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Briefing Paper :
Estimating Survival of Anadromous Fish through the Mid-Columbia PUD Hydropower Projects.

1 Purpose

The Mid-Columbia Habitat Conservation Plan (HCP) requires measurements of survival associated with passage through the Mid-Columbia Public Utility District hydropower dam projects for each anadromous species utilizing the reach as a migration corridor. The major objectives of this paper are to:

1) summarize relevant characteristics of each of the migrating salmonid populations using the Mid-Columbia reach;
2) briefly describe available tagging technologies (PIT tags, radio tags, balloon tags and acoustic tags).
3) develop recommendations for applying particular monitoring approaches given alternative objectives (e.g., dam passage survival vs total project survival, and
4) develop and describe protocols for evaluating future mark/recapture tools and strategies.

2 Upper Columbia - Species Characteristics

A number of salmon and steelhead runs pass through the Mid-Columbia PUD projects during juvenile migration. Juvenile migrants through this portion of the Columbia River enter from the major tributaries to the Columbia River below Chief Joseph Dam (the Wenatchee, Entiat, Methow and Okanogan rivers). Natural and hatchery runs of spring chinook, steelhead, sockeye, summer chinook and fall chinook use the reach for migration. Each of these run components has particular characteristics that need to be considered in developing passage related survival and mortality estimates. Run timing and size distribution are two key factors to consider in designing a sampling program. The following sections summarize available information on major components of the juvenile migration through the Mid-Columbia reach.

2.1 *Spring Migrants*

Juvenile spring chinook, steelhead and sockeye migrate through the Mid-Columbia reach during the spring (April through June). Specific information on run timing and migrational characteristics (age and size at migration) are summarized for each species in the following sections.

2.1.1 <u>*Yearling Chinook*</u>

2.1.1.1 Run timing

Smolt sampling at Rock Island Dam is the primary source of information on the run timing of juvenile chinook and steelhead through the mid-Columbia river reach (e.g., Peven & Fielder, 1988, Peven & Hayes, 1989). In general, yearling spring chinook of both hatchery and natural origin migrate past Rock Island Dam from early April through June. The bulk of the migration (traditionally expressed as the middle 80% of the run) passes between mid April and late May.

2.1.1.2 Size distribution
Upper Columbia spring chinook salmon migrate typically migrate to the ocean as yearling smolts. In the 1980's, a series of purse seine samples of migrating chinook and steelhead juveniles were obtained in the mainstem Columbia above Wells Dam (McGee et al, 1983, 1984, McGee,1985). Fork length measurements were taken on representative samples of the catch and reported as average fork length and range. Those results are summarized below in Table 1.

Table 1. *Spring Chinook: Fork length measurements of yearling migrants (hatchery and wild combined) obtained by purse seine sampling in mainstem above Wells Dam (McGee et al., 1983,1984 and,1985).*

Migration Year	***Sample Size***	***Sample Avg. Fork Length (mm)***	***Sample Range in Fork Length (mm)***
81	2388	132	73 - 185
82	1632	126.1	114.5 - 131.9
83	2678	131	74 - 193

In addition to yearling (natural and hatchery) spring chinook, hatchery releases of summer and fall chinook stocks reared to yearling size are present in the Mid-Columbia reach In general, the average fork length of out migrating summer and fall hatchery yearling releases is similar to that reported for spring chinook (average fork length of 110-130 mm). Hatchery releases of yearling summer chinook occur in April during the spring outmigration.

2.1.2 <u>*Steelhead*</u>
Steelhead originating in the upper Columbia region initiate migration to the ocean after 1 to 7 years (or more) of freshwater rearing (e.g., Peven, 1990, Brown, 1995). A relatively high proportion of the natural run migrates after 2 or 3 years of freshwater rearing. Hatchery produced smolts are reared on an accelerated schedule and released as yearlings.

2.1.2.1 Run timing
Run timing of migrating steelhead smolts through the mid-Columbia is similar to that described for spring chinook. The middle 80% of the run passes Rock Island Dam between early May and early June.

2.1.2.2 Size Distribution

The average size of migrating wild steelhead smolts sampled at Rock Island in the late 1980's was reported by Peven (1990). In 1988, smolt fork lengths averaged 167 mm, ranging from 127-270 mm. Average length in 1987 was reported as 172 mm. Sampling in 1989 estimated average length to be 179 mm with a s.d. of 24.7 mm.

2.1.3 *Sockeye*

Two major sockeye production areas exist upstream of some or all of the five Mid-Columbia PUD mainstem dam projects (e.g., Peven, 1986). Sockeye salmon originating in the Okanogan River system migrate past all five of the Mid-Columbia projects. The other major natural production area for sockeye in the region is the Wenatchee system. Production from this drainage migrates through the lower three of the Mid-Columbia PUD projects.

2.1.3.1 Run timing

Juvenile sockeye migrate downstream in the spring. Based on results from daily smolt trap collections at Rock Island dam since 1985, migrating sockeye are present from early April into June and July, with the bulk of the out-migration occurring from mid-April through late May. There are apparent differences in size at emigration, time of peak out-migration and migration speed through the Mid-Columbia reach for the two major components of the Upper Columbia sockeye run (see Chapman, et al., 1995 for detailed discussion).

2.1.3.2 Size Distribution

Length frequency data on juvenile sockeye migrating through the Mid-Columbia projects is available for Wells Dam, Rocky Reach Dam and Rock Island Dam. Those data sets demonstrate a strong difference in average length between fish originating in the Okanogan and the Wenatchee systems, respectively. Fish sampled at or above Wells Dam and at or above Rocky Reach dam most likely originate in the Okanogan system. Smolt migration from the Lake Osoyoos rearing area tends to be 2 to 3 weeks later than migration from Lake Wenatchee (e.g. Chapman, et al., 1995). Length frequency distributions generated from juvenile sockeye sampling at Rock Island Dam are characterized by a bimodal pattern (Peven, 1986). Smolts emigrating from the Wenatchee system are smaller on average than smolts originating above Wells Dam. Based on a review of the relative length frequency information for these two sources, Peven (1987) suggested a length cutoff of 100 mm to differentiate between Wenatchee and upper river origin smolts in the Rock Island samples.

Table 2. *Average and standard deviation of fork length measurements for Wenatchee an Okanogan origin sockeye juvenile sockeye (Peven, 1986).*

	Fork Length in mm: Average (Standard Deviation)	
Migration Year	**Wenatchee Origin Sockeye**	**Okanogan Origin Sockeye**
1988	***97.1 (11.8)***	***113.1 (18.3)***
1989	***81.1 (14.3)***	***108.4 (16.5)***

A high percentage of the migrants passing Rock Island Dam in April and May are sockeye that likely originate from the Wenachee system. The length frequency distributions for sample at Rock Island dam in late April early May support the hypothesis that fish migrating from the Wenachee are consistently smaller than fish from the Okanogan migration (Peven, 1986).

