INDEPENDENT SCIENTIFIC REVIEW PANEL
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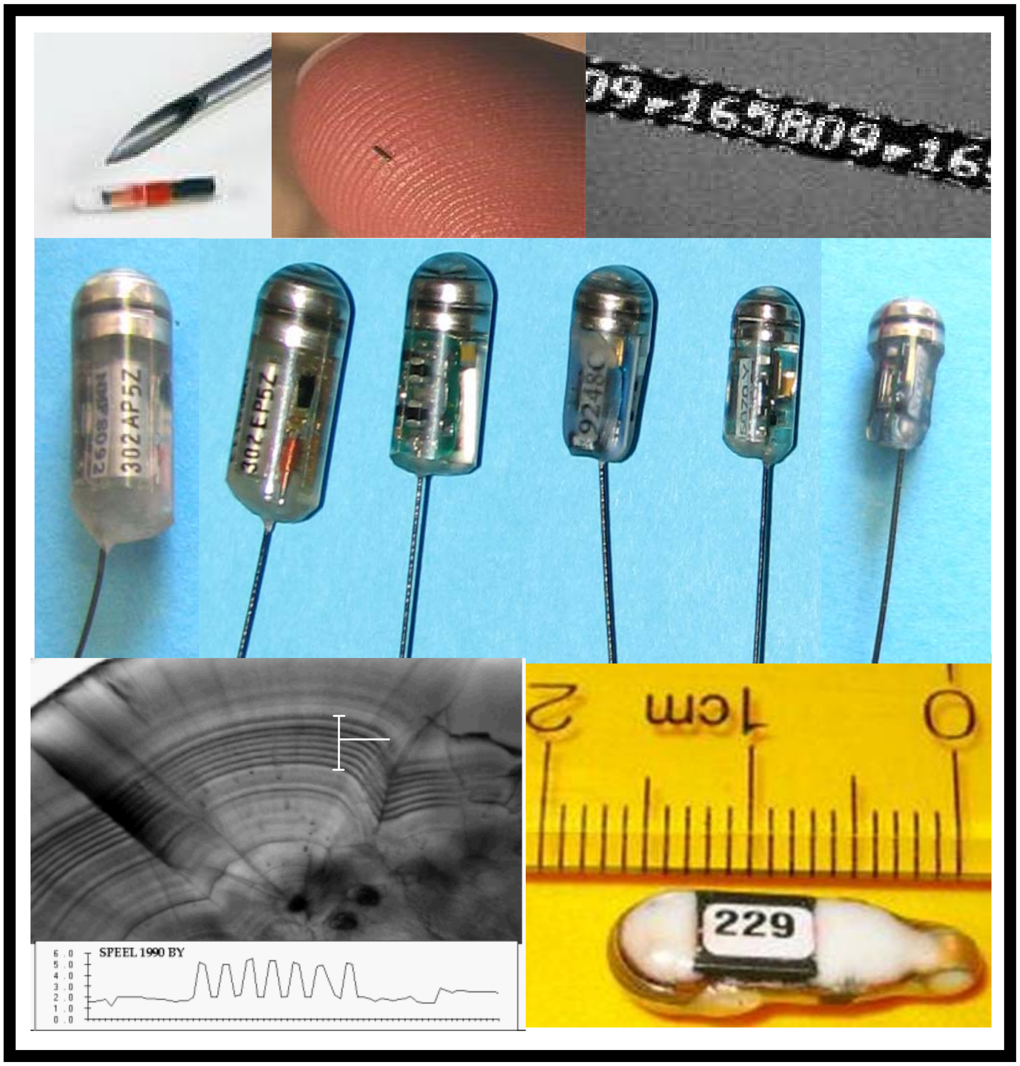
# TAGGING REPORT




A comprehensive review of Columbia River Basin fish tagging technologies and programs

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# Independent Scientific Review Panel

for the Northwest Power and Conservation Council; 851 SW 6th Avenue, Suite 1100; Portland, Oregon 97204

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for the Council, Columbia River Basin Indian Tribes, and NOAA Fisheries

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# ISRP and ISAB Tagging Report

## Contents

## List of Tables



## List of Figures

# Table of Acronyms

| | | | |
|---|---|---|---|
| ADFG | Alaska Department of Fish and Game | NMFS | National Marine Fisheries Service |
| AFEP | US Army Corps of Engineers' Anadromous Fish Evaluation Program | NOAA | National Oceanic and Atmospheric Administration |
| AT | Acoustic tag | NPAFC | North Pacific Anadromous Fish Commission |
| BiOp | Biological Opinion | NPT | Nez Perce Tribe |
| BON | Bonneville Dam | NWFSC | Northwest Fisheries Science Center |
| BPA | Bonneville Power Administration | NWPCC | NW Power and Conservation Council |
| CH | Chinook | ODFW | Oregon Department of Fish and Wildlife |
| CRITFC | Columbia River Inter-Tribal Fish Commission | PBT | Parental Based Tagging |
| CSMEP | Collaborative Systemwide Monitoring and Evaluation Project | PFMC | Pacific Fishery Management Council |
| CSS | Comparative Survival Study | PIT-tag | Passive Integrated Transponder (tag) |
| CTUIR | Confederated Tribes of the Umatilla Indian Reservation | PNAMP | Pacific Northwest Aquatic Monitoring Partnership |
| CWT | Coded-wire tag | PNNL | Pacific Northwest National Laboratory |
| DFO | Department of Fisheries and Oceans, Canada | POST | Pacific Ocean Shelf Tracking |
| DST | Data storage tags | PSC | Pacific Salmon Commission |
| EMG | Electromyogram | PSMFC | Pacific States Marine Fisheries Commission |
| ESA | Endangered Species Act | PUD | Public Utility District |
| ESU | Evolutionarily significant unit | RPA | Reasonable and Prudent Alternative |
| FCRPS | Federal Columbia River Power System | RSW | Removable Spillway Weir |
| FDX | Full-duplex technology (for PIT tags) | RT | Radio tag |
| FPE | Fish Passage Efficiency | SAR | Smolt to adult return rate |
| GSI | Genetic stock identification | SBT | Shoshone Bannock Tribe |
| HDX | Half-duplex technology (for PIT tags) | SMP | Smolt Monitoring Program |
| HTI | Hydroacoustic Technology Inc. | SNP | Single nucleotide polymorphism |
| IDFG | Idaho Department of Fish and Game | SPA | Scale pattern analysis |
| IEAB | Independent Economic Advisory Board | STHD | Steelhead |
| ISAB | Independent Scientific Advisory Board | TDA | The Dalles dam |
| ISRP | Independent Science Review Panel | TIR | Ratios of SAR of transported smolts to in-River smolts |
| JDA | John Day Dam | TRT | Technical Recovery Team |
| JSATS | Juvenile Salmon Acoustic Telemetry System | TSW | Temporary Spillway Weir |
| LMN | Lower Monumental Dam | USACE | US Army Corps of Engineers |
| LWG | Lower Granite Dam | USFWS | US Fish & Wildlife Service |
| MCN | McNary Dam | USGS | US Geological Survey |
| MFWP | Montana Fish, Wildlife and Parks | VIE | Visible implant elastomer tags |
| MPG | Major population group | WDFW | Washington Dept. of Fish and Wildlife |

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Interagency Tagging Technologies Focus Group contributors included:

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# ISRP and ISAB Tagging Report

# I. Introduction

## A. Review Origins

In 2006, the Independent Scientific Review Panel (ISRP) reviewed 112 tagging-related proposals. All were submitted in response to the Northwest Power and Conservation Council's solicitation for Fiscal Years 2007-2009 implementation of the Columbia River Basin Fish and Wildlife Program (ISRP 2006a). Based on its examination of those proposals, the ISRP recommended, as it has several times since 1998, that the Fish and Wildlife Program would benefit from a comprehensive review of fish tagging projects funded by the program (ISRP 2006b).

Over several review cycles and in numerous reports, the ISRP raised issues about:

- identifying potential impacts on coded wire tag programs from regulations requiring mass marking of hatchery fish with adipose fin clips and mark-selective fisheries (ISRP 2005),
- finding long-term solutions to mathematical and statistical problems in the estimation of smolt-to-adult return rates from tagging data (ISRP 2002),
- developing coordinated annual operations plan for the application of PIT tags in support of long-term monitoring and evaluation of out-migration survival of juvenile salmon and return rates of adults (ISRP 2005),
- establishing a comprehensive design for tag data collection for the Basin (ISRP 2000), and
- implementing forward-looking monitoring/tagging programs designed to address questions that may arise in the future (ISRP 2000).

The ISRP suggested a review addressing the complex interactions between projects and, at the same time, recommended inclusion of projects involving smolts, Passive Integrated Transponder (PIT) tags, radio tags, coded wire tags (CWT), and acoustic tags.

## B. Review Context

Fish tagging and marking play important roles in stock assessment, research, management, and recovery of salmonid and other fishes in the Basin. Data from tagged or marked fish are used to provide information useful for effective decision-making. Fish of various species, stocks, and sizes are tagged to obtain data on their numbers, harvest rates, behavior, habitat use, mortality rates, and the success of hatchery and other enhancement programs. Results from tagging investigations influence decisions on hydrosystem management such as water spill at dams and fish transport; harvest regimes in the ocean and river; hatchery practices; and endangered species risk assessment.

Investigations using tagged fish typically involve collecting, tagging, releasing, and recapturing or detecting fish, and analyzing data to estimate vital statistics. The design of tagging programs requires establishing effective sample sizes for groups to be tagged and developing capture or tag detection methods to recover sufficient numbers of tagged individuals for statistical purposes. These investigations require protocols for selecting and tagging fish, recovery or detection of tagged individuals, data handling, and data analyses. Ideally, management needs should be sufficiently clear to establish analysis protocols with adequate precision before monitoring activity begins. In practice, however, an adequate *a priori* protocol may not be practical when tagging methods and detection systems begin with pilot efforts, as they frequently do.

Coordination of effort is important for management success involving multiple species and agencies. The complex life-cycle of many fish results in stocks spending time in several different environments (e.g., freshwater tributary and mainstem reaches, estuary, and marine) and political jurisdictions (e.g., tribal, multiple state, Federal, and international treaty). As a result, even modest efforts to estimate important vital statistics through tagging may involve funding from multiple sources and participation from multiple agencies. Inadequate coordination of fish tagging and recovery among agencies could result in unnecessary duplication in some circumstances and data that are insufficient for analyses to support decision making in others. This report provides recommendations on these and related activities.

## C. Council Review Request and Questions

In response to concerns raised by the ISRP, the Council asked the ISRP and the Independent Scientific Advisory Board (ISAB) to review fish tagging projects funded by the Bonneville Power Administration (BPA) and the U.S. Army Corps of Engineers (USACE). The Council emphasized that the review should focus on projects designed to determine salmon survival and migration, as well as the effectiveness of hatchery and harvest programs. Specifically, the Council requested that the ISAB and ISRP address six questions:

1. Can the coordination of fish tagging projects and programs, both within and outside of the program, be improved?
2. Can the compatibility between the results of different tagging studies be increased?
3. Can the Council, through its Fish and Wildlife Program, best encourage the development and use of innovative tagging technologies relevant to program RM&E needs?
4. Do gaps exist in the Basin's capacity to collect life history information at the project or program scale because of lack of relevant technology?
5. Can criteria be developed for determining the most cost-effective tagging technology during the project review process?
6. How can this element of the program be made more cost-effective?

These questions were posed in the context of the management questions that tagging projects are intended to address.

## D. Review Approach

To establish a basis for a response to the Council's questions the ISAB and ISRP compiled and summarized fish tagging projects and programs in three management domains of importance: hydrosystem monitoring of juvenile and adult fish; salmonid hatchery/harvest evaluation and assessment; and estuary/near shore marine assessment. For each domain, we summarized the key management questions/decisions. We identified appropriate tagging technologies, projects, and sponsors. We evaluated whether the methods used are sufficient for management, where better data are needed, and if improved coordination is needed.

The summary of tagging for each management domain was drawn from three primary sources: (1) a draft Council staff report describing the fish tagging technologies used by both the BPA-funded Fish and Wildlife Program projects and the USACE Anadromous Fish Evaluation Program projects; (2) information gathered in briefings and interviews with staff from NOAA-Fisheries, BPA, Columbia River Intertribal Fish Commission (CRITFC), USACE, the Nez Perce Tribe, and the Lower Snake River Compensation Program; and (3) review of publicly available literature. The draft Council staff report also provided various management questions that tagging projects were designed to answer; listed the estimated number of tags of each type used in the Basin in 2007; categorized the various fish tagging technologies used to answer management questions (Table 1, p. 19); and briefly described several tag technologies.

Our report begins with responses to the Council's questions and our recommendations (Section II). This is followed by summaries of fish tagging projects and programs for three management domains (Section III). Our report concludes with a brief summary of statistical considerations in tag programs (Section IV). The appendices provide descriptions of the primary tagging technologies used in the Basin and tables identifying ongoing projects recently funded through the Council's Fish and Wildlife Program, the USACE Anadromous Fishery Evaluation Program (AFEP), and the Pacific Salmon Commission's (PSC) Northern and Southern Funds.

# II. ISAB and ISRP Recommendations and Responses to Council Questions

## A. Question 1: Can the coordination of fish tagging projects and programs, both within and outside of the program, be improved?

Yes, coordination can improve. If successful it could lead to efficiencies and better data for making research and management decisions.

A successfully coordinated program will have most or all the following attributes:

- clearly defined management objectives that are understood by technicians, managers, scientists, and administrators;
- a monitoring design and standardized protocols that generate data of sufficient precision to support good management decisions;
- trade-offs between data precision and costs that are transparent to scientists, managers, and administrators;
- evaluation of data sufficiency that provides feedback to technicians, managers, scientists, and administrators;
- effective distribution and archiving of primary data and derived analyses that permits free public access to information;
- feedback to develop the next cycle of work accomplishing adaptive management (e.g., see ISRP Retrospective for 2007);
- use of previous studies for more effective coordination of existing and proposed research, both within and among tagging methods; and
- a well-developed and implemented plan for coordination with other studies.

In the subsection, “Opportunities and necessity for improved coordination,” we use this list of attributes to rank overall coordination for each tagging technology reviewed in Appendix A, as follows:

- **Very good**—has all of the attributes of successful coordination (see bulleted list at the beginning of this section)
- **Good**—has most of the attributes of successful coordination
- **Fair**—has at least half of the attributes of successful coordination
- **Poor**—has few or none of the attributes of successful coordination

## Coordination in Columbia River Basin tagging programs

Coordination between Fish and Wildlife Program tagging projects often appears to be lacking. However, efforts by the Pacific Northwest Aquatic Monitoring Partnership (PNAMP) to standardize some tagging protocols and by the Collaborative Systemwide Monitoring and Evaluation Project (CSMEP) to summarize and integrate monitoring data (including tag data) have begun much needed improvement. Coordination of tagging/marking projects between the USACE Anadromous Fish Evaluation Program (AFEP) and the Fish and Wildlife Program has been partially accomplished by the 2008 AFEP Annual Review where investigators of Fish and Wildlife Program-funded PIT tag survival studies and the Pacific Ocean Shelf Tracking (POST) acoustic tag study made presentations of recent results.

The coordination that is required or can be achieved differs among individual projects that tag fish, the larger programs they form, and the tag technologies they employ. Specific research investigations with limited spatial and temporal scope may require little coordination. In contrast, evaluation of the Columbia River hydrosystem operations or managing salmon harvest requires extensive coordination among agencies that raise hatchery fish, capture wild fish for tagging, and recover tags, and those that maintain and analyze data, and report results for policy decisions. Often this can involve multiple agencies.

The legal foundation for Columbia River salmon management is fragmented among the Northwest Power Act, Endangered Species Act, Magnuson-Stevens Fishery Act, Pacific Salmon Treaty (with Canada), and *U.S. v. Oregon*, and the tasks to collect the information to ensure compliance with the legal requirements are decentralized among state, federal, and tribal agencies. Funding these activities usually involves multiple additional conduits. This fragmented administration complicates coordination.

In addition to the administrative complications, many other factors can affect coordination of tagging projects and programs, for example: (1) breadth of useful application to regional or coast-wide management, (2) competition among suppliers and users of tagging technologies, (3) vertical integration of technology suppliers, (4) infrastructure inertia, (5) stability and ease of application of technology, and (6) presence or absence of standardized tagging protocols and public-access databases.

Coordination may be enhanced by (1) wide breadth of application to regional or coast-wide management, (2) monopolistic position of the technology supplier, and (3) reduced vertical integration of the supplier. Infrastructure inertia can result if there is a reluctance of agencies to move away from an old technology in which they have heavily invested. Such inertia might be associated with good coordination if old technology has become institutionalized. Under these circumstances, good coordination and large investment in infrastructure does not create a healthy environment for new ideas or technologies.

Stable technology permits cost-effective development and maintenance of comparable long-term data sets, which are often the cornerstone of a successful management program. Stability also carries the risk of technological stagnation. Easy to use and widely-applied technologies often open doors for coordination. In contrast, the highly specialized expertise needed for some tag technologies can cause proprietary behavior among users and disincentives for coordination. It is unlikely that tagging and recovery methodologies can be coordinated and made uniform by simple exchange of protocols. Formalized standard protocols are needed to maintain statistical precision. Independent, centralized, accessible databases are important for archiving and accessing tagging and recovery data.

## Opportunities and necessity for improved coordination for each tagging technology

**Coded wire tags (see Appendix A.1.) – Overall coordination: Very good but deteriorating.** The CWT program began nearly 50 years ago to evaluate individual hatchery contributions to salmon harvest. Subsequently the program became an important contributor of data for wild and hatchery salmon harvest management instituted through the Pacific Fishery Management Council (PFMC) and the Pacific Salmon Commission (PSC). Data are now collated and available through the Pacific States Marine Fisheries Commission (PSMFC). Coordination among agencies has been remarkable despite the complications of management by the international treaty, councils, and statistical demands of the process.

The data required for harvest management have expanded because the number of salmon populations and fishing locations included in harvest planning has grown. The CWT program is now challenged to meet the needs. Nevertheless, the technology is expected to remain important in Columbia River Basin and regional salmon decision making in the foreseeable future. Steps are required to ensure that tagging and tag recovery remains robust for estimation of vital life-history and harvest management statistics. Mass-marking and mark-selective fisheries compromise the use of CWT data for estimating exploitation of natural populations, and that challenge remains unresolved.

**PIT tags (see Appendix A.2.) – Overall coordination: Very good**. Archiving and sharing of PIT-tag data are coordinated by the PSMFC. Currently most PIT tagging is associated with specific studies. When tagging project designs are robust, tagged fish from one project can be used by others; e.g., NOAA Fisheries uses fish tagged by the Comparative Survival Studies when appropriate. There is evidence of interest to employ PIT tags for integrated life-cycle monitoring of hydrosystem survival, hatchery straying, and estuary and tributary restoration effectiveness. Opportunities exist to refine the data collections to support salmon management in the Basin by coordinating PIT tagging across management domains. The magnitude of the required data collections, required detection sites, and trade-offs between the precision of estimates of vital statistics and sampling and recovery efforts are impediments to coordination and standardization. The longevity of tags and the rapidly evolving PIT tag technology presents a challenge. It will be important to avoid obsolescence of the data base and detection methodologies as new tags and detection methodologies develop.

**Radio tags (see Appendix A.3.) – Overall coordination: Good.** Coordination of projects using radio tag technology is *ad hoc* but appears adequate for the time being. For the most part, the major users operating on a set of radio frequencies keep track of other researchers that use the same frequency; e.g., the University of Idaho coordinates the use of 149 MHz, whereas the USGS coordinates the use of 150 MHz. As manufacturers get new orders, they contact other users and determine what tag frequencies are available. However, there are challenges in coordinating radio tag studies. Sharing of fixed detection sites can, at times, cause problems because researchers do not want to scan more frequencies than necessary for fear of missing transmitted signals from their own tags and losing data. Where possible, however, researchers can and do generally accommodate other researchers by adding their frequencies to receivers when asked. This sharing should be encouraged and, where feasible, demanded by funding agencies.

**Acoustic tags (see Appendix A.4.) – Overall coordination: Fair.** Acoustic tags are not compatible across tag detection platforms. Thus coordination is most relevant among projects using the same equipment. The scope of potential coordination is changing because the Corps is now using a uniform acoustic telemetry system, the Juvenile Salmon Acoustic Telemetry System (JSATS), in the Columbia River Basin. Battelle PNNL was contracted to develop the system, and they currently have the task of coordinating transmitter codes to eliminate overlap between projects. Standardization of data collection and formatting is being developed for JSATS tagging studies so that all data will be in a single database. Internet access to these data is needed so that anyone can use the data for research purposes, similar to that of CWT and PIT tag data housed with the Pacific States Marine Fisheries Council. VEMCO supplies the acoustic tags used by the Pacific Ocean Shelf Tracking project. In comparison to JSATS, few VEMCO tags are used in the Basin. Coastal arrays of VEMCO acoustic receivers can detect only VEMCO-tagged fish after they leave the river. Coordination would be improved by the development and deployment of compatible acoustic receivers so that data from all types of acoustic tags can be decoded, made available, and shared.

**Data Storage Tags (see Appendix A.5) – Overall coordination: Poor.** Data storage tags are not routinely used for management applications within the Basin. Nevertheless, there are many potential uses, such as addressing hydrosystem, ocean/estuary, and harvest/hatchery management questions related to juvenile and adult salmonid survival, behavior and habitat conditions. The sizes of some data storage tags that record time, temperature, and pressure (depth) are now small enough (e.g., 25-35 mm long) to use in studies of juvenile salmonids (Appendix A.5., Table 4.A.5.1). While cost per tag is relatively high (similar to acoustic tags), equivalent data on individual fish could not be obtained without more expensive research and monitoring surveys and process studies. Web-based coordination of the few projects in the Basin that use data storage tags might encourage new and innovative uses of data storage tags for management applications.

**Genetic Markers (see Appendix A.6) – Overall coordination: Fair and improving.** Standardized microsatellite baseline data has been developed for steelhead, Chinook and coho. Similar standardized single nucleotide polymorphism (SNP) baselines are being developed. Historically, there were standardized allozyme databases. A Coastwide Salmonid Genetics meeting has been held biennially for nearly two decades. So there is very good coordination at the level of data compatibility and exchange, but the information is not publicly available. There is considerable potential for allele frequency data from genetic markers to augment information on stock contributions to harvest, currently provided by the coded wire tag program. Several issues must be addressed before meaningful implementation occurs. First, baseline allele frequency collections from representative stocks need to be coordinated and completed for both microsatellite and SNP markers. Proof-of-concept of parental-based tagging is needed. Publicly available open databases of baseline allele frequencies need to be established. Finally, the derived parameters estimated from genetic data need to be incorporated into harvest models.

Genetic marks are also used to evaluate natural spawning by hatchery-origin adults and assess hybridization and population structure. For these purposes the existing data exchange is adequate.

**Otolith Thermal Marks (see Appendix A.7) - Overall coordination: Poor (within the Basin) to good (outside the Basin).** Otolith thermal marking, now used only on a limited basis in the Basin, has considerable potential to provide mass marking of hatchery fish. Tests of this approach are needed in the Basin. If successful, coordination of marks and recovery similar to the CWT system would be needed. The North Pacific Anadromous Fish Commission (NPAFC) coordinates international application and exchange of information on otolith mark patterns. To improve accuracy of mark recognition and to minimize duplication of thermal marks the Commission hosts an online database, where mark coordinators can enter and audit their otolith marks and users can download information and images of marks that have been released. Compliance among Pacific Rim hatcheries to avoid duplicate marks has been successful to date.

**Natural tags (see Appendix A.8): Trace elements, stable isotopes, scale patterns, parasites - Overall coordination: Fair to poor.** The use of microchemistry to reconstruct fish life histories is a promising technique. Water chemistry baseline data are a necessary precursor to successful completion of microchemisty projects. In past reviews, the ISRP has encouraged coordination among microchemistry researchers to establish water chemistry baseline data for the Basin (ISRP 2007-2009 Innovative Proposal Review). A website for the few people in the Basin working with otolith microchemistry and stable isotopes is suggested. The USGS would be a logical agency to coordinate such a site. Studies that use scales and parasites for stock identification often require establishing new, brood-year specific baseline data for each analysis. To be cost-effective, these projects usually involve independent coordination with agencies that can provide scale or other biological samples at little or no additional cost to researchers. This report does not contain a comprehensive review of all types of natural tags that are being used in the Basin, e.g., Battelle has used biomarkers for studies of head trauma on fish passing through spillways. In general, all Basin projects involving natural tags would benefit from improved coordination.

## Recommendations to improve coordination of Fish Tagging Projects and Programs

Our recommendations are based on information presented in sections III. and IV. and the appendices of this report. The order of listed recommendations is not prioritized.

**1.1** We recommend that all Fish and Wildlife Program proposals involving tagging or marking of fish include a coordination plan in the proposal that explicitly describes protocols for coordinating with other similar studies and plans for data archiving and data sharing.

**1.2** We recommend the development of a web-based information network for coordination of all Basin fish tagging projects and programs. Although data on CWT and PIT tag releases and recoveries are available on-line and easily accessible, networked websites maintained by each agency that fund tagging/marking projects and programs are recommended. These would improve coordination within and among existing tagging studies. More importantly, this network would enable investigators considering Fish and Wildlife Program proposals to review prior projects; avoid duplication of research, monitoring, and evaluation (RM&E); and supplement results of prior or active studies. Web-based information should include the type of study (tributary, hydrosystem, estuary, ocean); principal investigator's name and contact information; species studied; ESU; location of study; dates; tagging technology used; and links to reports or published research results.

**1.3** We recommend the establishment of a tagging/marking standing committee (panel of experts) designed specifically to improve coordination of tagging/marking projects and programs of the Fish and Wildlife Program, the AFEP, and the Lower Snake River Compensation Plan. Potential activities and objectives of this forum include but are not limited to the following:

- identify problems with coordination of Fish and Wildlife Program tagging/marking projects and programs that need immediate attention and action
- participate in regional (e.g., PNAMP, PSMFC) and international forums (e.g., PSC, NPAFC) involved in coordination of tagging projects and programs
- provide inter-agency coordination to ensure sufficient data for analyses that support decision making
- coordinate tag codes/marks to prevent duplication, and disseminate information to increase accuracy of tag/mark recognition
- coordinate tagging and handling protocols
- review and coordinate database management
- review and make recommendations concerning statistical analysis procedures
- coordinate exchange of information on Fish and Wildlife Program tagging projects and programs
- coordinate interagency collaboration in developing and implementing new cost-effective tagging technologies

- coordinate development and review of criteria for cost-effectiveness of Fish and Wildlife Program tagging projects and programs
- coordinate administrative and technical assistance during transitions to new tagging technologies that will improve and advance management and decision making
- coordinate development of targeted solicitations for application of innovative tagging technologies relevant to gaps in fish life history information and program RM&E.

**1.4** We recommend coordination of the Comparative Survival Study (CSS) PIT-tagging projects with other Fish and Wildlife Program and AFEP PIT-tagging projects to increase the number of PIT-tagged fish released per year, while avoiding redundancy, to improve precision of annual and seasonal estimates of Smolt-to-Adult Ratio (SAR), ratios of SAR of transported smolts to in-River smolts (TIR), etc. (See CSMEP, Section III).

## B. Question 2: Can the compatibility between the results of different tagging studies be increased?

Yes, improvements in compatibility of the results from different tag technologies and projects would be beneficial since it is unlikely that a single technology or project can fulfill all the data needs of management. One approach to improve data compatibility is top-down leadership from interagency groups.

Certainly within programs, and perhaps across both the Fish and Wildlife Program and AFEP, one option to consider would be to evaluate all proposals and projects that address a particular management domain together. The multiple participants from different agencies would describe the larger problem and identify how all the components serve to meet the management objectives.

### Recommendations to increase compatibility between the results of different tagging studies:

**2.1** For Fish and Wildlife Program project proposals during the next project review cycle, we recommend that those involved in ocean port sampling and lower river sampling for CWT recovery must address the tagging and tag recovery issues (statistical validity of tagging rates, tag recovery rates, and fishery sampling rates) presented in the Pacific Salmon Commission's Action Plan to Address the CWT Expert Panel (PSC Tech. Rep. No. 25, March 2008; www.psc.org/publications_tech_psctechreport.htm).

**2.2** We recommend the development of Fish and Wildlife Program and AFEP projects to evaluate and monitor the effects of handling stress and tagging on salmon growth, survival, migratory behavior, and other biological characteristics and to determine whether estimates of vital rates using data from tagged hatchery fish are representative of wild fish.

**2.3** We recommend websites maintained by each funding agency that provide easily assessable on-line data on projects they fund. These individual websites would be linked to form an information network for improving coordination of all Basin fish tagging projects and programs (see Recommendation 1.2).

## C. Question 3: How can the Council, through its Fish and Wildlife Program, best encourage the development and use of innovative tagging technologies relevant to program RM&E needs?

The first step in encouraging innovation in the tagging programs is to establish clearly defined management objectives and monitoring designs within existing programs. If there is consistent evaluation of the precision and sufficiency of the data, weaknesses in the program will become evident. The Council, with the Fish and Wildlife Program, along with other responsible entities can then request innovative proposals to resolve the problems.

