Feasibility of Radio-Frequency Identification Tags for Marking Juvenile Salmon for Pacific Salmon Commission Management Applications

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February 2017

Pacific Salmon Commission Technical Report No. 36

The Pacific Salmon Commission is charged with the implementation of the Pacific Salmon Treaty, which was signed by Canada and the United States in 1985. The focus of the agreement are salmon stocks that originate in one country and are subject to interception by the other country. The objectives of the Treaty are to 1) conserve the five species of Pacific salmon in order to achieve optimum production, and 2) to divide the harvests so each country reaps the benefits of its investment in salmon management.

Technical Reports of the Pacific Salmon Commission present results of completed or ongoing investigations carried out by the Pacific Salmon Commission that are deemed of sufficient interest to be made available to the scientific community and the public.

The contents of these reports may be reprinted, and reference to the source will be appreciated.

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For

Pacific Salmon Commission
Committee on Scientific Cooperation

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Executive Summary

LGL Limited was contracted by the Pacific Salmon Commission (PSC) to assess the current state of RFID technology, its suitability for application to juvenile Chinook and Coho salmon, and its potential to provide more useful and reliable information than the current CWT program. The PSC identified the following five objectives:

1. Review the current application of RFID tags for animal identification and management, including their advantages and limitations over current technologies.
2. Compare sizes, tag costs, and tag application costs of RFID tags (including PIT tags) with those of CWTs.
3. Review detection capabilities of RFID tags, including detection distances when embedded in animal tissue and when animals are moving through freshwater or seawater.
4. Evaluate the feasibility for mass screening for detection and reading of RFID tags in landings of Pacific salmon.
5. Evaluate the feasibility and cost of incorporating RFID microchips to replace CWT in marking juvenile salmon for coastwide Coho and Chinook salmon management.

These objectives were addressed by combining the information obtained through our review of the pertinent literature, CWT and RFID tagging programs; and structured inquiries of manufacturers of RFID tags used for tagging fish and detecting recoveries in marine fisheries, freshwater fisheries and spawning areas.

A summary of our findings and recommendations regarding each of the above objectives is provided in the following paragraphs:

Objective 1 – There are a wide variety of RFID tags (size, shape, operating frequency, performance) and applications, although their common use is to provide the unique identification of live beings or material assets. The numerous types of RFID tags developed for hard goods are not suitable for application to fish. Physical laws strictly govern the tag size and detection range. The frequency at which a RFID tag and respective reader operate is one of the parameters which directly influences the size of tags and the distance from the reader that the tag can be energized and reliably decoded. Passive Integrated Transponder (PIT) tags are the most commonly used and effective RFID technology suitable for fish. Application of PIT tags to fish over the past 25 years has shaped the physical specifications of tags and readers produced today to provide the best characteristics of application and performance that can be achieved (i.e., 134.4 KHz) using currently available technology. The major advantage of current RFID (PIT tag) technology over CWTs for fish studies are:

  a. PIT tag codes can be recovered from alive or dead fish in seconds by passing a scanner over the fish, whereas for CWT fish must be killed in order to extract and visually decode the tag. The ability to decode a PIT tag with a scanner eliminates collecting heads from fish that may or may not contain CWTs, extracting the CWT,

decoding the CWT, recording the data and analytically handling errors and tags lost in this process. Therefore, PIT tags provide more opportunity for recoveries and a process that is substantially more timely and efficient;

b. PIT tags can be detected in fish as they pass in proximity to a scanning device, including when the fish is in fresh water. CWT detectors can only be used in air. Further, standard PIT tags have a broader detection range than CWT. Therefore, PIT tags can be detected in more situations and conditions; and
c. Release and recovery data is higher quality in that there are significantly fewer errors in reading, recording, and exchange. Therefore, quality control of data requires less effort, data analyses are more reliable, and require less time and costs for analysis.

The major limitation of current RFID (PIT tag) technology relative to CWTs for fish studies is cost. PIT tags are approximately 11 times more costly than CWTs, and it can take approximately 2 to 8 times longer to tag a fish with a PIT versus a CWT.

Objective 2 – Biomark produces three sizes of PIT tags applicable to juvenile salmon (8, 9, and 12 mm in length, 1.0-1.4 mm in diameter). Read range for a 8 mm PIT tag (50 cm) is approximately half that for a 12 mm PIT tag (100 cm). The cost for these PIT tags are approximately CAD $1.95 per tag, *preloaded in a needle*. Comparable tags without the needle can be obtained from HID Global for approximately CAD $1.30 for bulk orders of 1 million tags. These tags are currently applied using manual (non-automated) techniques involving needles needle insertion or micro-surgery. A single trained staff using preloaded needles and a continuous supply of fish can tag approximately 100 fish per hour. Several other likely costs (e.g., location, mobile reader, available infrastructure and services, fish anesthesia method, and related data management) would need to be considered to provide an all-inclusive estimate of producing tagged fish for release. Assuming that these "other" costs are similar with CWT, then PIT application would cost approximately 11 times more for tags, and 8 times as much in technician labor for the same number of tagged fish. A broader programmatic comparison of PIT and CWT costs is provided in the section on Objective 5.

Objective 3 – There are two aspects of detection capability for RFID tags; Read Range and Read Speed. Read Range of a tag is directly related to the physical quantity and quality of core components (ferrite and windings), and influenced by the quality of the Reader and a host of environmental factors. Assuming optimal orientation in the antenna field, the smallest ultra and micro tags (2.5-6 mm) have a Read Range of 1 cm or less. Standard 12 mm tags can have a Read Range up to 100 cm (antenna array dependent), and 8 mm tags is less than 50 cm. In general, Read Range is the same in air and freshwater and is not appreciably effected by body tissue. Bit specification (e.g., 32 or 64 bit) of a Reader effects the Read speed, or how quickly a tag can be accurately scanned in the antenna field. Typically, tags can be read on the order of milliseconds. Tags passing through a field quickly (e.g., through the spillway of dam) require a faster processing speed compared to those scanned using a hand wand.

Objective 4 – It is technically feasible to design and implement a mass screening program that could include a variety of landing locations for Pacific Salmon. A large portion of the catch of Chinook and Coho are harvested by commercial trollers, recreational anglers, and First Nation fishers. All commercial trollers process their catch at-sea such that PIT tags in the abdominal cavity would likely be removed and lost before reaching a shore based processing facility. However, currently available PIT tag scanners are suitable for use by fishers on vessels to scan a fish before at-sea processing. On shore, creel surveyors and "fish pit" workers at fishing lodges can scan fish caught by anglers. If necessary, monitoring systems can be developed for fish processing plant operations too. There are off-the-shelf reader/antenna products that could be applicable to scanning landings, and custom applications can also be designed and fabricated.

Objective 5 – RFID (PIT) technology possesses several attributes which are preferable compared to CWT (see section on Objective 1). However, there is insufficient data at this time to determine if existing RFID (PIT tag) technology can successfully replace CWT for the purposes of the PSC. Basically, there are too few robust juvenile-to-adult-return PIT evaluation studies providing information on PIT tag loss rates and effects of PIT tagging on long term survival to confidently support the estimation of exploitation rates (see Appendix D). More specifically: there is a lack of evidence that PIT tagged subyearling Chinook have long term survival rates and tag loss rates on par with CWT subyearling Chinook.

With regard to the cost of replacing CWTs with PIT tag technology, it would not be possible to replace the coastwide CWT marking and recapture system for all Chinook and Coho stocks using currently available PIT tag technology without a very substantial increase in funding. For example: CAD $80.6 M would be required to purchase the PIT tags needed to replace the CWTs applied to 8.1 M Coho and 53.9 M Chinook for a single recent brood year (e.g., 2009). Consequently, we focused our assessment efforts on the feasibility using existing PIT tag technology to improve the tag recovery (detection) process and estimate the costs associated with replacing CWT with PIT tags for the Chinook and Coho exploitation rate (ER) indicator stocks, where CWT data has been important for management of Canadian and US fisheries for these species. Our calculations for Chinook suggest that the costs of replacing the CWT program for the Chinook indicator stocks with existing PIT tag technology would be roughly twice the cost of the current CWT program for the Chinook indicator stocks and roughly half the current costs for the entire CWT program for Chinook salmon. Our calculations for Coho suggest that that the costs of replacing the CWT program for the Coho indicator stocks with existing PIT tag technology, while tripling the number of tag recoveries, would be roughly four times the cost of the current CWT program for the Coho indicator stocks and roughly equal to the current costs for the CWT program BC and WA Coho salmon.

We have discussed the ideas related to improving tag recovery sampling and fisheries and escapements with several fisheries researchers, stock assessment biologist and fisheries managers in Canada and the US, and most were very interested in further exploring the feasibility of using PIT tag technology for some or all of the Chinook and Coho ER indicator stocks. Several fisheries researchers have expressed interest in how a transition from CWTs to PIT tag technology could occur. There would certainly be a period when sampling programs would need to include the capability of detecting both type of tags and combined program costs will certainly be greater during the transition years than after the transition was completed. However, a substantial reduction in the number of CWTs applied to Chinook salmon by shifting to just tag indicator stocks could save $15 M/year and more than cover the costs of applying PIT tags to these same indicator stocks.

While a comprehensive assessment of the cost of using PIT tag technology for some or all of the Chinook and Coho ER indicator stocks was beyond the scope of this small project, the information provided in this report provides an initial assessment of the potential costs, benefits and feasibility of using existing PIT tag technology to improve the quality and quantity of information collected for the management and assessment of Chinook and Coho fisheries on the Pacific Coast.

Recommendations:

1. Obtain new information from the Carson National Fish Hatchery USFWS study to determine comparable smolt-to-adult return rates and full life-cycle tag loss rates for PIT tagged and CWTs applied to spring Chinook, which should be available in the next six months.
2. Conduct a programmatic cost analysis that includes accounting for all costs from tag application through reporting. Cost information from the USFWS comparative study should be included in this assessment.
3. Develop a framework study design and costing to conduct a pilot program implementing the use of PIT tags on select indicator stocks. Proceed to conduct a study, if the study design and cost estimates are acceptable.
4. Invite selected RFID system producers to a workshop with PSC staff to explore detailed topics and develop a framework design for implementing a pilot program for a defined group of exploitation rate indicator stocks.

