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# A summary of the use of electronic tagging to provide insights into salmon migration and survival

**A. Peter Klimley · R. Bruce MacFarlane · Phillip T. Sandstrom · Stephen T. Lindley**

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## Introduction

The status of Pacific salmon populations has been of increasing concern for many decades, with many populations now under legal protection. The causes of their declining status are manifold and untangling them has been difficult due to the complex life histories, which involve migrations among freshwater, estuarine, and marine habitats. Finding solutions to salmon management problems requires understanding how salmon respond to threats in these different environments. Telemetry provides an attractive approach to monitoring salmon as they move among these environments, and advances in miniaturization and mass production have made it feasible to monitor salmon throughout their life cycle.

Recent advances in acoustic telemetry have provided for the first time an opportunity to greatly expand knowledge and understanding of mortality and the migratory behavior of salmonids on the western coast of North America. Firstly, these electronic tags have been reduced in size sufficiently to fit into the peritoneal cavity of smolts (ocean-ready juveniles). Secondly, the signals emitted from these beacons are unique so that each tagged fish can be recognized by its code, which enables recording movement patterns and mortality of individual fish. This has been accomplished with two types of coding, pulse interval modulation or frequency phase shifting (McMichael et al. 2010). Thirdly, automated monitors have been developed that identify and record the passage of individual fish from the unique signals emitted from these beacons (Klimley et al. 1998). The cost of these autonomous receivers has been reduced sufficiently to permit the establishment of large scale arrays that can monitor salmon throughout their migratory cycle.

These advances have led to a burst in telemetry studies of Pacific salmon (genus *Oncorhynchus*). Until recently, the movements and mortality patterns of juvenile salmonids were determined by a series of cross-shelf arrays of tag-detecting monitors that were established along the continental shelf, from Point Reyes in northern California to Prince William Sound in Alaska (Pacific Ocean Shelf Tracking Program - POST; Welch et al. 2002). Additionally, monitors have been deployed in many of the estuaries and rivers along this coastline. Coded tags and the POST array have been used to determine the overall survival of salmon smolts

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as they migrate downstream in large rivers with and without dams (Welch et al. 2008) and during early ocean life (Welch et al. 2009). Balfry et al. (2011) recorded the survival of hatchery raised steelhead smolts released in the Seymour River as they migrated through the estuary and along the continental shelf over a 4 year period using the POST array.

A large array of acoustic monitors has been established along the length of the Sacramento River, Sacramento/San Joaquin Delta, and San Francisco Estuary (Fig. 1) by the California Fish Tracking Consortium (Table 1) and is used to determine high resolution reach-specific survival of late-fall run Chinook salmon (*Oncorhynchus tshawytscha*) and steelhead trout (*O. mykiss*) smolts from California's Central Valley. This array has been used since 2006 by consortium researchers for various studies related to human and natural sources of mortality and alterations in migration pathways throughout the Sacramento River-Delta-San Francisco Estuary corridor (Table 2).

Telemetry researchers from California and other locales convened a symposium on 20–21 May 2010 at the University of California's Bodega Marine Laboratory. This two-day meeting was made possible


**Fig. 1** Array of tag-detecting monitors deployed in the mainstem of the Sacramento River, the Sacramento/San Joaquin Delta, and San Francisco Estuary. Monitor locations indicate with solid circles; release sites with clear circles with center dot

**Table 1** Geographical regions with tag-detecting monitors maintained by members of the California Fish Tracking Consortium

| Source | Agency Maintaining | Geographical Region | Type of Monitors[a] | Number of Monitors |
|---|---|---|---|---|
| CALFED | UC Davis | Sacramento River | VR1, 2, 2w | 70 |
| ERP | UC Davis | Sacramento/San Joaquin Delta | VR1, 2, 2w | 60 |
| US ACE | UC Davis | San Francisco Bay | VR2w | 120 |
| US ACE | NOAA | Golden Gate | VR2w | 19 |
| POST | NOAA | Point Reyes | VR3 | 12 |
| CDWR | CDWR | Feather River | VR2 | 12 |

*CALFED* California Bay-Delta Authority, *CDWR* California Department of Water Resources, *ERP* Ecosystem Restoration Program, *POST* Pacific Ocean Shelf Tracking Project, *UC Davis* University of California, Davis *US ACE* U.S. Army Corps