For the Council's Fish and Wildlife Program, a phased approach where technologies are considered exploratory (bench scale), then developmental (pilot studies), and finally proven (implementation phase) would be useful. The exploratory phase could be pursued through solicitations for innovation to address specific deficiencies.

In the second or developmental phase, if exploratory research has proved a technology's feasibility in the Basin, its use as a management tool should be evaluated more broadly. During this phase, pilot-scale efforts should include parallel treatment with existing technologies that need to be upgraded or replaced. This provides a direct comparison of the technologies.

In the third, or implementation, phase additional work must include a detailed plan for transitioning from one technology to another. Once a decision to replace a technology is made there will be a time-lag and probably substantial infrastructure commitments.

### Recommendations to encourage the development and use of innovative tagging technologies relevant to program RM&E needs:

**3.1** We endorse the development of standardized single nucleotide polymorphism (SNP) markers for all Columbia River salmon and steelhead ESUs.

**3.2** We endorse the development of fishery and management models that use genetic data for both ocean harvest and in-river fisheries.

**3.3** We endorse pilot and proof-of-concept trials for Parental Based Tagging of hatchery populations of salmon and steelhead.

**3.4** We recommend development of otolith thermal marking and pilot and proof-of-concept trials for using otolith thermal marking as an alternative to CWTs to mark 100% of Columbia River Basin hatchery salmon and steelhead.

**3.5** We recommend for PIT tags, further development of prototype in-stream transceivers for detection in tributaries to monitor smolt and adult movements in both large and small tributaries to better understand salmonid behavior and migration timing, fate of juvenile, smolt, and adult migrants before and after dam passage and to spawning grounds (Section III, PIT tags).

**3.6** We recommend for acoustic tag technologies: (1) continued miniaturization of acoustic tags to increase battery life while reducing battery and tag size (or use of variable pulse rate tags that can be switched on and off), (2) development of an acoustic receiver system that can track fish tagged with all types of acoustic tags used in the Basin through the river and nearshore ocean over the continental shelf, (3) continued development of ocean receivers that can be remotely downloaded, (3) development of sensors to detect death of acoustically tagged fish, and (4) evaluation of long-term effects of acoustic tags on salmon survival (Section III, acoustic tags).

**3.7** We recommend for radio tag technologies: (1) development of miniaturized radio tag transmitters with longer battery life and no trailing antennas, (2) use of underwater antennas in depths >9 m, (3) increased number of unique codes (Radio tags, section III), (4) development of sensor technology (depth, motion, water temp., etc.) for juvenile salmon tags, and (5) use in combination with PIT tags to address management needs in freshwater

**3.8** We recommend that the most effective strategy is to continue to develop several tag technologies that, when used in combination, are highly effective at addressing all Fish and Wildlife Program management needs. The alternative would be a single tag technology that addresses most of the needs well, but does a mediocre job at addressing the remainder of the needs.

**3.9** We recommend the further development of innovative techniques or improvement of existing techniques for surgical insertion of internal tags or external attachment of acoustic, radio, data storage tags that reduce handling times, injury, and stress.

A number of recent studies examining the effects of surgically or gastrically inserted radio or acoustic tags on the performance, behavior, or health of juvenile salmonids have found significant short- and long-term tag effects. Data from radio and acoustic tag studies should be used be used with great care, especially, when the "generally accepted" maximum tag weight of 6.5% of the fish's body weight is exceeded; the fish selected for tagging are not randomly selected from the representative group or do not represent the run-timing of a stock; or the period of data collection exceeds the rated duration of battery.

## D. Question 4: What gaps exist in the Basin's capacity to collect life history information at the project or program scale because of lack of relevant technology?

There are limitations with each primary tagging technology now in place. Some of the limitations are technological, and for others there is a lack of monitoring design and feasible infrastructure. Technological gaps include the fish size limitations associated with most PIT, radio, and acoustic tags. Even when using the smallest tags, there is concern for effects on behavior and survival that may bias results. Additionally, detecting PIT tags below Bonneville Dam is technologically difficult and limits the estimation of juvenile salmon survival in the lower river.

A significant infrastructure gap in the Columbia River Basin is the lack of PIT tag monitoring systems in the tributaries where significant populations of wild salmonids occur. Monitoring of PIT tagged adults into and PIT tagged juveniles out of these tributaries will provide data to better understand life histories and survival rates of salmonids and hatchery stray-rates in these tributaries.

There is currently no feasible way to tag and track juvenile lamprey ammocoetes with radio tag or acoustic telemetry. This is primarily due to the excessive tag size/weight. If significant downsizing occurs in the near future, this would be a high priority use for these tags. The use of the PIT tag systems may also be another important way to collect migration data on lamprey ammocoetes. As PIT tag monitoring systems are developed in tributary systems, the PIT tagging of ammocoetes may be an important tool to use in filling data gaps in this portion of the Pacific lamprey life cycle.

### Recommendations to close gaps in the Basin's capacity to collect life history information at the project or program scale because of lack of relevant technology (order of listed recommendations does not indicate priority):

**4.1** There is a large gap in capacity to collect data on the status and trends of wild fish populations. We recommend employing PIT tag technology in tributaries where complete counts of adults-in and smolts-out using weirs are not feasible. At sites where a complete count of adults-in and smolts-out using weirs is effective, this data collection needs to be maintained. In addition, the risks of capture and PIT tagging of wild fish are significant, and great care must be taken, especially if the population is small. Projects to determine whether hatchery fish can be used as surrogates for wild fish (raised to match size/weight) to reduce risks in handling wild fish for tagging are needed (Sec. III). We recommend 100% tagging/marking of Columbia River Basin hatchery fish to facilitate hatchery broodstock management and evaluations of the impacts of hatchery straying on natural populations.

**4.2** Some large gaps in capacity to collect information are associated with the lack of statistically valid sampling designs for tagging/marking studies. We recommend development of statistically valid sampling designs to estimate: (1) straying of adult hatchery-origin and natural-origin salmon and steelhead, (2) mortality of juvenile lamprey migrating downriver through the hydrosystem projects, and (3) mortality of adult lamprey migrating upriver through the hydrosystem projects.

In the next project review cycle, all tagging projects should address and document the statistical validity of tagging and tag recovery rates. Sample size calculations should be based on statistically valid methods and documented.

**4.3** We recommend implementation of the relative reproductive and long-term monitoring projects identified in the Ad Hoc Supplementation Monitoring and Evaluation Workgroup (AHSWG 2008) (Appendix A. Genetic Marks).

**4.4** We recommend projects to address the long-term effects of all tag types on juvenile and adult fish. For example, a comprehensive study should be initiated to determine why PIT-tagged Snake River wild spring/summer Chinook salmon are producing lower SARs than unmarked wild Chinook salmon (ISAB /ISRP 2007-6) and the extent of PIT tag losses (Knudsen et al., in press). Long-term data are especially needed on effects of acoustic and radio tags on juvenile and adult salmonids. Studies with objectives to better standardize surgical protocols, tag size/weight criteria, and battery performance should be continued.

**4.5** Studies should be conducted to determine the rate and extent of tag shedding or loss for all tag types.

**4.6** We recommend the development of PIT tag detectors that can be used in spillways, removable spillway weirs, turbines, and selected tributaries to collect PIT tag data on migration timing, straying, and survival by routes of passage to spawning tributaries, which currently cannot be done. Flat plate detector units, similar to the one developed for the corner collector at Bonneville's second powerhouse need to be developed for these other routes of passage and for dams and tributaries throughout the hydrosystem (see NOAA Fisheries Snake River Spill-Transport Study and Pit tags; Section III).

## E. Question 5: What are the criteria for determining the most cost-effective tagging technology during the project review process?

For proposal solicitations, the ISRP's technical review is not designed to address cost-effectiveness. If project budgets appear unreasonable, either too large or too small, concern is often expressed, although this is not a technical review task. This is an aspect of tagging that would be best addressed as part of the Fish and Wildlife Program amendment and program-level decision process. Evaluation of the cost effectiveness of alternative approaches should be completed ahead of proposal solicitations, and the appropriate technologies for specific problems provided to sponsors. The Independent Economic Advisory Board (IEAB) could collaborate with the ISAB or ISRP on evaluating the cost effectiveness of alternative tagging technologies.

As important as cost effectiveness is program effectiveness. Program effectiveness of tagging activities might be better incorporated into decision management frameworks where reference points from tagging activities trigger management response (e.g., return rates or harvest rates at a fixed limit or threshold).

### Recommendations to develop criteria for determining the most cost-effective tagging technology during the project review process:

**5.1** As noted above in section 1.3(9), we recommend establishment of a tagging/marking standing committee (panel of experts) that will coordinate future development and review of criteria for cost-effectiveness of Fish and Wildlife Program tagging projects and programs.

**5.2** For Fish and Wildlife Program project proposals during the next project review cycle, we recommend that sponsors provide a review of the applicability and costs of different tagging technologies that are appropriate for their research/management objectives. In addition, proposal budgets should include itemized costs per unit, e.g., cost per tag and cost per receiver, and number of units to be purchased. This information will aid in evaluation of the overall costs of tagging and marking programs in the Basin.

## F. Question 6: How can this element of the program be made more cost-effective?

There should be cost-savings whenever researchers or managers share resources and data collection tasks, and use the same group of tagged fish for multiple studies. The use of web-based information centers would provide contact information that should lead to better coordination of activities. It is reasonable to expect that agencies obtaining funding through the Fish and Wildlife Program should be able to be approached by other agencies for assistance and at least be required to respond to the request in writing, even if they provide reasons why they cannot assist in the activity in question. The Fish and Wildlife Program can in turn provide incentives and acknowledge such collaboration.

One approach to reduce costs would be to require proposals to tag fish to specifically document not only what other projects or studies in the Basin are involved with research in their area, but how they are communicating/coordinating activities with them. The tendency is for groups to inform other groups (i.e., “We know what they are doing and they know what we are doing”) but not necessarily pool resources or personnel to mutual benefit. Cost-effectiveness would improve if communication extended more often to coordination and actual cooperation. For this, web-based information on current and recent studies that provide basic information what was studied, where, and how, along with the contact information on principal investigators would be invaluable. This would avoid duplication and allow principal investigators to capitalize on ongoing and prior research (see Recommendation 1.3).

First noted by the ISRP in 2000, no organization has taken responsibility for a comprehensive design of tagging/marking data collections in the Basin. This remains true in 2009. The ISAB and ISRP are aware of efforts to initiate design of a comprehensive monitoring effort within the 2008 Biological Opinion for the Federal Columbia River Power System and the Collaborative Systemwide Monitoring and Evaluation Project, but the task has not been completed. The U.S. v. Oregon agreement establishes tagging and marking for some hatchery programs but does not ensure the statistical soundness of the actual tagging and tag recovery that takes place.

The absence of a comprehensive program for the essential environmental and management domains creates a situation that complicates evaluating the efficiency and cost effectiveness of the dispersed marking and tagging programs that are in place.

Encouraging technological improvements will also lead to cost savings. For example, telemetry studies are expensive, both because of the cost for individual transmitters ($230 to $300 each) and because sample sizes needed to develop usable survival estimates are large, especially with juvenile salmon studies where detection probabilities are relatively low. As technologies and coordination improve, costs may come down. For example, when detection ranges for JSATS receivers improve to the point that one node or one receiver with two hydrophones can detect most fish that pass, numbers of receivers and the numbers of tagged fish should decline.

### Recommendations to improve cost effectiveness of tagging projects:

**6.1** We recommend development of an inclusive Fish and Wildlife Program monitoring/tagging framework for all salmon and steelhead ESUs, major population groups, and independent populations, including both listed and unlisted species, to evaluate population status and trends, hydrosystem passage and operations, hatchery and harvest management, and estuary and ocean condition domains.

**6.2** The use of computer simulation models is recommended to determine conditions under which increasing tag numbers is, or is not, beneficial (See CSMEP, Section IV).

# III. Applications to Management – Integration and Coordination of Tagging Within and Across Management Domains

In this section of the report, we broadly describe and evaluate the programs that tag fish to inform management and policy decisions in three Basin management domains: hydrosystem passage and operations; hatcheries and salmon harvest management; and estuary and ocean conditions monitoring. For each domain, the following questions are posed:

A) What type of tags are presently being deployed and by whom?

B) What, if any, are the limitations of the technology and sampling designs?

C) Where is there a need for better data and improved coordination?

## A. Management Questions Addressed Using Data from Tagged Fish

**Hydrosystem Passage and Operations**
Tagging studies provide information on the movements of juvenile and adult salmon, including their migration timing and survival through the dams and reservoirs of the Snake and Columbia Rivers. These data are needed to understand the relationship between flow and survival. In particular, tagging data are used to examine (1) the effects of dam passage route (spillway versus turbine versus bypass), transportation, and spill operations on juvenile fish survival, migration rate, and behavior; (2) adult straying, fallback and pre-spawn mortality; and (3) the effect of management actions in specific river reaches on the juvenile-to-adult survival rates (SARs) of different species.

**Estuary and Ocean Conditions**
*Estuary* - Estimates are needed of migration rate and survival of salmon species and life-history types (i.e., spring, summer, fall Chinook; summer and winter steelhead) barged and in-river through the estuary, and how the timing of ocean entry is related to subsequent survival. Information on estuary residence and survival is needed to evaluate habitat restoration efforts in the estuary.

*Ocean* - Stock-specific data are needed on ocean abundance, distribution, density-dependent growth, survival, and migration. Effects of variable ocean conditions and climate change on salmon survival, as influenced by hydrosystem management is also needed, as well as how variable ocean survival influences the interpretation of freshwater recovery actions. Understanding ocean carrying capacity and density dependence is needed to establish hatchery production levels.

**Hatchery and Harvest Management**

Estimates are needed of stock-specific harvest rates by commercial, recreational, and tribal fisheries, including harvest in the ocean, mainstem lower Columbia River, Zone 6 and tributaries.

Estimates are needed of direct and incidental harvest impacts on Endangered Species Act listed ESUs and populations.

Estimates are needed for estimation of hatchery adult straying, hatchery broodstock composition, reconstruction of runs, prediction of adult run abundance, and effectiveness of hatchery operations.

**Table 1. Tagging technology application to management questions.**

**Key:** *1= Current technology addresses the management question or need*
*2= The ability to address the management question is in active development*
*3= The tag technology has the potential to address the management question but further development is necessary*

| Management Question | Tagging Technology | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | *Otolith* | | | | |
| | *PIT-Tag* | *Radio Telemetry* | *Acoustic Telemetry* | Micro-structure | Micro-chemistry | *Genetic Marker* | *Coded Wire Tag* | *Data Storage Tag* |
| ***Hydrosystem Operations*** | | | | | | | | |
| ***Survival Studies During Juvenile Migration*** | | | | | | | | |
| Hydrosystem Survival | **1** | **3** | **2** | | | | | |
| Reach Survival | **1** | **1** | **1** | | | | | |
| Longer Reach Survival (i.e., LWG to MCN) | **1** | **3** | **1** | | | | | |
| Project Survival (Tail race to tail race) | **1** | **1** | **1** | | | | | |
| Post Bonneville to Estuary Survival & Behavior | **1*** | **3#** | **1** | | | | | |
| Route-Specific Survival | **2**** | **1** | **1** | | | | | |
| ***Juvenile Behavioral Studies*** | | | | | | | | |
| Forebay/Project Delay | | **1** | **1** | | | | | |
| Migration timing | **1** | **1** | **1** | **1** | **1** | **2** | | **3** |
| Residence time within the river or reservoirs | **1^** | **1** | **1** | **1** | **1** | **2** | | **3** |
| Growth rates and bioenergetics | **1** | | | **1** | | | | **3** |
| Over Wintering of Juvenile Migrants: | **1** | **3** | **3** | **1** | **1** | **1** | | **3** |
| ***Adult Return Studies*** | | | | | | | | |
| Smolt-to-Adult Return Rates | **1** | | | | | | **1** | |
| Adult Survival and Passage through Hydrosystem | **1** | **1** | **1** | | | **1** | | **1** |
| Adult Survival Post Hydrosystem (i.e., survival to tributaries) | **3** | **1** | **1** | | | | | |
| Measuring physiological stressors & environmental conditions | | | | | | | | **1** |
| Tributary Survival and Spawning Success | **1^** | **1** | | | | **1** | | |

| | PIT-Tag | Radio Telemetry | Acoustic Telemetry | Otolith | | Genetic Marker | Coded Wire Tag | Data Storage Tag |
|---|---|---|---|---|---|---|---|---|
| ***Estuary and Ocean Conditions*** | | | | | | | | |
| Near Ocean Survival and Behavior | **3** | | **1** | **1** | **1** | **1** | **1** | **3** |
| Distant Ocean Survival & Behavior | **3** | | **1** | **1** | **1** | **1** | **1** | **1** |
| ***Hatchery and Harvest Management*** | | | | | | | | |
| Stock specific harvest by fishery | **3** | | **3** | **3** | | **2** | **1** | |
| Direct and indirect harvest of ESA listed salmon | **3** | | | | | **2** | **1** | |
| Straying of hatchery-origin adults | | | **3** | **3** | | **2** | **1** | |
| Broodstock composition | **1** | | | | | **2** | **1** | |
| Predicting run abundance | **3** | | **3** | **3** | | **2** | | |
| Hatchery operations effectiveness | **1** | | | | | | **1** | |
| ***Limitations by Species and Size Class*** | | | | | | | | |
| Ability to Tag or Evaluate Juvenile Lamprey | | | | **1** | **1** | **3** | | |
| Ability to Tag or Evaluate Fry (< 60mm) | | | | **1** | **1** | **1** | | |
| Ability to Tag or Evaluate Fish from 60 to 90 mm | **1** | **3** | **3** | **1** | **1** | **1** | **1** | |
| Ability to Tag or Evaluate Fish > 90mm | **1** | **1** | **1** | **1** | **1** | **1** | **1** | |
| Ability to Tag or Evaluate Large Sample Sizes (i.e., >20,000 fish) | **1** | **2** | **1** | | | **2** | **1** | |

**<u>Notes:</u>**

* PIT-tag detections in the estuary are limited to the surface pair-trawl.
**Currently the only routes measured are juvenile bypass systems and the Bonneville Corner Collector. PIT detections in other routes of passage (e.g., spillway, turbine, RSW) are in development.
^ Species-dependent
# Post Bonneville survival possible until tags reach saltwater in the estuary.

## B. Hydrosystem Passage and Operations

The major management information needs for hydrosystem decision making and monitoring of juvenile and adult salmonids passing through the mainstem lower Columbia and Snake rivers include the following:

- estimates of survival, migration timing, and movements of juvenile and adult salmon through the Snake and Columbia River dams, reservoirs, and tributaries
- relations between flow and survival of juvenile salmonids
- effects of dam passage route (spillway versus turbine versus bypass) on survival of salmonids
- effects of transportation and spill operations on juvenile fish survival, migration, and behavior
- effects of transportation of juveniles on subsequent adult straying, fallback and pre-spawn mortality, and juvenile-to-adult survival rates (SARs) for various species and populations
- tag data for determining similar hydrosystem effects on other non-salmonid anadromous species such as Pacific lamprey.

### What types of tags are currently being used in the hydrosystem and by whom?

Three primary tag types (PIT, radio, and acoustic) are being used in the hydrosystem to collect data regarding the above management information needs.

#### Programs and Projects Using Tags in Hydrosystem Research and Monitoring Studies

All USACE's AFEP projects (Appendix B. Table 7.B.2) and most of the Council's Fish and Wildlife Program projects (Appendix B. Table 6.B.1) use one or more of the three tag types for research, monitoring, and evaluation (RM&E) of juvenile and adult salmonids impacted by the hydrosystem in the Basin. The largest Fish and Wildlife Program projects using tags or tag data include the Smolt Monitoring Project (SMP), Comparative Survival Study (CSS), Collaborative Systemwide Monitoring and Evaluation Project (CSMEP), NOAA Fisheries Transport/Survival Studies, and the Pacific Ocean Shelf Tracking (POST) acoustic telemetry project.

**Anadromous Fish Evaluation Program (AFEP)**

The USACE's AFEP, ongoing since 1982, has been a major proponent, along with BPA support and funding through the Fish and Wildlife Program, for development of the PIT-tag use for hydrosystem RM&E of juvenile and adult salmonids. The AFEP program has also supported and funded the development of increased capabilities for radio tag and acoustic tag monitoring systems for mainstem dams and the downsizing of tags for use in juvenile salmonids.

The use of PIT-tag technology in the Snake and Columbia rivers, where each fish has a unique tag code, has provided an unprecedented opportunity to evaluate the survival rates of juvenile fish through mainstem Snake and Columbia River dams and reaches and for individual stocks. Typically, survival over the life cycle of salmon is calculated as smolt-to-adult return rate (SAR).

Numerous large-scale studies have used PIT-tags to examine differences in SARs between transported and non-transported (in-river) fish, examine delayed mortality observed of Snake River Chinook salmon, and to estimate rates of predation by birds.

Until 1995, and the ESA listings of salmon and steelhead, the AFEP relied heavily on PIT tags to estimate survival of juvenile salmonids passing the FCRPS dams. However, when the NOAA BIOP-mandated spill began, the primary route of passage for smolts became spillways and insufficient numbers of PIT tagged fish went through the bypass systems to make statistically significant survival estimates. The AFEP then turned to radio tag systems to monitor route of passage, and the program began making survival estimates with radio-tagged fish beginning in 1997. Since 1995, radio tags have worked very well for evaluating both adult and juvenile salmonid passage at mainstem hydropower dams, particularly for assessing fish behavior in the near-dam environment, resulting in improvements to dam structures and operations. Radio tags have been useful for estimating project survival, dam survival, pool survival, route-specific survival, passage efficiencies, forebay survival and delay, tailrace egress, travel times, and avian predation. The University of Idaho and NOAA Fisheries have also conducted joint studies of adult salmonid immigration behavior in the Columbia River Basin by intercepting previously PIT tagged adults at Bonneville Dam and applying radio tags to study straying of adult returns, spawning distribution and timing, and adult fallback at dams. A recent summary report of results from those studies can be found in Keffer et al. (2006).

The AFEP then switched to acoustic tag systems in 2005, because not only could the acoustic telemetry systems do everything that the radio tag systems could do, but they also had the ability to track the vertical and horizontal distribution of tagged juveniles (3-D). The acoustic telemetry systems can also be used in high salinity water (estuary), whereas radio tags cannot function well in that environment.

The primary acoustic telemetry system that the AFEP currently uses is the JSATS (Eppard 2008), and a list of the recent studies conducted with JSATS since 2005 is included in Appendix B, Table 7.B.2.

**Fish and Wildlife Program**

PIT-tags are used in the following Fish and Wildlife Program projects.

**Smolt Monitoring Program (SMP)**

The federal and non-federal Smolt Monitoring Program was established in 1982 to provide a long-term consistent database for monitoring annually the status of juvenile and adult fish migrations past the hydropower dams on the Snake and Columbia rivers as a foundation for development of hydrosystem operations to improve fish passage conditions. Subsequently, the Smolt Monitoring Program has provided the basis for downstream passage measures for the NOAA Fisheries Biological Opinion for listed Columbia and Snake River anadromous fish stocks. The Smolt Monitoring Program provides daily data on movement of both hatchery and wild smolts out of major tributary rivers and past the dams on the Snake and Columbia rivers. Indices of migration strength and timing are computed for the run-at-large at key monitoring sites. In addition, PIT-tagged smolts from hatcheries, traps, and mainstem dams provide measures of smolt speed and in-river survival through index reaches. Measures of fish quality, descaling and gas bubble trauma are taken on samples collected at each smolt monitoring site to supply indicators of the health of the run. Presently, smolt monitoring sites are located at Lower Granite, Little Goose and Lower Monumental dams on the Snake River; at McNary, John Day, Bonneville and Rock Island dams on the Columbia River; and at four traps in the Snake River Basin above Lower Granite Dam.

**Comparative Survival Study (CSS)**

The Comparative Survival Study is a field study of the survival of PIT-tagged spring/summer Chinook and PIT-tagged summer steelhead through the mainstem Snake and Columbia river(s) hydrosystem from the smolt life stage through returning adults, with a focus on relative survival of fish that traveled as smolts by alternative routes (e.g., in-river, transported, different routes of dam passage, and different numbers of dams passed).

The CSS is important because it is one of the few organized attempts to systematically release PIT-tagged hatchery-reared and wild smolts into the Snake and Columbia rivers for the purpose of comparative monitoring and evaluation. Most aspects of the study, from its design and methods to the analytical results, continue to be strongly debated in the region because the relative survival rates of salmonids under different hydrosystem operations and environmental constraints is a central concern of Basin water and fish management policies.

One of the major recommendations from a recent review of the CSS by the ISAB and ISRP (ISAB / ISRP 2007-6) was to "initiate a comprehensive study to determine why the PIT tagged Snake River wild spring/summer Chinook are producing lower SARs than the unmarked wild Chinook."

**Collaborative Systemwide Monitoring and Evaluation Program (CSMEP)**

The Collaborative Systemwide Monitoring and Evaluation Project was created for the shared, multi-agency development of a regional monitoring and evaluation (M&E) program for fish populations. CSMEP's goals are to: 1) document, integrate, and make available existing monitoring data on listed salmon, steelhead and other fish species of concern, 2) critically assess strengths and weaknesses of these data for answering high priority monitoring questions, and 3) collaboratively design and help agencies implement improved monitoring and evaluation methods related to key decisions in the Columbia Basin.

The CSMEP hydro workgroup used the Snake River Basin Pilot Study data (primarily CSS PIT tag study data) to evaluate alternate monitoring and evaluation designs (Marmorek et al. 2007). The ability to use the CSS study PIT tag data (i.e., SARs, TIRs, etc.) has allowed the hydro workgroup to estimate various cost-effectiveness/precision tradeoffs for the various design levels (status quo, low, medium and high). The long time series of SAR data from the CSS has indicated that the status quo monitoring design is a sufficient design for determining if the Fish and Wildlife Program's SAR target for wild Snake River spring/summer Chinook is being met. CSMEP has consciously decided to focus on broad scale decisions rather than issues such as reach survival, dam passage survival, spill passage efficiency, forebay delay, and travel time because other projects are working on these finer scale issues. Increasing the number of PIT-tags per year will improve the precision of annual and seasonal estimates, but for transportation evaluations a very large increase in tags would be required to make substantial improvements over the status quo. Such an increase may be redundant with other Fish and Wildlife Program and AFEP projects, hence such an increase is not warranted unless coordinated with these other tagging efforts.

While the CSMEP Status and Trends Group primarily uses weir and trap data for abundance estimates, and redd and carcass survey data for spawning information and the success rates, the process of identifying key information needs for the status and trends priority questions also enabled CSMEP to identify opportunities for integration. CSMEP's Hydro designs rely heavily on PIT-tagging efforts which could also be used to provide age structure data for the status and trends domain within an integrated design. A significant portion of status quo status and trends monitoring data is a result of hatchery effectiveness monitoring (e.g., hatchery managed weirs).

Ground-based redd surveys and weirs used to collect status and trends information can also provide the data needed for straying/RRS study designs developed by CSMEP's Hatchery group. Since carcass surveys are a key component of the hatchery straying design, aerial redd surveys can be replaced with ground-based redd/carcass counts in order to address both questions. As we better understand the key information needs (scale/frequency) for each question, the opportunities for integration become more apparent.

In the recent review of CSMEP (ISRP 2008-1), the ISRP stated that it was useful to combine data from multiple years to obtain alternative estimates of precision of estimates of SARs. However, the ISRP did not mean that methods to improve precision of estimation within a year should receive less attention. It is counter-intuitive that increasing the number of tagged fish would not necessarily equate to increasing the probability of correct decisions (CSMEP Rept., p. 86, Volume 2). Discussion of the conditions under which increasing tag numbers is, or is not, beneficial is helpful and illustrates the benefit of creative use of simulation models. Nevertheless, the conditions under which increased tagging is not beneficial must be clearly articulated to be credible. The cautionary statements that managers need to take into account when deciding on tag numbers for both short- and long-term objectives are clearly illustrated in the simulation results.

### NOAA Fisheries Snake River Spill-Transport Study

At NOAA Fisheries' request the ISAB recently conducted a scientific review (ISAB 2008-5) of seasonal variation in the benefit of transportation of spring migrating smolts from four Snake River Evolutionary Significant Units (spring/summer Chinook, steelhead, sockeye, and fall Chinook). As part of the review the ISAB considered the adequacy of available tagging data to characterize fish response to alternative spring spill and transport operations. In addition, the impacts of alternative spill-transport scenarios on Pacific lamprey were considered.

The ISAB concluded that the PIT-tagging data are generally adequate to characterize response in April and May to hydrosystem conditions for spring/summer Chinook and steelhead. The adequacy of tagging data for Snake River fall Chinook was not examined. The ISAB found the tagging data for Snake River sockeye were not adequate to evaluate the effect of alternative spill-transport scenarios (ISAB 2008-5). Specifically, the effect of route of passage through the hydrosystem on the incidence of sockeye descaling is unknown. In fact, limitations in tag detection technology mean that adequate data on route of hydrosystem passage are not available for all species. For example, PIT-tag detection is currently not possible during fish passage through a spillway. The paucity of data for downstream migrating juvenile Pacific lamprey was also noted as a limitation.

