. In this paper, we describe the system and evaluate its potential application to fisheries research.

## Study Area

The Taku River drains a watershed exceeding 16,000 km$^2$, mostly in British Columbia (Figure 1). The drainage is formed by several major tributaries that join and flow into the Taku River main stem. Water visibility in many areas is extremely poor due to glacial turbidity. The system is remote; access to most areas is limited to aircraft, and inclement weather and the mountainous terrain severely restrict air travel during the fall and winter.

Six species of anadromous salmonids spawn in the Taku River, including numerous chinook and coho salmon (Pacific Salmon Commission 1993). Chinook salmon return to the Taku River from April to early July. Most coho salmon return during fall, although there is a small summer run (Alaska Department of Fish and Game, Commercial Fisheries Division, Juneau, unpublished data).

## Methods

*Capture and handling.*—Chinook and coho salmon migrating upriver were captured with fish wheels (Meehan 1960) 4 km downstream from the U.S.–Canadian border (Figure 1). Coho salmon were also captured near the river mouth, 29 km downstream from the border, with gill nets 30 m long and 4 m deep with 7.6- and 8.9-cm stretch meshes. These small meshes were used to avoid injury to the fish.

The fish were placed in a tagging cradle submerged in a trough of fresh water. Anesthesia was not used during the tagging procedure. Radio transmitters were inserted through the mouth and into the stomach with a plastic tube (0.7 cm in diameter). The fish were also marked externally with a grey spaghetti tag below the dorsal fin (Wydoski and Emery 1983), then released in quiet water out of the main current. Handling, from removal from the capture device to release, took about 5 min.

*Radio transmitters.*—Pulse-coded transmitters made by Advanced Telemetry Systems[1] (Isanti,

[1] Reference to trade names does not imply endorsement by the National Marine Fisheries Service.

Minnesota) were used. The transmitters were 6.6 cm long and 1.9 cm in diameter, weighed 20 g, and had a 30.0-cm external transmitting antenna. Minimum battery life was about 5 months.

Individual transmitters were identified by frequency and signal pattern. The standard signal pattern was a wide pulse (20 ms) followed by two short pulses (5 ms). The time interval between pulses (hereafter referred to as the code) was the same for a given transmitter and unique for each transmitter on a frequency. The time interval of the three-pulse group was also unique for each code. Ten transmitters, distinguishable by code and pulse-group interval, were used per frequency. Fifty-two frequencies were used, spaced 20 kHz apart in the 150–151-MHz frequency range.

Transmitters were equipped with motion sensors (Eiler 1990) and activity monitors (commonly called mortality sensors, a less apt term because prolonged periods of inactivity do not necessarily signify death). If the motion sensor was not triggered for over 10 h, the activity monitor altered the signal pattern to a wide pulse followed by three short pulses (hereafter referred to as the inactive mode). The transmitter reverted to the standard signal pattern if the motion sensor was activated.

*Remote tracking stations.*—Radio-tagged fish that moved upriver were recorded by fixed, remote tracking stations (Figure 2) at selected sites in the drainage. Each station consisted of several integrated components, including a computer-controlled receiver developed by Advanced Telemetry Systems. The receiver and computer were used to detect, identify, and record transmitter signals. The 52 frequencies used for the radio-tagged fish were programmed into the computer. These frequencies were continually scanned by the receiver at 2-s intervals. When radio signals were detected, the frequency was scanned for 8 s, and the signals were analyzed by the computer with a series of pattern-matching routines to determine whether a transmitter was present and to identify its code. Transmitter signals were recorded once per hour as long as they were in reception range.

Telemetry data—including frequency, code, date and time that the transmitters were recorded, and activity (standard or inactive mode)—were stored by the computer. The computer could store data for over 22,000 observations. This information could be accessed and viewed directly from the computer's display screen or downloaded at the site to a portable computer for subsequent analysis.

Telemetry data were also transferred hourly to a second computer (data collection platform), manufactured by Handar, Inc. (Sunnyvale, California). When equipped with the appropriate sensors, this unit can also measure hydrological and meteorological conditions (e.g., water temperature, water level, barometric pressure) at the site. The information collected by the data collection platform was transmitted every 3 h to a geostationary operational environmental satellite (GOES) and relayed to a receiving station in Camp Springs, Maryland. The information was accessed daily via telephone modem, and the data files were downloaded into a computerized data base for analysis (Figure 3).