[a] Acoustic monitors from Vemco, Amirix Systems, Inc., Halifax, Nova Scotia, Canada

with funds from CALFED, a state-federal collaboration with the mission to improve California's water supply and the ecological health of the San Francisco Bay/Sacramento-San Joaquin River Delta. The purpose of the symposium, entitled "Electronic tagging studies of salmon migration," was to provide an update of recent salmonid telemetry findings. Forty talks were organized into four sessions: 1) tagging technology and its limitations and capabilities, 2) behavior and physiology of tagged fish, 3) movement and migration patterns, and 4) survival estimates and detection probabilities. Twenty-one articles have originated from this meeting. We briefly summarize the results of these articles under each category as a conclusion for this Special Issue. At the end, we will make some recommendations for future studies in the Sacramento/San Joaquin watershed and other rivers on the West Coast of North America.

## Tagging technology and its limitations and capabilities

Ammann et al. (2013) examined the effects of placing acoustic transmitters in the peritoneal cavity of late-fall Chinook salmon smolts. There were no significant differences in the relative growth or survival of smolts carrying passive integrated transponders (1) without any surgical operation, (2) with surgery without tag implantation, and (3) with the implantation of the electronic tag during a 221-day experiment. A second experiment was conducted with smolts with transponders (1) without a surgical operation, (2) with implantation of a tag with absorbable sutures and (3) with placement of a tag with non-absorbable sutures. Survival was 100 % for all treatments and there were no significant differences in growth over a period of 160 days; but the incisions with the absorbable sutures healed more rapidly and with less inflammation than the incisions with non-absorbable sutures. The results of this study indicate that acoustic transmitters, when ≤5.6 % of body weight, can be effectively used in one-year old Chinook salmon to study their migratory movements.

Steelhead trout are known to expel acoustic tags, and this action can negatively bias population survival estimates. Further, implanted tags may impede the development and compromise the behavior of smolts, thereby impacting the results of population and behavioral studies. Sandstrom et al. (2013) found that 20 % of the tags implanted in Sacramento River steelhead were expelled over 143 days, with larger tags (9 mm diameter) expelled at a greater rate than smaller tags (7 mm). Sandstrom et al. tested two techniques to adjust survival estimates for tag expulsion or failure, individual censorship in Program MARK and ATLAS, during outmigration through the Sacramento River and found adjusted survival estimates were not significantly different from the unadjusted rates. This indicated that it may be more important to focus on improving surgical techniques to reduce tag expulsion rather than adjusting survival estimates dependent on the study.

Premature electronic tag failure can cause a negative bias in fish survival estimates because tag failure is interpreted as fish mortality. Holbrook et al. (2013) used mark-recapture modeling to adjust estimates of fish survival for the Vernalis Adaptive Management Plan's (VAMP) study, where high rates of tag failure were recorded when estimating survival of fall-run

**Table 2** Vital statistics for tags implanted within Chinook salmon adults and smolts and steelhead smolts and kelts by members of the California Fish Tracking Consortium and other projects

