Monitoring fish behavior with a remote, bimodal (acoustic/radio) biotelemetry system

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ABSTRACT

Biotelemetry is a powerful tool for monitoring aquatic species in their natural environment, from a passive perspective, without the biases associated with conventional sampling and monitoring techniques. Advances in telemetry are necessary to monitor aquatic species in remote environments, with vast stretches of water, and in situations requiring both acoustic and radio transmissions (e.g. for diadromous fish). In this paper, a system is described, based upon a field proven radio telemetry receiver, and incorporating combined acoustic and radio smart transmitters, wireless hydrophones and two-way satellite communications.

The system was first deployed within Bay d'Espoir, NF, Canada, to determine whether aquaculture raised steelhead trout (*Oncorhynchus mykiss*) (1.5-2.0 kg), experimentally released in the vicinity of a commercial aquaculture site, remained at the site (site fidelity) or dispersed from it. Two sets of fish releases, summer and winter 1998, were performed to determine seasonal effects on movement of aquaculture raised steelhead trout in the wild. Results suggested strong site fidelity among steelhead trout when released during the growing season (summer). Less fidelity was displayed for the winter released steelhead with a higher degree of dispersal during this season.

Keywords: aquaculture escapees; biotelemetry; CART transmitters; site fidelity; *Oncorhynchus mykiss*; Newfoundland, Canada
INTRODUCTION

Extensive use of grow-out cages in the salmonid aquaculture industry, often in relatively harsh environments, has increased the risk for loss of domestic strains of fish to the wild. Escapement is expected to occur from all grow-out facilities and may be either chronic, due to human error or general wear and tear to the netting, or acute, large loss of fish resulting from storm damage or predation. This loss of aquaculture raised fish to the wild may result in substantial economic loss to the aquaculture industry (Bergen et al. 1991). In addition, these fish may represent a threat to wild fish stocks through direct competition for food, habitat and perhaps mates (Hansen et al. 1991 and Hutchinson 1997).

An obvious solution to the escapement issue is to eliminate the loss of farmed salmonids from grow-out cages. As this is not a simple solution other a posteriori solutions to the loss of fish should be investigated. One possible solution is based on the concept that fish entering the wild from aquaculture sites can be recaptured and returned to the cages for further growth. However, prior to developing the recapture methodologies, behavior of domestic fish in unconstrained environments must be determined. This will include determining, through the use of biotelemetry, whether fish exhibit site and cage fidelity or whether they disperse in set or random patterns after escape.

Several technical challenges have to be overcome to optimize telemetry to monitor the movement of domestic steelhead trout in the wild. First, diadromous fish utilize water with varying salinity throughout their life cycle. Second, commercial power supplies are often lacking for remote, fixed data-logging stations which may be inaccessible for data downloading and receiver configuration and interrogation for parts of the study season. Finally, extreme reaches of water may create problems for conventional tethered hydrophone systems. Each challenge was separately addressed and integrated to develop the remote, bimodal (acoustic/radio), biotelemetry as described in this paper.

Underwater biotelemetry has proven to be a powerful technique for studying the behavior and movement of aquatic animals since its introduction with acoustic transmissions (Trefethen 1956) and first application (Johnson 1960). It was apparent early in underwater telemetry development that acoustic and radio transmissions were suited for mutually exclusive environments. Acoustic transmissions offer greater range per unit power in conditions where the water has high conductivity and depth which cause unacceptable radio signal attenuation (Stasko and Pincock 1977). In contrast, radio transmissions offer a greater range per unit power in fresh, shallow water. As well, they are less affected by turbulent water and debris (Schieffer and Power 1972, Ziebell 1973) and may be detected through ice (Lonsdale and Baxter 1968).

