Quality Assurance Project Plan
for
Grid-based Juvenile Fish Abundance Estimation and Forecasting Using Snorkel Surveys and Electrofishing for Restoration Effectiveness Monitoring and Planning

Effective Date of Plan: February 13, 2023

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Caitlyn O'Connor, NWIFC Project Manager/Officer

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1.0 PROJECT MANAGEMENT

Distribution List

The following individuals will receive original copies of the approved Quality Assurance Project Plan (QAPP) and any subsequent revisions.

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Project Organization

The Director of Research and Recovery will be the responsible official for this project overseeing the overall project and budget and be responsible for reviewing and approving the Quality Assurance Project Plan (QAPP). The Director of Research and Recovery may provide technical input on proposed sampling design, analytical methodologies, and data review, and will assist in any adaptive changes to methods and updating of this QAPP as methods are refined.

The Biologist will have overall responsibility for developing and implementing this QAPP, including training appropriate staff to collected data as described within this QAPP, provide initial review of data for data quality objects and analysis and reporting. The Biologist will assign appropriate personnel to complete the tasks included in this plan and will communicate with the Director of Research and Recovery on work accomplished in this plan and any problems or deviations that need to be resolved. The Biologist will also operate as the internal Quality Assurance Officer providing data review to ensure data collect meet data quality objectives.

The Field Biologist will be responsible for coordinating research technicians and conducting field data collection according to methods described here, electronic data entry, and data QA in support of the project.

The Research Technicians will be responsible for assisting in conducting field data collection, electronic data entry, and data QA in support of the project.

The organization chart is at the end of the document in Figure 1-1.

Problem Definition/Background

Pacific salmon (*Oncorhynchus* spp.) are culturally vital and commercially important to Tribal communities who inhabit the Skagit River. Over recent years some species have declined from historical population sizes, and Chinook salmon (*O. tshawytscha*) and Steelhead trout (*O. mykiss*) are recognized as threatened under the Endangered Species Act (Federal Register 1999; 2007). The foundational document guiding Chinook salmon population recovery in the basin is the Skagit Chinook Recovery Plan, which identifies limiting factors for Chinook salmon recovery under the umbrellas of habitat protection, habitat restoration, and harvest management, and proposes actions to address each in turn (Skagit River System Cooperative and Washington Department of Fish and Wildlife 2005). The estimated benefits of each proposed habitat restoration action are expressed in terms of salmon capacity, measured in numbers of fish of a particular life stage. This presents a mismatch for common project monitoring techniques since the benefits of freshwater restoration and conservation actions are often described through habitat suitability indices, a qualitative ranking of 'how good' the habitat is for a species of interest (U.S. Fish and Wildlife Service 1981; Roloff and Kernohan 2018; Raleigh, Miller, and Nelson 1986).

Quantitative estimation of fish use in a restoration project area more closely matches the numerical projections from the Skagit Chinook Recovery Plan and allows better tracking of progress toward species recovery. Grid-based models that explicitly link fish occurrence, density, or abundance with habitat variables offer a useful option. One example currently being employed are N-mixture models, a type of probabilistic statistical model that reflect the idea that the observed abundance of a local population of interest derives from a hierarchy of factors - the true local abundance that we cannot observe, and our ability to detect it, both of which depend on factors influencing the metapopulation, like water depth or velocity in the case of small fish (Kery and Schaub 2012). Given hydrologic model inputs and multi-pass data collection, a hierarchical N-mixture ("N-mix") model can generate estimates of juvenile fish rearing abundance based on measured relationships between habitat covariates and species-specific occupancy and abundance. N-mix models of fish abundance have already been adopted in the Trinity River, California (Som et al. 2018), the Columbia River (Harris and Jolley 2017), Alaska (Sethi and Benolkin 2013), the southeastern U.S. (Mollenhauer and Brewer 2017), and elsewhere.

In the first implementation of the N-mix approach in the Skagit River, effectiveness monitoring for the Barnaby Slough restoration project uses N-mix model estimates to compare habitat use by juvenile salmonids before and after the restoration project in both treatment and reference areas. This pre- and post-project abundance metric allows quantitative evaluation of the effects of floodplain restoration on fish at the project site, in the same units of recovery as the Skagit Chinook Recovery Plan, and contributes to the development of a planning tool to forecast fish abundance in an area of interest based on robust in-basin fish use relationships (Som et al. 2018).

The planning benefit of the N-mix tool is its ability to forecast fish abundances of as-yet unbuilt restoration project alternatives to compare to each other and to other areas of the basin. These abundance forecasts can subsequently be used to evaluate the effectiveness of the constructed projects relative to pre-project fish use and to fish use in other projects and locations. Hydrologic models, required as inputs for the N-mix model, are increasingly being developed throughout the basin, enabling the N-mix model approach to leverage existing resources to provide fish estimates.

The goals of this Quality Assurance Project Plan (QAPP) are to 1) describe N-mix fish abundance estimation project design, methodology, data quality objectives and corrective actions, and 2) use floodplain restoration in Barnaby Reach as an example of how this QAPP will be implemented.

Project/Task Description

Objectives and hypotheses for a proposed restoration action help guide the action and allow the effectiveness of the action to be assessed. The main objectives of Barnaby Slough restoration are twofold, 1) to remove obsolete infrastructure and reconnect the historical floodplain habitat along 7 km of the Skagit River (Figure 2-1, at end of document), and thereby, 2) increase the number of juvenile Chinook salmon, coho, and *O. mykiss* rearing in the project area during summer and winter seasons.

The conceptual model connecting these two objectives with each other and the subsequent testable hypotheses begins with the fundamental understanding that floodplain connectivity and channel complexity support a diversity of freshwater habitats (Opperman et al. 2009). Freshwater habitat diversity supports species richness and diversity across a range of organisms and life stages (e.g., Armstrong et al., 2019; Takata et al., 2017). Floodplain connectivity allows migratory species to access habitats with suitable characteristics (Henning, Gresswell, and Fleming 2007). Freshwater-rearing Chinook salmon benefit particularly from backwater habitats and off-channel sloughs as protected rearing locations with suitable physical environmental characteristics and food resources (Jeffres, Opperman, and Moyle 2008); *O. mykiss* and coho salmon benefit from backwater rearing areas (Brown and Hartman 1988; Solazzi et al. 2000), as do stream-type juvenile Chinook salmon life history types (Sommer et al. 2001).

Accordingly, we have developed the following hypotheses to consider process, structure, and functional biological response to the restoration actions. From these hypotheses we designated parameters that can be used to evaluate our hypotheses. Finally, we describe anticipated results.

Objectives, hypotheses, parameters, and targets are defined in this monitoring plan as follows:

Objectives: what the restoration project aims to accomplish; in this case primarily to increase floodplain connectivity and increase numbers of Chinook, *O. mykiss*, and coho salmon rearing in the restoration project area.

Hypotheses: testable statements of relationship between variables leading to expected outcomes, generally expressed as an alternative hypothesis, in which change is detected, versus a null hypothesis, in which no change in detected.

Parameters: physical or biological variables about which data can be collected to test the hypotheses, such as water velocity or number of juvenile salmon.

Targets: numeric values indicating, for instance, rejection of a null hypothesis and support for an alternative hypothesis. An outcome that meets a target for a particular hypothesis that is linked to an objective demonstrates restoration project success for that objective.

1.7 Quality Objectives and Criteria for Measurement Data

1.7.1 Objectives and Project Decisions

Juvenile fish monitoring generates fish enumeration data from snorkeling and electrofishing and linked habitat data with associated objectives for data quality. These objectives comprise data characteristics or ranges over space and time and, if they fail to be met, trigger corrective actions to ensure that objectives can be met (Table 1-2).

1.7.2 Action Limits/Levels

See Table 1-2 for data measurements with corresponding corrective actions to be taken if expected characteristics or ranges are not met.

1.7.3 Measurement Performance Criteria/Acceptance Criteria

Field measurements and associated estimates have inherent associated error rates, which are critical to understand for interpreting results. Precision (uncertainty) and accuracy (bias) are measures of data quality used to assess agreement between measures and reality. Representativeness and completeness inform a sample's robustness for inference about broader population status and trends. Comparability addresses the relationship among the measures describing different systems.

Inherent in the sampling design are multiple passes for fish surveys (separate snorkelers making multiple observations each, or electrofishing multiple passes through the same water). Inherent in the statistical model structure is the calculation of probability of detection for each observer and sampling method, which allows evaluation or correction. For physical habitat data, careful documentation and tracking ensures that the data are retained. Habitat data are collected at the scale of the fish observation grid cell, 3 m^2. Water quality data, depth, and distance from cover are collected at the center of the grid cell.

1.7.3.1 Snorkel Survey Juvenile Fish Observations

Precision: Inherent in the sampling design are multiple snorkel pass replications both among and between observers. For each sampled grid cell four unique observations are made, two each by two separate snorkelers. From these observations a snorkeler-specific probability of detection can be quantified for each species, time of day, etc., which provide a quantitative basis for comparison and subsequent evaluation or correction.

Accuracy: Juvenile fish observations may be confounded by the same habitat covariates the model relates to fish abundance, for instance, if depth is related to abundance but also to detectability. To mitigate for this from the observational side as much as possible, snorkelers are instructed in fish identification and awareness of potential bias and given a training period before their observations are incorporated into the dataset. Snorkelers carry dive flashlights to illuminate deeper water and shadows. There is some variation in recommended time of day for observing salmonid species (O'Neal 2007). Paired data from day-night analyses in the first year of Barnaby N-mix sampling suggested that daytime counts and abundances were higher in summer and nighttime counts and abundances were higher in winter across the species of interest (LeMoine et al., *in prep*). Subsequent snorkeling observations have adhered to this diel seasonal design.