| Agency | Species | Tag Type | Release Site | 2001–2002 | 2002–2003 | 2003–2004 | 2004–2005 | Year[a] 2005–2006 | 2006–2007 | 2007–2008 | 2008–2009 | 2009–2010 | 2010–2011 | Reference |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| UCD/NOAA | Chinook | V-7, Vemco | Jellys Ferry, Irvine Finch, Battle Creek | | | | | | 200 | 304 | 300 | 306 | 300 | Chapman et al. 2012; Steel et al. 2013; Michel et al. 2013 |
| | Steelhead | V-9, Vemco | | | | | | | 200 | 300 | 300 | 300 | 300 | Chapman et al. 2012; Steel et al. 2013. |
| US ACE | Chinook | V-7, Vemco | Sacramento | | | | | | 50 | 50 | 500 | 497 | | Perry et al. 2013 |
| | Steelhead | V-9, Vemco | | | | | | | 49 | 50 | 500 | 499 | | |
| US F&WS | Chinook | V-7, Vemco | Sacramento | | | | | | 144 | 421 | 635 | 599 | | Singer et al. 2013 |
| US F&WS | Chinook kelts | V-13, Vemco | Battle Creek | | | | | 30 | 23 | | | | | Null et al. 2013 |
| UCD | Chinook | F1845, ATS | Butte Creek | | | | | | | | | 26 | | Mosser et al. 2013 |
| US F&WS | Coho | | Freshwater Creek | | | | | | | 34 | 54 | | | Pinnix et al. 2013 |
| Yurok Tribe | Chinook | F1845, ATS V16, Vemco | Klamath Estuary | | | 20 | 20 | 38 | | | | | | Strange 2013 |
| CDFG | Chinook | CT28-2, Sonotronics | San Joaquin, Montezuma Slough | 334 | | | | | | | | | | Strange 2013 |
| CDFG | Chinook | V16, Vemco | Suisun Marsh | | | | 197 | | | | | | | Vincik 2013 |
| US BOR | Coho | NTC-2–3, Lotek | Trinity River | | | | | | | | 25 | | | Chase et al. 2013 |
| POST | Steelhead | V9, Vemco | Cheakamus River | | 15 | 151 | 149 | 120 | 299 | | | | | Melnychuk et al. 2013 |
| USGS | Chinook | 795-s, HTI | Chipps Island | | | | | | | | 565 | | | Holbrook et al. 2013 |
| EBMUD | Steelhead | V9, Vemco | Mokelumne | | | | | | | 117 | 140 | 122 | | Del Real et al. 2013 |
| | Steelhead kelts | | | | | | | | | 6 | 10 | 9 | | |
| TOPP | Steelhead kelts | V7, Vemco, LAT2510, Lotek | Battle Creek | | | | | | | | 14 | | | Teo et al. 2013 |
| ECORP | Steelhead | V7, Vemco | Napa River | | | | | | | | | 20 | | Sandstrom et al. 2013 |
| Cramer | Chinook | JSATS | MokelumneRiver | | | | | | | | | 654 | | Cavallo et al. 2013 |

[a] Year designated by period of tagging and release; studies initiated in December of first year through spring of second year

Chinook salmon smolts during migration through the San Joaquin River and Sacramento-San Joaquin Delta. Their analysis indicated that fish survival estimates were low over a wide range of plausible tag survival probabilities. Available methods to adjust for the bias may perform poorly when tags fail at a high rate.

Teo et al. (2013) placed beta-version archival tags as well as coded acoustic tags on 14 steelhead kelts following spawning at the Coleman National Fish Hatchery on Battle Creek, a tributary of the Sacramento River. Two of the tagged steelhead were recovered at the hatchery 219 and 285 days later. One kelt moved out of the San Francisco Estuary into the coastal waters before returning, while the second remained in the watershed. The steelhead kelts from this study appeared to be less oceanic than those tagged in Scott Creek, a small coastal stream approximately 100 km south of the mouth of San Francisco Bay (Hayes et al. 2012). This suggests that steelhead kelts from a large river system, like the Sacramento River, may be relatively less oceanic than steelhead kelts from smaller coastal streams.

This pilot study underscored the feasibility of further placing archival tags on adult salmon to describe their oceanic movements. The advantage of this method over shipboard tracking is that it provides time series of positions on the temporal scale of a year rather than the two to five day temporal scale of shipboard tracking. However, the accuracy of the resulting positions, based on light measurements, is considerably less than those obtained by shipboard tracking, varying from ±1° for longitude and ±2° for latitude depending upon time of year (Welch and Eveson 1999; Qayum et al. 2006).

Determining the location of salmon carrying coded acoustic beacons during their migration in the open ocean can be challenging. Possible alternatives are to place tag detecting monitors at fixed sites or on mobile platforms such as ships or large oceanic migrators like elephant seals. Hayes et al. (2013) affixed acoustic receivers and satellite tags detectable by ARGOS satellites on adult elephant seals (*Mirounga agustirostris*) while at Año Nuevo Island off central California. These seals routinely travel great distances, moving throughout the northern half of the California Current northward to the Gulf of Alaska and westward to the edge of the Aleutian Islands (Le Boeuf et al. 2000), an area known to be used by juvenile Pacific salmon (Welch et al. 2004; Melnychuk et al. 2011). One of ten instrumented elephant seals detected a Chinook salmon smolt on 30 April 2010 as she moved across the continental shelf 31 km west of the Golden Gate at the mouth of the Sacramento/San Joaquin watershed. This pilot study indicates that it is feasible to use a large mobile vertebrate as a platform for a tag detecting monitor.

