PRILIMINARY RESEARCH PROPOSAL (COE) (FY07)

TITLE: Comparative Performance of Acoustic-tagged and PIT-tagged Juvenile Salmonids.

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PROJECT SUMMARY

Research Goals

The goal of this study is to compare relative performance of juvenile salmonids tagged with the Juvenile Salmonid Acoustic Tag System (JSATS) transmitter to those tagged with passive integrated transponder (PIT) tags. We propose to conduct the study in both laboratory and field settings. The results of this study will aid in determining the suitability of acoustic-telemetry to estimate short- and longer-term (30 to >90 d) juvenile-salmonid survival at Columbia and Snake River dams and through the lower Columbia River.

By including PIT tags along with the acoustic tag, a field comparison will be used to evaluate possible tag effects based on differences in reach and system-wide travel rates and survival among study treatments through detections at dams downstream from the release point. Performance measures will include travel time through Snake and Columbia River reservoirs and dams downstream from the release site, survival and detection probability estimates from the point of release to the tailrace of downstream dams, and susceptibility to avian predation. In addition, the logistics of conducting a survival study using electronic telemetry including tagging, holding, and release procedures will be evaluated. Two groups of fish will be released downstream of Lower Granite Dam each day of the study. The treatments will include fish with surgically-implanted acoustic tags weighing 0.6 g and fish with PIT tags. All acoustic tagged fish will also be PIT tagged to allow comparisons of downstream performance using passive detections in PIT-tag interrogation systems at Snake and Columbia River dams and using the pair trawl in the lower Columbia River. Run-of-the-river hatchery yearling Chinook and subyearling Chinook salmon captured from the juvenile bypass system at Lower Granite Dam will be used in this evaluation.

We propose to conduct a concurrent laboratory study of the effects of acoustic tags on the growth, mortality, tissue response, predator avoidance ability and salinity tolerance for both run-of-the-river yearling and subyearling Chinook salmon relative to those implanted with PIT tags over a 90-d period. This will enable evaluation of tag effects over a period more commensurate with the use of active tags to estimate survival over a longer period and reach, such as from Lower Granite Dam through the hydropower system and then through the estuary and into the Pacific Ocean. Tags used in the lab study will be identical to those used in the field evaluation. Depending on the water year, there is a very real possibility of low detection probability of the reference (PIT-tagged) fish in the field study, particularly downstream from McNary Dam. In that event, the field work described may evaluate tag effects over only about a 10-d period, as in Hockersmith et al. (2003).

Relevance

Numerous research methods are currently being used to evaluate fish passage and survival to determine the impacts of the Federal Columbia River Power System (FCRPS) on

endangered and threatened salmonids, including PIT tags, balloon tags, hydroacoustic evaluations, radio telemetry, and acoustic telemetry. Each method has advantages and disadvantages, but options are restricted in some situations because of limited capabilities of a specific technology, lack of detection capability downstream, or availability of adequate numbers of fish. In these situations, alternative telemetry technologies have been used to evaluate passage behavior and estimate survival. However, there remains concern about the comparative effects of the tag or tagging procedure on fish performance. Numerous evaluations of the effects of radio tags have been conducted under laboratory conditions, but few have been conducted in the field (Thorsteinsson 2002). Hockersmith et al. (2003) compared relative performance of juvenile salmonids which were either PIT-tagged, radio-tagged gastrically, or radio-tagged surgically. They found that yearling Chinook salmon surgically- and gastrically-tagged with a 1.4 g sham radio transmitter had survival and migration rates similar to PIT-tagged yearling Chinook salmon over 6 d 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 10 d. The recently developed JSATS acoustic transmitters (McComas et al.2005) are approximately 40% smaller than the radio transmitters used by Hockersmith et al. (2003). In addition to being a smaller transmitter, the acoustic tag does not require the trailing antenna associated with radio transmitters, which may affect swimming performance and survival. Determining whether fish tagged with a new acoustic-telemetry tag can provide unbiased estimates of passage behavior and survival within the performance life of the tag is highly important to regional managers.

PROJECT DESCRIPTION

Background

Recent advances in tagging technology (PIT tags and balloon tags) and statistical models to estimate survival have allowed survival estimates to be made at Snake and Columbia River Dams through various routes of passage (Mathur et al. 1996; Muir et al. 1994, 1998; Normandeau et al. 1995, 1997, 1998), as well as to estimate reach survival which incorporates both dam- and reservoir-related mortality (Iwamoto et al. 1994; Muir et al. 1995, 1996; Smith et al. 1998, 2004; Zabel et al. 2001). PIT tags have worked well for estimating both route-specific mortality at dams and reach survivals. However, PIT-tag evaluations require large numbers of smolts and adequate detection facilities downstream. Balloon and radio tags have worked well for route-specific survival estimates through dams (i.e., turbine or spillway survival), but have not been used for reach survival estimates because of concerns regarding the effects of the tags on fish performance over longer time periods.

In recent years, radio and acoustic transmitters have been miniaturized sufficiently for use in smaller fish such as juvenile salmonids. Telemetry has been used extensively in the Snake and Columbia Rivers to evaluate surface bypass collectors (Adams et al. 1996, 1997; Hensleigh et al. 1997), turbine survival (Absolon et al. 2003), and dam passage behavior and survival (Anglea et al. 2001; Axel et al. 2003, 2004a, 2004b; Eppard et al. 1998, 2002, 2005a, 2205b; Hockersmith et al. 2005; Ploskey et al. 2001). Sample sizes for telemetry survival studies are

generally smaller than for other methods because detection probabilities for these tags are usually high (Skalski et al. 1998). As more salmonid stocks in the Columbia River Basin have been listed under the Endangered Species Act, telemetry has become an attractive tool for studies involving juvenile salmonids.

The same models used to estimate survival in PIT-tag studies (SR Model or a Route Specific Survival Model [Skalski et al. 1998]) are used to estimate survival based on radio- and acoustic-tag detections. As with PIT-tag studies, certain assumptions must be met for valid survival estimation using these models. Two of the stated assumptions from Skalski et al. (1998) are: 1) individuals marked for the study are a representative sample from the population of interest, and 2) survival and capture probabilities are not affected by tagging or sampling, i.e., tagged animals should have the same survival probabilities as untagged animals.

Despite recent advances in downsizing of telemetry transmitters, meeting the first assumption is difficult, since a portion of the juvenile Chinook salmon population is smaller than the minimum size recommended for many tags available. Most radio- and acoustic-tag studies have therefore targeted larger smolts (fork lengths [FL] greater than 100 mm for the smaller acoustic tags and 120 mm for larger radio tags) from the overall population.

The second assumption requires that the presence of the tag and the tagging procedure do not significantly affect performance of tagged fish. If the behavior of smolts is altered by the tag, then application of survival estimates or passage timing using tagged smolts to the general (untagged) population would be invalid. For example, a tagged fish might swim at a different depth than non-tagged fish, and therefore could be differentially susceptible to juvenile fish bypass systems, spillway passage, surface bypasses, or predation.

Numerous laboratory studies have been conducted on the effects of externally-attached and gastrically- or surgically-implanted radio and acoustic tags on swimming performance, growth, feeding behavior, predator avoidance, and survival (Mellas and Haynes 1985, Greenstreet and Morgan 1989; Lucas 1989; Adams et al. 1998a, 1998b;; Martinelli et al. 1998; Brown et al. 1999; Moore et al. 1990, Anglea et al. 2004, Brownet al. in press;). However, these evaluations were conducted in laboratory tanks, or if conducted in the field, did not compare performance between electronically-tagged and untagged fish.

