Guidelines and Recommended Protocols For Conducting, Analyzing, and Reporting Juvenile Salmonid Survival Studies in the Columbia River Basin

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Glossary

Terms used in smolt survival studies conducted in the Columbia River Basin.

1. **Effect zone-** That segment of the hydroelectric system where fish encounter the mortality agents under study. An effect zone can be as small as a bypass outfall, or as large as the entire FCRPS.

2. **Zone of inference-** That segment of the hydroelectric system that extends from a release site through the last recapture[8] site that allows for survival estimation. This zone is defined by the tag being used for estimation and recapture locations.

3. **Direct survival/mortality-** Direct mortality occurs in close proximity in time and space to the causative mechanism (i.e., direct effects are localized and immediate—the impact causes mortality directly). Direct mortality is typically studied for fish passing a specific passage route (e.g., turbine or sluiceway) at a dam.[9] In terms of probabilities, direct survival is (1 – direct mortality).

4. Indirect survival/mortality- Indirect mortality occurs as a consequence of the causative mechanism, but *not* in close proximity in time and space to the causative mechanism. For example, fish passing through a turbine may be disoriented and become more susceptible to predation for some distance downstream. Resulting increased predation, then, would be mortality that occurred *indirectly* because of turbine passage. In terms of probabilities, indirect survival is (1 – indirect mortality).

5. Total survival/mortality- Total mortality is the combination of both *direct* and *indirect* mortality. In terms of probabilities, total survival is (1 – total mortality).

6. Delayed mortality- Delayed mortality is indirect mortality expressed beyond the of the *zone of inference*. Evidence for the existence of such effects can only be ascertained by sampling the tagged fish later in the life history, most commonly upon return as adults.

Because estimation of delayed mortality requires the measurement of adult returns, delayed mortality is outside the scope of a guidance document for juvenile survival studies.

7. Project survival- Survival of fish passing through a dam and the reservoir it impounds. The *effect zone* typically extends from the tailrace of the upper dam to the tailrace of the next dam.

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[8] We use the term "recapture" to denote detection of a tagged fish without handling throughout this document.

[9] Estimates of direct mortality are typically obtained using paired-release protocols, wherein treatment and control (reference) release sites bound the effect zone of interest. The zone of inference is also typically compact, with tagged fish recaptured shortly (minutes) after liberation and as close to the downstream end of the effect zone as practical.

8. Reach survival- Survival of fish passing through a segment of river that may include free-flowing sections or one or more hydroelectric projects.

9. Dam survival- Survival of fish going through the combined passage routes of the dam. The *effect zone* extends from the forebay to the tailrace. For example, in the mid-Columbia PUD's HCPs, this area is defined as 500 feet upstream of the dam to 1,000 feet downstream.

10. Reservoir survival- Survival of fish going through a reservoir. The *effect zone* extends from the tailrace of one dam to the forebay of the dam downstream. For example, in the HCPs, this area is defined as 1,000 feet downstream of the first dam, to 500 feet upstream of the next dam.

11. Absolute survival - The actual proportion of smolts surviving through the *zone of inference*.

12. Relative survival - The ratio of the absolute survival of two groups. For example, the ratio of absolute survival of two groups passing through different passage routes at a dam.

13. Survival estimate- An estimate of absolute survival through a particular *zone of inference*.

14. Route-specific survival- Absolute survival of fish going through a known passage route at a dam (e.g., spillway, sluice, turbines, etc.).

Executive Summary

Purpose of this paper:

The purpose of this document is to offer guidelines and identify opportunities for standardizing important aspects of smolt survival studies. We examine terminology, field methods, analytical frameworks, and reporting techniques, including suggestions to improve communication among managers and investigators.

Each year considerable funds and effort are expended toward estimating smolt survival through the hydroelectric projects on the Columbia and Snake rivers. The goal of most of this research, monitoring, and evaluation is to determine how effective assorted fish passage management actions have been at improving smolt survival during downstream migration. Fisheries and hydropower managers rely on results from smolt survival studies to assess progress toward that goal. It is critical that the resource managers clearly understand the results and their implications, as should investigators be attuned to the information the managers actually seek. This is not always the case. Managers have voiced concerns that survival reports from the different research organizations and agencies often use different terminologies, assumptions, and study designs, or they fail to clearly explain these topics. This document is an attempt to foster improved communication and informed decision-making by suggesting and promoting standards for conducting and reporting results from survival studies. Adopting these guidelines should assist in the preparation of clear research proposals and reports.

Study Designs: Methods for estimating smolt survival have evolved dramatically over the last decade with the advent of the Columbia Basin PIT-tag system, and further miniaturization of radio and acoustic transmitters. Today's experimental designs are founded on analytical models which provide smolt survival estimates for fish migrating through extended reaches of river, single projects (dam & reservoir), dams specifically, and individual passage routes at a dam. This paper presents a description of these experimental designs. Schematics depict the location of release and recapture site locations, as well as key parameters estimated within the geographical framework of the each study design. Importantly, key assumptions are listed specific to each design. Also, a method for estimating the sample size of tagged fish required to meet precision targets is described. This package of information provides the investigator with a roadmap to design sound survival studies. Managers can be confident that if these guidelines are followed sound estimates of smolt survival will be obtained.

Protocols for fish collection and release: Panel members felt there was a need and opportunity to identify guidelines for many protocols associated with the selection and handling of fish used in survival studies. Some of the key recommendations include:

- Fish transfers from rearing to tagging to release sites should be executed using water-to-water methods.

- During pre-tagging holding: ensure that O_2 levels exceed 7ppm; fish are held at least 12-36 hr prior to tagging, and in open systems; fish density does not exceed 15 g/l.
- Maximum tag-weight-to-fish-weight ratio of 5% for matching tag models with fish of appropriate size. For, example the smallest fish that can accommodate a 0.8 g tag is a 16 g smolt.
- The use of surrogate species may be the only option if populations are small, or the species are particularly sensitive to handling effects.
- Documenting tag performance is especially critical when active battery-operated tags are employed. A tag life profile test should accompany every such survival study.

A detailed example of one research team's methods and materials used in the collection tagging-holding-release phase is provided as an example.

Suggested guidelines for procedures that could be standardized glossary of terms typically used in the context of survival studies is presented. The panel suggests these be universally adopted to diminish confusion among managers and research teams. Additionally, a list of procedures and data that could be easily standardized among investigators is presented. Adopting these would help ensure that results are comparable across studies, a condition that is difficult to ascertain currently.

Reporting: The format and degree of detail currently presented in reports varies greatly. Often this makes comparisons among studies difficult. There are certain features that the panel recommends each research report contain:

- A summary page that lists the key features and results of each study. A template is provided.
- Documentation of environmental conditions monitored throughout the study period. Of particular concern are river conditions and relevant operating conditions during the course of the investigation.
- An Executive Summary that clearly states the key results and conclusions of the investigators.

Training: Standardized protocols for tagging fish with PIT tags are well established and documented. Refer to the "PIT tag marking procedures manual" at http://www.fpc.org/. However, procedures for acoustic and radio tagging have not been universally accepted or published. General guidelines have been established by individual groups of investigators, but no broad-based regional standards have been adopted. We see no immediate need or opportunity to establish a formal training program. However, we recommend investigators share the guidelines they have adopted internally. In-house training each season to initiate new staff appears adequate and is currently employed by most groups.

Data management: Procedures for managing PIT-tag data have been standardized over the last 10 years. Data management training is available for this technology, including a regional manual and hands-on sessions. Acoustic and radio telemetry data management procedures have not matured to the point PIT technology has. Different procedures and analytical methods have been used by different researchers. We suggest that researchers provide the following information in their reports:

- Identify criteria for identifying valid tag recaptures.
- Describe the data reduction process in a stepwise manner, preferably employing a flowchart.
- Provide the recapture history matrix used to calculate the survival estimates as an appendix.

Develop and report QA/QC procedures, including:

- Document water quality during holding (e.g., water temperatures, dissolved oxygen)
- Confirm tag operation at release
- Validate tags that are identified using any automated processing procedures. This can involve processing a subset manually and comparing recapture histories.

I. Introduction

The purpose of this document is to provide guidelines for standardizing terminology, analytical methods, and procedures used to conduct juvenile salmonid survival studies, and effectively report results to managers and decision-makers. Also, this report provides suggestions to improve communications among researchers and managers**.**

Background

One of the most important issues facing the management of Columbia River salmonids is determining the survival rate of juvenile salmon and steelhead as they migrate downstream past the complex of hydroelectric dams on the Columbia and Snake Rivers. Estimates of smolt survival form the basis of various critical performance measures used by fish managers, hydro-operators, and policy makers to evaluate the effectiveness of different management actions.

Within the Columbia Basin hydro-system, fishery managers have the responsibility to develop management actions that can foster the recovery and conservation of salmon and steelhead populations. The role of the research community is to evaluate the effectiveness of those actions, and being able to monitor changes in smolt survival is one of the key challenges. To ensure that the proper set of management actions is adopted, it is imperative that research investigations are properly conducted and results clearly presented. Unfortunately, the results of survival studies are not always clear and at times appear to conflict with similar studies. It is the researchers' responsibility to ensure that results are communicated to managers and hydro operators in a manner that can be easily interpreted and compared. This is critical when considering different conservation and management actions.

Regulatory processes that require estimates of smolt survival

<u>Northwest Power and Conservation Council (NPCC)</u>

The NPCC is a policy body made up of eight members, two from each of the states of Montana, Idaho, Washington and Oregon. It was established by the Pacific Northwest Electric Power Planning and Conservation Act of 1980, enacted by the United States Congress. The Act calls for the Council to develop a Fish and Wildlife Program intended to protect, mitigate, and enhance fish and wildlife on the Columbia River and its tributaries affected by the construction and operation of the hydroelectric system (NPCC 2000-19)

The Council has recommended funding of survival studies of juvenile and adult salmonids as they migrate through the system. The Council's Program has, in the past, included specific objectives for survival of juvenile salmonids as they pass downstream through the hydroelectric projects on the mainstem. Most recently, as an example of the Council's interest in the subject, in its "Mainstem Amendments to the 2000 Fish and Wildlife Program", the Council called for an experiment to evaluate the effects of modifying flow augmentation measures called for in the 2000 BiOp (NPCC 2003-4). Since flow augmentation has the objective of improving survival of juvenile salmonids as they migrate downstream in the lower Columbia River, it is obvious that there is a need for studies of survival in the lower river to evaluate the effects of this experiment for the Council

Army Corps of Engineers' (COE) Anadromous Fish Evaluation Program

Federal dam operators in the Columbia Basin are working to meet requirements in the Federal Columbia River Power System (FCRPS) Biological Opinion (BiOp). The BiOp prescribes 199 reasonable and prudent alternatives (RPA) that NOAA Fisheries believes will avoid jeopardizing the continued existence of Snake and Columbia River salmon and steelhead trout listed under the Endangered Species Act. In addition to specific RPAs, the BiOp defines performance standards for the hydrosystem that include adult and juvenile fish survival levels. These survival standards are to be achieved by 2010.

Many of the RPAs call for assessing the survival benefit associated with proposed changes to the configuration and operation of dams. In response to these RPAs, the Corps has been conducting studies that compare dam and route-specific fish survival under alternative operations or configurations to fish survival under the status quo. In addition, the Action Agencies (Bonneville Power Administration (BPA), COE, US Bureau of Reclamation (USBR)) are required to monitor smolt survival through the FCRPS as prescribed in the BiOp. However, the BiOp did not specify how these will be measured; therefore the Action Agencies are currently working with NOAA Fisheries to develop these methods. Producing this guidelines document is one element in that coordinated effort.

Most salmon and steelhead research conducted at FCRPS dams is funded under the Corps' Anadromous Fish Evaluation Program (AFEP). First, research needs and objectives are developed and prioritized through the Studies Review Work Group (SRWG). The SRWG consists of technical representatives from the COE, BPA, NOAA Fisheries (NOAA-F), US Fish and Wildlife Service (USFWS), States, and Tribes. The research community also plays an important role in SRWG-level work and contributes to research needs and priorities. Research needs and objectives are written up in the form of 1-page research summaries. These summaries provide the detail necessary to develop full research proposals. They typically define the management questions and specify the metrics to be measured, precision levels, hypotheses to test, and measurement tools to be used. Research summaries that are deemed high priority by SRWG are sent to research groups for development into full research proposals. The SRWG also serves as the peer review group for AFEP draft proposals and research reports. On the policy level, the Systems Configuration Team (SCT) prioritizes projects for funding under the Corps' Columbia River Fish Mitigation Program (CRFMP). AFEP research is a subset of the CRFMP, and a study's priority must fall above the funding cut-off identified by SCT to occur in a given year. Priorities developed by the SRWG are communicated to the SCT and factor into their prioritization of the overall program.

Habitat Conservation Plans

In 2002, after several years of negotiation, three mid-Columbia habitat conservation plans (HCPs) were signed by NOAA-F, USFWS, Washington Department of Fish and Wildlife(WDFW), Colville Confederated Tribes, and by either Douglas Public Utility District (PUD) or Chelan PUD. The overall objective of the HCPs is to achieve *no net impact*.[10] This is accomplished by achieving survival goals at the mainstem Columbia River dams owned and operated by the PUDs. Also, hatchery and tributary programs are designed to mitigate for unavoidable effects on salmon at the dams (Chelan PUD 2002, Douglas PUD 2002).

To determine if those survival goals are being achieved, the PUDs have been required to estimate the passage survival of smolts passing either through the entire project, or the dam.

Within the framework of the HCPs, four Committees are established per hydro project to implement the objectives that are established within the documents. The Policy Committee oversees disputes between the other committees. The Coordinating Committee oversees study implementation (including survival studies) and other issues, and oversees the Hatchery and Tributary Committees. The Hatchery Committee is responsible for implementing the hatchery program, while the Tributary Committee coordinates the spending of funds appropriated to the Tributary fund (which is set up in the HCP to fund habitat improvement projects).

In April, 2003, (COE) organized a workshop that brought together various research groups, biometricians, and management agencies (PUDs, WDFW, NOAA-F, United States Geologic Survey (USGS), University of Washington's Columbia Basin Research (CBR), BioAnalysts, Inc. (BIOA) and LGL Limited (LGL)) that oversee and assist in the research designed to estimate juvenile salmonid survival. The goal of the workshop was to share recent study results, experiences, lessons, and generally to increase each other's understanding of the most recent research methods and protocols.

At the workshop, a panel was convened that provided workshop attendees with an overview of their experience with various research methods and protocols. During discussions within the workshop, the panel agreed that it would be beneficial for the region to collectively prepare a technical paper that provides suggested guidance outlines the various protocols, methodology, and other issues related to juvenile salmonid survival studies. In December, 2003, a second workshop was held. The result of this workshop reinforced the need to write a paper that can provide guidance for standardizing important features of survival studies.

This guidelines document is the combined effort of the panel from the April workshop. The authors of this paper intend that this document be used not only as a reference for researchers, but also as a blueprint to facilitate communication between researchers and managers regarding the application of results in satisfying specific management questions.

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[10] "No net impact" is a virtual 100% survival of fish as they pass through a project's boundaries through mainstem survival, hatchery supplementation and tributary improvements. The combined adult and juvenile survival goal is 91% for each of the 3 HCP projects. Because the effects of the hydrosystem currently cannot be separated from natural mortality for adult salmonids, the HCP negotiators agreed that, until measured, adult mortality attributed to each project is assumed to be 2%. Thus, the main objective of the HCP is to achieve a minimum juvenile project survival of 93%.

This paper is organized into six main sections. Section I is the Introduction that provides important background and context. Section II identifies the key steps in planning a survival study. Section III describes a suite of analytical methods that are founded on a strong statistical framework. Section IV describes factors that investigators need to consider when selecting analytical models and tag types. Section V suggests a series of protocols for conducting the field phase of the investigations. Section VI identifies opportunities and guidelines for standardizing certain aspects of smolt survival studies, including elements in the reporting process.

II. Planning Framework

This section identifies the key steps in planning a survival study that will help ensure that the investigation will generate information that can be readily used to answer fish management questions and to achieve fish management goals.

Clearly communicate management goals and needs

The most important step leading to the design of a useful survival study is to ensure that the management goals are clearly defined before study objectives are developed by the funding agencies. This provides the context and rationale for considering the need to acquire specific types of survival estimates. Absent this step, research could be conducted without a clear purpose, leading to a design whose results will have limited or no general application. This can result in unnecessary delays in the implementation of fish recovery actions, as well as wasted financial and/or ecological resources. After the management goals and research needs are identified, specific research objectives should be developed. It is important that the study objectives be clearly articulated to the appropriate fish management forum (e.g., HCP, AFEP, etc.) prior to the initiation of the study to ensure that the focused research objectives to fit with the intended management question(s). Close coordination with associated studies may be essential, for example; survival studies by route of passage may require input from studies designed to describe routes of passage. Measures designed for coordination should be specified in the study plan.

Determine the appropriate tools and use of these tools

After the management goals are clearly defined and the study objectives have been approved in the appropriate fish management forum, the various study approaches (analytical methods and tag types) need to be analyzed. Selecting instructive and suitable approaches is paramount. Throughout this report we explore opportunities to accomplish this in an efficient manner.

Managing expectations

It is the responsibility of researchers not only to understand the proper use of the survival tools available, but also to communicate properly to managers the strengths and limitations associated with the various study designs and tag types presently available to researchers. Researchers need to play an active and significant role in *managing the expectations* of both the fisheries and hydro managers. Over-selling a tag type or study design by investigators will ultimately result in a waste of regional resources and will often result in contentious deliberations regarding the "real" results of the study. Researchers should inform managers and funding entities of the costs, benefits and expected results of a proposed study based upon their previous experience, realistic sample size calculations and the logistics required for each of the various tools being considered. Conversely, managers may demand information without regard to whether it can practically? be measured with scientific rigor. When this happens, it is the researcher's responsibility to temper the manager's expectations and to put forward a more realistic study alternative.

The managers should be made aware of their responsibility for provision of facilities where required, and of any possible impacts on plant operations. Particularly important is the need for management to take an "ownership" of the study to the extent of active participation in the study design, which most frequently will benefit by regulation of operations during the study, perhaps to the point of setting rigid schedules for sequencing operations of turbines, spill gates, or other standards where feasible. The result will be improvement in the study design, which can lead to conclusive results in less time and with less expense over the long term than if hydro operations are continued without reference to probable effects on the study.

Peer Review

We recommend that each study proposal go through a rigorous peer review (as many do now). This should include review by other researchers and managers to ensure consistency with regionally accepted protocols and alignment with stated management goals and objectives. If policy questions are not in step with scientific feasibility, the potential exists for misunderstanding and a large waste of resources (fish, equipment, manpower, and money).