Introduction

The evaluation of alternatives to the coded-wire tag (CWT) system for assessing the distribution, survival and exploitation rates for Chinook and Coho salmon stocks has been the subject of many studies and workshops over the past 20 years (e.g., Prentice et al. 1994; PSC 2005; 2015a). Passive Integrated Transponder (PIT) tags were identified in the early 1990s as a potential alternative to CWTs after initial studies showed no effect of tag type on overwinter survival for their 3 year study of two cohorts (Prentice et al. 1994; Peterson et al. 1994). More recent studies have identified concerns related to higher rates of tag loss and lower survival for PIT tagged Chinook Salmon than those marked with CWTs (Knudsen et al. 2009). These studies and the broad use of CWT and PIT tags, prompted a recent study at the Carson National Fish Hatchery to determine comparable smolt-to-adult return rates and full life-cycle tag loss rates for PIT tagged and CWTs applied to spring Chinook (USFWS 2014).

The PSC Expert Panel on the future of the CWT recovery program for Pacific salmon identified numerous deficiencies associated with the CWT program and encouraged the evaluation of alternative approaches (PSC 2005). The use of RFID technology was specifically referenced in their findings and recommendations:

> *"Finding 19. A number of existing or emerging electronic technologies could theoretically replace the CWT and may have substantial advantages over the CWT (e.g., tags can be read without killing the fish, unique tags for individual fish allow migration rates and patterns to be directly observed). Examples include at least Passive Induced Transponder (PIT) tags and Radio Frequency Identification (RFID) tags. PIT tags are currently too large to mark all sizes of juvenile chinook salmon released from hatcheries and are expensive relative to CWTs, but future technological improvements may reduce tag size and tag cost for these technologies."*

> *"Recommendation 14. We recommend that a feasibility study be conducted to determine how PIT, RFID or other electronic tags might be used to generate data suitable for full cohort reconstruction."*

This project was initiated to assess the current state of RFID technology, its suitability for application to juvenile Chinook and Coho salmon, and its potential to provide more useful and reliable information than the current CWT program.

Project Approach

We researched the current application of RFID tags for animals, birds and fish through industry and research contacts, literature, and the Web to assess the current state of technology and potential advances that may be coming in the future that could make RFID tags more suitable than current RFID tags and coded-wire tags (CWTs) for supporting the mandate and goals of the

Pacific Salmon Commission (PSC), and in particular the estimation of Chinook and Coho salmon exploitation rates.

A variety of characteristics regarding RFID application to fisheries research and management are of interest, but primarily include the suitability of RFID for application, identification, detectability, and cost. In this regard, we developed structured interview questions for each of industry and researcher (Appendix A and B). Industry questions focused on product characteristics, and researcher questions focused on what the desired attributes of a technology would be to replace CWT. Interview data were entered into a spreadsheet for documentation. A list of individuals contacted during this study is provided in Appendix C.

Consultations with members of the Committee on Scientific Cooperation (CSC) included: the kickoff teleconference in June 2016, a progress report teleconference in September 2016 and correspondence via phone and email with Alex Wertheimer. This report provides a summary of our findings regarding each of the project objectives.

Project Objectives

1) **Review the current application of RFID tags for animal identification and management, including their advantages and limitations over current technologies.**

There are a wide variety of RFID tags (size, shape, operating frequency, performance) and applications, although their common use is to provide the unique identification of live beings or material assets. The numerous types of RFID tags developed for hard goods are not suitable for application to fish. The largest market for RFID on animals is for pets and livestock; some tags are applied externally (e.g., ear tags) and some are injected subcutaneous (biocompatible glass capsules). Passive Integrated Transponder (PIT) tags are the most commonly used and effective RFID technology suitable for fish. PIT tags have been applied to numerous fish species and used extensively for many years to study the downstream migration of juvenile salmonids on the Columbia River and sturgeon populations on the Columbia and Fraser rivers. Regardless of the application, all RFID tags are comprised of a circuit board for operation, and an antenna for powering via a reader. Differences between tags relate mostly to their physical properties of material composition and architecture. Physical Laws strictly govern the range and limits of tag and reader performance to the extent that specific tag configurations are suitable to a similarly limited range of applications.

Physical laws strictly govern the tag size and detection range. The frequency at which a RFID tag and respective reader operate is one of the parameters which directly influences the size of tags and the distance from the reader that the tag can be energized and reliably decoded. In general, the higher the frequency, the smaller the tag and the shorter the read range. For example, 134.4 KHz PIT tags that are 1x12 mm in size will operate reliably to

50 cm, whereas 900 MHz tags that are 0.4x2.5 mm in size will operate reliably at less than 1 cm. Ultimately, there is a tradeoff between frequency, size, and read range that can't be compensated for; improvements can be made through materials and architecture (i.e., the future of RFID), however the basic physics are not changeable.

RFID tags that appropriate for insertion in fish and coding by readers in their respective environments are limited. Application of PIT tags to fish over the past 25 years has shaped the physical specifications of tags and readers produced today to provide the best characteristics of application and performance that can be achieved (i.e., 134.4 KHz) for marketable products. The smallest encapsulated *micro*-tag (6 mm operating at 13.56 MHz) is primarily used in laboratory applications where the tag and reader can be put in very close proximity (e.g., Cousin et al. 2012). *Ultra*-small wafer-style chips (non-encapsulated tags operating at 900 MHz) have been usefully applied to bees (Hitachi Chemical Co. 2015; Miller 2016; Gough 2016), bats, and birds because they are lightweight, and readers can be positioned in such close proximity to the target specimen as to be functional. However, these tags are presently not applicable or useful to the target fisheries applications of the PSC, largely because of their very small detection range (<1 cm), and the lack of proven application in fresh or salt water (Akira Nagse, Hitachi Chemical Co., pers. comm.). Further, these tags operate on a higher frequency than the more commonly used 134.4 KHz PIT tags, so they are also incompatible with the existing detection arrays in fisheries.

The use of Coded Wire Tags (CWT) to support fisheries assessment and management is longstanding and is presently the only technique used for the estimation of Chinook and Coho salmon exploitation rates by the PSC (PSC 2015a). However, changes in fish marking applications and in the time-space implementation of salmon fisheries, along with insufficient funding to operate a rigorous tag and recovery program, have made the use of CWT's less effective in achieving the goals of the PSC. Table 1-1 presents a comparison of attributes for CWT and PIT tags to context some of the similarities and differences between these methods.

Table 1-1. Attributes of CWT and RFID (PIT) tags and detection equipment.

1.	Tag suitable for insertion into subyearling salmon less than 60 mm	Y	Y	Tiffan et al. (2015) tagged 40-49 mm fish with 8 & 9 mm PIT, and 50-59 mm with 8, 9, and 12 mm PIT
2.	Tag suitable for insertion into adult salmon	Y	Y	
3.	Tag detectable in water	N	Y	NWT does not make an in-water tag detector
4.	Tag detectable in air	Y	Y	
5.	Tag can be READ in a non-lethal manner	N	Y	
6.	Tag is READ electronically	N	Y	
7.	Tag provides data number	7-10 digit binary	15 digit decimal	
8.	Tag unit cost (unit cost)	CAD $0.12	HID CAD $1.30 tag (bulk), Biomark $1.95 (bulk) with needle	HID RFID USD $1.00 (bulk). Biomark RFID USD $1.75 just tag, $1.50-$1.70 (bulk) preloaded in needle. NWT CWT USD $0.092
9.	Tag applicator (unit costs)[2]	multi-shot injector CAD $10,300 and mass injector CAD $29,000 OR rental fee	CAD $9 syringe implanter/needle, $52 gun implanter	Biomark RFID implanter & needle USD $7 ($5/$2) $40 implanter gun. NWT CWT multi-shot injector USD $7,900 and mass injector USD $22,000
10.	Hand held scanner (unit cost)	CAD $5,000 OR rental fee	CAD $450 (bulk)	Biomark RFID USD $350 (bulk). NWT CWT $3,825 T-wand
11.	Pass By scanner (unit costs) applicable to use on captured fish	CAD $5,000 OR rental fee	CAD $3,900 block & ring wand	Biomark RFID USD $3,000 block & ring wand. NWT CWT $3,825 V-block
12.	Fishway/weir system (unit cost) applicable to use for free swimming fish	not applicable	CAD $6,400 fixed reader and applicable antenna	Suitable for fishway or counting fence applications. Biomark RFID USD $1,425 fixed reader plus $3,500 pass over or $4,000 pass through or $4,700 pass under
13.	Tag does not have long term effects on fish survival	Y	Limited to a single study, Inconclusive	Short term survival of 95% (Dixon and Mesa 2011). Long term survival of 67% to adult with alternate analyses estimating 93%. See report appendix "Mortality and Tag Retention in PIT-tagged Fish"
14.	Long term tag loss rate is low enough to be cost effective and used for statistically valid analyses	Y	Limited to a single study, Inconclusive	Short term loss rate of 0% over 39 d (Prentice et al. 1990) to 7% over 28 d (Tiffan et al. 2015). Long term loss rate of 18% to adult (Knudsen 2009). See report appendix "Mortality and Tag Retention in PIT-tagged Fish"
15.	Tags can be detected using a mass screening process	Y	Y	Standard configurations available, but custom applications are possible
16.	Robust detectability short range (10 cm)	Y	Y	NWT v-detector 15 cm, NWT wand 5.5 cm
17.	Robust detectability long range (100 cm)	N	Y	PIT can be >100 cm for powered upward substrate applications using 12 mm tags

[1] All costs are retail pricing except where specifically indicated as bulk/discounted. RFID reader-antenna combinations are for a single antenna.