In recent evaluations using Chinook salmon, Martinelli et al. (1998) and Adams et al. (1998a) both found that the presence of gastrically-implanted radio tags significantly reduced growth over the long term (21 to 54 days), whereas surgically implanted radio tags had little or no effect on growth rate. Both studies observed “coughing behavior” in gastrically implanted fish, with 5% of the fish successfully expelling tags in the Martinelli et al. (1998) study. Both studies noted abrasions in the mouth near the antenna exit with gastric implantation, and that severity of abrasions increased over time. Adams et al. (1998b) found reduced swimming performance in both gastrically- and surgically-implanted Chinook salmon less than 120 mm FL. For fish greater than 120mm FL, swimming performance in surgically-implanted fish was reduced after 1 day, but not after 21 days. For gastrically-implanted fish the opposite was observed; swimming performance was not effected after 1 day, but was significantly lower after

21 days. Fish with either gastric or surgical implants had significantly reduced predator avoidance capabilities. Adams et al. (1998a, 1998b) and Martinelli et al. (1998) concluded that surgical implantation was the preferred method for most studies, although gastric implantation might be preferred for short duration studies.

Studies which examined the effects of an acoustic transmitter on growth, survival, and swimming performance of juvenile salmonids have been conducted by Anglea et al. (2004) and Brown et al. (in press). The former authors found no significant decrease in the critical swimming speeds of Chinook salmon tagged with an acoustic transmitter which weighed 1.5 g in air and represented 1.6 – 6.7% of the fish's body weight. Similar results were found by Brown et al. (in press) for Chinook salmon (94-125 mm FL) implanted with a 0.75g acoustic transmitter which represented 3.2 – 10.0% of the fish's body weight. However, Brown et al. (2005) found the growth rate decreased for acoustic-tagged Chinook salmon compared to control fish.

Hockersmith et al. (1999) compared the performance of surgically-radio-tagged fish with PIT-tagged fish from release at Lookingglass Hatchery on the Grande Ronde River to Lower Granite Dam on the Snake River, a distance of 238 Km. Their results indicated the presence of a radio tag significantly affected growth, travel time, and survival. Radio-tagged fish passed Lower Granite Dam sooner, at a smaller size, and with reduced survival compared to PIT-tagged fish. These results are not surprising since conditions smolts encounter in the wild, such as feeding and predator avoidance, would be expected to be less forgiving than in a laboratory setting. The negative effects of the radio tag on fish performance may have been exaggerated by the great distance over which performance was measured.

The recently developed JSATS acoustic transmitter measures 17 mm long x 5.5-mm wide and tapers from 4- to 2-mm high. The tag weighs 0.62 g, and the coding method provides over 64,000 individual tag codes. Studies conducted in 2003 and 2005 evaluated the effects of a larger JSATS acoustic tag on predator avoidance, growth, mortality, and tag expulsion in a laboratory setting for up to 30-d period. Possible effects of the recently-developed tag have not been evaluated in the field or longer than a 30-d period.

Relationship to Other Research

This study will provide critical information on the comparative effects between acoustic tags and PIT tags on juvenile salmonid performance in the field up to a 60-d period and in the laboratory over a 90-d period. If no significant differences exist in performance measures, managers will have more confidence in the results obtained using acoustic transmitters. If significant tag effects are found, knowing what those effects are and over what time and distance the effects occur will aid in designing more robust research. The acoustic-tagged fish released for the field component of this study will increase the available samples sizes (by providing additional fish) for USACE juvenile acoustic-telemetry-survival studies at, Bonneville Dam (SPE-P-02-01) and for the estuary survival study (EST-02-01).

Objective/Methods

Objective 1

Compare survival and associated detection probabilities of acoustic-tagged yearling and subyearling Chinook salmon relative to PIT-tagged fish migrating through the Snake and Columbia Rivers.

Task 1.A **During the spring of 2007, tag two groups of run-of-the-river hatchery yearling Chinook salmon at Lower Granite Dam. One group will be tagged with PIT tags only and the second group will receive a JSATS acoustic tag and a PIT tag.** Fish will be collected at the Lower Granite Dam juvenile collection facility and tagged at the NOAA tagging facility on 10 separate days. The PIT-tag only fish will come from a study conducted by Doug Marsh to evaluate latent mortality associated with passage of yearling Chinook salmon through Snake River Dams. The acoustic tagged fish (350 per release) will be collected from the same sorting line as the PIT-tagged fish and tagged simultaneously with the PIT-tagged fish. Matching the acoustic-tagged fish with the releases from the latent mortality study should supply ample fish to evaluate a minimum of a 5% difference in tag effects at 80% power.

Fish handling methods such as water-to-water transfers and pre-anesthesia will minimize damage and stress to fish during the sorting and tagging process (Matthews et al. 1977). Only non-PIT-tagged animals > 95 mm fork length clearly identifiable as hatchery-reared yearling Chinook salmon will be used as test animals in this study.

The PIT-tagged-only fish will be tagged by hand (Prentice et al.1990a, b) using individual syringes with a 12-gauge hypodermic needle. The acoustic-/PIT-tagged fish will be implanted with transmitters using methods similar to Anglea et al. (2004). Fish will initially be sedated with 80 mg/l MS-222 then transferred to a custom surgery table. During surgery, anesthesia will be maintained by providing water with 40 mg/l MS-222 through rubber tubing from a gravity fed bucket. With the fish facing ventral side up, a 5-7 mm incision will be made 2-5 mm from and parallel to the mid-ventral line anterior of the pelvic girdle. The acoustic tag will then be implanted, while weight, fork length, and tag code are recorded. A PIT tag will also be placed inside the body cavity at this time. The incision will be closed with 2, 5-0 Vicryl sutures. Post surgery, fish will be placed into a recovery bucket with fresh-oxygenated river water and monitored to insure they recover equilibrium.

Following recovery from anesthesia, all tagged fish will be returned through a water-filled pipe to a filter frame holding tank at the Lower Granite Dam juvenile fish facility. All holding tanks will be supplied with flow-through river water during tagging and holding. Fish will then be released at the tailrace of Lower Granite Dam. A subset of the acoustic tagged fish will be held back from each release to determination of post-tagging mortality and tag life.

Task 1. B **During the spring and summer of 2007, tag two groups of run-of-the-river hatchery subyearling Chinook salmon at Lower Granite Dam. One group will be tagged with PIT tags only and the second group will receive a JSATS acoustic tag and a PIT tag.** The same techniques and procedures will be used to tag hatchery subyearling Chinook as will be used for yearling Chinook. The only change will be to tag on 20 separate dates and have 20 separate releases which will each include 350 acoustic-tagged fish and 1,500 PIT-tagged only fish. We expect to begin tagging in late May and conclude in July, depending on the migration.

Task 1.C **Estimate survival and associated detection probabilities of acoustic-tagged yearling Chinook salmon relative to PIT-tagged fish migrating through the Snake and Columbia Rivers.** We propose to use an array of autonomous hydrophone receivers in the Snake and Columbia Rivers to substantially increase the numbers of detected acoustic-tagged fish below primary detection sites to estimate lambda. Increasing the number of fish detected below the primary detection site increases the precision of detection-probability and survival estimates to the primary detection site and allows the use of smaller sample sizes to achieve a given level of precision. For this study, we will deploy autonomous hydrophone receiver arrays near Windust Park below Lower Monumental Dam and near Irrigon, OR below McNary Dam. We will also use detections from autonomous hydrophone receiver arrays downstream of Bonneville Dam (Study Code EST-02-01) in our analysis.

The 80% detection powers for proposed treatments are presented in Table 1. Sample sizes were determined from PIT-tagged yearling Chinook salmon released to estimate survival in 2002 (Muir et al. 2003). Since this study is proposed for mid-April through May 2007, weekly detection probabilities for fish released over a similar period in 2002 were averaged and the resulting mean was used in the power analysis calculations. Sample size requirements are greatest for detecting significant differences in survival based on estimates from the SR Model. Sample sizes based on the power to detect differences in SR Model survival estimates give even greater power to detect differences in recovery percentages, detection probabilities, and travel times.