III. Analytical Methods

The appropriate release-recapture design is a function of the study objectives, the availability of recapture sites with adequate recapture probabilities, and satisfactory fulfillment of key model assumptions. With respect to the last issue, it is not often possible to demonstrate that all assumptions are fully met. Even so, some release-recapture models are more robust to all or some model violations than other models. For these reasons, the study design must take into account not only logistical concerns, but perhaps more importantly the analytical foundation. In general, the more robust designs require more effort and/or more detailed information from the release-recapture process. Consequently, investigations need to balance the often conflicting demands of cost, feasibility, robustness, and precision.

Appendix 1 describes analytical models that can be implemented to yield an assortment of survival estimates. These models are the foundation for building a sound study plan. For each model details are provided, specifying:

- Numbers and locations of release groups and tag recapture sites,
- Assumptions underpinning each model,
- Potential sources of bias.

Additionally, the Appendix describes a method for determining appropriate sample sizes, and procedures for producing a weighted estimate across replicated trials that span an extended experimental period.

In this section we briefly describe key features attending the nine models more commonly employed in the basin, as well as a new untested design.

There are basically two general approaches for estimating smolt survival through the hydropower system, the single release-recapture model of Skalski et al. (1998) and the paired release-recapture model of Burnham et al. (1987). The goal of both approaches are to estimate fish survival between two points in the river. These models can be used individually or in combination to estimate smolt survival through projects, dams, reservoirs and individual passage routes at dams. In addition a third, yet to be field tested, model ("triple release") can be used to partitioning survival at a dam into passage-route survival estimates (spillway, powerhouse and bypass/sluice). A complete set of minimum statistics, assumptions, sample size calculations, bias, and spatial release-recapture framework for the Single, Paired and Triple release-recapture models can be found in Appendix 1.

Single Release-Recapture Model (SRM) Design

The single release-recapture design consists of a single release group of tagged fish with a minimum of two downstream recapture locations. The focus of this design is to estimate survival through extended reaches of river (Figure 1 in Appendix 1). At a minimum, the tags used for this model must be individually identifiable with at least a portion of the recaptured fish re-released at each of the downstream recapture sites. In addition, the unique identity of each tagged fish must be accurately recorded at each recapture point.

Advantages and Limitations

The distinct advantage of the SRM is that only a single release group of fish is necessary in order to estimate survival. In the case of PIT-tags, radio-tags, and acoustic-tags, the fish also do not need to be physically re-handled to record recaptures downstream. The model is also generic enough that unique survival and capture parameters can be estimated for all reaches but the last. One potential limitation, however, is the need for a minimum of two downstream recapture sites below the release point.

In the case of radio-tag and acoustic-tag studies, the reaches are defined by the locations of the downstream antenna or hydrophone arrays. For PIT-tag studies, the reaches are defined by the mixing zone in the tailrace below the dam, where bypassed and non-bypassed fish ultimately mix. Because the processes that define the "mixing zone" are very dynamic, exact specification of its location is not possible. This non-specificity may be problematic if formal geographically based definitions of a reach are required (i.e., 500 m below tailrace).

Survival estimates generated with the SRM reflect all types of effects that cause fish mortality. In some instances the survival estimate generated with the SRM may be biased. As an example, if there is post-release delayed handling mortality, that effect would be expressed in the first one or two reaches below the initial release location. Also, the more invasive the tagging process (i.e., radio-tag, acoustic-tag), the more likely the chance for such a bias to be expressed. Post-release tag loss will also negatively bias survival estimates. A third potential source of bias for PIT-tag studies is post-recapture bypass mortality: should PIT-tagged smolts die after recapture but before mixing with the non-bypassed fish, reach survival estimates will be biased. Essentially, the mortality is mis-assigned. Radio-tag and acoustic-tag studies are not subject to the problem of post-recapture bypass mortality because the detected fish are never physically segregated from the non-detected fish crossing a recapture array.

Paired Release-Recapture Model (PRM) Design

The paired release-recapture design consists of a minimum of two release locations (one above and one below the zone of inference) and two downstream recapture sites. The focus of the design is to estimate survival in the reach between the two release points (Appendix 1). If there is only a single downstream recapture site, the data are inadequate to distinguish differences in survival from differences in downstream recapture probabilities between release groups. The ideal circumstance is what Burnham et al. (1987) describes as the "complete capture history protocol."

Advantages and Limitations

Mixing of the two release groups in the reach shared in common downstream of the zone of inference can assure that the groups share common survival processes. The farther apart the release locations, the more difficult the task of assuring downstream mixing through the common reach. Release times may need to be offset to accommodate for travel time of the first release group to the location of the second release. Even then, the arrival pattern of the upstream release group may be more spread out over time than the arrival pattern for the point release of the downstream control group.

Under the complete capture history protocol, the PRM estimate of reach survival for the paired-release design (Figure 3 in Appendix 1) is the ratio of two independent SRM survival estimates. Capture processes can therefore differ between release groups without invalidating estimation of reach survival. If mixing has not occurred, valid estimation of reach survival then depends on the (uncheckable) assumption that survival processes were constant over the reach traversed in common.

To avoid bias, the study design needs to ensure that both release groups experience the same degrees of handling and transportation mortality (See sections V and VI for details). Also the effects must be equally expressed prior to the arrival at the recapture sites. To accomplish this, the first downstream recapture site must be far enough downstream that the post-release handling mortality has been completely manifested in both release groups.

As an example, should two groups of PIT-tagged fish experience the same rate of post-release tag-loss, the effect of tag loss would cancel and the resultant PRM survival estimate would be unbiased. However, this is not generally the case for radio-tags or acoustic-tags, where tag failure is time-dependent. If the upstream and downstream releases occur at different times, the time-dependent tag failure will necessarily be different between release groups. As such, separate corrections for tag failure will be necessary for the upstream and downstream releases to obtain an unbiased estimate of project survival.

Special Uses for the SRM and PRM

In addition to the two basic statistical models used to estimate juvenile survival (SRM and PRM) a variety of approaches have been developed to estimate smolt passage survival through a hydroelectric project or dam and reservoir. Some approaches attempt to estimate dam passage survival directly; others attempt to partition project survival into pool and dam components.

Paired Forebay-Tailrace Releases

By releasing tagged groups immediately above and below the dam, the PRM can be used to estimate dam-passage survival (Appendix 1). The same logistical considerations and model assumptions must met in estimating dam-passage survival as for estimating reach or project survival using the PRM.

<u>Advantages and Limitations</u>

The close proximity of the paired release groups makes downstream mixing more likely. The relatively simple logistics of releasing fish in close proximity make it more likely that post-release handling mortality and tag loss will be equal between the release groups. Hence, the general assumptions of the PRM will likely be satisfied.

However, there is a significant problem with the use of paired forebay-tailrace releases: the forebay release, being released in close proximity of the dam, may not pass through the dam in the same manner or distributions as run-of-river fish. The potential for non-typical passage behavior may therefore misrepresent actual dam passage survival. The bias could be either positive or negative, depending on how the smolt passage deviates from the nominal distribution.

Moving the forebay release further upstream permits the tag-released fish to more closely approximate the arrival distribution of run-of-river fish; the further upstream the release, the more representative the passage distribution. Unfortunately, the further upstream the forebay release, the more opportunity these fish will have to experience pool-related mortality sources, resulting in a negative bias in the estimate of dam-passage survival. Hence, an investigator must balance a source of negative bias against another source of positive or negative bias with no clear opportunity to succeed.

Dam and Pool Survival Model

In the case of radio-tags and acoustic-tags, a recapture array can be placed in the forebay of the dam to detect tagged smolts that have arrived at the dam. These fish known to have arrived at the dam form a "virtual" forebay release group that can be paired with an actual tailrace release group to estimate dam-passage survival (Figure 5 in Appendix 1). This paired-release design, augmented with a forebay array, can be used to estimate project survival as well as dam and pool passage survival.

Limitations

The estimate of pool survival resulting from the use of this model may be negatively biased and the estimate of dam survival may be positively biased. The magnitude of the bias depends on the amount of the post-release handling mortality.

Passage Route Abundance Design

This route-specific passage survival model takes the previous concept(s) and adds a level of resolution. Rather than just identifying fish that have arrived at the dam, the route-specific model identifies fish known to have passed through the various routes of the dam and estimates survival for fish passing through those routes (i.e., powerhouse, spillway, sluiceway, etc.) (Figure 6 in Appendix 1). Using the arrival distribution at the dam and route-specific survival probability estimates, dam-passage survival is mathematically reconstructed.

Advantages and Limitations

The route-specific survival model suffers from the same possible limitations as that of the previous models (see above). Namely, to estimate route-specific survival probabilities, fish known to have passed through a specific route must be paired with a fresh tailrace release. If post-release handling mortality exists, the route-detected fish will have likely already expressed the delayed effect of handling while the tailrace fish have not fully expressed all of the effects by the time these fish are detected downstream. Consequently, the route-specific survival estimates are positively biased. The positively biased route-specific estimates will, in turn, positively bias dam- passage survival, which, in turn, will negatively bias pool-passage survival. The magnitude of the bias depends on the extent of post-release handling mortality.

Proper implementation of this model requires independent estimates of route-specific recapture probabilities. The logistics of developing these independent estimates are problematic (see Appendix 1). An overestimate of recapture probabilities and underestimate of route-specific passage abundance may occur. This will lead to underestimation of that route's passage proportion.

Triple-Release Design

To overcome some of the difficulties of post-pairing in-river fish with newly released fish as in the previous designs, a triple-release design has been developed. The sampling scheme (Figure 7 in Appendix 1) uses the same recapture fields as the abundance-based route-specific model but introduces a third release group to directly estimate absolute route-specific survival.

The assumptions of the triple-release design are essentially the same as the assumptions of the route-specific model and will not be repeated here (see Appendix 1). The difference between the triple-release approach and the route-specific model is how the route-specific survival estimates are obtained. In the triple-release method, two fresh release groups of tagged fish are used to estimate survival through one designated route. Because both groups are comparable, both groups should experience the same post-release handling mortality and tag loss, thereby providing a reliable estimate of passage survival.

In using the triple-release approach, we recommend for the route designated for the paired release a well-confined passage route such as a sluiceway or juvenile bypass. With such routes, there is limited discretion about where to release the downstream and in-route groups. This is not true of the powerhouse or spillways with multiple intakes.

Advantages and Limitations

This design has not yet been implemented at any hydroproject. Consequently, its deficiencies have yet to be exposed. Nevertheless, certain concerns need to be satisfied. The first necessity is to obtain unbiased estimates of fish proportions through the various routes of a dam. Valid Lincoln/Petersen estimates and proper recapture-array deployment are therefore essential.

Pivotal to this study design is the requirement that the product of the relative survival estimate of one route to the designated route and the estimate of absolute passage survival for the designated route provides a valid estimate of survival for the routes not directly measured. Hence, survival through the route designated for absolute estimation must be representative of the conditions over which relative survival was estimated. If relative passage survival was estimated over days, weeks, or months, then so must the absolute passage survival.

IV. Factors to Consider when selecting analytical models and tag types

When designing a smolt survival study there are a number of fundamental considerations that should be addressed to guide the selection of the proper tag type and analytical model. We briefly summarize those here. In some instances, the factors and considerations we list here address certain items that are further discussed in Section V. Also we draw on another document that previously treated many related matters. During the formulation of the Mid-Columbia HCP, Tom Cooney (NOAA-F) prepared a supporting document that addressed key issues associated with estimating smolt survival through that reach (see www.douglaspud.org). We include some of those issues here as well.

Size distributions of the run-of-river population and experimental groups

Ideally, the size (length, weight) distribution of the experimental fish should be identical to the run-of-river (ROR) population, to which inferences are intended. In actual practice, this has been difficult to accomplish. Usually experimental groups comprise larger fish. This has typically been the case when active tags have been used. However, now that acoustic and radio tags are as small as 0.75-0.80 gm, smaller fish can be tagged. For some species like steelhead and yearling Chinook the experimental groups likely can now represent the entire size distribution of the ROR population, whereas for sockeye and subyearling Chinook this may still be impossible. When the size distribution of the ROR and experimental populations differ, investigators should be prepared to explain caveats relevant to any inferences made from the study. As a guide, recommended minimum fish size for implantation with transmitters appears in Section V.

Passive drift of dead fish bearing active tags

When acoustic or radio tags are used, a portion of the smolts passing a dam are killed. Transmitters in these dead fish can continue to operate. These dead fish continue to be swept downstream toward the next recapture system. That system must de deployed far enough downstream to ensure that dead fish bearing active tags cannot be passively swept to the site and detected. Otherwise, dead fish will be counted alive and the survival estimate will be inflated. We recommend that a reconnaissance study be conducted to ensure the recapture site is a suitable distance downstream. This involves intentionally releasing known dead fish bearing active tags and documenting any recapture at the recapture system site. Drift distance will likely vary with flow. This suggests the test should be conducted during peak spring flows. We recommend such a study at any site where survival studies using active tags are initiated.

Tag life and smolt migration rate

This issue pertains only to studies using active tags. Ideally all tagged fish should clear the entire recapture grid prior to tag expiration. This can be difficult to accomplish. Slow migrating species (e.g., some ocean-type Chinook stocks), or the slower members of any species can thwart the realization of this condition. It is possible to incorporate adjustments into the quantitative analysis, but certain information is required. First, tag-life profile tests need to be performed using each year's delivered allotment of tags. Also, fish travel time estimates between release sites and recapture sites need to be documented. These can be depicted as cumulative fish arrival distributions and tag activity curves (see fig 4-2 in Skalski et al. (2003) as an example).

Fish availability can dictate tag selection

Survival estimates are supposed to represent the response of the population-at-large passing hydroelectric projects. Often, wild populations are of most concern, particularly if they are ESA-listed. Ideally, test fish would be randomly drawn from the migrating population, in numbers sufficient to yield the desired precision. This rarely occurs. As an example, the collection of ESA-listed fish for experimental purposes is typically discouraged or outright forbidden. Also, some stocks simply can't be easily collected from the river in sufficient quantities for use in PIT-tag investigations. One example of this is wild sockeye populations in the Mid-Columbia.

The solution involves a decision between using tens of thousands of hatchery fish in PIT-tag studies, or hundreds of ROR or hatchery fish using active tags. This decision must be balanced against fish- and tag-size issues and the adequacy of hatchery fish as surrogates for wild fish. The bottom line is that almost every survival study is a compromise from the ideal evaluation that managers and researchers seek.

Tag recapture system effectiveness determines sample sizes

Recovering adequate numbers of tagged individuals determines whether precision targets are met. Tag recapture rates are in large part determined by the effectiveness of the tag recapture system. Important features that contribute to the effectiveness of the recapture system include coverage at individual recapture sites, the number of recapture sites over the migration route and the distance between them. An example may best illustrate the issue. For several years studies have been underway at Rock Island Dam to determine if project survival complies with standards stated in the HCP. A study has been conducted using both PIT and acoustic tags using yearling fall Chinook, to determine if both tags yield comparable results. As part of the HCP process precision levels (SE = .025) for survival estimates were prescribed. In 2002, to achieve that precision, 90,003 smolts were PIT tagged, whereas only 800 smolts implanted with acoustic tags were required to achieve the same precision goal (Skalski et al. 2003).

The difference in sample sizes was dramatic, and entirely a function of the recapture rates realized by the two tag systems. For the PIT system, the first recapture site was located well downstream, at McNary Dam, with additional detectors further downstream. At those dams only a portion of the population was interrogated for tags (those guided into bypass systems by turbine screens). Also, the long distance from Rock Island Dam to McNary Dam permits the expression of considerable in-river mortality, reducing the number that survive to be interrogated at lower Columbia River dams. In contrast, for the acoustic recapture system the first recapture site was located at Crescent Bar, about 10 miles downstream from Rock Island Dam, and the entire population arriving at a dam could be interrogated for acoustic tag presence.

The manner in which tagged fish are released into, or volitionally enter, passage routes can affect passage-route-specific survival estimates. A number of investigations using hose releases have revealed that the location fish enter a turbine can affect resultant survival. It is impossible to mimic the actual spatial distribution of smolts entering a turbine using the hose method. To acquire a representative estimate, tagged smolts need to volitionally enter turbines and distribute naturally in three dimensions. The means to do this involves an approach developed by Skalski et al. (2002) using radio tags released well upstream from the dam. Hose releases can provide representative estimates through routes like fish bypasses, or sluiceways where entry location is generally accepted to have a neutral effect on the estimate. We cannot explore all of the potential scenarios here, but alert the investigator to address this matter in the initial study design.

To provide more context for these collective issues we present two tables (1 and 2) from the Cooney (2002) document. These tables are an example of how an investigator might organize and address these and related topics in the development of a study design. Many of the points in these tables pertain specifically to the Mid-Columbia situation.

Table 1. Reproduced from Cooney (2002).

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 2. Reproduced from Cooney (2002).

Table 8. Summary of key considerations and limitations on tagging methods with respect to estimating **DAM 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. Use 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.	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.		
Release & recap. method effects	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.	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.	
	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.		
Releases/Recovery samples sufficient for statistical precision	Release sizes required to be large because of the potential for low detection efficiencies at lower river projects resulting from spill programs.	Develop initial release sizes based on expected detection capabilities. Confirm statistical precision with analysis.	

V. Protocols for Conducting Field Studies

To summarize the key points in this section, we assembled a checklist for use in planning smolt survival studies (Appendix 2).

Origin and Capture of Study Fish

Once a study design has been selected, a fish source needs to be identified that meets sample size requirements and represents the population of interest. Two main options for acquiring the fish needed for a survival study include collecting fish at a hatchery or collecting actively migrating smolts at an in-river collection site (i.e. fish bypass facility). The method chosen is determined by a variety of factors that include sample size, species of fish, and whether the source of fish represents the population of interest.

One concern of studies has been the condition of the fish used. "High-grading" fish that have no visible injuries or sickness is a common practice. This may (or may not) bias the results, depending on the overall condition of fish of the population at large.

Hatchery

Collecting fish from a hatchery is beneficial when a study design calls for a large sample size to meet high levels of precision. Examples of this are the CPUD PIT-tag survival studies, where the goal is to estimate survival through a project with a 95% CI and a SE less than 2.5 percentage points. Approximately 100,000 fish are required to meet these goals for one hydro project, and collecting them at an in-river facility located in the mid-Columbia is not feasible.