## Behavior and physiology

Water management is a complex process that often provides alternative waterways and obstructions to fish movement. For salmon in California's Central Valley, there are numerous waterways through the upper estuary (Suisun Bay and Delta) that emigrating juveniles and returning adults can opt to take with varying degrees of success. Vincik (2013) investigated one important alternative waterway, Montezuma Slough, which has a salinity control gate, and found that acoustically-tagged returning adult Chinook salmon during their upstream migration were hindered or delayed in two of three alternative gate configurations. One configuration facilitated upstream movement. This practical study resulted in a recommendation to the National Marine Fisheries Service to request the state water management agency to maintain this configuration during the upstream adult migration, a phase when the time to reach spawning grounds is critical for reproductive success.

Steel et al. (2013) examined the behavior of juvenile Chinook salmon smolts at the juncture of two migratory pathways, where the Delta Cross Channel (DCC) diverges from the Sacramento River. The tracks of individual smolts were analyzed in respect to the different rates of flow in the mainstem and channel to determine whether this might influence their path of movement. The two routes differ significantly in the probabilities of survival. Hence, a better understanding of the factors underlying route selection would be germane to management of the species. The tagged smolts chose the mainstem when the current speeds were higher there than in the DCC, yet swam in more direct paths and at higher speeds then when in the DCC. The ratio of mean water velocities between the two routes was the strongest predictor of ultimate route selection based upon logistic regression models. The multivariate data also indicated that smolts that entered the junction near the bank opposite the DCC were more likely to continue in the Sacramento River than those near to the DCC.

Strange (2013) used shipboard tracking and stationary receivers to evaluate the factors affecting the behavior and duration of the residence of adult Chinook salmon in the estuary of the Klamath River in Northern California. The adults pass through the estuary quickly in <24 h with a mean rate of movement of 1.2 km/h. The rapid transit appeared not to be an attempt to conserve energy because the adult tracked entered both during inflowing and outflowing tides, and their forward movement did not appear to be enhanced by tidal transport. Rather it is possible that they did not hold within the estuary but remained outside the mouth of the river because of the abundance of predatory pinnipeds, especially California sea lions (*Zalophus californianus*) that inhabited the estuarine lagoon.

Zajanc et al. (2013) examined the behavior of Chinook salmon and steelhead smolts in a highly altered section of the Sacramento River. A binomial and negative binomial Generalized Linear Model was used to analyze two aspects of holding, the probability of holding and holding time. The probability of Chinook salmon holding increased as wood size and fine substrates increased; holding time increased as overhead shade increased. The holding behavior of steelhead trout was only weakly related to habitat type, in contrast to the strong relationships with spatial and temporal variables. For both species, the probability of holding increased when distance from the release location decreased and flows decreased. The results indicated that habitat features such as large woody material and overhead shade should be included in near shore bank rehabilitation to increase cover from predators and provide a refuge from strong flows during downstream migration.

## Movement and migratory patterns

The recent advances in acoustic telemetry technology (e.g., small transmitter size, greater battery life) have greatly improved our understanding of fine-scale movement patterns and rates during both juvenile and adult salmonid migrations. This, in turn, provides fishery research and management with insight and tools to improve preservation and recovery of imperiled stocks. Michel et al. (2013) determined the annual rate of movement of late-fall run Chinook salmon yearling smolts carrying acoustic tags as they passed an array of tag-detecting monitors deployed in the California's Sacramento River and San Francisco Estuary for 3 years. The migration rates varied from 89.1 km/day in the upper river between river km 518 and 486 to 15.3 km/day within the Sacramento-San Joaquin Delta. The smolts migrated more often during night than during day in the upper river but migrated throughout the day when in the lower river, delta, and estuary. Higher movement rates were also related to greater river sinuosity, river width-to-depth ratio, river channel velocity, flows and temperatures. Increasing yearly flows enhanced the migratory movement rates.

Chapman et al. (2012) presented 24-h plots of the detections of yearling late-fall run Chinook salmon and steelhead smolts by stationary acoustic monitors deployed along the length of the Sacramento River. These clock diagrams indicated that the Chinook salmon smolts exhibited a nocturnal pattern of migration in the upper river. The ratio between night and day detections decreased with distance downstream in the river. Nocturnal movement was preferred to diurnal movement in all reaches of the river except in the estuary. In contrast, steelhead smolts that reside longer upriver following release, showed less preference for nighttime movements in the upper river. However, they moved mainly during daytime in the middle river, delta, and estuary.