Table 1. Parameters used to develop sample size and associated detectable differences of survival between PIT-tagged and acoustic tagged hatchery yearling and subyearling Chinook salmon for 80% detection power. Fish would be tagged at Lower Granite Dam (LGR) and released through the bypass pipe. Proposed sample sizes are a total of 3,500 acoustic tagged yearling Chinook and 7,000 acoustic tagged subyearling Chinook salmon. Acoustic tagged yearling Chinook salmon releases will be paired with releases from a latent mortality study being conducted at Lower Granite Dam. Acoustic tagged subyearling Chinook salmon will be paired with PIT tag only subyearlings tagged at Lower Granite Dam specifically for this study.

	Yearling Chinook	SubyearlingChinook
	McNary Dam	McNary Dam
S (Estimated PIT tagged survival from release to detection site)	0.76	0.62
p (PIT-tag detection probability at detection site)	0.49	0.63
λ (Detection probability downstream of detection site for PIT tagged fish)	0.50	0.30
λ (Detection probability downstream of detection site for acoustic tagged fish)	0.80	0.50
Estimated detectable difference in survival (Release to detection site, α = 0.10, β = 0.20)	0.05	0.05

To increase power to detect differences among groups in survival probabilities, we will use the relatively liberal significance level of α=0.10 in our tests. The rejection rate is justified in light of observed tag effects in previous studies. The proposed sample sizes (3,500 acoustic-tagged yearling Chinook salmon and 7,000 PIT-tagged fish) will provide 80% power to detect a difference of 5% or more tag-related mortality rate under moderate flows from release to McNary Dam (276 rkm). Our ability to detect differences will be highly dependent on spill and river flow patterns over the course of the study, and detection probabilities for John Day and Bonneville Dams will be influenced by detection capability at the Bonneville Dam Second Powerhouse corner collector. With these sample sizes, we will almost certainly be able to detect biologically important differences in survival estimates and travel times.

Detection and survival probabilities will be estimated from PIT-tag-detection histories from individual fish at the juvenile collection/detection facilities at Little Goose, Lower

Monumental, McNary, John Day, and Bonneville Dams (Smith et al. 1994). To evaluate mixing of the release groups at downstream dams, we will use contingency table tests for differences between distributions of daily detections at each detection site. If groups are sufficiently mixed, differences in survival will be evaluated using ANOVA on recovery percentages for different release groups. Otherwise, tests will be based on survival estimates obtained using the SR survival model introduced by Cormack (1964), Jolly (1965), and Seber (1965).

Task 1.D **Estimate survival and associated detection probabilities of acoustic-tagged subyearling Chinook salmon relative to PIT-tagged fish migrating through the Snake and Columbia Rivers.** Survival and detection probabilities will be estimated using the same methods as described for yearling Chinook salmon. However, we expect that detection probabilities will be lower for subyearling Chinook salmon so we have increased our sample sizes to accommodate this likely reduction in detection efficiency.

Objective 2

Compare travel times of acoustic-tagged yearling and subyearling Chinook salmon to PIT-tagged fish migrating through the Snake and Columbia Rivers. Travel times will be calculated from time of release to time of first detection at each downstream dam (Little Goose, Lower Monumental, McNary, John Day, and Bonneville Dams). Differences in travel times will be evaluated using ANOVA, likelihood ratio tests, and/or nonparametric methods as appropriate.

Objective 3

Compare avian predation of acoustic-tagged yearling and subyearling Chinook salmon relative to PIT-tagged fish migrating through the Snake and Columbia Rivers. Ryan et al. (2003) identified substantial rates of avian predation on PIT-tagged juvenile salmonids migrating past Caspian tern *Sterna caspia* and double-crested cormorant *Phalacrocor axrtius* colonies in the Columbia River estuary. Though predation was lowest for Chinook salmon, the effect could be more pronounced for fish tagged with other types of tags. We will explore if this possibility can be used as an indicator of adverse effects of acoustic tags relative to PIT tags. Differences in avian predation will be evaluated using ANOVA on recovery percentages for all treatments.

Objective 4

If acoustic tag effects are identified in the field for yearling or subyearling Chinook salmon, determine the time frame over which the effects are manifested. If there is an effect due to the acoustic tag, it may manifest itself very quickly or over a longer period. To determine the time it take for a tag effect to take place, we will use PIT-tag detection and acoustic-tag detection to determine this time frame. We will not only use detection at hydroelectric facilities, but detection on bird colonies and on the acoustic arrays ranging from the mouth of the Columbia River to the Snake River.

Objective 5

In a laboratory setting, compare growth, mortality, tag loss, and tissue response for acoustic- tagged run-of-the-river yearling and subyearling Chinook salmon relative to PIT-tagged fish over a 90-d period. The recent improvements in the attributes of acoustic tags may enable studies of survival of juvenile salmonids through the Columbia and Snake Rivers, in the estuary, and in the ocean, which would entail longer study periods than typical for this technology. Thus, prior to such studies, the effects of the tags on fish and assessments of tag loss will be required over longer periods than generally studied. In an effort to answer some of these questions, we propose to conduct laboratory studies of the effects of acoustic tags on the growth, mortality, and, tag loss for run-of-the-river (ROR) yearling and subyearling Chinook salmon relative to those implanted with PIT tags. Several of the laboratory evaluations will asses tag effects over a 90-d period. This is a period commensurate with the use of active tags to estimate survival over a period of time for fish migrating through the hydropower system and into the estuary and Pacific Ocean. The tags (acoustic and PIT) and tagging methods used in the lab component will be the same as those used in the field component of this study (see previous objectives).

We propose to use ROR yearling and subyearling Chinook for all laboratory evaluations. While we understand there can be challenges with holding and maintaining condition in active migrants, we have elected to complete the proposed work with stocks because they are they are the best representatives of the fish that remain in the river.. In 2006 we conducted a pilot level study and have determined that both ROR yearling and subyearling fish can be used in lab experiments with relatively low holding mortality.

Run-of-the-river yearling and subyearling fish will be obtained from the juvenile bypass facility at Little Goose Dam in April and June, respectively. We expect that yearlings will range from ~15 to 80 g and 125 – 200 mm while the sub-yearlings will range from ~10 to 30 g and 100 -140 mm. The laboratory evaluations will be conducted at the PNNL laboratory , Richland, WA. and possibly at the NOAA laboratory in Astoria, OR.

We propose to assess growth, mortality, tag loss and tissue response of acoustic tagged yearling and subyearling ROR Chinook salmon relative to PIT-tagged and control ROR Chinook salmon over a period of 90 d. Evaluations at PNNL will compare two different groups of tagged fish to a control group of fish. Fish will be randomly assigned to one of three groups: (a) control – not implanted with any type of PIT tag or transmitter; (b) PIT tagged only; (c) acoustic transmitter and non-integrated PIT tag (these fish will be surgically implanted with a dummy JSATS acoustic transmitter and also a PIT tag is inserted during surgery; this is the standard field technique).

We will examine the survival, growth (gains in length and weight), tag retention, and tissue reaction of ROR yearling and sub-yearling Chinook salmon over a 90-day period with fish sampled at days 21, 30, 60, and 90. The 21-d time represents the typical life of active transmitters used prior to the development of the JSATS transmitter and is comparable to

examination times by Martinelli et al. (1998) and Adams et al. (1998a), Anglea et al. (2004) and Brown et al. (in press). The 30- and 60-d times represent the life of the JSATS acoustic transmitters currently being used in small juvenile salmonids for estimating survival through the hydrosystem. The 90-d time period represents the life expectancies of existing and future acoustic tags that could be used to study migration and survival through the hydropower system as well as in the estuary and ocean.

To conduct robust statistical analysis of differences in survival, growth, and tag retention among test groups, we will have a sample size of approximately 1,338 ROR fish (Tables 2 and 3; 630 yearling fish, 708 sub-yearling fish). This sample size was estimated so that we can detect a 15% difference in survival with an alpha of 0.05 (i.e., 95% confidence interval) and a Beta of 0.2 (i.e., a power of 0.8).