**Pacific Ocean Shelf Tracking Project (POST) Study**
The POST study has used surgically implanted acoustic tags in two populations of hatchery spring Chinook (Snake River - Dworshak Hatchery and Yakima River - Cle Elum supplementation fish) to measure in-river and early marine survival and test two major hypotheses: (1) Is additional "latent" or "delayed" mortality experienced after Snake River smolts pass the eight dams they encounter as in-river emigrants? and (2) Does transporting Chinook smolts by barge improve early marine survival rates over in-river migrants? The 2008 study year was the third year this study has been conducted and data from 2006 and 2008 (2007 data could not be used because of disease problems in the Yakima fish) indicate that the answer to both questions is no, although these results are based on small numbers of tagged fish and a small number of ocean entry dates (Welch et al. 2008).

The POST study data on early ocean entry survival of Columbia River Basin spring Chinook smolts has extended our knowledge to a portion of the life cycle that was previously unknown. The long-lived battery of the VEMCO acoustic tags and the ocean shelf hydrophone array have provided the tools to gain this much needed information.

## Limitations and Challenges for Smolt Monitoring

**PIT tags**
One of the major limitations of PIT tag systems for hydrosystem smolt monitoring is antenna size. The largest antenna currently deployed at the mainstem hydroelectric dams is 17 feet by 17 feet at Bonneville Dam's second powerhouse corner collector. Researchers currently cannot detect PIT-tagged fish passing through spillways or turbines at the mainstem dams and thus cannot get route-specific passage and survival information on fish passing through these routes.

The development of a fish-tracking system for the individual spill bays may require a new PIT-tag to be designed. Although it is not known what the tag dimensions will be, it is known that it will be a passive tag because an earlier investigation showed that the additional detection range gained by adding a battery to a PIT-tag would be modest.

Potentially, a fish's long-term survival rate (SARs) may be impacted by PIT-tagging in the juvenile life stage, as it appears that fewer PIT-tagged fish are returning as adults than would be expected (Williams et al. 2005, Knudsen et al. in press) as some of the returning fish lost their tags. For fish tagged as juveniles, the tag can be expelled during late maturation before or during spawning activity. To better understand if or why this may be occurring, the ISAB and ISRP recommended that the CSS study "initiate a comprehensive study to determine why the PIT tagged Snake River wild spring/summer Chinook are producing lower SARs than the unmarked wild Chinook." (ISAB / ISRP 2007-6).

A relatively new application of PIT tags in the Columbia River Basin is the placement of PIT tag detection systems in tributaries to be able to monitor both tagged smolt and adult movements in both large and small tributaries in order to better understand salmonid behavior and migration timing. For instance, in-stream PIT-tag detection systems in both the Twin Creeks on the Olympic Peninsula and Gold Creek in the Methow River Basin have documented significant movement of juvenile fish during the fall. Juvenile fish migration in the fall has also been documented in Beaver Creek in the Methow River Basin and Rattlesnake Creek in the White Salmon subbasin which are both using an in-stream PIT-tag detection system (Connolly et al. 2008). Migration timing of juveniles could be linked to subsequent survivals.

Furthermore, development of future tributary in-stream PIT tag monitoring systems will help advance our understanding of some of the life history strategies exhibited by fall Chinook salmon. The in-stream systems would also help us learn more about the fate of adult migrants after they have been detected at Lower Granite Dam; in other words, if critical tributaries had PIT-tag detection capability, the presence of adult fish could potentially be monitored on the spawning grounds. The goal is to have prototype in-stream transceivers developed and deployed in key tributaries in the near future.

**Radio Tags**

All radio tags currently used in the Basin require an external trailing antenna, which may affect swimming performance of juvenile fish or attract predators. Handling effects and gastric or surgical effects can also be significant. Although radio tags continue to decrease in size and weight, they are unlikely to become small enough to use for studying fry or juvenile lamprey. The radio tags currently used in the Basin do not have a tag life long enough to be used to evaluate adult returns for various juvenile migration histories. Depths greater than 9 m can also limit the detection of radio tags unless underwater antennas at depth are used. In addition, the radio tags currently used in the Basin have a limited code set that is much smaller than those available for other technologies, including PIT-tags, CWTs, and acoustic tags.

Future developments in radio tags are likely to include continued miniaturizing of transmitters while maintaining tag life needs, increasing the numbers of unique transmitters that can be used at the same time, improving sensor technologies, and possibly eliminating the external antenna. As transmitters continue to be miniaturized, radio tags may be useful to evaluate survival and behavior past multiple mainstem hydropower dams and over longer river reaches. Sensor technology applications of radio tags currently include depth, motion, and water temperature. While these sensors can be added to transmitters for adult fish studies, adding them to tags used for studying juvenile salmonids would significantly increase the size of the tag. This larger-sized tag limits sensor application to large fish. For example, Beeman et al. (1999) used miniature pressure-sensitive radio tags to determine migration depth of juvenile steelhead in the Snake and Columbia Rivers.

Much of the past radio tag research has focused on investigating salmon behavior at the mainstem Columbia River and Snake River hydropower projects. In this work, the pulse rates of the tags have been relatively high, ranging from 1 to 2 seconds. As a result, the life of the tag has been relatively short (between 9 and 18 days). However, setting the pulse rate on tags at a slower rate, e.g., once every 10 seconds, would significantly increase tag life and make it more suitable for systemwide applications.

Thus, there is a reasonable expectation that smaller and longer lasting tags can be developed with antennas that may have little to no measurable effect on the fish. Radio tags, when used in combination with PIT-tag technology, has the potential to address many of the management needs in the Basin. It is unlikely that radio technology will allow managers to address questions related to juvenile lampreys or estuaries (because of salt water interference). However, no single technology will be useful in all situations. The most effective strategy may be to continue to develop several tag technologies that, used in combination, are highly effective at addressing all of the management needs. The alternative would be a single tag technology that addresses most of the needs well but does a mediocre job at addressing the remainder of the needs.

**Acoustic tags (AT)**

At the present time, two types of acoustic telemetry systems are used with Columbia River salmonid smolts: VEMCO tags used by the POST Project with receivers in freshwater, the estuary, and coastal ocean and JSATS tags used in the river and estuary by USACE.

As with radio tags, acoustic tags have limitations due to handling and surgical procedures for insertion of the tag, the size of the tag, and the life of the tag. Surgical procedures are required to insert tags into the body cavity of the fish. This operation and the tag's weight may affect the swimming and feeding behavior, growth, susceptibility to disease and infection, and survival of the fish (Lacroix et al. 2004; Anglea et al. 2004; Brown et al. 2006; Welch et al. 2007; Chittenden et al. 2008). Suturing materials and procedures also affect implantation success (Deters et al. 2008). Presently tags are implanted only in smolts larger than 85-105 mm fork length. Tags may also be lost or rejected from fish; expulsion of tags has been observed in subyearling Chinook less than 108 mm (Brown et al. unpubl; Liedtke et al. unpubl).

Tag size is a function of power needs (battery size) and operating frequency; power needs are driven by operating frequency and transmission life requirements. The higher the operating frequency, the smaller the tag and the shorter the detection range. Lower frequencies have greater detection range requiring fewer receivers in a given detection array than higher frequency systems. However, lower frequency systems require a larger transducer than higher frequency systems, and thus require more power (larger batteries) to transmit a signal and are more susceptible to interference from ambient noise.

Transmitter life is directly correlated to available power as well as the transmission rate of the tag. As rate increases, the battery life of the transmitter decreases. The battery life of juvenile salmonid transmitters generally ranges from 20-90 days depending on the study objectives. Larger transmitters used to study other species, such as sturgeon, can last several years. Variation may also exist in transmission strengths of individual tags that may affect detection ranges, hence calibration of tags may be required. Some tags can be programmed to turn off for extended periods and be reactivated later.

Future development of acoustic telemetry technology will focus on smaller transmitters with longer life expectancies, enabling one type of tag and receiver system to track fish through the river and into the near-shore ocean. Variable pulse rate tags or tags that can be turned on and off after receiving an interrogation signal from a receiver need to be developed to achieve longer tag life.

Advances are being made to download the data from receivers in shallow water through uplinks that do not require their recovery. Downloads through satellite, radio or cell phone links, however, are not yet feasible for receivers in the open ocean. Here the information must at present be obtained by recovery of the data from underwater receivers, either directly or through acoustic linkage.

Life span or death tags are also needed that indicate where and when a fish becomes immobile, is eaten, dies, or its heart rate stops. Data-recording tilt tags are being developed that show when a fish tilts or goes belly up (Shardlow et al. 2007). A tag that sends out a strong "death throe" when this happens that could be recorded by a distant receiver is needed.

Long-term effects of acoustic tags need to be more thoroughly studied. More data are needed to compare SARs for double tagged acoustic and/or sham acoustic + PIT vs. PIT tags.

Further advances in the field of electronics will continue to result in smaller, longer-lived transmitters. Studies are ongoing to evaluate the biological effects of acoustic transmitters, which will provide further insight into the utility of using this technology to answer resource management questions related to the recovery of salmon stocks in the Basin. Future research needs to focus on the life history of juvenile salmonids in the Basin, from the mainstem above dams into the ocean.

## Where is there a need for better data and coordination?

PIT tag detectors in spillways, removable spillway weirs (RSWs), and turbines are needed to collect PIT tag data on migration timing and survival by routes of passage – which currently cannot be done. Flat plate detector units, similar to the one developed for the corner collector at Bonneville's second powerhouse need to be developed for these other routes of passage and for dams throughout the hydrosystem.

As described above on page 30, PIT tag detection systems in Basin tributary systems are needed to collect data on movements of smolts and adults to better understand migration behavior (including straying) and spawning success.

Data are needed to determine why untagged adult salmonids are returning at higher rates than PIT tagged fish.

Long-term data are needed on effects of acoustic and radio tags on juvenile and adult salmonids.

There is a need for better data on the status and trends of wild fish populations, but the data are difficult to obtain because of the risks in handling too many wild fish for tagging. Using hatchery fish as surrogates for wild fish by raising them to match size/weight is one way to do this, and it has been done before with moderate success.

Coordination for tag projects within the USACE's AFEP Program is fairly good, but coordination of tag programs/projects between AFEP and Fish and Wildlife Program projects could be much improved. This has been partially attempted by the recent 2008 AFEP Annual Review where Fish and Wildlife Program funded PIT tag survival studies and the POST study made presentations on recent results.

Coordination between Fish and Wildlife Program tagging projects appears to be often lacking, but efforts by PNAMP for standardizing some of the tagging protocols and CSMEP's summarization and integration of monitoring data (including tag data) several domains has begun much needed improvement.

## C. Hatchery and Harvest Management

Hatchery production and harvest management of salmon are appropriately considered together because hatchery salmon are produced primarily to provide harvest. The evaluations needed for management include:

1. What are the differences in the effectiveness of alternative hatchery operations?
2. What are the contributions of individual hatcheries and stocks to specific fisheries?
3. What is the extent of straying hatchery fish into natural spawning areas?
4. How does selection of broodstocks for hatcheries affect and the fraction of hatchery fish that spawn naturally and the productivity of wild fish?
5. The rates of exploitation by stock and fishery;
6. Plans for harvest management.

### What types of tags are currently being used in the hatchery and harvest management and by whom?

In the Basin, the primary information for hatchery and harvest management is drawn from fish marked with coded wire tags, with some information gathered from fish marked with PIT tags. Genetic marking is often used to examine demography and the fitness of hatchery-origin adults that spawn naturally. Thermal marking is limited to the monitoring and evaluation of chum salmon production in the lower Columbia River and estuary.

Coded wire tagging is BPA funded through the Northwest Power and Conservation Council's Fish and Wildlife Program and the Lower Snake River Compensation Program; federally funded through the Mitchell Act; public utility district funded in the upper Columbia (Grant, Douglas, and Chelan PUDs); and state funded. The U.S. v Oregon settlement details the current agreement on production and tagging within the Basin for most salmon and steelhead stocks. PIT tags are applied through the Council's Fish and Wildlife Program, Lower Snake Compensation Program, USACE, and PUD programs. Many of the PIT tags are primarily for hydrosystem monitoring, but serve ancillary purposes for hatchery management. Visible Implant

Elastomer (VIE) and fin clips are also used to identify hatchery fish in terminal locations (sorting and counting weirs in tributaries).

As an example, fin clips, CWT, Visible Implant Elastomer (VIE), and PIT tags are currently used to gather the data for evaluating and managing spring and fall Chinook and steelhead in the Snake River Basin (Table 2. J. Hesse personal communication). Salmon and steelhead are tagged and recovered by the Council Fish and Wildlife Program, the Lower Snake River Compensation Program, and COE projects.

**Table 2.** Tags Applied to Hatchery spring/summer and fall Chinook and steelhead in the Snake River Basin[1]

| Purpose | Spring/summer Chinook | Fall Chinook | Steelhead |
|---|---|---|---|
| Broodstock Management | CWT, VIE, Adipose Fin Clip | CWT, VIE, Adipose Fin Clip, (PIT) | CWT, Adipose Fin Clip |
| Run Prediction | (CWT, PIT) | (CWT, PIT) | (CWT, PIT) |
| Harvest Estimation | Adipose Fin Clip, CWT | Adipose Fin Clip, CWT | Adipose Fin Clip, CWT |
| Escapement Estimation | Adipose Fin Clip, (PIT, Oxytetracycline) | Adipose Fin Clip, CWT, (PIT) | Adipose Fin Clip, (PIT) |
| Run Reconstruction | Adipose Fin Clip (PIT), CWT | Adipose Fin Clip PIT, CWT, VIE | Adipose Fin Clip PIT |
| Distribution | (PIT), CWT | (PIT), CWT | (PIT), CWT, RT |
| Life Stage Specific Survival | PIT, RT, CWT | PIT, RT, CWT | PIT, CWT |
| Juvenile Production | PIT | PIT | PIT |
| Supplementation Effectiveness | Adipose Fin Clip, PIT, CWT | Adipose Fin Clip, PIT, CWT | Adipose Fin Clip, PIT, CWT |

1. The mark/tag types used for specific management applications by species is identified and mark/tags used opportunistically are in parentheses.

***Broodstock Management.*** This term generally pertains to the control/manipulation of the hatchery:natural composition and exclusion of strays within hatchery broodstocks. Ventral fin clips were used in past, but not currently, to identify supplementation production groups. The table does not include marks applied for broodstock management for small scale studies (i.e. PIT tags to assess merits of collecting steelhead broodstock in the fall to reduce straying).

About 30% of the Snake River hatchery-origin fall Chinook are un-marked (no fin clip or CWT). However, approximately 17% of the unmarked fish are PIT tagged, increasing the total percentage of "marked" hatchery production to approximately 75%. Estimation of the percent natural-origin fish incorporated in the broodstock uses PIT tag and scale pattern analysis. Thermal marking of otoliths is under consideration for future application.

***Run Prediction.*** Run prediction or forecasting is currently handled by the *U.S. v Oregon* Technical Advisory Committee (TAC). Generally these are age class structure regressions based on a number of index sites. Cohort size estimates use known age from CWT and estimated age based on fish size. In-season run size adjustments use PIT detections at mainstem dams. Concerns about whether estimates of survival of PIT tag fish are representative of unmarked fish with regard to hydrosystem passage route and accuracy are currently being assessed.

***Harvest Estimation***. Non-Indian spring/summer Chinook salmon and steelhead fisheries are selective and rely on adipose fin clips to allow retention of fish. Treaty fisheries are not always selective and fall Chinook harvest (non-Indian and Treaty) have been non-selective until 2008 when limited selective sport fisheries occurred in the Snake River Basin. In all cases creel surveys sample retained fish for CWTs and enable partitioning the harvest estimates to certain production groups. Fall Chinook salmon harvest monitoring in the ocean and Columbia River fisheries currently uses adipose fin clips to trigger CWT sampling.

***Escapement Estimation.*** This is the quantification of the number of fish of a hatchery and natural origin returning to a tributary/natal stream. The application of large numbers of PIT tags representatively across Basin-wide production programs is occurring with fall Chinook salmon and steelhead, and to a limited extent with spring/summer Chinook salmon. This tagging effort combined with extended array PIT tag detection systems and census detection at mainstem dams enables estimates of escapement to the Basin and some tributaries.

## What, if any, are the limitations of the technology and sampling designs?

### Limitations and Challenges for the CWT Program

The CWT program has been the primary source of data for hatchery evaluation and harvest management over the last 40 years. Nonetheless, there are some limitations to the program that have never been adequately addressed, and new challenges that have emerged over the past decade or so.

#### Insufficient Natural Escapement Sampling

A long-standing limitation of CWT data is inadequate sampling for tagged hatchery fish in escapements to natural spawning grounds (Hankin et al. 2005, Marmorek et al. 2007). This information is needed to estimate the number of surviving adults to complete exploitation rate calculations for conservation under the Pacific Salmon Treaty and to estimate hatchery straying. This later information is important for a thorough analysis of the status and trends of natural salmon and steelhead populations. The inadequacy of the existing estimates of hatchery straying is documented in the Collaborative Systemwide Monitoring and Evaluation Project (BPA 200303600) 2007 Snake River Basin Pilot Report (Marmorek et al. 2007) and Pacific Salmon Commission expert panel report on the CWT program (Hankin et al. 2005) and in a follow-up action plan to address recommendations in the expert panel report (PSC 2008b).

There are two more recent challenges to the adequacy of the CWT program to provide information for salmon harvest decisions. One is adequacy of tagging rates and fish sampling rates under altered fishing regimes and poor ocean survival. The other is mass marking hatchery salmon and steelhead with an adipose fin clip and then implementing mark selective fisheries.

**Reduced Hatchery Tagging and Fishery Sampling**

For management under the Pacific Salmon Treaty, tagging levels have been set at 200,000 for Chinook salmon indicator stocks at hatcheries and sampling rates of 20% in fisheries for the purpose of estimating brood year exploitation rates. These standards were adopted based on survival, fishery patterns, and brood year exploitation rates for fall Chinook fingerling releases observed during the late 1970s and early 1980s (PSC 2008b). With reduced fisheries and marine survival the number of recovered tags has decreased leading to increased uncertainty of the vital statistics estimated from CWT data. Additionally, tagging and fishery sampling have been reduced due to constrained budgets. There has also been an increase in uncertainty associated with increased total catch in recreational fisheries, because estimates from recreational fisheries are more challenging to sample and estimate.

*An Action Plan in Response to Coded Wire Tag (CWT) Expert Panel Recommendations* (PSC 2008b) evaluates CWT tagging levels and fishery sampling for Basin fisheries managed under the Pacific Salmon Treaty, provides alternative suggestions for establishing tagging and sampling levels, and summarizes recommendations from agencies participating in the response to the expert panel for correcting the deficiencies in the current program. The PSC Coded Wire Tag Workgroup recommended to the PSC that agencies be requested to respond to the PSC by October 2008 1, 2008, and that PSC technical committees review the responses. Modification of tagging and sampling programs directed at PSC management would likely affect several Fish and Wildlife Program (FWP) projects including: *FWP 198201301 – Coded-Wire Tag Recovery*: PSFMC; *FWP 198201302 – Coded Wire Tag – ODFW*; *FWP 198201303 – Coded Wire Tag – USFWS*; *FWP 198201303 – Coded Wire Tag – WDFW*.

It does not appear that CWT data used in the management of Pacific Fishery Management Council fisheries, Columbia River Fisheries Management Plan/*U.S. v Oregon* fisheries, and tributary fisheries in Oregon, Washington, and Idaho that are not also part of the PSC management have had a recent review of the statistical adequacy of the tagging and sampling elements.

**Hatchery Mass-Marking and Mark-Selective Fisheries**

Mass-marking and mark-selective fishing is being employed to more fully exploit hatchery fish while attempting to limiting mortality to natural populations of conservation concern that are encountered in the same ocean or river fishing locations. Typically mass-marking involves clipping the adipose fin to distinguish hatchery fish which may be retained during fishing, from unmarked natural fish which must be released. Some unmarked fish that are caught and then released will die because of injury and stress, but many are likely to survive. It is hoped that this scheme will enable harvest of abundant hatchery fish and conserve less abundant natural fish.

The impacts of ocean fishing on natural salmon populations is inferred from exploitation rates measured using CWT data from tagged hatchery fish. When hatchery fish that serve as surrogates for a natural population no longer experience the same pattern of capture, the mortality from fishing can no longer be estimated for the natural population. If a stock experiences a series of non-selective and selective fisheries, there could be appreciable mortality owing to harvest in the non-selective fishery and capture/release mortality in the selective fishery that cannot be observed (measured).

One proposal to provide the data to evaluate mark-selective fisheries is Double Index Tagging (DIT). In a double index tagging program two paired groups of fish with CWTs are released. The groups have different CWT codes. One group has a mass-mark (i.e., adipose clip). The other is unmarked. In mark-selective fisheries individuals from the mass-marked group are caught and retained and individuals from the unmarked group are released. In these mark-selective fisheries only the CWT from the mass-marked group will be recovered in the fishery. In non-selective fisheries both the mass-marked and unmarked individuals will be retained, and CWTs from both groups could be recovered. Escapement of unmarked fish with CWTs is estimated by hatchery returns. In theory, differences in the cumulative exploitation patterns between the two groups could be used to estimate the effects of mark-selective fishing on an associated natural population.

Using double index tagging programs expands the cost and complexity of CWT programs. The requisite number of tags required doubles because the number of fish in each group cannot be reduced without increasing uncertainty of the recovery statistics. Additionally, since CWTs must be recovered from both marked and unmarked individuals, electronic tag detection (ETD) methods are required to identify individuals with a CWT. Electronic tag detection is not employed everywhere (i.e. Alaska does not use it). If CWTs of unmarked double index tagged group pairs are not recovered in non-selective fisheries the impacts of mark selective fisheries cannot be estimated by differences in exploitation between mass-marked and unmarked double index tagged pairs (ISAB 2005). The ISAB summarized the status of mass marking/mark selective fisheries for Council in 2005 (ISAB 2005-4b).

Conservation benefits to natural populations from mark-selective fishing have yet to be documented (Hankin et al. 2005). Moreover, double index tagging methodologies remain in question. Zhou (2002) used Monte Carlo simulations to evaluate uncertainty in exploitation rates estimated based on double index tagging methods and concluded that fishing impacts on unmarked salmon cannot be adequately estimated using this method. There are double index tagged groups in the Basin. An evaluation of the actual application of double index tagging is not yet available.

## Where is there a need for better data and improved coordination?

Despite the difficulties, the CWT system is the only technology that provides data for the estimation of exploitation rates for Pacific Salmon Treaty stocks and fisheries (Hankin et al. 2005). Longstanding shortcomings of the CWT recovery system still pose problems, including inaccurate or non-existent estimates of freshwater escapement, especially stray (non-hatchery) escapement, and inadequate sampling of some fisheries (e.g., inadequate sampling of freshwater sport fisheries and direct sales) (Hankin et al. 2005).

Shortcomings of the existing coastwide CWT program are detailed in the *Action Plan in Response to Coded Wire Tag (CWT) Expert Panel Recommendations* (PSC 2008b), including identification of improvements needed in efforts to tag, recover, and report data by projects within the Council's Fish and Wildlife Program. Technical staff from the respective agencies should evaluate the statistical basis of their programs and identify remedial actions that are necessary to bring the system to a level sufficient to provide data for management. Some of the shortfalls have arisen because of budget constraints both within the Fish and Wildlife Program and within other programs. For example, proposals reviewed in the 2007-09 solicitation identified that tagging at some Mitchell Act hatcheries had been deferred or discontinued because of a lack of funding. Sampling programs receive funding from multiple sources. When budgets are frozen at existing levels, manpower is reduced and sampling efforts are curtailed.

The CSMEP Snake River Pilot study concluded that CWT data could be a useful source for estimating the straying of hatchery fish to natural spawning grounds, but identified that in many subbasins the survey design and sampling effort as well as the data collection and data reporting are inadequate to estimate stray rates. CSMEP provides alternative survey designs to make these estimates. Without endorsing any specific approach, the ISAB and ISRP recommend that a basinwide strategy is needed to design and implement survey methods to provide annual reports of hatchery stray rates. The University of Washington Columbia Basin Research internet portal provides annual SAR estimation from CWT data from Basin hatcheries (*FWP 199105100*). This type of reporting should be implemented basinwide.

**Status of Alternative Tools for Harvest/Hatchery Management**

Harvest management currently relies on cohort reconstruction which requires knowing the stock and age of each fish captured by fishing area and time. Ages are known for fish carrying a CWT because the tag code is associated with a specific stock, hatchery, and brood/release year.

Genetic methods (Genetic Stock Identification (GSI), and Parental-Based Tagging (PBT); see Genetic Markers, Appendix A) offer the potential to replace or augment CWT data for harvest management. Genetic stock identification methods provide estimates of proportions of specific stocks in mixtures, but the ages of the fish assigned to a particular stock is unknown. Parental-based tagging methods differ from conventional genetic stock identification that estimates stock composition of mixtures. In parental-based tagging, parents -- either as individuals or as mating pairs -- are genotyped at a large number of loci. Fish that are captured and harvested (or released) are genotyped and assigned to parents using pedigree analysis. By identifying the parents, the source hatchery and age of the fish are known. This approach has the potential to provide information sufficient for cohort reconstruction and stock-age-fishery exploitation rates.

While genetic stock identification alone could not provide the required data, it could complement the existing CWT system and, together with otolith thermal marking and other aging methods, produce the needed information (Hankin et al. 2005, PSC 2008a). If genetic stock identification were used to provide estimates of stock proportions for harvest management, fish would still need to be aged by some other method.

Ages also could be provided by analysis of annual growth rings on scales. The error associated with this aging is not well defined, and how aging error influences the uncertainty of harvest exploitation rates needs to be determined. Ages could also be provided by thermally marked otoliths (see Appendix A). The thermal mark on the otolith would identify an individual as having originated from a specific hatchery, stock, brood year, and release group. There is uncertainty about how many potential codes that can be marked on a salmon otolith. Volk (1994) estimated there is a limit of about 1000 tag codes for Chinook using this technology. This could provide sufficient codes for the Pacific Salmon Treaty indicator stocks, but not for the other harvest and management objectives evaluated using the CWT system. There may be sufficient resolution with thermal marking to provide enough codes for the Basin (Craig Busack, Washington Department of Fisheries and Wildlife, personal communication). Pilot evaluations of otolith thermal tagging are warranted.

Genetic stock identification has potential to be employed in-season in terminal harvest areas to provide additional support to management decisions. As an example, in-season adjustments are made to harvest regulations based on abundance of salmon passing Columbia River dams during particular periods. There are established cutoff dates to separate different stocks of fish. But migration timing can vary from year to year. In these circumstances the transition from one stock to another passing a specific location could be evaluated using genetic stock identification. CRITFC has recently completed an investigation of genetic stock identification of Chinook stock mixtures at Bonneville Dam, demonstrating that management cutoff dates over-estimated spring Chinook and under-estimated summer Chinook salmon in 2005 (Narum et al. 2007).

Genetic stock identification methods could also be used to test the assumptions in current harvest models. The Pacific Fishery Management Council (PFMC) and the Pacific Salmon Commission (PSC) harvest models are based on time and area distributions for base years determined from CWT data collected during the early 1980s. These and additional assumptions about the similarity of the ocean distributions and encounter rates of fish with and without a coded wire tag could be tested by comparing stock proportions estimates from coded wire tags versus genetic stock identification.

Proof-of-concept investigation of parental-based tagging is justified and timely. There is a proof-of-concept project underway with Chinook salmon at Feather River Hatchery in California, at Voights Creek Hatchery in Puget Sound and at George Adams on Hood Canal, and with steelhead in the Snake River Basin. For the Puget Sound investigations, initial results from juvenile hatchery fish should be available by the end of 2009. Until multiple proof-of-concept trials have been evaluated, it is premature to presume this approach will supplant coded wire tags, but the methodology is well worth pursuing. The principal questions are whether progeny from closely related hatchery populations can be discriminated at a reasonable cost, and there are logistical challenges to sampling all the parents and representative offspring.

**Mass Marking/Hatchery Mark Rates**

The ISAB and ISRP have supported marking all hatchery fish. This allows fish to be segregated at counting and broodstock collection weirs, so the ratio of hatchery-origin and natural-origin adults can be controlled. At the same time, the ISAB and ISRP share the concerns about using mark-selective fisheries as a conservation tool to maintain abundance of natural populations and the consequences of mass-marking and mark-selective fisheries on estimates of mortality on natural populations. Support for tagging all hatchery fish should not be confused with support for mass-marking to enable mark-selective fisheries. Applying a mark that is useful for hatchery and natural population broodstock management that is then used for mark-selective fisheries is problematic. In at least one project in the Basin (Johnson Creek) CWTs are applied to summer Chinook, but they are not fin clipped. Instead they are tagged with visible implant elastomer (VIE) tags (Jay Hesse, Nez Perce Tribal Fisheries).

Otolith thermal marking provides the opportunity to mark 100% of a population without leaving a visible mass-mark. For broodstock management a drawback of this approach is that it would require post-season assessment because fish are killed and otoliths removed for evaluation. The method could be used for evaluating straying from hatcheries, either used alone or in combination with CWTs. There is a coordinated system for the thermal marking of otoliths and a database for reporting both marks and recoveries (see Appendix A).