If a decision is made to use hatchery-origin fish it is important that the hatchery fish are representative of the population of interest. Size of hatchery fish is one factor to consider. Length distributions of tagged fish and run-of-river fish should be compared to determine if the hatchery population is comparable to the run-at-large. Another factor is the degree of physiological development (smoltification) since this may affect the readiness of hatchery fish to migrate. If non-smolted fish are tagged and released, their behavior will be different than the migrating population of interest. This difference in behavior could lead to survival estimates that may not be accurate for actively migrating smolts.

Run-of-River

Collecting run-of-river (ROR) fish at an in-river collection site is a good course of action if the sample size specified in the study design can be collected. The ability to use ROR fish can alleviate some of the concerns associated with using hatchery fish such as size[11] and degree of smoltification, since the collection is a direct sub-sample of population in the river.

Fish Transfer

Whether using fish from a hatchery or those collected from an in-river site, it is important to minimize direct contact with the fish when transferring fish to transport and holding containers. A water-to-water transfer is the preferred method; this limits contact of the fish with nets and containers, protecting its slime layer and limiting descaling and injuries. If a net must be used, the bottom should be solid, creating a “sanctuary” and the number of fish collected at one time should be minimized so that water covers all the fish in the net.

Pre-Tagging

The protocol for holding fish prior to tagging should be designed to limit stress on the fish thereby decreasing tag-related effects. As an example, handling and tagging methods adopted by Chelan PUD are presented in Appendix 3. One way a researcher can control this is to institute a maximum density limit. A safe maximum holding density is 52 g of fish per gallon of water. Another way to minimize stress is to maintain adequate dissolved oxygen levels in the holding containers. Standard hatchery practice is to maintain levels of 7-12 ppm. A protocol that includes scheduled monitoring and a source of supplemental oxygen should be instituted in order to maintain these oxygen levels. Instituting this protocol becomes more important as water temperatures rise and dissolved oxygen capacity decreases.

[11] The size concern is only alleviated if the marking method employed allows the majority of the size distribution to be utilized.

Following fish collection, and prior to tag implantation all fish should be held 12-36 h, either in-river or in open-system tanks supplied with river water. The minimum 12h holding time is to attain a post-absorptive state, which reduces stress during tag implantation and helps to minimize tagging mortality.

Pre-tagging holding densities depends on the size of holding container and fish size. As a general rule of thumb, we suggest using the following formula for short term holding prior to tagging: (mean fish wt (g) x # of fish)/liters (L) of water in holding tank, where g/L does not exceed 15. Tanks must have sufficient flow through water supplied at all times during holding and monitored and adjusted for proper water quality as needed

Tagging

Parameters for choosing fish

A number of parameters are important to consider when choosing fish suitable for tagging. Because fish must be able to withstand the initial handling, tag implantation, and release, measures of fish condition such as descaling, bruising, contusions, bloating, fungus, or other abnormalities should be used to determine if a fish is suitable for tagging. The criteria used should be specified in the report, since the selection of individuals that may lead to bias when applying the results to the run-of-river population.

When determining the minimum fish size, researchers should choose tags that minimize potential negative effects on fish while also attempting to represent a majority of the population. The most common index used to determine minimum fish size is the weight of the tag (in air) relative to the weight of the fish. Recommendations vary, with older works suggesting the tag should be no more than 2% of the body weight of fish (Winter et al. 1996). However, some of the more recent work supporting tag ratios of 6-12% (Brown et al. 1999). We suggest an intermediate tag ratio of between 5% and 6.5% be used as guideline for determining minimum fish size based on the laboratory tests by USGS (Adams et al. 1998a, 1998b), NMFS (Prentice et al.), and Battelle NW (Anglea et al. 2004). For example, Adams et al. (1998) found that swimming performance of juvenile Chinook salmon was compromised relative to controls when the tag ratio exceeded about 5%. For tag ratios <5%, the authors suggested that gastrically-implanted tags were more suitable for short term studies (days), whereas surgically implanted tags were best suited to longer term studies (weeks).

Laboratory tests similar to those conducted by USGS (Adams et al. 1998a, 1998b), NMFS (Prentice et al.) and Battelle NW (Anglea et al. 2004) are needed to establish the lower size limit for each tag type. Each species needs to be tested as well, since some species (e.g. sockeye) are more sensitive to handling than others. These tests only need to be conducted once and the results published. The community can then adopt the guidelines, if they appear sound.

Table 1. Examples of minimum fish size for implantation of transmitters based on maximum tag ratios between 4% and 7% and tag weights between 0.07 g and 1.8 g. The tag ratio is the tag weight in air divided by fish weight (x 100).

	Maximum tag ratio			
	4%	5%	6%	7%
Tag weight in air (g)	Minimum fish size (g) based on maximum tag ratios			
0.07[a]	1.8	1.4	1.2	1.0
0.20	5.0	4.0	3.3	2.9
0.40	10.0	8.0	6.7	5.7
0.60	15.0	12.0	10.0	8.6
0.80	20.0	16.0	13.3	11.4
1.00	25.0	20.0	16.7	14.3
1.20	30.0	24.0	20.0	17.1
1.40	35.0	28.0	23.3	20.0
1.60	40.0	32.0	26.7	22.9
1.80	45.0	36.0	30.0	25.7

[a] Weight of passage integrated transponder (PIT) tags currently used in the Columbia River Basin.

Although the tag weight ratio has been the most commonly used index for determining the minimum size of fish to tag, researchers should also consider other factors such as the tag's weight in water, its volume, and whether or not it has an antenna. The volume of the tag controls the amount of water displaced, and thus the weight of the tag in water. The weight of a tag in water represents the additional mass that a fish must carry, so this measure is just as important to consider as the tag's weight in air. Perry et al. (2003) showed that fish filled their bladder by the amount needed to offset the tag's weight in water, not in air. The implication here is that two tags may weigh the same in air, but if their volumes differ, the tag with lower volume will weigh more in water and have a larger effect on fish. Lastly, radio tags with antennas may affect swimming behavior due to increased drag caused by the protruding antenna (Anglea et al. 2004). In contrast acoustic tags have no external antenna. A researcher may therefore choose to tag slightly smaller fish for use with acoustic tags, than she would with a radio tag of similar weight.

Use of Surrogate Species or Stocks

While it is desirable to assess the effect of the hydrosystem on fish survival for all salmon and steelhead species and stocks, it is not always possible or practical to do so. For example, the FCRPS BiOp prescribes survival standards for Snake River sockeye salmon; however juveniles of this stock are too few to risk handling and tagging for a survival study. For comparative studies, the cost of evaluating sockeye, steelhead, and Chinook during the springtime is often cost-prohibitive. This issue has been dealt with by using a surrogate species or stock(s) to provide the best representation of the effect a dam configuration change on survival for all species of interest. The idea is that an effect of a dam configuration change on one species or stock should be reflected by other species or stocks migrating at the same time. Communication between researchers and managers is critical to ensure that information useful for decision-making is obtained when considering surrogate species. Risks and uncertainties need to be spelled out and weighed in light of the management decisions being made. Questions to consider when selecting a surrogate, or deciding if a using a surrogate is appropriate include:

- What is known about the possible differences in characteristics (i.e. run timing, size, behavior) between the target and surrogate species/stocks and how might this affect survival results?
- Is improving the survival of one species more important than others for managers?
- How would the management decision be affected if a configuration change showed a benefit for one species and a detriment for another (e.g. violation of the assumption that a benefit for one species would be reflected by all)?
- How will the existing information base be used for decision-making and what species-specific survival data currently exist that will be applied to the problem?

Data collected during tagging and release

During Chelan and USGS studies, biological and abiotic information is collected and recorded as part of the QA/QC process. Biological information that is recorded on the tagged fish includes weights, lengths, injuries and level of descaling. Abiotic information includes water temperature and dissolved oxygen levels in all containers that hold fish. This information is recorded through holding to the time of release.

Tagging procedures

External, surgical, and gastric implantation are the three methods of tag implantation normally used with fish, but tags attached externally typically have a large effect on swimming behavior of small fish (McCleave and Stred (1975) and will not be further considered here. Numerous published works have outlined methods for both surgical and gastric implantation of tags, but we recommend a combination of methods described by Adams et al. (1998a, 1998b) and Mid Columbia (e.g., Skalski et al. 2003) because they were adapted specifically for juvenile salmonids studies in the Columbia River Basin.

The following detailed descriptions should be considered suggestions; we understand that researchers may need to use other methods (e.g., other anesthetics or oxygen) for any given situation.

<u>Surgical Tagging Methods</u>

When surgical supplies and recovery buckets are ready small numbers of fish (~10-15) should be transported from in-river pens or tanks to a bucket that has a continuous supply of water and oxygen. This pre-surgery holding container should be located as close as possible to the tagging station. In addition to the main anesthetic container, the gravity feed buckets need to be filled. Gravity feed buckets are paired and have rubber tubing leading to an in-line valve. One gravity feed bucket contains a light anesthetic solution and the other contains fresh river water to initiate recovery prior to the end of the surgery. In the bucket marked “anesthesia” mix 2 ml of MS-222 stock solution and 2 ml of stock buffering solution into the 10 liters of water yielding a concentration of 20 mg/l MS-222 and 20 mg/l of buffering solution. The contents of the gravity feed buckets should be remixed every 10 fish and its temperature monitored.

The “anesthesia” bucket should be prepared just prior to tagging. About 15-30 s after losing equilibrium in the anesthesia bucket, the fish’s condition should be examined and the fish measured, weighed, and placed on the surgery table ventral side up. Insert the rubber tubing from the gravity feed into the fish’s mouth and turn on the flow of light anesthetic. Try to avoid getting anesthesia into the incision. Using an in-line valve allows switching from anesthesia to fresh water or a mixture of both. Visual signs that the fish displays determines the mixture of anesthesia and fresh water. Usually the fish is switched over to fresh water 1 minute prior to the end of surgery (at the time of the last stitch). If the fish is “gilling” and moving its fins, this is a good sign. However, if the fish is not gilling or moving its fins, provide fresh water via the gravity feed as soon as possible until the fish exhibits gilling.

At this point, the fish should be ready for transmitter implantation. A 10-mm incision is to be made 3-mm away from and parallel to the mid-ventral line starting about 3-mm anterior to the pelvic girdle. The incision should be deep enough to just penetrate the peritoneum. Once the incision is made an outlet for the antenna needs to be made. A shielded needle (i.e., catheter) is used and should puncture the body wall ~3-mm away from the mid-ventral line posterior to the incision between the pelvic girdle and anal fin. The catheter should be left in the body wall while the needle is extracted from the incision. To implant the transmitter, thread the antenna through the catheter and then gently pull the catheter and antenna until the transmitter enters the body cavity. The catheter should then be removed from the antenna. The position of the transmitter can easily be adjusted by gently pulling on the antenna. The transmitter should lie directly under the incision. Oxytetracycline should then be injected with a pipette into the incision. The concentration of oxytetracylcine is 100 mg/ml and should be pipetted into the fish at a dosage of 50mg/kg body weight. Pipette tips should be disposed of and replaced with a new tip for each individual fish.

Begin suturing the incision after the oxtetracycline has been pipetted into the fish. Depending on the size of fish and species 4-0 (larger fish) to 5-0 (smaller fish) sutures are used. For juvenile salmonids three stitches are needed to close the incision. To prevent the trailing antenna from tearing the body wall, one suture is used to anchor the antenna to the fish’s body and should be placed in muscle tissue posterior to the gut cavity and antenna exit site. Generally, just after the incision is closed and just prior to the initiating the antenna suture is a good time to switch the in-line valve to oxygenated fresh water. The surgery is now complete and the fish should be moved immediately from the surgery table to the designated recovery container. The fish should be in water during transport from surgery table to recovery container unless the recovery container is directly adjacent to the surgery table. In preparing for the next surgery, all surgical tools should be disinfected by submerging them in the tray of disinfectant solution and then transfer them into the saline solution.

A comprehensive list of tagging equipment required for surgical implantation of radio tags is listed in Appendix 4 as an example of this methodology.

Gastric tagging methods

The “anesthesia” bucket should be prepared just prior to tagging. Since gastric tagging can take as little as 15 s per fish, up to 5 fish may be anesthetized at once. As soon as a fish begins losing equilibrium examine its condition, then weigh and measure the fish. Place the fish in a tagging tray with water and stress coat, take hold of the transmitter and gastric plunger (in dominant hand) place the protruding antenna between the fifth and fourth fingers this allows a slight tension to be kept on the transmitter and prevents the transmitter from moving during insertion. After the transmitter is firmly in hand, gently take hold of the fish in the other hand (keeping the fish submerged) and place the transmitter into the fish’s mouth and gently push the transmitter into the esophagus until a slight resistance is felt (**Do Not Force**). After insertion, place the fish into the recovery container (no more than 2 fish per recovery bucket) and repeat the process. Fish that are dropped or handled too roughly are not suitable for tagging and should be documented on the tagging sheet and placed in the reject bucket. Gastric plungers should be disinfected after each tagging event before being reused.

Post-tagging holding times

Fish should be held in long-term recovery between 18 and 36 h after tagging. This period allows fish to recover from stress induced during the handling and tagging. Fish should also be allowed access to surface air to fill their air bladder and compensate for weight of the tag. This holding period also allows a final check to insure all tags are operating prior to release and to check for regurgitated tags (gastric only).

Tag-life study

As a measure of insurance, a tag-life study should always be conducted in conjunction with a survival study using active transmitters. A major assumption of survival studies is that no marks are lost during the study. Survival estimates may be biased if the transmitter’s battery expires (thereby losing the mark) prior to fish exiting the study area. Transmitters may expire prematurely because of malfunction or due to long migration times of fish during periods of low discharge. Information provided by a tag-life study can be used to adjust survival estimates for the premature failure of tags (Cowan and Schwarz 2003). However, if tag-life data is not collected and tags expire prior to fish exiting the study area, there is little recourse for adjusting potentially biased survival estimates.

We recommend conducting the tag-life study concurrent with the survival study and under ambient conditions at the study site. Taking this approach is important to emulate as close as possible the source of the transmitters and the ambient conditions they experience after they are released in fish. For example, some transmitters lose a constant percentage (per unit time) of their battery life after the battery has been attached to the transmitter. Second, tag-life may be affected by temperature. Last, transmitter life may vary among years or among production batches. Therefore post-hoc initiation of a tag-life study after problems have been identified in the survival study may not yield an accurate representation of the failure of transmitters used in the survival study.

The objective of a tag-life study is to develop a survival curve for the radio tags (proportion of tags alive over time) and fit a survival function to the tag-life data (e.g., Cowan and Schwarz (2003) used a Kaplan-Meier survival function). A random sub-sample of 50 transmitters from those to be used for the survival study is adequate to generate a survival curve. The transmitters should be turned on gradually over the survival study period, for example, in three batches (early, mid, late). Then it is simply a matter of holding the transmitters underwater at ambient water temperatures and monitoring the tags over time, noting the time at which each tag expires. The time to expiration is then used to generate the survival curve.

VI. Standardization and Suggested Guidelines

Managers have expressed concern that results from survival studies are sometimes difficult to interpret and place in context with other survival studies. They have suggested that standardization of certain features of survival studies could improve this situation. For example, terminology used to describe the type of survival estimate being produced can vary considerably among investigators, thus complicating comparisons among studies. In this section we explore opportunities for standardizing certain study features, and offer guidelines for consideration.

Recommended Terminology

The Columbia Basin salmon survival literature is replete with a dizzying array of terms used as descriptors. This is particularly evident for terms used to classify types of survival estimates. Often times these terms are confusing or poorly defined. Here is a sampling: Direct survival, indirect survival, delayed mortality, extra mortality, project survival, dam survival, system survival, combined survival, etc.

Definitions of these terms can often differ among investigators. Such fluid definitions can often confuse mangers that are seeking clear apples-to- apples comparisons, as well as other investigators trying to put their results in broader context. We think there is an opportunity to standardize many of these types of terms and offer a glossary of preferred definitions, for use in the region (see glossary). Absent that standardization, an explicit description of the geographic bounds and nature of the effects embraced by the reported survival estimate needs to be prominently stated in proposals and reports.

Protocols & implementation of studies guidelines

We believe it is advisable to standardize some protocols involved in the execution of survival studies. From the list of activities appearing in section III, we feel that a number of protocols and terms could be standardized, thus improving the overall utility of results from all future survival studies. These candidates include:

- Treatment and control groups should be treated the same in all respects, from selecting the test fish through release. For example, if experimental groups need to be transported to different sites, efforts should be made to standardize aspects such as transit time to the sites, water conditions during transport, etc. We recognize that all investigators attempt to execute studies in this manner, but we felt is deserved restating here. No amount of detail should be excluded from consideration.
- For each species, identify the smallest individual that can be tagged with each type and size of tag. Although treatment/control designs should theoretically correct for tag effects, particularly burdensome tags may elicit some additional effect that manifests itself through time. If treatment and control fish are at liberty for different amounts of time, the survival estimate could be affected. This concern applies to all commonly used tags including PIT and active-type tags.
- Uninjured and healthy fish should be selected for use in treatment/control experiments to ensure ample tag recaptures and satisfactory precision. Also, concerns expressed in the preceding bullet apply here as well.
- Conduct a tag life performance test in any study that uses active tags. Tag performance can vary from the manufacturer's nominal tag life guidelines, and vary among production batches. It may be necessary to use this information to adjust tag recoveries if experimental groups do not clear the recapture grid in a timely manner.
- Pre- and post-tagging holding period (time)
- Environmental & operations data collection (e.g., dam operations, river flows, temperatures, TDG)
- Biological data collection (e.g., length (tagged & tot. pop), weight, physiological conditions of the smolts (on a case by case), post tagging mort. and tag shedding and failure)
- Tagging technician rotation- To preclude the possibility of a technician's tagging competence affecting the condition of a particular experimental group; technicians should be systematically rotated among the tagging stations.

Reporting guidelines

The format and degree of detail presented in reports varies greatly. Often this makes comparisons among studies difficult. It may be impractical to ask investigators to adopt a standard outline for survival studies. The objectives and approaches vary too much among investigations. However, there are certain features that we recommend should appear in every survival report that would help aid in understanding a diverse array of studies. These include:

- A summary page that lists the key features and results of the study is recommended. We have created a template and offer it for consideration (Appendix 5). Some of these key features include: analytical model, release sites, sample size and number of replicates, species and source, tag recapture locations, type of estimate (e.g., direct, total effects), geographic bounds to which the estimate apply (e.g., project from Wells tailrace to RR tailrace), value of the estimates with standard errors, special features (e.g., dual sampling arrays).