Table 2. Proposed sample sizes for laboratory studies using run-of-the-river yearling Chinook salmon to detect a 15% difference in survival and growth ($\alpha = 0.05$, ß = 0.2).

	Days held				
Treatment	21	30	60	90	Total
Control	44	44	61	61	210
PIT tagged	44	44	61	61	210
Acoustic tag with unintegrated PIT tag	44	44	61	61	210
Total	132	132	183	183	630

Table 3. Proposed sample sizes for laboratory studies using run-of-the-river sub-yearling Chinook salmon to detect a 15% difference in survival and growth ($\alpha = 0.05$, ß = 0.2)

	Days held				
Treatment	21	30	60	90	Total
Control	53	53	65	65	236
PIT tagged	53	53	65	65	236
Acoustic tag with unintegrated PIT tag	53	53	65	65	236
Total	159	159	195	195	708

All fish will be held in water with temperatures that reflect the water temperatures of migrating run-of-river fish. River water from the Columbia River adjacent to the PNNL wet lab and/or well water will be pumped, into all test tanks. Fish will be fed Biodiet™ or Biomoist™ moist pellets daily ad libitum. If necessary, fish will be fed frozen brine shrimp when they first arrive in the laboratory before they are converted over to pellets. Fish selected for a given test

will not be fed for 24h before or 24h after surgery. Fish will be exposed to simulated or natural photoperiods.

In addition to the treatment tagging procedures, all control fish will be individually marked with visible implant elastomer tags, and the length and weight of each individual will be measured. The visible implant elastomer tags will not be needed to identify PIT tagged fish, but will be done (exluding the injection of elastomer) to PIT tagged and PIT and acoustic transmitter implanted fish so handling is consistent among all groups.

After PIT tagging or surgical implantation, fish will be held for one of four different time periods: 21 days, 30 days, 60 days, or 90 days. After these periods of time, all fish will be necropsied. Length and weight will be measured and the way that the transmitter or PIT tag interacted with the body of the fish will be examined.

A sub-sample of fish will also be histologically examined (by Ralph Elston; Aquatechnics Inc.) to explore finer scale interactions between tags and the fish body for fish held at PNNL. Fish will be examined to determine the locations where tags are expelled and determine the pathways of transmitter expulsion. To determine when expulsion is occurring, while fish are being held, tanks will be checked daily to determine if any transmitters have been expelled.

Objective 6

In a laboratory setting, compare detailed histological response of double tagged (acoustic and PIT) run-of-the-river yearling and subyearling Chinook salmon relative to PIT tagged fish in a time series over a 90-d period.

Concerns have been raised about the effects of having two tags implanted into a single fish (e.g., a radio/acoustic tag along with a PIT tag). Although due consideration has been given to concerns related to the combined mass of the tags, no data exists on tag loss or tissue response. Typically, a transmitter that has been implanted for an extended period (weeks to months, depending on the fish), will become encapsulated in fibrous tissue. This represents a typical foreign body response. The questions raised about double tagging include concerns over an exaggerated tissue response due to the presence of two tags.

The USGS proposes to address questions of double tagging and tissue response by using sequential histological sections of fish implanted with both acoustic and PIT tags. Using a regimented, time series and statistically robust approach, we anticipate being able to detect small differences in tissue response between groups. We will examine tissue response in three groups of fish: 1) PIT tag only, 2) acoustic tag only, and 3) PIT and acoustic combined. Fish will be held in tanks for 90 days. Each group will include 40 fish (120 total fish per experiment). At intervals of 21, 30, 60, and 90 d post-tagging we will remove 10 fish from each of the three groups for a total of 30 fish at each sample period. Sample size details are shown in Tables 4 and 5. Sampled fish will be necropsied and examined for evidence of partial tag loss,

encapsulation, necrosis, or other internal abnormalities due to the presence of the tags. Tissue sections (whole body sections) will be taken from sampled fish, mounted, examined using light microscopy, and analyzed by Dr. Diane Elliot of the USGS Western Fisheries Research Center.

Table 4. Proposed sample sizes for laboratory studies using ROR yearling Chinook salmon to evaluate detailed histological response of double tagging (Objective 6).

	Days held				
Treatment	21	30	60	90	Total
PIT tagged	10	10	10	10	40
Acoustic tag	10	10	10	10	40
Acoustic tag with unintegrated PIT tag	10	10	10	10	40
Total	30	30	30	30	120

Table 5. Proposed sample sizes for laboratory studies using ROR sub-yearling Chinook salmon to evaluate detailed histological response of double tagging (Objective 6).

	Days held				
Treatment	21	30	60	90	Total
PIT tagged	10	10	10	10	40
Acoustic tag	10	10	10	10	40
Acoustic tag with unintegrated PIT tag	10	10	10	10	40
Total	30	30	30	30	120

We propose to use ROR yearling and subyearling Chinook salmon for these experiments. Study fish will be collected from Lower Granite Dam or Little Goose Dam, and transported to the Columbia River Research Laboratory or one of the lower river dams for holding. The USGS completed this study design in 2006 using hatchery-reared yearling and subyearling Chinook salmon. At the time of this writing tissue analyses was on-going and results are not yet available. For the 2007 proposed work, we will incorporate any changes needed (e.g., larger sample sizes or additional groups) following data analysis of 2006 findings.

Objective 7

In a laboratory setting, compare the vulnerability to piscivorous predation of acoustic-tagged yearling and subyearling Chinook salmon relative to PIT tagged fish.

We propose to assess the predator avoidance ability of ROR yearling and subyearling Chinook salmon tagged with acoustic and PIT tags in a laboratory environment 30 d after tag implantation. Although predator avoidance studies have been conducted in the past to evaluate potential tag effects, the post-tagging period has been 1 day (Adams et al. 1998, Anglea et al. 2004). This evaluation will examine tag effects at 30 d post-tagging, when longer-term effects may influence the ability of fish to avoid predation. Experiments will compare the predator avoidance ability of fish implanted with PIT tags and fish implanted with both PIT and acoustic tags.

To best represent the natural system, we will use smallmouth bass as the predator and make every attempt to simulate the river environment. Predation trials will be conducted in large tanks, with low-light conditions, natural substrate, and cover for the predators. Trials will be conducted at either the USGS laboratory in Cook, WA, the PNNL laboratory, in Richland, WA, or possibly at The Dalles Dam.

Predation trials will be conducted using smallmouth bass collected from the Columbia River by electrofishing. Predators will meet a minimum size criterion of 300 mm FL, because fish below this minimum size may not seek prey items in the size class appropriate for our evaluation. Predators will be held in two 3.75 m diameter tanks, 1 m deep, lined with gravel and cobble substrate. Experimental tanks will be surrounded with curtains to minimize disturbance.

A concealed overhead ladder or scaffold system will be used to observe predator-prey interactions in the tanks and to count prey. The predation trials will be conducted under natural photoperiod conditions at14°C (yearling Chinook experiments) or 19°C (subyearling Chinook experiments).

Predators will be allowed to acclimate to experimental tanks for 20-30 days prior to the trials. During acclimation the bass will be fed a maintenance diet of juvenile salmon, and experimental work will not begin until the predators are consistently feeding. Predators will not be fed for 24 h before the start of a predation trial. We propose to use 12 bass in each of the two experimental tanks, and have a reserve of predators that can be used to replace experimental animals as needed.

We will collect yearling and subyearling Chinook salmon from Little Goose Dam to be used as the prey item in our predation trials. Fish will be randomly assigned to one of two groups: PIT tagged only or PIT and acoustic tagged. Tagging methods will follow those described for the field study. For the double-tagged group, the acoustic tag and PIT tag will be inserted into the body cavity separately, as will be done for the field evaluation. The PIT tag only group will have the tag injected following standard protocols for studies in the FCRPS using PIT tags. Fish will be stocked into holding tanks so that each tank contains both tagging treatments.