These characteristics make the study of diadromous fish at various depths, throughout their life cycle, a formidable task. Gradients, associated with depth and conductivity, requiring both acoustic and radio frequency (RF) transmissions to optimize a study, may
be considered bimodal in nature. Due to biocompatibility issues, such as weight and size restrictions of the transmitter, it is not feasible to double tag most animals with separate acoustic and radio transmitters. Most studies to date have been limited to either fresh water (Winter et al. 1973, McCleave et al. 1978, Eiler 1995), employing radio telemetry, or estuarine and salt water conditions (Stasko 1975, Fried et al. 1978, Tytler et al. 1978, Moore et al. 1990, 1992, 1995, Greenstreet 1992, Lacroix and McCurdy 1996), employing acoustic telemetry. A combined acoustic and radio transmitter (CART) was subsequently developed to operate in a bimodal environment and overcome these limitations (Potter 1988, Solomon and Potter 1988). These initial transmitters were however limited by power and battery life. Further, they were designed to transmit in acoustic mode for a predetermined number of days, according to the expected fish movement, after which the transmitter switched to radio transmission until the transmitter battery power was exhausted (Solomon and Potter 1988). This configuration limited the capability of study, particularly when animal movement patterns were not always predictable. To overcome this limitation, a new combined acoustic and radio transmitter (CART), which switches between transmission modes based on sensing the conductivity of the ambient environment, was developed (Niezgoda et al. 1997, Deary et al. 1998).

Traditional fixed acoustic telemetry systems have employed hydrophones that are tethered to the land-based receiver with the appropriate cable (Lacroix and McCurdy 1996, Voegeli et al. 1998). This type of set-up is not only limited by the effective range of the transmitter but also by the longest allowable cable length considered manageable, related to increased labor and costs associated with the cable, by the researcher. These considerations currently prevent studies of vast stretches of water from shore-based fixed receiver deployment. In addition, tethered hydrophones may be problematic in environmentally sensitive study areas. To alleviate these issues, a ‘sonar buoy’ was developed which produces a radio signal duplicating acoustic signals of a tag within its detection range (Solomon and Potter 1988, Moore et al. 1990). However, these initial ‘pioneer’ buoys utilized only one acoustic frequency therefore limiting the number of transmitters permitted within a study.

In the past, data retrieval from fixed data-logging stations required linking the receiver to a host computer via a hard wired connection. This becomes a concern when the fixed stations are in remote locations that are costly to repeatedly access or even inaccessible during certain times of the study period. Remote access to fixed telemetry stations has been documented employing a geostationary operational environmental satellite (GOES) (Eiler 1995). Collected data was transmitted every 3 hours to a satellite linked receiving station and accessed daily via telephone modem by the researcher. This system, however, lacked a two-way remote link with the receiver which allows researchers to adjust operational parameters such as frequency tables, antennae gain, and scan times to optimize the system under dynamic conditions.

In this study, a remote, bimodal (acoustic/radio), biotelemetry data-logging system is presented as a means to monitor vast stretches of water. It is based upon a combined
acoustic and radio transmitter (CART), for either conductivity or depth, integrated with fixed data-logging stations augmented with remote data links and wireless hydrophone systems (WHS) (Lotek Marine Technologies Inc., St. John’s, Newfoundland) (Figure 1). The first application of the system was in Bay d’Espoir, Newfoundland, Canada, in 1998, to monitor the movement patterns of aquaculture raised steelhead trout (*Oncorhynchus mykiss* Walbaum) released experimentally in the wild. Telemetry system performance and steelhead movement data are discussed in subsequent sections.

**METHODS**

**Study Area**

Bay d’Espoir, on the south coast of Newfoundland, Canada, is the largest salmonid aquaculture region in the province with aquaculture grow-out sites located throughout the bay (Figure 2, Figure 3). The bay is considered very dynamic with regards to its halocline that may vary in depth on an hourly basis (Newfoundland Salmonid Growers Association personal communication). Water flow from both tides (inward and outward) and hydroelectric discharge (outward), water depth (ranging from 6 - 250 m), remoteness of much of the bay, inaccessibility during the winter season and vastness of some stretches of water to monitor were all challenges to overcome for the telemetry system. Due to these issues, a remote biotelemetry system based upon a CART transmitter was necessary.