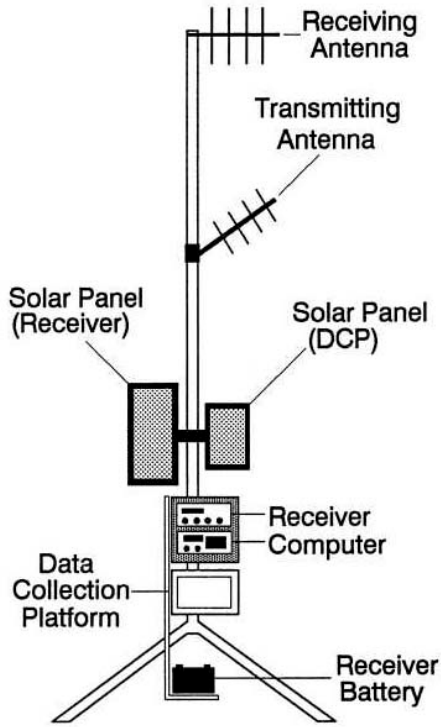


FIGURE 2.—Remote tracking station used to detect and record salmon tagged with radio transmitters. The battery powering the data collection platform (DCP) was inside the protective housing of the unit.

Power for the receiver and data collection platform was supplied by sealed lead–acid batteries charged by solar panels. The voltage for each battery was recorded hourly and transmitted with other information.

Station components were attached to a 10-m portable tower (Figure 2). Two four-element Yagi receiving antennas at the top of the tower were positioned about 90° apart to provide uniform re-

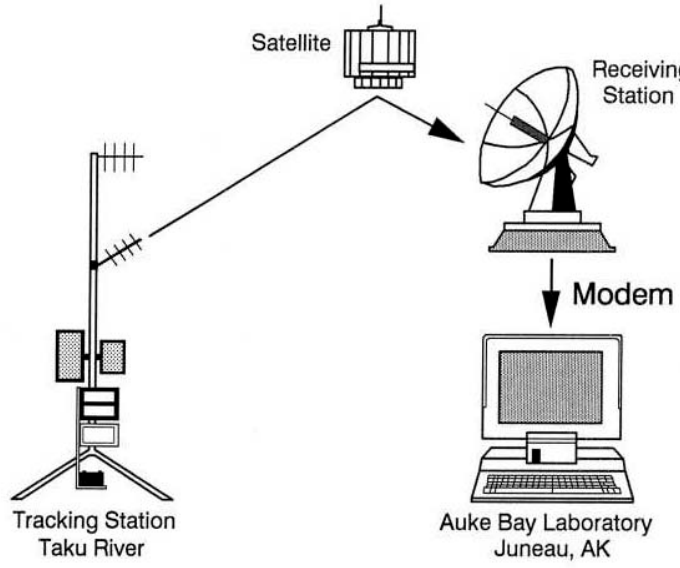


FIGURE 3.—Data transfer system used to retrieve information collected by remote tracking stations on the Taku River.

ception across and along the river. When possible, tracking stations were placed on relatively straight stretches of river to maximize reception range, because signal reception is along line of sight. Cables connecting the station components were encased in metal tubing to prevent damage from rodents and bears. Each station could be assembled or taken down in less than 2 h and was suitable for helicopter transport to remote sites.

Reference transmitters were placed at each site to help evaluate station performance. These transmitters provided a continuous check on whether the stations were receiving and recording signals. Stations that did not record the reference transmitter in the first 5 min of an hour were considered to be malfunctioning. The stations were designed so that malfunctioning components could be easily identified during on-site inspections.

*Field tests on chinook salmon.*—In 1990, stations were positioned at five sites in the Taku River drainage (Figure 4). The sites were on major travel corridors used by chinook salmon migrating upriver to spawning areas. Two stations were placed at each site (hereafter referred to as paired stations) to corroborate results and evaluate equipment performance. Aerial surveys were flown upriver from the stations to verify the movement of radio-tagged fish past the sites. The fish were located from fixed-wing aircraft and helicopters equipped with four-element Yagi receiving antennas.