Table 3. *Juvenile sockeye migrants: average (and standard deviation) of fork length measurements from biweekly sampling at Rock Island Dam.*

	Fork Length in mm: Average (Standard Deviation			
Migration Year	**Mid - April (e.g. 4/16-4/23)**	**Late April (e.g. 4/24 - 5/2)**	**Mid May (e.g., 5/4-5/15)**	**Late May into June (e.g. 5/16-6/8)**
1987	85.2 (10.3	82.3 (8.1)	87.3 (23.8)	114.6 (10.3)
1988	98.6 (13.7)	95.7 (9.7)	101.8 (13.6)	116.2 (18.6) 122.8 (15.4)
1989	77.9 (9.2)	81.0 (13.9)	92.6 (20.9)	113.1 (11.4)
1990	95.4 (9.6)	95.3 (9.9)	103.4 (17.4)	121.4 (12.3)
1991	95.3 (18.4)	104.6 (25.9)	100.8 (20.7) 108.0 (15.5)	110.4 (14.4) 118.9 (10.3)
1992	120.0 (14.1)	116.0 (15.5) 115.0 (14.2)	134.0 (26.4)	154 (21.7)

2.2 ***Spring/Summer Migrants***

2.2.1 <u>Subyearling Chinook</u>

Subyearling chinook migrating through the upper Columbia include natural and hatchery origin components of summer and fall chinook . Naturally produced ocean type (subyearling) chinook originating in the Upper Columbia use mainstem reaches for both extended rearing and directed migration (e.g., Chapman, et al., 1994). Similar life history patterns have been observed for Snake River fall chinook juveniles originating from spawning in the mainstem above Lower Granite Dam. Summer chinook mitigation and supplementation programs release both yearling and subyearling groups. Yearling releases are used in the various tributary supplementation programs underway in the region. The Wells and Turtle Rock hatchery facilities have made significant onsite releases of subyearling chinook into the mainstem Mid-Columbia in recent years (Table 4).

Table 4. *Subyearling (summer and fall) chinook releases in the Mid-Columbia reach (approximate average fork length in mm). Release information from Fish Passage Center on-*

line data base. Fish per lb to length conversions from WDFW Hatchery division.

Release Year	Periods					
	May 1-15	**May 15-31**	**June 1-15**	**June 16-30**	**July 1-15**	**July 16-31**
1988		1,562,520 (~90mm)			197,000 (~124mm)	
1989	386,269 (~71mm)	1,370,401 (~88mm)				411,387 (~117mm)
1990		1,310,656 (~90mm)				210,473 (~136mm)
1991			436,024 (152 mm)	329,669 (~105 mm)		
1992		630,238 (~65mm)		493,919 (~117 mm)		
1993				1,522,000 (~93mm)	134,000 (~90 mm)	
1994				1,025,682 (97-115 mm)		
1995				1,944,935 (97-126 mm)		
1996			408,000 (~117mm)	1,243,600 (~105mm)		
1997				1,335,515 (88-120mm)		
1998			541,923 (~104mm)	1,029,540 (98-120mm)		
1999			1,571,463 (~104mm)			
2000			363,600 (~136mm)	716,972 (95-120mm)		
2001				498,560 (~110mm)	1,054,194 (110-115mm)	

2.2.1.1 Run Timing

Subyearling chinook are present in the mid-Columbia reach from late May into August. Typically the middle 80% of the aggregate run passes Rock Island Dam between early/mid June and the first week in August. Releases of subyearling summer and fall chinook at Turtle Rock Hatchery and above have shifted later into the summer over the past 10-15 years (Table 4). Currently, subyearling hatchery releases at or above Turtle Rock Hatchery are in late June and early July.

2.2.1.2 Size Distribution
Subyearling chinook are released into the Mid-Colombia River at the Wells and Turtle Rock Hatchery facilities. Since the early 1980s, the timing for the majority of the releases has shifted to mid-June from mid-May (Table 4). Subyearling smolts in these releases average approximately 90-100 mm in fork length (based on reported fish/pound estimates and standard conversion tables (Bob Foster, NMFS pers. comm.). In some years additional releases reared under an accelerated growth program are made in July. Fish in these releases average approximately 130 mm. On-station subyearling releases from Wells Hatchery and the Turtle Rock facility are made into the mainstem Columbia below Wells Dam and above Rocky Reach dam.

Natural production of subyearling migrants occurs above all of the Mid-Columbia projects. Subyearling migrants are produced by runs of summer chinook and fall chinook. Life history patterns for these runs are similar to those reported for fall chinook in the Snake River (e.g., Connor et al., 2001). A significant portion of the juveniles (35-45mm) move downstream from natal areas soon after emergence. As the juvenile chinook feed and grow, downstream migration rates increase. The average size of subyearling migrants in samples increased in by approximately 10 mm over the extended juvenile migration period (June - October). These characteristics are similar to those reported for juvenile Snake River fall chinook migrants (e.g., Connor, et al., 2001).

Length frequency data collected at Rock Island (e.g., Peven & Fielder, 1991) for fish classified as subyearlings typically show a bimodal distribution for the out-migration. The first mode in the distribution is believed to represent naturally produced subyearlings. Early in the migration this mode is centered on fish 40-60 mm in length. Over the migration season this mode increases in size, with peak counts at lengths of 80-90 mm by late July. A second mode in the distribution centers on lengths of approximately 110 to 120 mm. The larger mode likely includes a combination of hatchery and natural juveniles.

Subyearlings migrating past Wells Dam are from natural production areas, primarily summer chinook produced in the Methow and Okanogan Rivers (see Chapman et al., 1994 for more detailed discussion). Subyearlings passing Wells Dam are typically 80-100+ mm in fork length (Fig. 1). Gatewell sampling during the summer migration period has been conducted at Rock Island Dam since the late 1980's. Two modes are typically found in subyearling length frequency distributions from Rock Island sampling in June and July (Fig. 2). One mode (peak count at approximately 50-60 mm) may represent downstream movement of rearing juveniles produced in the lower mainstem of the Wenatchee River that flows into the Columbia about 15 miles upstream of the Rock Island facility. The second mode (peak at approximately 110-120 mm) is made up of potentially more actively migrating smolts from natural production areas and the upstream hatchery releases. The difference in length frequency distributions between Wells and Rock Island is clear when the sampling data are summarized as cumulative distributions (Table 5). In both cases more than 70% of the sample population had fork lengths less than 100 mm. However, only 2% of the samples taken at Wells Dam had fork length of 60 mm or less in comparison to 35% of the samples from Rock Island.