[2] Costs for CWT multi-shot injectors and mass injectors represent capital costs for this equipment that should last for many years, therefore, these costs are not factored into the annual costs for the CWT program provided in later tables.

The major advantages of current PIT tag technology over CWTs for fish studies are:

a. PIT tag codes can be recovered from alive or dead fish in seconds by passing a scanner over the fish, whereas for CWT fish must be killed in order to extract and visually decode the tag. The ability to decode a PIT tag with a scanner eliminates collecting heads from fish that may or may not contain CWTs, extracting the CWT, decoding the CWT, recording the data and analytically handling errors and tags lost in this process. Therefore, PIT tags provide more opportunity for recoveries and a process that is substantially more timely and efficient;
b. PIT tags can be detected in fish as they pass in proximity to a scanning device, including when the fish is in fresh water. CWT detectors can only be used in air. Further, standard PIT tags have a broader detection range than CWT. Therefore, PIT tags can be detected in more situations and conditions; and
c. Release and recovery data is higher quality in that there are significantly fewer errors in reading, recording, and exchange. Therefore, quality control of data requires less effort, data analyses are more reliable, and require less time and costs for analysis.

The major limitations of current PIT tag technology relative to CWTs for fish studies are:

a. Cost per unit cost (CAD $1.30) of a PIT tag is approximately 11 times that of a CWT (CAD $0.12), and it can take approximately 2 to 8 times longer to tag a fish with a PIT versus a CWT (when using a "multi-shot" device or an electronic injector, respectively)[1]. Details are provided under Objective 2;
b. Large size of PIT tags relative to CWT's. Therefore, PIT tags have been intentionally limited in their use to fish 50 mm or greater but are being tested on salmon down to 40 mm (e.g., salmon fry); and
c. PIT tags are generally injected into the body cavity, therefore, fish must be scanned before any at-sea or shore-based processing occurs.

<u>Select Information from Interviews</u>

The PSC and its Chinook and Coho technical committees are not the only groups interested in identifying marking techniques that could replace the current CWT system. This goal is shared by many in the fisheries management community; in fact, the U.S. Bureau of Reclamation conducted an "Ideation Challenge Prize Competition" titled "New Concepts for Remote Fish Detection" in 2015 to generate innovative, new ideas from the general public on technologies that might address their wish list of attributes for fish tagging and recovery (Charles Hennig, USBR, Deputy Chief, Research and Development). Their premise is that the limitations with existing technologies have resulted in data that is insufficient to address

[1] The total cost of release, recovery, and data analysis for a fish using either PIT or CWT technology can be reasonably quantified, but a precise representation is beyond the scope of this project.

the management and fiscal challenges of today's fisheries. The competition generated an array of concepts (over 30 submissions); some were incremental improvements to existing fish tracking methods, while others were entirely new concepts. None of entries proposed solutions related to RFID technology, and none of the solutions were close to being fully developed or ready for testing (Fullard and Connolly, in draft). The USBR is presently considering its next course of action with respect to supporting directed research and/or a refined Idea-Challenge.

The industry representatives interviewed during this study identified the following areas of focus for the future development of RFID technology, as related to fisheries applications:

- Continually improve the operational performance between tags and readers in terms of detection range, detection speed, on-board data memory, and uploading of data to servers;
- Optimize shape and size for some applications as based on architecture; and
- Inform the user community regarding the variability and differences in product quality across producers.

2) Compare sizes, tag costs, and tag application costs of RFID tags (including PIT tags) with those of CWTs.

We have confirmed that the smallest available RFID tags suitable for implanting in juvenile salmonids is the Nonatec transponder; it is 1 mm in diameter and 6 mm in length, with a mass of 10 mg (http://www.nonatec.net/). These are high frequency tags (13.56 MHz) manufactured by Lutronic International in Rodange, Luxembourg (Cousin et al. 2012). Further details on this product were not pursued because of performance limitations; the read range is approximately 1 cm and the respective reader is designed for laboratory use rather than in the field (M. Begout, Ifremer French Research Institute for Exploration of the Sea, pers. comm.).

Biomark (Boise, ID) produces three sizes of PIT tags applicable to juvenile salmon (8, 9, and 12 mm in length, 1.0-1.4 mm in diameter). Read range for an 8 mm PIT tag (50 cm) is approximately half that for a 12 mm PIT tag (100 cm). The cost for these PIT tags are approximately CAD $1.95 per tag, *preloaded in a needle*. Comparable tags without the needle can be obtained from HID Global for approximately CAD $1.30 for bulk orders of 1 million tags. These tags are currently applied using manual (non-automated) techniques involving needles needle insertion or micro-surgery. A single trained staff using preloaded needles and a continuous supply of fish can tag approximately 100 fish per hour (Scott Gary, Biomark, pers. comm.). Several other likely costs (e.g., location, mobile reader, available infrastructure and services, fish anesthesia method, and related data management) would need to be considered to provide an all-inclusive estimate of producing tagged fish for release. Assuming that these "other" costs are similar with CWT, then PIT application would cost approximately 11 times more for tags, and 8 times as much in technician labor for the same number of tagged fish. A broader programmatic comparison of PIT and CWT costs is provided in the section on Objective 5.

Standard CWT's are 1.1 mm length and 0.25 mm diameter with options for half-length and double-length (http://www.nmt.us/products/cwt/cwt.shtml). Tags cost CAD $0.12/tag plus the cost of an injector (purchase CAD $41k or rental). A single trained staff using a standard injector and a continuous supply of fish can tag approximately 800 fish per hour (Northwest Marine Technology 2005). An auto-tagger device is also available for CAD $1.8M.

There are a plethora of PIT tag suppliers, and much fewer PIT tag manufacturers in the world. Some manufacturers could be considered high-end, quality research and development firms, while many more could be considered high volume, knock-off producers of low quality products. Individual PIT tags can be purchased for as little as CAD $0.50 each, but there is proportionally lower confidence in whether the tag will function when energized. Therefore, for large quantity, bulk purchase of PIT tags consideration should be given to complete a strong QAQC vetting process that includes on-site interviews at manufacturing facilities, independent testing, reference checks, and verification of performance with the fisheries research and management community. For high quality producers, tag failure rate is zero upon shipping. RFID manufacturers that were interviewed included:

Biomark (http://www.biomark.com/),
HID (https://www.hidglobal.com/products/rfid-tags/identification-technologies/animal-id),
Trovan (http://www.trovan.com/products.html).

3) Review detection capabilities of RFID tags, including detection distances when embedded in animal tissue and when animals are moving through freshwater or seawater.

RFID tags use radio wave frequencies to transmit the tag code and thus are largely not detectable in saltwater. PIT tags can be detected in fish moving through freshwater, but the detection range depends on the size (materials and architecture) of the tag and the amount of energy that can be transmitted through the water to energize the tag. As indicated previously, the electronic field created by a RFID reader and its antenna with a tag collapses down to several centimeters in salt water, and thereby limits the application to close proximity monitoring.

There are two aspects of detection capability for RFID tags; Read Range and Read Speed. Read Range of a tag is directly related to the physical quantity and quality of core components (ferrite and windings), and influenced by the quality of the Reader and a host of environmental factors. Assuming optimal orientation in the antenna field, the smallest ultra and micro tags (2.5-6 mm) have a Read Range of 1 cm or less. Standard 12 mm tags can have a Read Range up to 100 cm (antenna array dependent), and 8 mm tags half of that. However, more typical range is on the order of 50 cm. In general, Read Range is the same in air and freshwater and is not appreciably effected by body tissue. For comparison, CWT tags are “detected” (rather than read) by changes in a magnetic field at distances of 5.5 cm for a wand to 19x33 cm for an oval tunnel.

Bit specification (e.g., 32 or 64 bit) of a Reader effects the Read speed, or how quickly a tag can be accurately scanned in the antenna field. Typically, tags can be read on the order of milliseconds. Tags passing through a field quickly (e.g., through the spillway of dam) require a faster processing speed compared to those scanned using a hand wand.

RFID (PIT) tags can be read in a variety of conditions, both watered and in the dry, in moving or stagnant water, and in containments. Antenna have been developed to include the handheld wand, “pass by” flat substrate or floating mounted plates, and “pass through” periphery configurations such as fish transfer conduits. Detection of tags can be substantially reduced in environments where specific radio frequency noise is relatively high and in proximity to a reader-antenna. However, in practice, these conditions are not common as evidenced by the variety of installations at hydroelectric facilities where RF noise can be substantial.

4) Evaluate the feasibility for mass screening for detection and reading of RFID tags in landings of Pacific salmon.

It is technically feasible to design and implement a mass screening program that could include a variety of landing locations for Pacific Salmon. A large portion of the catch of Chinook and Coho are harvested by commercial trollers, recreational anglers, and First Nation fishers. All commercial trollers process their catch at-sea such that PIT tags in the abdominal cavity would likely be removed and lost before reaching a shore based processing facility. However, currently available PIT tag scanners are suitable for use by fishers on vessels to scan a fish before at-sea processing. On shore, creel surveyors and “fish pit” workers at fishing lodges can scan fish caught by anglers. If necessary, monitoring systems can be developed for fish processing plant operations too. As indicated under Objective 3, there are off-the-shelf reader/antenna products that could be applicable to scanning landings, and custom applications can also be designed and fabricated.