Sandstrom et al. (2013) found that emigration rates of yearling steelhead smolts in the Napa River, a small stream entering directly into San Pablo Bay, the northern extension of San Francisco Bay, were dependent on size - larger fish migrated faster. Their migration rates ranged widely from 5 to 49 km/day. This study also showed that steelhead smolts appeared to be focused on seaward movement; there was little investigation of or movement into recently restored salt pond habitats.

Del Real et al. (2013) recorded the passage of juvenile steelhead trout through the Mokelumne River into the San Joaquin River, and to the San Francisco Bay. The smolts migrated along four distinct pathways within the Delta before entering the San Joaquin River. There were significant differences in the migratory success between hatchery raised and natural Chinook salmon. Thirty-four of the 467 tagged salmon reached the mouth of San Francisco Bay. Thirty three were of hatchery-origin and 1 was of natural origin. Of the acoustically tagged natural-origin fish detected by the array of stationary receivers, the majority, 78 % exhibited no downstream movement, a minority 22 % migrated downstream some distance. The natural fish showed a greater tendency than the hatchery fish to stay or "residualize" within the river.

In the Trinity River, a major watershed in the Klamath River system, Chase et al. (2013) used a combination of PIT, elastomer, and radio tags to assess the use of rehabilitated habitats by ESA-listed threatened coho salmon (*Oncorhynchus kisutch*). Off-channel rehabilitation sites attracted naturally-produced juvenile coho, but abundance was different between upstream and downstream habitats. Upstream habitats contained more subyearling coho salmon than downstream sites, but mortality of tagged hatchery released yearling coho salmon smolts was greatest in these upstream habitats, indicating behavior and habitat use differs between these juvenile life stages.

The movement of coho salmon smolts carrying acoustic transmitters was monitored with a fixed receiver network and mobile tracking from a boat as they passed from freshwater into Humboldt Bay, California. Pinnix et al. (2013) detected coho in Humboldt Bay from April through the beginning of July. The smolts spent less time in the upper less saline estuary than in the lower estuary – spending on average 10–12 days migrating to Humboldt Bay. The smolts resided in Humboldt Bay, in oceanic salinities, for an average of 15–22 days prior to departing for the open ocean. Coho salmon smolts were more often detected in deep channels of central portions of Humboldt Bay. There were fewer detections in other shallower portions of the bay characterized by intertidal mudflats and eelgrass meadows.

Melnychuk et al. (2013) described the movements and mortality of juvenile coho salmon and steelhead trout by performing transect surveys using a portable receiver and hydrophone and recording their passage through cross-shelf arrays of stationary acoustic receivers in a coastal fjord on the western coast of Canada. The smolts moved through the fjord without preferring to stay close to the shore. Aberrant movement patterns of five to 20 % of the tags indicated that the tagged smolts had been eaten by predators. A rate of predation of 2.4 % per km was determined for the tagged smolts during their 40 km migration through the fjord based on their successive detection by the cross-fjord arrays.

Steelhead exhibit both anadromous and non-anadromous life histories, with some fish alternating life history strategies among years. Null et al. (2013) described the post-spawn movements of acoustically tagged steelhead kelts released during April 2005 and 2006 into Battle Creek, a tributary to the Sacramento River. The steelhead commonly remained near the release site for a short period prior to a sustained downstream emigration. They arrived at the head of San Francisco Bay from April to mid-July and re-entered the river from the ocean from late September through October during the year of release. Most returned to the site of release in Battle Creek from late-September through November. Ten percent of the kelts did not go to sea, but remained in freshwater, staying near the release location or elsewhere in the watershed. Overall survival was high with 36 % and 48 % of kelts released exhibiting repeated spawns in 2005 and 2006, respectively.

The Feather River, a large regulated river in Northern California, supports one of the largest populations of steelhead in the Central Valley. The population is supplemented by hatchery production. Kurth (2013) described the downstream migratory rate and success of natural-origin juveniles, natural-origin adults, and hatchery-origin fish using acoustic telemetry. The three groups displayed a mix of migratory and non-migratory life histories. Hatchery-origin adults exhibited more migratory behavior than natural-origin juveniles and natural-origin adults, 41 %, 24 %, and 13 % respectively.

Downstream migrants were also significantly larger than non-migratory fish. Migration timing was similar among the three groups. However, natural-origin juveniles displayed the most rapid rate of movement. The relative success of each group was highest for fish migrating through the Sacramento-San Joaquin Delta to the Pacific Ocean.