Table 5: *Averaged cumulative length frequency distributions from Wells and Rock Island sampling programs.*

	Percentage of juveniles in samples with fork lengths LESS THAN threshold	
Threshold Length	***Wells(1983 & 84)***	***Rock Island (1988-90)***
60 mm	2%	35%
80 mm	18%	58%
100 mm	72%	77%
120 mm	94%	93%

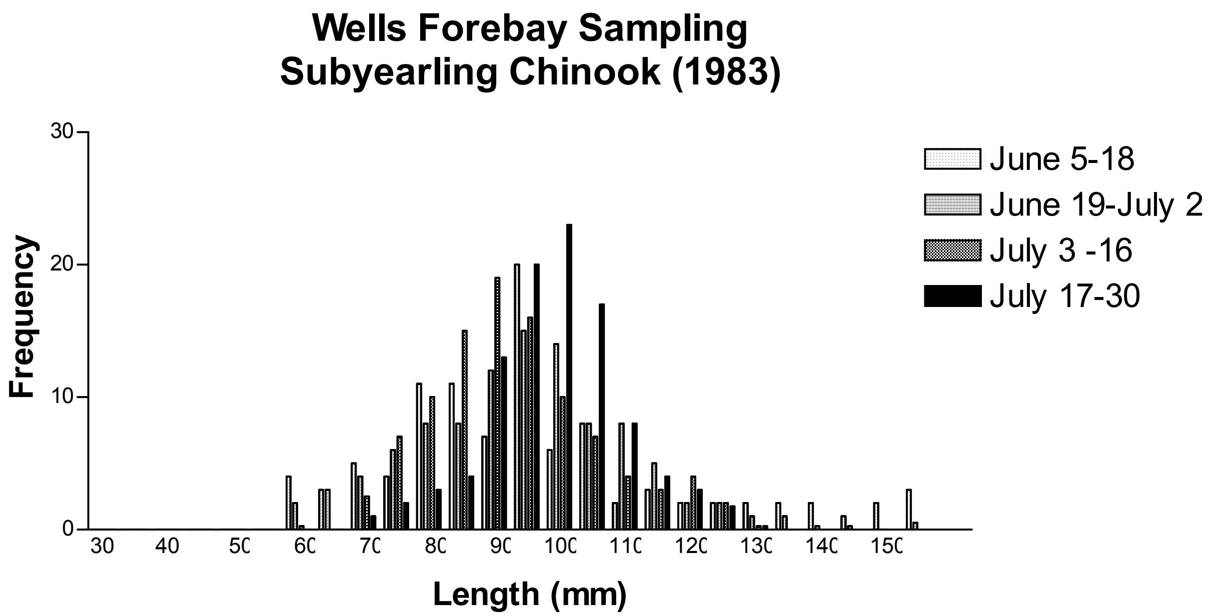


Figure 1 *Subyearling length frequencies from biweekly Wells Dam forebay sampling program in1983 (data from graphs in McGee,1984)*

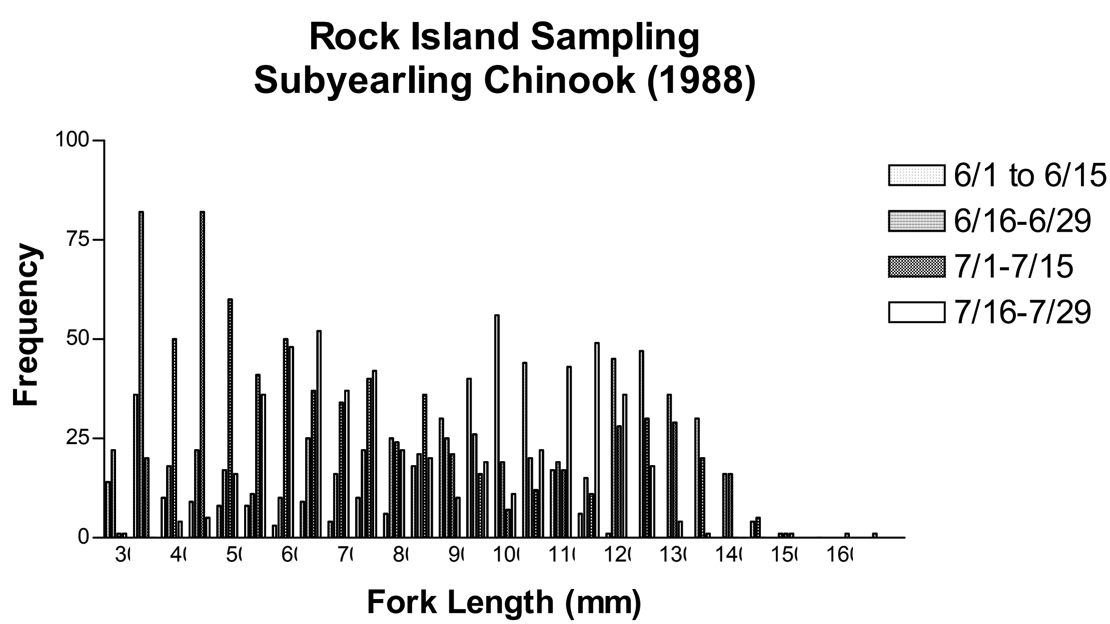


Figure 2 *Subyearling length frequencies from biweekly Rock Island gatewell sampling program in 1988 (data from graphs in Peven & Fielder, 1988)*

3 HCP Survival Objectives

The Mid Columbia HCP approach is predicated upon a basic mitigation goal: achieving the equivalent of no net impact (NNI) through a combination of passage survival measures, habitat improvements and hatchery mitigation. The passage survival component of the NNI goal is to achieve a 91% or higher cumulative survival (adult X Juvenile) as a result of passage through a particular Mid-Columbia project (reservoir, forebay, dam and tailrace). Improved direct juvenile survival through each upper Columbia dam is a major focus of the action plans incorporated into the Mid-Columbia HCP. Limitations associated with the best available technology have required the development of three standards for assessing juvenile survival at the Project. In order of priority, they are 1) Measured Juvenile Project Survival, 2) Measured Juvenile Dam Passage Survival, and 3) Calculated Juvenile Dam Passage Survival.

3.1 ***Juvenile Survival Measures***

With respect to juvenile migration through the Mid-Columbia PUD projects, the HCP clearly identifies Measured Juvenile Project Survival as the preferred metric of project performance for all species. However the HCP language also recognizes limitations on available technology and information may delay successful use this concept, at least for some migration types (e.g., subyearling chinook, sockeye). The HCP identifies alternative standards for use in evaluations of performance against overall survival objectives until it is possible to adequately measure Juvenile Project Survival for all species.

3.1.1 *Juvenile Project Survival - 93% Criteria*:

Juvenile project survival for each Plan species is defined as "*... the measurement of survival for juvenile Plan Species over 95% of each species migrating from tributary mouths and through the Project's reservoir, Forebay, Dam and Tailrace including direct, indirect and delayed mortality, wherever it may occur and can be measured (as it relates to the Project) given the available mark-recapture technology. "*

3.1.2 *95% Juvenile Dam Passage Survival*

Two different approaches to the estimation of survival impacts specifically associated with passage at the dams have been identified in the HCP discussions, Measured Juvenile Dam Passage Survival and Calculated Juvenile Dam Passage Survival.