The main advantage of RFID (PIT tag) technology over CWT technology is the ability to electronically scan a fish (live or dead) to obtain its individual digital tag code. PIT tag technology has been used successfully for many years on salmon studies within the Columbia River and ongoing studies of Columbia and Fraser River White Sturgeon. On the Fraser River, guides, anglers and test fishery operators have been given PIT tag scanners and trained to scan every Sturgeon they catch and record tag recovery data (Nelson et al. 2013). It is this significant advantage with regard to the catch sampling and tag recovery that must be exploited to make PIT tag technology a viable alternative to the current CWT technology for some stocks of Chinook, and provide more useful data for Coho than the current CWT program. For example: PIT tag scanners could be provided to every major recreational fishing lodge so that every fish landed at these lodges could be scanned and the data transmitted back to a central database. In addition, scanners could be provided to active fishing guides and "avid anglers" so they could also scan every fish caught, including those released. For commercial fisheries, it would be essential to provide PIT tag scanners to at least half, and possibly all, active trollers as a large portion of commercial catch of Chinook and Coho is taken by trollers that process their catch at sea. Since PIT tags are typically inserted into the abdominal cavity, fish would need to be scanned prior to processing. Each participating troller should be able to quickly pass every fish caught through a scanner that would record the number of fish scanned and the tag codes for each tagged fish. These data could be automatically uploaded to a central database along with date and fishing location data at the end of each fishing trip. For those stocks, where potential spawners (adults and jacks) are counted through fences, fishways or weirs, PIT tag scanners could be deployed to record the passage of any tagged fish. The strategic deployment of 400 portable PIT scanners and 50 swim-by PIT scanners should be able to increase our detection rates by at least 3 times over current CWT detection rates. Comparison of the observed and estimates recovery rates for CWTs for BC Chinook indicator stocks and all Coho indicator stocks suggests that recovery rates could be increased by 3 times by providing commercial fishers, 'avid" recreational anglers, sport fishing lodges, creel surveyors and First Nation catch monitors with PIT tag scanners; and deploying swim-by scanners at counting locations for each of the indicator stocks. At a unit cost of CAD $450 per handheld scanner and CAD $6,400 per swim-by scanner, the initial capital investment in a PIT tag scanning equipment would be CAD $500,000.

5) Evaluate the feasibility and cost of incorporating RFID microchips to replace CWT in marking juvenile salmon for coastwide Coho and Chinook salmon management.

Feasibility Assessment

The basic question of feasibility rests upon whether RFID (PIT tag) technology can provide the data/information that CWT presently supplies for implementation of the Pacific Salmon Treaty; and more specifically, to fulfill the need of making reliable inferences on stock-age-fishery exploitation rates *on natural stocks*. The PSC's Joint CWT Implementation Team concluded that "no other technology has been demonstrated to be capable of providing the coast wide data needed for PST and regional stock and fishery management" for Chinook and Coho (PSC 2015a). This statement echoed the sentiment of the PSC's earlier assessment (PSC 2005).

We have demonstrated through this present investigation that RFID (PIT) technology possesses several attributes which are preferable compared to CWT (see section on Objective 1). However, through our review of readily available information, there is insufficient data at this time for two key aspects to determine if RFID (PIT) technology can successfully replace CWT for the purposes of the PSC. Basically, there are too few robust juvenile-to-adult-return PIT evaluation studies providing information on PIT tag loss rates and effects of PIT tagging on long term survival to confidently support the estimation of exploitation rates (Appendix D). More specifically,

1. There is a lack of evidence that PIT tagged subyearling Chinook have long term survival rates on par with CWT or untagged subyearling Chinook.
2. There is a lack of evidence that PIT tagged Chinook and Coho have tag loss rates on par with CWT Chinook and Coho.

One relevant study to specifically address these issues is underway now by the US Fish and Wildlife Service (USFWS 2014). Preliminary data for the first returns of PIT and CWT marked fish show no statistically different values, and an update on the study is expected in 2017. While this study will provide valuable information, it is likely that additional studies are necessary to provide conclusive information on these aspects. In this regard, a comparative study could also serve as the information base to inform a transition from the current CWT program to a mark-recapture program based on PIT tag technology.

One consideration of feasibility for implementing the use of PIT tag technology is whether tags and reader equipment can be adapted to or integrated with existing CWT processes of tagging, recovery, and data analysis. In other words, are there aspects of PIT tag technology that can be combined or used side-by-side with the existing CWT platform to achieve efficiencies. They do have several common requirements such as power, a platform proximate to a supply of fish, and a database in which to house tag records. Other than that, the two technologies are dramatically different in functionality and they are not interchangeable. For example, a CWT detector can't code a PIT tag, and currently available PIT tag scanners can't detect a CWT. However, at least one manufacturer thinks that the two technologies are compatible in that a single unit such as a wand could be a platform to host both detection systems, should that be a desired consumer requirement. Similarly, coded wire tags can be automatically applied (no manual handling) using NWT's AutoFish system (http://www.nmt.us/products/afs/afs.shtml), and it can't implant a PIT tag in the same way. However, strong interest from PIT tag users has one manufacturer considering the fabrication of such a device. In any case, industry will only design and build tools for users when there is sufficient demand to warrant the R&D and the associated financial risk that goes along with it.

Cost Assessment

Given the current minimum bulk price of CAD $1.30/tag for PIT tags suitable for application to juvenile Coho and Chinook salmon, it would not be possible to replace the coastwide CWT marking and recapture system for all Chinook and Coho stocks using currently available PIT tag technology without a very substantial increase in funding. For example: CAD $80.6 M would be required to purchase the PIT tags needed to replace the CWTs applied to 8.1 M Coho and 53.9 M Chinook for a single recent brood year (e.g., 2009). Consequently, we have focused our assessment on the feasibility using PIT tag technology to improve the tag recovery (detection) process and estimate the costs associated with replacing CWT with PIT tags for the Chinook and Coho exploitation rate (ER) indicator stocks where CWT data has been important for management of Canadian and US fisheries for these species.

The next step in our evaluation was to identify a set of ER indicator stocks for each species that would be a high priority for including in a mark-recapture program using PIT tag technology. For Chinook, the ER indicator stocks were those identified as "current CWT exploitation rate indicator stocks" (Table 2.1, PSC 2015b). For Coho, the initial set of BC and WA indicator stocks included just those stocks that have historically been important ER indicator stocks and have escapement monitoring facilities where a PIT tag detector could be deployed to detect most of the fish returning to their natal stream or hatchery (Chuck Parken, DFO, pers. comm.; Jeff Haymes, WDFW, pers. comm.). Once the indicator stocks were identified, we extracted the CWT release and recovery data from available mark-recapture databases for the 5-6 most recent brood years with complete returns. Table 5-1 provides a summary of the total CWT releases for each of the 13 Canadian and 35 US Chinook ER indicator stocks for brood years 2005-2009. The CWTs applied to these Chinook indicator stocks represent 23.5% of the total CWTs applied to Chinook salmon for these brood years.

Table 5-2 provides similar information on CWT release numbers for 10 BC and 9 Washington State (WA) Coho ER indicator stocks for brood years 2006-2011. The CWTs applied to the 19 indicator stocks represent 21.3% of the total CWT releases for BC and WA, which intern represent 75.5% of the total releases of CWT Coho for all areas (California to Alaska).

The release numbers from Table 5-1 and Table 5-2 were combined with observed and estimated CWT recoveries and cost estimates for tags, tag application, tag recovery sampling and tag decoding to derive comparable estimates of the complete brood year costs mark-recapture programs using CWT versus a proposed application of PIT tag technology for Chinook and Coho salmon. In Table 5-3, we used the observed and estimated CWT recoveries for the indicator stocks to derive estimates of the observed and estimated recoveries for all CWT Chinook. The CWT program costs estimated for all CWT applied to Chinook salmon was the sum of the tag costs (CAD $0.12/tag), application costs (CAD $0.12/fish), sampling costs (CAD $26/observed tag), decoding costs (CAD $5/observed tag) and the cost for making the data publicly available (CDN $18/tag). The sampling, decoding and data processing costs are the CDN $ equivalents of the US $ costs reported in Clark (2004) and PSC (2005). All of these costs estimates are averages across the various agencies that pay for components of the CWT system and thus may not reflect the costs for any specific agency or group.

The CWT program costs for just the Chinook indicator stocks used the same calculations except the numbers of CWT applied and observed were just those for the indicator stocks. The cost estimates for using PIT tag technology for the Chinook indicator stocks were based on the following assumptions:

1. The number of PIT tags applied could be reduced to 1/3 of the number of CWTs applied but the numbers of tags observed could be maintained by increasing the tag recovery sampling efficiency and effort by 3 times;
2. The PIT tag costs are CAD $1.30/tag (11 times the cost of a CWT) and PIT tag application costs are roughly twice those for CWT application;
3. PIT tags scanner would be deployed at recreational fishing lodges, with “avid anglers”, commercial fishers, at processing plans and with creel survey staff in sufficient quantities to increase the tag sampling rate by 3 times;
4. The cost to maintain the PIT tag detection program would be CAD $10/observed tag, excluding the initial capital cost of the PIT tag scanners; and
5. The PIT tag recovery data would be digital transferred from the PIT tag readers to a central PIT tag database on a daily or weekly basis (depending on the sampling location) along with information on the number of fish scanned for each species.

The relative low sampling cost for the PIT tag approach excludes the initial capital investment in PIT tag readers and training fishers and samplers to use this equipment. We have also assumed that fishers, lodge owners, creel survey programs and other sampling programs would be willing to scan Chinook and Coho as part of their daily operations at no cost with the assurance that they would be provided all the information obtained from their portion of the sampling program. We have conducted a similar program with guides, anglers, government test fisheries and First Nations as part of a sturgeon mark-recapture program on the Fraser River for the past 16 years (Nelson et al. 2013). All the tagging and scanning of sturgeon caught is done by trained program volunteers at no costs other than providing the tags and scanning equipment. We have used and continue to use the hand held Biomark duel frequency scanners ($450/scanner) under typically wet fishing conditions. We have tested many different types of scanners and found significant issues with some scanner types. We have also tested many different models of PIT tags. The types of tags and scanners included in our cost estimates are field tested and proven equipment.

The above assumptions and calculations suggest that the costs of replacing the CWT program for the Chinook indicator stocks with existing PIT tag technology would be roughly twice the cost of the current CWT program for the Chinook indicator stocks and roughly half the current costs for the entire CWT program for Chinook salmon.