- Fish length and/or weight distribution of tagged population as compared to the population-at-large.
- Environmental conditions monitored throughout the study period. Of particular concern are river conditions and relevant operating conditions during the course of the investigation.
- Executive summary should clearly state the key results and conclusions of the investigators. This section of reports may be the only part that managers will read.

Training guidelines

The training we refer to here pertains to the proper handling, implantation of intrusive tags (PIT, radio, acoustic). Standardized protocols for tagging fish with PIT tags are well established and documented. Refer to the “PIT tag marking procedures manual” at http://www.fpc.org/. Also, training is often available by working with parties already engaged in PIT-tagging programs. However, procedures for acoustic and radio tag implantation have not been as formally accepted or published. General guidelines have been established by individual groups of investigators, but no broad based regional standards have been adopted. We see no immediate need or opportunity to establish a training program and recommend investigators share the guidelines they have adopted internally. Examples of some procedures adopted by Chelan PUD are attached (Appendix 3). They conduct in-house training each season to initiate new staff. This approach seems adequate and is currently employed by most groups.

Regionally recognized training associated with the processing and management of electronic tag data has only been formally established for the PIT tag. At least one acoustic tag vendor offers classes that treat this topic for its line of transponders. Investigators using radio telemetry rely on in-house training specific to the data management systems they have developed.

Data Management guidelines

The ISAB has suggested that the lack of data transparency and unavailability of access to recapture data associated with active tags has been problematic. They point to the PIT tag data system as the preferred model. Investigators have argued that the size and complexity involved in recapture systems (frequently scores of antennas, hydrophones and receivers) complicates this greatly, as does the multi-step process of identifying valid tag codes. They suggest that reporting raw tag recaptures as does the PIT system is neither practical nor instructive. We concur. Absent a standardized central database for active tags, we recommend that each investigation report the following:

- Identify criteria for identifying valid tag recaptures. These would vary by tag type (acoustic or radio) and can vary among investigators. Examples include the number of coded signals detected at a locale per unit time, power strength of the signal, etc.

- Describe the data reduction process in a stepwise manner, preferably employing a flowchart.
- Provide the recapture history matrix used to calculate the survival estimates as an appendix.

QA/QC

- Document water quality during holding (e.g., water temps., DO)
- Confirm tag operation at release
- Develop a formal QA/QC plan and append to the proposal.
- Validate tags that are identified using any automated processing procedures. This can simply amount to process a subset manually and comparing results with the auto-processed data.

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Appendix 1.

Overview of release-recapture designs for estimating smolt survival

Overview of Release-Recapture Designs
For Estimating Smolt Survival

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22 July 2004

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1.0 Introduction

The nature of the tag release-recapture design best suited to a particular study goal depends on the goal itself, the downriver availability of detection rates, and fulfillment of model assumptions. Because model assumptions are necessarily simplifications of fish behavior and subsequent sampling processes, they may not be fully achieved in reality. Some release-recapture models are more robust to model violations than other models, or are more robust to certain assumptions than others. For these reasons, the choice of study design must take into account not only logistical concerns but also flexibility in analysis and robustness. In general, the more robust designs require more effort and/or more detailed information from the release-recapture process. Consequently, investigations need to balance the often conflicting demands of cost, feasibility, robustness, and precision. In addition, certain tag-release study designs are better suited for one objective, other designs for other objectives.

In presenting alternative tag release-recapture designs, the methods have been organized according to estimation goals. Within a particular goal, alternative release-recapture designs are discussed along with their individual strengths, weaknesses, and assumptions.

2.0 Estimating Reach Survival

There are basically two alternative approaches to estimating reach survival, the single release-recapture model of Skalski et al. (1998) or the paired release-recapture model of Burnham et al. (1987). The goal of both approaches is to estimate fish survival between two points in the river. The most common interest is in estimating project survival: survival from the tailrace of an upstream dam to the tailrace of the next downstream dam. In many situations, the initial release is located at the tailrace of the immediate upstream facility. On occasion, the reach of interest may be defined by two intermediate detection sites downriver of the release location(s).

2.1 Single Release-Recapture Model (SRM) Design

The single release-recapture design requires as a minimum the following design elements:

1. Uniquely identifiable tagged fish.
2. Minimum of two downstream detection sites below the release locations.

3. Re-release of all or some of the marked fish recaptured at each detection location.
4. Recording of the identity of the marked fish recaptured at each location; no information on unmarked fish captured at downstream locations is recorded or used.

A schematic of the release design and estimable parameters is illustrated in Figure 1. Survival can be estimated from the tailrace below the initial dam to the mixing zone of the next downstream dam (i.e., S_1). From then on, survival is estimated from the mixing zone of one PIT-tag detector dam to the next mixing zone of the next downstream detector dam. Unique recapture probabilities can be estimated at each dam with a PIT-tag detector except farthest downstream. In the last reach, only the joint probability of survival to and being detected at the last dam can be estimated (i.e., $\lambda = S_K p_K$). It is for this reason the minimal study design must consist of at least two downstream detection locations.

The assumptions of the single release-recapture model are the following:

A1. Individuals marked for the study are a representative sample from the population of interest.

A2. Survival and recapture probabilities are not affected by tagging or sampling. That is, tagged animals have the same probabilities as untagged animals.

A3. All sampling events are "instantaneous." That is, sampling occurs over a negligible distance relative to the length of the intervals between sampling locations.

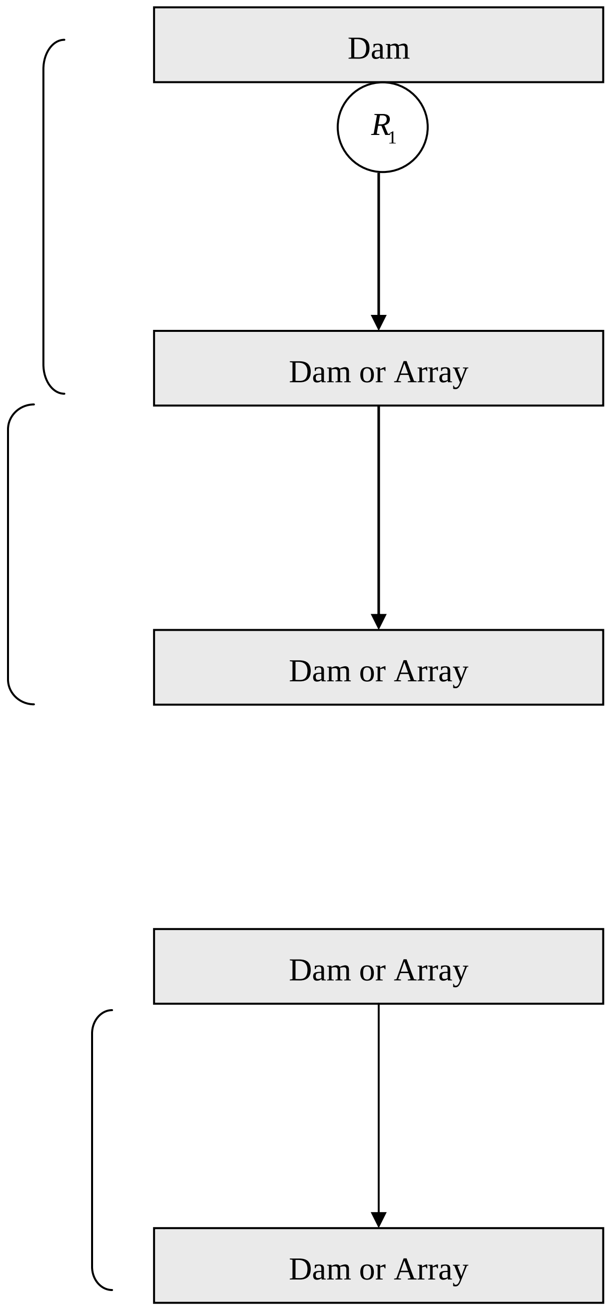
A4. The fate of each tagged individual is independent of the fate of all others.

A5. All tagged individuals alive at a sampling location have the same probability of surviving to the next sampling location.

A6. All tagged individuals alive at a sampling location have the same probability of being detected at that location.

A7. All tags are correctly identified and the status of each smolt (i.e., alive or dead), correctly assessed.

Figure 1. Schematic of a single release-recapture design with release location denoted R_1 along with estimable survival (S) and capture (p) parameters.



Project survival estimate: S_1

The first assumption (A1) concerns inferences from the sample to the target population. For example, if inferences are sought to chinook salmon smolts, then the sample of tagged fish should be drawn from that class of fish. Otherwise, nonstatistical inferences are necessary to justify the use of the marked population to make inferences to the target population. These assumptions could also be violated if smolts selected for tagging were on average larger than the population of smolts to which inferences are made.

Assumption (A2) again relates to making inferences to the population of interest (i.e., untagged fish). If tagging has a detrimental effect on survival, then survival estimates from the single release-recapture design will tend to be negatively biased (i.e., underestimated).

The third assumption (A3) specifies that mortality is negligible immediately in the vicinity of the sampling stations, so that the estimated mortality is related to the river reaches in question and not during the sampling event. In the case of outmigrating smolts, the time they spend in the vicinity of detection equipment is brief and small relative to the size of the river reaches in question (but see the discussion of post-detection bypass mortality for PIT-tagged fish below). This assumption is for the sake of mathematical convenience and should be fulfilled by the nature of the outmigration dynamics and deployment of the hydrophone or antenna array in the case of active tags.

The assumption of independence (A4) implies that the survival or death of one smolt has no effect on the fates of others. In the larger river system with tens of thousands of smolts, this is likely true. Furthermore, this assumption is common to all tag analyses, with little or no evidence ever collected to suggest it is not generally true. Nevertheless, violations of assumption (A4) have little effect on the point estimate but might bias the variance estimate (true variability would be greater than estimated).

Assumption (A5) specifies that a smolt's prior detection history has no effect on subsequent survival. This could be violated if some smolts were self-trained to repeatedly go through turbine or spill routes or alternatively to avoid routes because of prior experience. This occurrence is unlikely and can be assessed from the detection histories of the individual smolts. The lack of handling following initial release of acoustic-tagged or radio-tagged smolts further minimizes the risk that subsequent detections influence survival. Similarly, assumption (A6) could be violated if downstream detections were influenced by upstream passage routes taken by the smolts. Violation of this assumption is minimized by placing hydrophone or acoustic arrays across the breadth of the river or below the mixing zones for smolts following different passages at the dam.

Assumption (A7) implies that the smolts do not lose their tags and are subsequently misidentified as nondetected, or dead fish are falsely recorded as alive at detection locations. Tag loss and tag failure would result in a negative bias (i.e., underestimation) of smolt survival rates. The possibility of radio- or acoustic-tag failure will depend on travel time relative to battery life. Dead fish drifting downstream could result in false-positive detections and upwardly bias survival estimates . Tailrace hydrophone and antenna arrays are therefore not recommended because they are too close to locations of potential mortality.

Burnham et al. (1987) Tests 2 and 3 can be used to assess overall goodness-of-fit to single release-recapture assumptions, in particular whether upstream capture histories are independent of downstream histories.

Discussion of Bias

The distinct advantage of the SRM is that only a single release group of fish is necessary to estimate survival. In the case of PIT-tags, radio-tags, and acoustic-tags, the fish also do not need to be physically rehandled to record detections downstream. The model is also generic enough that unique survival and capture parameters can be estimated for all reaches but the last. One potential limitation, however, is the need for a minimum of two downstream detection sites below the release point.

In the case of radio-tag and acoustic-tag studies, the reaches are defined by the locations of the downstream antenna or hydrophone arrays. For PIT-tag studies, the reaches are defined by the mixing zones in the tailraces below dams, where bypassed and nonbypassed fish ultimately mix. Because the mixing zone is process-based, exact specification of its location is not possible. This nonspecificity may be problematic if formal geographically based definitions of a reach are required (i.e., 500 m below tailrace).

The reach survival estimates from the SRM may be negatively biased for three different reasons. If there is post-release handling mortality, that mortality would be incorporate in the first one or two reaches below the initial release location. Consequently, survival S_1 (Figure 1) may be most susceptible to handling bias. The more invasive the tagging process (i.e., radio-tag, acoustic-tag), the greater the chance of bias. Post-release tag loss will also negatively bias survival estimates. For PIT-tag studies, the third source of bias is post-detection bypass mortality. Should PIT-tagged smolts die after detection but before mixing with the nonbypassed fish, reach survival estimates will be negatively biased. Radio-tag and acoustic-tag studies are not subject to bias from post-detection bypass mortality because the detected fish are never physically segregated from the nondetected fish crossing a detection array.

2.2 Paired Release-Recapture Model (PRM) Design

The paired release-recapture design consists of a minimum of two release locations and one downstream detection/recapture site. The focus of the design is to estimate survival in the reach between the two release points (Figure 2). With only a single downstream recovery site, the data are inadequate to distinguish differences in survival from differences in downstream detection probabilities between release groups. For this reason, a minimum of at least two downstream detection/recovery sites are recommended (Figure 3). The ideal circumstance is what Burnham et al. (1987) describes as the “complete capture history model.”

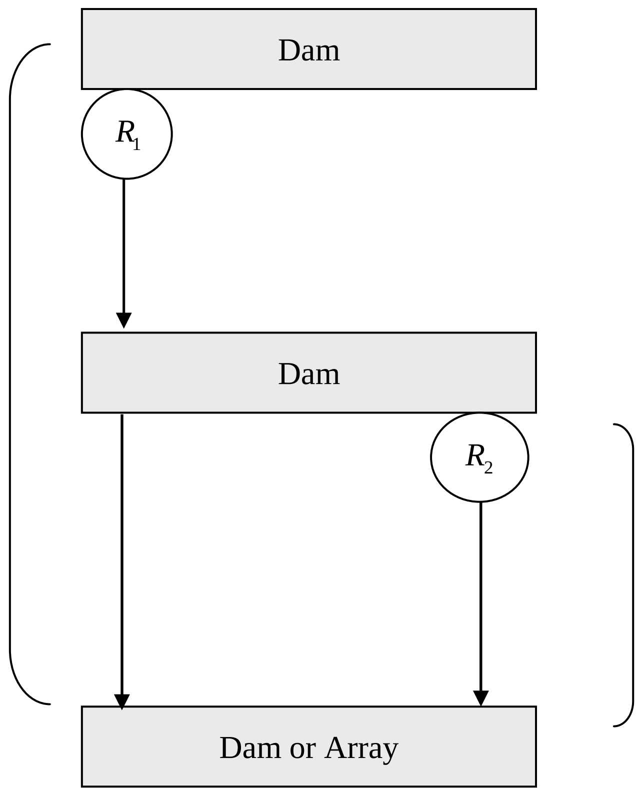
The minimum design elements for a paired release-recapture study with complete capture histories is as follows:

1. Uniquely identifiable tagged fish
2. Releases above (R_1) and below (R_2) the reach of interest
3. A minimum of two downstream detection sites below the downstream release (R_2) location.
4. Re-release of all or some of the marked fish recaptured at each detection location.
5. Recording of the identity of marked fish recaptured at each location; no information on unmarked fish captured at downstream locations is recorded or used.

Separate estimates of reach survival and location-specific detection probabilities can be calculated for each release group separately using the SRM. In the last reach, only the joint probability of survival and detection $(\lambda = S \cdot p)$ can be estimated, again, independently for each release group.

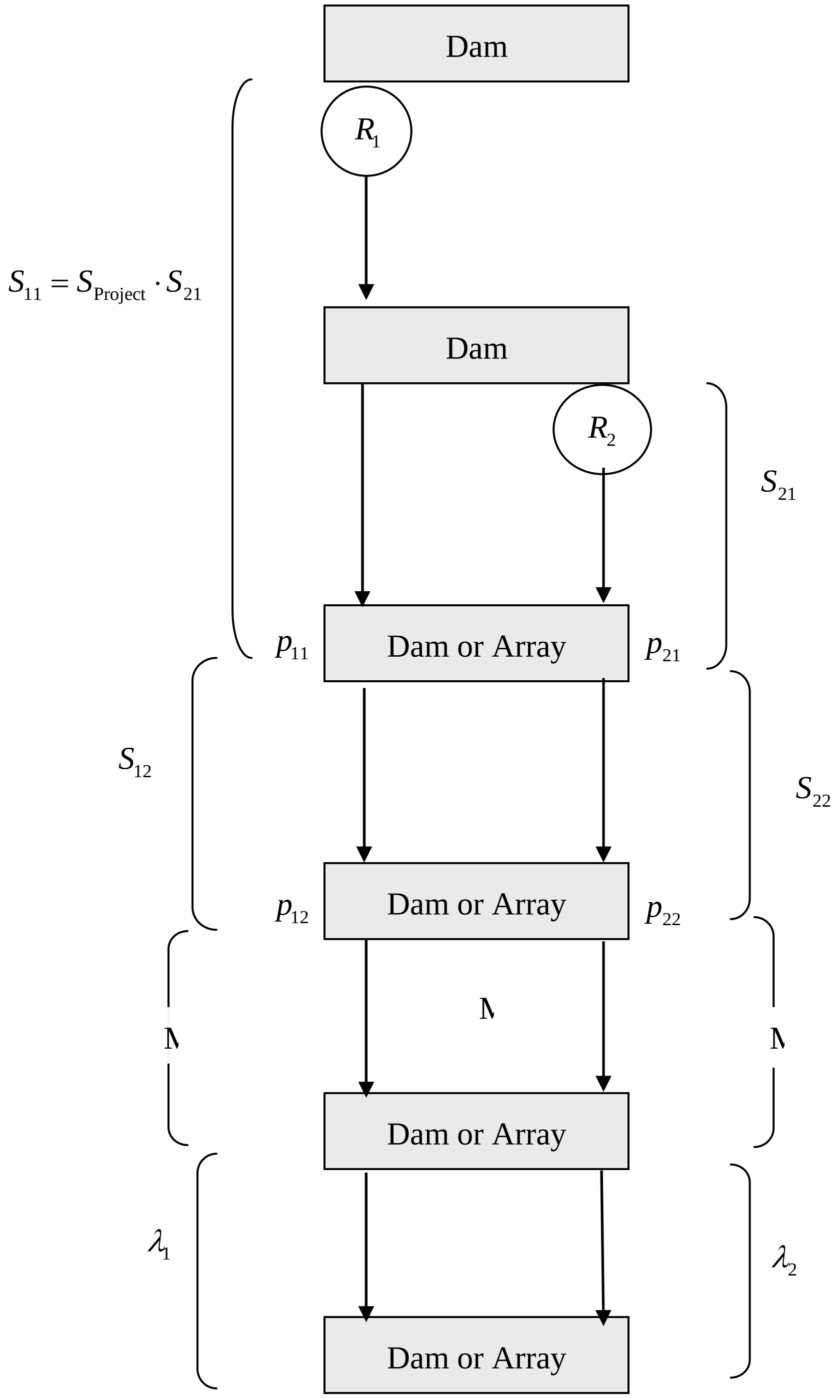
The assumptions of the paired release-recapture model are the following:

Figure 2. Schematic of a minimal paired release-recapture design with two release sites (R_1 and R_2), one downstream detection site, and associated estimable parameters.