## Survival

Releasing hatchery-reared salmonid smolts is a common management tool aimed at enhancing depleted wild stocks and maintaining fisheries. In the Sacramento River watershed, smolts must pass through the river, delta and estuary on their way to the Pacific Ocean. Singer et al. (2013) released 500 late-fall Chinook salmon and 500 steelhead acoustically-tagged smolts in 2009 and 2010 at river kilometer 207 of the Sacramento River (~20 km north of Sacramento). Less than 25 % of smolts reached the Pacific Ocean in both years. The reach-specific survival varied by reach between the 2 years. Success of >60 % in the delta during 2009 contrasted with <33 % during 2010, whereas this pattern was reversed in the bay where it was <57 % in 2009 and >75 % in 2010.

Juvenile salmon emigrating from their natal rivers to the ocean may traverse alternative migratory pathways on successive years and this may influence their rates of survival. Branching off the mainstems of the Sacramento and San Joaquin Rivers is a network of channels that comprise the delta. Fishery management attempts to increase survival of Chinook salmon emigrants by confining smolt migration to the mainstem of the Sacramento River by preventing them from passing through the Delta Cross Channel into that network of channels where survival is lower than the mainstem (Perry et al. 2009). Perry et al. (2013) used 3 years of records of route-specific survival to show that diverting smolts away from the lower-survival routes through the DCC increased population survival, but by less than expected given prior knowledge of the differences in survival among routes. This was because smolts used yet another, previously unassessed alternative route at the upstream river junction leading to Sutter and Steamboat Sloughs. These results reveal the flexibility and responsiveness of acoustic telemetry coupled with analytical computer modeling to evaluate management strategies thought to increase overall survival in rivers.

Not only can changes in flow and other physical parameters impact survival of juvenile salmon during outmigration, but also changes in the abundance of predators can be significant. The survival of acoustically-tagged juvenile Chinook salmon increased significantly after the initial predator removal effort (but not a second follow up removal) (Cavallo et al. 2013). When flow increased and the tidal effect decreased during the opening of the Delta Cross Channel, the time taken by smolts to traverse the experimental reach on the North Fork of the Mokelumne River decreased and smolt survival increased. This experimental study demonstrated that predator control in conjunction with habitat manipulation (here, flow management) can be an effective strategy to enhance salmon survival in the tidal transition zone in the Delta of the Sacramento-San Joaquin watershed.

Mosser et al. (2013) evaluated the feasibility of transporting returning adult spring-run Chinook salmon upstream of two dams so that they could reach the cool waters of their summer holding habitat in Butte Creek, a tributary of the Sacramento River. The adults were netted, transported by truck, given an esophageal radio tag/temperature tag, and released upstream of the dams. Twenty three tags (88 %) were recovered from the 26 tagged adults, compared with a 10 % tag recovery rate for an earlier study using fin clips. Most of the salmon died within 2–6 days after relocation, and no fish survived to spawn. Future relocations should consider (1) intervention as soon as fish cease volitional migration but before they are exposed to further deleterious conditions, (2) monitoring environmental conditions to choose appropriate release sites, (3) evaluating the degree of disease transmission risk, and (4) using handling practices that minimize potential stress due to air thermal shock.

## Future directions

The studies of juvenile salmonids reported here were mainly confined to late-fall run Chinook salmon and steelhead trout smolts, which tend to outmigrate as yearlings. The beacon-to-body mass ratio of the transmitters used was near or below the 5 % value acceptable for juvenile salmonids. The smolts of the three other Chinook salmon runs are considerably smaller in total length. Hence, smaller transmitters are needed to delineate their migratory pathways, rates of movement, and their reach-specific survival. These transmitters have been developed as part of the Juvenile Salmon Acoustic Tracking System (JSATS) in the Columbia River (McMichael et al. 2010). This will make it possible to track the smaller individuals of these other runs and other salmonid species in the near future.

The stand-alone monitors used in the current studies were interrogated four times yearly to provide seasonal records of movement throughout the watershed. There is need for the acquisition of tag detection records more frequently. The monitors could provide information on a weekly basis or on-demand, if they were cabled to shore station with a cellular MODEM to send via a packet radio signal the files of detections to a processing center. Many detection nodes could communicate with a single base station, and the information could be disseminated to the scientific community from the latter.

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