Summary of Fish Tagging and Evaluation Techniques Currently Used in the Columbia River Basin

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INTRODUCTION

This document is intended to provide fisheries managers, researchers and other interested parties with a concise description of the fish tagging technologies currently used by the State, tribal and Federal fish management agencies in the Columbia River Basin. Perhaps more importantly, this document will also serve as a vehicle to convey the fish management communities' needs and desires for future fish tagging technologies.

The ultimate goal in the future would be to have a fish tagging system that would allow the measurement of in-river reach and route-specific fish survivals in terms of both juvenile survival and smolt-to-adult returns. This means the tag itself must be small and inexpensive enough to mark large numbers of juveniles early in their life history and benign enough to have little effect on fish behavior. It also needs to be able to measure long-term survival. This future tag would need to have the capability to be read through all routes of passage in the outmigration corridor and again as the adults return. Ideally, the system that is developed would not require any further handling of the fish after initial handling and tagging occurs. The following list summarizes some of the management needs (in no particular order):

1. Route-specific survival and passage efficiencies
2. Forebay survival and delay
3. Project-specific survival
4. Reach and system survival and travel times
5. Estuary and near-ocean survival and passage metrics
6. Adult returns for various migration histories (latent mortality)
7. Lamprey survival and passage
8. Fry survival and migration characteristics

The currently available tagging technologies listed below are arranged in no particular order. Each tag technology treatment will include the following sections: 1) Background – a brief description of the technology (including detection and information network infrastructure) and history of development with major changes and dates; 2) Current uses of the technology with a focus on the Columbia Basin; 3) Advantages and disadvantages of the technology in the context of the management needs listed above; 4) Future development given what we currently know; and 5) Funding, including adequacy of current funding and future needs.

PASSIVE INTEGRATED TRANSPONDER (PIT) TAG TECHNOLOGY

Introduction

Passive-Integrated-Transponder (PIT) tags are glass encapsulated, implantable radio-frequency identification (RFID) devices that contain integrated circuit chips. They are passive, which means they do not contain an internal energy source, e.g., batteries. Consequently, the tag remains functional for the entire life of a tagged animal. After implantation, the PIT-tag remains inactive until it is energized by the electromagnetic field generated by low radio frequency waves emitted by an antenna connected to a transceiver. A PIT-tag system consists of the tag, antenna and transceiver. Improvements in the performance of a system can be made by improving any of the three main components.

Most of the PIT-tag equipment installed throughout the Columbia River Basin for monitoring salmonids utilizes full-duplex (FDX) 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, and 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.

Although the half-duplex (HDX) technology also includes a 134.2 kHz carrier field, it operates quite differently from the FDX technology. In the HDX technology, the antenna generates the 134.2-kHz field for X amount of time (typically ~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 actually do actively transmit their tag codes.

In this summary for the Tagging Technologies Work Group, the two PIT-tag technologies will be addressed separately. In each section, the current status and applications, and future direction of the PIT-tag technologies will be presented. In addition, a list of advantages and disadvantages for each tagging technology is provided. At the end is a table listing the different management questions that the region's fisheries managers want addressed, and which of those questions the PIT-tag technologies are able to address.

FULL-DUPLEX PIT-TAG TECHNOLOGY

Background

Full-duplex (FDX) PIT-tag technology was chosen for monitoring salmonids for several reasons. It can detect tagged fish moving at high speeds and it has tags that are small enough (12.5-mm length by 2-mm diameter; 0.1 g in air) to tag 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 caused by the small 12-mm tags. As a result, the FDX-B systems typically have relatively small antennas (95percent or more 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 tag's read ranges are relatively short (measured in feet and inches) compared to active tag technology, which is measured in yards and miles.

Currently, most of the FDX components used throughout the Columbia River 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 will be switching 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 3 years ago.

NOAA Fisheries is currently leading an effort supported by BPA and the Corps 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 are around 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; however, fisheries researchers have stipulated that any new tag that is designed must be capable of being read by the existing FDX PIT-tag systems.

Tags

Starting with the 2007 outmigration year, the standard 12-mm PIT-tag model will be 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 Columbia River Basin since 2003. Tests conducted in 2006 in the Bonneville Dam corner-collector antenna that measures 17' by 17' demonstrated that this was true, as approximately 70percent of the SST-tagged fish were detected compared to around 40percent for the ST-tagged fish. This difference in detection levels was also 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 read range is similar to a 12-mm BE 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 that they are based on is now about 10 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 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 costs almost three times the price of a FS1001 transceiver.

Antennas

To be able to make antennas larger over the past few years, PIT-tag researchers have experimented with different types of wire and different brands of capacitors. 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 solutions that work for them. The general push at this time is to try to improve 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 obviously limits the types of research questions that can be answered with this technology in saline environments. Accordingly, researchers are encouraging the PIT-tag manufacturers to investigate ways to improve the performance of this technology in these types of environments.

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

A dam's spillway is another unfavorable tag detection environment, as the spillway gates are made from metal and that metal has to 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 of the 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

Since the late 1980s, PIT-tags have been the main tool used for monitoring salmonid migrational behavior and timing in the Columbia River Basin. They are also used extensively for determining survival rates of juvenile fish through Columbia and Snake river reaches and for 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. PIT-tags are also being used in research to examine delayed mortality observed in the Snake River Chinook salmon and to estimate avian predation rates.

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. 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

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

- It is a small tag (most tags used are 12.5 mm by 2 mm; new 8 mm tag now available)
- Can tag small smolts (60 mm with 12-mm tags and down to 50 mm with 8-mm tags)
- Can tag adult salmonids
- 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
- Tags are 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.
- 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.
- Interrogation systems are currently being installed into Columbia 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:

- There are limitations on antenna size; the largest antenna currently deployed at the mainstem hydroelectric dams is 17 feet by 17 feet.
- Researchers currently cannot detect PIT-tagged fish passing through spillways or turbines at the mainstem dams and so we cannot get route-specific passage and survival information on fish passing through these routes.
- 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.
- Not enough in-stream PIT-tag detection systems are currently installed to yield information on the research questions outlined in the in-stream applications sectionbelow, e.g., fish movement during the fall and winter months, or learning about different life-history strategies of salmonids.
- 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.

- 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.
- The existing range of auto tuning in the current set of transceivers is limited.
- Unable to tag salmonid fry or juvenile lamprey with current PIT-tags (even using the 8-mm tags).
- 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. (John Williams, pers. comm.)
- For fish tagged as juveniles, the tag can be expelled during late maturation before or during spawning activity.

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 BPA and the Corps from purchasing tags that will be injected into fish from other tag manufacturers.[2] This patent is active until 2010. Because of this exclusive patent, BPA and the Corps have negotiated fixed prices for the tags they will purchase until 2010. The price per tag in 2007 will be $1.90 for each SST tag. In 2008 and 2009, the price for each SST tag will be $1.80. Then in 2010, it will be $1.70.

As indicated in the Introduction section above, 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 amount of read 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, 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. The goal is to have prototype in-stream transceivers installed by the end of 2007. Juvenile fish migration in the fall has also been documented in

[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.

Beaver Creek in the Methow River Basin and Rattlesnake Creek in the White Salmon subbasin using an in-stream PIT-tag detection system.

Furthermore, development of future in-stream 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 utilize 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 O&M tasks easier for the Pacific States Marine Fisheries Commission, 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 in-stream users of the technology have indicated to Digital Angel a preference for antennas that do not need an air gap.

In-stream Applications

In-stream 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 in-stream detection systems will yield fish movement, survival and habitat use information related to:

- 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 research includes the need to design a study to investigate NOAA Fisheries scientists' concerns about long-term tag effects on salmonids.

Current Funding and Future Needs

Both BPA and the Corps of Engineers have been, and are presently supporting research projects that use PIT tags. BPA also currently funds a NOAA Fisheries-sponsored project that is developing future PIT-tag technology. Funding for this project varies from year to year depending on what technology is being developed. Currently, BPA is providing some of the funding for development of a new multiplexing transceiver and for investigating the feasibility of developing a system for interrogating PIT-tagged fish in individual spillway bays. NOAA Fisheries is also contributing some funds to support these efforts.

BPA should be commended for its funding support in development of new and improved PIT-tag technologies over the past 25 years. During that time, BPA has recognized that not every R&D undertaking would lead to an improved product, but overall its support has enabled advances in PIT-tag technologies to keep pace with regional research needs. It is important to keep this development process active or there will not be the necessary improvements to PIT-tag technology to expand our understanding of salmonids. Besides looking into potentially developing a PIT-tag detection system for spillbays, there is interest in developing PIT-tag systems for turbines and for applications that are not directly associated with the mainstem federal hydroelectric facilities (e.g., in-stream and estuarine applications). As PIT-tag projects have grown in scale and have broader application, the funding of these developments has come from multiple agencies. We envision that this trend will continue into the future.

HALF-DUPLEX PIT-TAG TECHNOLOGY

Current Uses and Application

Currently, half-duplex (HDX) PIT-tag technology is being used in the Northwest for fish species such as bull trout and adult lamprey. Researchers for these species have chosen to utilize HDXPIT-tag technology for various 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 to purchase. The PIT-Tag Steering Committee, which is a subcommittee of CBFWA’s Fish Passage Advisory Committee, also decided several years ago that lamprey should not be tagged with FDX PIT tags because their behavior in fish ladders could cause tagged migrating salmonids to be missed, i.e., lamprey tend to take 4-5 minutes to pass an orifice and that would mean, any tagged salmonids passing during that time would go by undetected.

NMFS and Oregon RFID have tested the HDX technology under saline conditions to determine how well it might perform for estuary studies. It performed better than FDX technology, although its detection fields were still attenuated.

Advantages

The biggest advantage of the HDX technology is that it is possible to construct simple, large antennas. Since the antennas typically consist of single strands of wire, they are also inexpensive to produce and, if needed, their shapes can easily be modified.

Other advantages of HDX PIT-tag technology include the following:

- Antennas are simple to construct (only need a single strand of welding wire)
- Antennas do not need an air gap – can be in contact with water
- Antennas can be much larger than FDX antennas (one antenna could span a small to mid-sized stream; the largest antenna in use is 200 feet by 1 foot)
- Transceiver equipment is inexpensive (<$1,000 for one transceiver)
- Inexpensive tag (about $3/tag)
- HDX technology handles saline conditions better than FDX technology
- All transceivers can auto tune and auto sync with each other

Disadvantages

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

- It is a larger tag (23 mm by 4 mm) than the current FDX tag, and it is too large to be used for tagging salmonid smolts.