The information and methods used to estimate the current CWT program costs for all CWT applied to Coho salmon in BC and WA were similar to those described above for Chinook. The CWT program cost estimates for the 10 BC and 9 WA Coho indicator stocks were based on the total number of tags released and observed recoveries for those stocks (Table 5-4). The cost estimates for using PIT tag technology for these Coho indicator stocks were based on the following assumptions:

1. The number of PIT tags applied would be the same as the number of CWTs applied but the numbers of tags observed would be increased 3 fold through improvements to the tag recovery process;
2. The PIT tag costs are CAD $1.30/tag (11 times the cost of a CWT) and PIT tag application costs are roughly twice those for CWT application;
3. PIT tags scanner would be deployed at escapement monitoring sites, recreational fishing lodges, with “avid anglers”, commercial fishers, at processing plans and with creel survey staff in sufficient quantities to increase the tag sampling rate;
4. The cost to maintain the PIT tag detection program would be CAD $10/observed tag, excluding the initial capital cost of the PIT tag scanners; and
5. The PIT tag recovery data would be digital transferred from the PIT tag readers to a central PIT tag database on a daily or weekly basis (depending on the sampling location) along with information on the number of fish scanned for each species.

These assumptions and calculations suggest that the costs of replacing the CWT program for the Coho indicator stocks with existing PIT tag technology, while tripling the number of tag recoveries, would be roughly four times the cost of the current CWT program for the Coho indicator stocks and roughly equal to the current costs for the CWT program BC and WA Coho salmon.

We have discussed the ideas related to improving tag recovery sampling and fisheries and escapements with several fisheries researchers, stock assessment biologist and fisheries managers in Canada and the US, and most were very interested in further exploring the feasibility of using PIT tag technology for some or all of the Chinook and Coho ER indicator stocks. Several fisheries researchers have expressed interest in how a transition from CWTs to PIT tag technology could occur. There would certainly be a period when sampling programs would need to include the capability of detecting both type of tags and combined program costs will certainly be greater during the transition years than after the transition was completed. However, a substantial reduction in the number of CWTs applied to Chinook salmon by shifting to just tag indicator stocks could save $15 M/year and more than cover the costs of applying PIT tags to these same indicator stocks.

While a comprehensive assessment of the cost of using PIT tag technology for some or all of the Chinook and Coho ER indicator stocks was beyond the scope of this small project, the information provided in this report provides an initial assessment of the potential costs, benefits and feasibility of using PIT tag technology to improve the quality and quantity of information collected for the management and assessment of Chinook and Coho fisheries on the Pacific Coast.

Table 5-1. Total CWT release numbers for Canadian and US Chinook exploitation rate indicator stocks for brood years 2005-2009.

	Total CWT release by broodyear					
Canadian Indicator Stocks	**2005**	**2006**	**2007**	**2008**	**2009**	**Total**
Atnarko Summer	159,150	152,767	151,449	151,608	415,107	1,030,081
Big Qualicum	223,084	199,619	205,857	203,540	449,683	1,281,783
Chilliwack (Harrison Fall Stock)	87,801	95,382	99,465	99,451	189,707	571,806
Cowichan Fall	200,183	200,290	408,849	666,580	397,269	1,873,171
Harrison Fall Stock (Chehalis)	102,312	205,396	208,179	195,420	213,243	924,550
Kitsumkalum Summer	192,438	125,939	153,435	209,144	207,658	888,614
Kitsumkalum Yearling	247	25,888	21,657	46,999	58,546	153,337
Middle Shuswap	0	0	0	103,180	146,854	250,034
Nicola River Spring	138,728	146,476	143,178	127,215	193,131	748,728
Puntledge Summer	185,285	179,227	177,086	127,513	87,853	756,964
Quinsam Fall	208,300	228,141	531,550	237,193	537,575	1,742,759
Robertson Creek	201,013	201,524	216,442	498,054	451,196	1,568,229
Lower Shuswap River Summers	193,040	199,357	268,844	249,206	483,739	1,394,186
Total Release	1,891,581	1,960,006	2,585,991	2,915,103	3,831,561	13,184,242
US Indicator Stocks						
Alaska Central Inside	47,601	53,690	46,241	64,279	47,111	258,922
Alaska Deer Mountain	9,148	10,902	10,185	7,914	6,751	44,900
Alaska Herring Cove	76,911	79,330	76,325	65,946	66,215	364,727
Little Port Walter	133,165	212,379	208,616	235,812	184,455	974,427
Alaska Macaulay Hatchery	35,577	21,794	32,194	31,486	12,696	133,747
Alaska Neets Bay	59,615	66,107	64,273	61,948	56,247	308,190
Chilkat Spring	20,557	31,148	24,085	16,982	44,304	137,076
Cowlitz Fall Tule	178,376	201,746	202,953	199,872	196,409	979,356
Elk River	189,177	78,068	53,022	27,182	212,149	559,598
George Adams Fall Fingerling	450,473	441,061	440,889	452,919	454,699	2,240,041
Hanford Wild	203,929	208,092	53,618	202,320	201,606	869,565
Hoko Fall Fingerling	67,347	78,892	210,854	67,479	155,144	579,716
Columbia Lower River Hatchery	230,174	444,337	453,945	225,164	451,148	1,804,768
Lewis River Wild	99,452	77,629	54,717	46,476	24,380	302,654
Lyons Ferry	200,369	191,436	194,762	191,403	199,152	977,122
Nisqually Fall Fingerling	247,447	408,834	360,599	412,578	402,643	1,832,101
Nooksack Spring Fingerling	407,937	278,614	413,532	346,739	393,328	1,840,150
Queets Fall Fingerling	194,075	201,780	186,540	218,187	214,648	1,015,230
Samish Fall Fingerling	384,575	412,204	428,420	403,772	405,502	2,034,473
Skagit Spring Fingerling	249,673	254,739	220,789	253,993	265,931	1,245,125
Skagit Spring Yearling	149,100	136,619	117,117	152,435	161,000	716,271
Skykomish Fall Fingerling	410,728	411,706	399,536	403,194	401,265	2,026,429
Sooes Fall Fingerling	252,446	194,614	252,628	238,849	242,077	1,180,614
Spring Creek Tule	889,324	892,618	891,550	799,882	807,781	4,281,155
South Puget Sound Fall Yearling	163,716	154,223	160,196	101,067	76,984	656,186
Salmon River	208,080	207,362	205,216	157,478	175,033	953,169
Skagit Summer Fingerling	206,009	231,662	216,200	108,180	206,128	968,179
Stillaguamish Fall Fingerling	202,669	212,636	214,567	185,967	219,608	1,035,447
Columbia Summers	748,075	699,759	701,297	746,653	784,449	3,680,233
Taku Spring	9,843	24,022	16,063	30,804	17,698	98,430
Unuk Spring	37,521	55,578	22,167	53,125	25,953	194,344
Upriver Brights	199,445	424,706	422,322	216,131	1,646,129	2,908,733
White River Spring Yearling	57,391	56,687	54,416	58,596	56,503	283,593
Willamette Spring	806,504	751,621	722,007	846,067	1,735,282	4,861,481
Total Release	7,826,429	8,206,595	8,131,841	7,630,879	10,550,408	42,346,152
All Chinook CWT releases	**2005**	**2006**	**2007**	**2008**	**2009**	**Total**
AK	1,191,889	1,492,497	1,425,425	1,520,049	982,146	6,612,006
BC	2,790,440	3,042,266	3,460,940	3,704,486	4,691,301	17,689,433
CA	6,971,488	14,703,430	14,592,227	13,600,171	14,935,993	64,803,309
ID	2,499,693	2,742,247	2,903,223	3,763,301	4,080,584	15,989,048
OR	4,763,223	4,562,086	4,728,730	5,905,552	6,780,518	26,740,109
WA	20,939,636	20,774,214	19,135,113	20,839,997	22,480,827	104,169,787
Total Release	39,156,369	47,316,740	46,245,658	49,333,556	53,951,369	236,003,692
Indicator % of total CWT releases	**24.8%**	**21.5%**	**23.2%**	**21.4%**	**26.7%**	**23.5%**

Table 5-2. Total CWT release numbers for BC and WA Coho exploitation rate indicator stocks for brood years 2006-2011.

	Total CWT release by broodyear						
	2006	**2007**	**2008**	**2009**	**2010**	**2011**	**Total**
Canadian Indicator Stocks							
Big Qual	45,004	85,841	42,103	28,261	140,081	142,788	484,078
Black Cr	10,266	18,810	8,071	9,658	8,236	11,003	66,044
Coldwater	43,686	39,798	45,128	43,049	58,517	63,805	293,983
Eagle				22,252	21,956	39,009	83,217
Keogh	32,590	39,241	26,041	53,124	50,714	48,284	249,994
Quinsam	88,083	89,630	87,384	88,148	85,654	146,531	585,430
Robertson	40,272	40,381	21,099	40,161	38,982	39,899	220,794
Salmon		40,689					40,689
Toboggan	37,284	34,349	34,690	28,029	34,982	33,601	202,935
Zolzap			33,311	14,395	45,324	30,280	123,310
Sub-Total	297,185	388,739	297,827	327,077	484,446	555,200	2,350,474
US Indicator Stocks	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**Total**
Marblemount Hatchery	94,278	88,778	86,927	87,819	83,940	90,718	532,460
Wallace River H.	90,576	90,914	84,395	85,359	89,598	88,481	529,323
Quilcene NFH	68,486	75,415	78,261	80,532	127,789	142,038	572,521
George Adams Hatchery	98,580	91,338	89,984	91,513	90,827	89,546	551,788
Big Beef Creek (Wild)	24,709	38,547	21,278	51,932	18,732	24,028	179,226
Sol Duc Hatchery	153,123	150,469	154,630	153,097	160,942	152,635	924,896
Salmon R. Fish Culture	151,879	144,023	151,365	161,183	159,441	149,903	917,794
Bingham Cr. H. (Satsop)	236,251	187,960	143,941	183,328	142,987	145,970	1,040,437
Bingham Creek (Wild)	20,046	33,916	31,471	56,110	42,376	38,584	222,503
Sub-Total	937,928	901,360	842,252	950,873	916,632	921,903	5,470,948
Total	1,235,113	1,290,099	1,140,079	1,277,950	1,401,078	1,477,103	7,821,422
% of all CWT releases	16.7%	16.2%	14.7%	15.7%	16.5%	16.7%	16.1%
% of BC & WA releases	22.5%	21.9%	19.1%	20.3%	21.4%	22.6%	21.3%
All Coho CWT releases	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**Total**
AK	917,837	900,220	792,637	957,352	943,927	1,021,809	5,533,782
BC	513,208	705,982	614,223	794,521	874,786	941,740	4,444,460
CA	190,737	442,959	329,374	335,997	391,325	508,469	2,198,861
ID	155,137	241,722	177,022	121,547	116,811	159,954	972,193
OR	636,068	505,922	493,325	414,379	525,271	621,969	3,196,934
WA	4,970,998	5,182,072	5,346,575	5,497,802	5,662,276	5,591,408	32,251,131
Total	7,383,985	7,978,877	7,753,156	8,121,598	8,514,396	8,845,349	48,597,361
BC & WA Total	5,484,206	5,888,054	5,960,798	6,292,323	6,537,062	6,533,148	36,695,591
BC & WA %	74.3%	73.8%	76.9%	77.5%	76.8%	73.9%	75.5%

Table 5-3. Summary of total CWT release and recovery numbers for BC and US Chinook and an example of alternative cost estimates for using CWT and PIT tag technology for all BC and US Chinook indicator stocks for brood years 2005-2009.