*Field tests on coho salmon.*—In 1992, 17 stations at 13 sites tracked the movements of radio-tagged coho salmon throughout the drainage (Figure 4). Fifteen stations were on major travel corridors; two other stations were on minor tributaries of the Taku River main stem (Yehring and Fish creeks) used by coho salmon as spawning areas. Aerial surveys were limited by inclement weather to occasional flights over the main stem. The performance of the tracking system was evaluated by comparing data between paired stations at three sites (U.S.–Canadian border, Inklin River, and Tatsatua Creek). A fourth site (Taku River main stem) had two stations, but these were not considered paired because they covered different sections of the river. In addition, results from each station were compared with other available information (e.g., records from other stations, aerial surveys of the Taku River main stem) to determine whether tracking records for individual fish showed a logical progression of movement between areas.

Stations on major travel corridors were operating by early July. The two stations on main-stem tributaries (Yehring and Fish creeks) were activated later in the fall. All stations were deactivated during the last week of November.

*Range and performance tests.*—To determine accuracy and reception range of the remote tracking system, control tests were conducted during spring 1992 at Auke Lake, a small lake near Juneau, Alaska. Prior to these tests, the hardware and software

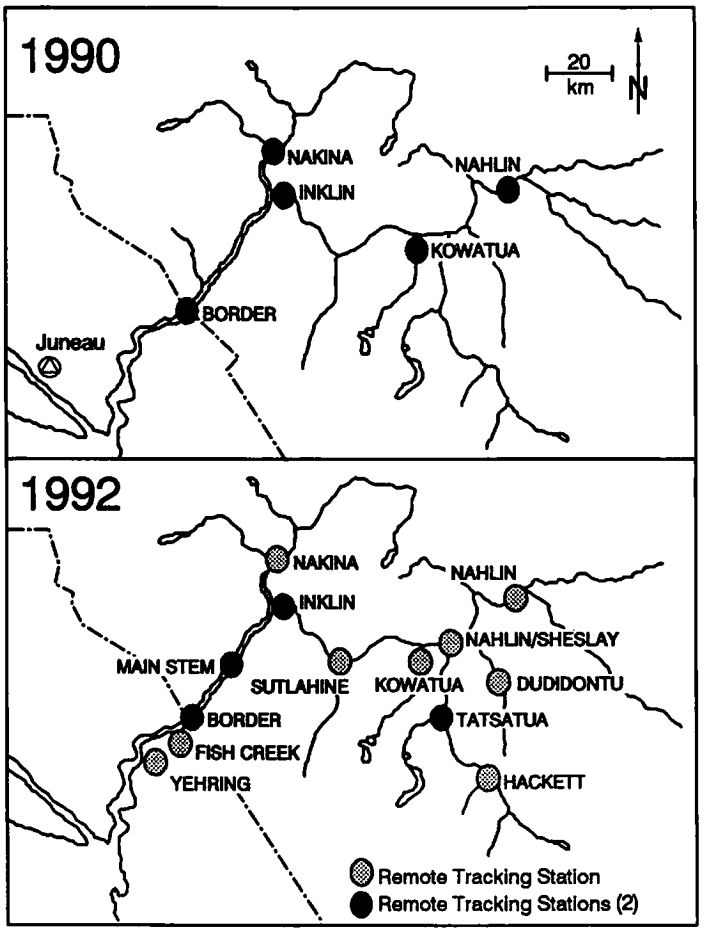


FIGURE 4.—Locations of remote tracking stations on the Taku River drainage, 1990 and 1992. Sites with two stations are indicated by solid circles.

of the receiver and computer were modified to improve performance. Fourteen transmitters were placed 200 m from a station at a water depth of 3 m. Ten transmitters were on individual frequencies; two frequencies had two transmitters each, differentiated by code. The 52 frequencies used during the Taku River field studies were scanned by the receiver. The transmitters decoded successfully, and the times required to complete one scan cycle were recorded. Trial scans were conducted with 26 receivers. Each receiver was tested at least twice.

A second test was conducted to estimate maximum reception range. A transmitter was placed 600 m from the tracking station at a water depth of 2 m. During the tests, different levels of signal attenuation were introduced with a calibrated attenuator placed in a coaxial line between the receiving antenna and receiver. Attenuation, 0–18 decibels (dB), was introduced as a measure of how much the transmitter signal exceeded the minimum level needed for detection.

## Results

### *Field Tests on Chinook Salmon*

In 1990, 306 radio-tagged chinook salmon moved up the Taku River past the U.S.–Canadian border. Nearly all the fish that passed the five tracking sites were recorded by the stations. Tracking success for 9 of the 10 stations ranged from 97.8 to 100.0% (Table 1); the Nahlin River lower station, damaged during installation, recorded only 86.1% of the fish and exhibited chronic problems recording the reference transmitter.