- Texas Instruments has no interest in modifying their equipment in any way to make it work better for fisheries research purposes, i.e., the company refuses to consider producing smaller tags or to make any changes to their transceivers.
- Message transmission is slower and so HDX systems cannot be installed where tagged fish would be moving quickly. Specifically, the technology is too slow to handle detection at locations with water velocities greater than 10 feet per second, i.e., at routes of fish passage at most mainstem Columbia and Snake river hydropower projects.
- Because the HDX system requires a quiet time period to receive the tag code, it can be interfered with by FDX systems installed in close proximity to it; thus these systems cannot be used together.
- Transceivers do not record or transmit diagnostic messages that would help to monitor situations when problems occur intermittently

Future Development

Based on its superior performance under saline conditions over FDX technology, 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 their equipment to broaden its use for fisheries research applications. For example, TI refuses to consider manufacturing a smaller tag or to make changes to their transceivers to correct an identified problem. The TI transceivers are also based on older electronics technology and it is unclear when the company might discontinue manufacturing them.

Current Funding and Future Needs

Since the TI HDX PIT-tag -technology is proprietary and since the company has no interest in modifying its equipment, no funding is currently being requested to improve the HDX equipment for fisheries research applications. In the future, however, if TI or any other tag manufacturers become interested in producing smaller tags, it would probably be worthwhile for the fisheries community to evaluate how well a smaller HDX tag would perform in the field (a smaller tag would need smaller antennas to operate effectively) to determine if it would become an effective tool for fisheries research.

RADIO TELEMETRY

Background

Trefethen (1956) reported the first use of telemetry to study fish in 1956. This study used acoustic telemetry to examine the passage of adult Chinook salmon at Bonneville Dam. Acoustic telemetry was used extensively to examine fish passage issues in the Columbia River Basin until 1970. However, acoustic telemetry worked poorly in turbulent areas such as those downstream of dams especially during periods of spill. In addition, acoustic telemetry required the receiving unit to be submerged in water which resulted in tracking limitations for highly mobile species or over great distances. Because of these limitations, NOAA Fisheries began developing an extended range radio transmitter for use in the Columbia River Basin in 1970 (Monan and Liscom 1971). 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 detail or are not as applicable for tracking individual fish within the freshwater portion of the basin.

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

Current Uses and Application

NOAA Fisheries are the only researchers in the basin using 30 MHz radio transmitters. The NOAA Fisheries transmitters are on one of 9 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 Columbia 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 telemetry in the Columbia River 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 Columbia 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 telemetry 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 telemetry receiver systems for studies in the Columbia River 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 telemetry 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

Radio telemetry has worked very well for evaluating both adult and juvenile salmonid passage at dams, resulting in structural and operational improvements. Radio telemetry has also worked very well in assessing fish behavior in the near-dam environment. Radio telemetry has 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. Currently, radio telemetry 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 Columbia River Basin. Unlike with acoustic transmitters, turbulent hydraulic environments do not effect 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.

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 transmitter, 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. However, they further found that regardless of tagging method, 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 greater than 10 days.

It is noteworthy that juvenile radio transmitters used today 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 the radio-tagged fish was due to the size of the tag, today's smaller radio transmitters may allow radio telemetry to be used to estimate survival for juvenile salmonids over longer distances and longer time periods.

Disadvantages

Radio telemetry is 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. Depths greater than 9 meters can also limit the detection of radio transmitters unless underwater antennas at depth are used. All radio transmitters currently used in the Columbia River Basin require an external trailing antenna, which may effect swimming performance of juvenile fish or attract predators. Although radio transmitters continue to decrease in size and weight, they are unlikely to become small enough to use for studying fry or juvenile lamprey. The radio transmitters 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. In addition, the radio transmitters currently used in the basin have a limited code set that is much smaller than those available for other technologies, including PIT-tags, coded wire tags and acoustic transmitters.

Future Development

Future developments in radio telemetry 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 telemetry may be useful to evaluate survival and behavior past multiple mainstem hydropower dams and over longer river reaches. Sensor technology applications of radio transmitters 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 limits sensor application to large fish in the population. In addition, electromyogram transmitters have been used to measure physiological responses for free-swimming fish in other systems.

Much of the past radio telemetry work has focused on behavior at the mainstem Columbia and Snake river hydropower projects. To accomplish this behavior 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 system wide 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 antennas 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 telemetry, 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 technology will allow managers to address estuary or lamprey needs. However, it should be pointed out that no single technology may be able to accomplish all of the eight needs effectively. 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.

ACOUSTIC TELEMETRY

Background

Advances in the field of electronics have led to significant reductions in the size and function of acoustic telemetry systems since their first use in the 1950s. These advances have led to an increase in the utility of these systems to monitor the migration behavior and survival of juvenile salmonids in the Columbia River Basin. Researchers now utilize this technology to look at finer scale behavior, including behavior in three dimensions. Additionally, these smaller transmitters are allowing for studies of yearling Chinook salmon and steelhead to be more representative of the untagged population, relative to the size distribution of migrating smolts.

Acoustic telemetry (AT) systems utilize sound waves to transmit information from a transmitter, through the water, and then into a hydrophone, and ultimately to a data logger or receiver. By their nature AT systems are susceptible to interference from ambient noise, however, the operating frequency and complexity of an encoding scheme can help minimize such interference. Current AT systems offer varying degrees of tag size, transmission life, frequencies, and encoding schemes; each system offers different advantages and disadvantages.

Current Uses and Application

The AT systems currently being used in the Columbia River Basin are the Vemco system, Hydroacoustic Technology Inc. system (HTI), and the Juvenile Salmon Acoustic Telemetry System (JSATS). Relevant specifications for each system are provided in the following matrix. These specifications are based on the smallest commercially available tag described on the vendor’s website and are typical of systems used in 2006 field studies.

	HTI	JSATS	Vemco
Weight in Air (g)	0.65	0.62	3.1
Dimensions (mm)	16.4 x 6.7	17.0 x 5.5	20.0 x 9.0
Frequency	307 kHz	416.7 kHz	69 or 81 kHz

Tag life	24-28 days[3]	30 days[4]	20-22 days[5]
3-D tracking capability	Yes	In development	In development
# of unique codes	100,000+	65,536	64,000

Advantages

General advantages of AT technologies include:

- **No External Antenna on Transmitters.** The absence of an external antenna translates to a less invasive implantation of the transmitter and precludes any potential drag 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.** Allows user to precisely locate a tagged animal in three dimensions and may aid in determining the cause and effect of changes in the animals environment.
- **Detection Depth**. Although not unlimited, detection capability is not adversely affected by the depth of the tagged animal.
- **Detection Range**. Greater detection range underwater than radio telemetry.[7]

Disadvantages

General Disadvantages of AT technologies include:

- **High Velocity Environments**. Detection capability and/or efficiency are reduced in high velocity environments.
- **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. These requirements are ultimately user defined. The higher the operating frequency, the smaller the tag.
- **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

[3] Referenced to 1 ping/4-8 seconds
[4] Referenced to 1 ping every 5 seconds
[5] Referenced to 1 ping/5-15 seconds
[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.

[7] While a greater detection range can be a benefit for AT, a longer range means that the ability to determine the position of the transmitter decreases. For example, a transmitter with a range of 200 meters upstream of a dam allows one to make some inference about the location of the tag, i.e., either upstream of the powerhouse or spillway. A transmitter with a range of 1 Km upstream of the dam eliminates the ability to make such an inference.

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.

- **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 must be deployed in the water to detect acoustic transmitters. Therefore, aerial mobile tracking is not applicable for acoustic telemetry.

Generally, tag size and transmission life are driven by the power needs and components required to operate at a given frequency. Both high and low frequency AT systems are commercially available. Systems utilizing lower frequencies offer a greater detection range (in both fresh and saltwater) requiring fewer receivers in a given detection array than higher frequency systems. However, lower frequency systems require more power to transmit a signal and are more susceptible to interference from ambient noise, specifically, in and around hydroelectric dams. Further, the transducer is the acoustic tag component that determines frequency; the higher the frequency, the smaller the transducer.

Therefore, lower frequency systems have a larger transducer that requires more power than higher frequency systems and ultimately results in an overall larger transmitter size. The rate of transmissions will also directly influence the life of a transmitter; rate being defined by the elapsed time between transmission pulses. A faster pulse rate (or shorter pulse repetition interval) equates to shorter transmitter life. A slower pulse rate (or longer pulse repetition interval), while equating to longer tag life, will ultimately have lower detection efficiencies (particularly in areas of rapidly moving water) than a transmitter with a shorter pulse rate.

Future Development

AT technology has the potential to address all of the eight management needs outlined in the introduction. Future development of AT technology should focus on smaller transmitters with life expectancies long enough to address system survival. Variable pulse rate tags, or tags that can be turned on and off, also need to be developed. A variable pulse rate tag would allow it to pulse slow, thereby conserving power, when a fish is traveling through the reservoirs (and past survival gates) and then pulse faster when it approaches a dam to allow route of passage and behavior data to be collected. Similarly, the same objective could be accomplished by developing a tag that could be turned on and off during a fish's outmigration. The transmitter could be set to pulse relatively fast, but only turn on when it passes through an area of interest, e.g., a survival gate or at a hydroelectric dam. These are only examples of the types of future development that need to occur to develop a tool or combination of tools that can be used to address the management needs.

As is apparent from the table presented above, several different AT systems currently exist. Each of these systems has inherent pros and cons. There are many areas within each of the existing systems where resources could be directed to improve their capabilities. While it is beyond the scope and intent of this document, discussions are needed to compare and contrast the current capabilities of each of these systems before making decisions about allocating resources to move AT technology forward. Initial discussions have occurred within the recently formed JSATS working group. The outcome of these technical discussions will allow the region's limited resources to be directed in the most efficient manner to produce timely results and will eliminate any duplication of effort.

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 manage questions related to the recovery of salmon stocks in the Columbia River Basin.

OTOLITH MICROSTRUCTURE AND MICROCHEMISTRY TECHNIQUES

Introduction

Otoliths, or ear stones, are found in heads of all bony fishes. These small bony structures range in size from a few micrometers to centimeters. Housed in three separate fluid-filled chambers within the inner ear, otoliths help fish sense up from down and also have a role in hearing (taken from NOAA's National Center for Coastal Ocean Science web site).