Tagging and holding will begin 30 days ahead of our target windows for predation trials: May-June (yearling Chinook) and July-August (subyearling Chinook). Fish will be fed to satiation at a rate of at least 3% of body weight per day. Food will be withheld for 24-h prior to tagging and for 24-h after tagging. After a 30 d holding period, the predator avoidance ability of the groups will be compared.

We will use a series of replicate trials to evaluate predator avoidance. Each trial will consist of adding 30 prey (15 PIT tagged only and 15 PIT tagged and acoustic tagged) into a predator tank. Prey will be netted from their holding tanks, and placed behind a moveable partition positioned in the predator tank. As per Anglea et al. (2004), fish will be allowed to acclimate for 5 minutes, the barrier will be removed, and the trial will begin. Predation will be allowed to continue until 50% of the prey are consumed. We will make observations at 30 min intervals for the first 2 h of the trial, and as often as needed after that to ensure that the trial ends when 50% of the prey are consumed. At the end of each trial all surviving prey will be netted from the tank and identified to group based on unique tags. Sample sizes of ROR yearling and subyearling Chinook salmon for the predation trials are presented in Tables 6 and 7.

To encourage consistent feeding by predators, we will separate trials by 2-3 days depending on the level of feeding activity. Anticipating up to 30 trials, experiments for each run type could take 6-7 weeks each. We will schedule tagging and holding so that spring fish have completed their 30 d holding period by early May and trials conducted in May and June. Tagging and holding for summer fish will be planned so that the 30 d holding period is complete in early July. This timing matches closely with the migrations and physiological and lighting

conditions of the corresponding in-river migrants. Our ability to meet this schedule will depend on how well the predators adapt to feeding in the tank environment.

Table 6. Proposed sample sizes for laboratory studies using ROR yearling Chinook salmon to evaluate predator avoidance ability (Objective 7).

Treatment	Fish per trial	Number of trials	Total number of fish
PIT tagged	15	30	450
Acoustic tag with unintegrated PIT tag	15	30	450
Total	30	30	900

Table 7. Proposed sample sizes for laboratory studies using ROR subyearling Chinook salmon to evaluate predator avoidance ability (Objective 7).

Treatment	Fish per trial	Number of trials	Total number of fish
PIT tagged	15	30	450
Acoustic tag with unintegrated PIT tag	15	30	450
Total	30	30	900

Objective 8

In a laboratory setting, compare the salinity tolerance of acoustic-tagged yearling and subyearling Chinook salmon relative to PIT-tagged fish.

Recent developments in acoustic technology have led to the feasibility of conducting juvenile salmon survival studies over longer periods than traditional for this technology. The current field evaluation proposes to estimate the survival of juvenile salmon as they travel from Lower Granite Dam, through the hydropower system, through the estuary, and into the Pacific Ocean. Due to the expanded monitoring duration relative to other acoustic systems, transmitter effects, especially long-term effects, are a concern. Few studies have addressed transmitter effects over the extended time periods (30 -90 d) which are relevant to the scope of the proposed field evaluation.

The ability of tagged fish to adapt to the seawater environment is a critical uncertainty for the proposed work since fish will be actively monitored in the estuary. The osmoregulatory

ability of tagged fish may have ramifications for the assumptions of the survival calculation, transmitter loss, and for marine predator avoidance ability. Salinity tolerance tests can be used to evaluate the effects of prior stress on osmoregulatory function. If the presence of the acoustic transmitter is stressful to the tagged fish they may have impaired ability to adapt to seawater. In theory, the higher the stress level within a group of fish, the less capable these fish will be of osmoregulating in seawater. For fish adapted to freshwater, the inability to osmoregulate in seawater results in death, so differences in mortality among groups of variably stressed fish can be used to compare stress events.

Salinity tolerance has been used as a performance measure to compare hatchery rearing conditions (Schreck et al. 1985), handling and transportation stress (Matthews et al. 1986), and exposure to toxicants (Lorz et al. 1979). Studies of transmitter effects in the Columbia River Basin have not traditionally used salinity tolerance as one of the suite of performance measures evaluated. The extended length of the current study, combined with estuary entrance and monitoring make salinity tolerance an important question that needs to be addressed.

The USGS proposes to compare the salinity tolerance of acoustic and PIT-tagged fish through the use of a seawater challenge. Study fish will be ROR yearling and subyearling Chinook salmon collected at Lower Granite Dam or Little Goose Dam. To simulate the timing of seawater entry and to best align with transmitter effect studies completed in 2006 and planned for 2007, we will challenge fish 30 days after tagging. Experiments will be conducted at the seawater facility at Bonneville Dam, at The Dalles Dam, or at the Columbia River Research Laboratory. Fish will be randomly assigned to one of three groups: control (minimally handled), PIT tagged only, or PIT and acoustic tagged. Tagging methods will follow those described for the field study. For the double-tagged group, the acoustic tag and PIT tag will be inserted into the body cavity separately. The PIT tag only group will have the tag injected following standard protocols for studies in the FCRPS using PIT tags. Fish will be fed to satiation at a rate of at least 3% of body weight per day. Food will be withheld for 24-h prior to tagging and for 24-h after tagging. Experimental temperatures will mimic river temperatures for the appropriate outmigration period. After a 30 d holding period, the salinity tolerance of the groups will be compared.

Yearling and subyearling Chinook salmon will be collected from Lower Granite or Little Goose Dam on two dates (total of four collection dates). Since the level of smoltification is important to osmoregulatory ability and is variable through the course of the outmigration, we want to collect ROR fish at two points during the run. Fish collected on each date will be used to conduct one salinity experiment. We will conduct two experiments for yearling Chinook salmon and two experiments for subyearling Chinook salmon. For each experiment, fish will be randomly assigned to one of the three study groups (control, PIT tagged or acoustic, and PIT tagged), tagged/handled as appropriate, and placed into one of nine replicate tanks. Each study group will consist of three replicate tanks with 25 fish per tank (total of 75 fish per group). Sample sizes are described in Tables 8 and 9. Following the 30 day holding period fish will be transferred from freshwater to full strength seawater (28-30 ‰) at the same temperature. Preliminary tests will be used to calibrate sensitivity by determining the highest seawater concentration that allows 90% survival of controls. Mortalities will be tabulated 24 h after the

challenge (Matthews et al. 1986). Surviving fish will remain in seawater following the challenge so that we can observe delayed mortalities or reduced condition beyond the 24 h test period.

To improve our ability to detect small differences in salinity tolerance between test groups, we will assess salinity tolerance by monitoring plasma sodium concentrations after the seawater challenge (Clarke and Blackburn 1977). Using survival as an endpoint may not be sensitive enough to detect differences between groups, especially for yearling Chinook salmon who are larger and may be less affected by the presence of the transmitter. Since plasma sodium concentration level is a continuous variable it serves as a more sensitive index than survival (Schreck 1990). Plasma sodium samples will be collected from 10 fish in each replicate tank for each treatment group, 24 h after seawater exposure.

Table 8. Proposed sample sizes for laboratory studies using ROR yearling Chinook salmon to evaluate salinity tolerance (Objective 8).

Treatment	Fish per Experiment	Number of Experiments	Total number of fish
Control (minimally handled)	75	2	150
PIT tagged	75	2	150
Acoustic tag with unintegrated PIT tag	75	2	150
Total	225	2	450

Table 9. Proposed sample sizes for laboratory studies using ROR sub-yearling Chinook salmon to evaluate salinity tolerance (Objective 8).

Treatment	Fish per Experiment	Number of Experiments	Total number of fish
Control (minimally handled)	75	2	150
PIT tagged	75	2	150
Acoustic tag with unintegrated PIT tag	75	2	150
Total	225	2	450

STATISTICAL ANALYSES

Field Evaluations

Differences among the acoustic-tag and PIT- tag treatments in travel time and detection probabilities will be evaluated using ANOVA, likelihood ratio tests, and/or nonparametric methods as appropriate.