Project survival estimate: $\hat{S}_1 = \dfrac{\hat{\lambda}_1}{\hat{\lambda}_2}$

Figure 3. Schematic of a paired release-recapture design with multiple downstream detection locations.



Project survival: $\hat{S}_{\text{Project}} = \dfrac{\hat{S}_{11}}{\hat{S}_{21}}$

A1. Individuals marked for the study are a representative sample from the population of interest.

A2. Survival and capture probabilities are not affected by tagging or sampling. That is, tagged animals have the same probabilities as untagged animals.

A3. All sampling events are "instantaneous." That is, sampling occurs over a negligible distance relative to the length of the intervals between sampling events.

A4. The fate of each tagged individual is independent of the fate of all others.

A5. All tagged individuals alive at a sampling location have the same probability of surviving until the end of that event.

A6. All tagged individuals alive at a sampling location have the same probability of being detected on that event.

A7. All tags are correctly identified and the status of smolt (i.e., alive or dead), correctly assessed.

A8. Survival in the lower river segment of the first reach is conditionally independent of survival in the upper river segment (i.e., $S_{11} = S_{\text{Project}} \cdot S_{21}$)

A9. Releases R_1 and R_2 have the same probability of survival in the lower segment of the reach they share in common (i.e., S_{21}; between the downstream release location and the first recapture location).

Assumptions (A1-A7) were previously discussed in Section 2.1.1. Assumption (A8) implies there is no synergistic relationship between survival processes in the two river segments of the first reach. In other words, smolts that survive the first river segment are no more or less susceptible to mortality in the second river segment than smolts released in the second river segment. Assumption (A9) is satisfied by the inriver mixing of the release groups but can also be satisfied if the survival processes are stable over the course of smolt passage for the two release groups. A stable survival process might well be expected for one to a few days under similar flow and spill conditions.

Burnham et al. (1987) Tests 2 and 3 can be used to assess overall goodness-of-fit to single release-recapture assumptions—in particular, whether upstream capture histories affect downstream histories of occurrence. Chi-square R x C contingency table tests can be used to assess whether the two release groups are mixed upon arrival at downstream sites. Alternatively, Kolmogorov –Smirnov tests of equal distribution can be used to test for mixing and homogeneous arrival distributions at downstream sites (Conover 1980:369-373).

Discussion of Bias

Mixing of the two release groups can assure the two releases share common survival processes in the first common reach segment. The farther apart the release locations, the more difficult is the task of assuring downstream mixing. Release times may need to be offset to accommodate for travel time of the first release group to the location of the second release. Even then, the arrival pattern of the upstream release group may be spread out over time when matched with the point release of the downstream control group.

The simple paired-release design of Figure 2 does not permit the differentiation between effects on survival and capture probabilities when the relative recovery rates (i.e., $\hat{\lambda}_1, \hat{\lambda}_2$) are used to estimate absolute survival (S_1). However, when there are two or more downstream detection sites, survival and capture probabilities can be differentiated and estimated separately for each release group. As such, the estimate of reach survival for the paired-release design of Figure 3 is the ratio of two independent estimates of absolute survival (i.e., $\hat{S}_{11} / \hat{S}_{21}$). Therefore, capture processes can differ between release groups without affecting valid estimation of reach survival. If mixing does not occur, valid estimation of reach survival then depends on the assumption that survival processes were constant over the course of the passage of the two smolt release groups through the first reach segment of interest.

Care is also needed to assure both release groups experience the same degrees of handling and transportation mortality, so that if post-release handling mortality occurs, it will be the same in both groups. By taking the ratio of the survival estimates (i.e., $\hat{S}_{11}$ and $\hat{S}_{21}$), handling effects may cancel, yielding an unbiased estimate of reach survival. However, for the cancellation to occur, the first downstream detection site must be sufficiently far that post-release handling mortality has been totally manifested in both release groups.

The same also holds for the post-release tag loss. If both groups experience the same degree of tag-loss, the effect is cancelled in taking the ratio of the survival estimates. However, this is not the case for tag failure of radio-tags or acoustic-tags, because failure is time-dependent. If the upstream and downstream releases occur at different times, the time-dependent tag failure will necessarily be different between release groups. As such, separate corrections for tag failure will be necessary for the upstream and downstream releases to obtain an unbiased estimate of project survival.

3.0 Estimating Dam-Passage Survival

A variety of approaches have been used to estimate smolt passage survival through a hydrofacility or dam. The goal is to estimate dam-passage survival independent of pool survival. Some approaches attempt to estimate dam-passage survival directly; others attempt to partition project survival into pool and dam components. This section describes some of these approaches and discuss their strengths and weaknesses.

3.1 Paired Forebay-Tailrace Releases

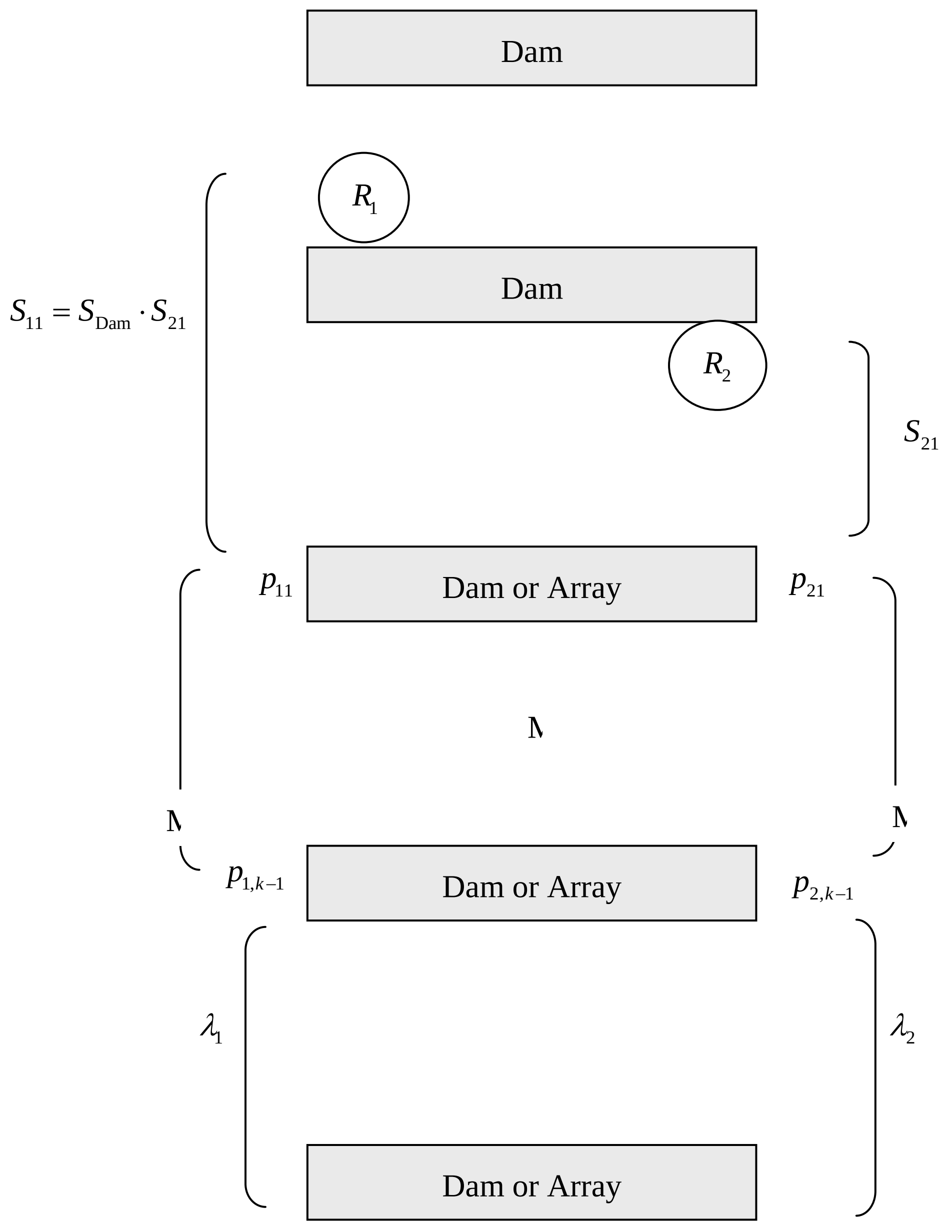
By strategically releasing tagged groups immediately above and below the dam, the paired release-recapture method of Section 2.2 is used to estimate dam passage survival (Figure 4). The same logistical considerations and model assumptions need to be met in estimating dam-passage survival as in estimating reach or project survival using the paired-release model. See Section 2.2 for discussion of assumptions.

Discussion of Bias

The close proximity of the paired release locations is likely to satisfy the assumption of downstream mixing in this design. The logistics of releasing fish in close proximity is also likely to satisfy the needs for the same post-release handling mortality and tag loss among the release groups. Hence, the general assumptions of the paired-release model will likely be satisfied in most occurrences.

The limitation of this method is not in meeting the demands of the paired-release design. Instead, the problem is that the forebay release, being released in close proximity of the dam, may not pass through the hydrofacility in the same manner or distributions as run-of-river fish. The nontypical passage may therefore misrepresent actual dam passage survival. The bias could be either positive or negative, depending on how the smolt passage deviates from the nominal distribution.

Figure 4. Schematic of a paired release-recapture design used to estimate dam-passage survival.



Dam passage survival: $\hat{S}_{\text{Dam}} = \dfrac{\hat{S}_{11}}{\hat{S}_{21}}$

Moving the forebay release further upstream away from the dam permits the tag-released fish to more closely approximate the arrival distribution of run-of-river fish. Further upstream, the release, the more typical the passage distribution. Unfortunately, the further upstream the forebay release, the more opportunity these fish will have to experience pool-related mortality sources. The pool-related mortality sources will result in a negative bias in the estimate of dam passage survival. Hence, an investigator must balance a source of negative bias against another source of positive or negative bias with no clear opportunity to succeed.

3.2 Partitioning Project Survival into Dam and Pool Components Using Forebay Detections

In the case of radio-tags and acoustic-tags, a detection array can be placed in the forebay of the dam to detect tagged smolts that have arrived at the dam. These fish known to have arrived at the dam form a conceptual forebay release that is paired with an actual tailrace release to estimate dam passage survival (Figure 5). This paired-release design, augmented with a forebay array, can be used to estimate project survival as well as dam- and pool-passage survival. The estimate of project survival is predicated on the assumptions of the paired-release design previously described in Section 2.2 The assumptions and properties of that design will not be discussed again here.

From Figure 5, the project survival is estimated using the traditional upstream (R_1) and downstream (R_3) release groups where

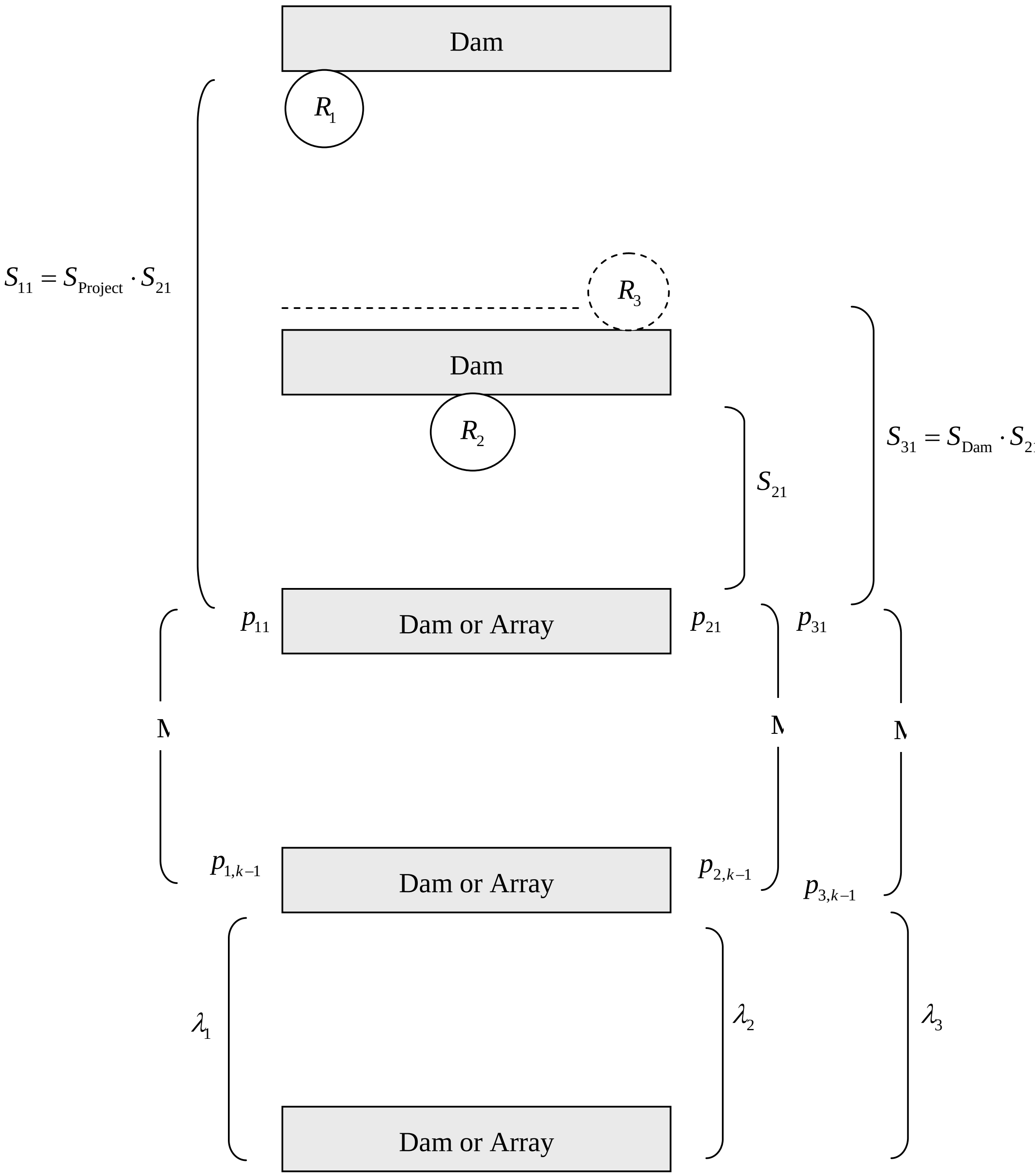
$$\hat{S}_{\text{Project}} = \frac{\hat{S}_{11}}{\hat{S}_{21}}.$$

Dam-passage survival, in turn, is estimated using the conceptual release of R_3 fish known to have arrive at the dam and the tailrace release (R_2) where

$$\hat{S}_{\text{Dam}} = \frac{\hat{S}_{31}}{\hat{S}_{21}}.$$

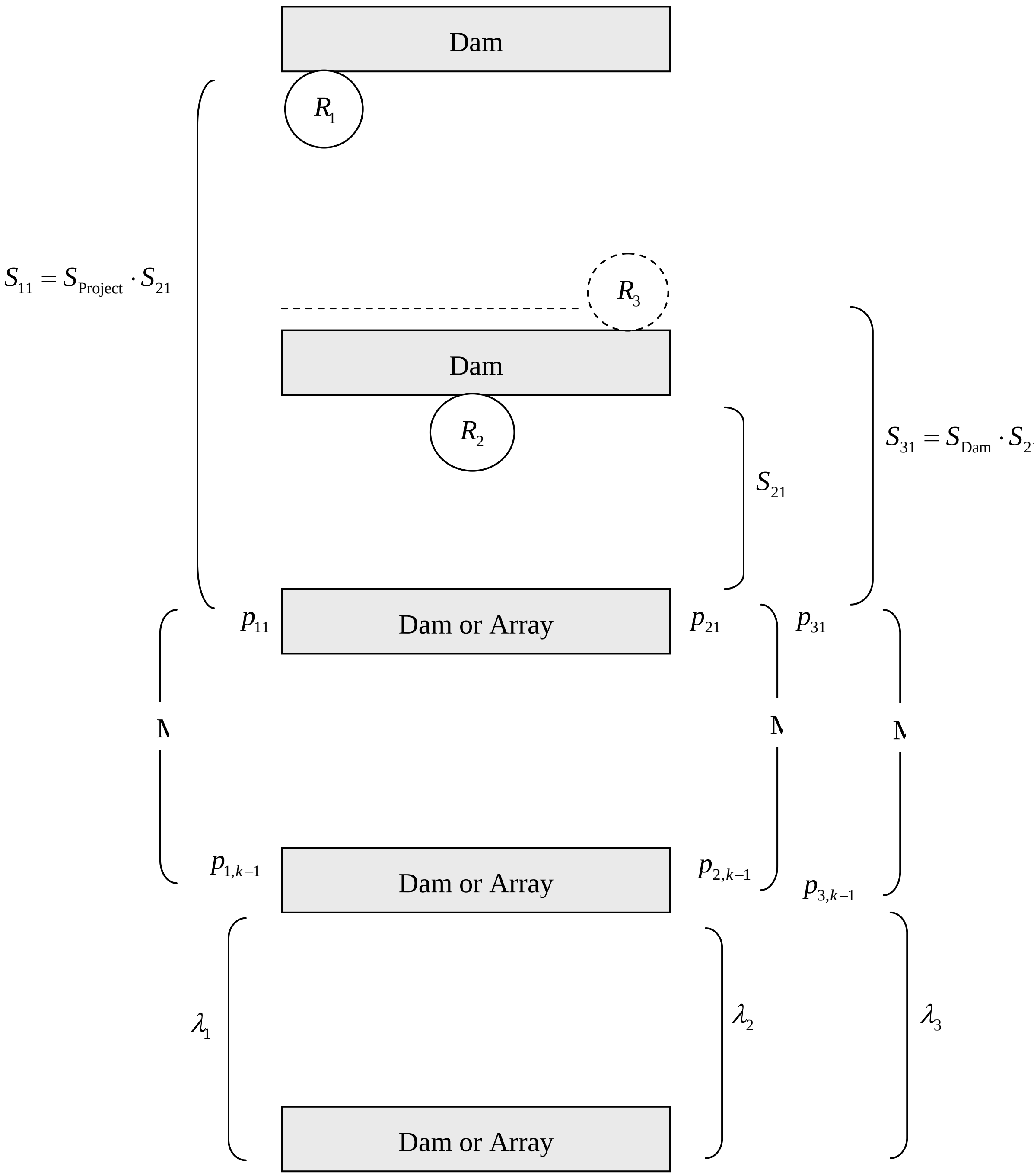
Pool passage survival is estimated as the quotient of project and dam survival estimates where

Figure 5. Schematic of the paired release-recapture design augmented with a forebay detection array to partition project survival into pool and dam components.