**Experimental Animals**

Conne River Aquaculture (CRA), owned and operated by the Council of the Conne River Micmacs, provided steelhead trout for the study. All steelhead were triploid females from the 1996 year class ranging from 1.5-2.0 kg in weight. In total, 150 steelhead trout were surgically implanted with a combined acoustic/radio transmitter and released from a summer grow-out site. An additional 90 steelhead were implanted and released from the overwintering site (Figure 3). Following the surgical procedure, steelhead were allowed to recover in a designated holding cage for 48 hours to ensure proper physiological recovery from the anaesthetic and surgical trauma. ‘Escapee scenarios’ were performed to determine site fidelity, defined as the return of steelhead to the area within 500 m of the farm site after release.

**System Description**

Monitoring the movement of the steelhead involved nine fixed data-logging stations strategically placed throughout Bay d’Espoir in the spring of 1998 (Figure 3). These stations were equipped with the appropriate number of 4 element Yagi antennas and tethered hydrophones to create ‘virtual gates’ throughout the bay. These gates essentially recorded the passing of transmitter implanted fish. In addition, manual tracking was performed to augment the fixed station data and acquire more accurate steelhead positions within the bay.
**Combined Acoustic and Radio Transmitter**

CART transmitters were cylindrical, measuring a minimum of 14 mm diameter by 53 mm length and 12.2 g fresh water weight with a variable external antenna length. Each CART transmitter broadcast a unique identification code at a study specific repetition rate. The acoustic frequencies were quartz crystal derived for 65.535 Khz and 76.8 Khz and transmitted omnidirectionally with a source level of 154 and 156 dB re 1 uPa @ 1 m, respectively. Radio frequencies were also crystal controlled and factory programmed to suit local regulations. In addition, conductivity and depth data was transmitted to the receiver.

Both static and dynamic CART transmitters were used for the study. Static CART alternated transmission mode between acoustic and RF irrespective of the ambient conductivity or depth. As acoustic signal requires much more power to transmit compared to RF transmissions, it is considered inefficient to be transmitting in the least optimal mode for the ambient environment. Dynamic CART measured the ambient electrical conductivity, with the appropriate sensor, to choose the optimal mode of transmission thereby maximizing detection range and increasing transmitter longevity (Niezgoda et al. 1997).

**Remote Data-Logging Stations**

Remote data-logging stations were fixed and entirely self-sustaining. A platform was built to keep the system off the ground and hold all components. An insulated and watertight enclosure, constructed to house the electronic components, was bolted to the platform. The system included a Lotek SRX_400 radio receiver, ASP_8 (antenna switching peripheral), UUC (ultrasonic up converter), photocontroller and battery supply, and satellite data transceiver. A drainpipe was fitted in the top of the enclosure to act as a vent for the batteries and allow passage of external wires into the enclosure, while preventing precipitation from entering (Figure 4).

Remote stations, lacking a public power source, had to generate enough power from the environment to be self-sustaining for an indefinite period of time. A hybrid system of wind turbines and photovoltaic cells was installed on each platform (Figure 4). This configuration maintained a 400 amp-hour battery and was designed to withstand 10 days of autonomy (i.e. no wind or sun). Each system was effectively maintenance free requiring only annual inspection.

The SRX datalogger, with a memory capacity of up to 35,000 records, will cease data collection after the memory is filled. Fixed data logging stations were strategically located, some in areas that were difficult to access either some or most of the year, thereby limiting traditional data retrieval methods. A necessity existed for a remote data link to these stations for data downloading and initialization of the SRX data memory. Within the current study, a satellite based data link was established utilizing the MSAT communication system due to a lack of other potential data links (e.g. telephone, cellular, local radio data network (ie. [VHF or UHF]). Transmitted data included the
date and time of transmitter detection, channel, code, antenna, power level, number of
events and hourly battery status indication. A two-way link was necessary between the
fixed receiver and a local PC to allow remote interrogation and configuration.

RESULTS AND DISCUSSION

Steelhead Movement
Of the steelhead trout released on-site during the summer, 75% remained within a 500
m radius of the grow-out site for 4 weeks following release. The location of steelhead
in May Cove varied with time and there was no evidence that steelhead preferred to
remain at their specific grow-out cage. Similar results were evident for off-site released
steelhead with 26% of the steelhead returning to the grow-out site within 4 hours of
release. Within 2 days of this release, 65% of the steelhead had displayed site fidelity
toward the summer grow-out site. Of these returning steelhead, 66% remained for 4
weeks following their release. After this time, steelhead dispersed throughout the bay
with a directed movement towards the spillway waters (large fresh water inflow), also
the location of the hatchery for the Bay d’Espoir salmonid aquaculture industry.