Representativeness: The large dataset generated through a randomized grid sampling scheme was designed to provide representative observations from across a suite of habitat covariate values without selection bias. Initially, water depth, water velocity, and distance from overwater cover values from the hydrologic model for the project area were binned by quantiles and sites were randomly selected from within each bin, with an effort to visit more random sites at the extremes, e.g., the deepest slowest water, or the deepest fastest water, etc., in order to provide the model enough information to converge, as in Som et al. (2018). Pilot model runs demonstrated that the model converged sufficiently to abandon the extreme bin effort and merely sample as many of the randomized grid cells as possible. The grid cells come from every wetted area in the hydrologic model, including mainstem river, side channel, backwater, bar, bank, off-channel, oxbow, slough, flooded marsh, tributary, and alluvial fan habitats.

Completeness: Data are collected throughout the period of stable seasonal low water conditions, i.e., March-April and July-September, with the spatial coverage described above. As fish are mobile and respond to hydrologic conditions, and the fish-habitat relationships derive from habitat characteristics experienced by juvenile fish at a given point in time, this temporal and spatial structure provides as complete a picture as possible for abundance calculations during the two respective seasons.

Comparability: Fish-habitat relationships should ideally be derived for each watershed of interest, as this project is doing in the Skagit River. At present, the dataset does not extend much beyond Barnaby Reach, but validation datasets are planned to evaluate the comparability of fish-habitat relationships developed in the Barnaby Reach with upstream and downstream locations in the Skagit basin.

1.7.3.2 Electrofishing Juvenile Fish Observations

Precision: Inherent in the sampling design for electrofishing are multiple pass replications with the anode(s) and nets. For each sampled grid cell three separate, sequential observations are made. From these observations a method-specific probability of detection can be quantified for each species, etc., which provide a quantitative basis for comparison and subsequent evaluation or correction.

Accuracy: Juvenile fish observations may be confounded by the same habitat covariates the model relates to fish abundance, for instance, if depth is related to abundance but also to catchability by netters. To mitigate for this from the sampling side as much as possible, two methods of electrofishing are employed in different depths of water: backpack electrofishing in wadeable streams and sloughs, and boat electrofishing in deeper ponds and rivers. The diffuse cable design of the boat anodes and the higher amperage of the boat electrofishing rectifying unit allows better coverage of deeper water. Once stunned fish are netted, fish identification is corroborated for accuracy by two observers.

Representativeness: See description in 1.7.3.1.

Completeness: See description in 1.7.3.1.

Comparability: See description in 1.7.3.1.

1.7.3.3 Physical Habitat Data Collection

Precision: Water quality instruments have factory pre-determined precision, e.g., 2100 series Swoffer current velocity meters record within ±0.01 m/s from 0.152 – 0.762 m/s and YSI ProODO Dissolved Oxygen probes record DO within ±1% of the reading from 0-20 mg/L and temperature within ±0.2°C from -5-70°C. Depth is measured in the center of the grid cell by stadia rod with 0.01 m graduations but due to the 3 m^2 area being described, is rounded to the nearest 0.1 m. The median substrate

classification size in each grid cell is measured to 0.01 m precision, but likewise is rounded to the nearest 0.1 m. Distance to the nearest overwater cover (riparian vegetation, cut bank, overhanging trees) is measured from the center of the grid cell to within 1 m. Presence of submerged cover is noted as presence/absence, with presence consisting of cobble >10 mm that is not embedded, wood >10 mm long in any dimension that is not embedded, or aquatic vegetation >10 mm in any dimension.

Accuracy: The accuracy of habitat data is assessed by daily dissolved oxygen probe calibration checks with distilled water, periodic assessments of current velocity rotor rotation and cleaning as needed for debris removal, and frequent conference among observers in assessing cover presence or other metrics as needed.

Representativeness: Habitat measurements are collected from the center of each fish observation grid cell in order to standardize collection among sites. Representativeness of habitat metrics is approached with a large dataset of randomized grid cells. For habitat type coverage representativeness, see 1.7.3.1.

Completeness: Habitat measurements are collected for every instance of fish observation, and indeed the N-mix model cannot include any fish observations with missing habitat data. For habitat type coverage completeness, see 1.7.3.1.

Comparability: Sampling protocols and analysis are consistent with those used in regional and national research (e.g., Som et al. 2018; Harris and Jolley 2017). For within-watershed comparability of habitat metrics, see 1.7.3.1.

See Table 1-3. Sampling Design and Rationale

See Table 1-4. Summary of Field Samples to be Collected

1.8 Special Training Requirements/Certification

Snorkelers are provided fish identification training and standardization of protocol implementation prior to their observational data being included in the dataset. Electrofishing field leads are certified in Electrofishing Principles and Safety from Smith-Root. All individuals involved have prior experience in the work.

1.9 Documents and Records

1.9.1 QA Project Plan Distribution

It is the responsibility of the Skagit River System Cooperative Research Scientist to prepare and maintain amended versions of the QAPP and to distribute the amended QAPP to the individuals listed in Section 1.3.

1.9.2.1 Field Data Sheets

Pre-printed weather-resistant field data sheets will be used to record field observations and measurements (Appendix A). These sheets will be kept in a permanent file in the office of the Skagit River System Cooperative Research and Salmon Recovery Program and digitally scanned for backup to a cloud-based server for the duration of SRSC operations. At a minimum, information to be recorded in the field data sheets at each survey includes:

- Date,
- Sampling site location and description,
- Observer names,
- Grid cell identification number,
- Grid cell survey start time,
- Electrofisher settings (backpack or boat electrofishing),
- Field measurement instrument readings including water temperature (°C), dissolved oxygen (mg/L), depth (m), and velocity (m/s), distance from cover (m), cover in site, substrate size (m),
- Pass number overall,
- Pass number per observer (snorkeling),
- Visibility (m; snorkeling),
- Field observations related to fish collection, including counts, species, fork length/total length (mm), and any mortalities,
- Deviations from the QAPP or SOPs required in the field.

1.9.2.2 Field Notebooks

Separate field notebooks may be carried for additional observations as needed and will be stored and backed up as stated in 1.9.2.1.

1.9.2.3 Digital Data

Digitized and QCd datasets of data collected through the methods described in this QAPP will be maintained on the cloud-based server described above, for the duration of SRSC operations.

1.9.2.4 Summary Reports

Analysis and reporting resulting from data collected through the methods described in this QAPP may be completed, and if so, will be stored on the cloud-based server described above, for the duration of SRSC operations.

1.9.3 Laboratory Documentation and Records

Not applicable.

1.9.4 Reports

The Skagit River System Cooperative Research Scientist is responsible for the preparation of annual FEATS technical summaries (one following each sampling season and covering the year's activities) to be submitted to the US EPA Grants Project Officer by December of each year. The annual summaries should include, at a minimum:

- Description of the project,
- Brief discussion of field activities, as well as any deviations or modifications to the plans,
- Results table and description
- Discussion of measures relative to data quality objectives

The Skagit River System Cooperative Research Scientist is also responsible for the preparation of a final multi-year FEATS report to be submitted to the US EPA Grants Project Officer at the conclusion of the project. The final report should include, in additional to the contents of the annual summaries:

- Description of the overall BACI design of the project,
- Project results and synthesis.

2.0 DATA GENERATION AND ACQUISITION

2.1 Sampling Design

Barnaby restoration effectiveness monitoring is proceeding along two simultaneous analytic approaches to account for two types of sampling and their associated survey designs. One is a traditional (but frequently challenging to properly implement) Before After Control Impact (BACI) design. The other is a field-validated before-after modeling comparison based on fish-habitat relationships modeled on the protocol developed by Som et al. (2018) in the Trinity River, California. Both approaches require recognition that fish count data are not normally distributed and Poisson distributions are more appropriate to describe fish observations. The use of Poisson distributions precludes standard student's t-test power calculations, which are based on normal distributions, so simulations are being developed to determine the number of survey sites and repeat visits required to generate reasonable power to detect change. The N-mix approach also specifically accounts for imperfect detection, or the recognition that observations of fish in a study inherently consist of a subset of the true number of fish in the study area, in a possibly non-random relationship over space, species, or other covariates.

The BACI approach entails monitoring environmental and biological variables at the restoration site pre- and post-treatment, as well as monitoring those same variables in untreated sites pre- and post-treatment as a reference in case of concurrent environmental or fish use changes (Underwood 1992; 1994). Such changes might otherwise impact the restoration site at the same time as project actions, show up as trends in the monitoring data, and be wrongly attributed to the restoration treatment. BACI designs allow quantitative comparisons using Analysis of Variance (ANOVA) for continuous environmental variables and Poisson regression modeling for fish counts, enabling detection of statistically significant changes specifically due to restoration actions.

The fish-habitat modeling approach leverages existing hydrological modeling to predict fish density and occurrence using expected relationships and spatially referenced, grid-based environmental variable values, specifically water depth, water velocity, and distance to cover. These spatially explicit variable values facilitate environmental and biological sampling across the environmental gradient in order to build a comprehensive model of fish occurrence and abundance in the restoration area. This hand in hand modeling and model validation will also be performed pre- and post-treatment at the restoration site to quantitatively assess fish benefit from the project.