Twenty-five recordings were made by stations when no tagged fish were present (false positives). This problem was more pronounced for certain receivers, and in several cases was specific to cer-

TABLE 1.—Tracking success for paired remote stations tracking radio-tagged chinook salmon in the Taku River, 1990. Potential targets were verified by aerial surveys upriver from the sites. Percentages of the potential targets, by station, are in parentheses.

| Site and station | Potential targets | Tags recorded | Tags missed | False positives |
|---|---|---|---|---|
| Border | | | | |
| Lower | 306 | 306 (100.0) | | 1 |
| Upper | 306 | 301 (98.4) | 5 (1.6) | 1 |
| Nakina | | | | |
| Lower | 92 | 92 (100.0) | | |
| Upper | 92 | 90 (97.8) | 2 (2.2)[a] | 2 |
| Inklin | | | | |
| Lower | 125 | 125 (100.0) | | 17[b] |
| Upper | 156 | 156 (100.0) | | |
| Kowatua | | | | |
| Lower | 18 | 18 (100.0) | | 4[c] |
| Upper | 17 | 17 (100.0) | | |
| Nahlin | | | | |
| Lower | 36 | 31 (86.1) | 5 (13.9)[d] | |
| Upper | 33 | 33 (100.0) | | |
| Total | 1,181 | 1,169 (99.0) | 12 (1.0) | 25 |

[a] Both on frequency 150.840 MHz; no other fish with this transmitter frequency moved past this site.
[b] All on frequency 151.860 MHz.
[c] All on frequency 151.760 MHz.
[d] Station damaged by electrical surge during installation. Chronic problems were also experienced recording the reference tag.

tain frequencies (Table 1). All false positives were recorded as single entries, i.e., not recorded over consecutive hourly periods—a pattern rarely observed for radio-tagged fish passing a site.

*Field Test on Coho Salmon*

In 1992, radio-tagged coho salmon were recorded by stations at 12 sites (Table 2). Telemetry data from the three sites with paired stations provided the best indication of station performance. All fish that passed the U.S.–Canadian border and Tatsatua Creek sites and 98.8% of the fish that passed the Inklin River site were recorded by both stations of the pair (Table 3). The one fish not recorded by the upper Inklin River station was later recorded by other stations upriver from the site. Timing (i.e., arrival at and departure from the site) and number of hours in reception range for individual fish were also comparable for paired stations, indicating that the information collected by stations was reliable.

Station information also appeared to be reliable based on tracking records for individual fish. All fish recorded by the stations had been previously recorded downstream. Aerial surveys of the Taku River main stem verified the presence of coho salmon that remained there after passing the U.S.–Canadian border. Nearly all (97.0%) of the fish passing the stations were recorded over several consecutive hours (mean, 5 h; SE, 4 h); false positives were never observed over consecutive hourly periods.

Two false positives were recorded in 1992, both

TABLE 2.—Tracking records for radio-tagged coho salmon recorded by remote tracking stations on the Taku River, 1992. Station operations were terminated in late November.

| Site and location | Operating period | Tags recorded | Tags missed | False positives |
|---|---|---|---|---|
| Yehring[a] | Oct–Nov | 20 | | |
| Fish Creek[a] | Aug–Nov | 106 | | |
| Border | | | | |
| Lower | Jul–Nov | 271 | | |
| Upper | Jul–Nov | 259 | | |
| Main stem | | | | |
| East[b] | Jul–Sep | 92 | | |
| West[b] | Jul–Oct | 105 | | |
| Nakina | Jul–Nov | 6 | | |
| Inklin | | | | |
| Lower | Jul–Oct | 84 | | |
| Upper | Jul–Nov | 80 | 1 | |
| Sutlahine | Jul–Nov | 74 | | 2 |
| Kowatua | Jun–Nov | 9 | | |
| Nahlin–Sheslay | Jun–Sep | 47 | | |
| Nahlin | Jun–Nov | 5 | | |
| Dudidontu | Jun–Nov | 0 | | |
| Tatsatua | | | | |
| Lower | Jun–Nov | 35 | | |
| Upper | Jun–Nov | 35 | | |
| Hackett | Jun–Nov | 32 | | |

[a] Located off-channel on a minor tributary in the U.S. section of the Taku River main stem.
[b] Tracking stations covering different sections of the Taku River main stem.