## D. Estuary and Ocean Conditions

These are questions that the ISAB believes are relevant to the management of Columbia River salmonids after they pass through the hydrosystem.

1. What are the survival rates of juvenile salmonids through the estuary? And in the nearshore ocean? And until return to freshwater?
2. How do these rates differ among stocks, passage times at Bonneville, in-river vs. transported? Is there significant delayed mortality in the estuary or in the ocean? Are survival rates affected by tag types?
3. How are survival rates related to residency time in the estuary or migration rates along the coast?
4. How are they affected by predation rates by birds in the estuary?

### What types of tags are currently being used in the hydrosystem and by whom?

Tags that have been used or are being used to detect smolts below Bonneville include PIT, radio, and acoustic tags. Research has been supported by the USACE, NMFS, and the NWPCC.

Studies have estimated the migration rates of juvenile salmonids below Bonneville Dam into or through the estuary using all three tag types (Ledgerwood et al. 1998; Schreck et al. 2006; McMichael et al. 2006, 2007; Welch et al., 2008). Travel times, usually about 2-5 days, vary depending upon the species, size, season, year, and flows. Yearling Chinook and steelhead smolts generally travelled faster and in a more directed manner than subyearling fish. Mean travel time from Bonneville to the mouth of the Columbia River (about 140 miles) was about 3-4 days for yearling Chinook and steelhead and 4.5 for subyearling Chinook, and both groups tended to migrate on the northern side of the channel on an ebb tide as they approached the Columbia River bar (McMichael et al. 2006, 2007; Welch et al. 2008).

Schreck et al. (2006) estimated from radio tags that smolt mortality was low from Bonneville Dam to the estuary, but was 11-17% due to bird predation in the estuary. Welch et al. (2008) estimated survival of Snake spring Chinook (62%) and two steelhead tag groups (76% and 63%) from Bonneville Dam to the Astoria Bridge with V9 VEMCO acoustic tags. Survival estimates of juvenile Chinook salmon tagged with JSATS acoustic tags, released from the Bonneville Dam bypass through the Columbia River estuary, averaged about 55% for yearlings and 7.5 to 15%- for subyearling fish in 2005 (McMichael et al. 2007). For these JSATS studies, acoustic receiver arrays were deployed across the Columbia River estuary at river mile 5.6 and 2.0, some were stationary, some had acoustic releases, and others had a radio communication system buoy attached that could transmit data in near real-time. Date, time, pressure and water temperatures were recorded on some of the receivers (PostFCRPS-2005-06_SynthTechMemo.pdf; ColMouth-HabitatUse-2005.pdf).

PIT tags are detected in trawl surveys in the Columbia River estuary and on bird colonies. The goal of the trawl surveys is to detect 2-3% of the millions of PIT tagged fish (both barged and in-river migrants) that pass Bonneville Dam. Recently the efficiency of the trawl system has been improved by using a larger Matrix antenna system to detect fish as they pass through the trawl. Any differences in SARs for in-river and transported smolts passing Bonneville Dam and entering the ocean in the same time periods would suggest delayed mortality that could be attributed to differences in freshwater and ocean survival between these two groups of fish (Ledgerwood et al., 2007, pers. comm.).

Mortality from some avian predations has been estimated from PIT tags recovered on colonies of nesting birds in the estuary. Based on PIT tag recoveries in 2007, about 5.5 million smolts (95% C.I.= 4.8-6.2) were consumed by Caspian terns on East Sand Island, similar to the estimates for 2006. Tern predation on steelhead smolts was particularly high, about 14% for in-river migrants and 8% for transported smolts. Consumption by cormorants was similar or greater than that of terns and was estimated to be over 10 million smolts in 2006. These predation rate estimates are corrected for biases associated with detection efficiency of PIT tags on the colonies and on-colony deposition rates (by the percent of PIT tags fish fed to terns that were subsequently recovered on the colony). Predation rates based on the number of PIT tags interrogated at Bonneville Dam (in-river) or released from barges and subsequently detected on tern and cormorant colonies, ranged from less than 1% to 16% for in-river wild steelhead (corrected only for detection efficiencies) (Roby et al. 2008). Predation rates by birds vary over time and depend on timing of smolt outmigration and the breeding seasons of the piscivorous birds (Roby et al. 2007; Ryan 2003).

Marsh et al. (2008) compared bird predation and SARs of PIT-tagged yearling Chinook and steelhead that were released at rkm 225 (Skamania) and in the estuary at rkm 10 (Astoria). All Astoria releases were made after dark on an outgoing tide to reduce avian predation from nearby colonial nesting birds. Abandoned bird colonies were scanned for PIT tags from released fish. Based on tag recoveries, this release strategy was apparently successful as avian rates were about 3 times higher for Chinook salmon and about 7 times higher for steelhead released at Skamania vs. Astoria. However, preliminary data indicate that transportation and release in the estuary provided only modest improvement in SARs for steelhead, but not for Chinook salmon. These results are similar to the tagging study in 2005 using JSATS tags that found no significant advantage to releases of steelhead smolts at Astoria vs. Skamania (McMichael et al. 2006).

## What, if any, are the limitations of the technology and sampling designs?

In summary, based on our knowledge at the present time, PIT and acoustic (JSATS and VEMCO) tags are being used below Bonneville Dam, in the estuary, and the coastal ocean. Each of these tag types are used to address important management issues and each has unique applications and limitations. PIT tags sampled by trawling in the estuary provide estimates of the relative abundances and timing of different tag groups (e.g., in-river vs. barged) entering the estuary. PIT tag recoveries on the bird colonies provide estimates of mortality by avian predators in the estuary. PIT tags, at present, are the only tags used to estimate SARs because of their long life, lower cost, and the large numbers implanted. JSATS and VEMCO tags provide estimates of travel times and survival until ocean entry, whereas the VEMCO tags, with longer life, have been used to track juvenile salmonids in the coastal ocean as they migrate to the north. Integration of all of these studies using different tag technologies could provide better data on when and where critical periods occur in the life history of juvenile salmonids. Deploying adequate numbers of PIT-tagged fish (or double tagged with PIT/acoustic tags) from individual stocks, timed so that they depart Bonneville, enter the estuary and/or ocean at the same and different times during outmigration could help to partition route-specific mortality relative to migration timing and locations.

## Where is there a need for better data and improved coordination?

At the present time JSATS and VEMCO tags are only decoded by their respective receivers. Therefore duplicate receivers are used in the mainstem and estuary. Coordination among these acoustical systems is recommended. Universal or compatible receivers, both in-river and in the ocean, could improve tag detection data.

The response of salmon and steelhead to many management and restoration actions in the Basin cannot be adequately interpreted without better understanding how climate-ocean ecosystem, density-dependent, and anthropogenic processes (including fishing) regulate salmon growth and survival and migrations in marine environments. Addressing these uncertainties is warranted.

# IV. Statistical Considerations

Statistical adequacy of fish tagging programs and projects implies having adequate data to confidently estimate metrics of interest within a meaningful margin of error. In addition adequate data are essential to identify important differences among treatment groups with adequate statistical power. The statistical properties of metrics of interest are complex, making estimation of sample sizes challenging (Newman et al., 2003). Add to this the necessity to consider multiple perspectives on what amount of uncertainty is acceptable and the exercise of sample size determination, even for a relatively narrow question, becomes even more difficult. In addition to sample size determination, a difficult issue that must be addressed is how well the tagged fish represent untagged fish (Zhou, 2002). Nevertheless, all tagging projects should present justification and documentation of sample size determination and identify the population(s) being represented at the proposal stage and progress reporting stage.

As the demands for more and more tagging to answer management questions are identified, it is useful to maintain the perspective that tagging in the Columbia River Basin is an aggregate of many research and monitoring activities. Consequently, tagging programs should be developed to answer several inter-related questions as suggested by Paulsen, 2005. (http://www.cbfwa.org/csmep/web/documents/general/Documents/PITtagV4-12-14-05.pdf).

As a general rule, tagging adequacy should be investigated under several scenarios reflecting varying levels of uncertainty accompanied by an evaluation of the consequences of the uncertainty. As an example, Marmorek et al. (2007) identified different levels of PIT tagging effort that could be used depending on acceptable decision making uncertainty. Activities, such as the CSMEP PIT Tag Integration Exercise, represent promising strategies for developing wise use of tagging resources and should be encouraged. (http://www.cbfwa.org/csmep/web/documents/Documents.cfm?searchstring=PIT+tag)

Important considerations that must not be overlooked in the evaluation of the statistical adequacy of fish tagging projects and programs within the Basin are the effects of tagging on survival, growth, and behavior of fish (Knudsen et al., in press). These effects, as well as tag loss and tag malfunction, must be quantitatively considered under study conditions to produce reliable estimates of the metrics that inform management decisions. Cooperation among tagging programs is vital to allow efficient estimation of tagging effects that may be used in multiple tagging projects, rather than having each project devote resources to determining tagging effects.

Millions of salmonids have been tagged in the last 20 years. The resulting data have been processed, analyzed, and archived, but the information content has not been thoroughly mined. The amount of available data and advances in statistical methods present an opportunity to gain additional knowledge from tagging data with little cost. Recent studies illustrate advantages of using advanced statistical methods to explore tagging data (Buchanan and Skalski 2007, Newman et al. 2004).

# Appendix A. Tagging Technologies

In the Columbia River Basin, at least seven tag types or natural tag methodologies are currently used to collect vital statistics and other information on fish needed for management decisions: coded wire tags (CWTs), PIT tags, radio tags, acoustic tags, data storage tags, genetic markers, otolith thermal marks, otolith microstructure and microchemistry (Interagency Tagging Technologies Focus Group, 2007). Applications of these tag types can function broadly to detect presence, recognize groups, recognize individuals, and determine parentage (Goodman 2005). The information can be used to estimate fish population size, harvest rates and contribution, movements, habitat use, mortality (survival) rates, hatchery contributions, and natural reproductive success. Each of these tags and their methods of application has advantages and limitations associated with tag cost; tag life; tag effects on fish survival and behavior; tag detection; tag retention; and detection efficiency (Goodman 2005). We elaborate the advantages and limitations for each methodology and provide a summary description below.

## A.1. Coded Wire Tags

### Background

Coded wire tags are small pieces (1.1 mm long x 0.25 mm diameter) of magnetized stainless steel wire, encoded to identify either a cohort or an individual. The original tags developed in the early 1960s had longitudinal colored stripes. These were replaced in 1971 with binary tags, constructed with the presence or absence of a laser etched notch in six positions along the wire. Current tags are coded with laser etched numbers 0 – 9 in six positions along the wire, with up to one million unique tag codes.

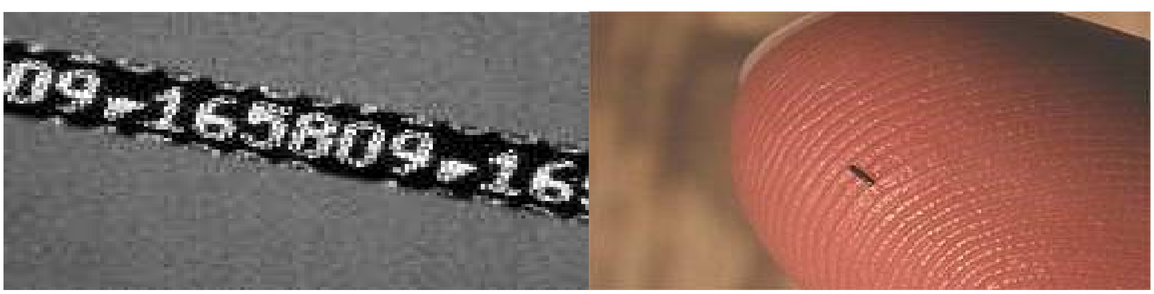
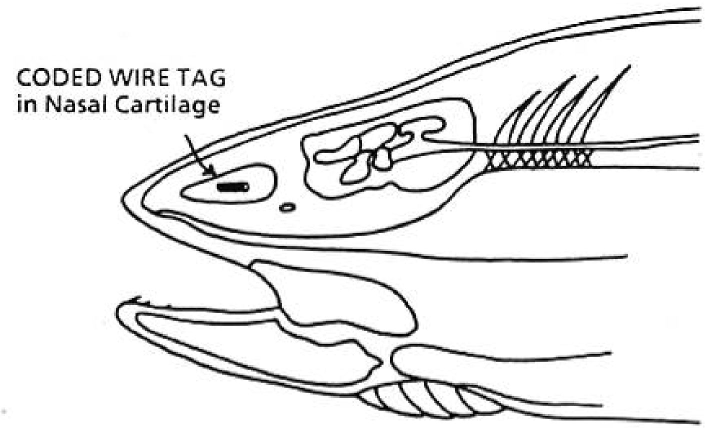


**Figure 1.A.1.1.** A decimal coded wire tag (0.25 mm x 1.1 mm; Northwest Marine Technology photos)

CWT tags are usually inserted into the nasal cartilage of salmon or steelhead juveniles, before the fish are released from hatcheries. Tags are sequenced end-to-end, along a roll of wire. A machine cuts the wire slightly longer than the length required for a single tag, loads it into a hollow needle, and then injects it into the snout of a parr or smolt.




Extracted from Johnson (2004)

**Figure 2.A.1.2.** Longitudinal section through the head of a juvenile salmonid showing the correct placement of a coded wire tag in the nasal cartilage. (After Koerner 1977).

Using CWT technology involves reporting the tagging of specific stocks, then sampling fisheries, hatcheries, and natural escapement for fish with CWTs, and then reporting CWT recoveries. Fish marked with CWTs cannot be identified by inspection of an intact fish, so some sort of external mark must accompany a fish with a CWT. By a 1977 agreement of managers, the external mark is a clipped adipose fin. Snouts are removed from adipose fin-clipped fish at check-stations and sent to laboratories for dissection and tag decoding.

Coded wire tags are applied by federal, state, and tribal agencies to juvenile salmon and steelhead at hatcheries and to a few wild stocks that are trapped and tagged. Ocean and coastal recovery of tagged fish is undertaken by the Alaska Department of Fish and Game, Canadian Department of Fisheries and Oceans, Washington Department of Fish and Wildlife, Oregon Department of Fish and Wildlife, and California Department of Fish and Game, the Northwest Indian Fisheries Commission, Quinault Nation, and Quileute Tribe. In the lower Columbia River, ODFW and WDFW jointly sample Columbia River tribal, sport and commercial fisheries. WDFW and the Yakama Nation sample Washington tributaries and the upper Columbia River. The Idaho Department of Fish and Game and the Nez Perce Tribe sample fisheries, hatcheries, and spawning grounds for marked fish. The ODFW and the Confederated Tribes of the Umatilla Indian Reservation sample fisheries and spawning grounds in the Umatilla River.

The agencies that remove and decode the tags then report the recoveries to the Pacific States Marine Fish Commission (PSMFC) Mark Process Center. The PSMFC web-accessible database maintains records of all the fish tagged and recovered. Records include hatchery origin; release site and dates; average size at release; brood year; date and location of capture; and capture size.

## Current Uses and Management Application

Currently, CWT data are used in:

- hatchery management to evaluate rearing and release experiments, estimate adult production, and manage broodstock
- harvest management (Pacific Salmon Treaty and Pacific Fishery Management Council ocean fisheries, Columbia River Fish Management Plan and *U.S. v Oregon* in-river commercial, sport, and tribal fisheries, and state managed fisheries in tributaries), and
- natural stock management (hatchery straying and natural spawning stock composition).

In addition, CWTs provide extensive data on stock-specific migrations, ocean distribution patterns and migration corridors of juvenile salmonids in the North Pacific, especially for coho and Chinook salmon (Pearcy and Fisher 1988; Trudel et al. 2008). Migration speeds and growth rates after release can also be estimated. Weitkamp and Neely (2002) illustrated the latitudinal segregation of returning adult coho salmon from hatcheries along the coast, which provide an opportunity for implementing stock-selective fisheries.

Bonneville Power Administration supports CWT marking through both the Northwest Power and Conservation Council Fish and Wildlife Program (FWP) and through funding for the Lower Snake River Compensation Program.

Numerous Fish and Wildlife Program projects are involved in various aspects of tagging, tag recovery, and data management, and analysis for CWT-marked salmon and steelhead. These projects include:

*FWP 198201301 – Coded-Wire Tag Recovery*: supports PSFMC Regional Mark Processing Center - Regional Mark Information System (RMIS) database, ODFW ocean sampling, ODFW and WDFW Columbia River sampling, and ODFW Clackamas tag recovery and decoding lab.

*FWP 198201302 – Coded Wire Tag - ODFW*: provides coded wire tags and supports tagging and tag recovery at several Oregon salmon hatcheries.

*FWP 198201303 – Coded Wire Tag – USFWS*: provides coded wire tags and supports tagging and tag recovery at Carson, Eagle Creek, and Little White Salmon National Fish Hatcheries.

*FWP 198201303 – Coded Wire Tag – WDFW*: provides coded wire tags and supports tagging and tag recovery at Elochoman, Kalama Falls, Fallert Creek, Washougal, Klickitat, and Toutle State Fish Hatcheries.

*FWP 198335000 – Nez Perce Tribal Hatchery O&M*: NPT – provides tagging support to apply CWTs to 625,000 spring Chinook and 1,000,000 fall Chinook at the Nez Perce Tribal Hatchery.

*FWP 198335005 – Nez Perce Tribal Hatchery M&E*: NPT – provides CWT tags and support to CWT-mark 625,000 spring Chinook and 1,000,000 fall Chinook at the Nez Perce Tribal Hatchery.

*FWP 198343500 – Umatilla Hatchery Satellite Facilities O&M*: CTUIR – provides support to collect snouts from CWT-marked spring and fall Chinook, summer steelhead, and coho adults returning to the Umatilla River.

*FWP 198802200 – Umatilla Fish Passage Operations:* CTUIR – provides support to collect data on tagged adults at Three Mile Falls Dam.

*FWP 198805308 – Hood River Powerdale Trap/Pelton Ladder O&M*: ODFW – provides tags and support for coded wire tagging of steelhead and spring Chinook for release in the Hood River.

*FWP 199000500 – Umatilla Hatchery M&E*: ODFW – provides support for CWT- tagging of salmon and steelhead released into the Umatilla River, and for analysis of harvest and adult return data.

*FWP 199000501 – Umatilla Basin Natural Production Monitoring*: CTUIR – provides support to monitor Three Mile Falls Dam and natural spawning grounds for steelhead and salmon with CWTs.

*FWP 199105100 – M&E Statistical Support for Life-Cycle Studies*: U of W – provides estimates of smolt-to-adult survival (SARs) for 100 hatchery populations of salmon and steelhead in the Basin using CWT data.

*FWP 199306000 – Select Area Fisheries Enhancement*: ODFW – Provides CWTs and support for tagging coho and Chinook salmon reared in net pens in the lower Columbia River for harvest, and tag recovery from fisheries and analysis of tag data.

*FWP 199604000 – Mid-Columbia Coho Restoration Project*: Yakama Tribe – provides CWTs and support for tagging, tag recovery, and analysis to monitor reintroduction of coho salmon to the Wenatchee and Methow subbasins.

*FWP 199604300 – Johnson Creek Artificial Propagation Enhancement*: NPT – provides CWTs and support for tagging, tag recovery and analysis to monitor supplementation of summer Chinook in Johnson Creek.

*FWP 200303600 – CSMEP – Collaborative Systemwide Monitoring and Evaluation Project*: CBFWA – supports analysis of existing data to evaluate suitability of monitoring designs to address management decisions by hatchery subgroup evaluating hatchery straying, using CWT recovery from natural spawning grounds.

*FWP 200735500 – Determining the Accuracy of Adult Coho Salmon Population Estimates from a Random, Spatially Balanced design using Area-Under-the-Curve*: WDFW – An investigation of evaluation methods to estimate adult coho salmon spawning populations. Fish with clipped-fins will have snouts removed for CWT recovery, decoding, and submission to the tagging database.

*FWP 200736800 – Adult coho salmon monitoring proposal for the lower Columbia River province*: WDFW – An investigation to estimate the status and trends of natural and hatchery coho salmon in the lower Columbia River. Fish with detectable CWTs will have the snouts removed, tags dissected and decoded, and the information submitted to the tagging database.

In addition to Fish and Wildlife Program projects, fish production and tagging at hatcheries and some natural populations involve funding through the USACE; Bureau of Reclamation; Chelan, Douglas and Grant County PUDs; Idaho Power Company; Lower Snake River Compensation Plan (BPA funded); Mitchell Act (NOAA funding); Pacific Coast Salmon Recovery Fund; Pacific Gas and Electric; and U.S. Fish and Wildlife Service. The *2008 – 2017 United States v. Oregon Management Agreement* sets out the production and tagging/marking regimes at Basin salmon and steelhead hatcheries (U.S. v Oregon 2008).

## Advantages and Disadvantages

***Advantages*** **- Advantages of CWTs include:**

- **Fish Size.** Tags can be inserted into very small animals. Half-tags have been inserted into chum and pink salmon fry.
- **Tag effects.** Research has demonstrated minimal effects to survival and migration.
- **Tag Retention.** High retention rates from juvenile to adult ages.
- **Large code capacity.**
- **Inexpensive Tags.** Tags cost about $ 0.10 each.

***Disadvantages*** **- Disadvantages of CWTs include:**

- **Tags not externally visible.** A fish with a tag needs to have an ancillary mark to segregate that individual from a mixture of fish for tag recovery.
- **Tag recovery and decoding.** Tag recovery is lethal, and it takes several minutes for a lab technician to dissect the tag from a snout and decode the tag under magnification.
- **Equipment and personnel to tag the fish and detect tags is expensive.** Tagging crews often move from one hatchery to another, tagging batches of fish. The equipment for tagging is sophisticated and moderately costly. Equipment (wands, etc.) for detecting CWT-marked fish is not sophisticated (basically a metal detector), but manufacturer's costs are high.
- **Effort requires a dedicated lab for processing large numbers of samples.**

## Future Needs/Developments

The CWT program has been the primary source of data for hatchery evaluation and harvest management for over 40 years. There are nevertheless some limitations to the program that have never been adequately addressed, as well as new challenges that have emerged over the past decade or so, among them:

### Insufficient Natural Escapement Sampling

A long-standing limitation of CWT data is inadequate sampling for tagged hatchery fish in escapements to natural spawning grounds (Hankin et al. 2005, Marmorek et al. 2007). This information is needed to estimate the number of surviving adults to complete exploitation rate calculations for conservation, under the provisions of the Pacific Salmon Treaty and to estimate straying of hatchery fish. The information is important for a thorough analysis of the status and trends of natural salmon and steelhead populations. The inadequacy of the existing estimates of hatchery straying is documented in the Collaborative Systemwide Monitoring and Evaluation Project's (BPA 200303600) 2007 Snake River Basin Pilot Report (Marmorek et al. 2007); the PSC's expert panel report on the CWT program (Hankin et al. 2005); and in a follow-up action plan to address recommendations in the expert panel report (PSC 2008b).

### Reductions in Hatchery Tagging and Fishery Sampling

For management under the Pacific Salmon Treaty, tagging levels have been set at 200,000 for Chinook salmon indicator stocks at hatcheries and sampling rates of 20% in fisheries for the purpose of estimating brood year exploitation rates. These standards were adopted on the basis of survival, fishery patterns, and brood year exploitation rates for fall Chinook fingerling releases observed during the late 1970s and early 1980s (PSC 2008b). With reduced fisheries and marine survival, the number of recovered tags has decreased, leading to increased uncertainty of the vital statistics estimated from CWT data. Additionally, there has been a reduction in tagging and fishery sampling, due to constrained budgets. There has also been an increase in uncertainty associated with increased total catch in recreational fisheries, because recreational fisheries are more challenging to sample and estimate.

### Hatchery Mass-Marking and Mark-Selective Fisheries

In ocean or river locations where fisheries encounter mixtures of natural and hatchery salmon, mass-marking and mark-selective fishing is being employed to more fully exploit hatchery fish, thus limiting mortality to natural populations of conservation concern. Typically, mass-marking involves clipping the adipose fin, providing identification of hatchery fish for retention during fishing. The requirement is that unmarked natural fish are to be released. Some unmarked fish that are caught and then released will die because of injury and stress, but many are likely to survive. It is hoped that this scheme will enable harvest of abundant hatchery fish and provide for conservation of less abundant natural fish.

The impacts of ocean fishing on natural salmon populations is inferred from exploitation rates measured with CWT data from tagged hatchery fish. When hatchery fish that serve as surrogates for a natural population no longer experience the same pattern of capture, the mortality from fishing can no longer be estimated for the natural population. If a stock experiences a series of non-selective and selective fisheries, there could be appreciable mortality, due to harvest in the non-selective fishery and capture/release mortality in the selective fishery that cannot be observed (or measured).

## A.2. PIT Tags

### Background

Passive Integrated Transponder (PIT) tags are glass encapsulated, implantable radio-frequency identification devices that contain integrated circuit chips. They are passive, i.e., do not contain an internal energy source such as a battery. Consequently, the tag remains functional for the entire life of a tagged animal. To tag a fish, a single PIT tags is pre-loaded into a disinfected hypodermic syringe, and the tag is injected into an open space in the chest cavity of the anesthetized fish. After implantation, the PIT tag remains inactive until it is energized by the electromagnetic field generated by low-frequency radio waves emitted by an antenna connected to a transceiver. A PIT-tag system consists of the tag, antenna, and transceiver. The performance of a PIT-tag system is a function of characteristics of all three components.

**Figure 3.A.2.1**. A PIT tag and hypodermic syringe needle (photo courtesy of Digital Angel's Destron Fearing subsidiary)

Since the late 1980s, PIT-tags have been the main tool used for monitoring salmonid survival, migratory behavior, and timing in the Basin. The application of using PIT tags in salmonids and development of PIT tag monitoring systems at hydroelectric dams in the Columbia and Snake rivers was pioneered by Earl Prentice and other fishery scientists at NOAA Fisheries during the late 1980s (Prentice et al. 1990a;1990b; and 1990c.). In 1993, NOAA Fisheries and University of Washington scientists demonstrated the feasibility of estimating the survival of PIT tagged yearling Chinook passing through lower Snake River dams and reservoirs (Iwamoto et al. 1994). The Single-Release (Cormack 1964; Jolly 1965; and Serber 1965), Modified Single-Release (Skalski et al. 1993) and the Paired-Release (Burnham et al. 1987) models were used to make the estimates under various study designs.

Most of the PIT-tag equipment installed throughout the Basin for monitoring salmonids utilizes full-duplex (FDX) technology, although a relatively small number of PIT tags utilize half-duplex (HDX) technology. In FDX technology, the electromagnetic fields created by the antennas are always active (i.e., on) and the PIT-tags are detected only when they enter the electromagnetic field produced by the antennas. The passive tags enter the field, become energized, and begin to modulate the field. Then the transceiver determines what their tag codes are by interpreting how they modulate the field. In the ISO-based FDX-B technology that is currently being utilized, the frequency of the electromagnetic field is 134.2 kHz, and it takes 31 msec for a complete tag message to be decoded.

The HDX technology also includes a 134.2 kHz carrier field: however, it operates quite differently from the FDX technology. In the HDX technology, the antenna generates the 134.2-kHz field for a short period of time (typically about 50 msec) and then it shuts off the field for a short period of time so that it can "listen for" the tag code being transmitted by the HDX PIT-tag. Unlike the FDX tags, the HDX tags actively transmit their tag codes. Currently, HDX PIT-tag technology is being used in the Pacific Northwest for fish species such as bull trout and adult lamprey. Researchers for these species have chosen to use HDX PIT-tag technology for several reasons: a) the individual fish can handle larger tags (23 mm x 3.85 mm; 0.6 g); b) the fish do not swim as fast, and therefore the slower tag detection is not a factor; c) researchers are able to use single antennas that can span an entire stream bed; and d) the HDX transceivers manufactured by Texas Instruments (TI) cost significantly less than FDX transceivers.

In this review we will focus on the FDX PIT tag technology as this is the tag used in the Basin for anadromous salmonid research and monitoring.

**Full Duplex Technology**

FDX technology enables investigators to detect tagged fish moving at high speeds. The tags are small enough (12.5-mm length by 2-mm diameter; 0.1 g in air) to be implanted in juvenile salmonids as small as 60 mm in fork length. However, because the tags are so small, the transceiver needs to interpret the small level of modulation. As a result, the FDX-B systems typically have relatively small antennas (at least 95 percent of the antennas installed are smaller than 3 feet by 3 feet), though many larger antennas of various dimensions have been successfully installed. Furthermore, the ranges over which tags may be read are relatively short (measured in feet and inches) compared to ranges for active tag technology, which is measured in yards and miles.

Currently, most of the FDX components used throughout the Basin are manufactured by Digital Angel Corporation. Recently, to make a system work in the corner-collector flume at Bonneville Dam with a 12-mm tag, Digital Angel had to improve all three components of a PIT-tag system. As a result of that effort, the fisheries community switched to the new 12-mm SST-tag model in 2007. It was also necessary for Digital Angel to design a new transceiver to enable PIT-tag interrogation systems to work in remote stream locations. NOAA Fisheries worked with Digital Angel to produce a transceiver that can handle multiple antennas (the multiplexing transceiver can switch among six antennas and it auto-tunes each antenna) while basically using the power needed to operate one transceiver. Furthermore, researchers have worked hard to improve how they design antennas for in-stream research on fish passage and survival. As a result, today's largest antennas are twice the size they were when the multiplexing transceivers were first introduced three years ago.