Evaluation of otoliths has become an important research tool for understanding the life history of fish and fish populations. Research on otoliths is also improving scientists' understanding of coastal and marine ecology, thus helping managers become more informed on issues such as management of fish stocks, conservation of coral reefs and nursery habitats, and siting of marine protected areas (taken from NOAA's National Center for Coastal Ocean Science web site).

Growth rings have been used to age fish for over 100 years. Structures which encode age information in fish are bones (including fin rays, vertebrae, cleithra, opercular bones), scales and otoliths. Since otoliths are the first calcified structures that appear during early development of most fish, they have been the most reliable indicators of age. Otoliths show annual, and for juvenile fish, daily patterns of growth and therefore form a permanent record of life history events (Jones 1992).

OTOLITH MICROSTRUCTURE TECHNIQUE

Background

Otoliths grow incrementally through differential deposition of calcium carbonate (usually aragonite) and protein that generally occurs on a daily cycle. Thus, like trees' annual concentric growth rings, the number of otolith increments can be used to age fish in days. In addition to the daily patterns in increment deposition, an annual pattern is also evident. Fish and otolith growth is slower at some times of the year than at others (typically slower in winter). Growth rates are often slower during freshwater phase of juvenile anadromous fish, leading to daily otolith increments that are closer together. This seasonal pattern in growth results in both daily and annual growth rings (annuli) in otoliths, allowing determinations of the age of fish in years (taken from NOAA's National Center for Coastal Ocean Science web site).

When viewed through a microscope, daily growth rings from the first year of life reveal detailed information about age-related growth patterns of larvae and juvenile fish. Distinctive patterns can also be observed at life history stage transitions, such as the transition of anadromous fish from freshwater to saltwater environment. A distinctive pattern, or settlement mark, commonly occurs in the otoliths of many fish species at the time of larval or juvenile transition (taken from NOAA's National Center for Coastal Ocean Science web site).

The daily otolith increment technique, which provides an estimate of daily growth rates, was developed in the 1970s and has since gained widespread acceptance. Many investigators are now using this technique for early life history investigations, which previously could not generate reliable age estimates (Jones 1992).

Current Uses and Application

Information on age and growth rates is fundamental to fishery science and can help explain selective processes that determine why some individual fish survive while others do not. Otoliths provide a key to understanding whether fish mortality is dependent on the size of the fish, or whether faster growing fish have a higher probability of survival. Otoliths can also help determine whether certain larval stage characteristics convey a "survival advantage" to post-settlement individuals. They can also determine the length of time a fish has reared in freshwater and saltwater (taken from NOAA's National Center for Coastal Ocean Science web site). In adult fish, knowledge of age and growth is used to: a) determine the effect of fishing on the stocks; b) determine the efficacy of management policies; c) understand life history events; and d) maximize yield while ensuring the future of the resource (Jones 1992).

For example, use of microstructural analyses of SR fall Chinook otoliths, sampled from both juveniles and adults, has been proposed to examine important management questions such as: a) growth rates and bioenergetics; b) residence times in freshwater and saltwater habitats; and c) migration timing.

Advantages

Otoliths have an advantage over other hard fish parts: experimental evidence shows no resorption of otoliths under stress conditions. It is apparent from the literature that aging fish based on otoliths is often more reliable than other techniques. The difficulty in aging juvenile fish by any means other than daily increments demonstrates why this technique is widely used (Jones 1992). The chronological properties of otoliths are unparalleled in the animal world, allowing accurate estimates of age and growth at both the daily and yearly time scale.

There are many reasons to select otolith microstructure to determine both age and growth of fish. The otolith is the only structure that consistently records daily events in the early life stages and annular events throughout life. With the advent of computer image analysis systems, the task of increment identification, daily and annular counts and increment width calculations has been made quicker and more precise (Jones 1992). With today's computer and data management systems, these data can be downloaded or plotted almost instantaneously.

Disadvantages

However, there are also drawbacks to otolith microstructure analysis. A fish must be sacrificed to extract the otoliths. Also, otoliths can be difficult to read during certain life phases, such as at metamorphosis or in older fish. Even with automation, the technique is time consuming, may call for specialized facilities, and it requires training and experience to analyze otoliths. Estimates of increment count and increment width, measurements fundamental for modeling growth, rely on the investigator's ability to correctly interpret otolith microstructure. Important considerations in using this technique include the choice of the correct counting and measuring axis, selection of criteria for defining a daily increment and image optimization through choice of a microscope and image analysis system, as well as an evaluation of potential sources of analysis error (Jones 1992).

Future Development

Otolith microstructure analysis can provide information and insights not available through other research or fish tagging techniques. Annual rings in otoliths have been used to age fish for over 100 years, and the finding of daily growth increments in the 1970s enabled an understanding of the dynamics and ecology of the pre-recruitment stages of fish (taken from NOAA's National Center for Coastal Ocean Science web site). Use of this technique in the Columbia River Basin, particularly for Snake River fall Chinook salmon, could provide an improved understanding of its different life histories and thus could improve the scientific basis of management and recovery options for this listed stock.

Current Funding and Future Needs

There are several proposed or ongoing otolith microstructure analysis studies in the Columbia River Basin. One such study was proposed by NOAA Fisheries in 2006 (project proposal #200716800) during the Council's FY07-09 project selection process under the Columbia River Basin Fish and Wildlife Program, but it did not receive a funding recommendation due to budget limitations. Nevertheless, a scaled down version of this project will be funded and implemented by NOAA Fisheries this year. (Pers. communication, Rich Zabel, NOAA Fisheries).

The project, however, received a "fundable" rating from the ISRP. In its science review of this project, the ISRP stated "The authors propose to use otolith microstructure … to study growth patterns and spatial structure of Snake River fall Chinook salmon with a specific objective of gaining understanding of the reservoir-type migrants. They hope to learn when and where these migrants spend their time during downstream migration. The proposal … provides a logical reasoning to refining when and where these fish reside and migrate within the Columbia River hydrosystem." (ISRP, 2006).

The ISRP also noted that "The proposal suggests using recent advances in microchemistry along with standard microscopy to evaluate where in the hydrosystem fall Chinook were residing and growing prior to ocean entry, and then estimate food consumption rates. The methods are innovative (but used elsewhere with notable success) and have a potential to provide insights into the life cycle of fall Chinook unavailable traditionally." (ISRP, 2006)

OTOLITH MICROCHEMISTRY TECHNIQUE

Background

In addition to providing information on fish age and growth, otoliths also record information on the environment in which fish live. As the otolith grows, trace elements are incorporated into the calcium carbonate matrix. Daily changes in the ambient aquatic environment of individual fish can be observed with microchemistry analysis of the otolith, i.e., they contain chemical signatures of the environments in which the fish resided at particular times in its life history. One particular characteristic that makes otoliths ideal for chemical analysis is that, unlike the other calcified structures in fish skeletons, they are chemically inert. Material laid down at one point does not get reworked or absorbed later on (taken from NOAA's National Center for Coastal Ocean Science web site).

Another characteristic that makes otoliths ideal for chemical analysis is that more than 90 percent of the otolith is composed of calcium carbonate and trace elements derived from the ambient water, as modified by temperature (taken from NOAA's National Center for Coastal Ocean Science web site). These geochemical signatures provide unique "fingerprints" of elemental and stable isotope compositions that are based upon the underlying differences in bedrock geology. Thus, these "elemental fingerprints" vary little within sites but predictably vary across different sites (taken from NOAA Fisheries' FY07 project #200716800 proposal). Sophisticated microchemical techniques, using state-of-the-art instrumentation, can construct an "elemental fingerprint" of the water chemistry from wherever a fish happened to be on a given day, and thus can provide a virtual "diary" of its early life (taken from NOAA's National Center for Coastal Ocean Science web site).

How an otolith is prepared for study depends on what information is sought. Dissolving a whole otolith provides a record over a fish's entire life history. Sampling a particular location on the otolith's growth rings yields information about both an individual fish's physiology and the ambient environment from a particular time in its development (taken from NOAA's National Center for Coastal Ocean Science web site).

Current Uses and Application

Otolith microchemistry has become an important tool for tracking fish movement in aquatic systems. This technique works best for fish that move between or inhabit very different environments with respect to nearness to land and elemental composition of water. Freshwater, estuarine and near-coastal waters tend to have more pronounced differences in water chemistry. Studies have used the elemental composition of otoliths to infer the timing of daily environmental changes or changes in physical habitat. For example, the change in the strontium/calcium ratio can be used in combination with increment number to estimate the dates of migration of anadromous and catadromous species (Jones 1992). In addition, otolith chemistry has been used successfully to determine whether certain reef species are using estuarine nursery areas, and may soon provide a method to determine the specific nursery estuary of origin (taken from NOAA's National Center for Coastal Ocean Science web site).

In fish like migratory salmon, otoliths show striking changes in chemistry, e.g., the ratio of strontium and calcium, that reflect their migration from spawning ground streams, to the estuary, to the ocean and then back to the spawning grounds. Chemical analysis of micro-samples taken across the growth axis of an otolith's cross-section, joined with annular growth lines, allow for the reconstruction of migration patterns and life history. How long did the developing juvenile reside in freshwater streams and then the estuary before migrating out? How long did the fish live at sea before migrating back to freshwater to spawn? What dietary changes occurred over the migration period? Because of their unique growth pattern, otoliths can answer questions such as these and have become an important tool used to understand the evolution and ecological context of salmon life history (taken from PSU, UW, OSU research proposal entitled "Microchemistry of Archaeological Salmon Otoliths").

Use of microchemical analysis of SR fall Chinook otoliths, sampled from both juveniles and adults, has been proposed in the Columbia Basin to examine important management questions such as: a) growth rates and bioenergetics; b) residence times in freshwater and saltwater habitats; and c) migration timing. In 2007, a NOAA Fisheries-funded research project will analyze geochemical signatures, such as strontium:calcium ratios and strontium isotopes, to identify the location and duration of juvenile SR fall Chinook residences during their downstream migration to rearing areas, through the hydropower system and through the estuary (taken from NOAA Fisheries' FY 07 project #200716800 proposal).