TABLE 3.—Tracking records for radio-tagged coho salmon moving past paired remote tracking stations on the Taku River, 1992. Analysis was limited to paired stations covering the same section of river.

| Site and station | Tags recorded | Station comparison: Recorded by both | Recorded by single station | Not recorded |
|---|---|---|---|---|
| Border | | | | |
| Lower | 271 | 254 | 16,[a] 1[b] | |
| Upper | 259 | 254 | 5[b] | |
| Inklin | | | | |
| Lower | 84 | 80 | 1, 3[b] | |
| Upper | 80 | 80 | | 1 |
| Tatsatua | | | | |
| Lower | 35 | 35 | | |
| Upper | 35 | 35 | | |
| Total | 764 | 738 | 1, 16,[a] 9[b] | 1 |

[a] Fish moved past site before other tracking station was operational.
[b] Fish remained downriver from site, but close enough to be recorded by one station.

TABLE 4.—Areas of last observation of radio-tagged coho salmon returning to Canadian reaches of the Taku River, 1992. Percentages of all fish tracked past the U.S.–Canadian border, by release site, are in parentheses.

| Area | Release site: U.S.–Canadian border, Summer[a] | Release site: U.S.–Canadian border, Fall[b] | Release site: River mouth, fall[b] |
|---|---|---|---|
| **Fishery** | | | |
| Main stem[c] | 18 (30.5) | 1 (5.3) | 6 (3.2) |
| **Tracked past fishery** | | | |
| Main stem | 6 (10.2) | 11 (57.8) | 137 (72.5) |
| Nakina River | 0 | 2 (10.5) | 7 (3.7) |
| Inklin River | 5 (8.5) | 1 (5.3) | 14 (7.4) |
| Kowatua Creek | 2 (3.4) | 1 (5.3) | 3 (1.6) |
| Nahlin–Sheslay[d] | 12 (20.3) | 0 | 1 (0.5) |
| Nahlin River | 5 (8.5) | 0 | 0 |
| Tatsatua Creek | 1 (1.7) | 2 (10.5) | 0 |
| Upper Sheslay River | 10 (16.9) | 1 (5.3) | 21 (11.1) |
| Subtotal | 41 (69.5) | 18 (94.7) | 183 (96.8) |
| All areas | 59 | 19 | 189 |

[a] Fish tagged July to mid-August.
[b] Fish tagged late August to mid-October.
[c] From U.S.–Canadian border to 15 km upriver. Radio-tagged fish were not re-released after capture.
[d] Lower section of the Sheslay and Nahlin rivers, including Tseta Creek.

at the Sutlahine River site (Table 2). The receiver had continual electronic noise and was replaced. Subsequently, no false positives were recorded.

Reference transmitters were consistently recorded by the stations when power levels were adequate. Station performance deteriorated at several sites in late fall when day length became so short that solar panels could not maintain receiver battery voltages at required levels. Voltage levels were adequate year-round to operate the data collection platform and satellite uplink.

The remote tracking system provided detailed information on coho salmon movements and distribution. Three hundred fifty-one fish moved upriver after being tagged. Eighty-four remained in the U.S. section of the drainage, although a few of these crossed the U.S.–Canadian border before returning to the U.S. section. The remaining 267 fish traveled upriver to Canada, where 25 were caught in the river fishery and 242 were tracked to various areas in the drainage (Table 4).

### *Range and Performance Tests*

During the first control test, when 14 transmitters were placed 200 m from the station, the receivers accurately decoded an average of 98.3% of the transmitters during the first scan cycle and 100% of the transmitters in two scan cycles. The average scan cycle with 14 transmitters present was 165 s (SE, 10 s).

During the second test, when different attenuation levels were introduced with a transmitter 600 m from the station, all 26 receivers consistently decoded the transmitter at 15-dB attenuation. Some receivers sporadically recorded the transmitter at greater attenuation. No false positives were recorded during any Auke Lake test.

## Discussion

The telemetry system developed during this study provided an effective method for remotely tracking the movements of radio-tagged salmon in the Taku River drainage. Nearly all (99.0%) chinook salmon that moved past tracking sites in 1990 were recorded by the stations, and indirect observations indicated that the 1992 stations accurately recorded the movements of coho salmon. Tracking success was much higher with the remote tracking system than in previous studies when conventional tracking methods were used. Contact was maintained with only 77% of the radio-tagged salmon during telemetry studies on the Taku River in 1986 (Eiler 1989), although comparable numbers of fish were tracked.