The percentage of tagged smolts from each group detected at least once at Little Goose, Lower Monumental, Ice Harbor, McNary, John Day, Bonneville Dams, and from the Jones Beach pair trawl will be calculated. Differences in detection percentages among groups and recoveries from bird-island interrogation sites will also be evaluated using ANOVA. Chi-square, goodness-of-fit tests will be used to test equal probability of detection (mixing) over time. Adult return rates of fish from this study are expected to be too small for formal analysis.

Laboratory evaluations

Response measures will be evaluated separately for each study at the time of final sampling at 21, 30, 60, and 90 days and compared across the treatment groups. Statistical analysis for the dichotomous response of survival will use a logistic regression model taking the

treatment groups as a multi-level factor variable with the control or PIT tag groups as the reference level. This model will be assessed for 'goodness-of-fit' and could possibly include addition independent variables as deemed necessary. Similarly, trend analysis on survival across studies of the 4 different durations (21, 30, 60, 90 days) will be performed by extending the logistic model. Tag retention analyses will follow a similar approach with designation of the reference treatment level TBD.

Growth will be assessed by considering changes in length and/or weight as measured on each individual fish from beginning to end the studies. Analysis of Variance (ANOVA) modeling will be applied appropriate for the response distribution on changes in size for each fish. As above, the treatment groups as a 4-level factor variable with the control group as the reference level, and will include assessment of model fit as well as possible inclusion of additional independent variables if deemed necessary. Trend analysis can also be performed by pooling across treatment groups.

Analysis of predation trial data will be similar to Mesa (1994). We will first use a heterogeneity Chi-square analysis to determine if the individual trials were homogeneous (Sokal and Rohlf 1981). Chi-square goodness-of-fit tests can then be used on pooled data to test whether predation was random (e.g., 50% PIT-tagged, 50% acoustic-tagged). The Chi-square test has low power (i.e., low probability of correctly rejecting the null hypothesis) for small sample sizes, so we will set alpha to 0.10 to reduce the probability of the more serious Type II error. Trials where less than 30% or more than 70% of the prey are consumed will be omitted from analysis to account for changes in prey availability during a trial (i.e., the decreasing abundance of the preferred group; Coutant 1973; Mesa and Warren 1997).

Salinity tolerance data analysis will include comparisons of experiments and treatment groups within each run type. Mortalities will be structured as contingency tables and groups will be compared with Chi-Square or the G-statistic (Sokal and Rohlf 1981). Mean sodium plasma levels for each experiment and treatment group will be compared with Analysis of Variance.

FISH REQUIREMENTS

FY 2007 Field Evaluations

Up to 100,000 run-of-the-river yearling Chinook which will be shared with a latent mortality study and 40,000 hatchery run-of-the-river subyearling Chinook salmon from the Snake River will be collected and either PIT tagged or tagged with both a PIT and an acoustic transmitter at Lower Granite Dam.

Laboratory evaluations

Objective 5 (PNNL)

Up to 1,000 run-of-the-river yearling Chinook salmon and 1,000 run-of-the-river subyearling Chinook salmon will be used to assess tag effects in the laboratory.

Objectives 6-8 (USGS)

Up to 1,500 run-of-the-river yearling Chinook salmon and 1,500 run-of-the-river subyearling Chinook salmon will be used to assess tag effects in the laboratory.

FYs 2008 and Beyond

Large numbers of fish may be required during future implementation. The numbers of fish required for each target group will be determined dependent on outcomes obtained in 2007 and future years, variability about these estimates, detection probabilities, and requirements of the SR model.

SCHEDULES

Projected timeframe completion of all tagging during 2007 is late-April through July. Laboratory studies should be completed by September, with necropsies and histological examinations completed by October. Preliminary analysis of evaluations in the field including survival, timing, detection probability estimates, and bird predation rates should be available by mid-November. We anticipate delivery of the draft report by 30 January 2008.

Outyear work (2008 and beyond) will depend on the results of this study. It is important to consider this work in the context of environmental variability, since river flows, spill scenarios, and detection capability at various sites may vary annually. Therefore, we propose to implement the study over a number of years.

LIMITATIONS AND EXPECTED DIFFICULTIES

The degree of success of this project will be contingent upon five primary factors: 1) whether adequate numbers of fish can be collected for tagging at Lower Granite Dam during the time frame indicated, 2) whether the pre-determined sample sizes will provide the necessary precision for the comparisons of performance, 3) whether detectors and bypass systems at downstream dams will be operational during the duration of the study, 4) whether spill/transport scenarios are in effect during the duration of the study, and 5) whether the assumption of random mixing of the treatment releases will be satisfied.

PROJECT IMPACTS

Collection, tagging, and fish-holding operations at Little Goose and Lower Granite Dams during April through June will be coordinated with the project office and Smolt Monitoring Program personnel.

BIOLOGICAL EFFECTS

These studies will be carried out using an ESA Section 10 Permit issued to the National Marine Fisheries and WDFW permits in 2007.

TECHNOLOGY TRANSFER

Information acquired during the proposed work will be transferred to the fisheries community by presentations at meetings and workshops, by personal contact, by annual and final reports to the U.S. Army Corps of Engineers, and through scientific publications.

KEY PERSONNEL AND DUTIES

Brad A. Ryan	NOAA Fisheries Principal Investigator
Michelle W. Rub	NOAA Fisheries Principal Investigator
Lynn McComas	NOAA Fisheries Principal Investigator
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REFERENCES

Absolon, R. F., M. B. Eppard, B. P. Sandford, G. A. Axel, E. E. Hockersmith, and J. W. Ferguson. 2003. Effects of turbines operating at two different discharge levels on survival and condition of yearling Chinook salmon at McNary Dam, 2002. Report to U.S. Army Corps of Engineers, Contract W68SBV20655422. 26 p. (Available from the Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097).

Adams, N. S., D. W. Rondorf, and E. E. Kofoot. 1996. Migrational characteristics of juvenile spring Chinook salmon and steelhead in the forebay of Lower Granite Dam relative to the 1996 surface bypass collector tests. Report to the U. S. Army Corps of Engineers, Contract E-86930151, Walla Walla, WA. 260 p.

Adams, 1997. N. S., D. W. Rondorf, and E. E. Kofoot. 1997. Migrational characteristics of juvenile spring Chinook salmon and steelhead in the forebay of Lower Granite Dam relative to the 1997 surface bypass collector tests. Report to the U. S. Army Corps of Engineers, Contract E-86930151, Walla Walla, WA.

Adams, N .S., D. W. Rondorf, S. D. Evans, and J. E. Kelley. 1998a. Effects of surgically and gastrically implanted radio transmitters on growth and feeding behavior of juvenile Chinook salmon. Trans. Am. Fish. Soc. 127:128-136.

Adams, N .S., D. W. Rondorf, S. D. Evans, J. E. Kelley, and R.W. Perry. 1998b. Effects of surgically and gastrically implanted radio transmitters on swimming performance and predator avoidance of juvenile Chinook salmon (*Oncorhynchus tshawytscha*). Can. J. Fish. Aquat. Sci. 55:781-787.

Anglea, S., T. Poe, and A. Giorgi. 2001. Synthesis of radio telemetry, hydroacoustic, and survival studies of juvenile salmon at John Day Dam (1980-2000). Report to U.S. Army Corps of Engineers, Portland, Oregon.

Anglea, S. M., D. R. Geist, R. S. Brown, K. A. Deters, and R. D. McDonald. 2004. Effects of acoustic transmitters on swimming performance and predator avoidance of juvenile chinook salmon. N. Am. J. Fish. Mgmt. 24, 162-170.

Axel G. A., E. E. Hockersmith, M. B. Eppard, B. P. Sandford, and D. B. Dey. 2003. Passage and survival of hatchery yearling Chinook salmon passing Ice Harbor and McNary Dams during a low flow year, 2001. Annual report to U.S. Army Corps of Engineers, Walla Walla, Washington, Contract W68SBV92844866, 43p. (Available from Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097.)