There is potential to provide novel information on different types of life history variation by combining well-established, traditional methodologies, e.g., otolith microstructure analyses, with more recent and promising techniques, e.g., elemental and isotopic analyses of otoliths**.** Past research has demonstrated the utility of elemental and isotopic analyses to determine the timing of estuarine and ocean entrance (Secor et al. 2001, Bacon et al. 2004, Zimmerman 2005) and identify river or hatchery of origin (Ingram and Weber 1999, Veinott and Porter 2005). These techniques can be combined to quantify patterns of freshwater, estuarine, and early ocean residence and ultimately link those patterns to early ocean survival and adult returns. Additionally, seasonal changes in prey resources may be identified by analyzing $^{13}C/^{12}C$ and $^{18}O/^{16}O$ ratios in otoliths (taken from NOAA Fisheries' FY 07 project #199801400 proposal).

While otoliths can tell us much about the daily and yearly life of fishes, otoliths can also provide important insights into ancient climates in which the fish lived. Strontium thermometry uses the strontium/calcium ratios in calcium carbonate to reconstruct modern and ancient temperature histories. In research reported in the February 22, 2002, issue of Science, Fred T. Andrus and colleagues examined the oxygen isotope profiles in otoliths from 6,000-year-old sea catfish at two Peruvian archeological sites, finding temperatures three to four degrees warmer than they are today (taken from NOAA's National Center for Coastal Ocean Science web site).

These findings suggest that the modern El Nino Southern Oscillation (ENSO) pattern began after the mid-Holocene sea epoch, creating a very productive fishery that may have contributed to the growth in human population and cultural complexity that occurred in Peru roughly 5,000 years ago. The pattern Andrus observed from fish otoliths has been corroborated by archeological data on the kinds of species excavated, providing further evidence, in his view, that climate change has occurred throughout the history of the Earth (taken from NOAA's National Center for Coastal Ocean Science web site).

Advantages

Research has demonstrated the utility of otolith microchemistry in freshwater systems showing that this technique can provide valuable insights into the environmental life histories of species residing in freshwater. For example, differences in otolith microchemistry have been used successfully in recent years to identify natal habitat for salmon, weakfish, spotted sea trout and freshwater trout, study fish life history, and stock delineation (Bickford et al. 2003). It may also be possible to use this technique to determine residence times in freshwater and saltwater habitats, as well as migration timing, of Columbia Basin salmonids.

Disadvantages

Elemental fingerprinting becomes more difficult in the open ocean, and where chemical differences among sites of interest are subtle or non-existent. Many tropical reef systems, for example, lack sufficient runoff from adjacent continental or island land masses to generate ecologically significant differences in water chemistry (taken from NOAA's National Center for Coastal Ocean Science web site).

Although otolith microchemistry applications have been successful, there remain some unanswered questions about its application, such as how might growth affect otolith microchemistry? For example, growth in juvenile trout appears to play an important role in otolith microchemistry, so any comparisons using this technique on trout need to take into account size classes before analysis.

In addition, protocols used to collect and prepare otoliths for chemical analysis may result in either contamination or loss of elements, thus biasing population studies in unknown ways. Researchers using otolith microchemistry need to understand and use the correct procedures and elemental ratios to fully utilize this powerful technique (Bickford et al. 2003).

Future Development

Otolith microchemistry analysis can provide information and insights not available through other research or fish tagging techniques. Advances in this technique make it possible to examine the specific environment(s) experienced by fishes (taken from NOAA's National Center for Coastal Ocean Science web site). Use of this technique in the Columbia River Basin, particularly for Snake River fall Chinook salmon, could provide an improved understanding of its different life histories and thus could improve the scientific basis of management and recovery options for this listed stock.

Current Funding and Future Needs

There are several ongoing or proposed otolith microchemistry analysis studies in the Columbia River Basin. One such study was proposed by NOAA Fisheries in 2006 (project proposal #200716800) during the Council's FY07-09 project selection process under the Columbia River Basin Fish and Wildlife Program, but it did not receive a funding recommendation due to budget limitations. Nevertheless, a scaled down version of this project will be funded and implemented by NOAA Fisheries this year. (Pers. communication, Rich Zabel, NOAA Fisheries).

This project received a "fundable" rating from the ISRP. In its science review of this project, the ISRP stated "The authors propose to use otolith microchemistry … to study growth patterns and spatial structure of Snake River fall Chinook salmon with a specific objective of gaining understanding of the reservoir-type migrants. They hope to learn when and where these migrants spend their time during downstream migration. The proposal … provides a logical reasoning to refining when and where these fish reside and migrate within the Columbia River hydrosystem." (ISRP, 2006).

The ISRP also noted that "The proposal suggests using recent advances in microchemistry … to evaluate where in the hydrosystem fall Chinook were residing and growing prior to ocean entry, and then estimate food consumption rates. The methods are innovative (but used elsewhere with notable success) and have a potential to provide insights into the life cycle of fall Chinook unavailable traditionally." (ISRP, 2006)

Otolith microchemistry is also included as a sub-task in an approved and ongoing Fish and Wildlife Program project in the Columbia River Basin for FY07-09, e.g., survival and growth of Columbia River basin salmonids in the Columbia River Plume and northern California Current (project #199801400). Otolith elemental composition of archived and future juvenile salmon collections can be assayed to provide information on past rearing, and growth histories (Volk et al. 1984, Secor et al. 2001, Bacon et al. 2004, Zimmerman 2005) and potentially to identify fish origin, i.e., hatchery vs. wild. Since otoliths grow continuously, spatially-explicit sampling methods can provide information from distinct periods in the life history. For example, Laser Ablation Inductively Coupled Plasma Mass Spectrometry (LA-ICPMS) allows for the determination of certain elemental ratios at discrete regions on the otolith. By combining these analyses with otolith microstructural analyses, information on growth during residence within various rearing habitats (i.e., freshwater, estuarine, and ocean) can be generated (taken from NOAA Fisheries' FY 07 project #199801400 proposal).

Thus, the elemental (e.g., Mn/Ca, Sr/Ca and Ba/Ca), isotopic (e.g., $^{87}Sr/^{86}Sr$), and microstructural analyses of juvenile Chinook and coho salmon otoliths will be examined under this project to: 1) identify and quantify rearing behavior (i.e., document the relative duration of freshwater and estuarine residence and timing of ocean entrance); 2) determine growth within each representative habitat (plume vs. non-plume); 3) make inter-annual comparisons of rearing and foraging behaviors; and 4) evaluate the ability to identify hatchery fish based on otolith structural and elemental data. The information generated will be compared with studies on juvenile salmon feeding and habitat requirements, as well as climate and oceanographic data, to determine whether there is consistency with the hypothesis of regime shifts or El Niño events (taken from NOAA Fisheries' FY 07 project #199801400 proposal).

Another research project funded by the Corps of Engineers, entitled "Estuarine habitat and juvenile salmon—current and historic linkages in the lower Columbia River and estuary," will characterize juvenile Chinook salmon life history characteristics, habitat use and growth rates utilizing otolith analyses this year. Analysis of chemical transects across sectioned otoliths will be conducted using Sr/Ca ratios to track chemical changes in otolith composition to reconstruct salmonid habitat use. When combined with water quality data, Sr/Ca ratios can correspond with the migrations of juvenile salmon from freshwater to estuarine habitats. In 2007, this project will analyze previously collected fish samples from selected lower (saltwater portion) and upper (freshwater portion) estuary sites to track strontium and other chemical constituents of otoliths to determine juvenile salmon life history traits, including size at estuary entrance, estuarine residence time and growth rates.

Finally, there is a joint feasibility study being proposed by Portland State University, University of Washington and Oregon State University to analyze the microchemistry of ancient Chinook salmon otoliths discovered in the Columbia River Basin. Evaluating otoliths from archaeological sites can provide a unique way of studying salmon life history and migration patterns from ancient time periods and over extended time scales.

GENETIC MARKERS

Background

Genetic markers can be used to analyze the composition of mixed populations of fish. Genetic variation is routinely used to identify origins of salmon caught in mixed fisheries, intercepted by foreign fisheries, and taken as by-catch in fisheries directed at other species. Genetic analyses of mixed populations of salmonids began around 1980 and subsequently have been increasing; applications have included estimates of geographic origins in marine and freshwater fisheries, and of ancestral origins in populations reestablished from multiple sources.

The potential for applications of genetic analyses of population mixtures is more limited in most marine species because such species are typically less genetically subdivided than salmonid species. However, genetic analyses are feasible in any species in areas of intermingling of genetically distinguishable populations. In addition, genetic marking by preferential breeding of genetically distinguishable individuals may be used to establish genetically distinct cultured populations within species amenable to artificial propogation (Utter and Ryman, 1993). These analyses require: (1) the existence of genetic differences identified in base-line data from contributing populations; and (2) an adequate sampling of individuals from the mixture to characterize its composition.

In trying to define the population structure of salmon and steelhead in the Columbia River Basin, the debate centers on how much consideration should be given to the distribution of neutral molecular markers versus functional life-history attributes, as well as to how large a difference is needed for legitimate differentiation. For this reason the distribution of genetic variation within a species is one source of information used to determine the operational units for management concern, whether they are termed populations, stocks, demes, ESUs, Viable Salmonid Populations, First-order Metapopulations, or something else.

The distribution of genetic variation among populations within a species reflects not only that species' evolutionary history (e.g., the pattern of colonization of the habitats within their current range, the level of gene flow among populations over time, the suite of mutations that occurred among various individuals, and the level of differential selection on different populations over time), but also recent changes to their population ecology (e.g., alterations in patterns of historical gene flow, substantial reductions in abundance of mature adults, and major changes to the environment) (ISAB, 2003). Neutral molecular genetic markers appear to be largely unaffected by natural selection, so that geographical differences in gene frequencies can be interpreted in terms of genetic flow and genetic drift. The analysis of the geographical distributions of these markers may reveal historical dispersals, equilibrium levels of migration (gene flow), and past isolation.

Variation at other genetic markers known to have functional roles, such as the major histocompatability complex (MHC), is mediated by forces of natural selection and thus do not provide unbiased perspectives on dispersal, population connectivity and isolation. Under certain circumstances, markers under selection may provide resolution for discrimination among alternate life-histories that may not be available using neutral markers, but data from markers under selection should not be used to make evolutionary inferences for populations such as those detailed above.