Steelhead released in the winter displayed a different degree of fidelity. On-site released
steelhead in the winter displayed less fidelity than those released in summer. Of the 30
steelhead released 200 m from the CRA site only 5 (16%) returned to the site within 2
days of the release. This percentage declined over time with 4 (13%) steelhead
remaining on-site 6 days after the release and finally 3 (10%) of the fish remaining 16
days after the release. Similar results were present for those released 1000 m from the
CRA site. Of the 30 steelhead released, 2 (6%) displayed site fidelity to the CRA site
within 4 days after the release. These fish remained in the vicinity of the cages for the
remaining 16 days of monitoring.

The present study showed site fidelity does exist for steelhead trout during the summer
growing season when feeding opportunities are present within Bay d’Espoir. These
results suggest a recapture methodology for the steelhead trout aquaculture industry,
during the summer season, may be feasible. This solution will reduce both the
economic loss incurred to the farmer through fish loss and the potential ecological
interactions between aquaculture raised steelhead and wild stocks.

Telemetry System Performance

At the start of the project, concerns existed with the reliability of the dynamic CART
conductivity sensor and the effects of the environment on that sensor. Throughout this
study, data showed that the sensor performed as designed. Switching of the dynamic
CART between acoustic and radio modes of transmission in saline/estuarine and fresh
water conditions, respectively, was recorded. However, examination of some returned
dynamic CART transmitters from anglers indicated biofouling of the probe may be an
issue requiring further research and development.
Fixed data logging stations were successful at tracking steelhead trout. However, tethered hydrophones were problematic in the installation stages of the project and proved difficult to maintain and were considered to become increasingly unreliable with time. In order to overcome these issues, the wireless hydrophone system (WHS_1000) was developed.

**Wireless Hydrophone System (WHS)**

Wireless hydrophone systems (WHS) are moored in a similar fashion as a tethered hydrophone without the concern of deploying the cable. It possesses a comparable acoustic detection radius as previous conventional acoustic systems. It can however be placed several kilometers from the fixed SRX data-logging receiver, therefore increasing the overall detection range of the system. In addition, the unit minimizes the labor and maintenance costs associated with traditional tethered hydrophones and the environmental damage associated with cables running along the bottom.

WHS units consist of an acoustic receiver and a RF transmitter. The WHS detects an acoustic signal, on either CART acoustic frequency, triggering a radio beacon emulating the received acoustic signal preserving all coding schemes. Each WHS unit has an associated transmit radio frequency that is scanned by the SRX according to a study specific frequency table. WHS units possess a wide range automatic gain control (AGC) allowing operation within highly dynamic noise environments. This is accomplished by automatically reducing system gain in the presence of ambient noise which limits the amount of noise received by the fixed data-logger. WHS units have an expected longevity of 4-6 months on a battery pack and transmitted a battery status signal hourly.

**Conclusions**

The 'state-of-the-art telemetry technology described in this paper incorporated static and dynamic combined acoustic and radio transmitters (CART), fully remote and maintenance free deployment, two-way satellite communications, and wireless hydrophones to provide a sophisticated remote, bimodal biotelemetry system. This system offered a powerful technique for monitoring the movement and behavior of aquaculture raised steelhead trout covering vast stretches of water (Figure 1). Other applications for such a system may include migration studies of aquatic diadromous species, fish behavior with respect to fish attractant devices (FADs) and pollutant sources, reef fish studies with minimal environmental damage and monitoring the behavior of aquaculture raised species within large grow-out ponds.
REFERENCES


Figure 1. Components of the remote, bimodal (acoustic/radio), biotelemetry system.
Figure 2. Location of the study site in Bay d'Espoir, Newfoundland, Canada
Figure 3. Bay d'Espoir study area depicting aquaculture farm sites, virtual gate locations and seasonal release sites.
Figure 4. Schematic of a fixed data-logging. Each station monitored 1 or 2 'virtual gates' composed of the necessary number of 4-element Yagi antennas and tethered hydrophones (not shown).