See Figure 2-1. Site Map with Sampling Locations

See Table 2-1. Sampling Design and Rationale

See Table 2-2. Summary of Field Samples To Be Collected

2.2 Sampling Methods

2.2.1.1 Snorkel Survey Juvenile Fish and Habitat Data Collection

Observers will navigate to a wetted area suitable for snorkeling and identify a grid cell location from pre-loaded Global Positioning System unit coordinates. At each grid cell, observers will approach slowly at a distance and agree among themselves on the sampling bounds with landmarks and descriptions. Observers will periodically re-calibrate their visualization of 3 m^2 grid cells with the stadia rod and double checking among observers. They will survey for fish presence and abundance first, in the direction that least disturbs the fish, e.g., snorkeling upstream in shallow moving water, and allow fish to settle between passes. Each of two snorkelers will make two separate passes, identifying and counting individuals of each species observed. Fish fork length or total length as relevant will be estimated and reported to 10 mm bins. General methods are described by O'Neal (2007).

After fish surveys, surveyors will take a depth measurement in m in the center of the grid cell, velocity measurement in m/s at 60% of the water column height in the center of the grid cell, distance

to cover in m from the center of the grid cell to the nearest over-water cover that is within 0.5 m of the water surface (or a distance of 0 m if there is cover in or touching the site), size in mm of most commonly occurring substrate size, and presence or absence of underwater cover in site.

When a failure in data collection is observed, the technicians or Field Biologist may be able to correct it immediately in the field, such as in the case of equipment malfunction or observer fish identification error. In this case, the error and correction are documented in the field data and adjusted accordingly at the data digitization stage by correcting or removing the erroneous measurement(s). Some issues may be identified and corrected at the Biologist level, such as a pattern of missing conductivity or electrofisher settings data, and a meeting will be called among all staff involved in the project to reinforce the protocol and expectations and correct the problem from then onward. This correction will be observable in the dataset by an improvement in data completeness.

2.2.1.2 Electrofishing Juvenile Fish and Habitat Data Collection

Surveyors will ascertain temperature and DO before proceeding. If temperature is >18 °C or DO <5 mg/L, greater caution is recommended and upon salmon mortality, electrofishing will cease for the day. Observers will navigate to a wetted area with depth and access suitable for backpack or boat electrofishing, respectively, and identify a grid cell location from pre-loaded Global Positioning System unit coordinates. At each grid cell, the backpack or boat operator will approach slowly at a distance and agree with netter(s) on the sampling bounds with landmarks and descriptions. Observers will periodically re-calibrate their visualization of 3 m^2 grid cells with the stadia rod and double checking among observers. They will survey for fish presence and abundance first, in the direction that least disturbs the fish, e.g., nosing the raft toward an obstacle in a pond, and allow fish to settle between passes. Shockers will will make three separate passes, netting fish into separate tubs or buckets. Upon completion of the three passes, surveyors will identify, count, and measure individuals of each species observed, using fork length or total length in mm as relevant. Incidental mortalities will be recorded and disposed of on the bank, unless Chinook salmon or *O. mykiss*, which will be retained in vials.

After fish surveys, surveyors will take habitat measurements as described in 2.2.1.1.

When a failure in data collection is observed, the technicians or Field Biologist may be able to correct it immediately in the field, such as in the case of equipment malfunction or observer fish identification error. In this case, the error and correction are documented in the field data and adjusted accordingly at the data digitization stage by correcting or removing the erroneous measurement(s). Some issues may be identified and corrected at the Biologist level, such as a pattern of missing conductivity or electrofisher settings data, and a meeting will be called among all staff involved in the project to reinforce the protocol and expectations and correct the problem from then onward. This correction will be observable in the dataset by an improvement in data completeness.

2.2.2 Field Health and Safety Procedures

New staff will be oriented to site locations and roadways, communications plans, emergency contact information, and the location of nearby hospitals. New staff will work with experienced staff so an experienced person is present to provide assistance and/or call in an emergency from the field if/when needed. All staff will be familiar with cell phone coverage limitations and emergency procedures. Personal protective gear to be worn includes breathable or neoprene chest waders and sturdy wading boots, or a waterproof dry suit with neoprene hood and wading boots and non-cotton layers for insulation.

2.3 Sample Handling and Custody

Not applicable.

2.4 Analytical Methods

2.4.1 Field Measurements Methods

For each random sampling grid cell (3x3m), staff will navigate to near the cell, begin with fish presence and identification for all the requisite passes, then conclude with habitat measurements that would otherwise disturb the fish.

For snorkeling, the first snorkeler navigates by swimming or holding position by hand in a slow upstream direction, counting and identifying fish as they go and keeping a mental tally including fish lengths by 10mm size bins. In case of faster current that cannot be swum or held against, it might be necessary to float downstream over the grid cell in a directed fashion. This constitutes one pass by one observer. This process is repeated for a second pass or more and for all snorkelers present. The data taker records fish observations and lengths in mm (fork length or total length as appropriate) by 10mm bin for each separate pass and grid cell by site point ID. After visual fish observations are completed, environmental variables are measured and recorded for the center point of each grid cell. Depth is taken in m with the stadia rod. Velocity is taken in m/s with a flow meter set to average reading in m/s, with the rod in a vertical position and the propeller at 60% of the depth of the water column, waiting a minimum of 30 seconds for the reading to stabilize. Distance from cover is taken in m with the laser range finder, defined as shoreline vegetation or overhanging vegetation or other rock/log/etc. within 0.5 m of the water surface. Cover in site is defined as woody debris, cobble, or algae and macrophytes >10 cm in the smallest dimension. An example of the dominant site substrate size is recorded in mm. This process is repeated for each grid cell.

For backpack electrofishing this process is identical except that fish observations are conducted by the shocker, who sweeps the grid cell for 30 seconds to adequately cover the water while the dip netter(s) collect fish and deposit them into one bucket during a 20 second pause. This constitutes one

pass. This process is repeated for a second pass and a third pass, with fish deposited into different buckets. After electroshocking, fish are identified and measured with lengths in mm (fork length or total length as appropriate) for each separate pass and grid cell by site point ID. After electrofishing passes are completed, environmental variables are measured and recorded for the center point of each grid cell as described above.

This process is identical for boat electrofishing except for rowing a cataraft with a frame-mounted electrofisher between sites rather than walking; each grid cell of water in a slough or mainstem is shocked for 10 seconds, owing to the wider radius of the anodes, with a pause for 10 seconds between passes, keeping the boat in place by rowing.

When a failure in data collection is observed, the technicians or Field Biologist may be able to correct it immediately in the field, such as in the case of equipment malfunction or observer fish identification error. In this case, the error and correction are documented in the field data and adjusted accordingly at the data digitization stage by correcting or removing the erroneous measurement(s). Some issues may be identified and corrected at the Biologist level, such as a pattern of missing conductivity or electrofisher settings data, and a meeting will be called among all staff involved in the project to reinforce the protocol and expectations and correct the problem from then onward. This correction will be observable in the dataset by an improvement in data completeness.

See Appendix A-2. Standard Operating Procedures

2.4.2 Field Analyses Methods

2.4.2.1 Screening

Field data are subject to weekly screening for completeness, legibility, and flagging for measurements outside of standard ranges. Flagged measurements receive follow up between the Biologist and field staff to ensure accuracy, e.g., if 60 juvenile Chinook are noted in one grid cell, it will be ascertained that the unusual observation is in fact correct, or a depth measurement of 5 cm, which could not be snorkeled but may have been clear still water in which fish were visible and water quality measurements could be taken.

2.4.2.2 Definitive

Screened, entered, and QCd data will be submitted for analysis using hierarchical N-mixture models in Program MARK.

See Appendix A-3. Model assessment and power analyses.

2.4.3 Laboratory Analyses Methods (Off-Site)

Not applicable.

2.5 Quality Control Requirements

Field and data processing methods have multiple steps built in to address quality control, as described throughout this document. A critical place for focus in data collection though is the accurate identification, communication, and transcription of data in the field onto field forms, since the observations are of transitory states like fish abundance in a grid cell of water and cannot be confirmed or replicated after. Thus, it is impressed on field staff to speak clearly and with repetition in the delivery of fish counts and lengths to the transcriber to provide a double check. Field forms are also error screened weekly by the Biologist to ensure values are logical and to inquire about outliers while Field Technician memories are still fresh.

QC procedures implemented at the time of data entry include the use of separate people for entry and QC, and/or separate times for entry and QC, and 100% QC of spreadsheet entry accuracy relative to paper field forms.

2.5.1 Field Sampling Quality Control

Not applicable.

2.5.2 Field Measurement/Analysis Quality Control

2.5.2.1 Field Measurement QC

Not applicable.

2.5.2.2 Field Analysis QC (Screening and Definitive)

Not applicable.

2.5.3 Laboratory Analysis Quality Control

Not applicable.

2.6 Instrument/Equipment Testing, Inspection, and Maintenance

2.6.1 Field Measurement Instruments/Equipment

Electrofishing units themselves do not generate data in the protocol described here but their operation is required for fish sampling. Units will be set to the lowest frequencies and durations necessary to stun fish without inflicting damage. Pacific Northwest freshwaters are generally of low electrical conductance, so starting settings for the backpack electrofisher is typically 0.1 amps, 700 volts and for the boat electrofisher is typically 3 amps, 200 volts, which may be adjusted upward if the current is found to be ineffective at stunning fish.