NOAA Fisheries is currently leading an effort supported by BPA and the USACE to investigate expanding PIT-tag detection into mainstem Columbia and Snake river hydropower project spillways and turbines. NOAA Fisheries issued a contract in 2006 to Digital Angel to investigate the technical feasibility of designing a detection system for a spillbay at Bonneville Dam. Digital Angel has indicated that to be able to implement tag detection into the unfavorable spillbay environment, it may be necessary to design a non-ISO system. For example, since water velocities reach 60 ft/sec as the water explodes out of the spill gate on the tailrace side, the company may need to reduce the message length significantly in order to get multiple reads when the fish (and tag) is traveling that fast. Furthermore, the company may need to design a larger tag. Fisheries researchers have stipulated, however, that any newly designed tag must be capable of being read by the existing FDX PIT-tag systems.

### Tags

Starting with the 2007 salmon outmigration year, the standard 12-mm PIT-tag model became the SST tag (TX1400SST) manufactured by Digital Angel. This tag was designed to work in large antennas better than the ST tag, which has been the standard tag for the Basin since 2003. Tests conducted in 2006 in the Bonneville Dam corner-collector antenna that measures 17 feet by 17 feet demonstrated that this was true, as about 70 percent of the SST-tagged fish were detected compared to about 40 percent for the ST-tagged fish. This difference in detection levels also occurred in part because the transceiver and antenna for this system were optimized to detect the SST tags.

The SST tags are also making it possible for researchers to design larger antennas for in-stream interrogation systems with the current multiplexing transceiver (FS1001M). With the SST tag, they are now able to design antennas that measure 20 feet by 4 feet. The SST tags have basically the same physical characteristics as the ST tags (length = 12.5 mm, diameter = 2.1 mm, and weight in air = 0.102 g). Because of their small size, it is possible to tag smaller smolts and parr (down to about 60 mm in fork length), as well as adult salmonids. Digital Angel designed this newer PIT-tag so that they will be able to fabricate it using an automated process developed for the ST model. This keeps tag manufacturing costs down.

In 2006, Digital Angel also introduced a shorter 8-mm tag model (8 mm by 2 mm) that has a shorter read range than the longer 12-mm tags. These shorter tags were requested by researchers wanting to tag fish in the 50-60 mm range who were willing to settle for getting detection in the juvenile fish facilities but not in the corner-collector or some of the larger vertical-slot antennas for returning adult salmonids. This 8-mm tag model is based on the ST-tag technology and not the SST-tag technology, and thus the detection range is similar to a 12-mm tag, which was the tag model used in the Basin before the ST tag. Digital Angel also produces larger FDX-B tags (18-23 mm in length and 3-mm in diameter) that are also based on the ST tag technology.

### Transceivers

Digital Angel currently manufactures four different models of FS1001 transceivers.[1] The FS1001J transceivers are used in the small flumes and pipes at the juvenile fish passage facilities. The FS1001A transceivers are used to detect migrating adult salmonids in the fish ladder orifices and the smaller vertical-slot locations, and in larger pipes, e.g., the full-flow systems, at the juvenile fish passage facilities. The FS1001AB transceivers are used in the vertical-slot locations at Bonneville Dam. The FS1001M transceivers are the auto-tuning and multiplexing transceivers that are used for the in-stream interrogation systems. It should be noted that this entire series of FS1001 transceivers is in its last years of use because the electronic technology

[1] Digital Angel also manufactures a 2001 transceiver that is used for hand scanning and smaller in-stream applications.

that they are based on is now about ten years old. Moreover, some of the FS1001 transceiver parts are starting to become difficult to procure.

Digital Angel had to manufacture a new transceiver model (G2) for the Bonneville Dam-Second Powerhouse corner collector fish passage system to ensure detection of a 12-mm tag in a 17 foot by 17 foot antenna. To accomplish this, the manufacturer incorporated Digital Signal Processing (DSP) into the transceiver design. As a result of changes needed for improved performance, these new G2 transceivers cost nearly three times that of a FS1001 transceiver.

### Antennas

PIT-tag researchers have experimented with different types of wire and different brands of capacitors over the past few years in an effort to make larger antennas.. For example, the Bonneville Dam corner-collector antenna used Litz wire. Different shield designs have also been integrated into antenna designs in order to improve performance. Currently, there are no real standards in antenna design and construction as different groups have found different solutions that work for them. The general trend at this time is to seek improvements in the transceivers so that they have higher signal sensitivity, which will enable larger antennas to be constructed. This was the approach Digital Angel took for both the G2 transceiver and the FS1001M developments. Currently, the antenna width is the most limiting factor in expanding the applications where PIT-tag technology can be incorporated.

Environmental conditions also place limitations on antenna designs. NOAA Fisheries has been working on trying to apply PIT-tag technology to learn more about salmonid movement in estuaries. At this time, because high salinity conditions significantly reduce the field that an antenna can produce, only small antennas can be used. This field reduction obviously limits the types of research questions that can be answered.. Researchers are therefore encouraging the PIT-tag manufacturers to improve the PIT-tag system performance in saline environments.

A dam's spillway is another unfavorable tag detection environment. The spillway gates are made from metal that must remain in place, unlike in past installations, e.g., in the Bonneville Dam-Second Powerhouse corner collector, where it was structurally possible to remove all rebar in the immediate vicinity. Water itself reduces the performance of the current antennas with the current transceivers – in order to generate the required fields, it has been necessary to incorporate air gaps into the orifice antennas, vertical slot antennas, in-stream antennas, and the corner-collector antenna.

## Current Uses and Applications

In addition to determining survival rates of juvenile fish through Columbia and Snake river reaches, PIT tag data have also currently been used to determine the status of individual stocks; typically, this is done by calculating smolt-to-adult return rates (SARs). Numerous large-scale studies using PIT-tags have been undertaken to examine differences in SARs between transported and non-transported fish (Muir et al. 2006, Williams et al. 2005). PIT-tags are also being used in research to examine delayed mortality observed in the Snake River Chinook salmon (Muir et al. 2006) and to estimate avian predation rates (Ryan et al. 2001, 2003, 2007).

Research applications expanded dramatically in the mid-1990s when the ability to collect sub-samples of targeted fish using separation-by-code was added to many of the PIT-tag systems at the mainstem Columbia and Snake river hydropower dams (Marsh et al. 1999). Using separation-by-code, researchers have investigated route-specific passage information, as sub-samples of the tagged fish are collected so they can be examined physically. These sub-samples can be collected at the same hydroelectric facility or at another dam downstream. PIT-tags are also commonly used in radio-telemetry studies, either as a double tag or to identify groups of fish that should or should not be radio-tagged (e.g., fish from the Snake River or fish from the Upper Columbia River). Researchers have also used the separation-by-code tool to collect some of their study fish at multiple dams to monitor how physiological changes occur as the salmonids migrate downstream.

## Advantages and Disadvantages

### *Advantages*

The advantages of FDX PIT-tag technology include the following:

- **Tag size.** It is a small tag (most tags used are 12.5 mm by 2 mm; new 8 mm tag now available)
- **Fish size.** Can tag adult salmonids as well as small smolts (60 mm with 12-mm tags and down to 50 mm with 8-mm tags)
- **Tag life.** Tags are long-lived since they are passive, i.e., no battery is needed, thus the tags can last longer than the lifespan of salmonids
- **Tag cost.** Tags are relatively inexpensive (about $2/tag). A cheaper tag means that large numbers of fish can be tagged. This enables the fisheries community to tag groups of fish from the same hatcheries every year to learn more about year-to-year variation in migration and survival.
- **Tag detection.** Almost all of the mainstem Columbia and Snake river hydropower dams are now outfitted with PIT-tag systems that detect both migrating juvenile and adult salmonids.
    - Interrogation systems are currently installed in the juvenile fish bypass facilities located at most of the federal Columbia and Snake river hydroelectric dams.
    - Installation of full-flow detection systems at many mainstem dams (currently, these juvenile detection systems are installed at Ice Harbor, Lower Monumental, McNary, John Day and Bonneville dams) would enable PIT-tag systems to be operated year round.
- **Expanding tag use.**
    - Interrogation systems are currently being installed into Columbia River Basin tributary streams and yield fish movement information that was unknown previously.
    - Intensely monitored watersheds are starting to utilize PIT-tag technology in their monitoring programs.
    - Digital Angel is willing to work with the region’s fisheries community in developing new technologies to enable detection of tagged fish in locations currently

inaccessible. For example, researchers are currently working on determining whether it will be possible to detect PIT-tagged fish transiting individual spillway bays at mainstem Columbia and Snake river dams.

### *Disadvantages*

The disadvantages of FDX PIT-tag technology include the following:

- **Fish size.** Unable to tag salmonid fry or juvenile lamprey with current PIT-tags (even using the 8-mm tags).
- **Tag effects**. Potentially, a fish's long-term survival rate (SARs) may be impacted by being PIT-tagged in the juvenile life stage, as it appears that fewer PIT-tagged fish are returning as adults than would be expected. However, some of the returning fish could have lost their tags. (Knudsen et al. Ms; John Williams, pers. comm.)
- **Tag retention.** For fish tagged as juveniles, the tag can be expelled during late maturation before or during spawning activity.
- **Detection limitations.**
    - **Spill and Turbines.** Researchers currently cannot detect PIT-tagged fish passing through spillways or turbines at the mainstem dams and thus cannot get route-specific passage and survival information on fish passing through these routes.
    - **Estuary.** Estuarine applications are very limited because the saline water attenuates the electromagnetic field produced by the antennas and thus, it is only possible to install small shielded antennas (5 feet x 2 feet) in these locations.
    - **Tributary infrastructure limitations.** Not enough in-stream PIT-tag detection systems are currently installed to yield information on the research questions outlined in the in-stream applications section below, e.g., fish movement during the fall and winter months, or learning about different life-history strategies of salmonids.
- **Antenna and transceiver limitations.**
    - **Antenna size.** There are limitations on antenna size; the largest antenna currently deployed at the mainstem hydroelectric dams is 17 feet by 17 feet.
    - **Antenna installation expenses.** Due to detection interference, the technology normally requires the removal of all rebar from the area where antennas are installed and therefore, installations can be expensive.
    - **Antenna numbers.** The current multiplexing transceiver can only handle six antennas, yet researchers already have sites that need more antennas or larger antennas to answer the management questions.
    - **Auto-tuning range.** The existing range of auto tuning in the current set of transceivers is limited.

## Future Development

**Tags.** Digital Angel has indicated that it plans to make a larger PIT-tag in the near future that incorporates the SST technology. The company has a patent on PIT-tag implantation that prevents Bonneville and the Corps from purchasing tags from other tag manufacturers[2] that will be injected into fish. Because of this exclusive patent, which is active until 2010, BPA and the USACE have negotiated fixed prices for the tags they will purchase until 2010. The price per SST tag in 2007 was $1.90, will be $1.80 in 2008 and 2009, and $1.70 in 2010. As indicated, the development of a fish-tracking system for the individual spill bays may require a new PIT-tag to be designed. Although it is not known what the tag dimensions will be, it is known that it will be a passive tag because an earlier investigation showed that the additional detection range gained by adding a battery to a PIT-tag would be modest.

**Transceivers.** In order to meet the demands of stream researchers as they try to expand PIT-tag detection into larger streams, NOAA Fisheries is leading an effort to develop a new multiplexing transceiver. NOAA Fisheries recognizes that the fisheries community needs to be able to monitor fish movement in both large and small tributaries in order to better understand salmonid behavior and migration timing. For instance, instream PIT-tag detection systems in both the Twin Creeks on the Olympic Peninsula and Gold Creek in the Methow River Basin have documented significant movement of juvenile fish during the fall. The goal is to have prototype instream transceivers installed by the end of 2007. Juvenile fish migration in the fall has also been documented in Beaver Creek in the Methow River Basin and Rattlesnake Creek in the White Salmon subbasin which are both using an instream PIT-tag detection system (Connolly et al. 2008).

Furthermore, development of future instream systems will help advance our understanding of some of the life history strategies exhibited by fall Chinook salmon. The in-stream systems would also help us learn more about the fate of adult migrants after they have been detected at Lower Granite Dam; in other words, if critical tributaries had PIT-tag detection capability, the presence of adult fish could potentially be monitored on the spawning grounds. The goal is to have prototype in-stream transceivers developed by the end of 2007.

Moreover, the region will soon need to support the development of a new line of transceivers to replace the three models used at the mainstem hydroelectric fish-passage facilities. This effort should be able to use what was learned in both the G2 transceiver and multiplexing transceiver developments to speed up its development. It is likely that the three FS1001 transceiver models will be replaced with a single model, which will make operation and maintenance tasks easier for the Pacific States Marine Fisheries , which manages the regional PIT-tag database system.

**Antennas.** It is anticipated that antenna construction and size will change when the next generation of transceivers is produced. The instream users of the technology have indicated to Digital Angel a preference for antennas that do not need an air gap.

**Instream Applications.** Instream PIT-tag detection systems are now starting to reveal new fish migration patterns, such as more active movement during the fall months. Further development of instream detection systems will yield fish movement, survival and habitat use information related to:

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[2] Note that FDX tags manufactured by other companies can also be read in the fish passage facilities of the mainstem Columbia and Snake river hydropower projects.

- investigating questions about whether or to what degree some populations of salmonids (steelhead/rainbow trout and cutthroat trout) are resident or anadromous, since both life histories can occur in the same watershed. The resident or anadromous question has implications for Endangered Species Act interpretations and rulings.
- investigating different life history strategies of salmonids within streams and how they contribute to the full salmonid population within a watershed.
- collecting information on the behavior, survival, and life history strategies of wild versus hatchery fish. Again, collecting this type of data has implications for Endangered Species Act interpretations and rulings.
- investigating the different ways that salmonids utilize different types of habitats available to them throughout the year.
- advancing our understanding of some of the life history strategies exhibited by fall Chinook salmon.
- monitoring adult fish presence on the spawning grounds of critical tributaries. These systems could yield information on whether an individual adult fish that was successfully detected at a mainstem hydroelectric project goes on to spawn in its native stream, i.e., post-hydropower system spawning success.
- anchoring techniques for smaller streams are still being developed, and in streams with high or swift flows and heavy debris loads, keeping antennas installed and operating is challenging.
- if "grid" power is unavailable, options for alternative power sources can be an issue in determining where these in-stream systems can be deployed.

*Other Future Developments.* Based on its superior performance of HDX technology over FDX technology under saline conditions, researchers might explore applying HDX technology in future estuary tagging studies. However, the chief disadvantage of the HDX PIT-tag technology is that the vendor has little or no interest in modifying its equipment to broaden its use for fisheries research applications. For example, Texas Instruments refuses to consider manufacturing a smaller tag or to make changes to their transceivers to correct an identified problem. The Texas Instruments transceivers are also based on older electronics technology, and it is unclear when the company might discontinue manufacturing them.

## A.3. Radio Tags

### Background

Radio tags are transmitter-bearing tags attached (externally) or implanted (internally) on or in animals that transmit radio-frequency signals detectable through a system of one or more antennas and receivers. A radio telemetry system consists of tags, antennas, and receivers. The tags function much like conventional radio transmitters such as those found in a HAM radio or CB, only at different frequencies. Similarly, the antennas and receivers function similar to conventional antennas and radios associated with detection of standard broadcast signals.

Radio tags have been used to study passage and migration behavior for adult salmonids in the Basin since 1971 (Monan and Liscom 1971) and juvenile salmonids since 1980 (Faurot et al. 1982). The first application of radio tags to assess juvenile survival in the Basin occurred in 1997 (Hockersmith et al. 1999). Most radio tag studies for fish within the Basin have used transmitters operating at 30 MHz or 150 MHz.

Radio-tagged fish can be mobile-tracked by vehicle, on foot, by boat, or by air, which allows efficient surveys of remote or very large study areas. Other tag technologies (e.g., freeze brands, CWT or PIT-tags) typically either do not provide the same level of migration detail or are not as applicable for tracking individual fish within the freshwater portion of the Basin. Radio tag detection probabilities on riverine gates are typically between 90 and 98 percent, while detection probabilities within the various passage routes at mainstem Snake and Columbia river hydropower projects are typically 95 to 100 percent.

Radio tags have worked very well for evaluating both adult and juvenile salmonid passage at mainstem hydropower dams, particularly in assessing fish behavior in the near-dam environment, resulting in structural and operational improvements. Radio tags have been a useful tool to evaluate project survival, dam survival, pool survival, route-specific survival, passage efficiencies, forebay survival and delay, tailrace egress, travel times, avian predation, straying of adult returns, spawning distribution and timing, and adult fallback at dams. Transmitters have been getting smaller and smaller over the years (Figure 4.A.3.1.). Note that the tag size is now down to 0.6 g and is five times smaller than the radio tags used in 1980 and three times smaller than the tag used in 1997.

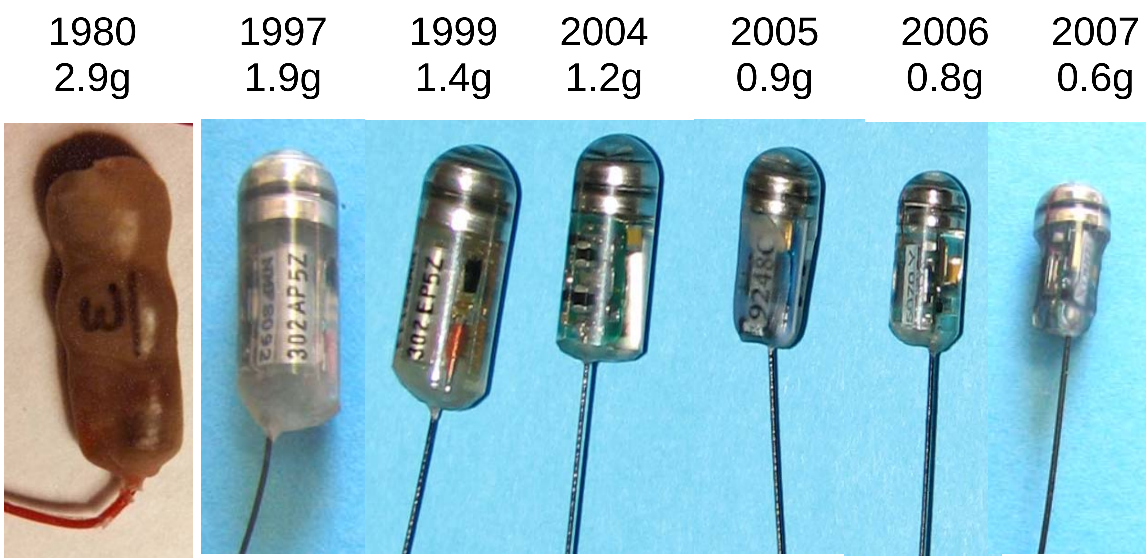


**Figure 4.A.3.1.** Development of radio tag transmitters over time.

Currently, radio tags can be used to study all species of adult salmonids, adult Pacific lamprey, and juvenile salmonids as small as 90-mm fork length within the freshwater portions of the Basin. Unlike with acoustic transmitters, turbulent hydraulic environments do not effect detection of radio transmitters. In addition, the ability of radio tags to be detected in the air is a major advantage over acoustic telemetry for studying highly migratory species through large river systems such as the Columbia and Snake rivers.

While a 2003 juvenile salmonid radio tag effect study (Hockersmith et al. 2003) indicated that 1.4 g radio-tagged fish had similar survival and migration rates as PIT-tagged fish over a period of six days or less and a migration distance of about 100 km, the radio-tagged fish had significantly lower survival than PIT-tagged fish when the migration distance was increased to 225 km and the travel time was more than 10 days. However, the juvenile radio tags used today are more than 50 percent smaller than the transmitters used in 1999, and now have shorter and lighter antennas. If the reduced survival for the radio tag fish in 2003 was due to the size of the tag, today's smaller radio tags may allow radio tag technology to be used to estimate survival for juvenile salmonids over longer distances and longer time periods.

Although radio tags continue to decrease in size and weight, they are unlikely to become small enough to use for studying fry or juvenile lamprey. The radio tags currently used in the Columbia River Basin also do not have a battery life long enough to be used to evaluate adult returns for various juvenile migration histories. In addition, the radio tags currently used in the Basin have a limited code set compared to those available for other technologies, including PIT-tags, CWTs, and acoustic tags.

## Current Uses and Application

NOAA Fisheries are the only researchers in the Basin using 30 MHz radio transmitters. The NOAA Fisheries radio tags transmit at one of nine frequencies spaced 0.01 MHz apart (30.17 to 30.25 MHz). For each frequency, the NOAA Fisheries code set has 505 unique codes or a total of 4,545 unique transmitters (code and frequency combinations). For studies requiring sample sizes greater than 4,545 individuals the code/channel combinations are repeated. The smallest NOAA Fisheries transmitters currently used in the Basin weigh 0.6 g, are 200 $mm^3$ in volume, and have a tag life of 10+ days at a 2 second pulse rate.

All other researchers using radio tags in the Basin use 149-151 MHz transmitters and the majority of these tags are manufactured by Lotek. The Lotek transmitters are on 1 of 25 frequencies ranging between 149.320 to 149.800 MHz (spaced 0.02 MHz apart) or from 150.320 to 150.800 MHz (same spacing). For each frequency the Lotek code set has 521 unique codes for a total of 12,500 unique transmitters (code and frequency combinations). This code set became available in 2003. Prior to this, the Lotek code set was 5,300 unique transmitters. The code/channel combinations are repeated for studies requiring sample sizes greater than 12,500 individuals. Due to the numbers of studies using Lotek transmitters in the Basin extensive coordination of frequency and codes among various research projects is required. The smallest Lotek transmitters currently used in the Basin weigh 0.37 g, have a volume of 215 $mm^3$, and have a tag life of 5+ days at a 2 second pulse rate. Larger transmitters are available with commensurate increases in signal strengths and battery life.

Radio tag receiving equipment can vary but typically are either sequential scanners, which are programmed to scan a frequency for a set period of time and then move on to the next frequency of interest, or digital spectrum processors (DSP), that are capable of scanning all frequencies (within a defined range) simultaneously.

Radio tag receiver systems for studies in the Basin use multi-element Yagi air antennas or tuned loops at riverine passage gates. A variety of underwater antennas (Beeman et al. 2004) including stripped coax, underwater dipoles, or underwater quad-poles are used to isolate passage routes at dams. Radio tag detection probabilities on riverine gates are typically between 90 and 98 percent. Detection probabilities within the various passage routes at mainstem Snake and Columbia River hydropower projects are typically 95 to 100 percent.

## Advantages and Disadvantages

### *Advantages*

- **Strong track record for application of results:**
    - **Dam passage.** Radio tags have worked very well for evaluating both adult and juvenile salmonid passage at dams, resulting in structural and operational improvements.
    - **Fish behavior.** Radio tags have also worked very well in assessing fish behavior in the near-dam environment.
    - **Multiple uses.** Radio tags have been a useful tool to evaluate project survival, dam survival, pool survival, route-specific survival, passage efficiencies, forebay survival and delay, tailrace egress, travel times, avian predation, straying of adult returns, spawning distribution and timing, and adult fallback at dams.

- **Multi-species tag, tag size.** Currently, radio tags can be used to study all species of adult salmonids, adult Pacific lamprey, and juvenile salmonids as small as 90-mm fork length within the freshwater portions of the Basin.

- **Detection in numerous environments.** Unlike with acoustic transmitters, turbulent hydraulic environments do not affect detection of radio transmitters. In addition, the ability of radio transmitters to be detected in the air is a major advantage over acoustic telemetry for studying highly migratory species through large river systems.

- **Technological advances.** As cited above, the most recent juvenile salmonid radio tag effect study evaluated the effects of 1.4 g transmitters relative to fish that were only PIT-tagged (Hockersmith et al. 2003). In that study the authors concluded that yearling Chinook salmon, which were either surgically- or gastrically-tagged with a 1.4 g radio tag, had survival and migration rates similar to PIT-tagged fish over a period of six days or less and a migration distance of 106 km. It is noteworthy that radio tags used today to tag juvenile salmon are more than 50 percent smaller than the transmitters used in 1999, and are suitable for tagging fish as small as 90 mm. In addition to smaller tags, shorter and lighter antennas are currently available. If the reduced survival for radio tag fish was due to the size of the tag, today's smaller radio transmitters may allow radio tags to be used to estimate survival for juvenile salmonids over longer distances and longer time periods.

*Disadvantages*

- **Detection limitations:**
    - **Freshwater only.** Radio tags are limited to use in the freshwater environment because salinity attenuates the signal from the transmitter. Therefore, this tag technology cannot be used to evaluate estuary or near-ocean behavior or survival.
    - **Depth limits.** Depths greater than 9 m can also limit the detection of radio tags unless underwater antennas at depth are used.

- **Potential behavioral effects, swimming performance.** All radio tags currently used in the Basin require an external trailing antenna, which may affect swimming performance of juvenile fish or attract predators.

- **Size limits.** Although radio tags continue to decrease in size and weight, they are unlikely to become small enough to use for studying fry or juvenile lamprey.

- **Tag life.** The radio tags currently used in the Basin do not have a tag life long enough to be used to evaluate adult returns for various juvenile migration histories.

- **Code limits.** In addition, the radio tags currently used in the Basin have a limited code set that is much smaller than those available for other technologies, including PIT-tags, CWTs, and acoustic tags.

## Future Development

Future developments in radio tags are likely to include continued miniaturization of transmitters while maintaining tag life needs, increasing the numbers of unique transmitters that can be used at the same time, sensor technologies, and possibly eliminating the external antenna. As transmitters continue to be miniaturized, radio tags may be useful to evaluate survival and behavior past multiple mainstem hydropower dams and over longer river reaches. Sensor technology applications of radio tags currently include depth, motion, and water temperature. While these sensors can be added to transmitters for adult fish studies, adding them to tags used for studying juvenile salmonids would significantly increase the size of the tag. This larger-sized tag limits sensor application to large fish. For example, Beeman et al. (1999) used miniature pressure-sensitive radio transmitters to determine migration depth of juvenile steelhead in the Snake River and Columbia River. In addition, electromyogram (EMG) transmitters have been used to measure swimming activity of adult salmon in the Basin (Brown et al. 2006, Geist et al. 2003).

Much of the past radio-tag research has focused on investigating salmon behavior at the mainstem Columbia and Snake river hydropower projects. In this work, the pulse rates of the tags have been relatively high, ranging from 1 to 2 s. As a result, the life of the tag has been relatively short (between 9 and 18 d). However, setting the pulse rate on tags at a slower rate, e.g., once every 10 s, would significantly increase tag life and make it more suitable for systemwide applications.

Additionally, vendors have been continuing to reduce the size of the radio tags, and tags that are as small as 0.25 g are not far off, especially if resources are directed towards that effort. Regardless of the potential for longer life and smaller radio tags, some have voiced concern over the presence of the external antenna and the potential effects that may have on the fish. However, recent advancements in antenna material and length have been made. Available information on the effects of the antenna on fish was collected using the original, longer antenna designs. Thread-like material is now available and the length can be reduced to less than half of the historical length. Further testing may show that these advancements have significantly reduced or eliminated any measurable effect of the antenna on the fish.

Thus there is a reasonable expectation that smaller and longer lasting tags can be developed with antennas that may have little to no measurable effect on the fish. Radio tags, when used in combination with PIT-tag technology, has the potential to address six of the eight management needs outlined in the introduction. It is unlikely that radio tags will allow managers to address questions related to estuaries or lampreys. However, no single technology will be useful in all situations. The most effective strategy may be to continue to develop several tag technologies that, used in combination, are highly effective at addressing all of the management needs. The alternative would be a single tag technology that addresses most of the needs well, but does a mediocre job at addressing the remainder of the needs.

Lastly, while it appears not to be an area of need at the time, the need to collect information on the energy expenditure of juvenile fish migrating past mainstem hydroelectric dams may be identified in the future. EMG tags used to collect this information have been successfully applied using larger fish in the past. It is reasonable to expect that this technology could be miniaturized for use in the future. This will likely take time and resources, but waiting until the need exists to begin to develop a tag for this capability will only lengthen the time it will take to develop the ability to gather this type of information.

## A.4. Acoustic Telemetry

### Background

Acoustic telemetry systems use sound waves to transmit information from a transmitter, through the water to a hydrophone, and then ultimately to a data logger or receiver. Current acoustic telemetry systems offer varying degrees of tag size, transmission life, frequencies, encoding schemes, and receiver capabilities.

### Current Uses and Application

Fish movements, migration rates, duration of residency, and survival rates can be estimated using acoustic tags. Partitioning the survival of salmon and steelhead from smolt out-migration through the hydrosystem to Bonneville Dam, from Bonneville Dam through the estuary to ocean entrance, and then in the ocean, is feasible with acoustic tags (see Table 1). This includes survival estimates during juvenile migration through the hydrosystem, including reach and route specific movements through surface bypass, spillways and turbines, as well as migration rates and survival after passing Bonneville Dam, through the estuary, and into the coastal ocean during the first several months.