Most evidence for genetic population structure has been based on the analysis of protein variants (allozymes), microsatellite loci (variable numbers of short tandem DNA repeats), and mitochondrial DNA (mtDNA). Since microsatellite DNA markers typically have the most number of characters per locus (higher level of polymorphism), they often can detect stock structure on finer spatial and temporal scales than can other DNA or protein markers (Gustafson et al. 2000).

Current Uses and Application

The Northwest Power and Conservation Council received three proposals for Fiscal-Year 2007-2009 for projects using genetic markers, as follows:

Genetic Stock Identification - Both environmental and genetic factors determine if individual *O. mykiss* remain as resident rainbow trout, or undergo the necessary physiological changes (smoltification) to prepare for anadromy. While some of the associated environmental factors (i.e., water flow and temperature) have been evaluated, the genetic mechanisms that contribute to life history selection are unknown. Unknown origin smolts can be collected and genotyped and assigned to their population of origin based on genetic information. This method is commonly referred to as Genetic Stock Identification or GSI (CRITFC 2007).

Single Nucleotide Polymorphisms - Analyses using Single Nucleotide Polymorphisms, or SNPs, have been proposed for assessing intraspecific hybridization between coastal and interior *O. mykiss*. Once identified SNPs can be used as fixed diagnostic markers for identifying and distinguishing between pure populations of redband trout that should be protected and hybridized redband trout populations where invasive management actions may be needed. SNPS markers can also help distinguish between natural hybridization between sympatric redband trout and westslope cutthroat trout, and hybridization between non-native hatchery rainbow trout and westslope cutthroat trout (IDFG 2007).

Sex-specific Biomarkers - Sex-linked genetic markers have been used to assess whether exposure of fish to estrogens and contaminants has occurred. For example, there is evidence from Hanford reach sexual disruption (females testing positive for male-specific genetic markers) is associated with biomarkers indicative of contaminant exposure (CRRL 2002).

Advantages

- Individuals from a listed population can frequently be found co-mingling with individuals of populations from the same species that may not share protection under the ESA, e.g., wild fish found in the same stream as hatchery fish. In cases where no external, physical characters (e.g., a fin clip) distinguish listed fish from unlisted fish, DNA markers may identify an individual's population of origin.

- Current fish identification databases are not specific enough for many forensic cases and must be augmented by this kind of genetic data.

- Of the various DNA markers, single nucleotide polymorphisms (SNPs) assayed through high-throughput technologies are particularly appropriate for by-catch applications where Pacific Rim-wide databases are required. Unlike marker types based on fragment size, SNPs are based on the actual DNA sequence, require no inter-laboratory standardization, are cost-effective, and can be easily automated. Note, however, that SNPs are largely bi-allelic (like allozymes), thus each SNP itself would likely provide less information on population history, connectivity, etc. than likely available from more polymorphic marker types on a per locus basis. Thus management applications requiring high resolution would require characterization of more SNPs to access the same power as attained with lesser number of more polymorphic marker types. But a greater number of SNPs would sample information from a larger component for the genome and thus gain additional power. The relative merit of SNPs or microsatellites is a function of technology, data availability and remains an important question of current research and to evaluate for alternate applications.

Disadvantages

First, fish need to be collected and handled to conduct genetic marker analysis. In the past, neutral marker genetic variability surveys relied primarily on using starch-gel electrophoresis. However, this method has some drawbacks, such as a limitation on the scope of the genetic variability resolved and a requirement for quality tissue samples that often necessitates the use of liquid nitrogen or dry ice in the field. DNA-based methods, on the other hand, offer an opportunity for exposing much more genetic variation and have less rigorous requirements for sample quality (Gharrett et al. 1997).

Future Development

Scientists at the NOAA-Northwest Fisheries Science Center (NWFSC) and elsewhere (Greig et al. 2002; Kvitrud et al. 2005) have developed molecular techniques for rapidly identifying salmon species using DNA markers and are now working to identify individual populations within those species. Genetic databases for individual species make it possible to estimate the level of resolution that these markers can provide in determining the population of origin for a given fish. Researchers are also in the process of compiling genetic data from multiple agencies (e.g., U.S. Fish and Wildlife Service, Washington Department of Fish and Wildlife, Alaska Department of Fish and Game) in order to expand these species databases. Recent ESA listings in the Puget Sound region, where the impact of human activities on salmon habitat is high, will lead to increased legal action on the part of the NOAA Fisheries' Enforcement Division. As a result, the technical support provided by researchers at the NWFSC will become increasingly important because genetic markers are a major tool for determining the population to which a given fish belongs.

Current Funding and Future Needs

Use of natural genetic markers is the best method for stock identification of wild fish in the marine environment; and substantial effort has been (and continues to be) devoted to genetic studies of North Pacific salmon stocks. An extensive allozyme baseline was developed in the last two decades to address those questions, but the logistics of sampling and increasing costs of storing and processing the samples have reduced their use. Most labs have terminated allozyme operations. Moreover, allozymes do not appear to provide the fine-scale resolution needed to address some important management questions, for example those involving the origins of western Alaskan chum salmon stocks.

Two promising approaches include analysis of microsatellite variation and the recent development of tools to resolve single nucleotide polymorphisms (SNPs) from both nuclear and mitochondrial DNA. Both approaches have challenges and all genetic methods require that substantial baseline data, which includes most of the geographic range of a species, have been assembled before these tools can be confidently applied.

The University of Alaska Fairbanks genetics laboratory has been examining both the microsatellite and SNP approaches, by using a common set of DNA samples from populations that represent most of the geographic range of chum salmon. They are surveying microsatellite variation and using loci that are being applied by other labs acquiring microsatellite data from Alaskan chum salmon. Preliminary comparisons of data from samples analyzed by two labs indicate that the data are highly concordant. The lab is also developing and evaluating SNP markers. One of the lab’s goals is to find or create inexpensive methods to resolve SNP variation and be able to resolve multiple variants that occur in a short region of DNA. The advantage of the SNP markers is that by their nature, the data should be concordant from lab to lab. The lab is still in the process of developing and evaluating these microsatellite and SNP tools (Gharrett et al. 2006).

CODED WIRE TAGS[8]

Background

The coded wire tag (CWT) was introduced in the 1970s and has provided unparalleled information about ocean distribution patterns and fishery impacts for numerous stocks of salmon along the west coast of the United States. Prior to the advent of the CWT, fisheries researchers had relied principally on ocean tagging of adults or fin clipping of juveniles to gather information about harvest patterns of salmon. Adult tagging provided information that confirmed that ocean fisheries were harvesting complex mixtures of stocks, but could not provide information required to determine exploitation patterns of individual stocks; tag recovery programs were incomplete due to the numerous fisheries and stream destinations involved. Fin-clip studies of juvenile salmonids provided some information on patterns of exploitation of a few stocks, but marking, fishery sampling and reporting of recoveries were not coordinated across geographic and political boundaries.

Because of limitations in the number of fin-clip combinations available, researchers could conduct experiments on at most 15-20 groups of fish at a time. With hundreds or even thousands of stocks of interest, fin clipping technology provided little hope of providing the stock- and fishery-specific information desired by managers.

The CWT is a small piece of magnetized wire (0.25 x 1.1 mm) which is implanted in the nasal cartilage of juvenile salmonids. Tags are cut from rolls of wire by an injector that hypodermically implants them into suitable tissue. The standard length of a tag is 1.1 mm. For very small animals half-length (0.5 mm) are used. For larger specimens or improved magnetic detection, one and a half (1.6 mm) or double length (2.2 mm) tags may be utilized.
Each piece of wire contains a code that uniquely identifies an individual group of fish (batch coding). Original color codes were replaced in 1971 by a binary coding system implemented through notches etched in the wire. The binary CWTs eliminated errors in decoding colored tags and expanded the number of available codes to over 250,000. Since about 1998, CWTs have been available in a decimal printed format which virtually eliminates reading errors. The very large number of available unique codes has allowed all experimental mark groups to be identified accurately regardless of place or time of recovery.

In the late 1970s, management agencies agreed to institute catch sampling and reporting protocols to facilitate sharing of data on where and when fish from individual release groups were harvested. CWT codes are issued by and reported to a central location so as to avoid duplication of codes and maintain unambiguous assignment of recoveries to specific release groups. The Pacific States Marine Fisheries Commission (PSMFC) has continued to provide the lead CWT data coordination role and maintains the RMIS database (Johnson 2004).

[8] Largely excerpted from REPORT OF THE EXPERT PANEL ON THE FUTURE OF THE CODED WIRE TAG RECOVERY PROGRAM FOR PACIFIC SALMON. November 2005. Available from: Pacific Salmon Commission, 600 – 1155 Robson Street, Vancouver, BC V6E 1B5, Canada

In the mid 1980s, the integration of CWT-based cohort analysis into simulation models provided the primary means to inform decisions regarding the degree to which fishery impacts needed to be reduced to constrain exploitation rates to levels appropriate for the status and productivity of individual stocks. These models proved instrumental in enabling the U.S. and Canada to reach agreement on a coast-wide Chinook rebuilding program that became a cornerstone for the 1985 Pacific Salmon Treaty (PST).

Current Uses and Application

In addition to cohort analysis and simulation modeling, the CWT was being widely employed for evaluation of hatchery production, identification of migration and exploitation patterns, estimating and forecasting abundance, and in-season regulation of fisheries (Cooney 2004; Johnson 2004). Particularly for Chinook (*Oncorhynchus tshawytscha*)[9] and coho (*O. kisutch*)[10] salmon, the CWT quickly became indispensable to fishery managers. Recognizing that no other data or methods existed which were capable of providing the information to evaluate the effectiveness of the agreements reached under the PST, the United States and Canada entered into a special Memorandum of Understanding when signing the PST: *"The Parties agree to maintain a coded-wire tagging and recapture program designed to provide statistically reliable data for stock assessments and fishery evaluations."*.

Advantages

Some of the advantages of the CWT are:

- Can be used in very small animals.
- Minimal biological impact.
- High retention rates over the life of the host.
- Enormous code capacity (batch or individual identification).
- Tags are inexpensive.
- Potential for automatic scanning of large samples.