Water quality instruments in daily use, the YSI probe and Swoffer velocity meter, will be visually inspected at the beginning of each day to ensure clean, undamaged devices and correct any dirt, residue, battery failure, or other damage.

See Table 2-3. Field Equipment/Instrument Calibration, Maintenance, Testing, and Inspection

See Appendix A-1. Equipment/Instrument Manuals

See Appendix A-3. Standard Operating Procedures

2.6.2 Field Instruments/Equipment (Screening and Definitive)

Not applicable.

2.6.3 Laboratory Analysis Instruments/Equipment (Off-Site)

Not applicable.

2.7 Instrument/Equipment Calibration and Frequency

2.7.1 Field Measurement Instruments/Equipment

Electrofishing units themselves do not generate data in the protocol described here but their operation is required for fish sampling. Units will be set to the lowest frequencies and durations necessary to stun fish without inflicting damage and adjusted at the beginning of each day of use and within each day as water conductance, depth, and fish observations require.

Water quality instruments will be calibrated prior to the beginning of the sampling season and assessed throughout the season at frequencies dependent on the instrument. The YSI temperature logger will be single point calibrated prior to the beginning of the season to 0°C, while the YSI dissolved oxygen logger will also be calibrated at the beginning of every day using the distilled water in the internal %DO calibration function. The Swoffer velocity meter will be calibrated at the beginning of its first use using a pace per time propeller revolution comparison protocol.

See Table 2-1. Field Equipment/Instrument Calibration, Maintenance, Testing, and Inspection

See Appendix A-1. Equipment/Instrument Manuals

See Appendix A-3. Standard Operating Procedures

2.7.2 Field Instruments/Equipment (Screening and Definitive)

Not applicable.

2.7.3 Laboratory Analysis Instruments/Equipment (Off-Site)

Not applicable.

2.8 Inspection/Acceptance Requirements for Supplies and Consumables

2.8.1 Field Sampling Supplies and Consumables

The dissolved oxygen sensors for the YSI probe and the Onset logger, available from standard suppliers and the manufacturer, need replacing once prior to each sampling season.

2.8.2 Field Measurement/Analyses (Screening and Definitive) Supplies and Consumables

Not applicable.

2.8.3 Laboratory Analyses (Off-Site) Supplies and Consumables

Not applicable.

2.9 Data Acquisition Requirements (Non-Direct Measurements)

Hydrologic models describing water depth, velocity, and other metrics, possibly as related to estimated fish presence and abundance, are needed for random grid sample designation and model validation. These models are not generated as part of this QAPP, but obtained from an internal or external source for use in sample design and analysis through the data collection described here.

2.10 Data Management

Skagit River System Cooperative uses traditional paper field data sheets, field notebooks, and electronic Microsoft (MS) Excel spreadsheets. Traditional paper field sheets are used to record site conditions, fish counts and marking information during trap efficiency and standard juvenile fish trap collection operations. Paper field data sheets are sorted by stream and stored in chronological order at a secure office location. The Biologist will be responsible for working with the Field Biologist and Research Technicians to ensure data are recorded clearly, checked for potential errors and complete prior to being entered into project spreadsheets. All paper field data sheets are entered into MS Excel spreadsheets. All data entered are checked by either the Research Technicians or Field Biologist. MS Excel spreadsheets are stored on an offsite, secure server which is backed up regularly.

3.0 ASSESSMENT AND OVERSIGHT

3.1 Assessments/Oversight and Response Actions

During the sampling period, the Field Biologist will report weekly regarding fish observations, environmental data measures and any issues to the Biologist. Data will be reviewed formally on a weekly basis by the Biologist to identify if data quality objectives were met by comparing data with the action limits described in this QAPP. The Biologist will work with the Field Biologist to correct issues identified. If data quality objectives are not met for two times within a four-week period, the Biologist will call a meeting with the Field Biologist and the Senior Research Scientist (Internal QA Officer) to discuss issues and further seek resolution and documentation of the issue. If consistent issues occur, the NWIFC Project Officer will be notified and solutions will be discussed.

Any data collected that fall outside the data quality objectives in this QAPP will be documented within spreadsheets.

3.2 Reports to Management

The Biologist prepares a short report discussing QA objectives and the data quality annually. The report compares expected data quality objectives, fish outmigrant enumeration, and measured trap efficiency. The Research Scientist will discuss potential improvements to study design, field methods or data curation to improve data quality.

The Director of Research will review and provide comments to the QA report. Subsequently, the revised QA report will be provided to EPA coordinator and Skagit River basin co-managers for comment to improve project design and data quality.

4.0 DATA REVIEW AND USABILITY

4.1 Data Review, Verification, and Validation Requirements

Juvenile fish observation and habitat data will be used to assess the effect of restoration actions within the floodplain. Multiple years of pre- and post-project fish abundance estimates and related data will be used in an ANOVA type model structure or Generalized Linear Model, and as such annual data will necessarily undergo a data quality assessment process, using the quality objectives described in prior sections.

This section describes steps of annual data review for the purpose of future usability that will feed into a multi-year assessment. This QAPP does not discuss data screening for the multi-year assessment rather it discusses screening and documentation of the data collected within a year.

4.2 Verification and Validation Methods

Abundance estimate outputs will be reviewed for output reasonableness compared with previously published literature and abundance estimates from other sources within the watershed, e.g., previous species- and habitat-specific snorkel- or electrofishing-based densities or smolt trap off-channel rearing habitat emigration abundances. If the difference between the N-mix estimate and literature estimates approaches an order of magnitude or otherwise raises the suspicion of the Biologist and Research Director based on literature understandings of fish use in particular habitats, then the abundance estimate for that year/season/species will flagged as recommended not to be used in assessing restoration effect size until further investigations are conducted. For environmental data, data quality objectives will be used to screen data and flag any data to be recommended not to be used in assessing restoration effect size.

4.3 Reconciliation with User Requirements

This QAPP covers within year data collection. Data measures outside the data quality objectives will be flagged so that future analyses can easily make determinations whether to include or exclude data that do not meet data quality objectives.

5.0 REFERENCES

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FIGURES:

Figure 1-1. Organization Chart

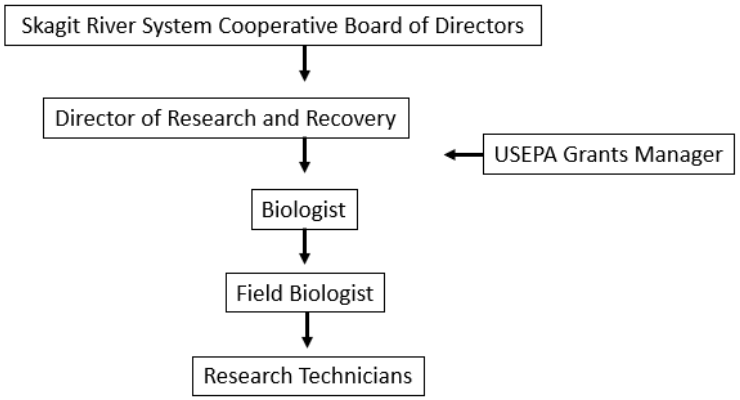


Figure 2-1. Site Map with Example Sampling Locations

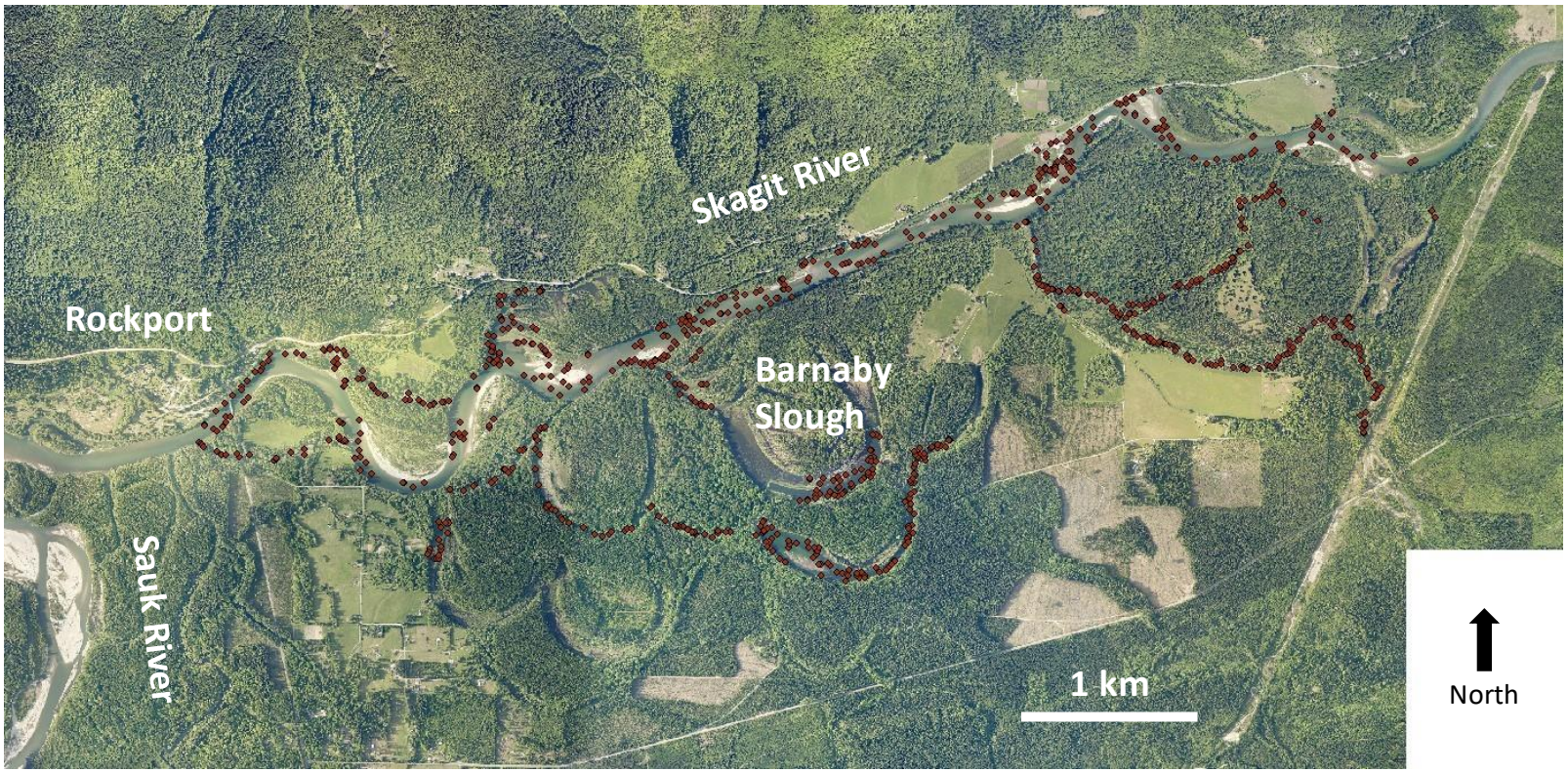


Figure 2-1. Example of N-mix floodplain fish sampling locations for the Barnaby Reach restoration project, 7 km reach of Skagit River mainstem and off-channel habitats reconnected through restoration of Barnaby Slough and associated waterbodies, where red points represent sites surveyed in a season.

TABLES:

Table 1-1. Floodplain Restoration Snorkeling and Electrofishing Survey Workplan

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Juvenile fish surveys												
Environmental data surveys												
Data entry/QA/ reporting												

Table 1-2. Data Measurements with Corrective Actions

Measurement	Description	Measurement Criteria	Corrective Action
Fish identification	Species or genus of enumerated fish	Sudden change in species occurrence or representation in data screening	Field verify fish identifications with staff
Fish capture rate	Species specific sum of fish captured in electrofishing	Sudden increase or decrease in fish capture rate in a known habitat type	Assess water quality metrics (especially conductivity) and electrofisher setting for mismatch
YSI DO calibration	Daily point measurement DO calibration	Calibration value <90.00%	Do not collect data from occasions with low calibration accuracy; investigate possible equipment malfunction

Table 1-3. Sampling Design and Rationale in Barnaby Reach Restoration

Sampling Location	Media	Depth (Appropriate Units)	Analytical Parameter[1]	Rationale for Sampling Design[2]
Barnaby Slough	Fish	NA	Fish counts, observer identify	To assess emigrating abundance of juvenile fish and impact of observer
Barnaby Slough	Water	60% of water column depth	Temperature, dissolved oxygen, conductivity, velocity	Comparison among survey sites and environmental covariate for assessment of factors impacting fish abundance
Barnaby Slough	Habitat	NA	Distance from cover, presence of underwater cover, substrate size	Comparison among survey sites and environmental covariate for assessment of factors impacting fish abundance
Reference sites	Fish	NA	Fish counts, observer identity	To assess emigrating abundance of juvenile fish and impact of observer
Reference sites	Water	60% of water column depth	Temperature, dissolved oxygen, velocity	Comparison among fish trap sites and environmental covariate for assessment of potential factors impacting fish abundance
Reference sites	Habitat	NA	Distance from cover, presence of underwater cover, substrate size	Comparison among survey sites and environmental covariate for assessment of factors impacting fish abundance

[1] Analytical parameters include all planned field measurements (e.g., dissolved oxygen, etc.).
[2] Rationale supports the selection of sampling locations and associated analytical parameters.

Table 1-4. Summary of Field Samples to be Collected

Media	Analytical Parameter [1]	No. of Sampling Locations	Depth [2] (surface, mid, or deep)	Sampling Interval	Total No. of Samples
FIELD MEAUREMENTS:					
Fish	Count	~600/season	all	Daily during season	Survey-dependent
Fish	Length	~600/season	all	Daily during season	Survey-dependent
Water	Velocity	~600/season	mid	Instantaneous	~600
Water	Temperature	~600/season	mid	Instantaneous	~600
Water	Conductivity	~600/season	mid	Instantaneous	~600
Water	Dissolved oxygen	~600/season	mid	Instantaneous	~600
Habitat	Distance from over-water cover	~600/season	surface	Each site	~600
Habitat	Presence of underwater cover	~600/season	all	Each site	~600
Habitat	Substrate size	~600/season	deep	Each site	~600

[1] Analytical parameters include all field measurements.
[2] When samples are collected at different depths at the same location, information for each depth category (e.g., surface, mid, or deep/bottom) is provided on a separate line.

Table 2-1. Field Equipment/Instrument Calibration, Maintenance, Testing, and Inspection

Analytical Parameter	Field Equipment/ Instrument	Calibration Activity	Maintenance Activity	Testing/ Inspection Activity	Frequency	Acceptance Criteria	Corrective Action
Temperature	YSI probe	Single point ice bath 0°C calibration	Clean and replace parts as needed		Prior to use for the season	Components and connections in working order	Clean and replace parts as needed
Conductivity	YSI probe	Factory calibrated	Clean and replace parts as needed		Prior to use for the season	Components and connections in working order	Retest, and replace sensor as needed
Dissolved oxygen	YSI probe	Distilled water calibration	Clean and replace parts as needed		Daily	Reading >95%	Retest, and replace sensor as needed
Velocity	Swoffer meter	Paced rotation calibration procedure	Clean and replace parts as needed		Upon initiation of new meter		Reset rotation setting in the display unit as needed

APPENDICES

APPENDIX A. Field Documentation

A-1. Equipment/Instrument Manuals
A-2. Standard Operating Procedures
A-3. Field Data Forms

APPENDIX B. Laboratory Documentation

B-1. QA Manual
B-2. Standard Operating Procedures
B-3. Data Report Format

APPENDIX C. Data Evaluation

C-1. Data Evaluation/Documentation Form

APPENDIX A

Field Documentation

Appendix A-1.
Equipment/Instrument Manuals

Water Quality Instrument Manuals

YSI probe:
https://www.ysi.com/File%20Library/Documents/Manuals/626279-YSI-ProODO-User-Manual-RevC.pdf

Swoffer flow meter:
https://www.swoffer.com/manuals.htm

Appendix A-2.

Standard Operating Procedure for Fish Surveys – Snorkeling and Boat/Backpack Electrofishing

Field protocol for Barnaby restoration fish/habitat monitoring via snorkel/efish grid cell

Map and instructions

GPS unit with points pre-loaded and spare batteries

YSI – charged

Telescoping stadia rod

Swoffer velocity meter rod and unit in Pelican case with allen wrench and spare propeller

Laser range finder

Rite-in-the-Rain data sheets, clipboard, pencils

For backpack efishing:

Smith-Root backpack unit

Wand with ring (anode)

Cable rat tail (cathode)

Battery and spare – charged

Long handled dip nets

Buckets or tubs for three pass fish collection

Length boards

For boat efishing:

Pontoon cataraft with two-piece fishing/rowing frame and straps attached

Four 7’ cinch straps to attach to trailer

Truck battery-powered pump for pontoons

K-pump for hand finishing fill level in pontoons

Raft oars

Chain anchor

Raft repair kit

Generator – filled, and spare fuel can

Efishing rectifying unit and cables/cords

Anodes (medusa cables on yellow poles)

Cathode (cables on metal rod, if not attached to raft frame already)

Two long handled dip nets – Sharpie marked with length in tenths of meters

Cooler with two small buckets nested inside

Aquarium net

Length boards

For snorkeling:

Dry suits, neoprene hoods, neoprene booties, wading boots, gloves if desired

Mask and snorkel, rechargeable dive lights

Workflow narrative:

Nighttime

If night snorkeling, arrive onsite in the afternoon (probably between 2 and 4 pm, depending on day length and walk distance) and perform the following habitat data collection but not the fish observations, making each site with a glow stick and flagging, writing the number on it in Sharpie. Data can be collected on the first of four otherwise blank lines to leave room for the fish observations later. Wait out the shift to full darkness in the field or back at the truck, then return to the sites after the onset of astronomical twilight for that day to do the fish observations, checking that the site numbers align with the data previously recorded. Strive for maximal site count with accuracy, but keep in mind snorkeler safety and comfort at night; 12-18 sites is reasonable, more if there is walking in between, and fewer if snorkelers are in the water the whole time (e.g., Harrison Pond, Washington Eddy).

Sampling limits for efishing

If electrofishing, check temperature and DO with the YSI before beginning. If >18 C or <5 mg/L, do not proceed.

Survey site identification

Identify a site from GPS coordinates.

If there are no points in the area (due to no hydrologic model, etc), institute a randomized method for site selection, e.g., every linear 50 m along the channel, survey a site in the middle, halfway to the edge, and touching the edge in a repeating pattern to avoid bias about where you will or won't find fish. Mark these as waypoints on the GPS and record the waypoint number as a haphazard site in the data.

Fish observations

At each 3 x 3 m site, approach slowly at a distance and agree among observers on the sampling bounds with landmarks and descriptions. Periodically re-calibrate your 3 m eye with the stadia rod. Survey fish first, in the direction that least disturbs them, e.g., snorkeling upstream in shallow water, nosing the raft toward an obstacle in a pond.