Advances in the field of electronics have yielded significant advances in acoustic telemetry systems since their first use in the 1950s. These have led to smaller transducers and increased utility to monitor the migration behavior and survival of juvenile salmonids in the Basin.

There are three BPA-funded projects currently (2007-2009) using acoustic telemetry systems in the Basin. These include (1) Acoustic Tracking for Survival (Kintama Research Corp; POST; project 2003114000), (2) Recondition of Wild Steelhead (CRITFC; 200001700), and (3) Snake River Fall Chinook Salmon Life History (USGS; 200203200) (see Table 1). Six projects were funded by the USACE AFEP in 2008 (Table 7.B.2). These include: (1) a comparison of the performance of acoustic-tagged and PIT-tagged juvenile salmonids, (2) evaluation of the surface spillway treatments at John Day Dam, (3) spillway survival at Bonneville Dam, (4) behavioral guidance at Bonneville Dam second powerhouse, (5) survival of juvenile salmonids through the Columbia River estuary, and (6) effects of in-river and transportation migration strategies on differential delayed mortality of yearling Chinook in the Snake and Columbia rivers and estuary.

The Hydroacoustic Technology Inc. system (HTI) has also been used by the USACE (or CALFED) to assess the behavior and survival of juvenile salmonids during passage at hydro dams using both 2-D and 3-D detection systems (e.g., Anadromous Fish Evaluation Report 2006-W68SBV60478899, 2008; Ransom et al. 2008). Acoustic tags for scientific studies are, or have been, deployed in the mainstem, estuary, and ocean.

Relevant specifications for each of these tag types used in 2008 are provided in the following table.

**Table 3.A.4.1.** Comparison of acoustical tags used in the Columbia River Basin.

| | HTI | JSATS | VEMCO |
|---|---|---|---|
| Weight in Air (g) | 1.5 | 0.62 | 1.4 |
| Dimensions (mm) | 18 x 6.8 | 15.8 x 5.1 | 7.0 x 18 |
| Frequency | 307 kHz | 416.7 kHz | 69 or 81 kHz |
| Tag life | 25 days[3] | 115 days[4] | 127 days[5] |
| 3-D tracking capability | Yes | Yes | In development |
| # of unique codes | 100,000+ | 65,536 | 64,000+ |

[3] Referenced to 1 ping/4-8 seconds
[4] Referenced to 1 ping every 5 seconds
[5] Referenced to 1 ping/240seconds


**Figure 5.A.4.1.** JSATS Acoustic Micro-Transmitter with ruler for scale (Photo: courtesy of Pacific Northwest National Laboratory, operated by Battelle for the US Department of Energy).

Each of these tagging systems has inherent pros and cons, and studies using them have different objectives and methodologies. However, improved coordination among systems could provide integrated data on movement of juvenile salmonids through the hydrosystem into the estuary and coastal ocean. However, current technology requires the use of low frequency, relatively large tags for sufficient detections on ocean arrays. This may limit acoustic tag use in the coastal ocean for some stocks, particularly smaller wild smolts (<100mm). Nonetheless, the technology is evolving rapidly; tag size and weights are declining accordingly.

## Advantages and Disadvantages

### *Advantages*

General advantages of acoustic tag technologies include:

- **No External Antenna on Transmitters.** The absence of an external antenna translates to a less invasive implantation of the transmitter than for radio tags and precludes any potential drag or effect associated with an external antenna.

- **Detection Environment**. Useable for detection of tagged animals in both fresh and saltwater environments. Higher tag frequencies work better in fresh water and lower frequencies work better in saltwater.[6]

- **Three-dimensional Behavior.** With well-designed receiver arrays, allows precise location of tagged animals in three dimensions (e.g., near dams) and may aid in determining the cause and effect of changes in the animal's environment.

- **Detection Depth**. Although not unlimited, detection capability is usually not adversely affected by the depth of the tagged animal.

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6 However, using a mid-frequency to try and make a tag that works in both fresh and saltwater environments will not perform as well as a tag that is designed to work better in fresh or saltwater.

- **Detection Range**. Greater detection range underwater than radio tags.

- **Receiver Capability**. Receivers can be programmed to record environmental information such as temperature and pressure to compare with times of detection of tagged fish. In shallow water, a radio, cell phone or satellite uplinks can be used to download data in near real time.

***Disadvantages***

General disadvantages of acoustic tag technologies include:

- **Tag effects**. Surgical procedures are usually required to insert tags into the body cavity of the fish. This operation and the tag's weight may affect the swimming and feeding behavior, growth, susceptibility to disease and infection, and survival of the fish (Lacroix et al. 2004; Anglea et al. 2004; Brown et al. 2006; Welch et al. 2007; Chittenden et al. 2008). Suturing materials and procedures also affect implantation success (Deters et al. 2008). Presently tags are implanted only in smolts larger than 85-105 mm fork length. Tags may also be lost or rejected from fish; expulsion of tags has been observed in subyearling Chinook less than 108 mm (Brown et al. unpubl.; Liedtke et al. unpubl.).

  Studies have been conducted comparing the survival of fish tagged with acoustic and PIT tags. Some of these have reported little evidence that acoustic-tagged fish greater than 100 mm FL had reduced survival, migration rates or performance compared to PIT-tagged fish over about 90 d. (Liektke et al. unpubl., Hockersmith et al. 2008; Brown et al. unpubl.; Welch et al. 2008). However, some of these studies held fish in hatcheries or laboratories, and others did not compare fish of similar size and condition released at the same time and place. Eppard (unpubl. 2008) provided preliminary evidence that survival of JSATS tagged yearling Chinook at Lower Granite diverged (i.e., lower) from the PIT-tagged fish downstream of McNary, and that subyearling Chinook survival was lower and travel times were slower than PIT-tagged fish from Lower Granite to McNary dams. Long-term studies are obviously needed on the effects of acoustic tags and all tags.

- **High velocity environments**. Detection capability and/or efficiency are reduced in high velocity, turbulent environments (Thorstad et al. 2002).

- **Transmitter size (length and weight)**. Size is a function of power needs (battery size) and operating frequency; power needs are driven by operating frequency and transmission life requirements. The higher the operating frequency is the smaller the tag and the shorter the detection range. Lower frequencies have greater detection range requiring fewer receivers in a given detection array than higher frequency systems. However, lower frequency systems require a larger transducer than higher frequency systems, and thus require more power (larger batteries) to transmit a signal and are more susceptible to interference from ambient noise.

- **Transmitter life**. Transmitter life is directly correlated to available power as well as the transmission rate of the tag. The higher the rate, the shorter the life of the transmitter. The battery life of juvenile salmonid transmitters generally ranges from 20-90 days depending on the study objectives. Larger transmitters used to study other species, such as sturgeon, can last several years. Variation may also exist in transmission strengths of individual tags that may affect detection ranges, hence calibration of tags may be required. Some tags can be programmed to turn off for extended periods and be reactivated later.

- **Limit to unique codes**. Compared to passive tag technology, acoustic telemetry systems are limited to the number of unique codes available in a given year. Based on the complexity of a system's coding scheme, the number of transmitters that can be accurately detected by a single receiver can also be limited, which is influenced by encoding schemes. The number of unique codes available to researchers varies by tag vendor, but it generally exceeds 50,000.

- **Tracking limitations**. A hydrophone receiver must be deployed in the water to detect acoustic transmitters within the range of the tag. Either mobile hydrophones are used to track tagged fish or stationary receivers are used to record when tagged fish are within the detection range. Detection efficiency may be less than 100% depending on the location and number of receivers. Detection efficiency needs to be measured. In highly dynamic environments or where trawling occurs, receivers may be lost or buried in sediment. Generally, the underwater receivers must be recovered to download the data from detected tags. This may require accurate relocation and reliable methods of recovery including acoustic release devices on the receivers. Newer technologies may allow acoustical downloading from a surface vessel. Monitors located inshore with surface antennas may be interrogated by satellite or cell phone.

- **Non-detection**. Non-detection of a tag may result from fish mortality, non-migratory or residency by fish, fish not passing close enough to a receiver, noise interference, or problems with the tag or receivers that are inoperable.

- **Cost and number of tags**. In order to estimate survival for any stock or group of fish with any reliability, a large number of tags are needed in specific experiments (4,200 JSATS were proposed to compare survival estimates of yearling Chinook with 45,000 PIT tags, PNNL and NMFS Study, SPE06-2). Acoustic tags are expensive compared to PIT tags. In general, however, the increased level of detection (and recovery that does not require fish sacrifice) with acoustic tags compared to most other tags justifies the initial marking expense.

## Future Developments

Future development of acoustic tag technology will focus on smaller transmitters with longer life expectancies. Variable pulse rate tags or tags that can be turned on and off after receiving an interrogation signal from a receiver need to be developed to achieve longer tag life.

Advances are being made to download the data from receivers in shallow water through uplinks that do not require their recovery. Downloads through satellite, radio or cell phone links, however, are not yet feasible for receivers in the open ocean. Here the information must at present be obtained by recovery of the data from underwater receivers, either directly or through acoustic linkage.

Acoustic tags and receivers need to be developed that can be reliably deployed and interrogated from water deeper than 200 m to provide complete coverage by arrays along the coast.

Life span or death tags are needed that indicate where and when a fish becomes immobile, is eaten, dies, or its heart rate stops. Tilt tags are being developed that show when a fish goes belly up. A tag that sends out a strong "death throe" when this happens that could be recorded by a distant receiver is needed.

Long-term effects of acoustic tags need to be more thoroughly studied. Data are needed to compare SARs for double tagged acoustic and/or sham acoustic + PIT vs. PIT tags.

Data on ocean conditions from instrumented receivers, satellites, ocean cruises, and buoys should be correlated with information on the movement, survival, and distribution of salmon from acoustic tags for a series of years so that location at sea and subsequent survival and growth can be related to variable ocean conditions, good and poor ocean survival years, El Niños and La Niñas, climate change, etc. This might provide better estimates of subsequent adult run sizes. In addition, ocean tracking arrays of multiple ocean listening lines could provide detailed information on juvenile survival as the smolts migrate up the coast experiencing different conditions.

In summary, further advances in the field of electronics will continue to result in smaller, longer-lived transmitters. Studies are ongoing to evaluate the biological effects of acoustic transmitters, which will provide further insight into the utility of using this technology to answer resource management questions related to the recovery of salmon stocks in the Basin. Future research needs to focus on the life history of juvenile salmonids in the Basin, from the mainstem above dams into the ocean.

## A.5. Data Storage Tags

### Background

Data storage tags (DSTs), sometimes called archival tags or data logging tags, are small computers that contain a real-time clock, various sensors, and internal memory for data storage. Data storage tags can be attached to fish, birds, and wildlife to study their behavior, physiology, and habitat conditions (e.g., Metcalfe and Arnold 1997; Boehlert 1997; Sibert 2001; Reddin et al. 2006). Data storage tags can be attached externally or implanted internally (generally recommended for salmon smolts). The features most frequently recorded in fish applications to date include water temperature, internal (body) temperature, water pressure (for estimating depth), and ambient light intensity (for estimating geoposition). The tags are programmed to sample the sensors at pre-set intervals, and sampled sensor data are stored in internal memory. Data storage tags operate independently of external data recording devices, and require retrieval of the tag to download the data. Because of the relatively long battery life (up to 5 years) and data retention (up to 25 years) for some tag types, it is now feasible to tag salmon as smolts before they leave the river and recover the tags when adults return to freshwater. After recovery, data are downloaded from the tag with hardware connected to a personal computer. Many types of data storage tags can be re-programmed and reused after recovery, if the battery has sufficient power remaining. While there are several types of data storage tags that can be downloaded wirelessly, e.g., "pop-up" satellite tags and "CHAT" tags, as yet they are too large to attach to salmon.

## Current Uses and Application

To our knowledge, data storage tags are not routinely used for management applications within the Basin, although there are many potential uses, i.e., to address hydrosystem, ocean/estuary, and harvest/hatchery management questions related to juvenile and adult fish survival, behavior, and habitat conditions. The University of Idaho has used data storage tags for USACE-funded adult migration studies in Columbia/Snake to record swimming depth and ambient water temperature. Relevant specifications for several different commercially manufactured data storage tags are provided in the following summary table. Specifications are based on the smallest available data storage tags, as described on the vendor's website, and are typical of systems used in current field studies to measure time, temperature, and pressure (used to estimate depth).

**Table 4.A.5.1.** Specifications for three of the smallest data storage tags available from commercial manufacturers in 2008.

| **Tag Name** | **LAT1500**[1] | **DST micro**[2] | **iBKrill**[3] |
|---|---|---|---|
| **Manufacturer** | Lotek | Star-Oddi | Alpha Mach |
| **Weight in air (g)** | 2.5 (estimate) | 3.3 | 3.2 |
| **Weight in freshwater (g)** | ~0.9 | 1.9 | 1.0 |
| **Size (diameter x length, mm)** | 8.0 x 35.0 | 8.3 x 25.4 | 13.2x25.4 |
| **Memory** | 128k, 512k | 21,738 measurements per sensor | |
| **Typical battery life** | >2 years | >1 year* | Up to 500,000 temperature conversions |
| **Data Resolution** | Up to 12 bits | | ±0.125°C |
| **Sampling rate setting** | ≥1s in 1 sec. intervals | *1s in 15 min. intervals | 1s to 273 hrs; start delay up to 10 yrs |
| **Sensors** | Time, internal temperature & pressure | Time, temperature, pressure | Time, temperature |
| **Temperature measurement** | -5° to 35°C | -1° to PP+40°C | -40° to 70°C |
| **Depth Range/ Rating (m)** | 0-2000 | 0-1200 | 600 |

| Tag Name | LAT1500[1] | DST micro[2] | iBKrill[3] |
|---|---|---|---|
| **Cost** | $458 ea. (128K memory); $575 ea. (512K), if purchasing 1000 tags; quote from Lotek 8/08 | $432 ea., if purchasing 150 or more tags; quote from Star-Oddi 8/08 | $99 ea. , if purchasing 1000 tags |

[1]Lotek time, temperature, and depth recording tag (http://www.lotek.com)
[2]Star-Oddi DST micro-small TD logger (http://www.star-oddi.com)
[3]iBKrill miniature temperature DST tag (http://www.alphamach.com)

Many other types of commercially-manufactured data storage tags are still too large for salmon smolts, but could be used for post-smolt life stages as well as for other species in the Basin (e.g., sturgeon). For example, geolocation tags provide daily estimates of latitude and longitude, estimated from light levels (LTD 2410, size: 11 mm x 35 mm; sensor stalk size: 1 mm diameter x 10 cm long; weight in air/in water: 6 g/3 g; www.lotek.com/). CTD tags record and store temperature, salinity, and pressure (depth) data (size: 15 mm x 46 mm; weight in air/in water: 19 g/12 g; must be attached externally; http://www.star-oddi.com). A pitch-and-roll logger has been used to analyze fish movements and orientation in relation to buoyancy (gas in/out from swim bladder) and for improving acoustic survey estimates of biomass (size: 15 mm x 46 mm; weight in air/in water: 20.4 g/13 g; www.star-oddi.com). A geographic positioning system (GPS) tag has been developed for use in rivers, lakes, and small ocean areas. This tag measures temperature and pressure (depth), and listens to an acoustic GPS signal from sonar to record its geographic position (fish must be within 4 km range of the GPS sonar; size: 15 mm x 46 mm; weight in air/in water: 20.4 g/13 g; www.star-oddi.com). A compass logger can measure temperature, depth, and relative compass heading of the data storage tag, with reference to the magnetic north (size: 15 mm x 46 mm; weight in air/water: 19 g/12 g; www.star-oddi.com).

## Advantages and Disadvantages

***Advantages*** - General advantages of data storage tag technologies include:

- **Sensors.** Unlike current acoustic tag technology, data storage tags can measure and record many different types of environmental and physiological parameters.
- **Battery life/storage capacity.** Batteries last longer than current acoustic tag technology used for Basin applications, which enables long-term, whole life-cycle data collection; stored data are retained for many years and can be recovered, even after batteries have lost power. Storage/memory capacity is increasing.
- **Tag attachment.** Tags can be attached either internally or externally.
- **Deployment environment**. Useable for fish and other aquatic animals in both freshwater and saltwater environments; data storage tags can also be used to tag birds and terrestrial wildlife.

- **Detection depth**. Temperature-depth data storage tags permit precise recording of water temperature and vertical movements of salmon throughout their known temperature-depth range, including the open ocean.
- **Identification codes**. Each tag can be labeled with a unique identification code (no limit to the number of codes), as well as other identifiers such as email addresses/telephone numbers to improve tag recovery rates.
- **Cost**. While cost per tag might seem expensive, equivalent data could not be obtained without much more expensive research and monitoring surveys and process studies.

***Disadvantages*** - General disadvantages of data storage tag technologies include:

- **Tag recovery/return limitations**. Data storage tags must be recovered from the fish in order to download data. Tag recovery/return rates can be low.
- **Tag Effects**. Size and weight of data storage tags (largely a function of battery size) and method/body location of attachment might affect the health and behavior of fish. Tag extrusion or shedding should be evaluated.
- **Geographic position**: At present, geolocation and GPS data storage tags can be used only on relatively large salmon (>40-45 cm); for smolts and small post-smolt salmon, temperature-depth data storage tags could be used in combination with acoustic or PIT tags to obtain location information as fish pass through hydrosystem detectors or coastal-ocean acoustic tag arrays; in the open ocean, geographic position can be estimated using oceanographic data.
- **Environmental data**: Data storage tags do not record data on the environment avoided by fish; i.e., they record only the environment selected by fish, which also might be an advantage (Boehlert 1997). Depending on the application, might need simultaneous monitoring of the physical environment.
- **Possible sources of error**. There are many possible sources of error in data storage tag data; e.g., solar heating can cause an error of more than 1°C in water temperatures recorded for tagged fish (http://www.star-oddi.com/Top/Fish_marine_animal_Tagging/icex/); one study indicated that daily position of an animal tagged with geoposition (light-detecting) data storage tags can potentially be estimated within an average error of about 140 km (SDs of 0.9° longitude and 1.2° latitude; Welch and Eveson 1999). As with any measurement device, users need to calibrate and validate accuracy, precision, and consistency of data storage tags and their sensors.
- **Size (length and weight)**. Size is largely a function of battery size; limits the capability of fish to carry the tag.
- **Tag failure**. As with any new technology, rates of data storage tag failure can be high when newly-developed tags are used in environments, beyond the lab- and field-testing capabilities of the manufacturers.

### Management Applications

Data storage tags can provide accurate, fishery- or survey-independent data on the behavior, physiology, and habitat conditions of individual fish throughout their life cycle in freshwater and ocean habitats. Management applications using data storage tags can lead to a mechanistic understanding of the factors that affect the growth and survival of fish and wildlife. To date, the most frequent uses of data storage tags have been to study the distribution and behavior of post-smolt salmon and steelhead in coastal and open ocean habitats, as well as roundtrip migrations of steelhead kelts between freshwater and ocean habitats (e.g., Walker et al. 2000, 2007; Friedland et al. 2001; Ishida et al. 2002; Hinke et al. 2005a,b; J. Nielsen, pers. comm.). The potential for use of data storage tags to address management questions in the Basin is increasing, as manufacturers continue to miniaturize data storage tags, increase recording capacity and battery life, develop additional sensors, and reduce prices.

Future projects using data storage tags for management applications related to anadromous fish in the Basin should be fully coordinated both within the Basin and internationally. For example, since 1998, scientists from the U.S., Canada, Russia, and Korea have collaborated in the deployment and recovery of data storage tags for international cooperative high seas salmon research programs coordinated by the North Pacific Anadromous Fish Commission (www.npafc.org).

### Future Needs/Developments

- Increased miniaturization, recording capacity, and battery life of data storage tags
- Wireless communication with data storage tags
- Advances in methods applied to interpretation of data storage tag data
- Merging of data storage and acoustic tag approaches (e.g., VEMCO V8 acoustic tag, potted with a VEMCO minilog temperature-depth data storage tag; Jackson et al. 2005)
- Development of data storage tags with new sensors for vital stressors (e.g., oxygen, pH)
- Further improvements in accuracy of geoposition estimates from light data

## A.6. Genetic Markers

### Background

Inherited differences among individuals for specific traits can be used as natural tags or marks to distinguish individuals, populations, and species. Employing this approach requires a fairly large number of traits (genes) that exhibit variation (alleles) that can be assayed in fish with a reasonable effort and cost. Once the inherited basis of the markers is established (to ensure that alternate characters or alleles are not variable due to variable environmental conditions) the genes and their alleles can be used to establish the relationships among populations; estimate the proportions of different populations in mixtures; identify parent - offspring relationships in natural populations; and assess hybridization between species.

Molecular products of genes (such as enzymes or mRNAs) and genes themselves (the DNA molecule in the genome) provide the material for genetic markers in fisheries applications. Allozymes (alternate forms of enzymes), a product of structural genes, provide modest allelic variation and served as genetic markers for large-scale fishery management applications from the mid-1960s until the mid-1990s. Advances in biotechnology throughout the 1980s produced innovation in the direct assay of variation in the DNA molecule. DNA variation can now be identified using very small pieces of fin, or even from the skin attached to scale samples. Moreover, any tissue preserved in a non-degrading manner, including archived scales, may be used, providing a historical reference source. The extracted DNA can be amplified by polymerase-chain-reaction (PCR), providing sufficient material for detection. Protein assays, by contrast, usually required lethal sampling of the fish to obtain a sufficient quantity of body tissue for laboratory analysis (but see Van Doornik et al. 1999). DNA variation has become the standard genetic tool in Pacific salmon management, because fish do not need to be sacrificed, and also because many DNA markers exhibit more variation than proteins.

Different kinds of DNA markers are used for different purposes in genetic analysis of Pacific salmon and steelhead, including restriction fragment length polymorphisms (RFLPs) of nuclear and mitochondrial DNA, microsatellite (short tandem repeat, or STR) polymorphisms of nuclear DNA, and single nucleotide polymorphisms (SNPs, called "snips") of either nuclear or mitochondrial DNA. Importantly, the amount of variation each kind of DNA marker exhibits is a critical consideration for selecting an appropriate marker class. For example, there are questions that require very specific information about individuals, their offspring or their parents. Alternately, there are other questions that require only information about populations or batches. Careful advance consideration is required, relative to the specific question(s) being addressed.

Microsatellites and SNPs are the most common polymorphism assayed at this time. Microsatellites are repeating sequences of two to six base pairs, and there are hundreds interspersed throughout the genome. As an example, the base sequence $(CTAC)_n$ is a tetra-nucleotide repeat with $n$ tandem copies. Typically, the sequence would be repeated many times, say $n$ = 10 to 100. Different alleles have different numbers of repeated sequences ($n$); there are usually from 10 to 30 alleles for a given microsatellite gene, although occasionally there are a half-dozen or fewer. Because there are so many alleles for a given microsatellite gene, they are suitable for pedigree analysis and for estimating component population proportions in mixtures. Single nucleotide polymorphisms (SNPs) yield DNA sequence variation when a single nucleotide (A, T, G, C) differs between otherwise identical sections of the genome. SNPs could potentially have four alleles, an A, T, G, or C at a specific position in the DNA molecule, but there are usually only two alleles. SNPs can occur as often as every 200 – 500 base pairs and are found in both coding and non-coding portions of the genome (Morin et al. 2004).

## Current Uses and Management Applications

Genetic markers are currently being used in fishery management in the Basin to assess the population structure of related populations, estimate the proportion of fish from different stocks in mixed catches, determine the relative reproductive success of hatchery fish spawning in the wild, and evaluate hybridization between introduced and native resident trout.

**Relationships among populations.** In contemporary fisheries management, analysis of genetic marker data are used, along with spatial, temporal, and life-history information, to define naturally related groups for management purposes (Brannon et al. 2002, Winans et al. 2004, Waples et al. 2004). For example, NOAA Fisheries has used genetic relationships among populations to inform the establishment of Evolutionarily Significant Unit (ESU) [distinct population segment] boundaries for anadromous salmon, under the Endangered Species Act. The Interior Columbia Technical Recovery Team (TRT) used genetic data to further subdivide seven of the Columbia River ESUs into Major Population Groups (MPGs) and Independent Populations. These independent populations are the units that are assessed for status and viability, as a means of gauging progress toward recovery under the ESA (IC-TRT 2003; www.nwfsc.noaa.gov/trt/col_docs/independentpopchinsteelsock.pdf).

**Mixture analysis.** Estimating proportions of populations in mixtures is referred to as Genetic Stock Identification (GSI) and has application in harvest management as a tool for shaping annual harvest plans and for in-season management (PSC 2008a). While used primarily as a tool for *post hoc* modeling of population composition for a specific harvest, in fact, the approach may be used to examine composition of any mixture where discernable groups co-mingle. In the past, there have been in-season applications in Columbia River Chinook net fisheries (Shaklee et al. 1990) and currently in the Queen Charlotte Islands troll Chinook fishery (Wither and Beacham 2006) and Fraser River and Bristol Bay sockeye fisheries (PSC 2008a). The PSC undertook a thorough review of the status of genetic stock identification, as part of considering whether it could replace or augment CWT data for harvest management, under the Pacific Salmon Treaty (PSC 2008a). With funding from the PSC's Southern Fund, CRITFC has used genetic stock identification to assess stock origins of Chinook salmon mixtures at Bonneville Dam (Narum et al. 2007). ProjectCroos (Collaborative Research on Oregon Ocean Salmon) in Oregon is conducting a pilot investigation to test the potential of using genetic stock identification, together with temporal, spatial, and oceanographic data, to develop tools to predict the oceanic location of different populations of Chinook salmon. The purpose is to develop management tools to facilitate harvest of hatchery and productive wild populations, while protecting populations at risk, so large area fishery closures can be avoided. The project was initiated in response to fishing closures aimed at protecting Klamath River Chinook salmon (http://projectcroos.com).

**Parentage analysis.** Assigning offspring to their parents is possible for salmon and steelhead in both natural settings and hatcheries, when there is an opportunity to sample genes from spawning parents and then subsequently from either juvenile or adult offspring. In natural and hatchery settings, parentage analysis is being employed to evaluate the reproductive success of hatchery-origin adults, relative to their natural-origin counterparts. In hatchery settings, there are exploratory investigations underway to use Parental Based Tagging (PBT; formerly termed Full Parental Genotyping, FPG), as a way to provide a genetic mark for every smolt, allowing use of this strategy to augment or replace the CWT system.

**Relative reproductive success of hatchery-origin salmon**. Parental assignment has been used to evaluate the relative reproductive success of hatchery fish that are spawning naturally, which was identified in the 2000 FCRPS BiOp as an uncertainty confounding analysis of the status of natural populations under ESA protection. There was a solicitation for proposals (in 2003) to evaluate the relative reproductive success of hatchery salmon and steelhead from each of the listed ESUs. That solicitation established funding for the following projects:

- 2003-039-00 *Monitor reproduction in Wenatchee, Tucannon, and Kalama spring Chinook*;
- 2003-050-00 *Evaluation of reproduction of steelhead*;
- 2003-054-00 *Reproduction of steelhead in Hood River*;
- 2003-062-00 *Evaluate the relative reproductive success of recondition kelt steelhead*;
- 2003-063-00 *Natural Reproductive Success & Demographic Effects of Hatchery-Origin Steelhead in Abernathy Ck, Washington*; which uses pedigree analysis, and,
- 2003-0620-00 *Evaluating relative reproductive success of wild and hatchery-origin Snake River fall Chinook spawners upstream of Lower Granite Dam*, which uses GSI methods.

The relative reproductive success of spring Chinook salmon in the Imnaha and Pahsimeroi rivers, respectively, is being evaluated under the auspices of projects:

- 1989-096-00 *Genetic monitoring of Snake River Chinook and steelhead*, and
- 1989-098-00 *Idaho Supplementation Studies*.

Apparently anticipating development of genetic markers capable of facilitating parentage analysis, scientists with ODFW and the Confederated Tribes of the Warm Springs Reservation collected tissue from all the adult steelhead passing Powerdale Dam on the Hood River since the early 1990s, under the auspices of projects 1988-053-03 *Hood River Production M&E Warm Springs* and 1988-053-04 *Hood River Production Program – ODFW M&E*. This tissue archive proved extremely valuable, providing an opportunity to evaluate the reproductive success of both long-established traditional hatchery fish and recently established local populations of fish for supplementation, under Project: 2003-054-00 *Reproduction of steelhead in Hood River*.

While the sponsors documented whether or not individual fish passing over Powerdale Dam were of hatchery- or natural-origin, it was especially fortunate that they also collected tissue from parents used in hatchery matings and identified whether specific parents were of wild origin or whether they were the progeny of hatchery-reared fish of the previous generation. Consequently, with the advent of high throughput approaches to molecular genetic markers, the sponsors have been able to complete analyses in a relatively short time frame, rather than having to wait for the fish to complete one or two generations, which takes several years. They have published results demonstrating poor relative reproductive performance of hatchery-origin adults from a long-term line of Big Creek hatchery steelhead. They demonstrate similar reproductive performance between natural- and hatchery-origin parents when the parents of the hatchery fish were of natural-origin. Finally they have been able to infer genetic causation for reduced performance by comparing the relative natural spawning performance of hatchery-origin adults that had one or two hatchery-origin parents (Araki et al. 2007a and 2007b).