The advantages of CWTs over fin clipping quickly became obvious and the special characteristics of Pacific salmon made the CWT ideally suited for life history research. Because Pacific salmon are semelparous, the entire fate of a marked cohort is *a priori* certain to be completed over a relatively short period of time (3-4 years for coho, no more than 7 years for Chinook). Strong homing fidelity enables the freshwater search for CWTs in adult fish escaping marine harvest to be confined to well-defined geographic areas, usually near release sites. Because CWTs can be inserted into juvenile fish prior to ocean migration, the technology provides a means to track the fate of specific groups of salmon from release through to maturity.

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[9] Chinook are the largest and longest lived species of Pacific salmon and tend to spawn in larger river systems. More than a thousand spawning populations (stocks) of this species are found in rivers along the eastern Pacific (several distinct spawning populations - often characterized by river entry timing – e.g., spring, summer, fall, winter - defined by a combination of timing and physical location may be found in a single river system). Individual stocks can migrate over thousands of miles and be exploited over an extended period of time at various stages of maturity.

[10] Several thousand coho stocks are believed to exist in rivers along the eastern Pacific. This species is characterized by an extended period of freshwater rearing (1 to 2 years) followed by approximately 18 months of rearing in marine areas prior to returning to the rivers to spawn. From Southern British Columbia southward, coho are predominantly produced on a three year life cycle (one year freshwater). In more northerly areas, coho with four year life cycles are common (two years freshwater). Coho are harvested predominantly during the last few months of marine residence. Most coho return to their rivers of origin in late summer and fall, although some stocks are known to have very early or late timing. Coho tend to be distributed over a much smaller range than Chinook.

The CWT's unambiguous identification of the specific release group from which a fish originated was essential for evaluation of individual release experiments typically carried out with hatchery fish. All experimental groups could be treated identically during the tagging process, distinguished only by a coded wire tag number, thereby eliminating confounding effects that had been presented in many earlier fin clipping studies when contrasting groups might have been released with, say, a left ventral fin clip or an anal fin clip.

Since the late 1970s, CWT tag recovery data have provided an essential technical basis for Chinook and coho salmon management. Through this coordinated, coast-wide system, CWT tag recovery data have enabled fisheries scientists to determine exploitation patterns for individual groups of fish, ended debate over "who was catching whose fish", and have assisted decision-making required to conserve the resource.

In the mid 1980s, stock and fishery assessment methods based on CWT tag recovery data provided the means to define exploitation patterns for individual stocks. The high levels of exploitation in fisheries in the mid 1980s resulted in sufficient CWT recoveries to provide statistically reliable data. Cohort analysis methods[11] applied to CWT recovery data permitted estimation of age- and fishery-specific exploitation rates, age-specific maturation rates, survival from release to age 2, and total mortality. These methods quantified and characterized the timing and location of fishery impacts for the entire migratory range and life cycle of individual stocks. Exploitation patterns of natural stocks were assumed to be the same as those determined for CWT release groups of hatchery fish that had similar brood stock origin, similar maturation schedule, and that were reared and released in a manner believed similar to natural stocks.

Disadvantages

Some of the disadvantages of the CWT include:

- Capital equipment is expensive (but it can be rented or borrowed from other agencies).
- In most applications, tags must be excised, usually from dead animals, for reading decimal codes.
- Tags usually not externally visible.

Because CWTs are not externally visible, an external mark was needed to indicate that a fish contained a CWT. By agreement of management agencies in 1977, the adipose fin clip[12] (adipose mark - Ad) was sequestered (reserved) for fish that also received a CWT (Ad+CWT). Harvested or collected fish could then be inspected visually and snouts removed from those with missing adipose fins (i.e., from Ad+CWT fish).

CWTs are recovered coast-wide with agencies generally attempting to sample at least 20percent of the ocean catch. Freshwater recovery programs are less standardized. Returns of Ad+CWT

[11] Cohort analysis involves the backwards reconstruction of a population, beginning with estimated spawning escapements of the oldest aged fish, estimated fishery recoveries, and assumptions regarding natural mortality rates. The capacity to reconstruct the complete demographic history of discrete groups of fish from CWT recoveries is vital to the capacity to perform cohort analyses on Pacific salmon. For a description of general theory, methods, and data requirements, see CTC 1988 and Morishima and Alexandersdottir (2004).

[12] The functional purpose of the adipose fin is unclear. Once thought to be a vestigal fin that could be removed without effect, recent research suggests that the adipose may control vortices enveloping the caudal fin during swimming or function as a turbulence sensor. The authors suggested that: *"the current widespread practice in fisheries of removing the adipose fin as a marking technique may have significant biological costs."* Reimchen and Temple (2004).

fish to hatcheries are usually sampled at a 100percent rate, but sampling rates for stray escapement are highly variable and there is generally substantial uncertainty in estimates of stray (non-hatchery) escapement to natural spawning grounds for hatchery CWT groups.[13]

Current Funding and Future Needs

Today, millions of dollars are expended annually to tag and recover CWTs. Johnson (2004) reported that some 54 state, federal, tribal, and private entities in the USA and Canada conduct CWT experiments involving some 1200 new codes annually. Over 50 million juvenile salmon and steelhead are now tagged annually[14] at a total cost in excess of $7.5 million annually (U.S.). Approximately 275,000 CWTs are recovered each year in commercial and recreational fisheries and in spawning escapements, at an additional annual cost of $12-13 million (U.S.). CWTs are being increasingly employed in conjunction with other stock identification technologies such as genetic markers, scale pattern, and otolith banding to provide a better analysis of' salmonid population dynamics (Johnson 2004). Consistent funding for adequate tagging and recovery is vital to maintaining the current program level, and expanding the CWT program to untagged stocks of critical interest.

ARCHIVAL TAG TECHNOLOGY

Background

Archival tags, also referred to as data storage tags (DSTs), record information from onboard sensors for later retrieval. Archival tags are a relatively new tool for freshwater fish research. Sizes of devices have recently been reduced to a size where they can start to be used with smaller-sized and even some juvenile fish. Currently archival tags used in freshwater applications are produced primarily by two companies Lotek and Star-Oddi.

Most commonly used sensors on archival tags include temperature, depth, salinity, and light. Platforms are somewhat flexible in the configuration of sensors included. Typically combinations are temperature and depth (TD), conductance (salinity) temperature, and depth (CTD), or light, temperature and depth (LTD). Tag size is dictated by sensor and memory size and somewhat by battery size. Other novel capabilities are GPS recorders (record GPS coordinates transmitted through the water by specially equipped bouys or ships), and pitch and roll recorders (Star-Oddi), saltwater switches, and separate internal and external (body) temperature sensors (Lotek). Lotek will also match a radio or acoustic transmitters with an archival tag in a package that can be used with larger fish such as adult salmon and trout.

The small TD tag produced by Star-Oddi weighs 3.3g in air, 1.9g in water, 8.3 x 25.4 mm, and stores a total of 47,476 records. Start dates and sampling intervals are programmable; one temperature and one depth reading per hour would result in 120 d of records. Once the tag is retrieved and data downloaded it can be re-deployed on another fish for up to about 12 months of total use on the battery. Another important criteria are sensor accuracy and precision. For the

[13] In some systems, a very large proportion of returning hatchery fish may fail to return to hatcheries.
[14] Chinook salmon tagging levels are the highest (~39 million), followed by coho salmon (~9-10 million).

tag described above, manufacturers stated temperature accuracy was ±0.5°C and ±0.5% of depth range (150m). Lotek produces a TD archival tag 2.5g in air, 0.9g in water, 8mm x 35 mm, with 128k memory, with sensors accuracies of ±0.2°C and ±1% depth with estimated battery life of 24 months.

Current prices for these products were not available at this writing but have typically been relatively high, $400 to $800 each.

A third manufacturer, Alpha Mach, provides a low cost alternative for an archival tag that records temperature only. Their smallest version weighs 3.2 g in air, 1 g in water, 13.2 x 25.4 x 8 mm in size. These tags will store 8192 readings at a resolution and precision of ±0.5°C and can last up to about one year. Larger versions are available. Prices for the small tag range $68 to $102 each depending on configuration and quantity purchased. Record intervals and start times are programmable.

Archival tags are most often externally sutured to the dorsal surface. However, they can also be surgically implanted and gastrically implanted as well. Externally-mounted tags are visually obvious, which simplifies tag retrieval. All archival tags contain internal clocks so records are date and time stamped.

Current Uses and Application

To date, archival tags have primarily been used to record environments experienced by migrating adult salmon and steelhead in the Columbia River. Examples include documenting swimming depths for salmon and steelhead to determine risks for adult migrants related to gas bubble trauma, effects on body temperatures for fish that temporarily stray into cooler tributaries of the Columbia River during summer, temperature exposures for fish as they swim through reservoirs and fishways at dams during summer, and to determine if temperature exposures while adult salmon migrate may affect gamete development and quality. Reports and papers for these studies are available from the University of Idaho Fish Ecology Research Laboratory (www.cnr.uidaho.edu/uiferl/).

Archival tags could also be used for energetic evaluations for migrants since many bioenergetic models currently in use require temperature as a key input. Another use for archival temperature tags could be to track movements of fish through river systems with differential temperature environments when telemetry or other tracking mechanisms are not available. For example, archival temperature records could be used to determine when an upstream migrant moved from the Columbia into the Willamette or Snake rivers, and then into secondary tributaries containing spawning areas.

Archival tags may also be useful to obtain information on movement patterns and behavior in the estuary, nearshore ocean, and pelagic portions of salmon, trout, and Pacific lamprey environments.

Advantages

Archival tag information can provide valuable information on the various environments fish experience while migrating through or reside in a system. This information can be used to estimate effects of environmental conditions on fish physiology, bioenergetics, disease risk and development. Archived depth readings would be useful to interpret how fish react behaviorally to different system manipulations or management actions (e.g., surface bypass structures, extended-length screens, cool water releases from upstream reservoirs, etc.) or exposure to fisheries. These tags have low power requirements and thus long battery lives. This means retrieved tags can be re-used once data are retrieved and their memory is cleared.

Disadvantages

The primary disadvantage of archival tags is the need to retrieve the tags to obtain the stored data. Because of this limitation, archival tags must either be used in locations were fish have a high degree of interception (an intensive fishery or a river where a large portion of a population can be trapped) or a large number of fish must be tagged to assure enough tags are recovered to gain usable information (similar to current strategies with PIT-tagged juveniles). A secondary limitation is the relatively large size of archival tags, which limits their use to adult and sub-adult life stages for most fish species. The cost for most archival tags is relatively high. The one less expensive alternative for temperature recorder (Alpha Mach) trades lower cost for smaller memory. Anecdotal evidence also indicates the lower priced units had higher failure rates than the more expensive units available at the time (C. Peery, University of Idaho, pers. comm.)