Allow fish to settle between passes.

Make two passes of snorkeling observations per observer, or three passes with the shocker, retaining fish after each pass (sampling without replacement).

Snorkeling, identify species and estimate fork or total length in 10 mm bins for each observer for each pass. Efishing, collect fish in separate buckets by pass, then at the end of shocking that site, identify species and measure fork or total length in mm for each pass.

Note in the data sheet what was done with incidental mortalities, generally Chinook and O. mykiss will be retained in vials and/or frozen and all others disposed of on the bank.

Habitat observations

After fish surveys, take a depth measurement in m in the center of the grid cell, velocity measurement in m/s at 60% of the water column height in the center of the grid cell, distance to cover in yds (to convert later) from the center of the grid cell to the nearest over-water cover that is within 0.5 m of the water surface (or "0" if there is cover in or touching the site), size in mm of most commonly occurring substrate size. Note whether there is underwater cover in site, defined as cobble >10 mm that is NOT embedded (i.e., has a shadowed place for fish to hang out), wood >10 mm long in any dimension that is not embedded, or aquatic vegetation >10 mm in any dimension. Note whether site is non-homogenous, i.e., substantially varying in depth or velocity across the 3 x 3m.

All habitat data must be collected for that site to count in the model. The model can accept 'missing' fish observations (i.e., one pass, or one snorkeler), but cannot accept data with missing habitat metrics.

Record for each site:

Location Name, e.g. "Skagit mainstem"

Location Description (road/trail access, direction, comments), e.g., "RB side channel downstream from Cascadian Farm MP 101, accessed via Skagit Land Trust trail, working downstream" (also note if doing a day/night comparison and if so, which time of day these surveys represent)

Date

Crew initials

Page ___ of ____ (in which each side of a sheet counts as a page)

PointID (the multidigit site number assigned to the waypoint on the GPS or the waypoint marked in the GPS for the haphazard site surveyed)

Start time (of the first survey at that site, for cross referencing in case of confusion later, not analysis)

Water temperature in C

Dissolved oxygen in mg/L

Specific conductance in uS/cm

Depth in m

Velocity in m/s

Distance from cover in yards

Cover in site yes or no

Substrate size in mm

Note and briefly explain in margins if habitat is not homogenous across 3x3 m grid

Pass # for efishing (1-3), or total pass order for snorkeling (1-4 for 2 snorkelers)

Snorkeler initials

Pass # each (1-2 per snorkeler)

Visibility (1,2, or 3 m) minimum distance to seeing a fish given water clarity

Count x Fish Species Name (Length bin (mm)) – e.g., “3xCO(30-40), 1xCO(60-70), 2xCK(50-60)”

Comments, e.g., whether the site was dry and thus had no data associated, any issues with site numbers or access, any issues with equipment or observations, confirmation of an unusual observation like 80 x CK in one site (“high density Chinook fry”) or a very large fish (“one adult steelhead swam by”), etc.

Appendix A-3.
Field Data Forms

ERROR CHECK by ______ Date: ___/___/___

Grid Electrofishing Data Form **Site Metadata, Habitat, Fish**

Location Name: ___________________________ Crew: ____________________ Date: ___/____/_____ Pg _____ of _____

Location Description (road/trail access, direction, comments), waypts or PointID of top and bottom of sampling reach:

Backpack /boat	Amps	Volts	DC/ Pulse *	If pulse, Freq *	If pulse, Duty Cycle *	Total Shock Time (Sec)	Start Temp <18C	Start DO >5mg/L	*Backpack only. Notes:

Site Point ID (double check please)	Start Time	Shocker Initials	Temp (C)	DO (mg/L)	Specific Conductance	Depth (m)	Velocity (m/s)	Distance from Cover (yds)	Cover in Site? (y/n)	Substr. size (mm)	Pass #	Shock time all 3 passes*	Count x Fish Species Name (Fork Length (mm)) for captured and measured fish

ERROR CHECK by _____ Date: ___/___/___

Snorkeling Data Form **Site Metadata, Habitat, Fish**

Location Name: _____ Crew: _____ Date: ___/____/_____ Pg _____ of _____ (count front and back sep)

Location Description (road/trail access, direction, comments), waypts/PointID of top and bottom of sampled reach: | Day survey? Night survey?

Site Point ID (double check please)	Start Time (24 hr)	Temp (C)	DO (mg/L)	Spec Cond (us/cm)	Depth (m)	Vel (m/s)	Dist from Cov (yds)	Cov in Site? (y/n)	Subst size (mm)	Total Pass Ord (1-4)	Snork ID	Pass # Each (1-2)	Vis. (1,2,3)	Count x Fish Species Name (Length bin (mm)) (*add on margin if too cramped)

and
Chain-of-Custody Documentation

Not applicable.

APPENDIX B

Laboratory Documentation

Not applicable.

Appendix B-1.
QA Manual

Not applicable.

Appendix B-2.
Standard Operating Procedures

Not applicable.

Appendix B-3.
Data Report Forms

Not applicable.

APPENDIX C

Data Evaluation

Not applicable.

Appendix C-1.
Data Evaluation/Documentation Form

Not applicable.

APPENDIX D

Power Analyses and Sampling Design

SRSC Passive and Active Fish Sampling Techniques

Power Analyses and Sampling Design

Catherine Austin and Mike LeMoine

January 2023

Introduction

A desired outcome of floodplain habitat restoration projects is typically a fish response in the form of increased presence, occupancy, or abundance (Roni et al. 2019). In monitoring restoration outcomes for species of concern it is necessary to collect field based data for the target species

under well-directed objectives (Lindenmayer 2020). In the Skagit River, Chinook salmon (*Oncorhynchus tshawytscha*) are listed as threatened under the Endangered Species Act and is a target species for conservation that includes floodplain habitat restoration. The Skagit Chinook Recovery Plan (SRSC and WDFW 2005) estimates restoration project-specific changes in Chinook Salmon capacity – annual numbers of fish when the system is at capacity – which make it meaningful to prioritize restoration actions and assess project effectiveness in comparable terms. Monitoring toward this end has been designed to target various metrics of fish use, including emigration of freshwater rearing juvenile fish in winter and spring from restoration and reference areas, and baseflow abundance of juvenile fish rearing in winter and summer in restoration and reference areas. These metrics require different survey gear types and different analytical approaches. Emigration can be assessed using passive gear types like smolt traps, while rearing abundance is assessed with active survey techniques such as snorkeling and electrofishing (Zale, Parrish, and Sutton 2012).

Study design for implementation of these techniques seeks to balance sufficient data to detect a fish response related to restoration with monitoring cost effectiveness (Liermann and Roni 2008). As a case study, Skagit River System Cooperative developed a power analysis to guide the timeline and sampling design of post-project sampling as part of the Barnaby Slough floodplain restoration effectiveness monitoring. The proposal corresponded to a timeline for restoration implementation and thus a fixed number of years of possible pre-project monitoring, with a goal to assess specific combinations of sites and years of passive gear monitoring required to detect a change in juvenile fish emigration abundance from the project area attributable to restoration. A second goal was to assess the number of sites and model structure options for active monitoring required to detect change in juvenile fish rearing abundance in the project area attributable to restoration. This document reports the findings from that power analysis effort, generalized for wider use in passive and active technique fish monitoring study design. Analyses were conducted in R (R Core Team 2020).

Passive techniques (smolt trapping)

A common method of assessing abundance and change in juvenile fish use in mainstem and tributary habitats has been smolt trapping over a seasonal emigration period for the species of interest (e.g., Kinsel et al. 2013; Molin, Kagervall, and Rivinoja 2010). Smolt trap designs can vary from floating rotary screw traps that sample a portion of the river width and depth to a fence weir design that spans most or all of the stream, but they have in common that they are a passive gear type with which fish interact as they are moving, typically downstream (Zale, Parrish, and Sutton 2012).

Barnaby Slough restoration monitoring includes fence weir smolt trapping of discrete floodplain habitats from February through May, encompassing the majority of stream-rearing juvenile Chinook Salmon (O*. tshawytscha*), Coho Salmon (*O. kisutch*), and Rainbow/Steelhead trout (*O.*

mykiss) seasonal outmigration from overwinter rearing habitats. Daily or near-daily fish data are collected over four months in each sampling year and sampling site. These sampling techniques return raw catches and mark-recapture based trap efficiency estimates that permit expansion of raw catch into estimated emigrant abundance with variation for each year-site (Zale, Parrish, and Sutton 2012).

To begin evaluating the best study design for fence weir smolt trapping to evaluate floodplain restoration, we first evaluated a simplest-case scenario treating our fish count data as normally distributed in a general linear model construction with two fixed covariates: a binary variable for treatment (restoration/reference site) and a binary variable for time (before/after restoration) with no interaction term. We considered a basic sampling plan scenario with 20 data points, which could come from five sites monitored over four years or from some other combination of sites and years whose sum is 20. Power analysis in this case takes the form of F-tests of significance for the regression covariates; if the covariates treatment and time are not significantly different from zero, we would fail to reject the null hypothesis that treatment and time explain some proportion of variance in the data. We used the R package 'pwr' and the function 'pwr.f2.test' with α=0.05 and β=0.80 to calculate power for a range of possible effect sizes (Champely 2020). Under these assumptions we found that there was low power to detect small changes in fish abundance, but acceptable power to detect changes > 60% (Table 1; Figure 1). Weaknesses of this approach included the fact that count data are generally not normally distributed and no variance in the data or interaction terms were considered, leading to a likely overestimation of the design's true power to detect change.