Axel, G. A., E. E. Hockersmith, M. B. Eppard, and B. P. Sandford. 2004a. Passage and survival of hatchery yearling Chinook salmon at McNary Dam, 2002. Report to the U.S. Army Corps of Engineers, Walla Walla District, Contract W68SBV92844866. 35 p. (Available from the Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097).

Axel, G. A., E. E. Hockersmith, M. B. Eppard, and B. P. Sandford. 2004b. Passage and survival of hatchery yearling Chinook salmon at McNary Dam, 2003. Report to the U.S. Army Corps of Engineers, Walla Walla District, Contract W68SBV92844866. 40 p. (Available from the Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097).

Brown, R. S., S. J. Cooke, W. G. Anderson, and R. S. McKinley. 1999. Evidence to challenge the "2% rule" for biotelemetry. North American Journal of Fisheries Management 19, 867-871.

Brown, R. S., D. R. Geist, and K. A. Deters. 2005. Laboratory evaluation of surgically implanted acoustic transmitters on the swimming performance, buoyancy compensation, survival, and growth of juvenile sockeye and fall Chinook salmon. Prepared by Battelle for Public Utility District No. 1 of Chelan County, Wenatchee, Washington.

Brown, R. S., D. R. Geist, K. A. Deters, and A. Grassell. In press. Effects of surgically implanted acoustic transmitters greater than 2% body mass on the swimming performance, survival, and growth of juvenile sockeye and Chinook salmon. J. of Fish Biol.

Clarke, W. C., and J. Blackburn. 1977. A seawater challenge test to measure smolting of juvenile salmon. Canadian Fisheries and Marine Service, Research and Development Directorate Technical Report 705.

Cormack, R. M. 1964. Estimates of survival from sightings of marked animals. Biometrika 51: 429-438.

Coutant, C. C. 1973. Effect of thermal shock on vulnerability of juvenile salmonids to predation. Journal of the Fisheries Research Board of Canada 30:965-973.

Eppard, M. B., G.A. Axel, B.P. Sandford, and G.M. Matthews. 1998. Ice Harbor Dam spill efficiency determined by radio telemetry, 1997. Report to U. S. Army Corps of Engineers, Contract E86940101, 23p plus Appendices. (Available for Northwest Fisheries Science Center, 2725 Montlake Boulevard E., Seattle, WA 98112-2097.

Eppard, M. B. , E. E. Hockersmith, G. A. Axel, and B. P. Sandford. 2002. Spillway survival for hatchery yearling and subyearling Chinook salmon passing Ice Harbor Dam, 2000. Report of the National Marine Fisheries Service to the U.S. Army Corps of Engineers, Walla Walla, (Available from Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097.) Washington.

Eppard, M. B., B. P. Sandford, E. E. Hockersmith, G. A. Axel, and D. B. Dey. 2005a. Spillway passage survival of hatchery yearling and subyearling Chinook salmon at Ice Harbor Dam, 2002. Report to the U.S. Army Corps of Engineers, Walla Walla District, Contract W68SBV92844866. 104 p. (Available from the Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097).

Eppard, M. B., B. P. Sandford, E. E. Hockersmith, G. A. Axel, and D. B. Dey. 2005b. Spillway passage survival of hatchery yearling Chinook salmon at Ice Harbor Dam, 2003. Report to the U.S. Army Corps of Engineers, Walla Walla District, Contract W68SBV92844866. 60 p. (Available from the Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097).

Greenstreet, S. P. R., and R. I. G. Morgan. 1989. The effect of ultrasonic tags on the growth rates of Atlantic Salmon, *Salmo salar* L., parr of varying size just prior to smolting. J. Fish Biol. 35:301-309.

Hensleigh, J. E., H. C. Hansel, R. S. Shively, R. E. Wierenga, J. M. Hardiman, R. H. Wertheimer, G. S. Holmberg, T. L. Martinelli, B. D. Leidtke, R. E. Wardell, and T. P. Poe. 1997. Movement and behavior of radio-tagged yearling Chinook salmon and steelhead in John Day, The Dalles, and Bonneville dam forebays. Preliminary report to the U. S. Army Corps of Engineers, Portland, OR.

Hockersmith, E.E., S. G. Smith, W.D. Muir, B.P. Sandford, J. G. Williams, and J. R. Skalski. 1999. Survival estimates for the passage of juvenile salmonids through Snake River dams and reservoirs, 1997. Annual Report to the Bonneville Power Administration, Project 93-29, Contract DE-AI79-93BP10891, 71p. (Available from Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097).

Hockersmith, E. E., W. D. Muir, S. G. Smith, B. P. Sandford, R. W. Perry, N. S. Adams, and D. W. Rondorf. 2003. Comparison of migration rate and survival between radio-tagged and PIT-tagged migrant yearling Chinook salmon in the Snake and Columbia Rivers. N. Am. J. Fish. Mgmt. 23: 404-413.

Hockersmith, E. E., G. A. Axel, M. B. Eppard, D. A. Ogden, and B. P. Sandford. 2005. Passage Behavior and Survival for Hatchery Yearling Chinook Salmon at Lower Monumental Dam, 2004. Report to the U.S. Army Corps of Engineers, Walla Walla District, Contract W68SBV92844866. 69 p. (Available from the Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097).

Hockersmith, E. E., G. A. Axel, D. A. Ogden, R. F. Absolon, and B. P. Sandford. *In prep.* Spillbay survival for hatchery yearling Chinook salmon at Lower Monumental Dam, 2005. Report to the U. S. Army Corps of Engineers, Walla Walla, WA. (Available from Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097).

Iwamoto, R. N., W. D. Muir, B. P. Sandford, K. W. McIntyre, D. A. Frost, J. G. Williams, S. G. Smith, and J. R. Skalski. 1994. Survival estimates for the passage of juvenile salmonids through dams and reservoirs. Annual Report to the Bonneville Power Administration, Project 93-29, Contract DE-AI79-93BP10891, 140p. (Available from Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097.)

Jolly, G. M. 1965. Explicit estimates from capture-recapture data with both death and immigration—stochastic model. Biometrika 52: 225-247.

Lorz, H. W., S. W. Glenn, R. H. Williams, C. M. Kunkel, L. Norris, and B. R. Loper. 1979. Effects of selected herbicides on smolting coho salmon. U.S. Environmental Protection Agency, EPA-600/3-79-071, Corvallis, Oregon.

Lucas, M. C. 1989. Effects of implanted dummy transmitters on mortality, growth, and tissue reaction in rainbow trout, *Salmo gairdneri* Richardson. J. Fish Biol. 35:577-587.

Martinelli, T. L., H. C. Hansel, and R. S. Shively. 1998. Growth and physiological responses to surgical and gastric radio transmitter implantation techniques in subyearling Chinook salmon (*Oncorhynchus tshawytscha*). Hydrobiologia 371/372:79-87.

Mathur, D. P., G. Heisey E. Euston, J. R. Skalski, and S. Hays. 1996. Turbine passage survival estimation for Chinook salmon smolts (*Oncorhynchus tshawytscha*) at a large dam on the Columbia River. Can. Jour. of Fish. Aquat. Sci. 53:542-549.

Matthews, G. M., D. L. Park, S. Achord, and T. E. Ruehle. 1986. Static seawater challenge test to measure relative stress levels in spring Chinook salmon smolts. Trans. Am. Fish. Soc. 115: 236-244.

Matthews, G. M., N. N. Paasch, S. Achord, K. W. McIntyre, and J. R. Harmon. 1997. A technique to minimize the adverse effects associated with handling and marking salmonid smolts. The Progressive Fish Culturist 59:307-309.

Mesa, M. G. 1994. Effects of multiple acute stressors on the predator avoidance ability and physiology of juvenile Chinook salmon. Trans. Am. Fish. Soc.123: 786-793.

Mesa, M. G. and J. J. Warren. 1997. Predator avoidance ability of juvenile Chinook salmon (*Oncorhynchus tshawytscha)* subjected to sublethal exposures of gas-supersaturated water. Canadian Journal of Fisheries and Aquatic Sciences 54: 757-764.