> *Measured Juvenile Dam Passage Survival*: The Mid-Columbia HCP defines this criteria as follows: *"Juvenile Dam Passage Survival" means that 95% of each juvenile Plan Species over 95% of each species migration survive Projects effects when migrating through the Project's Forebay, Dam and Tailrace including direct, indirect and delayed mortality wherever it may occur and can be measured (as it relates to the Project), given the available mark-recapture technology.*
>
> *Calculated Juvenile Dam Passage Survival* for each Plan species is consistent with Measured Juvenile Dam Passage Survival except that offsite information is utilized where site-specific information is not available (e.g., a synopsis of turbine survival

information may provide more robust information than that currently available at a single location).

Calculated Juvenile Dam Passage Survival would require an estimate of the proportion of the migration passing each project by route (spillway, turbine, bypass).

PIT tag reach survival experiments involving the juvenile passage of yearling spring chinook and steelhead smolts through Lower Snake river mainstem projects are available for several migration years. It is clear from examining those results that there is substantial year to year variability in mean annual survival given relatively similar flow/spill regimes. The Mid-Columbia HCP documents all call for the use of three year averages in first phase evaluations of project survival against the specific standards described above.

4 Survival Study Criteria and Protocols

Juvenile passage survival through various mainstem hydropower projects on the Columbia and Snake Rivers has been the subject of a large number of studies over the past 20-30 years (e.g., Raymond (1979), Muir et al., (2000a),Muir et al., (2000b), Smith et al., (in press), Williams et al., (2001), and Bickford and Skalski (2000).

The objectives for juvenile survival studies on salmonid migrants in the Columbia River system fall into three general categories:

1) studies designed to determine the relative survival through a particular passage route;
2) studies designed to identify causal factors for mortality within a particular passage route and,
3) single or multiple reach experiments designed to measure the net project effect on the run.

4.1 *Study Design Considerations*

There is general agreement that a good study design should clearly reflect the specific survival study objectives or potential uses. A number of authors have identified protocols or criteria for studies designed to evaluate different aspects of juvenile passage survival. For example, Iwamoto and Williams (1993) summarized a set of key considerations that should be addressed in the design and interpretation of passage survival experiments:

> *"Species, size, condition, physiological state, and source of fish should be evaluated carefully. If feasible, the same stock of fish should be used to evaluate survival at different dams. Given the standardization of conditions, the generality or specificity of the results could be determined.. ...release and recovery methods should be standardized.*
>
> *....evaluation of (such) new developments should follow a systematic and consistent plan to eliminate as many confounding variables as possible.*

> *Different species of fish might have different vertical distributions in the water column (refs). This might affect the percentage of fish guided away from turbines into gatewells or the pathway through the turbine (refs). ...degree of smoltification affected fish guidance, and that less smolted fish had a greater tendency to pass through turbines rather than bypass systems.*

The following general criteria are based on a review of recent Columbia River survival studies and study critiques:

> test fish should have similar physical and behavioral characteristics as the target population
>
> release and capture methods for marked fish should not impact survival estimates.
>
> Tag releases and recovery samples should be of sufficient size to meet statistical criteria
>
> Experimental design should conform to the migration patterns of run of the river fish
>
> Passage conditions prevalent during the migration of marked fish should be representative of conditions during the migration of run of the river fish.

Additional criteria reflecting the specific experimental objectives and the particular tagging/sampling scheme will also be identified below.

4.1.1 <u>Statistical Models</u>
Most reach survival studies are variations on either a single or paired release and recapture/detection experiment. Basic statistical models for those variations have been adapted from Burnham et al. 1987 and described in several recent papers and reports (e.g., Dauble et al., 1993; Eppard, et al., 1999; Skalski, et al., (1998), Normandeau et al., 1998; Lady et al. 2000).

Basically, the models rely on comparison of recoveries from known releases or (or an initial release and particular recapture/detection/releases) to generate an estimate of the relative difference in survival. In addition to point estimates of the difference in survival, the basic statistical models allow for the estimation of variance associated with a particular experimental measurement.

For example, Skalski et al. (1998) lists the following key assumptions for reach survival experiments using PIT tag technology:

> A1. Test fish are representative of the population of inference.
> A2: Test conditions are representative of the conditions of inference.
> A3: The number of fish released is exactly known.
> A4: Tags are accurately recorded at the time of tagging and at all detection sites.
> A5: For replicated studies, data from different releases are statistically independent.

A6: The fate of each individual fish is independent of the fate of others.
A7: All fish in a release group have equal survival and detection probabilities.
A8: Prior detection history has no effect on subsequent survival and detection probabilities.

4.1.2 *Annual Survival Estimation*

Most reach survival experiments of mainstem Columbia or Snake River hydropower projects are aimed at characterizing the average survival across the migration of a particular type of anadromous fish: yearling chinook, subyearling chinook, yearling steelhead, etc. Experiments are designed, usually incorporating multiple releases across the target smolt out-migration, to generate an estimate of average survival during the migration.

In most cases, the expected survival difference generated by passage through a reach is relatively small, on the order of 2 to 20%. The statistical precision of a particular estimate is a function of the relative change in survival and the recapture/detection sample sizes. Often the basic recapture/detection rates are limited by physical conditions or operational considerations, leaving release size as the only variable that can be adjusted to achieve a desired level of precision.

Target levels of precision are often expressed as a 95% confidence interval or as a standard error of the mean estimated survival across replicates within a particular migration year. Release levels sufficient to generate estimates with standard errors on the order of 1-2.5% are typically the objective in designing annual studies. The Mid-Columbia HCP recommends that survival estimates should have a standard error of 2.5% or less.

5 Alternative Tagging Methods

Several different tagging methods have been developed and applied to estimate passage survivals for juvenile salmonids in the Columbia River system. The following sections describe each of those technologies, including a basic description of key assumptions, uncertainties and potential limitations/problem areas.

5.1 ***PIT tagging***

PIT (passive integrated transponder) tags were developed by NMFS in the mid-1980's as a tool for assessing juvenile salmon and steelhead migration in the Columbia basin (e.g., Prentice et al., 1990). Statistical approaches adapted to the characteristics of PIT tag use have been developed and described in a number of reports (e.g., Smith et al., 1994, Skalski et al.,1998). In recent years, PIT tag experiments have played an important role in estimating project level survivals in the Snake River for spring chinook, steelhead and subyearling migrants (e.g., Achord et al., 1996, Muir et al.,2000a; Muir et al., 2000b; Smith et al., in press; Williams et al.,2001). Establishment of lower river detection (dam and trawl based) has extended the application of PIT tag experiments to include statistically valid estimates of survival through lower Columbia reaches. PIT tag experiments to estimate reach survivals for yearling migrants (chinook and steelhead) have also been conducted in the Mid-Columbia river in recent years (e.g., Bickford, et al., 1999, 2001; Eppard, et al., 1999).