Table 1. General linear model effect sizes and associated statistical power from F-tests in a scenario with 20 data points from a combination of sample sites and years and a range of proportions of variance explained (model R^2) where α=0.05, effect size is the multiplier for fish abundance detected, and power is the percentage of the time the study identifies a real result compared to one observed by chance.

Sites*years	Model R^2	Effect size	Power
20	0.02	0.02	0.06
20	0.05	0.05	0.08
20	0.10	0.11	0.19
20	0.20	0.25	0.38
20	0.30	0.43	0.60
20	0.40	0.67	0.80
20	0.50	1.00	0.93
20	0.60	1.50	0.99
20	0.70	2.33	1.00

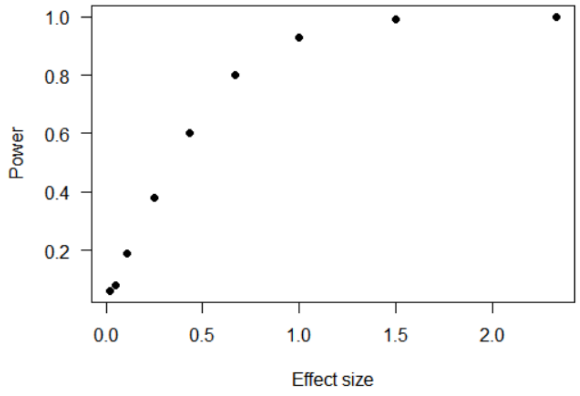


Figure 1. The relationship of restoration treatment effect size (fish abundance) and statistical power for a scenario with twenty site and year-specific data points, which could consist of various combinations of sampling locations and years, using F-tests on the covariates of a general linear model where α=0.05.

Further context for this line of inference came from model runs of various scenarios using the same structure of general linear models with passive gear count data as a function of time (before/after) and treatment (restoration/reference). Again using the R package 'pwr' and the function 'pwr.f2.test' with α=0.05 and β =0.80, we varied the number of sites and years across several values and tested effect sizes until power of 0.99 was reached for each scenario (Table 2). We found that increasing the number of sites or years of sampling improved the power, but that logistical constraints at these levels of sampling effort might limit feasibility. Power at 25 site-year combinations required 30% of the variance in Chinook abundance to be explained by model covariates, which equates to a detectable change in fish abundance (effect size) of 0.43. No combinations of sites and years from these scenarios generated enough power to detect small (>0.10) effect sizes.

Table 1. General linear model effect sizes and associated statistical power from F-tests in several scenarios with a combination of sample sites and years and a range of proportions of variance explained (model R^2) where α=0.05. Combinations resulting in statistical power >0.80 are highlighted.

Sites	Years	Sites*years	Model R^2	Effect size	Power
5	5	25	0.05	0.05	0.15
5	5	25	0.10	0.11	0.28
5	5	25	0.20	0.25	0.56
5	5	25	0.30	0.43	0.81
5	5	25	0.40	0.67	0.95
5	5	25	0.50	1.00	0.99
5	10	50	0.05	0.05	0.27
5	10	50	0.10	0.11	0.52
5	10	50	0.20	0.25	0.52

5	10	50	0.30	0.43	0.88
5	10	50	0.40	0.67	0.98
5	10	50	0.50	1.00	0.99
8	5	35	0.05	0.05	0.20
8	5	35	0.10	0.11	0.37
8	5	35	0.20	0.25	0.72
8	5	35	0.30	0.43	0.92
8	5	35	0.40	0.67	0.99
8	10	80	0.05	0.05	0.42
8	10	80	0.10	0.11	0.75
8	10	80	0.20	0.25	0.98
8	10	80	0.30	0.43	0.99

An additional consideration in this study design question is the tradeoff between Type I error and Type II error, which we set at commonly accepted levels in the first two sets of scenarios. Setting α in power analyses determines the acceptable threshold for the error occurring by rejecting the null hypothesis if it is in fact true. The value for α is often set conservatively to 0.05 for this reason, which we have done here to minimize the possibility of erroneously thinking we have detected a change in fish use due to restoration when in fact it is variation due to chance. The value for β is generally set more liberally, such that 1- β is 0.80, leaving a 20% margin for inaccurately accepting the null hypothesis of no change in fish use in a restoration area when it is in fact true. However, we also wish to minimize our chances of failing to detect a restoration effect, since background ecological noise can easily swamp the signal. For this reason, it may be valuable to consider a range of even more lenient β values (e.g., 0.60-0.80) that would help prevent us fail to detect an effect of restoration on fish use if it in fact exists.

One shortcoming with the F-test method described above is the incorrect application of data distributions. Count data such as those from smolt trap observations are inherently positive integers and tend to contain many zeros, such that they are not accurately described by a normal distribution. The final method that we applied to understanding combinations of sites and years needed in passive fish monitoring was that of Liermann and Roni (2008) who used lognormal distributions of smolt trap counts in paired watersheds to assess the number of sites and/or years of sampling required to detect a change in fish abundance due to restoration. Liermann and Roni also addressed variance in the data in their analyses, which was one of the other shortcomings we noted in the F-test method.

We developed alternative scenarios following the methods of Liermann and Roni (2008) as applied by Hinrichsen and Sharma (2011) to compare combinations of sites and years needed to achieve acceptable power, and their sensitivity to within and between site variance. For this method, one site consisted of two paired traps (one restoration and one reference) and a range of

possible fish abundance effect sizes were explored at two different variance levels. The first set of scenarios assumed two years of pre-project monitoring, between site variance of 4.00 and temporal variance of 0.05 as calculated from two years of smolt trap outmigration data from Barnaby Slough and reference sites (Skagit River System Cooperative unpublished data), and α of 0.05. As Liermann and Roni (2008) also found, the resulting power curves were insensitive to increases in number of years of post-project monitoring between 2 and 10, so these results not plotted separately here. Our results showed that substantial increases in the number of paired sites were generally insufficient to reach reasonable power at effect sizes <2 (Figure 2). With >20 site pairs and an effect size of 1, however, given the discussion above, the design would be sufficient to detect a restoration effect with a power of 60%.

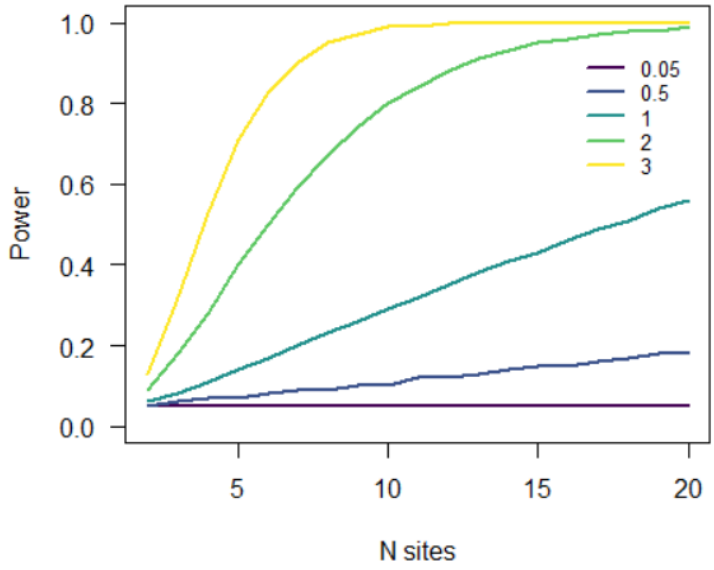


Figure 2. Statistical power to detect change in fish abundance with a two-tailed t-test at varying numbers of paired sites monitored for up to ten years after restoration given five possible effect sizes, with between site variance=0.05 and within site variance=4.00, according to methods from Liermann and Roni (2008).

A second more conservative scenario considered outmigrant cohort sizes with higher interannual variation (temporal variance=4.00), showing that for higher effect sizes, more site pairs are required to detect a treatment effect and at smaller effect sizes no practical combinations of sites and years yield acceptable power (Figure 3). A shortcoming in the application of the Liermann and Roni method to our data is that it does not account for a restoration site that is matched to multiple reference sites rather than a single site. Nonetheless, the incorporation of variance provides an improvement over F-tests for assessing power, providing evidence that a relatively large number of sites will be required to detect small effect sizes in fish use following restoration.

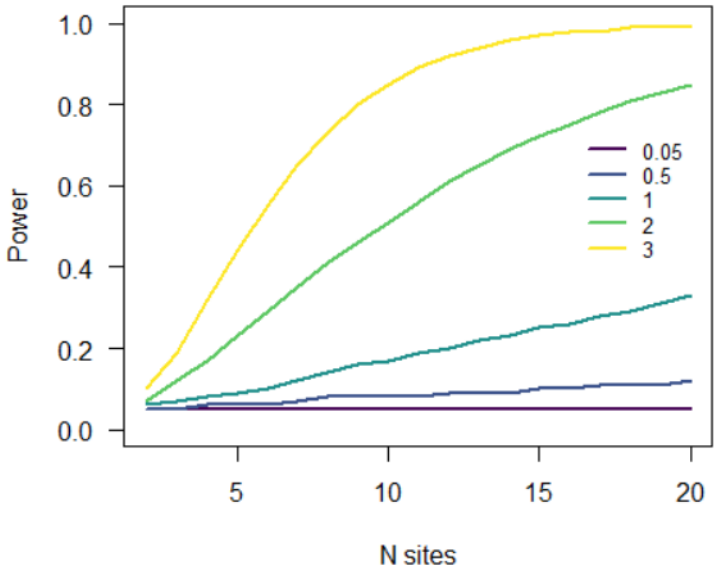


Figure 3. Statistical power to detect change in fish abundance with a two-tailed t-test at varying numbers of paired sites monitored for up to ten years after restoration given five possible effect sizes, with between site variance=4.00 and within site variance=4.00, according to methods from Liermann and Roni (2008).