In 1992, the telemetry system provided the first detailed information on the distribution, stock timing, and movement patterns of coho salmon in the Taku River basin. This information could not have been obtained with conventional tracking methods, because the drainage is isolated and its fall weather is inclement. Spurious information generated by the remote tracking system was only a minor problem. Few false positives were recorded during the study, particularly in 1992 when the more advanced version of the equipment was used.

Reception range was suitable for the Taku River, where river width at many sites exceeded 200 m, and the results indicate that the system can detect tagged fish over a greater range than required for this study. Transmitters were decoded consistently from 200- and 600-m distances during control tests at Auke Lake, and the test transmitter 600 m from the station was consistently recorded with attenuation of 15 dB. Signal reception with at least 12-dB attenuation generally indicates that the maximum range is about twice the actual distance from the transmitter (Bullington 1947). Maximum range under field conditions is difficult to determine because many factors can affect signal reception, including water conductivity and depth (Winter 1983; Eiler 1990), transmitter orientation (Schober

et al. 1993), topographic characteristics (Garrott et al. 1986; Jansen et al. 1991), and electronic noise (Kuechle et al. 1982).

Other factors enhanced the performance of the remote tracking system. The short scan time, typically under 3 min when 14 transmitters were present, reduced the potential for fish to pass before being recorded. Maximum scan time for the system would be about 10 min if transmitters were present on all 52 frequencies. Although chinook and coho salmon are strong, fast swimmers, the wide reception range and brief scan time usually resulted in the fish being recorded for several consecutive hours.

The remote tracking system was used under a variety of environmental conditions ranging from heavy rain, high temperatures (>30°C), and extended daylight (>18 h/d) during summer to extremely low temperatures (below −30°C) and limited daylight (<7 h/d) during winter (L. Lie, National Weather Service, Juneau, Alaska, unpublished data). The loss of power at certain sites late in 1992 indicates that stations equipped with greater power-generating capabilities (e.g., multiple batteries, higher-capacity solar panels) may be needed for studies extending into late fall and winter.

The data transfer system (Figure 3) efficiently retrieved information collected at isolated sites. The satellite uplink made it possible to regularly access and summarize station output, a feature not possible with conventional methods. Frequent data retrieval reduces concerns over data loss from equipment malfunction or station damage. The data can also be analyzed within a single season, making it possible to coordinate other research activities effectively. Along roads or at other accessible sites, the system can be operated without the satellite uplink, and the data can be retrieved manually. Because the primary components of the remote tracking system are software controlled, the functions of the equipment, such as recording interval and number of frequencies, can be changed for different research objectives.

The continuous coverage provided by the remote tracking system has several advantages over periodic tracking. By collecting precise timing information at standardized sites, one can calculate movement rates that are directly comparable for different reaches of the drainage or for different stocks in the same reach. With conventional tracking methods, fish are not recorded at standardized sites, making direct comparisons difficult. Although movement rates can be estimated and error minimized by more frequent surveys, this costs time, effort, and money. One advantage of conventional tracking surveys is that they provide information on movement patterns between sites. This information, however, can be obtained most effectively by using both tracking surveys and the remote tracking system. By knowing in advance where the fish are, conventional tracking can be concentrated in the areas that will provide the most information. Stations near known holding or spawning areas can also provide detailed information on timing and residence period that would be difficult to obtain by other methods.

The continuous coverage provided by a remote tracking system also enables one to accept or reject observations that might be questioned if less information were available. In 1992, for example, a coho salmon was tracked 200 km upriver, where it remained 8 d before moving back downriver. In 48 h it had moved past the U.S.–Canadian border, and it ultimately left the drainage. An aerial survey located the fish while it was in the Taku River main stem, but this single record would probably have been dismissed as a tracking error had it been the only datum available. The remote tracking system provided a series of observations that documented the fish's movement downstream.

In summary, the remote tracking system accurately recorded the movements of hundreds of radio-tagged fish past selected sites in a large, isolated drainage. The system functioned under a wide range of field conditions. A satellite uplink provided immediate, reliable access to the information collected. Tracking success with the remote tracking system was greater than with aerial surveys used under similar circumstances. The remote tracking system collected telemetry data that could not have been obtained with conventional tracking methods due to the isolation, inclement fall weather, and mountainous terrain typical of this area. This unique method can be used to obtain detailed information on movements of hundreds of fish over large areas, and it has numerous applications to fishery research.

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