Current Funding and Future Needs

Current use of archival tags in the Columbia River basin is relatively low and has been limited to adult migrant studies. In other systems archival tags are more likely to be used in closed water systems (lakes and reservoirs) and with resident fish where chances of retrieval of tagged fish are greater, or in the open ocean where information is so sparse that recovery of even a few archival tags would justify expense of a tagging program.

Future needs include developing smaller tags with sufficient memory to capture life stage data for periods of interests, from several months to several years. Pairing an archival tag with a PIT-tag so that the sort-by-code utility can be used at mainstem Columbia and Snake river hydropower dams may improve the probability of retrieving data from downstream migrants at juvenile fish collection facilities. The utility of archival tags would be increased significantly if data could be retrieved remotely, without the need to physically re-capture a tagged fish. At least one manufacturer (Lotek) has developed a version of an archival tag with this feature that could be used in adult salmon. However, a significant reduction in tag size is needed before this application is possible with juvenile salmonids.

Table 1 — Various tagging technologies used in the Columbia River Basin in 2007.

Tagging Technology	Est'd. # Tags Used in 2007[15]	Estimated Cost per Tag Unit[16]
Coded Wire Tags	20,775,000	$0.08 (90-day bulk order)
Full Duplex PIT tags	409,050 (COE); 1,211,200 (BPA); 55,000 (Chelan PUD); 20,000 (Colville Tribe)	$2.03
Half Duplex PIT tags	3,000 (COE)	$3.00
Radio tags:	18,000	
NOAA Fisheries	9,090	$145 to $150
USGS	8,000	$195 average (range $140 to $250)
Acoustic tags:		
HTI	16,000	$205 to $305 (depending on model)
JSATS	27,000	$247 average (range $243 to $252)
VEMCO	1,000	$260
Otolith Micro analysis	N/A	$60 to $75 per otolith
Genetic Marker analysis	N/A	N/A
Archival tags	none	$400 to $800 (depending on tag)

[15] The number of tags used in 2007 is primarily related to Corps-funded research and monitoring projects, i.e., estimated numbers of tags used in BPA-funded projects are not all included.
[16] Note that the cost per tag information does not include the cost for any tag detection equipment, e.g., receivers and infrastructure.

Table 2 — Tagging Technology Application to Management Questions

5/29/2007

Management Question	*Tagging Technology*: *PIT-Tag* Full Duplex (SST/ST)	*PIT-Tag* Half Duplex	*Radio Telemetry*	*Acoustic Telemetry*	*Otolith* Micro-structure	*Otolith* Micro-chemistry	*Genetic Marker*	*Coded Wire Tag*	*Archival Tag*
Route-Specific Life Cycle Studies	**3**		**3**	**3**					
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 (TR BRZ to TR BRZ)	**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**
Ocean/Estuary Studies									
Near Ocean Survival and Behavior	**3**			**1**	**1**	**1**	**1**		
Ocean Survival & Behavior				**1**	**1**	**1**	**1**	**1**	**1**

Adult Return Studies

Smolt-to-Adult Return Rates	**1**							**1**	
Adult Survival and Passage through Hydrosystem	**1**	**1^**	**1**	**1**			**1**		**1**
Adult Survival Post Hydrosystem (i.e., survival to tributaries)	**3**	**3**	**1**	**1**					
Measuring physiological stressors & environmental conditions									**1**
Tributary Survival and Spawning Success	**1^**	**1^**	**1**				**1**		

Species and Size Class Suitability

Ability to Tag or Evaluate Juvenile Lamprey					**1**	**1**	**3**		
Ability to Tag or Evaluate Fry					**1**	**1**	**1**		
Ability to Tag or Evaluate Fish 90+ mm	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	
Ability to Tag or Evaluate Fish from 60+ mm	**1**		**3**	**3**	**1**	**1**	**1**	**1**	
Ability to Tag or Evaluate Large Sample Sizes (i.e., >20,000 fish)	**1**	**1**	**2**	**1**			**2**	**1**	

Bold text indicates a priority to regional managers

<u>Key:</u>

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

<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.

EXECUTIVE SUMMARY

PIT-tag Technology

Since the late 1980s, PIT-tags have been the main tool used for monitoring the migrational behavior and timing of salmonids in the Columbia River Basin, with over 15 million tags having been applied to fish over the years. In 2007, nearly 1.7 million PIT-tagged fish will be released by various entities in the Columbia Basin (Table 1). Much of the PIT-tag data and historical information is maintained in a database at the Pacific States Marine Fisheries Commission (PSMFC) called the PIT Tag Information System (PITAGIS database; http://www.ptagis.org/ptagis/index.jsp/).[17]

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 for fishery researchers to evaluate the survival rates of juvenile fish through mainstem Snake and Columbia river reaches and for individual stocks. Typically, evaluations over the life cycle of salmon are 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, as well as in research to examine delayed mortality observed in the Snake River Chinook salmon and to estimate avian predation rates.

Most of the PIT-tag detection equipment installed throughout the Columbia River Basin for monitoring salmonids utilizes full-duplex (FDX) technology. FDX PIT-tag detection systems have now been installed in the juvenile bypass facilities at most mainstem federal Columbia and Snake river hydropower dams and in the adult fish ladders of half the dams that Snake River anadromous fish pass. This technology allows for the evaluation of migration and survival on a much finer scale than provided by older tagging technologies.

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 detection systems at the mainstem Columbia and Snake river hydropower dams. 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.

[17] This database includes data access tools and a useful library menu linked to documents and peer-reviewed journal publications.

Some of the major advantages of the FDX PIT-tag technology are as follows. It can detect tagged fish moving at high speeds and it has tags that are small enough to tag juvenile salmonids down to 60 mm in fork length. PIT-tags can also be implanted in adult salmonids. However, because the tags are so small, the FDX systems typically have relatively small antennas (95 percent or more 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 tag's read ranges are relatively short (measured in feet and inches) compared to active tag technology, which is measured in yards and miles.

Another advantage of PIT-tags is their long-life. As the tag is passive, i.e., no battery is needed, it can last longer than the lifespan of salmonids. Since these tags are also inexpensive, large numbers of fish can be tagged. This enables the fisheries community to tag large groups of fish from the same hatcheries every year to learn more about year-to-year variation in migration and survival.

Moreover, PIT-tag interrogation systems are currently being installed into Columbia Basin tributary streams to evaluate fish migration and survival information that was unknown previously. Finally, the vendor for FDX PIT-tag technology 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 the feasibility of detecting PIT-tagged fish migrating through individual spillway bays at mainstem Columbia and Snake river hydropower dams.

However, the FDX PIT-tag technology also has some disadvantages. For example, there are limitations on antenna size, with the largest antenna currently deployed at the mainstem hydroelectric dams being 17 feet by 17 feet in the Bonneville Dam-Second Powerhouse corner collector. Also, researchers currently cannot detect PIT-tagged fish passing through spillways or turbines at the mainstem dams. Thus it is infeasible to get route-specific passage and survival information on fish passing through these routes. Moreover, due to detection interference, the technology normally requires the removal of all rebar and metal from the area where antennas are installed. Therefore, some installations can be expensive.

In addition, use of this technology in estuarine applications is extremely limited because in saline water, it is only possible to install small shielded antennas. Even using the smallest 8 mm PIT-tag, researchers are unable to tag salmonid fry or juvenile lamprey. Finally, it has been hypothesized that a fish's long-term survival rate (SARs) may be impacted by having been PIT-tagged in the juvenile life stage, as it appears that fewer PIT-tagged fish are returning as adults than would be expected. Future research should design a study to investigate this concern, if warranted.

Radio Telemetry

Radio telemetry has been used to study passage behavior for adult salmonids in the Columbia River Basin since the early 1970s and for juvenile salmonids since 1980. The first application of radio telemetry to assess juvenile survival in the Columbia Basin was in 1997.

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 telemetry 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 telemetry has 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 telemetry has 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. Currently, radio telemetry 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 Columbia River Basin. Unlike with acoustic transmitters, turbulent hydraulic environments do not effect 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 such as the Columbia and Snake rivers.

While a 2003 juvenile salmonid radio tag effect study 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 transmitters 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-tagged fish in 2003 was due to the size of the tag, today's smaller radio transmitters may allow radio telemetry technology to be used to estimate survival for juvenile salmonids over longer distances and longer time periods.

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

The use of radio telemetry is limited to 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. Depths greater than 9 meters can also limit the detection of radio transmitters unless underwater antennas at depth are used.

Future developments in radio telemetry 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 telemetry may be useful to evaluate fish survival and behavior past multiple mainstem hydropower projects and over longer river reaches. Thus there is a reasonable expectation that smaller and longer lasting radio tags can be developed with antennas that may have little to no measurable effect on the fish. Radio telemetry, when used in combination with PIT-tag technology, has the potential to address six of the eight management needs outlined in the introduction.

Acoustic Telemetry

AT systems utilize sound waves to transmit information from a transmitter, through the water, and then into a hydrophone, and ultimately to a data logger or receiver. By their nature, AT systems are susceptible to interference from ambient noise, however, the operating frequency and complexity of an encoding scheme can help minimize such interference. Current AT systems offer varying degrees of tag size, transmission life, frequencies, and encoding schemes; each system offers different advantages and disadvantages.

AT systems are used to monitor the migration behavior and survival of juvenile salmonids in the Columbia River Basin. Researchers are also using this technology to look at finer scale fish behavior at or near mainstem hydropower dams, including behavior in three dimensions. This capability has been used to improve the functional design and location of surface bypass systems at mainstem federal hydropower projects. Additionally, the smaller transmitters are allowing for AT studies of yearling Chinook salmon and steelhead to be more representative of the untagged population, relative to the size distribution of migrating smolts.

The AT systems currently being used in the Columbia River Basin are the Vemco system, Hydroacoustic Technology Inc. system (HTI), and the Juvenile Salmon Acoustic Telemetry System (JSATS). Each system has advantages and disadvantages.

One of the advantages of AT technologies is that, unlike radio transmitters, no external antenna is needed for these transmitters. AT systems can be used for detection of tagged animals in both fresh and saltwater environments. Although not unlimited, AT detection capability is not affected by the depth of the tagged animal. It also allows detection in three dimensions, which can assist in determining the cause and effect of changes in the animal’s environment.