The Ad Hoc Supplementation Workgroup (AHSWG) recently completed a design to integrate the results from the various ongoing studies of relative reproductive success in the Basin and elsewhere as a component of evaluating supplementation (AHSWG 2008). The workgroup was formed in response to an ISAB and ISRP memo to the Council concerning the monitoring of supplementation (ISAB/ISRP 2005-15). They propose expanding the number of relative reproductive studies underway in the basin, formalizing the collection of data on long-term trends in abundance and productivity in supplemented and reference locations, small-scale research to determine the mechanisms by which hatchery fish influence natural population productivity.

**Parentage-based tagging.** If the parents that are used as broodstock in a hatchery or from natural populations are genotyped, the screened loci/alleles provide a trans-generational tag that can be subsequently recovered through parentage-analysis (Garza and Anderson 2008). The progeny of genotyped hatchery parents will inherit these alleles and the parentage analysis will associate a captured fish with a unique parent pair, which will provide the stock, hatchery, and age of the fish. This system has the potential to provide all the information now obtained using the CWT system. Anderson and Garza (2006) have explored the statistical and genetic requirements for this system and propose that 100 SNP markers would provide sufficient precision and high throughput for data collection. An ancillary benefit from this system would be the associated genetic and survival parameters that could be estimated from the data. Parentage-based tagging is currently being tested in Sacramento River fall Chinook salmon at Feather River Hatchery, and in Puget Sound Chinook Salmon. Related individuals in the parental database that would lead to an assignment to the wrong hatchery or age, and the logistics and cost of the analysis of the large number of individuals that need to be genotyped are non-trivial uncertainties about using this system.

**Hybridization analysis.** Markers that discriminate between species can serve to identify any hybrid progeny from interbreeding and have been important in the management of resident salmonids. For example, the persistence of resident native westslope cutthroat trout (*Oncorhynchus clarki lewisi*) in the upper Basin is affected by hybridization with other *Oncorhynchus* spp. (especially, rainbow trout, *Oncorhynchus mykiss*) or cutthroat subspecies (especially, Yellowstone cutthroat trout (*O. c. bouvieri*). Yellowstone cutthroat trout in the upper Snake River Basin, too, have been affected by hybridization with rainbow trout and Snake River "finespotted" cutthroat trout, while bull trout (*Salvelinus confluences*) throughout the entire Basin is affected by hybridization with transplanted eastern brook trout (*Salvelinus fontinalis*) and potentially lake trout (*S. namyacush*). Finally, coastal cutthroat trout and steelhead have historically hybridized, and it is important to avoid amplifying the rate or extent of hybridization where it occurs naturally. Removal of hybrid and non-native individuals, as the primary direct threat to the native species, is often followed by the construction of barriers to limit further distributional expansion of non-native individuals. Analysis of hybridization employs genes for which the species of interest share no alleles in common. Nuclear restriction fragment length poplymorphisms (Baker et al. 2002), insertion/deletion markers (Ostberg and Rodriguez 2004), and SNPs (Garza, personal comm.) are available for investigating rainbow (including steelhead) x cutthroat trout hybridization. Hybridization in populations of west-slope cutthroat trout is being evaluated by labs associated with Hungry Horse Mitigation projects.

The use of genetic markers for establishing population relationships, investigating the relative reproductive success of hatchery-origin adults, and investigating hybridization are on sound scientific bases. The need to employ these approaches for management should be evaluated on a case-by-case basis.

## Advantages and Disadvantages

***Advantages*** **–** the advantages associated with genetic tagging are:

- **No handling to attach tags.** The fish are "tagged" with genetic markers inherited from their parents, so no time, effort, or expense is required to apply the tags to fish.
- **No effects on survival or behavior.** Since there is no surgery, mutilation of vital appendages (clipped fins or jaws), or attachment of a physical tag, there should be no particular survival or behavior effects associated with the tagging method.
- **100% tagging rate.** Every fish is tagged by virtue of the data associated with specific alleles.

***Disadvantages*** **–** the disadvantages associated with genetic tagging are:

- **Handling required for recovery.** Fish must be collected and tissue sampled for analysis, precluding remote sensing - as with PIT, radio- and acoustic tags.
- **No unambiguous association of a fish with a tag.** Fish are assigned to particular groups, based on a multi-locus genotype, not a particular batch or individual tag. There will be a small but real (← *n.b.*) sampling error associated with all assignments of interrogated individuals.

## Future Needs/Development

### Data Archiving and Management

Applying genetic marks to management activities requires understanding the power and limitations of each of the available markers and the analytical frameworks used to interpret the data. New markers and new analytical methods are being developed as molecular technology advances and as managements needs have changed. There is a need for development of the same sort of databases for genetic information as exist now for PIT tag (PITAGIS) and CWT (REMIS) data, integrating genetic information into harvest models, testing the potential of parentage-based tagging, systematic evaluation of the adequacy of existing baselines, and comparative evaluation of microsatellites and SNP loci.

### Choice of Genetic Markers

There is currently debate among geneticists about the class of marker (microsatellite or SNP) that is likely to be most useful in the next decade. For years allozymes, and more recently microsatellite markers, have served as primary tools in GSI. Microsatellites provide many alleles and consequently are very useful for a variety of purposes. But, the large number of alleles makes standardization within and among labs challenging. For this reason SNPs are endorsed by a number of individuals.

The ISAB and ISRP believe it is premature to predict that SNPs will replace microsatellites in the next few years, even if they are demonstrated to be as effective. We believe it is unwise to undertake a "top down" directive to transition from one marker platform to another. It is now time to explore future options carefully. Microsatellites are problematic because of challenges for standardization and intrinsic error associated with electrophoretic conditions and the small size differences between alleles. SNPs will be more expensive, at least initially, but the data quality will be much improved. If there is a transition from microsatellites to SNPs it is likely to be evolutionary rather than revolutionary, and should be based on sustained empirical evidence.

For coastwide genetic stock identification, a standard panel of genes needs to be analyzed for all baseline populations and for mixtures. The coastwide microsatellite database for Chinook salmon has been standardized by ten agencies/labs (Seeb et al. 2007), with funding primarily from the PSC. There is also some interagency standardization for coho and chum salmon. Standardization is complicated for microsatellites because different automated DNA sequencers produce slightly different allelic mobilities for the same DNA fragment. Standardization may be achieved with allelic ladders (LaHood et al. 2002) or by exchanging samples. Nonetheless, at this time microsatellite markers provide broader application than SNPs.

There are currently about 51 SNP assays for Chinook, 19 for coho, 44 for sockeye, 77 for chum, and none for pink salmon (PSC 2008a). SNPs do offer the benefit of easier allele standardization across labs and less genotyping error. However, SNPs have been established as useful markers only within regions, not coastwide. Until there is more SNP development, and a broader survey of baseline populations, it would be premature to advocate transitioning to near exclusive use of SNPs. SNP variation in one region may not provide adequate resolution of populations from another region. Regional analysis may require additional specific markers. More work is needed to establish SNP loci, but there are likely thousands from which to choose.

Additional SNP development is justified, and a side-by-side comparison of genetic stock identification results using both microsatellite and SNP genes is needed. Once the SNP development is sufficient to provide resolution of fishery mixtures, and side-by-side comparisons yield comparable results, SNPs may become the markers of choice. In the past the transition from one marker type to another – from allozymes to mitochondrial DNA to microsatellites – has been spearheaded by the genetics scientific and technical staffs within agencies, because improved information could be provided to managers at reduced cost. The shift to any new marker or detection technology is likely to create some discomfort and resistance.

The development of SNPs and coastwide baselines would benefit from administrative coordination. At this time, most of the funding for development has been provided through the PSC's grants program, but some support for the Chinook baseline has come from the Fish and Wildlife Program (project 1989-096-00 *Genetic monitoring of Snake River Chinook and steelhead*). It would potentially be efficient to identify which program would take the lead in funding and coordinating the development of both SNP markers and comparisons of SNPs and microsatellites.

## A.7. Otolith Thermal Marks

### Background

Thermal marking of otoliths is a well-known and well-established technique that is widely used to identify and manage hatchery-released salmon in Asia and North America (e.g., Volk et al.

1999, 2004; http://npafc.taglab.org/MarkFAQ.asp; http://tagotoweb.adfg.state.ak.us/). Otoliths are calcareous structures in the inner ears of fish, functioning as part of their organ of equilibrium. As the fish grows, calcium carbonate is deposited within a protein matrix, appearing as alternating bands or increments that are produced on a daily basis in many species. A number of studies have demonstrated that short duration temperature changes can dramatically influence the appearance of daily increments, inducing a series of dark bands corresponding to thermal events, that are easily recognizable in a sectioned otolith using transmitted light microscopy (Figure 6.A.7.1.). Thermally induced increments are created by abrupt, short duration (4-48 hrs.) temperature changes followed by a return to ambient conditions between thermal events. These thermal events have a planned periodicity to create specific patterns of induced increments or rings, similar to bar code labels on commercial packaging. Because otoliths form prior to hatching in salmonids, thermal marks can be induced during pre-and post-hatch incubation, creating opportunities for a large number of unique patterns (see below). When fish are counted and measured during harvest or research, sagittal otoliths (largest of 3 pairs of otoliths) can be removed, sectioned, and examined microscopically for thermal marks that identify the hatchery brood year and stock of origin.

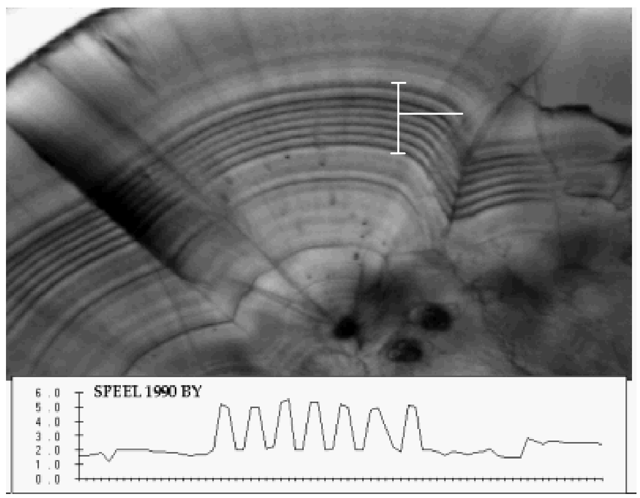


**Figure 6.A.7.1.** Photograph of a thermally-marked otolith from a sockeye salmon fry. The identifying thermal mark appears as a band of seven dark rings. The temperature cycles that create the mark consisted of two days of warm temperatures followed by two days of cold temperatures. Photo and description courtesy of the North Pacific Anadromous Fish Commission (http://npafc.taglab.org/MarkFAQ.asp).

## Current Uses and Application

Thermal marking enables in-season tracking of adult hatchery salmon through commercial fisheries and onto the spawning grounds. For example, thermal marks have been used by the Alaska Department of Fish and Game (ADFG) since the mid-1990s to obtain accurate and precise estimates of the proportions of hatchery-reared salmon in mixed-stock fisheries in Alaska and U.S.-Canada transboundary rivers (Hagen et al. 1995, Jensen and Milligan 2001; Joyce and Evans 2000; PSC 2005). The technique is particularly effective when coded-wire tagging or other types of tagging are not sufficient to assess the relative abundance of a particular hatchery stock in a specific area (e.g., Heinl et al. 2007). Methods of processing and decoding otoliths at the Alaska Department of Fish and Game, Division of Commercial Fisheries, Mark, Tag and Age Laboratory, are summarized by Scott et al. (2001). Guides for salmon otolith port sampling and voucher sampling for hatcheries are available from the Laboratory website (http://tagotoweb.adfg.state.ak.us/OTO/Files/PortSamplingGuide.pdf; http://tagotoweb.adfg.state.ak.us/OTO/Files/VoucherSamplingGuidelinesforHatcheries.pdf)

Thermal marking has also provided new research opportunities for life history and population dynamics studies of individual hatchery stocks in high seas and coastal waters (e.g., Farley and Munk 1997; Farley and Carlson 2000; Boldt and Haldorson 2002, 2003, 2004; Cross et al. 2005, 2008; Moss et al. 2005). Future use of thermally-marked fish for ocean research might be limited by the number of unique patterns that can be created during the relatively short pre- and post-hatch incubation period. As the number of marked fish increases, there is concern that duplicate thermal marks originating from different hatcheries will be encountered during ocean sampling. As a result, the North Pacific Anadromous Fish Commission (NPAFC) established the Working Group on Salmon Marking in 1998 to coordinate international application and exchange of information on otolith mark patterns and to improve accuracy of mark recognition among scientists and managers using this technique. The primary objective of this working group is to minimize duplication of thermal marks released by hatcheries around the Pacific Rim. The NPAFC hosts an online database, where mark coordinators can enter and audit their otolith marks, and from which users can download information and images of marks that have been released. (http://npafc.taglab.org/default.asp). Compliance among Pacific Rim hatcheries to avoid duplicate marks has been successful, and NPAFC reported no mark duplications among countries for all species in 2007 (NPAFC Annual Report 2007; www.npafc.org).

## Advantages and Disadvantages

***Advantages*** – the advantages associated with thermal marking are:

- **100% tagging rate**. The ability to mark 100% of fish from a particular hatchery and brood year with an identical mark greatly reduces sample sizes needed to estimate proportions of hatchery fish in mixed-stock catches or spawning escapements (Hagen 2001).
- **Fish size, mark retention, and handling.** Unlike many other types of marks and tags (e.g., fin clips, coded-wire tags, and pit tags), embryonic or larval fish can be permanently marked without having to handle individual fish.
- **No known effects on survival or behavior**. Otolith marking does not appear to harm fish or alter their behavior (Volk et al. 1999).
- **One-time capital equipment costs.** Initial capital equipment costs include those for distributing and altering the temperature of incubation water. No specialized equipment beyond microscopes and grinding tools are needed to recover marks. An entire hatchery release can be thermally marked at a lower cost than with CWTs (Geiger et al. 1994).
- **Low error rate in detecting marks.** Errors in detecting otolith marks are relatively low, and most result from misclassification of unmarked fish (e.g., Bergstedt et al. 1990; Volk et al. 1999).

***Disadvantages –*** the disadvantages associated with thermal marking are:

- **Otolith marks are not externally visible.**
- **Mark recovery lethal.** Fish must be dead in order to remove the otoliths and examine them for thermal marks.
- **Limit to unique marks.** Volk et al. (1994) estimated that as many as 1000 unique marks might be possible under ideal conditions, including short mark duration and nearly constant ambient thermal regime. A great deal of practical experience that has been gained since then suggests the maximum number of unique marks might be less than 1000 (E. Volk, pers. comm., Oct. 20, 2008). Background thermal regimes at hatcheries, difficulties of marking several to many groups at different developmental stages, and other constraints make it hard to achieve a theoretical maximum and still be able to accurately distinguish marks. A likely outcome of pushing the limit on marks that closely resemble one another is that detection error rates will increase. The potential number of marks could be increased dramatically by combining thermal and chemical marks, but technology, cost, and FDA approval can become an issue.
- **Not practical for marking wild fish:** Thermal marking requires special equipment for chilling or heating water, and the technique is not yet practical for quickly marking wild fish in the natural environment.
- **Costs of mark recovery can be significant:** Otoliths must be removed from a large numbers of fish. Mark detection requires specialized skills to prepare and accurately detect marks on different sizes and shapes of otoliths. Requires a dedicated lab for processing large numbers of samples.

## Management Applications

Thermal marking has proven to be a cost-effective and powerful tool for accurate identification of hatchery stocks in mixed-stock catch and escapement samples. As a result, releases of thermally-marked hatchery fish have grown to 1.62 billion fish in 2007 (approximately 35% of all hatchery releases in Asia and North America; Table 5.A.7.1). Despite extensive national and international use of thermal marking, to our knowledge, only four funded project proposals reviewed in the 2007-09 Northwest Power and Conservation Council Fish and Wildlife Program Solicitation use this technique (Table 2). Two hatcheries in Washington (Grays River and Washougal) and three in Oregon (Willamette, McKenzie, and Marion Forks) have reported the use of thermal marks to NPAFC (http://npafc.taglab.org/default.asp).

**Table 5.A.7.1.** Preliminary number of otolith-marked salmon released from Pacific Rim hatcheries in 2007 (source: NPAFC Ann. Rept. 2007; www.npac.org)

| | Sockeye | Pink | Chum | Coho | Chinook | Cherry | Total |
|---|---|---|---|---|---|---|---|
| **Canada** | 5,000,000 | 0 | 37,500,000 | 21,100,000 | 90,000 | 0 | 63,690,000 |
| **Japan** | 179,678 | 14,969,000 | 149,744,176 | 0 | 0 | 2,835,694 | 167,728,548 |
| **Korea** | 0 | 0 | 5,000,000 | 0 | 0 | 0 | 5,000,000 |
| **Russia** | 9,815,817 | 416,200 | 36,115,903 | 799,000 | 2,797,997 | 276,107 | 50,221,024 |
| **USA*** | 43,386,516 | 729,544,233 | 546,154,049 | 6,147,875 | 3,359,995 | 0 | 1,328,592,668 |
| **Total** | **58,382,011** | **744,929,433** | **774,514,128** | **28,046,875** | **6,247,992** | **3,111,801** | **1,615,232,240** |

*USA includes only Alaska, as data were not available from Washington, Oregon, California, and Idaho.

## Future Needs/Developments

Future needs and developments in otolith marking technology will likely focus on methods to reduce the time and cost of mark recovery, for example, the development and use of artificial vision technology to partially or fully automate detection of otolith mark patterns (e.g., Guillaud et al. 2002; Cao and Fablet 2004; Palmer et al. 2005).

# A.8. Natural Marks and Tags (Otoliths, Scales, and Parasites)

## Background

Natural marks include a variety of morphological or body characteristics that can be used to identify the geographic source area where a given fish developed. The markers include biological and chemical "signatures" that biologists can use to determine important ecological information on migration routes and residency of specific populations of fish in the freshwater and marine environment. Natural marks such as scale characteristics and parasite tags have been used to identify certain stocks of Columbia River salmon. More recently, sophisticated chemical methods such as microelement and stable isotope analysis have been developed, but are not yet widely used.

## Management Applications

The main application for this technology is to identify the specific geographic area where the mark originated in an individual fish, after which it has migrated to another area. Migration routes can be estimated. Conversely, if the fish has not moved from an area, its time of residency can be measured. Natural marks can also be used to determine the population mix in commercial fisheries. Hatchery and wild fish can also be distinguished in a mix of adult specimens, if their rearing environments were sufficiently different to have imposed differential signatures.

Some natural marks require sacrifice of the fish (e.g., internal parasites, otolith microchemistry) before a determination can be made, while others only require a small piece of tissue or a scale (e.g., scale microchemistry, scale analysis) so the fish can be released alive.

## Trace Element Concentrations in Otoliths, Fin Rays and Scales

The trace elements identified in otolith microchemistry have been suggested as a natural tag for identifying the origins of wild salmon caught at sea, movements between various freshwater habitats, and other fisheries applications (Campana and Thorrold, 2001). Fish otoliths absorb certain elements in proportion to those elements' occurrence in the water they are growing in – which may be unique for particular populations. The possibility of using this method was tested with chum salmon in Korean hatcheries by Sohn et al. (2005). The chemical composition of rearing water and otoliths of the salmon fry at specific sites did not differ significantly through the study period. The ratios of some trace elements to Ca in rearing water, such as Sr:Ca and Ba:Ca, was clearly reflected in the chemical composition of the otoliths. Similar methods were used by Veinott and Porter (2005) in a study of stream samples of Atlantic salmon parr. Discriminate function analysis, based on the concentrations of Mg, Mn, Sr, and Ba in the otoliths, was used to separate the parr into their natal streams. In Arctic charr (*Salvelinus alpinus*), otolith strontium has been used to record emigration of juveniles and adults from freshwater and coastal nursery habitats (Secor and Rooker, 2000). Strontium in fin rays was used to determine whether white sturgeon from the lower Fraser River (BC) migrate to sea (Veinott et al. (1999).

Volk et al. (in review) used strontium abundance and daily growth increments to reconstruct the date and size of juvenile Chinook salmon entering the Salmon River estuary (Oregon). Sr levels reflected increases in salinity (see also Bacon et al. 2005)

Wells et al. (2003) quantified Mg:Ca, Mn:Ca, Sr:Ca, and Ba:Ca molar ratios from an area representing the summer growth season on otoliths and scales from 1-year-old westslope cutthroat trout (*Oncorhynchus clarki lewisi*), collected from three streams in the Coeur d'Alene River (ID). The Mg:Ca, Sr:Ca, and Ba:Ca ratios varied significantly in otoliths from the three streams and could be used in concert to reclassify individual fish to the streams from which they were collected with 100% accuracy. The corresponding ratios from scales varied significantly in the three streams and could also be used to classify individuals with 82% accuracy. Given the heterogeneity of Basin geology, the stability of water chemistry, and the degree of discrimination noted for the three streams sampled, the authors concluded that examination of the elemental composition of fish otoliths and scales could be used to describe the movements of fish in this and similar freshwater systems. Further, the high correlation between the ratios in scales and those in otoliths suggested that scales may offer a nonlethal sampling alternative.

Although showing promise, microelement analysis does have its detractors and problems. For example, Secor and Rooker (2000) observed a positive relationship between otolith strontium and habitat salinities and cautioned against using the method without due attention to salinity variation, when investigating salmonid movement into and out of estuaries. In addition, for freshwater applications, the method relies on the assumption that the fish reside long enough in a specific location to acquire a unique microelement signature. For juvenile salmonids moving downstream while growing this may be an assumption that is hard to meet, especially as they may take up temporary residency in a variety of habitats en route.

To our knowledge, elemental microchemistry has not been used in the Basin for tracking fish migrations of anadromous salmonids. However, two projects reviewed in the recent Innovative Proposal round suggested the use of this methodology for investigation of the migratory habits of Snake River fall Chinook and Upper Columbia White Sturgeon (Project Proposals 20075550 and 200755200, respectively).

## Stable Isotopes in Otoliths, Scales and Tissues

Isotopes are forms of elements with the same chemical properties, differing in atomic mass because of differing numbers of neutrons in the nucleus. Stable isotopes are chemical isotopes that do not undergo radioactive breakdown, and there may be several stable isotopes of the same element. Elements in media such as water and soils in various geographic areas can have unique stable isotopes, and these are absorbed into otoliths, scales, and other biotic tissues.

Ingram and Weber (1999) were among the first to use stable isotopes to determine the source populations of anadromous salmonids. Working in the San Joaquin River in California, they showed a strong relationship between the $Sr^{87}$**:**$Sr^{86}$ ratio in hatchery water and the $Sr^{87}$**:**$Sr^{86}$ ratio in the otoliths of juvenile Chinook salmon that had developed in those waters. As a result of differences in basin geology from north to south along the western slope of the Sierra Nevada, important salmon spawning rivers within the Sacramento-San Joaquin river system have distinct $Sr^{87}$**:**$Sr^{86}$ ratios. The combination of distinct river $Sr^{87}$**:**$Sr^{86}$ ratios and the relationship between water and otolith Sr isotope ratios indicated that this geochemical method could be used to identify the origin (and potentially the migration history) of juvenile, out-migrating salmon from the Sacramento-San Joaquin system. Bacon et al. (2005) found that Sr isotopes varied among watersheds with contrasting geology in the Skagit River.

Analytical methods for using Sr isotopes are becoming increasingly sophisticated. For example, Barnett-Johnson et al. (2005) recently used new probe-based methods, including laser ablation (LA) sampling, in conjunction with inductively coupled plasma mass spectrometry (ICPMS), to determine the geographic sources of juvenile Chinook salmon in two California rivers.

To our knowledge, this method has not yet been used for salmonids in the Columbia River Basin.

Stable isotopes of carbon, nitrogen, and sulfur are frequently used to investigate food web pathways in aquatic ecosystems. In these studies, the isotopes are assessed in soft tissues of fish, typically muscle, since this tissue reflects past history of feeding in habitats with different food signatures.

Because of variation in metabolic rates, turnover time of stable isotopes in soft tissue such as muscle, and variability of the isotopes in food, establishing geographic-specific residence and movement patterns with this method is probably less reliable than methods involving isotopes in hard parts such as otoliths and scales. This may be because the turnover rate of the isotopes is relatively slow (e.g., annual deposition) of the organic matrices of otoliths and scales, relative to that of muscle tissue.

However, the method may have utility for specific problems. For example, some investigators in the Basin have recently proposed using stable isotopes of carbon and nitrogen to compare the movements of net-pen reared and wild rainbow trout in a reservoir. The proposal hypothesized that net-pen reared fish would acquire the isotopic signatures of their artificial food, which would be different than those of natural food. The ISRP recently reviewed the proposal and recommended a pilot study on this topic (ISRP 2008-3).

### Scale Pattern Analysis

Scale pattern analysis (SPA) is another tool to estimate stock-specific catch in mixed stock salmon fisheries. Scale pattern analysis is based on differences in the arrangement of circuli (growth rings) that record the growth history of the fish. Marshall et al (1987) provide a good description of a typical application to sockeye salmon in Alaska. Salmon with similar histories have similar scale patterns, and those with different histories exhibit different patterns. The first step in a scale pattern analysis for anadromous salmonids is to collect scales from escapement (or other source of known origin) and from catches. Several aspects of the scales are measured, thereby building baseline data sets of variables that describe the typical pattern for each stock or group of stocks. Next, the data sets from the escapements are compared against each other, using statistical techniques to build a decision rule that can be used to classify scales as belonging to one of the groups. The decision rule and a correction matrix are used to allocate fish of unknown origin from a mixture (the catches) to one of the groups.

The precision of estimates from scale pattern analysis is dependent upon: (a) the accuracy of the uncorrected decision rule (not corrected for errors in the classification matrix), (b) the size of the sample used to construct and evaluate the rule, (c) the size of the sample drawn from the mixed stocks, and (d) the precision of the estimated contribution for each age, when the analysis is stratified by age group.

This method has been used in a study to discriminate stocks of natural and wild Chinook from several subbasins of the Basin. According to Swartzberg and Fryer (1993), linear discriminant analyses of scale pattern data identified hatchery and natural-origin stocks within each subbasin with a relatively high degree of accuracy. Bernard and Myers (1996) used baseline data sets from Columbia River hatchery steelhead to develop and evaluate a maximum likelihood estimator that is independent of age to identify hatchery and natural-origin stocks.

Scale pattern analysis has also been used for the past 20 years to identify the two major stocks of Columbia River sockeye salmon (Okanogan and Wenatchee) in mixed-stock samples of adult salmon collected at dams in the Basin (Schwartzberg and Fryer 1988, 1989, 1990; Fryer and Schwartzberg 1991, 1993, 1994; Fryer et al. 1992; Fryer and Kelsey 2001, 2002, 2003; Fryer 2004, 2005, 2006, 2007). One project reviewed in the recent Innovative Proposal round proposed the use of an automated scale image analysis system for developing Chinook salmon stock identification baselines (200750400). In general, however, scale pattern analysis has been replaced by genetic methods of stock identification both within and beyond the Basin.

## Parasites

The use of freshwater parasites as natural tags to follow the oceanic distribution of Pacific salmon has a long history. The basic tenet of this method is that specific river systems have unique parasites that develop in the bodies of juvenile salmon, while they are growing in freshwater. The parasite can be sampled from older salmon, in the later oceanic phase of life, identifying the source from which they originated. The methodology was reviewed in detail by Margolis (1992) and Konovalov (1995), with special reference to sockeye salmon (cited in Mackenzie (2002) – which is also a good review on the topic of parasites as natural tags). Urawa and Nagasawa (1995) examined samples of five species of salmon caught on the high seas of the North Pacific Ocean and the Bering Sea for infections with the brain parasite *Myxobolus* spp. *Myxobolus kisutchi*, was found only in Chinook originating from the Columbia River and vicinity, and so could serve as a marker for this population (Urawa et al. 2006). A freshwater trematode parasite (*Nanophyetus salmincola*) has been used to estimate proportions of U.S. Northwest origin (including Columbia River) steelhead in the Central North Pacific Ocean (Dalton 1991). Because of interannual variation in the prevalence of parasites (% of stock with the parasite), baseline data for quantitative estimates of stock composition might need to re-established annually (Margolis 1998). Parasites are also being used in BPA-funded research to characterize trophic interactions, habitat, migration, and salmon population origins during early marine residence (Jacobson et al. 2004). While this method is definitive, specialized identification methods and training are required.