		2005	2006	2007	2008	2009
Total Releases						
BC		2,790,440	3,042,266	3,460,940	3,704,486	4,691,301
US		36,365,929	44,274,474	42,784,718	45,629,070	49,260,068
Total		39,156,369	47,316,740	46,245,658	49,333,556	53,951,369
Indicator Stock Releases						
BC		1,891,581	1,960,006	2,585,991	2,915,103	3,831,561
US		7,826,429	8,206,595	8,131,841	7,630,879	10,550,408
Total		9,718,010	10,166,601	10,717,832	10,545,982	14,381,969
Estimated CWT Recoveries (All)						
BC		8,601	4,184	9,891	6,267	6,555
US		206,640	208,481	335,019	241,564	362,720
Total		215,241	212,665	344,909	247,831	369,275
Observed CWT Recoveries (All)						
BC		2,334	1,097	2,798	1,703	2,173
US		97,113	99,699	152,133	120,404	184,781
Total		99,447	100,797	154,931	122,107	186,954
Estimated CWT Recoveries (Indicators only)						
BC		5,830	2,696	7,390	4,932	5,354
US		44,472	38,643	63,675	40,398	77,687
Total		50,302	41,339	71,065	45,330	83,040
Observed CWT Recoveries (Indicators only)						
BC		1,582	707	2,091	1,340	1,775
US		20,900	18,480	28,915	20,136	39,576
Total		22,482	19,187	31,006	21,476	41,351
	Cost/unit	**2005**	**2006**	**2007**	**2008**	**2009**
CWT Costs (All)						
Tags	$ 0.12	$4,698,764	$5,678,009	$5,549,479	$5,920,027	$6,474,164
Application	$ 0.12	$4,698,764	$5,678,009	$5,549,479	$5,920,027	$6,474,164
Sampling	$ 26.00	$2,585,615	$2,620,715	$4,028,214	$3,174,774	$4,860,815
Decoding	$ 5.00	$497,234	$503,984	$774,657	$610,533	$934,772
Data process	$ 18.00	$1,790,041	$1,814,341	$2,788,764	$2,197,920	$3,365,180
Total		$14,270,419	$16,295,058	$18,690,593	$17,823,281	$22,109,095
CWT Costs (Indicators only)						
Tags	$ 0.12	$1,166,161	$1,219,992	$1,286,140	$1,265,518	$1,725,836
Application	$ 0.12	$1,166,161	$1,219,992	$1,286,140	$1,265,518	$1,725,836
Sampling	$ 26.00	$584,532	$498,862	$806,156	$558,376	$1,075,126
Decoding	$ 5.00	$112,410	$95,935	$155,030	$107,380	$206,755
Data process	$ 18.00	$404,676	$345,366	$558,108	$386,568	$744,318
Total		$3,433,940	$3,380,147	$4,091,574	$3,583,360	$5,477,872
PIT Costs (Indicators only)						
Tags/3	$ 1.30	$4,211,138	$4,405,527	$4,644,394	$4,569,926	$6,232,187
Application/3	$ 0.96	$3,109,763	$3,253,312	$3,429,706	$3,374,714	$4,602,230
Sampling x3	$ 10.00	$224,820	$191,870	$310,060	$214,760	$413,510
Decoding	$ -	$0	$0	$0	$0	$0
Data process	$ 12.00	$269,784	$230,244	$372,072	$257,712	$496,212
Total		$7,545,721	$7,850,709	$8,384,160	$8,159,400	$11,247,927

Table 5-4. Summary of total CWT release and recovery numbers for BC and WA Coho and an example of alternative cost estimates for using CWT and PIT tag technology for all BC and WA Coho indicator stocks for brood years 2006-2011.

		2006	2007	2008	2009	2010	2011
Total Releases							
BC		513,208	705,982	614,223	794,521	874,786	941,740
WA		4,970,998	5,182,072	5,346,575	5,497,802	5,662,276	5,591,408
Total		5,484,206	5,888,054	5,960,798	6,292,323	6,537,062	6,533,148
Indicator Stock Releases							
BC		297,185	388,739	297,827	327,077	484,446	555,200
WA		937,928	901,360	842,252	950,873	916,632	921,903
Total		1,235,113	1,290,099	1,140,079	1,277,950	1,401,078	1,477,103
Estimated CWT Recoveries (All)							
BC		4,460	2,403	4,416	4,457	8,043	4,121
WA		92,483	45,855	56,526	44,322	50,121	114,425
Total		137,105	147,201	149,020	157,308	163,427	163,329
Observed CWT Recoveries (All)							
BC		961	673	1,279	979	1,566	950
WA		36,943	21,759	24,639	17,896	23,004	46,670
Total		37,904	22,432	25,918	18,875	24,570	47,620
Estimated CWT Recoveries (Indicators only)							
BC		3,029	962	2,329	2,470	5,706	2,834
WA		36,416	17,971	26,997	22,575	23,439	28,413
Total		39,445	18,934	29,326	25,045	29,146	31,247
Observed CWT Recoveries (Indicators only)							
BC		554	270	531	517	1,062	618
WA		13,948	6,923	10,195	7,691	9,436	9,570
Total		14,502	7,193	10,726	8,208	10,498	10,188
	Cost/unit	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**
CWT Costs (All)							
Tags	$ 0.12	$658,105	$706,566	$715,296	$755,079	$784,447	$783,978
Application	$ 0.12	$658,105	$706,566	$715,296	$755,079	$784,447	$783,978
Sampling	$ 26.00	$985,504	$583,232	$673,868	$490,750	$638,820	$1,238,120
Decoding	$ 5.00	$189,520	$112,160	$129,590	$94,375	$122,850	$238,100
Data process	$ 18.00	$682,272	$403,776	$466,524	$339,750	$442,260	$857,160
Total		$3,173,505	$2,512,301	$2,700,574	$2,435,033	$2,772,825	$3,901,336
CWT Costs (Indicators only)							
Tags	$ 0.12	$148,214	$154,812	$136,809	$153,354	$168,129	$177,252
Application	$ 0.12	$148,214	$154,812	$136,809	$153,354	$168,129	$177,252
Sampling	$ 26.00	$377,052	$187,018	$278,876	$213,408	$272,948	$264,888
Decoding	$ 5.00	$72,510	$35,965	$53,630	$41,040	$52,490	$50,940
Data process	$ 18.00	$261,036	$129,474	$193,068	$147,744	$188,964	$183,384
Total		$1,007,025	$662,081	$799,193	$708,900	$850,661	$853,717
PIT Costs (Indicators only)							
Tags	$ 1.30	$1,605,647	$1,677,129	$1,482,103	$1,661,335	$1,821,401	$1,920,234
Application	$ 0.96	$1,185,708	$1,238,495	$1,094,476	$1,226,832	$1,345,035	$1,418,019
Sampling x3	$ 10.00	$435,060	$215,790	$321,780	$246,240	$314,940	$305,640
Decoding	$ -	$0	$0	$0	$0	$0	$0
Data process	$ 12.00	$522,072	$258,948	$386,136	$295,488	$377,928	$366,768
Total		$3,748,487	$3,390,362	$3,284,495	$3,429,895	$3,859,304	$4,010,661

Recommendations

1. Obtain new information from the Carson National Fish Hatchery USFWS study to determine comparable smolt-to-adult return rates and full life-cycle tag loss rates for PIT tagged and CWTs applied to spring Chinook, which should be available in the next six months.

2. Conduct a programmatic cost analysis that includes accounting for all costs from tag application through reporting. Cost information from the USFWS comparative study should be included in this assessment.

3. Develop a framework study design and costing to conduct a pilot program implementing the use of PIT tags on select indicator stocks. Proceed to conduct a study, if the study design and cost estimates are acceptable.

4. Invite selected RFID system producers to a workshop with PSC staff to explore detailed topics and develop a framework design for implementing a pilot program for a defined group of exploitation rate indicator stocks.

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Appendix A

Pacific Salmon Commission's study on the Feasibility of RFID tag for marking juvenile salmon for management applications – Product Inquiry

1) Does your company manufacture RFID tags suitable for internal placement in live fish?

2) Are you aware of your tags being used for fish?

3) What is the shape and composition of the tag(s)?

4) What are the dimensions (mm) of the smallest tag (LxWxH)?

5) How many data digits does the tag have?

6) What is the unit price of an individual tag?

7) What is the mechanism and related cost of applying the tag?

8) Are there any specific advantages or limitations of the tag?

9) Are you aware of any contacts or documentation regarding the long term effects of tagging on fish or tag loss rates?