Unlike radio telemetry technology, a disadvantage of AT technology is that the detection capability and/or efficiency are reduced in high velocity hydraulic environments. Systems utilizing lower frequencies offer a greater detection range (in both fresh and saltwater) and require fewer receivers in a given detection array than higher frequency systems. However, lower frequency systems require more power to transmit a signal and are more susceptible to interference from ambient noise, specifically, in and around the large mainstem hydroelectric dams.

Tag size and transmission life are driven by the power needs and components required to operate at a given frequency. Lower frequency AT systems have a larger transducer that requires more power than higher frequency systems and ultimately results in an overall larger transmitter size. The rate of transmissions will also directly influence the life of a transmitter; rate being defined by the elapsed time between transmission pulses. For example, a faster pulse rate (or shorter pulse repetition interval) equates to shorter transmitter life. A slower pulse rate (or longer pulse repetition interval), while equating to longer tag life, will ultimately have lower detection efficiencies (particularly in areas of rapidly moving water) than a transmitter with a shorter pulse rate.

AT technology has the potential to address all eight management needs outlined in the Introduction section and in Table 2. 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 manage questions related to the recovery of salmon stocks in the Columbia River Basin.

Future development of AT technology will continue to result in smaller transmitters with life expectancies long enough to address system survival. Tags with variable pulse rates, i.e., tags that can be turned on and off, also need to be developed.

Otolith Microstructure and Microchemistry Techniques

Evaluation of otoliths has become an important research tool for understanding the life history of fish and fish populations. Otoliths show annual, and for juvenile fish, daily patterns of growth, thus forming a permanent record of life history events. The daily otolith increment technique, which provides an estimate of daily growth rates, was developed in the 1970s and has since gained widespread acceptance. Many investigators are now using this technique for early life history investigations, which previously could not generate reliable age estimates.

Information on age and growth rates is fundamental to fishery science and can help explain selective processes that determine why some individual fish survive while others do not. Otoliths provide a key to understanding whether fish mortality is dependent on the size of the fish, or whether faster growing fish have a higher probability of survival.

Otoliths have an advantage over other hard fish parts: experimental evidence shows no resorption of otoliths under stress conditions. The chronological properties of otoliths are unparalleled in the animal world, allowing accurate estimates of age and growth at both the daily and yearly time scale. With the advent of computer image analysis systems, the task of increment identification, daily and annular counts and increment width calculations has been made quicker and more precise.

However, there are also drawbacks to otolith microstructure analysis. A fish must be sacrificed to extract the otoliths. Also, otoliths can be difficult to read during certain life phases, such as at metamorphosis or in older fish. Even with automation, the technique is time consuming, may call for specialized facilities, and it requires training and experience to analyze and interpret otoliths.

However, otolith microstructure analysis can provide information and insights not available through other research or fish tagging techniques. Use of this technique in the Columbia River Basin, particularly for Snake River fall Chinook salmon, could provide an improved understanding of its different life histories and thus could improve the scientific basis of management and recovery options for this listed stock.

In addition to providing information on fish age and growth, otoliths also record information on the environment in which fish live. As the otolith grows, trace elements are incorporated into the calcium carbonate matrix. Daily changes in the ambient aquatic environment of individual fish can be observed with microchemistry analysis of the otolith, i.e., they contain chemical signatures of the environments in which the fish resided at particular times in its life history. One particular characteristic that makes otoliths ideal for chemical analysis is that, unlike the other calcified structures in fish skeletons, they are chemically inert.

Another characteristic making otoliths ideal for chemical analysis is that more than 90 percent of the otolith is composed of calcium carbonate and trace elements derived from the ambient water, as modified by temperature. Microchemical techniques, using state-of-the-art instrumentation, can construct an "elemental fingerprint" of the water chemistry from wherever a fish happened to be on a given day, providing a virtual "diary" of its early life.

Thus otolith microchemistry has become an important tool for tracking fish movement in different aquatic environments such as fresh water, estuarine and near coastal waters. In fish like migratory salmon, otoliths show striking changes in chemistry, e.g., the ratio of strontium and calcium, that reflect their migration from spawning ground streams, to the estuary, to the ocean and then back to the spawning grounds. Chemical analysis of micro-samples of an otolith's cross-section, joined with annular growth lines, allow for the reconstruction of migration patterns and life history. For example, use of microstructure and microchemical analyses of SR fall Chinook otoliths, sampled from both juveniles and adults, has been proposed to examine important management questions such as: a) growth rates and bioenergetics; b) residence times in freshwater and saltwater habitats; and c) migration timing.

Research has demonstrated the utility of otolith microchemistry in freshwater systems showing that this technique can provide valuable insights into the environmental life histories of species residing in freshwater. There is growing interest in the use of otolith chemistry as a natural tag of fish stocks. It may also be possible to use this technique to determine residence times in freshwater and saltwater habitats, as well as migration timing, of Columbia Basin salmonids.

However, elemental fingerprinting using otoliths becomes more difficult in the open ocean, and where chemical differences among sites of interest are subtle or non-existent. In addition, care must be taken in the collection and preparation of otoliths for chemical analysis so that neither contamination nor loss of elements occurs, thus biasing population studies in unknown ways.

In summary, otolith microstructure and microchemistry techniques have the ability to address three of the management needs identified in the Introduction (Table 2), and can provide information and insights not available through other research or tagging techniques. Annual rings in otoliths have been used to age fish for more than 100 years. The finding of daily growth increments in the 1970s opened a door into understanding the dynamics and ecology of the pre-recruitment stages of fish. Advances in otolith microchemistry now make it possible to examine the specific environment(s) and habitat(s) experienced by fishes, including migration timing and age at saltwater entry. The management questions that can be addressed with otolith techniques are not necessarily answerable with genetic studies, suggesting that genetic and otolith studies complement rather than compete with each other.

Use of this technique in the Columbia River Basin, particularly for Snake River fall Chinook salmon, could provide an improved understanding of its different life histories and thus could improve the scientific basis of management and recovery options for this listed stock. The techniques and applications of the study of otoliths are still developing, but otolith microstructure and microchemical research will continue to offer important insights on fish ecology and improve the scientific basis of fisheries management and conservation.

Genetic Markers

Genetic markers can address three of the eight management questions identified in the Introduction. Genetic markers can be used to analyze the composition of mixed populations of fish. In trying to define the population structure of salmon and steelhead in the Columbia River Basin, the debate centers on how much consideration should be given to the distribution of neutral molecular markers versus functional life-history attributes, as well as to how large a difference is needed for legitimate differentiation. Under certain circumstances, markers under selection may provide resolution for discrimination among alternate life-histories that may not be available using neutral markers, but data from markers under selection should not be used to make evolutionary inferences for populations. Because microsatellite DNA markers typically have the most number of characters per locus (higher level of polymorphism) they often can detect stock structure on finer spatial and temporal scales than can other DNA or protein markers. Two promising approaches include analysis of microsatellite variation and the recent development of tools to resolve single nucleotide polymorphisms (SNPs) from both nuclear and mitochondrial DNA.

Coded Wire Tags

For three decades, the CWT has provided a practical, efficient, and cost-effective means for stock- and fishery-specific assessment. Coordinated, coast-wide sampling and reporting systems facilitate sharing of information on CWT releases and recoveries via internet access. Recoveries of CWTs are expanded for catch sampling rates and are reported, usually within a few months of harvest, by time and fishery strata. CWT release records provide information on location and timing of release, study purpose, stock (hatchery or natural), age at recovery, size at tagging and size at recovery. Standardized methods for CWT data analysis reduce opportunities for misinterpretation. The capacity to conveniently analyze experimental results for individual CWT release groups in a timely manner has proven invaluable for salmon fishery management, research, and monitoring (e.g., estimation of hatchery contributions to catch, abundance forecasting, identify variations and trends in marine survival over time, determine the scale of stock-dependent differences). The Pacific Salmon Commission's (PSC) Ad-Hoc Selective Fisheries evaluation Committee (ASFEC, 1995) summarized the main reasons why all salmon fishery management agencies in the Pacific Northwest rely upon the CWT:

1. The CWT program includes fully integrated tagging, sampling, and recovery operations along the entire west coast of North America;

2. The CWT provides sufficient resolution for stock-specific assessments; and

3. The CWT is the only stock identification technique for which a historical record (generally back to the mid 1970s) of stock-specific assessments may be computed.

No other practical mark-recovery system has yet been devised that is capable of providing this level of detail in such a timely fashion. The historic success of the CWT program has been in no small part due to the high level of coordination and cooperation among the coastal states and British Columbia and to the consistency of CWT tagging and recovery efforts across the many political jurisdictions. Despite the emergence of other stock identification technologies, including various genetic methods and otolith thermal marking, the CWT tag recovery program remains the only method currently available for estimating and monitoring fishery impacts on individual stocks of coho and Chinook salmon for implementation of fishing agreements under the Pacific Salmon Treaty (PST). The CWT, however, addresses only two of the eight management questions identified in the Introduction section.

Archival Tags

Archival tags, also referred to as data storage tags (DSTs), are used to record conditions experienced by fish and other aquatic species, for later retrieval. The most common sensors on archival tags are water temperature and depth, but can also include light, salinity, and GPS in specialized applications. Archival tags can be packaged with radio and acoustic transmitters to allow matching fish movements with environmental conditions fish experience.

Archival tags are declining in size (the smallest tag at this time is 2.5 g in air, 0.9 g in water) but are still not of a small enough size the allow their use with juvenile salmonids. As such, most applications in the Columbia and Snake rivers has been limited to adult salmon, steelhead, lamprey and some resident trout studies. Archival tags can be mounted internally or externally, depending on species and application. Costs per unit are relatively high. One cheaper alternative for a temperature archival tag with reduced memory capacity is available.

The utility of archival tags is that they provide information on environmental conditions fish actually experience while migrating or resident in aquatic systems. This information can be used to assess fish exposure to physiological stressors, track behavior/movements (i.e., evaluate passage methods), and estimate bioenergetics, among other uses. The limitations of archival tags are the requirement that tags must be retrieved so the data can be downloaded, their large size and relatively high cost. Current efforts to incorporate the ability to remotely download data without the need to recapture fish will greatly improve the utility of archival tags.

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