Project survival estimates: $\hat{S}_{\text{Project}} = \dfrac{\hat{S}_{11}}{\hat{S}_{21}}$, $\hat{S}_{\text{Dam}} = \dfrac{\hat{S}_{31}}{\hat{S}_{21}}$, $\hat{S}_{\text{Pool}} = \dfrac{\hat{S}_{11}}{\hat{S}_{31}}$

Figure 6. Schematic of the paired release-recapture design augmented with a forebay detection array to partition project survival into pool and dam components.



Project survival estimates: $\hat{S}_{\text{Project}} = \dfrac{\hat{S}_{11}}{\hat{S}_{21}}$, $\hat{S}_{\text{Dam}} = \dfrac{\hat{S}_{31}}{\hat{S}_{21}}$, $\hat{S}_{\text{Pool}} = \dfrac{\hat{S}_{11}}{\hat{S}_{31}}$

The estimate of project survival is predicated on the assumption of the paired-release design previously described in Section 2.2 The assumptions and properties of that design will not be discussed again here.

From Figure 5, the project survival is estimated using the traditional upstream (R_1) and downstream (R_3) release groups where

$$\hat{S}_{\text{Pool}} = \frac{\hat{S}_{\text{Project}}}{\hat{S}_{\text{Dam}}} = \frac{\hat{S}_{11}}{\hat{S}_{31}}.$$

Discussion of Bias

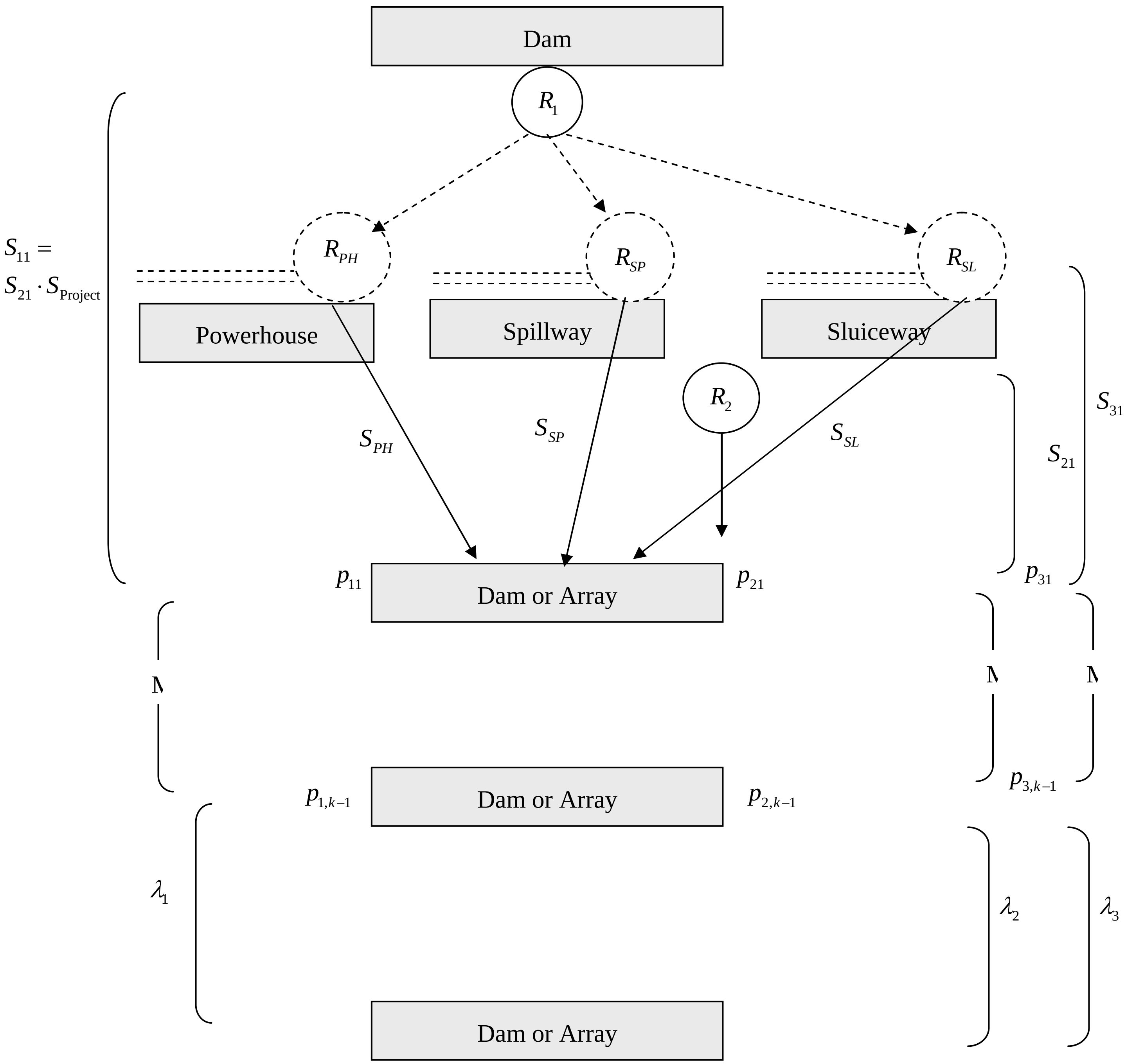
The estimate of project survival $(\hat{S}_{\text{Project}})$ is robust to post-release handling mortality and tag loss as long as both upstream (R_1) and downstream (R_2) release groups have adequate time for full expression of these effects. However, when estimating dam-passage survival, the conceptual release of R_3 fish known to have arrived at the dam are paired with the freshly released tailrace groups (R_2). The R_3 fish have had time to experience post-release handling mortality and tag loss, the R_2 fish have not. As a result, $\hat{S}_{21}$ is biased negatively by handling effects, the $\hat{S}_{31}$ is not. When their quotient is used to estimate dam-passage survival, the consequence is a positive bias in the dam survival estimate.

Conversely, the estimate of pool survival will be negatively biased because the estimate of $\hat{S}_{11}$ will include any post-release handling mortality, while the denominator $\hat{S}_{31}$ will include little or none. The greater the extent of the post-release handling mortality, the more severe the positive bias in dam-passage survival and the negative bias in pool-passage survival.

3.3 Route-Specific Survival Model

The route-specific survival model takes the idea of an extra forebay detection array (Section 3.2) farther. Rather than just identifying fish that have arrived at the dam, the route-specific model identifies fish known to have passed through the various routes of the dam (i.e., powerhouse, spillway, sluiceway, etc.) (Figure 6). These route-specific groups are used two-fold:

Figure 7. Schematic of a route-specific survival design with paired releases R_1 and R_2 and route-specific detection capabilities at the dam of interest.



Project survival: $\hat{S}_{\text{Project}} = \dfrac{\hat{S}_{11}}{\hat{S}_{21}}$; Route-specific survival: $\dfrac{\hat{S}_{31}}{\hat{S}_{21}}$

1. To estimate the arrival distribution of smolts to the various routes of the dam.
2. To estimate the survival of smolts through the various routes of the dam.

With information on the arrival distribution at the dam and route-specific survival probabilities, dam-passage survival is mathematically reconstructed.

For example, consider a hydrofacility with a powerhouse, spillway, and sluiceway. Dam passage survival can be expressed as follows:

$$S_{\text{Dam}} = P_{PH} \cdot S_{PH} + P_{SP} \cdot S_{SP} + \left(1 - P_{PH} - P_{SP}\right) \cdot S_{SL}$$

where

P_{PH} = the proportion of smolts going through the powerhouse,

P_{SP} = the proportion of smolts going through the spillway,

$1 - P_{PH} - P_{SP}$ = the proportion of smolts going through the sluiceway,

S_{PH} = survival through the powerhouse,

S_{SP} = survival through the spillway,

S_{SL} = survival through the sluiceway.

Pool-passage survival, in turn, is estimated from the quotient of project and dam-passage survival estimates where

$$\hat{S}_{\text{Pool}} = \frac{\hat{S}_{\text{Project}}}{\hat{S}_{\text{Dam}}}.$$

For the estimation of proportions of fish arriving via various routes, dual antenna or hydrophone arrays are needed to estimate absolute passage abundance of arriving tagged smolts. Fish detected at one or both arrays are used to estimate passage numbers of tagged smolts using the Lincoln/Petersen single mark-recapture model (Seber 1982:59-70). The dual array does not require the assumption of equal detection probabilities at each route. Instead, the approach requires independence of the detection probabilities between the primary and secondary detection arrays within a route. With only a single array per route, there is no way to confirm detection probabilities are homogeneous between routes.

Assumptions of the route-specific model include those of the paired release-recapture method (Section 2.2) as well as assumptions specific to this method. The assumptions are as follows:

A1. Individuals marked for the study are a representative sample from the population of interest.

A2. Survival and capture probabilities are not affected by tagging or sampling. That is, tagged animals have the same probabilities as untagged animals.

A3. All sampling events are "instantaneous." That is, sampling occurs over a negligible distance relative to the length of the intervals between sampling events.

A4. The fate of each tagged individual is independent of the fate of all others.

A5. All tagged individuals alive at a sampling location have the same probability of surviving until the end of that event.

A6. All tagged individuals alive at a sampling location have the same probability of being detected on that event.

A7. All tags are correctly identified and the status of smolt (i.e., alive or dead), correctly assessed.

A8. Survival in the lower river segment of the first reach is conditionally independent of survival in the upper river segments (i.e., $S_{11} = S_{\text{Project}} \cdot S_{21}$).

A9. Releases R_1, R_2, and route-specific (R_{PH}, R_{SP}, R_{SL}) experience the same survival probabilities in the lower river segment of the first reach they share in common.

A10. Fish are identified correctly according to their route of passage at the dam.

A11. The dual-detection arrays within a passage route provide independent probabilities of detection.

Assumptions (A1-A9) have been previously discussed in Sections 2.1 and 2.2, and the discussions will not be repeated here. Classification of a fish to an incorrect passage route will bias the estimate of dam passage (i.e., P_{PH}, P_{SL}, etc.), as well as the subsequent estimate of route-specific survival probabilities (i.e., S_{PH}, S_{SL}, etc.). Such bias can be minimized or completely avoided by using stringent detection criteria when assigning a recaptured fish to a particular passage route.

To obtain unbiased estimates of arrival distribution at the dam (i.e., P_{PH}, P_{SL}, etc.), valid estimates of route-specific, tagged fish abundance are required. The Lincoln/Petersen estimator is very sensitive to nonindependence between the first and second detection events. At a hydroproject, this translates into placing antenna or hydrophone arrays in such a manner that detection in one array has no effect on fish detections in the second array. There is no empirical way to detect violations of assumption (A11). Instead, the detection arrays need to be physically located such that a fish detected in the first array has no more or less chance of being detected in the second array than a fish not detected in the first array.

Discussion of Bias

The route-specific survival model suffers from the same possible limitations as that of the previous model in Section 3.2. Namely, the estimation of the route-specific survival probabilities is based on pairing fish known to have passed through a specific route with a fresh tailrace release. If post-release handling mortality exists, the route-detected fish will have already experienced the delayed effect of handling while the tailrace fish have not. Then if these two groups are used to estimate route-specific survival probabilities, the result is a positively biased survival estimate. The positively biased, route-specific survivals will, in turn, positively bias dam passage survival, which, in turn, will negatively bias pool passage survival.

A positive correlation between the detection arrays within a route of passage will result in overestimation of detection probabilities and underestimation of route-specific passage abundance. This will lead to underestimation of that route's passage proportion. A negative correlation between the detection arrays within a route of passage will result in underestimating detection probabilities and subsequent overestimation of the route-specific passage abundance. This will, in turn, lead to overestimation of that route's passage proportion.

A single detection array at each route of passage will bias estimates of the arrival distribution in various ways if detection probabilities are not homogeneous. There is no empirical way of detecting or correcting for unequal detection probabilities when single within-route arrays are used. Different fields of detection, water velocities, or passage times may contribute to unequal detection probabilities.

3.4 Triple-Release Design

To overcome some of the difficulties of post-pairing inriver fish with newly released fish as in the previous designs (i.e., Sections 3.2 and 3.3), a triple-release design may be used. The sampling scheme (Figure 7) uses the same detection fields as the route-specific model (Section 3.3) but introduces a third release to directly estimate route-specific survival through one designated route.

The study design is devised to provide the following information directly from the tagging data:

1. Project passage survival using the paired releases R_1 and R_2.
2. Passage proportions through the various routes using release R_1 and the dual-detection arrays at the various dam routes.
3. Relative survival quotients using the relative recovery information from the tagged fish known to have passed through the various dam routes.
4. Route-specific survival using the paired releases R_2 and R_3 for a single selected route at the dam.

With release R_1 sufficiently upriver, the arrival distribution at the dam should be adequately characterized using a properly implemented dual-array system at each passage route. The fish detected at the various passage routes can then be tracked downriver to estimate relative survival. For instance, let

R_{PH} = the number of tagged fish known to have passed through the powerhouse,

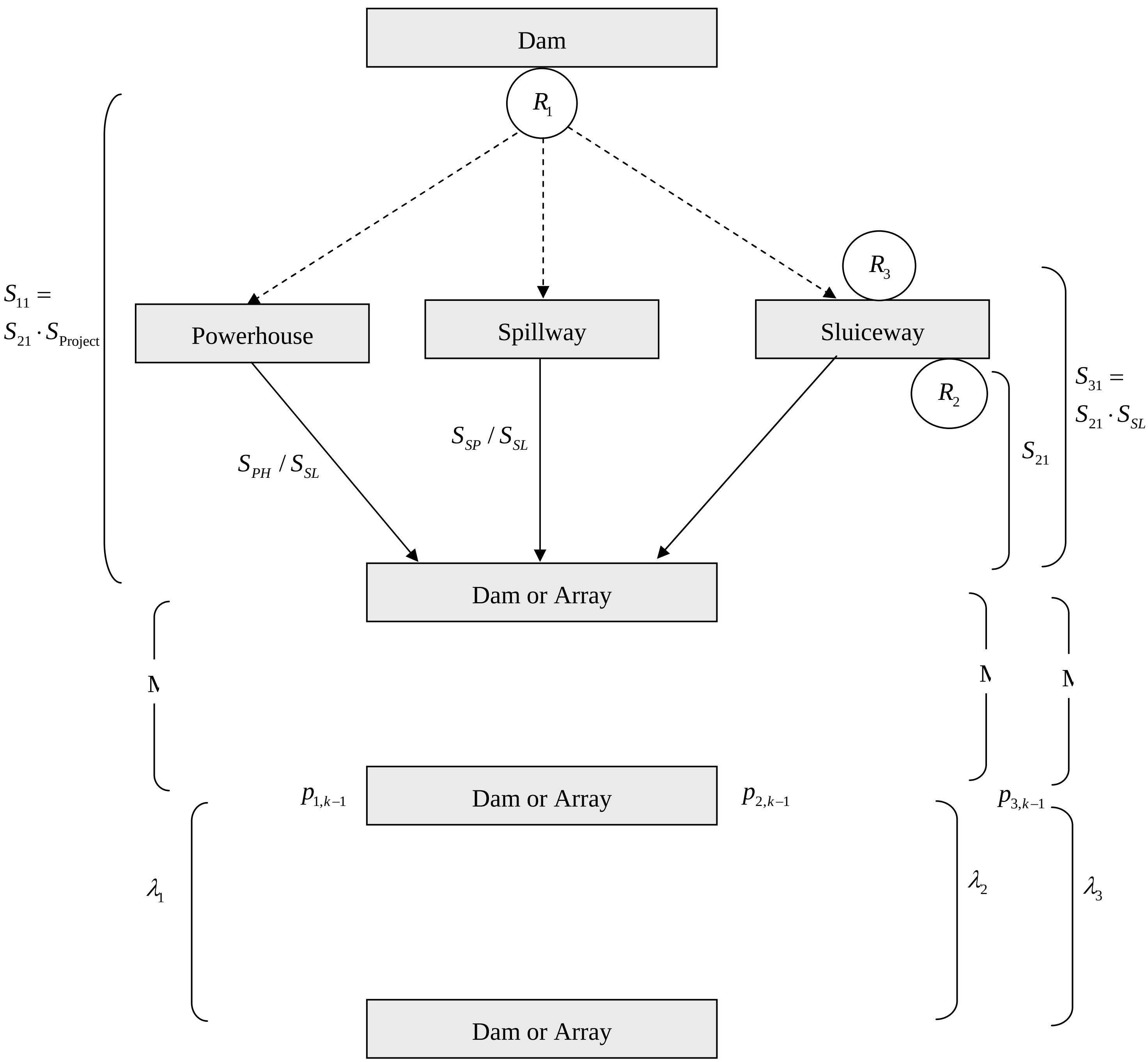
x_{PH} = the number of fish from R_{PH} subsequently detected downriver,

R_{SL} = the number of tagged fish known to have passed through the sluiceway,

x_{SL} = the number of fish from R_{SL} subsequently detected downriver.

Then the quotient $\left(R_{SP/SL}\right) = x_{PH} R_{SL} / x_{SL} R_{SP}$ has the approximate expected value

Figure 8. Schematic of triple-release design with releases R_1, R_2, and R_3 and route-specific detection capabilities at the dam of interest.



Project survival: $\hat{S}_{\text{Project}} = \dfrac{\hat{S}_{11}}{\hat{S}_{21}}$; Sluiceway survival: $\hat{S}_{SL} = \dfrac{\hat{S}_{31}}{\hat{S}_{21}}$

$$E\left[\frac{\left(\dfrac{x_{PH}}{R_{PH}}\right)}{\left(\dfrac{x_{SL}}{R_{SL}}\right)}\right] \mathrm{B} \, \frac{S_{PH} \cdot p}{S_{SL} \cdot p} = \frac{S_{PH}}{S_{SL}},$$

the ratio of powerhouse passage survival to sluiceway passage survival.