5.1.1 Requirements

Protocols for tagging representative groups for PIT tag experiments have been described in detail in a number of studies (e.g., Skalski, et al., 1998, Connor et al., 1998). PIT tags have been applied to sample groups collected from the river as well as to sample groups obtained from hatcheries. Studies to determine the effect of tagging on performance and survival have been described by several authors (e.g., Skalski et al., 1998, Muir et al., 1998). Direct handling and tagging losses are generally low. For example, Muir et al. (1998) reported direct mortality rates for spring chinook juveniles PIT tagged at Lower Granite Dam were less than 1% and 2% or less for steelhead migrants. Post-tagging mortalities averaged less than 0.4% (measured over 24 hours) for both species. PIT tags have been applied to subyearling chinook as small as 60 mm in fork length with little direct mortality (e.g.Connor, et al., 1998).

PIT tag experiments are generally variations on basic mark/recapture designs as discussed above. Survival estimates for a specific component of the migration route of a target population are generated by comparing survival rates from points that bracket the targeted reach or dam passage route to a common point of detection downstream. Estimates of the relative survival through the target reach or dam passage route are generated through statistical analysis of the relative recovery rates of the PIT tag groupings at the downstream sampling location (s). Two basic experimental design variations have been used in PIT tag experiments involving Snake and Columbia river juvenile salmonid migrants. Paired release designs are based on downstream recoveries from two or more release groups that are put into the river at the upper and lower ends of the target reach or dam passage route. Single Release experiments are based on one upstream release and the ability to identify a specific subset of the tagged group at a location immediately downstream of the target reach. This subset of observed tags at the downstream location serves the same role as the downstream release in the Paired design. Detailed descriptions and discussion of the two experimental designs can be found in a number of reports and papers including Skalski et al. (1998) and Muir et al. (1998). Statistical routines for estimating component survivals from release/recovery information for a given series of release groups have been developed (Dauble, et al., 1993),

The basic requirements are: counts of treatment and control groups at three points 1) immediately upstream of the reach of interest, 2) immediately downstream (control release or census) and 3) consistent samples of the survivors from the two groups at two or more points downstream of the control release. Downstream detection of PIT tags is accomplished through the use of electronic detectors. There are serious constraints on detection capabilities related to limitations on electronics regarding detection distance and the extremely large volume of water flowing through the mainstem Columbia. In most instances, downstream detection capabilities are associated with major bypass facilities at Columbia River mainstem dams. For the Mid-Columbia, detection facilities are limited to a temporary installation in the bypass at Rocky Reach dam. The next downstream detection site is at McNary Dam, additional facilities are operational at John Day and Bonneville dams.

Sample sizes of PIT tag experiments are determined based on a desired level of statistical precision, rough estimates of the survival characteristics in the reaches traversed by migrants between release and detections, and the sampling fraction or detection rates at the downstream sites. Given the need to rely on detections at major lower river dams for most mid-Columbia reach experiments, detection rates at those facilities are an extremely important consideration in experimental design. Since the detection apparatus are directly tied to bypass systems, the level of spill during the juvenile migration is a key determinant of the required marking levels..

5.1.2 Mid-Columbia Considerations

PIT tagging has developed into a major tool for estimating reach survivals in the Snake River. PIT tag detectors have been operational at the upper three lower Snake River dams, and at McNary, John Day and Bonneville dams in the Lower Columbia. These detectors rely on the dewatering systems associated with bypasses at those projects. The lack of detection capabilities at mid-Columbia projects (except for the current, temporary operation at Rocky Reach Dam) has a major impact on the experimental design requirements for reach survival studies of Mid-Columbia hydropower projects.

1.Statistical Design. The lack of detection capabilities in the Mid-Columbia restricts the statistical design options for PIT tag experiments. Single release strategies are not practical, therefore PIT tag experiments aimed at estimating juvenile passage survival past Mid-Columbia PUD projects are limited to Paired Release designs.

2. Obtaining sufficient numbers of representative test fish. There is no current detection capability between Rocky Reach bypass system and McNary Dam. Therefore paired comparison studies of survival through Mid-Columbia project reaches below Wells Dam depend upon downstream detections at lower Columbia mainstem projects (McNary, John Day and Bonneville dams). Detection rates at those sites are typically low due to spill program requirements. As a result, release numbers have to be very high in order to meet basic within year precision requirements.

Bickford et al. (1999) compared survival estimates for mark groups obtained from hatcheries with mark groups obtained from trapping actively migrating hatchery juveniles. Arrival timing patterns recovery facilities differed substantially between the two groups. In addition, the estimated survivals for the initial reach in the study were significantly different between the two study groups. Bickford et al. (1999) recommended that if hatchery smolts are used as test subjects for reach survival experiments, using “volitionally migrating’ hatchery smolts could minimize the differences between run of the river migrants and test fish taken from a hatchery program.

Release sizes to achieve a particular level of precision can be calculated given a rough estimate of the expected average survival through the experimental reach and estimates of detection rates at downstream federal facilities with detection capabilities. Mid-Columbia PIT tag experiments have used recoveries from a combination of downstream sites including McNary Dam, John Day

Dam, Bonneville Dam, and lower river trawling based sampling conducted by NMFS. Eppard et al. (1998) summarized the results from a pilot survival estimation program in the Middle Columbia using PIT tagged yearling fall chinook. Release levels in the pilot program were on the order of 22,500 juveniles per release site. Based on the results of this study, Eppard et al. (1998) recommended that careful consideration should be given to pre-release holding/rearing strategies for marked groups given the potential effect on survival; experienced personnel should be used for applying tags in critical experimental situations, 4) avoid exposure to super saturated water.

Expected detection rates can be generated given recent year experiences. Spill level at the lower projects is an important determinant of the number of fish to be tagged in order to achieve a desired level of precision in reach survival estimates (see Example below).

For comparison, detection capabilities associated with the temporary bypass operations at Rocky Reach dam have allowed for more efficient PIT tag based project survival studies for Wells project. Sample sizes to achieve equivalent standard errors (.017 to .025) ranged from 80,000 to 40,000 for paired release sample designs (see Skalski memo, 11 Jan. 1999).

Example 1a (S. Smith, personal communication)
Estimated number of marked fish required to achieve a target precision level on project survival (head of pool to tailrace) for mid-Columbia projects BELOW and including Rocky Reach Dam. Example based on yearling chinook/steelhead information.