# Appendix B. Summary of the Projects addressing Anadromous Salmon Management Using Tags for the Northwest Power and Conservation Council Fish and Wildlife Program (BPA Funded), Army Corps of Engineers' Anadromous Fish Evaluation Program (USACE Funded), and Pacific Salmon Treaty Southern and Northern Fund Programs

**Table 6.B.1. Funded Project Proposals Reviewed in the 2007-09 Northwest Power and Conservation Council Fish and Wildlife Program Solicitation that included tagging, tag recovery, data archiving, or analysis and coordination**

**Table B1**

| Prop. Id | Project Title | Sponsor | Tag Type | Purpose |
|---|---|---|---|---|
| 198201301 | Coded Wire Tag Recovery | PSMFC | CWT | Hatchery-Harvest |
| 198201302 | Annual Stock Assessment – CWT | ODFW | CWT | Hatchery-Harvest |
| 198201303 | Coded Wire Tag | USFWS | CWT | Hatchery-Harvest |
| 198201304 | Coded Wire Tag | WDFW | CWT | Hatchery-Harvest |
| 198331900 | New Marking and Monitoring Technology | NOAA | PIT | Hydro |
| 198335000 | Nez Perce Tribal Hatchery O&M | Nez Perce T | CWT, PIT | Hatchery-Harvest/Hydro |
| 198335003 | Nez Perce Tribal Hatchery M&E | Nez Perce T | CWT, PIT | Hatchery-Harvest/Hydro |
| 198343500 | Umatilla Hatchery Satellite Facilities O&M | CTUIR | CWT | Hatchery-Harvest |
| 198343600 | Umatilla Passage O&M | Westlands | CWT | Hatchery-Harvest |
| 198503800 | Coleville Hatchery | Coleville Tribe | Fin Clip | Hatchery-Harvest |
| 198605000 | White Sturgeon Mitigation Above Bonneville Dam | ODFW | PIT | Hatchery-Harvest - Sturgeon |
| 198712700 | Smolt Monitoring by Federal & Non-Federal | PSMFC | PIT | Hydro |
| 198802200 | Umatilla Fish Passage Operations | CTUIR | CWT – Adult Interrogation | Hatchery-Harvest |

**Table B1**

| Prop. Id | Project Title | Sponsor | Tag Type | Purpose |
|---|---|---|---|---|
| 198805303 | Hood River Production M&E - CTWSR | CTWSR | PIT, CWT | Hatchery-Harvest |
| 198805304 | Hood River Production M&E - ODFW | ODFW | PIT, CWT | Hatchery-Harvest |
| 198805308 | Hood River Powerdale Trap/Pelton Ladder O&M | ODFW | CWT | Hatchery-Harvest |
| 198810804 | StreamNet (CIS/NED) | PSMFC | | |
| 198902401 | Evaluation of Juvenile Salmon Out-migration Umatilla River | ODFW | PIT | Hydro |
| 198909600 | Genetic Monitoring of Snake River Chinook and Steelhead | NWFSC | Genetic | Life-history/Hatchery<br>Relative Reproductive Success |
| 198909800 | Idaho Supplementation Studies | IDFG/NPT/SBT/USFWS | PIT, Genetic | Life-history/Hatchery |
| 198910700 | Statistical Support for Salmonid Survival Studies | U of W | | |
| 199000500 | Umatilla Hatchery – M&E | ODFW | PIT, CWT Analysis | Life-history/Hatchery/Harvest |
| 199000501 | Umatilla Basin Natural Production Monitoring | CTUIR | Radio (application)<br>PIT, CWT Analysis | Life-history<br>Hatchery/Harvest |
| 199004400 | Coeur D'Alene Habitat Enhancement | Coeur D'Alene Tribe | PIT (West slope CT) | Life-History |
| 199005500 | Idaho Steelhead Monitoring and Evaluation | IDFG | PIT, Genetic | Life-history, abundance |
| 199007700 | Systemwide Predator Control for Pikeminnow | PSMFC | PIT (other Marks) | Harvest |
| 199008000 | PIT-Tag Information System | PSMFC | PIT | |
| 199101903 | Hungry Horse Mitigation | MFWP | Genetic (West slope CT) | Life-history/Hybridization |
| 199102800 | PIT Tagging Wild Chinook | NOAA | PIT | |
| 199102900 | Research, Monitoring, Emerging Issues – Fall Chin | USFWS | PIT | Snake R. Fall Chinook |
| 199104600 | Spokane Tribal Hatchery | Spokane Tribe | Thermal Otolith | Kokanee – Lake Roosevelt |
| 199105100 | M&E Statistical Support for Life-Cycle Studies | U of W | PIT, CWT, Analysis | |
| 199107100 | Snake River Sockeye Salmon Habitat | Shoshone Bannock Tribe (SBT) | PIT | Sockeye – Life History/Hydro |

**Table B1**

| Prop. Id | Project Title | Sponsor | Tag Type | Purpose |
|---|---|---|---|---|
| 199107200 | Redfish Lake Sockeye Salmon Captive Broodstock Program | IDFG | PIT | Hatchery/Hydro |
| 199107300 | Idaho Natural Production Monitoring | IDFG | Genetic | Life-history |
| 199202604 | Life History of spCh and smStl in Grande Ronde Subbasin | ODFW | PIT | Life-history/Hydro |
| 199302900 | Survival Estimates for the Passage of Juvenile Salmon through Snake and Columbia River Dams and Reservoirs | NWFSC | PIT | Hydro |
| 199304000 | Fifteenmile Creek Habitat Restoration & ME | ODFW | PIT | Life-History, Habitat M&E |
| 199305600 | Research to advance hatchery reform | NWFSC | PIT, Genetic | Hatchery |
| 199306000 | Select Area Fisheries Enhancement | ODFW | CWT | Hatchery/Harvest |
| 199402600 | Pacific Lamprey Research and Restoration | CTUIR | Radio (Lamprey) | Life History |
| 199404300 | Lake Roosevelt Fisheries Evaluation | Spokane Tribe | Floy | Hatchery/Harvest |
| 199404200 | Trout Creek Habitat Restoration | ODFW | Smolt and Adult Trapping | Life History/Habitat Evaluation |
| 199403300 | The Fish Passage Center | States ? | | |
| 199404700 | Lake Pend Oreille Fishery Recovery Project | IDFG | Hydroacoustic Otolith | Kokanee |
| 199405400 | Migratory Patterns, Structure, Abundance and Status of Bull Trout in Subbasins of the Columbia Gorge, Plateau, and Blue Mountain Provinces | ODFW | PIT | Bull Trout Life History |
| 199500100 | Kalispel Tribe Resident Fish Project | Kalispel Tribe | CWT/Fin Clip | Large Mouth Bass Project |
| 199500400 | Libby Mitigation Program | MFWP | Genetic | Cutthroat Trout Hybridization |
| 199502700 | Lake Roosevelt White Sturgeon Project | Spokane Tribe | PIT | Sturgeon |
| 199506335 | YKFP – Klickitat Subbasin Monitoring and Eval | Yakama Tribe | PIT, Radio | Hatchery/Harvest, Life History |
| 199601900 | Technical Management Team | U of W | | DART |
| 199602000 | PIT Tagging Spring/Summer Chinook (CSS) | CRFPO | PIT | Hydrosystem |
| 199604000 | Mid-Columbia Coho Restoration Project | Yakama Tribe | CWT, PIT | Hatchery/Harvest, Life History |

**Table B1**

| Prop. Id | Project Title | Sponsor | Tag Type | Purpose |
|---|---|---|---|---|
| 199604300 | Johnson Creek Artificial Propagation Enhancement | Nez Perce Tribe | CWT, PIT | Hatchery/Harvest, Life History |
| 199700100 | Idaho Chinook Salmon Captive Rearing | IDFG | CWT, PIT, VIE | Hatchery/Life History |
| 199701500 | Imnaha River Smolt to Adult Return Rate and Smolt Monitoring Project | Nez Perce Tribe | PIT | Hatchery/Life History/Hydro |
| 199703000 | Chinook Salmon Adult Abundance Monitoring | Nez Perce Tribe | Didson Acoustic | Life-History |
| 199800200 | Snake River Native Salmonid Assessment | IDFG | Genetic | Cutthroat Trout Hybridization |
| 199800702 | Grande Ronde Supplementation Lostine O&M/M&E | Nez Perce Tribe | PIT | Hatchery/Harvest, Hydro |
| 199800703 | Grande Ronde Supplementation O&M | CTUIR | PIT (others?) Adult Interrogation | Hatchery/Harvest, Hydro |
| 199800704 | Grande Ronde spCh Supplementation O&M | ODFW | PIT (others?) redd surveys | Hatchery/Harvest, Hydro |
| 199801001 | Grande Ronde Captive Brood O&M | ODFW | PIT | Hatchery |
| 199801003 | Spawning Distribution of Snake River fall Ch | USFWS | Redd Surveys | Hatchery/Life History |
| 199801004 | Monitor and evaluate performance of Snake River fall Chinook from acclimation facilities | Nez Perce Tribe | PIT | Hatchery/Harvest, Hydro Not Funded – What Consequence? |
| 199801006 | Captive Broodstock Artificial Production | Nez Perce Tribe | PIT, VIE, Adult interrogation, redd surveys | Hatchery/Harvest |
| 199801400 | Ocean Survival of Salmonids | NOAA | M&E | Estuary Ocean |
| 199801600 | Salmonid Productivity, Escapement, Trend, and Habitat Monitoring in the John Day Subbasin | ODFW | PIT | Hydro |
| 199900301 | Evaluate spawning of fall Ch and Chum just below the four lowermost mainstem dams | ODFW | PIT, Didson, CWT | Life-cycle, Hydro, Hatchery |
| 199902000 | Analyze Chinook salmon Spatial and Temporal Dynamics and Persistence | USFS | Redd Surveys, Tissue Collection, Analysis | Life-cycle |
| 200000100 | Anadromous Fish Habitat & Passage | Coleville Tribe | PIT – Adult Detection | Life-cycle |
| 200001200 | Evaluate factors limiting Columbia River chum salmon | USFWS | ? Mark/Recapture Juvenile chum | Juvenile abundance |
| 200001400 | Evaluate population dynamics and habitat use of lamprey in Cedar Creek | USFWS | PIT | Life-cycle |
| 200001700 | Recondition Wild Steelhead kelts | CRITFC | PIT, Radio, Acoustic | Life-cycle, Hatchery |

**Table B1**

| Prop. Id | Project Title | Sponsor | Tag Type | Purpose |
|---|---|---|---|---|
| 200001900 | Tucannon River Sp Ch Captive Broodstock Prog | WDFW | PIT | Hatchery/Harvest |
| 200002800 | Eval Pacific Lamprey in Clearwater River | IDFG | Radio | Life-cycle |
| 200003900 | Walla Walla Subbasin Collaborative Salmonid Monitoring & Evaluation Project | CTUIR | Radio, PIT | Life-cycle, Hydro, Harvest |
| 200100300 | Adult PIT Detector Installation | PSMFC | PIT | Hydro, Life-cycle, H/H |
| 200102800 | Banks Lake Fishery Evaluation Project | WDFW | Thermal | Life-cycle, H/H |
| 200102900 | Ford Hatchery Operations & Maintenance | WDFW | Otolith – Thermal | Hatchery/Harvest |
| 200105300 | Reintroduction of chum salmon into Duncan Creek | PSMFC | Floy, Otolith (thermal), Otolith (strontium) | Hatchery/Harvest |
| 200201600 | Evaluate the status of Pacific lamprey in the lower Deschutes River Subbasin, Oregon | CTWSR | Radio | Adult Abundance, Life-cycle |
| 200203000 | Develop Progeny Marker for salmonids to evaluate supplementation | CTUIR | Elemental Otolith, Genetic | Relative Reproductive Success |
| 200203200 | Snake River fall Chinook salmon Life History | USGS | PIT, Radio, Acoustic ? | Life-cycle |
| 200205300 | Assess salmonids Asotin Cr Watershed | WDFW | PIT, Floy | Life-cycle |
| 200206000 | Nez Perce Harvest Monitoring | NPT | Field Sampling and Data Analysis | Hatchery/Harvest |
| 200300900 | Canada-USA Shelf Salmon Survival Study | Canada | Genetic/Others? | Ocean Survival |
| 200301700 | ISEMP – Integrated Status and Effectiveness Monitoring | NWFSC | Genetic, PIT, Didson | Life-cycle |
| 200302200 | Okanogan Basin Monitoring and Evaluation | Colville Tribes | Need Confirmation | Life-cycle |
| 200303600 | CSMEP – Collaborative Systemwide Monitoring and Evaluation Project | CBFWA | PIT, CWT, Other Analysis & Evaluation | Hydro, Hatchery/Harvest, Life-cycle (status and trends) |
| 200303900 | Monitor Reproduction in Wenat/Tuc/Kal | WDFW/NWFSC | PIT, Genetic | Hatchery – Relative Reproductive Success |
| 200304100 | Evaluate Latent Mortality | NWFSC | PIT | Hydro |
| 200305000 | Evaluation of Reproduction of Steelhead | University of Wash | Genetic | Hatchery – Relative Reproductive Success |
| 200305400 | Reproduction of Steelhead in Hood River | University of Oregon | Genetic | Hatchery – Relative Reproductive Success |
| 200306200 | Evaluate the relative reproductive success of reconditioned kelt steelhead | CRITFC | Genetic | Hatchery – Relative Reproductive Success |
| 200311400 | Acoustic Tracking for Survival | Kintama | Acoustic | Hydro, Ocean/Estuary |

**Table B1**

| Prop. Id | Project Title | Sponsor | Tag Type | Purpose |
|---|---|---|---|---|
| 200400200 | PNAMP Funding | USGS | M&E Coordination | |
| 200500200 | Operation of the Lower Granite Dam Adult | NWFSC | Adult Fish Interrogation | Hydro, Hatchery/Harvest |
| 200600800 | Evaluation of the biological effects of the NWPCC's mainstem amendment on fisheries upstream and downstream of Hungry Horse and Libby Dams, MT | MFWP | PIT, Radio | Life-cycle |
| 200700300 | Dworshak Dam resident fish mitigation | IDFG | Acoustic | Kokanee Abundance |
| 200703700 | North Fork Toutle River fish passage | Steward and Assoc | Radio | Tributary adult migration |
| 200704600 | Steelhead spawning ground surveys of small tributaries of the upper middle mainstem Columbia River | WDFW | Redd and Carcass Survey, tissue collection | Life-cycle (adult abundance) |
| 200715000 | Expand salmonid monitoring in Grays River to meet monitoring needs identified in the Lower Columbia Salmon Recovery and Subbasin Plan and maintain an at risk chum salmon population through supplementation | WDFW | Thermal Otolith | Hatchery/Harvest, Life-cycle |
| 200721600 | PNAMP – Fish Monitoring RME design and protocols | PNAMP | M&E Coordination | Fish Counting Protocol Standardization |
| 200722900 | Development of protocols and priorities for reestablishing naturally producing populations of Upper Willamette River Ch salmon above US ACE dams in the Willamette subbasin | ODFW | PIT, Genetic | Life-cycle, Population Structure |
| 200724900 | Evaluation of Live Capture, Selective Fishing Gear | Coleville Tribe | Not Specified | Life-cycle |
| 200733300 | Timing and survival of PIT tagged Juvenile fall Chinook from the Hanford Reach | CRITFC | PIT | Hydro, Hatchery/Harvest |
| 200735500 | Determine the accuracy of adult coho salmon population estimates | WDFW | CWT recovery and analysis | Hatchery/Harvest |
| 200736800 | Adult coho salmon monitoring proposal for the lower Columbia River province | WDFW | CWT recovery and analysis | Hatchery/Harvest, Life-cycle |

**Table 7.B.2. Tags used by the U.S. Army Corps of Engineers' (USACE) funded projects in its Anadromous Fish Evaluation Program (AFEP) in 2008.**

**Table B2**

| Project | Species[7] | Sponsor[8] | Tag Type[9] | N Tags[10] | Purpose |
|---|---|---|---|---|---|
| Post-FCRPS Survival | CH1, CH0 | CE-NWP | JSATS/PIT | 1,740 | Reach survival from Bonneville Dam to Columbia R. mouth |
| Bonneville Spillway | CH1, CH0 | CE-NWP | JSATS/PIT | 3,260 | Spillway survival including high vs. low deflectors |
| Bonneville B2-Behavioral Guidance Structure | CH1, CH0, STHD | CE-NWP | JSATS/PIT | 1,250 | Evaluate effect of BGS on changes to corner collector efficiency |
| Bonneville B2 Gatewell Condition | CH1, CH0 | CE-NWP | PIT | 17,500 | Evaluate fish condition at varying flows within the 1% peak efficiency range |
| Bonneville Lamprey Passage | Adult Lamprey | CE-NWP | RT/PIT; PIT | 600; 1,400 | Effects of prototype and final modifications to aid lamprey passage |
| John Day Temporary Spillway Weir | CH1, CH0, STHD | CE-NWP | JSATS/PIT | 7,000 | Evaluate changes from historical FPE relative to installation of a TSW; route-specific survival included |
| Comparative Performance AT and PIT (Tag Effects) | CH1, CH0 | CE-NWP | JSATS/PIT; PIT | 5,500; 20,000 | Determine the limitations of the JSATS for conducting long reach/system survival studies (both field and lab studies) |
| Turbine Survival Program Pressure testing | CH1, CH0 | CE-NWP | JSATS/PIT | 200 | Evaluate the effects (injury and survival) of turbine passage on tagged fish. |

7 Studies were on juvenile fish unless otherwise noted (CH1 = yearling Chinook, CH0 = subyearling Chinook. STHD = steelhead).
8 CE-NWP = Portland District and CE-NWW = Walla Walla District.
9 All studies utilizing JSATS also implanted a PIT tag at time of tagging.
10 Multiple studies in the Lower Columbia utilized JSATS tagged fish released upstream, these number represent the number of tags purchased and used but do not necessarily reflect study sample sizes (e.g. Bonneville BGS and Spillway studies utilized CH1 and STHD tagged for the JDA TSW study)

**Table B2**

| Project | Species[7] | Sponsor[8] | Tag Type[9] | N Tags[10] | Purpose |
|---|---|---|---|---|---|
| John Day River Instream PIT detector evaluation | Adult STHD | CE-NWP | RT/PIT | 100 | Evaluate the detection efficiency of an instream PIT-tag detector in the John Day River |
| McNary Passage and Survival | CH1, SH, CH0 | CE-NWW | AT-HTI/PIT | 7,730 | Behavior, passage, and survival at McNary Dam |
| LMN Post Construction Evaluation | CH1,SH,CH0 | CE-NWW | RT/PIT | 9,090 | RSW Post construction evaluation |
| LGS Adult studies | CH, SH | CE-NWW | Lotek | 900 | Determine adult behavior |
| Delayed Mortality | CH1 | CE-NWW | JSATS/PIT | 4300 | Estimate delayed mortality |

**Table 8.B.3. Projects funded by the Pacific Salmon Commission (PSC) in 2008 that include Columbia River Basin tagging, tag recovery, data archiving, or analysis and coordination and PSC-funded tagging projects in other locations.**

## Table B3

| Fund | Project Title | Sponsor | Tag type | Purpose | Project Objective | Location |
|---|---|---|---|---|---|---|
| SF | SNP Development and Lab Infrastructure Support for Genetic Stock ID | CRITFC | Genetic (SNP) | Harvest | Develop SNP markers to differentiate summer/fall Chinook | Columbia R. |
| SF | Chinook Baseline Expansion with Additional Genetic Markers. Year 4 | CRITFC | Genetic (SNP) | Harvest | Improve capabilities for genetic stock identification of Chinook from mixed fisheries by adding SNP markers for 20 populations (26 pops already in database) | Columbia R. |
| SF | Use of PIT tags to determine upstream migratory timing and survival of Columbia Basin sockeye salmon, Year 3 | CRITFC | PIT, Thermal Otolith | Hydro, Life History | Determine stock-specific adult migratory timing and migration mortality | Columbia R. |
| SF | Ocean harvest real-time forecasts of fall Chinook salmon (Oncorhynchus tshawytscha) returns to the Columbia River | CRITFC | CWT | Harvest | Develop accurate real-time run forecast using ocean catch data | Columbia R. |
| SF | Coho Fishery Regulation Assessment Model (FRAM) validation | DFO | CWT | Harvest | Validate model used to evaluate pos-season compliance with management-unit-specific exploitation rate caps | Coast-wide |
| SF | Optimal Allocation of Chinook Stock Assessment Funding | WDFW | CWT, Genetic | Life Cycle | Provide objective, comprehensive framework for evaluating trade-offs in the cost, accuracy and precision of marking, tagging, sampling, and escapement estimation programs | Coast-wide |
| SF | Allele ladder-based standardization of existing coho salmon microsatellite data and implementation in the GAPS database | NOAA-NMFS-NWFSC | Genetic (microsatellite) | Harvest | Simplify microsatellite DNA standardization and to consolidate existing data for coho salmon microsatellite loci currently in common use among multiple laboratories | Coast-wide |

**Table B3**

| Fund | Project Title | Sponsor | Tag type | Purpose | Project Objective | Location |
|---|---|---|---|---|---|---|
| SF | Chinook and coho genetic stock identification | DFO | Genetic (Microsatellite, SNP) | Harvest | Develop standardized baselines for Chinook and coho salmon | Coast-wide |
| SF | Expand and refine the GAPS Chinook database to support Genetic Stock Identification studies relevant to the Pacific Salmon Treaty | NOAA-NMFS-NWFSC | Genetic (SNP/microsatellite) | Harvest | Expand existing database by adding new data already available | Coast-wide |
| NF | Expand and Refine the GAPS Chinook Database to Support Genetic Stock Identification Studies Relevant to the Pacific Salmon Treaty | NOAA-NMFS-NWFSC | Genetic (Microsatellite, SNP) | Harvest | Development of standardized genetic baselines for Chinook | Coast-wide |
| NF | Estimating the Chinook Salmon Stock Composition of Southeast Alaska Fisheries, 2009. Year 3 | ADFG | Genetic (microsatellite, SNP) | Harvest | Stock identification of Chinook salmon in commercial troll and sport fisheries in Southeast Alaska; directed drift gillnet harvests in several fishing districts | Coast-wide |
| SF | The Origin of Marked-Untagged Chinook Found on the Skagit River Spawning Grounds | WDFW | Genetic | Hatchery | Identify stock of origin of adipose-clipped and untagged (ACU) salmon on spawning grounds and river traps | Washington |
| SF | South Fork Nooksack Chinook Supplementation: Genetic Analysis and Rearing | WDFW | Genetic | Hatchery | Develop baseline to improve ability to identify wild stock at high risk of extinction and hatchery strays on spawning grounds | Washington |
| SF | Development of a SNP genetic baseline for Chinook populations in Puget Sound | WDFW | Genetic (SNP) | Harvest | Develop a single nucleotide polymorphism (SNP) baseline for 30 Chinook populations in Puget Sound | Washington (Puget Sound) |

**Table B3**

| Fund | Project Title | Sponsor | Tag type | Purpose | Project Objective | Location |
|---|---|---|---|---|---|---|
| SF | Parent-Based Tagging as an Identification Tool in Mixed Fishery Analysis: Test of Concept on Closely Related Fall Chinook Populations | WDFW | Genetic (DNA), Parent-based tagging (PBT), CWT | Hatchery, Harvest | Proof of concept of parent-based tagging for stock identification of adult returns to fisheries and hatcheries | Washington (Puget Sound, Hood Canal) |
| SF | Impact of Growing Sea Lion Populations on the Ocean Survival and Productivity of | DFO, WDFW | Genetic | Life Cycle, Predation | Use genetic techniques applied to bones recovered in sea lion scats to identify the salmon species and stocks being impacted by sea lions | Washington, B.C. |
| SF | Increase Southern BC indicator stock coded-wire tagging to improve the quality of Chinook and coho indicator stock analyses | DFO | CWT | Harvest, Life Cycle | Funds tagging of an index stock beyond the base level provided by CDFO | B.C. |
| SF | West Coast Salmon | DFO | CWT | Harvest | increase coded-wire tagging (CWT) for an index stock | B.C. |
| SF | Improvements to the Harrison River Chinook key stream program: an alternative release strategy for hatchery-reared Harrison Chinook to improve CWT recoveries Year 2. | DFO | CWT | Hatchery, Harvest, Life Cycle | Increase survival of CWT juveniles by rearing to a larger size for an index stock | B.C. |
| SF | Assessment of a live capture and tagging facility for salmon and steelhead below Mission and in the Fraser canyon | LGL Limited | External tags, Radio Tag, DIDSON Acoustic Imaging | Life Cycle, Harvest | To provide managers with more reliable estimates of spawning escapement, harvest, environmental impacts and en route losses | B.C. |

## Table B3

| Fund | Project Title | Sponsor | Tag type | Purpose | Project Objective | Location |
|---|---|---|---|---|---|---|
| SF | Estimates of the abundance of hatchery Chinook in wild spawning populations, Year 5 | DFO | Otolith thermal mark | Hatchery | Provide otolith mark reading service for WCVI, estimate hatchery Chinook straying, evaluate accuracy of CWT estimates of hatchery contributions to catch and escapement | B.C. |
| SF | Estimates of the abundance of hatchery Chinook in wild spawning populations. Year 5 | DFO | Thermal Otolith, CWT | Hatchery | To develop understanding of the extent of hatchery Chinook straying; evaluate accuracy of CWT as indicator of hatchery contribution | B.C. |
| SF | DNA Sampling of Broodstock Used for the Recovery of Cultus Sockeye. Year 3. | PSC | | Hatchery | Use DNA to evaluate traditional hatchery supplementation and complex captive brood stock procedures at two hatcheries | B.C. |
| SF | Collection and Analysis of DNA Based Stock Composition Data – WCVI Chinook Troll Fishery. Year 5 | DFO | Genetic | Harvest | Evaluate stock-specific impacts of the WCVI troll fishery | B.C. |
| SF | Sampling & Processing of Chinook Double Index CWT Recoveries in Southern BC Commercial Fisheries. Year 2 | DFO | Double Index Tagged (DIT) | Hatchery, Harvest | Sample unclipped Chinook for CWTs in southern BC to improve PSC estimates of exploitation rates of ESA-listed stocks | B.C. |
| NF | Recreational Chinook Creel Survey | DFO | CWT, DNA | Life Cycle, Harvest | Estimate stock composition, compare CWT & DNA estimates | B.C. |
| NF | Stikine, Taku, and Alsek River Sockeye and Chinook Salmon Baseline DNA, Profiles. Year 3 | DFO | Genetic (Microsatellite, SNP) | Harvest | Develop DNA baseline for Chinook and sockeye salmon | B.C. |
| NF | Live capture and Tagging of Skeena Chinook Feasibility Study | LGL Ltd | Radio Tag, DNA | Life Cycle | Assess the distribution, abundance, migratory behavior, and stock origin | B.C. |

## Table B3

| Fund | Project Title | Sponsor | Tag type | Purpose | Project Objective | Location |
|---|---|---|---|---|---|---|
| NF | Skeena River Steelhead Genetics | B.C. Ministry of Environment | Genetic (Microsatellite) | Life Cycle, Harvest | Provide information on summer steelhead timing, stock composition and abundance; assess impacts of commercial fisheries | B.C. |
| NF | Analysis of Alsek River Sockeye Salmon Radiotelemetry Data Collected from 2001 to 2003 | LGL Ltd | Radio Tag | Life Cycle, Harvest | Estimate stock-specific escapement, run timing in river and through commercial fisheries, migration rates, identify spawning locations | B.C., Alaska |
| NF | Development of Thermal Mark Data Sharing Methods | DFO | Thermal Otolith | Hatchery, Harvest | Develop a system for the exchange of thermal mark data between DFO and ADFG | B.C., Alaska |
| NF | Chickamin River Chinook Salmon Escapement Sampling. Year 3 | ADFG | CWT | Life Cycle, Harvest | Provide high-quality escapement enumeration data for index stocks as PSC and coast-wide fishery management agencies shift to stock-specific abundance-based management regimes | Alaska |
| NF | Chilkat River Chinook Salmon Coded Wire Tagging. Year 3 | ADFG | CWT | Life Cycle, Harvest | Estimate number of fry rearing in river/marine harvest of adults for an index stock | Alaska |
| NF | Genetic Changes Associated with In-basin Supplementation of a Population of Sockeye Salmon; Feasibility | UAF | Genetic | Hatchery | Evaluate reproductive success of fish produced artificially for wildstock supplementation through parental analysis | Alaska |
| NF | Developing Baselines for Chinook and Sockeye Salmon Genetic Stock Identification | ADFG | Genetic (SNP) | Harvest | Development of standardized genetic baselines for both Chinook and sockeye | Alaska |
| NF | Northern Boundary Area Sockeye Genetic Stock Identification. Year 3 | NOAA-NMFS-AFSC, Auke Bay Laboratory | Genetic (SNP) | Harvest | Accurate estimates of the stock-specific catch in commercial fisheries | Alaska |
| NF | Thermal Mark Recovery Validation | ADFG | Thermal Otolith | Hatchery. Harvest | Assess role of thermal mark placement relative to the hatch event in mark detectability and recovery | Alaska |

**Table B3**

| Fund | Project Title | Sponsor | Tag type | Purpose | Project Objective | Location |
|---|---|---|---|---|---|---|
| NF | Northern and Transboundary Sockeye Matched Scale-Tissue Sampling. Year 2 | ADFG | Thermal Otolith, Genetic, Scale | Hatchery, Harvest | Use otoliths to assess relative contribution of hatchery and wild returns and to compare/validate DNA and scale pattern stock composition estimates | Alaska, B.C. |
| NF | Tatsamenie Lake Extended Rearing | Mercer and Associates | Thermal Otolith | Hatchery | Evaluate extended netpen rearing of sockeye salmon at Tatsamenie Lake with the expectation of significantly improving survival rates | Yukon Territory |

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