10) Are there plans for future tags that are smaller?

11) Do you manufacture Reading equipment?

12) What type of Readers do you manufacture?

13) Are you aware of any contacts or documentation regarding custom Reader applications?

Appendix B

Pacific Salmon Commission's study on the Feasibility of RFID tag for marking juvenile salmon for management applications – Researcher Inquiry

1) Have you considered alternative technologies, and in particular RFID, as a method to replace CWTs?

2) Do you want more information (quantity) or better information (quality) from an alternative technology? Describe

3) Are there aspects of technology of application, detectability, or recovery that would improve the quality of the dataset or make it more cost effective?

4) Any reason other than improved information or cost that would be desired in an alternate technology?

5) Where (location and process) and in what media (air or water) would you want scanning for tags to take place?

6) What would be the key attributes of a tag / detection system for your applications?

7) Are your specimens for detection live or dead or both?

8) If currently available PIT tag detection systems for standard 12 mm long PIT tags were deployed at commercial landing sites for major fisheries, provided to recreational and First Nations catch monitoring crews, volunteer guides/anglers, would you consider using PIT tag technology in place of CWT tagging programs for some or all of its Chinook and Coho indicators stocks?

9) Specific advantages or limitations of an alternative technology relative to CWT?

10) Are you aware of any documentation regarding the long term effects of tagging on fish or tag loss rates?

11) Do you have any specific questions related to our RFID Review Project Objectives that you would like answered?

Appendix C

List of individuals contacted as part of this study

Begout, Marie-Laure. French Research Institute for Exploration of the Sea.

Brignon, Bill. U.S. Fish and Wildlife Service.

Brown, Gayle. Department of Fisheries and Oceans, Canada.

Carlile, John. Alaska Dept. Fish and Game.

Chose, David. HID Global, Sales Manager.

Cook-Tabor, Carrie. U.S. Fish and Wildlife Service.

Gary, Scott. Biomark, Vice President Sales.

Hagen-Breaux, Angelika. Washington State Dept. of Fish and Wildlife.

Haymes, Jeffery. Washington State Dept. of Fish and Wildlife.

Hennig, Charles. U.S. Bureau of Reclamation, Deputy Chief of Research and Development.

Herriott, Doug. Department of Fisheries and Oceans, Canada.

Katinic, Peter. Department of Fisheries and Oceans, Canada.

LaVoy, Larrie. U.S. Fish and Wildlife Service.

Masin, Barbara. Electronic Identification Systems (Trovan), Vice President.

Nagse, Akira. Hitachi Chemical Co., RFID Group.

Parken, Chuck. Department of Fisheries and Oceans, Canada.

Ridgway, Brenda. Department of Fisheries and Oceans, Canada.

Tiffan, Kenneth. U.S. Geological Survey.

Tompkins, Arlene. Department of Fisheries and Oceans, Canada.

Webb, Dan. Pacific States Marine Fisheries Commission.

Winther, Ivan. Department of Fisheries and Oceans, Canada.

Zimmerman, Bill. Bonneville Power Administration.

Appendix D

Mortality and Tag Retention in PIT-tagged Fish

Literature providing a thorough analysis of PIT tag effects on salmon survival in the natural environment is limited. As a result, the USGS Columbia River Research Lab (CRRL) in Cook, WA has relied on the extensive lab-based literature describing PIT tagging effects. These effects are summarized in tables (Tables 1-3) created by Ian Jerozek, fisheries researcher with USGS.

Dixon and Mesa (2011) noted that several factors can affect the survival and tag retention of PIT- tagged fish, including: methodology, tagger experience, species and size of fish, and environmental conditions.

Size of Fish

Several researchers within the Columbia Basin were contacted, but none them had personal experience using 6-mm PIT tags. However, Ian Jerozek, from the Columbia River Research Lab in Cook, WA, has lately been using 9-mm PIT tags to mark Steelhead from 55 to 69-mm FL. In Steelhead 70-mm FL or greater, 12-mm PIT tags are used.

Ian Jerozek, recommended reading Tiffan's et al. (2015) publication which discusses the effects of tagging on survival, especially when fish are small relative to tag size. The ability to represent a population of migratory juvenile fish with PIT tags becomes difficult when the minimum tagging size requires a fish that is larger than the average size at which fish begin to move downstream (tag weight should be less than 5% of the fish body weight ratio, ideally less than 2%). Within the Columbia River basin, the minimum size at which juvenile anadromous salmonids can be implanted with 12-mm PIT tags ranges from 55- to 60 mm FL. Based on a review of a 15-year data set collected in Idaho (Johnson Creek), two–thirds of the sub-yearling Chinook emigrants were estimated to be smaller than 60 mm FL. Recent developments of the shorter and lighter PIT tags (8- and 9-mm PIT tags) have allowed researchers to tag smaller fish, and thereby more fully represent the population prior to size-related emigration. Tiffan et al. (2015) was the first group to evaluate the 8-mm PIT tag on juvenile salmon and reported 97.8% to 100% survival rate across all trials in the 28 day study and concluded that there was no appreciable fish-size or tag size related tagging effects. Similarly, tag retention was also very high across all tests (93%-99%). However, it was emphasized that actual implantation of the smaller tags may be a bit more challenging in the field (i.e. capture and handling stressors) compared to application in the lab.

Tagging methods

Survival

With the 9-mm PIT tags, Ian Jerozek's lab (from CRRL) uses a micro-scalpel to make the incision. With 12-mm tags they use the standard needle method. The literature does suggest that use of scalpels minimizes effects on smaller fish (Ian Jerozek, pers. comm.). The USGS and NOAA researchers (Ian Jerozek, Theresa Liedtke, and Michelle Rub, pers. comm.) all emphasize that sharp needles and scalpels are key. However, they will use the same needle and scalpel on multiple fish, but in order to prevent horizontal transmission of disease between fish, needles are disinfected between uses (i.e. with 70% ethanol). Conversely, Biomark Inc., was recently contracted to tag approximately 750,000 endangered Snake River Fall Chinook and Sockeye salmon and their protocol is to use new needles for each fish to prevent infection (Biomark Inc., pers. comm.).

Dixon and Mesa (2011) showed that the use of the micro-surgical technique probably contributed to the high survival of their study fish (95.6%). The advantage of using the surgical technique for implanting PIT tags in small fish is that the depth of penetration can be precisely controlled with the special micro-scalpels. In preliminary experiments, they noticed the 12-gauge needles typically used for implanting PIT tags tend to dull quickly and can cause abdominal tissue tears and occasional hemorrhages from over-insertion.

Tag Retention

The US FDA requires food fish to be tagged in a non-edible location of the fish. The body cavity is the typical place for implanting PIT tags (i.e. in salmonids, Biomark Inc., pers. comm.). However, there are some researchers who tag endangered species in the muscle (i.e. endangered sturgeon are tagged in the dorsal muscle or in the muscle at the back of the head). In contrast, commercial fish hatcheries in Idaho, tag brood fish (i.e. rainbow trout) in the pelvic girdle so they can easily remove the tags without damaging the edible part of the fish. Many fish hatcheries will simply cut the pelvic girdle off the fish after the final spawning, and send the remainder of the carcass to the fish market (Biomark Inc., pers. comm.). Tagging in the pelvic girdle may increase tag retention as, Bateman et al. (2009) reported a number of PIT tags in redds of coastal cutthroat trout (up to 20) indicating that tags can be lost from the body cavity via the vent during egg release. Bateman also indicated that four tags were identified as males, suggesting that both sexes can lose tags. Therefore, body cavity tagging works quite well for most species except salmonids, if recoveries are required post-spawning.

Earlier studies conducted by researchers at the Northwest Fisheries Centre (Seattle, WA) showed insertion of a PIT tag or other foreign body into a fish may cause trauma provoking a host reaction, such as, inflammation, encapsulation, and rejection. However, the Prentice et al. (1990) study, reported 100% tag retention during the 39 day study and noted no host reaction to the tag in any of the fish, concluding that the fish did not recognise the tag as a foreign body. The glass-encapsulated PIT tag appears to be biologically inert (Prentice et al. 1990).

Tagger experience

Richard et al. (2013) evaluated the effect of 12-mm PIT tag implantation on age-0 Brown Trout. The effects of implantation methods (i.e. surgical or injection) and individual tagger on survival, tag retention and growth were assessed during a 60 day hatchery experiment. Two size classes of fish (total length) were considered: small (50-55 mm FL) and large (56-63 mm FL). Of the two size classes assessed, survival, growth and tag retention significantly varied among taggers in the smaller size class as opposed to the larger class size. Based on the results, Bateman et al. (2013) recommend a minimum fish size of 55 mm (total length) for tagging with 12-mm PIT tags. Over this size, either surgical implantation or direct injection can be performed by different taggers without altering survival, tag retention, and growth.

Dare (2003) reported that most of the tags shed in the study were collected during the first 2-d of tagging (159 tags). Although the relationship was not quantifiable, the frequency of sheds appeared to be linked to the experience of tagging personnel at the start of the study and the continuity of personnel at the tagging station. The high shedding rates observed during the first 2 days of the tagging project were most likely attributed to the learning process of the tagging crew, which was associated with the start of the project. Shed rates declined substantially by day 3 of the tagging project as the skill the tagging crew improved.

Environmental conditions

Knudsen et al. (2009) tagged upper Yakima River hatchery spring Chinook salmon (length averaging 75-78 mm FL) with PIT tags and coded wire tags in a double-tag study to see the effects of survival, behaviour, and growth on recaptures returning 6 months to 4 years after release. The study showed a 2% loss of PIT tags in juveniles prior to release and 18.4% in recaptures returning 6 months to 4 years after release. The results indicated that tag shedding did not increase significantly over time with age as most of the tag loss occurred within the first 6 months after release. After correcting for tag loss, tag induced-mortality was as high as 33.3% over all brood years.