Dam-passage survival can be reconstructed from the release-recapture data where

$$\begin{aligned}
\hat{S}_{\text{Dam}} &= \hat{P}_{PH} \cdot \hat{S}_{SP} + \hat{P}_{SP} \cdot \hat{S}_{SP} + \left(1 - \hat{P}_{PH} - \hat{P}_{SP}\right)\hat{S}_{SL} \\
&= \hat{P}_{PH} \cdot \hat{R}_{PH/SL} \cdot \hat{S}_{SL} + \hat{P}_{SP} \cdot \hat{R}_{SP/SL} \cdot \hat{S}_{SL} + \left(1 - \hat{P}_{PH} - \hat{P}_{SP}\right)\hat{S}_{SL} \\
&= \hat{S}_{SL}\left[1 + \hat{P}_{PH}\left(\hat{R}_{PH/SL} - 1\right) + \hat{P}_{SP}\left(\hat{R}_{SP/SL} - 1\right)\right].
\end{aligned}$$

The assumptions of the triple-release design are essentially the same as the assumptions (A1-A11) of the route-specific model (Section 3.3) and will not be repeated here. The difference between the triple-release approach and the route-specific model is how the route-specific survival estimates are obtained. In the triple-release method, fresh releases of tagged fish are used to estimate survival through one designated route. Because both groups are comparable, both groups should experience the same post-release handling mortality and tag loss, thereby providing a reliable estimate of passage-route survival. In the route-specific model of Section 3.3, fish previously released and that have survived to the dam are paired with newly released fish in the tailrace. The difference in experience at the point of pairing is a source for potential bias in the route-specific model.

In using the triple-release approach, a well-confined passage route such as a sluiceway or juvenile bypass is recommended. With such routes, there is limited discretion about where to release the downstream and in-route release groups. This is not true of the powerhouse or spillways with multiple intakes.

Discussion of Bias

This design has not yet been implemented at any hydroproject. Consequently, its deficiencies have yet to be exposed by the light of day. Nevertheless, certain concerns need to be satisfied. The first necessity is to obtain unbiased estimates of fish proportions through the various routes of a dam. Valid Lincoln/Petersen estimates and proper detection-array deployment are therefore essential.

Pivotal to this study design is the requirement that the product of the relative survival estimate of one route to another (i.e., $R_{SP/SL}$) and estimate of absolute passage survival (S_{SL}), e.g.,

$$\hat{R}_{SP/SL} \cdot \hat{S}_{SL} = \hat{S}_{SP} ,$$

provides a valid estimate of survival for the routes not directly measured (i.e., S_{SP}). Hence, survival through the selected route for absolute estimation must be representative of the conditions over which relative survival was estimated. If relative passage survival was estimated over days, weeks, or months, then so must the absolute passage survival. If the estimate of absolute passage survival is not comparable to the estimate of relative survival, bias of dam passage survival will occur, either high or low.

4.0 Estimating Route-Specific Survival Studies

The purpose of route-specific survival studies is to obtain an estimate of absolute survival through a particular passage route at a hydroproject. Typically, these routes include spillways, turbine units, sluice ways, or juvenile bypasses. In general, these studies are limited to making inferences to a particular passage route under specified operating conditions. The intent of the studies is to characterize mortality rates, identify sources of mortality, or compare mortality rates under alternative operating conditions or after an alteration of existing equipment.

4.1 Paired-Release Design

The route-specific version of the paired release-recapture design was the original intent of Burnham et al. (1987). That book describes a variety of approaches to estimating route-specific survival probabilities. The ideal design is the complete capture-history protocol with at least two downstream detection sites (Figure 3). This model was described in detail in Section 2.2 for estimating project survival. The only difference in this situation is that the two tag groups are released in closer proximity and concurrent in time. The upstream release is injected directly into the route of interest. The downstream release is typically released immediately below the route in the tailrace of the dam. For the assumptions of the paired-release design, see Section 2.2, assumptions (A1-A9).

Discussion of Bias

The close proximity of the control (i.e., downstream) and treatment (i.e., in-route) releases almost assures mixing of the fish at the downstream detection sites. The detection and survival processes should in most circumstances therefore be homogeneous, permitting parsimonious modeling and precise parameter estimations.

Bias can occur if the release processes are dissimilar between control and treatment groups. Bias can also occur if the treatment release location is atypical of the usual passage of fish through the route. In addition, for the estimated mortality rate to be representative of both acute and long-term effects of route passage, recoveries need to occur sufficiently downstream for such effects to become exhibited. Premature recovery may result in underestimating the chronic or delayed effects of route passage.

4.2 Balloon-Tag Release-Recapture Design

The balloon-tag release-recapture design is very similar to the paired-release design previously described in Section 4.1. However, there are two important distinctions. First, both live and dead fish are susceptible to recapture. Second, the recaptures occur very shortly after release. For this reason, survival estimates refer to only the survival of the immediate effects of route passage. The balloon-tag technique achieves very high recovery rates, usually in excess of 90%, often in the range of 98-99% of the fish released. A depiction of a balloon-tag study design is illustrated in Figure 8.

The assumptions of the balloon-tag technique (Mathur et al. 1996) include the following:

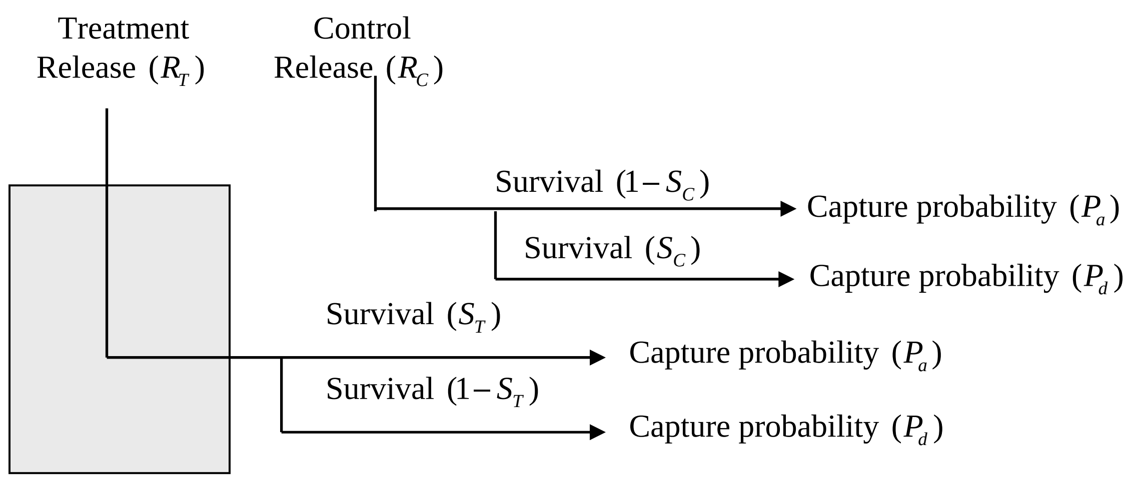
B1. Individuals marked for the study are a representative sample from the population of interest.

B2. Route conditions during the study are representative of the operating conditions of inference.

B3. Tagging does not affect passage survival.

B4. The fate of each tagged individual is independent of the fate of all others.

Figure 9. Schematic of a balloon-tag release-recapture design with control (R_C) and treatment (R_T) releases and subsequent model parameters.



B5. All fish are correctly identifiable to treatment.

B6. All live fish, regardless of treatment, have equal probability of detection.

B7. All dead fish, regardless of treatment, have equal probability of detection.

B8. The status of fish (i.e., alive or dead) is correctly assessed.

B9. Survival in the control zone is conditionally independent of survival through the route.

B10. The treatment (R_T) and control (R_C) releases experience the same survival probability in the portion of the control zone they share in common.

Discussion of Bias

The potential sources of bias in the paired-release design of Section 4.1 also pertains to the balloon-tag studies as well. In addition, it must be reemphasized, the balloon-tag studies estimate only direct effects of route passage and do not incorporate any sublethal mortality component. Balloon-tagged smolts are routinely held 48 hours – 96 hours pre-release to observe any delayed mortality due to injury. However, these delayed effects do not incorporate any increased chances of predation due to disorientation or injury.

Finally, if the presence of a balloon-tag has a synergistic effect with route passage, then subsequent passage estimates will be biased. For example, if the presence of a balloon-tag interferes with turbine passage and causes additional stress, survival estimates may be negatively biased.

The structure of the balloon-tag study is very similar to that of the paired-release design of Section 4.1. The major distinction between the traditional paired-release design and that of the balloon-tag design is that both alive and dead fish are recovered in the balloon-tag study. The recovery of the dead fish potentially increases the precision of the study and affords the investigators the opportunity to examine fish to determine the causes of death. A practical distinction between the two designs is that balloon-tagged fish are released one at a time, while entire groups are released at once in the paired-design. Hence, the balloon-tag studies are more labor-intensive but benefit from high recovery rates, and therefore, greater precision for fewer fish.

5.0 Estimating Relative Survival

In some circumstances, estimates of absolute survival are not needed, but rather, simply a comparison of relative survival (i.e., S_1/S_2) between passage routes or hydro-operating conditions. By estimating relative survival, defined as

$$R_{S_2/S_1} = \frac{S_2}{S_1},$$

where

S_1 = the survival under condition 1,

S_2 = the survival under condition 2,

tests of equality of survival can be performed. For instance, the set of hypotheses

$$\begin{gathered} \mathrm{H_o}: \quad S_2 \le S_1 \\ \text{versus} \\ \mathrm{H_a}: \quad S_2 > S_1 \end{gathered}$$

are equivalent to

$$\begin{gathered} \mathrm{H_o}: \quad R_{S_2/S_1} \le 1 \\ \text{versus} \\ \mathrm{H_a}: \quad R_{S_2/S_1} > 1. \end{gathered}$$

The advantage in estimating relative survival is that sampling effort may be less than that required for estimating absolute survival under both conditions.

5.1 Relative Recovery Method

In this approach, paired-releases are performed concurrently with a single downstream recovery site to detect alive fish (Figure 9). Figure 9 illustrates the schematic of estimating relative survival between a spillway and powerhouse. The two releases can either be freshly tagged and released fish or fish known to have passed through the relevant routes at the dam. In either case, the two groups of fish are comparable in all respects except for the unique routes of passage at the dam.

Assumptions of the paired, relative recovery method are as follows:

B1. Tagged fish are representative of the fish population of inference.

B2. The fates of each tagged individual is independent of the fate of all others.

B3. Both tagged groups experience the same survival probability in the downstream reach they share in common (i.e., S_{Pool}, Figure 9).

B4. The route-specific survival probability is conditionally independent of the downstream survival processes (i.e., $S_{\text{Route}} \cdot S_{\text{Downstream}}$).

B5. Both tag groups experience the same downstream detection probability (i.e., p, Figure 9).

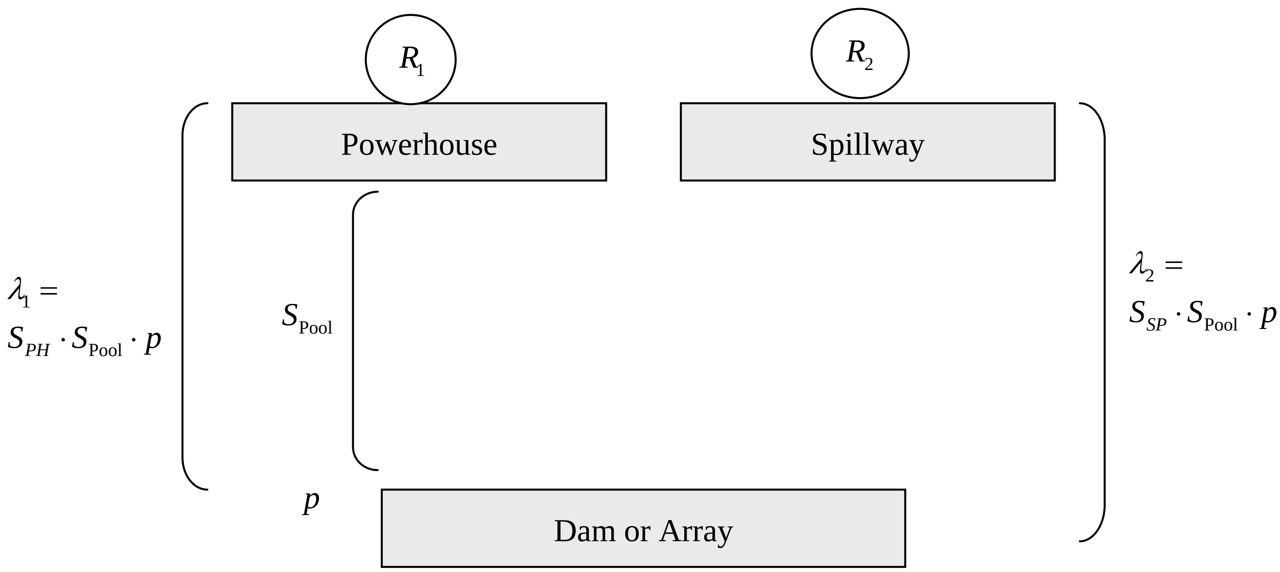
Assumption (B3) can be violated if the handling and tagging processes leading up to the release routes are different. Care must be taken to use the same release mechanisms at both locations in order to assure assumption (B3) is not violated. With concurrent releases, both tag groups should be adequately mixed, resulting in shared survival processes downriver. Assumption (B5) cannot be directly tested or evaluated, because the release-recapture data are inadequate to separately estimate capture and survival probabilities. Chi-squared R x C contingency table tests of homogeneity can be used to test for homogeneous arrival distributions to the downstream detection site. Homogeneous arrival distributions over time might be used to infer homogeneous differences in relative recovery rates (i.e., λ_1 and λ_2) will be attributed to differences in passage survival.

Discussion of Bias

An noted above, if the paired-releases are not mixed and arrive heterogeneously through time at the detection site, detection rates might differ between groups. Unequal detection rates will bias the estimates of relative survival either high or low.

Post-release tag loss, tag failure, and handling mortality are likely to be similar for simultaneously released tag groups. Hence, the model should be quite robust compare to alternative strategies that attempt to estimate absolute survival.

Figure 10. Schematic for a relative survival study with two release locations (R_1 and R_2) and one downstream recovery site.



Relative survival: $\hat{R}_{S_{PH}/S_{SP}} = \dfrac{\hat{\lambda}_1}{\hat{\lambda}_2}$

5.2 Using Absolute Survival Estimates

Building upon the previous paired-release method, multiple (at least two) downstream detection sites permit estimation of absolute survival probabilities separate from the detection probabilities (Figure 10). Relative survival between passage routes is then estimated as the ratio of two absolute survival estimates where

$$R_{S_{PH}/S_{SP}} = \frac{\hat{S}_{11}}{\hat{S}_{21}}$$

in Figure 10. This design is simply a special case of the paired release-recapture method of Section 2.2. For this reason, detailed discussion of the assumptions and sources of bias will not be repeated here.

Discussion of Bias

With the close proximity and simultaneous release of tag groups within two passage routes, the requirement of downstream mixing will be almost assured. In the case where all downstream reach survival and detection probabilities are equal between the two release groups, the statistical model is equivalent to that of Section 5.1 and relative survival is estimated as the ratio of recapture proportions. The advantage of this study design over that of Section 5.1 is the ability to formally test for equivalence and the higher overall detection rates by the use of multiple detection sites.

6.0 Illustration of Sample Size Calculations

6.1 Single Release-Recapture Design

Release size (R_1) for a single release-recapture study were determined when estimating project survival (Figure 11). The study design consisted of a single release and detection at three downstream detection sites. The objective is to estimate the first reach (i.e., release to the tailrace of the first downstream dam). For simplicity, it was assumed each of the three projects had a survival rate of S = 0.93 and each detection site, a common detection rate of p (Figure 11).

Figure 12 plots the anticipated precision (i.e., ε = half-width of a 95% confidence interval) as a function of the initial release size for various detection probabilities p. Each curve

Figure 11. Schematic of a single release-recapture design used to illustrate sample size requirements. Project survivals assumed to be $S_1 = S_2 = S_3 = 0.93$ with a common detection probability p at each of the three downstream detection locations.