Scenario assumptions: Constant survival for replicates in target reach (e.g., head of Rock Island Pool to Rock Island tailrace). Survival from lower project (e.g., Rock Island) to McNary = .765
to John Day Dam = .85.

Potential Spill levels at Lower River Detection Projects	***Detection Rates (Proportion of Tags Passing the Downstream Facility that are Detected)***		
	McNary	John Day	Bonneville
High Spill (2000)	.116	.100	.075
Low Spill (late 2001)	.400	.223	.150
No Spill (Early 2001)	.750	.380	.230

Total Release level required to estimate survival as a function of desired precision, potential survival estimate and detection rates at mainstem projects. ***Precision*** is defined as the expected half-width of a 95% confidence interval around the mean of the replicate survival estimates. It is calculated as 1.96 times the standard error of that mean estimate.

Expected Reach Survival	**Spill Level at Detection Projects**	**Precision Level**		
		.05	**.03**	**.02**
.90	***High***	317,000	880,000	1,974,000
	Low	27,300	75,600	169,800
	None	4,750	13,200	29,700
.93	***High***	333,000	923,000	2,079,000
	Low	28,500	79,200	177,600
	None	4,900	13,580	30,500
.96	***High***	349,000	966,000	2,178,000
	Low	29,800	82,800	185,600
	None	5,040	14,000	31,500

5.2 *Radio Tagging*

Radio tagging approaches to monitoring migrant smolt survival have evolved significantly since initial applications in the 1980's (e.g., Skalski, et al., 2001). The basic components of radio tags used for smolt survival studies are a small transmitter, battery and whip antenna. The standard sizes of Lotek transmitters currently used in survival studies are approximately 1.4 grams and 1.7 grams (A. Giorgi, personal communication). Smaller tags are being used on an experimental basis by USGS. Radio tags have been implanted into test fish using one of two methods - direct gastric implantation and surgical implantation into the peritoneal cavity. Surgical implantation reduces the risk of tag loss and has less potential impact on subsequent behavior and survival (Hockersmith et al, 2000)

5.2.1 <u>Criteria</u>

Minimum size criteria for smolt radio tag experiments reflect the results of laboratory and field experiments on the effects of tag and tag implantation methods on health, behavior, and vulnerability to predators. (e.g., Adams et al., 1998, Perry et al., 2000). For yearling migrant chinook, the minimum size criteria for tagging (based on use of the 1.4 gm Lotek tag) is 120 mm. The minimum size juvenile salmonid that can be tagged with the larger 1.7 gm tag is on the order of 150 mm. For steelhead virtually all migrants are above any potential lower size thresholds. The limiting size criteria for subyearling chinook is 110 mm fork length, but tag wt/fish wt measures are also used. For USGS tagging studies (using small tags), fish needed to be longer than the 110 mm fork length cutoff and had to weigh more than 13 grams.

Radio tag experiments to estimate reach survivals are generally analyzed as a multiple release-recapture/detection design (e.g., Skalski, et al., 2001). The relatively high detection rates possible for radio tags translates into relatively small release sizes compared to PIT tag studies to achieve a given level of precision. From a statistical perspective radio tag release sizes on the order of a few hundred individual fish could give the same precision as release PIT tag release sizes of approximately 100,000.

5.2.2 Previous Radio tagging Studies

The results of upper Columbia pilot studies on the use of radio tags to estimate smolt survival are described in Stevenson et al. 1999, Lady et al., 1999. Giorgi et al. (1988) summarized assumption tests for radio tag based survival estimates through Lower Granite project.

Table 6. *Summary of assumption tests for radio tag based survival estimates at Lower Granite project (from Giorgi, et al. 1988).*

Test	**Conclusion**
1. Survival of tagged vs controls exposed to pressure changes simulating turbine passage.	"(Radio-)tagged fish exhibit same survival as untagged fish."
2. Tag regurgitation under ambient and simulated spill and turbine passage.	"Tag regurgitation ....is negligible."
3. Fish guidance - behavioral differences between large (taggable) smolts vs general population	"Large smolts are representative of the general population with respect to guidance behavior."
4. Tag failure rate under ambient and simulated spill, turbine passage.	"Pressure changes associated with turbine, spill-like impact does not affect tag performance."
5. Tag interference with air bladder volume regulation.	Impairment noted. May affect vertical distribution - "recommend against using radio-tag for FGE work."
6. Tag impairment of swimming using swimming stamina as a response measure.	"Radio tags do not decrease swimming performance".

Initial attempts to use this technology in the Mid-Columbia were promising for larger sized migrant groups (e.g., steelhead). Given the size of radio tag transmitter units, there are significant size limitations on tagging vs size range of in-river migrating smolts for some species. A very high percentage of subyearling chinook and sockeye migrants (from Wenatchee) as well as a portion of the spring chinook yearlings are below the current minimum size threshold for radio tags (see section 2.1.3 and 2.2.1 above and figure 3).

Detection Considerations

Detection of dead smolts: The Lower Granite radio tagging studies identified a potentially serious problem with the use of radio tagging results to estimate project or passage survival - ".. these data would indicate that dead radio-tagged fish cannot be consistently differentiated from live ones in the tailrace. " Downstream detection arrays for the Lower Granite experiments were immediately downstream of the tailrace. Skalski et al. (2000) described a series of radio tagging experiments using radio tagged steelhead smolts to estimate project survival through Mid-Columbia PUD hydroelectric projects. Downstream antenna arrays were deliberately located well below the tailrace area in an attempt to avoid detections of dead radio tagged fish. Tests involving releases of dead radio tagged smolts resulted in no downstream detections in the Mid-Columbia experiments. Skalski et al. (2000) concluded that placement of the downstream detection site(s) some distance downstream (typically 5-10 km) can eliminate the problem of detection of dead radio tagged smolts. The particular placement of downstream detectors is a function of the specific setting and hydraulic conditions.

Detections outside of target areas: In a prototype radio tagging study, Rock Island forebay antennas "recorded not only smolts in forebay but also large numbers of smolts in the tailrace areas." (Lady et al., 1999). Reviewers also noted need for more detailed description of how electronic detection records were transcribed into accepted detections.

Radio Tag life vs travel time: At the Smolt Survival Workshop (fall of 2000 at Montlake), results from recent Rocky Reach project survival studies were discussed. In that work, radio tags expired sooner than expected, with the onset of tag failures occurring before fish cleared the project, "Consequently, reliable survival estimates could not be produced at Rocky Reach dam." Independent assessment of radio tag performance should be conducted on each years production lot to avoid mis-interpretation of survival studies based on detections. Tag life is a special consideration for the 'nanno' tags that would allow for tagging smaller migrants. Workshop participants noted that the current versions of 'nanno' tags have relative short active life - approx. 7 days. This significantly limits the value of such tags for reach survival estimates.