Knudsen et al. (2009) paper was reviewed by many Columbia River basin researchers, including USGS Connolly group. Study fish in Knudsen et al. (2009) were tagged and then held for 70 to 125 days prior to release. The Connolly group thought the Knudsen et al. (1990) study should have reported if there was a growth difference in PIT and non-PIT tagged (NPT) fish between tagging and release. The Connolly group hypothesized that in a crowded raceway or holding pond type area, PIT tagged fish would have a tougher time competing for food and experience greater stress (possibly more so than in a less crowded and competitive stream environment) as they recovered from tagging and would end up outmigrating at smaller size. Smaller size fish outmigrating would result in smaller fish returning to spawn, and fish that are more at risk for predation.

The Connolly group also remarked that the Knudsen et al. (2009) reported an average reduction in survival of PIT-tagged fish compared to NPT fish of 10.3%, but the distribution was fairly skewed by the value from the 1999 brood year (33.3%). The overall median reduction in survival value was approximately 7%; although, if 1999 brood year valve was excluded it would be 4.3%. Outmigrant conditions were very tough for the 1999 brood year. However, Knudsen et al. (2009) paper records 1999 as the second highest number of fish reared, but does not address possible crowding, disease, or stress issues while rearing. After reviewing the data, the Connolly group thought the data suggested a possibility that the PIT tag mortality effect may be more pronounced with increased numbers of fish rearing. Leading to the final thought that recovery and growth potential may be higher in a natural environment than in a crowded hatchery rearing situation, particularly in streams that may not be at carrying capacity.

Summary

In conclusion, the above lab-based literature does support the experimental use of smaller PIT tags (<12 mm) for studying survival and tag retention in salmonids. However, further field trials are required to establish the actual minimum fish size for tagging and the appropriate tag size, keeping in mind the differences between laboratory and river environments. Tiffan et al. (2015) indicated that preliminary works has been initiated to determine the efficiency of PIT tag monitoring systems in detecting 8 and 9-mm tags at dams on the Snake and Columbia rivers.

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Table 1. Results from published literature from PIT tagging mortality studies on Chinook salmon *Oncorhynchus tshawytscha*, steelhead *O. mykiss*, and sockeye salmon *O. nerka*. (Created by Ian Jerozek, USGS, CRRL, Cook, WA).

Species	N	Mortality (%)	Tag loss (%)	Tag length (mm)	Fish length (mm)[a]	Implant method	Study period (d)	Statistically different from control fish?	Reference
O. tshawytscha[b]	201	0.5	0.0	12	66 FL	needle	139	No	Prentice et al. 1990
O. tshawytscha[b]	200	0.0	0.0	12	78 FL	needle	135	No	Prentice et al. 1990
O. tshawytscha[b]	201	0.0	0.0	12	84 FL	needle	134	No	Prentice et al. 1990
O. tshawytscha[b]	200	0.0	0.0	12	99 FL	needle	137	No	Prentice et al. 1990
O. tshawytscha[c]	200	5.0	1.0	12	66 FL	needle	139	No	Prentice et al. 1990
O. tshawytscha[c]	200	2.0	0.0	12	77 FL	needle	135	No	Prentice et al. 1990
O. tshawytscha[c]	203	5.0	0.0	12	85 FL	needle	134	No	Prentice et al. 1990
O. tshawytscha[c]	202	2.0	0.0	12	100 FL	needle	137	No	Prentice et al. 1990
O. tshawytscha[d]	-[e]	2.0	-	12	yearling	needle	14	No	Prentice et al. 1990
O. tshawytscha[f]	-	4.0	-	12	age-0	needle	14	No	Prentice et al. 1990
O. tshawytscha[f]	-	14.0	-	12	yearling	needle	14	No	Prentice et al. 1990
O. tshawytscha[f]	-	36.0	-	12	age-0	needle	14	No	Prentice et al. 1990
O. tshawytscha[g]	-	0.0	0.0	12	67 FL	needle	-	No	Prentice et al. 1990
O. tshawytscha[g]	-	0.0	0.0	12	89 FL	needle	-	No	Prentice et al. 1990
O. tshawytscha[f]	30	43.3	0.0	12	137 FL	needle	-	No	Prentice et al. 1990
O. tshawytscha[f]	30	70.0	0.0	12	111 FL	needle	-	No	Prentice et al. 1990
O. mykiss[d]	-	1.0	-	12	smolt	needle	14	No	Prentice et al. 1990
O. mykiss[f]	-	11.0	-	12	smolt	needle	14	No	Prentice et al. 1990
O. mykiss[g]	-	0.0	0.0	12	83 FL	needle	-	No	Prentice et al. 1990
O. mykiss[g]	-	0.0	0.0	12	112 FL	needle	-	No	Prentice et al. 1990
O. mykiss[g]	-	0.0	0.0	12	171 FL	needle	-	No	Prentice et al. 1990
O. mykiss[f]	30	30.0	0.0	12	201 FL	needle	-	No	Prentice et al. 1990
O. nerka	200	0.5	0.0	12	68 FL	needle	-	No	Prentice et al. 1990
O. nerka	200	1.0	1.5	12	83 FL	needle	-	No	Prentice et al. 1990
O. nerka	200	3.5	0.0	12	99 FL	needle	-	No	Prentice et al. 1990

[a] Reported as mean length, length range, or life stage at time of tagging. FL = fork length, TL = total length.
[b] Fish were held in well water.
[c] Fish were held in stream water.
[d] Run of the river fish collected and held at Lower Granite Dam, OR.
[e] "-" = Not reported.
[f] Run of the river fish collected and held at McNary Dam, OR.

[g] Fish were held in laboratory at Big Beef Creek, WA.

Table 2. Additional results from published literature on PIT tagging mortality studies of *Oncorhynchus tshawytscha* and *O. mykiss*, and results from PIT tagging mortality studies of Atlantic salmon *Salmo salar* and brown trout *S. trutta*. (Created by Ian Jerozek, USGS, CRRL, Cook, WA).

Species	N	Mortality (%)	Tag loss (%)	Tag length (mm)	Fish length (mm)[a]	Implant method	Study period (d)	Statistically different from control fish?	Reference
O. tshawytscha	4,977	1.3	0.1	12	parr	needle	1	-[b]	Achord et al. 1996
S. salar	33	21.2	15.2	23	64-94	surgical	32	-	Roussel et al. 2000
S. salar	-	<1.0	<1.0	23	parr	surgical	-	-	Zydlewski et al. 2001
S. salar	3,037	5.7	0.2	12	115 FL	surgical	270	No	Gries and Letcher 2002
S. salar	135	22.0	-	12	60-69 FL	surgical	60	Yes[c]	Sigourney et al. 2005
O. mykiss	200	14.0	3.0	23	73-97 FL	surgical	30	Yes	Bateman and Gresswell 2006
O. mykiss	2,392	1.8	7.2	23	163 FL	surgical	120	Yes[d]	Hill et al. 2006
S. trutta	145	20.9	20-30[e]	12	41-70 FL	needle	27	Yes[f]	Acolas et al. 2007

[a] Reported as mean length, length range, or life stage at time of tagging. FL = fork length, TL = total length.
[b] "-" = Not reported.
[c] Fish size had a significant effect on survival.
[d] Significantly higher mortality than control in 4 of 6 trials.
[e] Tag loss was higher in fish <57 mm.
[f] For fish ≥57 mm, mortality was 1.0%.

Table 3. Results from published literature of PIT tagging mortality studies of largemouth bass *Microterus salmoides*, African catfish *Heterobranchus longfilis*, Eurasian perch *Perca fluviatilis*, bullhead *Cottus gobio*, roach *Rutilus rutilus*, rudd *Scardinus erythrophthalmus*, gilthead seabream *Sparus auratus*, bluehead sucker *Catostomus discobolus*, mottled sculpin *C. bairdii*, bonytail chub *Gila elegans*, and Gila chub *G. intermedia*. (Created by Ian Jerozek, USGS, CRRL, Cook, WA).

Species	N	Mortality (%)	Tag loss (%)	Tag length (mm)	Fish length (mm)[a]	Implant method	Study period (d)	Statistically different from control fish?	Reference
M. salmoides	500	4.0	-[b]	21	254 TL	needle	-	-	Harvey and Campbell 1989
H. longifilis	20	10.0	10.0	-	age-0	surgery	28	-	Baras and Westerloppe 1999
P. fluviatilis	212	12.3[c]	0.0	11	55-96 FL	surgery	126	-[d]	Baras et al. 2000
C. gobio	6	0.0	0.0	12	>70 TL	surgery	28	-	Bruyndoncx et al. 2002
R. rutilus	200	<6.0	0.0	23	117-163 TL	surgery[g]	37	No	Skov et al. 2005
S. erythrophthalmus	200	<6.0	0.0	23	117-163 TL	surgery[g]	37	No	Skov et al 2005
S. auratus	36	2.8	14.0	12	fingerling	surgery	30	No	Navarro et al. 2006
S. auratus	668	3.4	1.7	12	fingerling	surgery	52	No[e]	Navarro et al. 2006
C. discobolus	18	5.5	0.0	-	164-278 TL	-	2-6	-	Ward and David 2006
C bairdii	26	3.8	3.8	12	56-83 TL	needle	28	-	Ruetz et al. 2006
G. elegans	180	1.1	<3.0	12	84-132 TL	needle	30	-	Ward et al. 2008
G. elegans	121	14.9	6.6	12	68-143 TL	needle	30	-[f]	Ward et al. 2008
G. intermedia	210	1.9	<3.0	12	75-129 TL	needle	30	-	Ward et al. 2008

[a] Reported as mean length, length range, or life stage at time of tagging. FL = fork length, TL = total length.
[b] "-" = Not reported.
[c] Mortality for fish in the three groups of largest size fish was 7.1%.
[d] Mortality for the smallest size class of fish was statistically different from the other seven size classes.
[e] Mortality for the smallest size class of fish was statistically different from the other three size classes.
[f] Fish were allowed access to abundant prepared feed for twelve hours prior to tagging.
[g] Only fishes with incisions closed with sutures dies during the experiment.