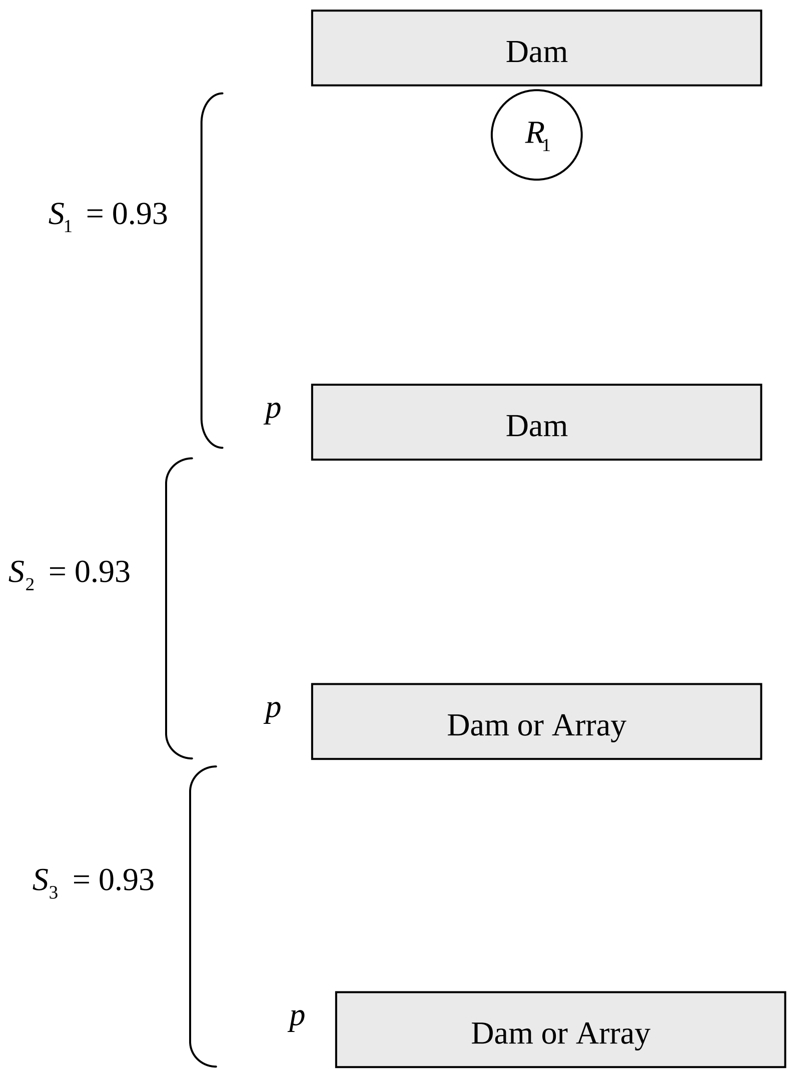
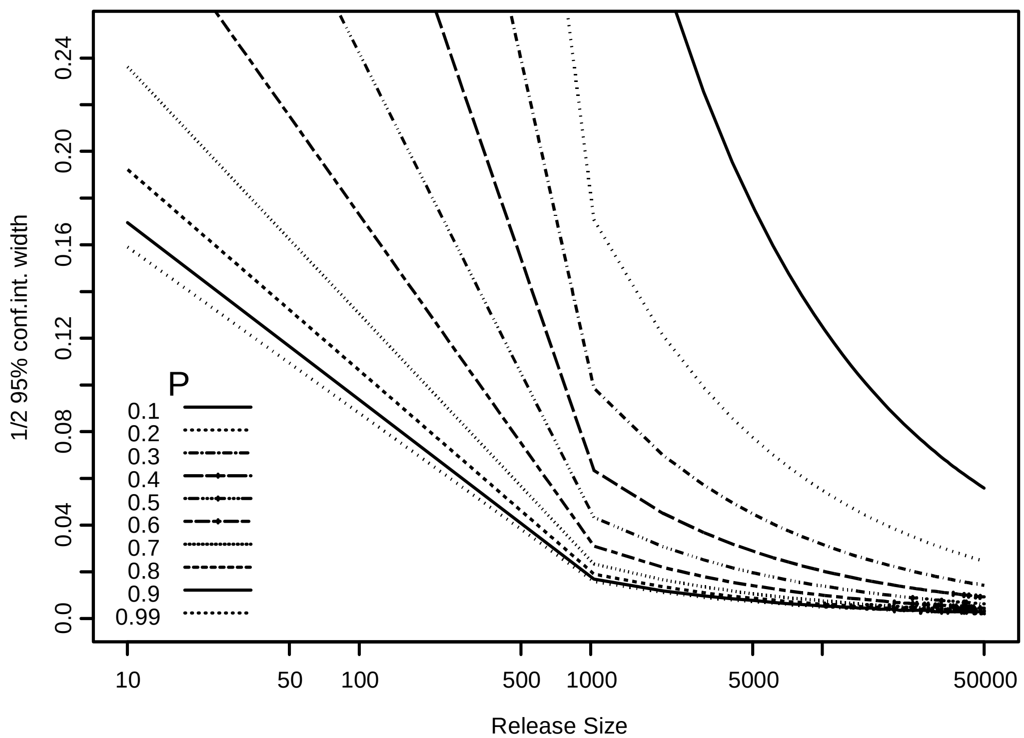


Figure 12. Precision curves for the single release-recapture design illustrated in Figure 11. Precision (ε) is expressed as the anticipated half-width of a 95% confidence interval for a given release size (R) and a per-site detection rate of p.



represents a different detection probability p = 0.10, 0.20, . . ., 0.90. As expected, as the detection probability increases, the required release size (R) decreases for a given level of precision ε. Conversely, as the desired level of precision (ε) becomes more stringent, release size (R) and/or detection probability (p) must increase.

Precision curves for single release-recapture designs similar to Figure 12 can be generated using the free software, Program SampleSize 1.1 (http://www.cbr.washington.edu/paramEst/SampleSize/). This sample size program provides a flexible platform to evaluate the precision of a variety of design configurations, including the number of detection sites, unique survival and detection probabilities per reach, censoring due to transport removal and staggered entry. The instruction manual for Program SampleSize can also be obtained at the same web address.

7.0 Literature Cited

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Skalski, J. R., S. G. Smith, R. N. Iwamoto, J. G. Williams, and A. Hoffmann. 1998. Use of PIT-tags to estimate survival of migrating juvenile salmonids in the Snake and Columbia Rivers. Canadian Journal of Fisheries and Aquatic Sciences 55:14 84-1493.

Appendix 2.
Recommended checklist for use in planning survival studies and during conduct of the study.

Below is a list that we suggest researchers should consider while developing survival studies. It is written to stimulate researchers to consider all aspects (and details) of the proposed study. Most of these considerations should be outlined in the final report of the study.

Fish

1) Where are fish collected?

2) Is the collection facility at a dam?
   i) Note if capture dam is different than where tagging or releasing will occur.

3) Describe the capture method used (seining, electro-shocking, trawling, trap, etc.).

4) Are any other marking and/or sampling procedures done in conjunction with proposed procedures (i.e. pit tagging, run sampling)?

5) Is there any transport involved with the capture of fish?

6) Describe the criteria for the selection of fish to be tagged (comparison of tagged fish to run of the river fish).

   i) Are length and weight criteria used? Describe criteria.

   ii) Are condition criteria used when selecting fish to tag (descaling, free of injuries, disease, presence of tag or mark, etc.)? Describe the criteria.

7) What species of fish do you study?

8) Describe the number of fish you typically collect, hold, tag, and reject.

9) Describe the source of fish you tag if known (Hatchery or wild, fin clip/no clip)?

10) Are the fish active migrants?

11) Describe the tag to fish weight ratio range that you have used in past studies and propose to use in this one.

12) Describe the size range (FL (mm), wt (g)) of the fish that you typically have tagged during your studies.

Fish Handling Procedures

1) Provide a description of your holding tanks.

2) Do you supply O_2 to the tanks?

3) Are fish held in-river or at a facility?

4) Describe the water flow/source and general water quality parameters that fish are held (DO, Temperature, etc.).

    i) Pre-tagging
    ii) Post-tagging

5) What is the stocking density of your holding tanks?

6) How long do you hold fish?

    i) Hours held pre-tagging
    ii) Hours held post-tagging

7) Describe the recapture methods you use for tag insertion (netting, dewatering, etc.).

8) Describe your anesthesia procedures.

    i) Type of anesthesia
    ii) Concentration used
    iii) Do you use buffering agents? If so what kind and at what concentration do you use.
    iv) How long do you hold fish in the anesthesia?
    v) Are the fish subjected to any previous anesthesia from general collection, transport, or sampling occurring at the collection site?

Tagging methodology

1) Describe the tagging method you use (gastric, surgical, pit, etc.).

2) How many tagging personnel are typically involved in your studies?

3) Describe the experience of your tagging staff. Do you retain staff year-round or do you have lead staff that trains new employees in the procedure every year.

4) What data are collected during tagging operations?

5) Do you use sterilization procedures for your tagging equipment? Describe them.

Recovery procedures

1) Do you supply oxygen to the recovery container?
2) What type of recovery container do you use (i.e., Bucket)?

3) What is the typical stocking density of your recovery containers?

Transportation

1) Describe your transport procedures for both pre- and post-tagging.
   - i) Do you supply oxygen, ice, or other amendments to maintain the water quality of your transport containers?
   - ii) What type of container (size), do you use for transport?
   - iii) What type of vehicle is used for transport (truck, boat, etc.)?
   - iv) Describe the range of transportation times that you encounter.
   - v) Do you employ procedures to equalize treatment and control groups if you employ a design that calls for them?
   - vi) What is the stocking density of your transport containers?
   - vii) Do you monitor water quality parameters during transport?

Release methods

1) Describe the types of release mechanisms that you use during your studies.
   - i) Do you release fish via a hose mechanism?
   - ii) Do you release fish from boats?

2) How do you select release locations?
   - i) Tailrace locations
   - ii) Forebay locations
   - iii) Pool release sites
   - iv) Releases into a particular passage route

3) How do you select release times for the various release groups?
   - i) Tailrace locations
   - ii) Forebay locations
   - iii) Pool release sites
   - iv) Releases into a particular passage route

4) Do you monitor water quality at release sites? If so, then do you employ any procedures to account for differences between the release location and the holding site?

Tags

1) Please describe the type of tags you use.
   i) Manufacturer
   ii) If active transmitters are used, are they coded tags or beeper tags?
   iii) What is the frequency range of the transmitters?
   iv) What is the size (length and weight) of the tags you use?
   v) What is the antenna length of the transmitter if applicable?
   vi) What is the expected battery life of the tags you use?
   vii) What is the size or number of batteries for the tags you use?

2) Please describe the following tag handling procedures:

3) Do you test your tags before releasing them?
   i) Do you water test the tags prior to implanting them?
   ii) Do you perform a recapture test at the release site?
   iii) Do you perform a check to see whether they are operating properly (i.e., coding, off/on, etc.) when received, prior to tag implantation, and before release?
   iv) Do you pull tags from batches and then perform tests of battery life, etc.?

4) Do you re-use tags (i.e. tags used from mortalities or spitters)? If so are there criteria for re-use?

Description of equipment components (general)

1) Provide a general description of the telemetry technology you use, along with a description of the some of its major components.

2) Indicate which telemetry technology you use in your studies.

   i) Radio
   ii) Acoustic
   iii) PIT

3) Describe the following attributes of the radio-telemetry system you use, if applicable.
   i) What is frequency range associated with you telemetry receivers?
   ii) Who is the manufacturer of the receivers?
   iii) What type of antennas?
      a) Aerial – what types?
      b) Underwater – stripped coax, dipole, other?

4) Describe the following attribute of the acoustic-telemetry system you use if applicable.
   i) What is the frequency range of the receivers that you use?
   ii) Who manufactures the receiver?

iii) Describe the data that you collect with your acoustic-telemetry system.
a) 1-D
b) 2-D
c) 3-D
iv) What types of hydrophones do you use?
v) Do you use different types of hydrophones for different applications?

5) Describe any attributes regarding PIT tag recapture systems that you feel are pertinent in the context of this survey.

Elements of Reporting

1) Describe some of the elements included in your reports that might help the reader interpret and understand results from a survival study.

2) Describe the ambient environmental conditions during the study you typically report.
i) Temperature
ii) Dissolved gas
iii) Discharge (total, spill, turbine, other discharge routes)
iv) Turbidity
v) Other?

3) What is typically reported for the water quality parameters?
i) Descriptive Statistics – central tendency and variation
ii) Daily – variation over the study period
iii) Hourly – diel variation

4) What do you typically report about your tagging procedures?
i) Tagging mortality rates
ii) Holding mortality rates
iii) Regurgitation rates (gastric only)
iv) Shed rates (PITs)
v) Fish condition

5) What is typically reported about the size of the fish used in your studies?
i) Tagged fish size
ii) Maximum tag to fish weight ratio
iii) Population fish size

6) How do you typically report the above regarding the size of fish used in your studies?
i) Mean, standard deviation, standard error
ii) Length/weight frequency distributions **(and how does this compare to the population at large?)**
iii) Proportion of population represented by tagged fish

Other Logistical Constraints

1) Describe the following logistical constraints that you may encounter while conducting your studies.

2) Do you encounter dissolved gas levels in either your holding tanks or release locations that exceed acceptable limits? If so, what measures do you take if any to mitigate for them?

3) Do you encounter water temperatures in either your holding tanks or release locations that exceed acceptable limits for the species of fish you are studying or that would cause temperature shock? If so, how do you mitigate for these conditions?

4) Have you encountered a situation where the sample size requirements of your study exceeded the number of fish available for collection? If so, how did you deal with this situation?

5) Do you typically rely on recapture systems at hydroelectric facilities? If so, are there logistical or other considerations that affect your study?

6) Do you typically use or rely on within-reservoir telemetry receiver locations? If so, are there logistical or other considerations that affect your study?

7) Have you ever encountered a situation where limitations on experienced or skilled staff affected your study design?

Appendix 3.
Example of Handling and Tagging Protocols Adopted by Chelan PUD

Acoustic/Radio Tagging Procedures

1) Set up double bucket system with connecting hoses
   a) Fill one bucket with fresh water
   b) Fill the other bucket with a MS-222 solution of 2ml/gal of water (1/2 solution)

2) Fill a pan with a MS-222 solution of 4ml/gal of water (knock-down solution), monitor water temperature and change when it increases by 2º C, do this for the recovery bucket also

3) Sterilize surgical equipment and acoustic in a Novalson solution

4) Sanctuary net one fish and put in “knock-down” solution

5) When fish has lost equilibrium (rolling over) take fish and put on surgical tray

6) Put hose leading to “½ solution” into the fishes mouth

7) Make an incision approximately 1 cm in length starting at the tip of the pectoral fin. Incision should be off-set of the ventral line.

8) Irrigate wound with antiseptic (100mg Oxytetracycline HCL)

9) Gently place tag through the incision into the body cavity
   a) If radio tagging, insert cannuli through incision, and bring through about 2/3 of the way down the fish.
   b) Put antennae through the cannuli and insert tag into incision.

10) Suture the incision at two points

11) Place fish in recovery bucket, when fully recovered place in release vessel

12) Monitor fish condition throughout surgery; if the fish starts to crash, add fresh water to the ½ solution entering the fish’s mouth

13) Sterilize surgical equipment in Novalson solution and rinse off prior to using the equipment on another fish

DO and Temperature Protocol

1. DO and temp readings need to be taken and recorded once every hour at the following sites
   a. Onshore holding tank

   b. Release tanks 1 and 6.
   c. At Rocky Reach DO and temperature also to be taken in buckets marked DO and in containers located in the totes near the shack when fish are in them.
2. If DO drops below 7ppm on the holding or release tanks turn on the oxygen to the tank that needs it.(If DO is less then 7ppm in one of the release tanks then all tanks must be checked)
   a. Open flow meter gauge first
   b. Open main oxygen valve from bottle
   c. Adjust oxygen on flow meter to get DO' s in tanks to 7ppm- 12ppm
   d. <u>Important</u>: when oxygen is on DO needs to be checked every 15 minutes.
   e. When DO is at proper levels (7-12ppm) turn oxygen off.

Appendix 4.
Tagging equipment and set up.

Prior to tagging, recovery buckets (dark-colored preferable) should be filled with fresh river water and supplied with a continuous flow of oxygen. Oxygen should be supplied to recovery buckets at a minimum rate of 50 ml/min? (overall rate may fluctuate depending on volume of recovery buckets). Oxygen should be supplied to recovery buckets for at least 5 minutes before handling fish and 5 minutes after fish have regained equilibrium.

Tagging equipment should be set-up during the period the recovery buckets are being oxygenated. Necessary equipment for gastric and surgical tagging include:

Weighing scale to the nearest 0.1 gram with large plastic weigh boats

A. Measuring board to the nearest millimeter
B. Thermometer
C. 100 g/l stock solution of Tricaine methanesulfonate (MS-222) (anesthesia)
D. 100 g/l stock solution of Sodium Bicarbonate (buffer)
E. Stress Coat (both un-dilute and dilute (250ml/750ml water))
F. 70% ethyl alcohol or bleach
G. Data sheets and writing implements.
H. Radio tags (pre-checked for operation and soaking in disinfectant)
I. One (or two) 5-gallon bucket designated as the "<u>anesthesia</u>" bucket marked at 10 L (2.8 gallons) – clearly labeled
J. Recovery buckets – clearly labeled
K. Reject bucket (for fish that are not tagged) – clearly labeled
L. Oxygen bottle with regulator (typically 40-70 L bottles are used for transport and 40-175 L bottles are used during tagging, depending on the application)
M. Air lines with air stones
N. Oxygen transport cradle – one for each size oxygen bottle.

<u>Surgery-specific supplies</u>:

O. Nolvasan (disinfectant)
P. Rock salt for saline solution
Q. Distilled water
R. Oxytetracycline (antibiotic)
S. Surgery tray table (foam pad with a groove cut out placed inside a zip-lock bag or a cradle made out of plastic - surgeon's preference)
T. Needle drivers, forceps, scalpel blades and handle (3- or 5-mm blades depending on species)
U. Sutures (4-0 or 5-0 depending on species)
V. Catheters (shielded needle) 18 gauge x 2.0 –3 in for smaller fish and 16 gauge x 4 –5.5 in for larger fish.

W. Gravity feed buckets equipped with shut-off valves and rubber tubing approximately 2-3 feet long (to be used to supply freshwater and anesthesia during surgery)
X. Antibiotic cream (bacitracin) and cotton swabs

<u>Gastric-specific supplies</u>:

Y. Gastric plungers (Plexiglas pipettes cut to a length of 14-15 cm)

A number of solutions must be prepared for both surgical and gastric methods of implantation:

A. Nolvason, or some other disinfectant is used to clean surgical tools after each surgery. Mix 1.5 oz of Nolvasan concentrate per 1 liter of distilled water.
B. Saline solution is needed to rinse surgical tools following disinfectant. Mix 50 g of rock salt (no iodized salt) per 1 liter of distilled water.
C. Stress coat should be used in all water sources that fish are exposed (including anesthesia and recovery buckets). Add 10 ml of the dilute stress coat stock solution to each 10 L bucket of water, to get a final concentration of 0.25 ml/L. The stress coat stock solution can be used undiluted on tagging platforms, weigh boats, and measuring boards.
D. When preparing anesthesia, we always use a stock solution of 100 MS-222 g per liter of distilled water. We recommend an anesthetic concentration of 60 mg/l for surgical implants and 50 mg/l for gastric implants of juvenile salmonids. We use 6 ml of MS-222 stock solution for surgical tagging, 5 ml for gastric tagging, in 10 L of river water in the anesthesia container. However, the effectiveness of MS-222 as an anesthesia varies with factors such as temperature and fish density. Adjustment to the anesthesia concentration should be based on the amount of time it takes for a group of fish to lose equilibrium. Induction time should average 2-3 min. and not exceed 5 min. If induction time is longer or shorter the concentration of the anesthesia should be adjusted accordingly
E. MS-222 can alter the Ph of the anesthetic solution and should therefore always be buffered with a solution of sodium bicarbonate. To make stock solution for anesthetic buffering, mix 100 grams of sodium bicarbonate (baking soda) per liter of distilled water. Use equal amounts of stock buffering solution and MS-222 stock solution into the anesthesia container.

Appendix 5.
Framework of a summary page
recommended for use in all survival reports.

Survival Study Summary- Framework:

Year
Study site(s)
Objectives of study
State hypothesis, if applicable
Fish • Species-race • Source
Size (median & range) • Weight • Length
Tag • Type/model • weight (gm)
Implant procedure • Surgical • Gastric • Injected
Survival estimate (per species or objective) • Type (project, etc.) • Value & SE • Sample size/replicate • # replicates • Analytical model
Hypothesis test and results (if applicable) H_o H_a conclusion
Characteristics of estimate • Effects reflected (direct, total, etc.) • Absolute or Relative
Environmental/Operating conditions • Relevant discharge indices • Temperature • TDG • Treatment(s)
Unique study characteristics