Tag Effects on Survival: As noted above, early work on the application of radio tags to large salmonid smolts indicated no significant effect of the tag on laboratory swimming ability, etc. Participants at the Survival Study Workshop raised uncertainties about assumption violations regarding the effect of radio tags on susceptibility to predation, swimming ability etc. over longer reaches.

As a result of recent work in both the upper Columbia and Snake Rivers, comparative estimates of reach survivals based on PIT tag and Radio tagging efforts are available for some reaches. Hockersmith et al. (2000) includes a summary of previous studies of tag effects and reports the results of a comparative reach survival experiment on the effects of gastric and surgical implantation of radio tags vs PIT tags. Over relatively short reaches (Lower Granite to Lower Monumental Dam, 106 km) the "....detection probabilities and survival were not significantly different among tag types between release sites and Lower Monumental Dam...but survival decreased for surgically and gastrically implanted sham radio-tagged fish compared to PIT tagged fish downstream." The results of Ice Harbor study comparisons of PIT vs Radio tag reach survivals were contrasted by D. Hockersmith. Participants at the Smolt Monitoring Workshop noted that the difference of approximately 2.7% in average survival could be accounted for by differences in size distributions between test groups of PIT tagged and radio tagged smolts. Radio tagging is restricted to larger fish because of transmitter size. Some investigators believe that the results of the comparisons are evidence that fish below radio tagging size threshold survived at a lower rate.

5.3 *Balloon Tags*
Balloon tags were developed to allow for the recapture of experimental fish subjected to particular passage routes (Heisey et al. 1992). Tagged fish are released into or immediately above targeted passage routes and collected immediately downstream of the project. Balloon tags are a useful tool for comparing relative survivals through particular passage routes. The specific requirements of a balloon tagging experiment (e.g., the need to place fish with known tag codes into specific passage routes, the potential for the tag itself affecting survival immediately downstream of the dam and typical recovery strategies) restrict the use of this tag to direct studies. This technology is not suitable for estimating total project survival or the direct measurement of total dam passage survivals.

5.4 **Acoustic Tags**
While acoustic tags have some of the same issues as radio tags, there are some significant differences as well. Smaller versions of acoustic tags are feasible. Radio tags have a long trailing antenna that may affect performance and therefore survival, acoustic tags do not. Current information indicates that tag failure rates are lower than rates for radio tags. Initial attempts to monitor passage of juveniles tagged with acoustic tags indicate that tag detection rates are good.
Tag life for acoustic tags depends on the ping rate and the strength. Preliminary tests indicate that 1.5 gram acoustic tags have a battery life of 19 to 25 days depending largely on ping rate. The potential tag life of smaller acoustic tags will presumably be shorter.

A committee set up by Chelan PUD is reviewing the potential application of acoustic tags in estimating project and dam survivals in the basin. The committee includes participants from NMFS, the USGS, Univ. of Washington, Chelan PUD and private consultants.

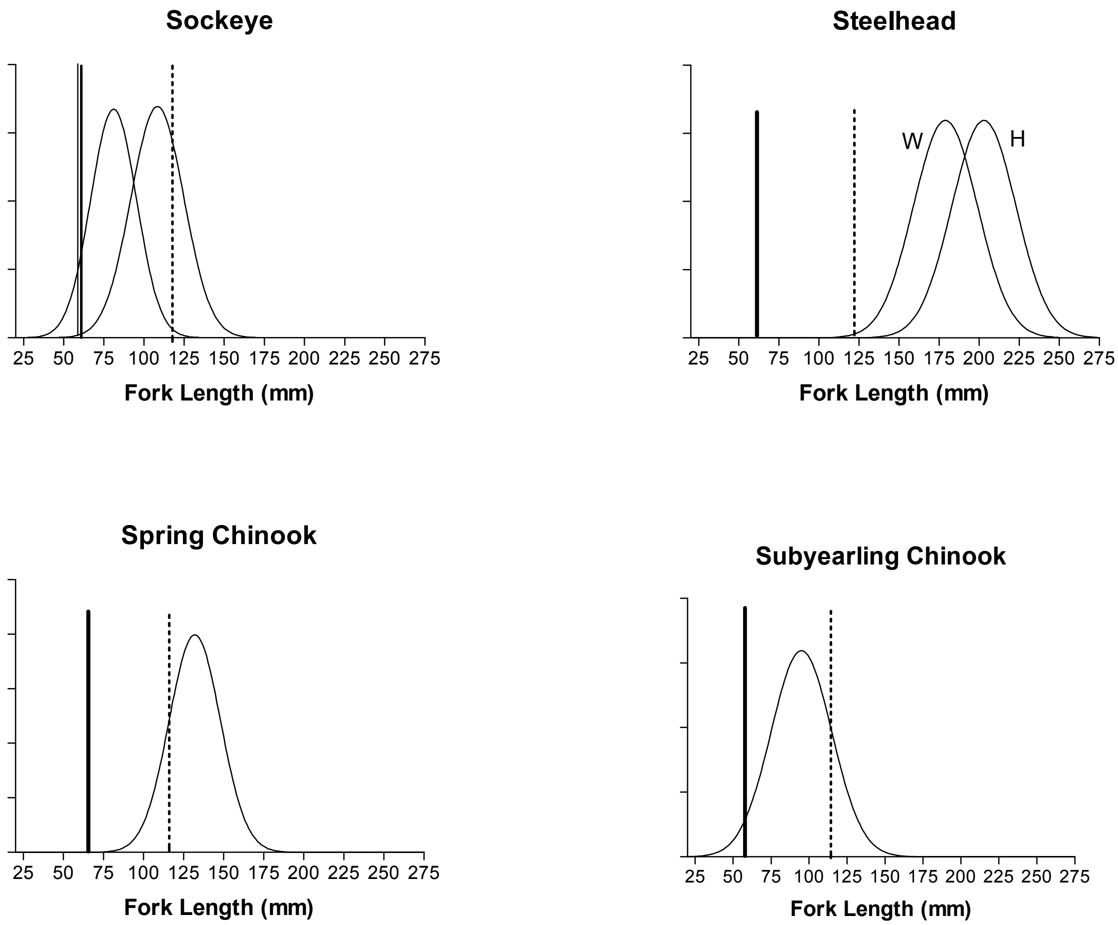
6 Recommendations
The following sections summarize key considerations and limitations for estimating different components of juvenile outmigration survival. Each of the tagging methods described above has specific strengths and weaknesses relative to the basic categories of survival estimates relevant to the Mid-Columbia HCP.

The draft summary of the fall 2000 Smolt Survival Workshop includes the following statement resulting from a panel discussion of survival estimation methodologies.

"..it is important to use the methodology best suited to the objectives of the study. The indefinite operational life of PIT tags makes them well suited for estimating survival over long river reaches. However, the limited operational life of radio tags, coupled with high detection rates and the relative ease of installing detection arrays make radio telemetry methodology best suited for estimating survival in relatively short river reaches."