Mellas. E. J. , and J. M. Haynes. 1985. Swimming performance and behavior of rainbow trout (*Salmo gairdneri*) and white perch (*Morone americana*): effects of attaching telemetry transmitters. Can. J. Fish. Aquat. Sci. 42:488-493.

McComas, R. L., D. Frost, S. G. Smith, J. W. Ferguson, T. Carlson, and T. Aboellail. 2005. A study to estimate juvenile salmonid survival through the Columbia River estuary using acoustic tags, 2002. Report to U. S. Army Corps of Engineers, Contract E86910060, 78p (Available from Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097.)

Moore, A., I. C. Russell, and E. C. E. Potter. 1990. The effects of intraperitoneal implanted dummy acoustic transmitters on the behavior and physiology of juvenile Atlantic salmon, *Salmo salar* L. J. of Fish Bio. 37:713-721.

Muir, W. D., C. Pasley, P. Ocker, R. Iwamoto, T. Ruehle, and B. P. Sandford. 1994. Relative survival of juvenile Chinook salmon after passage through spillways at Lower Monumental Dam. Report to U. S. Army Corps of Engineers, Contract E86940101, 28p plus Appendices. (Available for Northwest Fisheries Science Center, 2725 Montlake Boulevard E., Seattle, WA 98112-2097.

Muir, W. D., S. G. Smith, R. N. Iwamoto, D. J. Kamikawa, K. W. McIntyre, E. E. Hockersmith, B. P. Sandford, P. A. Ocker, T. E. Ruehle, J. G. Williams, and J. R. Skalski. 1995. Survival estimates for the passage of juvenile salmonids through Snake River dams and reservoirs, 1994. Annual report to Bonneville Power Administration, Portland, OR, Contract DE-AI79-93BP10891, Project 93-29, and U.S. Army Corps of Engineers, Walla Walla, WA, Project E86940119, 187 p. (Available from Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097.)

Muir, W. D., S. G. Smith, E. E. Hockersmith, S. Achord, R. F. Absolon, P. A. Ocker, B. M. Eppard, T. E. Ruehle, J. G. Williams, R. N. Iwamoto, and J. R. Skalski. 1996. Survival estimates for the passage of yearling Chinook salmon and steelhead through Snake River dams and reservoirs, 1995. Annual report to Bonneville Power Administration, Portland, OR, Contract DE-AI79-93BP10891, Project 93-29, and U.S. Army Corps of Engineers, Walla Walla, WA, Project E86940119, 150 p. (Available from Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097.)

Muir, W. D., S. G. Smith, K. W. McIntyre, and B. P. Sandford. 1998. Project survival of juvenile salmonids passing through the bypass system, turbines, and spillways with and without flow deflectors at Little Goose Dam, 1997. Report to U. S. Army Corps of Engineers, Contract E86970085. (Available for Northwest Fisheries Science Center, 2725 Montlake Boulevard E., Seattle, WA 98112-2097.

Muir, W. D, S. G. Smith, R. W. Zabel, D. M. Marsh, J. R. Skalski. 2003. Survival estimates for the passage of spring-migrating juvenile salmonids through Snake and Columbia River dams and reservoirs. Annual report to Bonneville Power Administration, Portland, OR, Contract 1993BP10891, Project 1993-02900, 96 p. (Available from Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097.)

Normandeau Associates, Inc., J. R. Skalski, and Mid Columbia Consulting, Inc. 1995. Turbine passage survival of juvenile Chinook salmon (*Oncorhynchus tshawytscha*) at Lower Granite Dam, Snake River, Washington. Report to U.S. Army Corps of Engineers, Walla Walla, WA.

Normandeau Associates, Inc, J. R. Skalski, and Mid Columbia Consulting, Inc 1997. Juvenile steelhead passage survival through a flow deflector spillbay versus a non-flow deflector spillbay at Little Goose Dam, Snake River, Washington. Report to U.S. Army Corps of Engineers, Walla Walla, WA. Contract No. DACW68-96-D-0003.

Normandeau Associates, Inc., J. R. Skalski, and Parametrix. 1998. Feasibility of estimating smolt survival with radio telemetry through the Priest Rapids hydroelectric project, Columbia River, Washington. Draft Report for Grant County Public Utility District No. 2, Ephrata, WA.

Ploskey, G., T. Poe, A. Giorgi, and G. Johnson. 2001. Synthesis of radio telemetry, hydroacoustic, and survival studies of juvenile salmon at the Dalles Dam (1982-2000). Report to U.S. Army Corps of Engineers, Portland, Oregon.

Prentice, E. F., T. A. Flagg, and S. C. McCutcheon. 1990a. Feasibility of using implantable passive integrated transponder (PIT) tags in salmonids. Pages 317–322 in Parker et al (1990).

Prentice, E. F., T. A. Flagg, C. S. McCutcheon, D. F. Brastow, and D. C. Cross. 1990b. equipment, methods, and an automated data-entry station for PIT tagging. Pages 335–340 in Parker et al. (1990).

Ryan, B. A., S. G. Smith, J. M. Butzerin, and J. W. Ferguson. 2003. Relative vulnerability to avian predation of juvenile salmonids tagged with passive integrated transponders in the Columbia river estuary, 1998 – 2000. Trans. Am. Fish. Soc. 132: 275-288.

Schreck, C. B., R. Patino, C. K. Pring, J. R. Winton, and J. W. Holway. 1985. Effects of rearing density on indices of smoltification and performance of coho salmon. Aquaculture 45: 345-358.

Schreck, C. B. 1990. Physiological, behavioral, and performance indicators of stress. American Fisheries Society Sympsium 8: 29-37.

Seber, G. A. 1965. A note on multiple recapture census. Biometrika 52: 249-259.

Skalski, J. R., R. L. Townsend, A.E. Giorgi, and J. R. Stevenson. 1998. The design and analysis of salmonid tagging studies in the Columbia River Basin. Volume XI: Recommendations on the design and analysis of radiotelemetry studies of salmonid smolts to estimate survival and passage efficiencies. Draft Report to Bonneville Power Administration, Project 89-107.

Sokal, R. R., and F. J. Rohlf. 1981. Biometry. Freeman, New York.

Smith, S. G., J. R. Skalski, W. Schlechte, A. Hoffmann, and V. Cassen. 1994. Statistical Survival Analysis of Fish and Wildlife Tagging Studies. SURPH.1 Manual. (Available from Center for Quantitative Science, Box 355230, University of Washington, Seattle, WA 98195.)

Smith, S. G. W. D. Muir, E. E. Hockersmith, S. Achord, M. B. Eppard, T. E. Ruehle, J. G, Williams, and J. R. Skalski. 1998. Survival estimates for the passage of juvenile salmonids through Snake River dams and reservoirs, 1996. Annual report to Bonneville Power Administration, Portland, OR, Contract DE-AI79-93BP10891, Project 93-29 (Available from Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097.)

Smith, Steven, W. D. Muir, R. W. Zabel, D. M. Marsh, R. McNatt, J. G. Williams, and J. R. Skalski. 2004. Survival estimates for the passage of spring-migrating juvenile salmonids through Snake and Columbia River Dams and reservoirs. Annual report to Bonneville Power Administration, Portland, OR, Contract DOE/BP-00004922-4, Project 199302900. 118 p. (Available from Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097.)

Thorsteinsson, V. 2002. Tagging Methods for Stock Assessment and Research in Fisheries. Report of Concerted Action FAIR CT.96.1394 (CATAG). Reykjavik Marine Research Institute Technical Report (79), 179 p.

Zabel R. W., S. G. Smith, W. D. Muir, D. M. Marsh, J. G. Williams , and J. R. Skalski. 2001. Survival estimates for the passage of spring-migrating juvenile salmonids through snake and Columbia River dams and reservoirs, 2000. Annual report to Bonneville Power Administration, Portland, OR, Contract 1993BP10891, Project 199302900, 62 p. . (Available from Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA 98112-2097.)