In addition to direct sampling considerations, the ability to apply tags to a representative set of the particular target population is an important consideration. As illustrated in Fig. 3 below, current limitations on the size of fish that can be fitted with radio tags limits the ability to apply this tag to a representative set of the population for subyearling chinook, fall chinook and sockeye. The lower limit for PIT tag application is approximately 60mm (solid lines in fig. 3), allowing application to a significant majority of each of the different races/species of salmon/steelhead using the mid-Columbia reach for migration.

Figure 3. *Representative length frequency distributions and threshold tagging lengths. Solid vertical lines represent lower size threshold for PIT tags, dashed lines the lower threshold for 1.4 gram radio-tags*.



6.1 Project Survival

Project survival estimates reflect the impact of passage through the pool and dam of a particular hydroelectric project. PIT tags, radio tags and acoustic tags have been used in attempts to measure project survival. The following table summarizes key considerations, limitations and uncertainties for each tagging approach.

In general, PIT tagging approaches to estimate reach survivals have the potential to produce the most representative estimates of reach survivals of run of the river fish. PIT tags can be applied to significantly smaller fish than radio tags or acoustic tags. Therefore it is theoretically possible to generate estimates of reach survival for subyearling chinook and sockeye. However the lack of detection capabilities at most mid-Columbia projects combined with the difficulty in obtaining and tagging large numbers of representative test fish for these species are major logistic considerations.

6.2 Passage Survival Estimation

Studies in the Snake River and pilot experiments in the mid-Columbia have demonstrated that it may be feasible to use radio tags to get representative estimates of passage survival for larger sized juvenile migrants, particularly steelhead and spring chinook. Studies using radio tags must be carefully designed to be representative of the run of the river fish and to deal with potential detection problems.

Measured Juvenile Dam Passage survival through a dam is difficult to estimate with PIT tag technology due to problems in establishing a representative treatment group. PIT tagged fish released just upstream of the project are not likely to pass through the dam passage routes in proportionally with run of the river fish. PIT tagged fish released well upstream of a project may pass through various dam passage routes in proportion to run of the river fish, but detecting the particular PIT tags entering each route with that route is not feasible under most circumstances.

PIT tag experiments have been used to estimate route specific passage survivals for use in estimating Calculated Juvenile Dam Passage Survival. Expanding from PIT tag based route specific survivals to an estimate of Juvenile Dam Passage survival requires additional information on the proportion of the run of the river fish passing the project via alternative routes and the assumption that injecting PIT tagged groups into the passage routes has no effect relative to the survival of run of the river fish through the same route.

Acoustic tag technology has considerable promise for use in estimating dam passage survivals and, potentially, project survivals. As noted above, discussions are underway on designs for acoustical tag studies. Downstream recovery strategies for acoustic tags will need to take tag life and expected migration rates into account to minimize attributing battery failures to mortalities.

As noted above, Balloon tag methods are not suited for generating passage survival estimates in the context of the HCP criteria.

Table 7. Summary of key considerations and limitations on tagging methods with respect to estimating **PROJECT SURVIVAL.**

Consideration	PIT Tags	Radio Tags	Acoustic Tags
Test fish representative of run of the river fish	Run of the river samples: Potential effects of capture/tagging on subsequent survival of test fish. Inability to get sufficient numbers of representative fish to meet statistical requirements. Hatchery surrogates - potential for size and/or behavioral differences. Adjust rearing strategies to mimic run of the river fish.	Subyr Chinook & Sockeye: High proportion of run of the river migrants below minimum size for radio tagging. Requires validation that larger fish are representative (paired tests with PIT tag releases, inference from paired studies)	Current technology limited to larger fish, same concern as for radio tags. Possibility for reducing tag size.
Passage conditions during experiment representative of conditions for run of the river migrants.	Under moderate to high flow conditions, within year variation in survival high compared to between year. Need replicate groups across runs within years.		
Release & recap. method effects	Hatchery releases as surrogates for run of the river fish - may effect survival. Monitored volitional releases possible solution.	Detection of downstream fish by upstream detectors. Detection of dead fish Battery life limits downstream detection distances. Consider battery life in designing downstream detection strategies. releases sufficient distance upstream, design and site detection arrays to avoid inappropriate detections.	
	Survival estimates may be influenced by differences between test fish and run of the river fish in terms of timing and spatial distribution as a result of release methods (treatment and controls) Ensure sufficient mixing of test fish with run of the river fish after release. Apply statistical tests for mixing.		
Releases/Recovery samples sufficient for statistical precision	Release sizes required to be large because of detection efficiencies for projects below Rocky Reach dam.		

6.2 *Dam Passage Survival*

Table 8. Summary of key considerations and limitations on tagging methods with respect to estimating **DAM SURVIVAL.**

<table>
<tr><th>Consideration</th><th>PIT Tags</th><th>Radio Tags</th><th>Acoustic Tags</th></tr>
<tr><td>Test fish representative of run of the river fish</td><td>Run of the river samples: Potential effects of capture/tagging on subsequent survival of test fish. Inability to get sufficient numbers of representative fish to meet statistical requirements.

Hatchery surrogates - potential for size and/or behavioral differences. Use rearing strategies to mimic run of the river fish.</td><td>Subyr Chinook & Sockeye: High proportion of run of the river migrants below minimum size for radio tagging.

Requires validation that larger fish are representative (paired tests with PIT tag releases, inference from paired studies)</td><td>Current technology limited to larger fish, same concern as for radio tags. Possibility for reducing tag size.</td></tr>
<tr><td>Passage conditions during experiment representative of conditions for run of the river migrants.</td><td colspan="3">Distribution of test/control releases vs the distribution of run of the river fish relative to spillway, turbine bays, etc at target project. Matching spill conditions, etc. during tests to conditions applying during migration of run of the river fish.</td></tr>
<tr><td rowspan="2">Release & recap. method effects</td><td>Route specific passage estimates difficult but possible. Measured Juv. Dam passage very difficult because of inability to release test fish in a manner representative of the distribution of run of the river fish.</td><td colspan="2">Detection arrays designed and sited to avoid downstream detection of dead fish, upstream detection of tagged fish that are actually downstream of the dam.

Battery life limits downstream detection distances. Consider battery life in designing downstream detection strategies.</td></tr>
<tr><td colspan="3">Ensure sufficient mixing of test fish with run of the river fish after release, recapture locations should provide for discrimination of delayed effects at least through the immediate downstream reach (to the next dam).

Apply statistical tests for mixing.</td></tr>
<tr><td>Releases/Recovery samples sufficient for statistical precision</td><td>Release sizes required to be large because of the potential for low detection efficiencies at lower river projects resulting from spill programs.</td><td colspan="2">Develop initial release sizes based on expected detection capabilities. Confirm statistical precision with analysis.</td></tr>
</table>

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