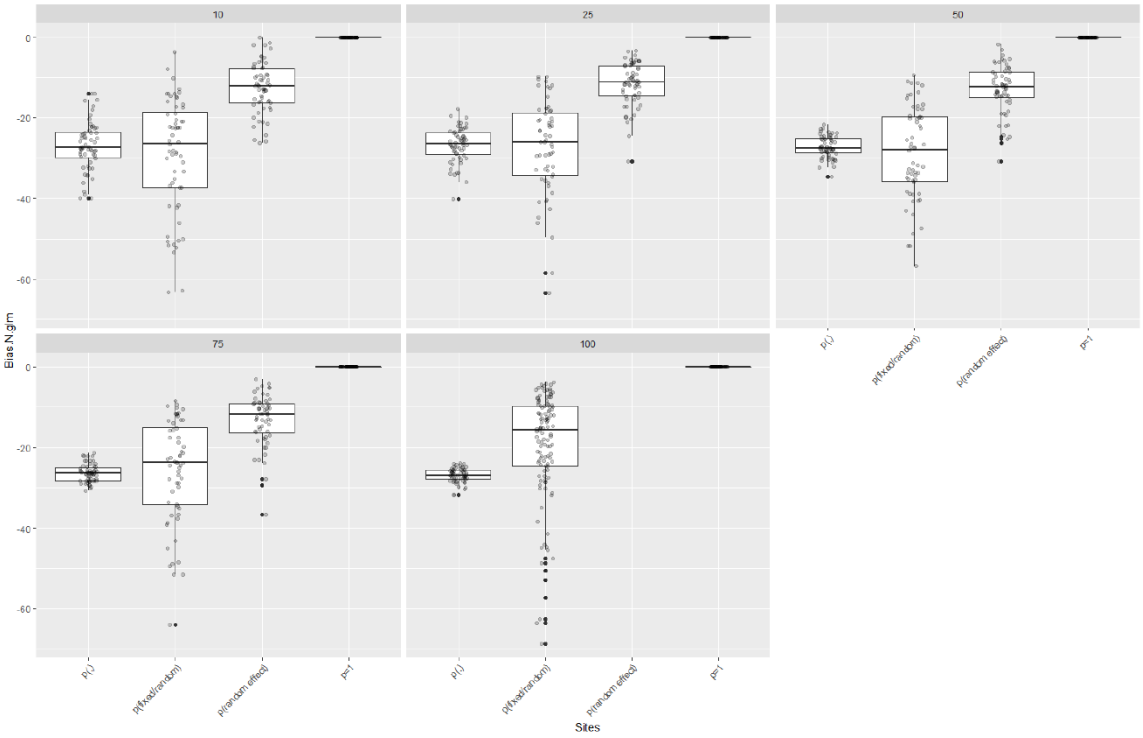
From these scenario explorations, the size of the change in fish abundance related to restoration dictates the number of site*years required for a good passive smolt trap design that can detect the change with reasonable certainty (>60-70%). A change in annual fish abundance of 1 likely requires upwards of 40 site*years, while a change in annual fish abundance of 0.50 or less requires some hundreds of site*years. Fewer site*years would be required at higher fish abundances. It currently costs ~$100,000 to monitor for 5 site*years; if we ended up needing 20 site*years the cost would be $400,000-$500,000. This level of funding is challenging. The Barnaby Slough monitoring project is currently funded for 3 years (15 site*years). Our currently funded design will have a slightly greater than 60% power to detect change at an annualized fish abundance increase of 1, but little confidence at lower levels of fish abundance.

Active techniques

Fish abundance estimation using active techniques such as electrofishing has often been described using catch per unit effort (Zale, Parrish, and Sutton 2012), but probabilistic estimates of occupancy and density can be modeled (e.g., Reid and Haxton 2017). Longitudinal sampling methods are common (e.g., Rodtka et al. 2015), but randomized grid-based sampling provides an additional benefit of linking quantitative habitat metrics to fish use for more habitat specific abundance estimation (e.g., Mollenhauer and Brewer 2017). N-mixture models are a type of grid-based hierarchical occupancy model that reflect the idea that the observed abundance of a local

population of interest derives from a hierarchy of factors: the true local abundance that we cannot observe, and our ability to detect it, both of which depend on factors influencing the metapopulation, like water depth or velocity in the case of small fish (Kery and Schaub 2012). Given hydrologic model inputs and multi-pass fish observation, a hierarchical N-mixture ("N-mix") model can generate estimates of juvenile fish rearing abundance based on measured relationships between habitat covariates and species-specific occupancy and abundance. This method can also accommodate other active survey techniques, such as snorkeling, which has been shown to be effective and benign (Roni and Fayram 2000). N-mix models of fish abundance have been adopted in the Trinity River, California (Som et al. 2018), the Columbia River (Harris and Jolley 2017), Alaska (Sethi and Benolkin 2013), the southeastern U.S. (Mollenhauer and Brewer 2017), and elsewhere.

In planning the first implementation of an N-mix based survey design for effectiveness monitoring of restoration project area, we found it useful to calculate power analyses based on simulated data in both generalized linear models (glm) and N-mix models. In general, uncertainty was substantially lower and less directionally biased in N-mix formulations than glms for sample size (Figure 4). For both beta coefficients, uncertainty and bias were similar between N-mix and glms, especially at larger sample sizes (Figures 5; Figure 6). From this we determined that N-mix would be a preferable analytical method to glm, and that a sample size of >100 sites with 4 visits per model stratum would be needed to reduce estimate confidence intervals reasonably. Stratum is important consideration because multiple strata can exist in floodplain restoration monitoring. The simplest strata is the comparisons of treatment areas that are receiving restoration and control areas that are not receiving restoration. Next possibly important strata are the locations within the treatment areas and the control areas. Barnaby Slough restoration area for instance is composed of Barnaby Slough and in part Harrison Slough. Further, each control area is discrete. We have then 2 areas that are receiving a treatment and 4 areas within the control for a project like Barnaby Slough, resulting in 600 sites with 4 independent visits.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Sites

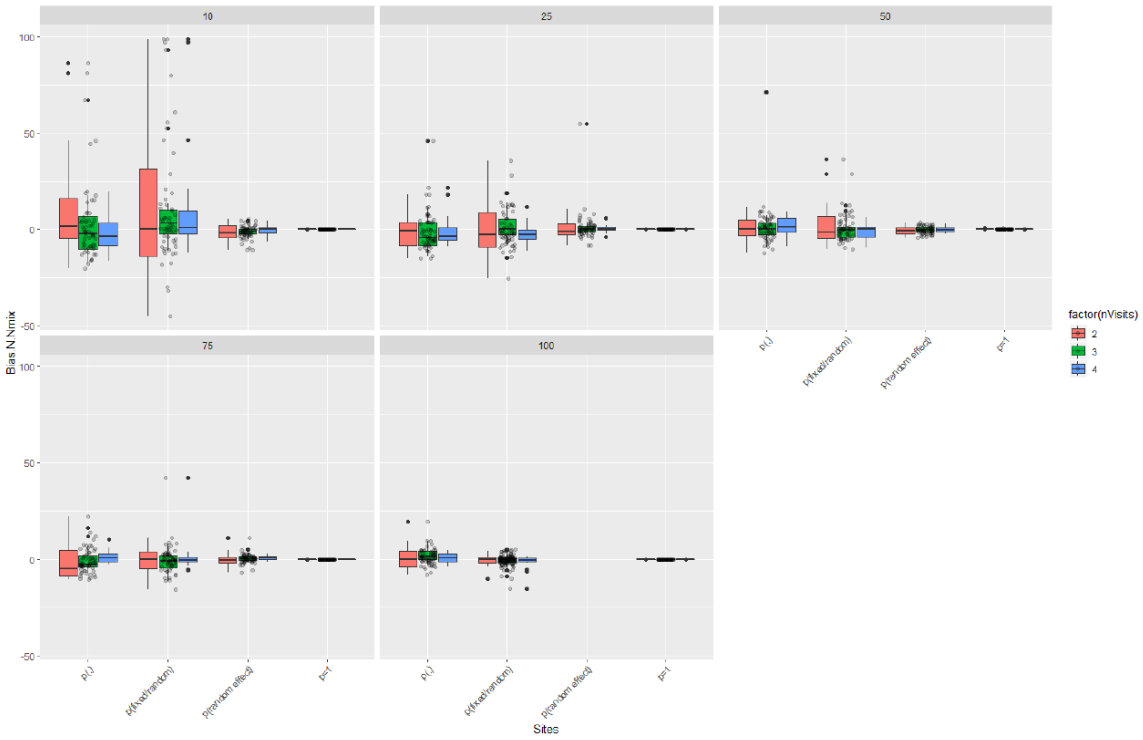

Figure 4. The upper panel shows uncertainty and bias for samples site at probability of detection estimates (p) for simulated multiple pass fish observation data at a range of sample sizes using a generalized linear model, while the lower panel shows the same using a hierarchical N-mixture model.

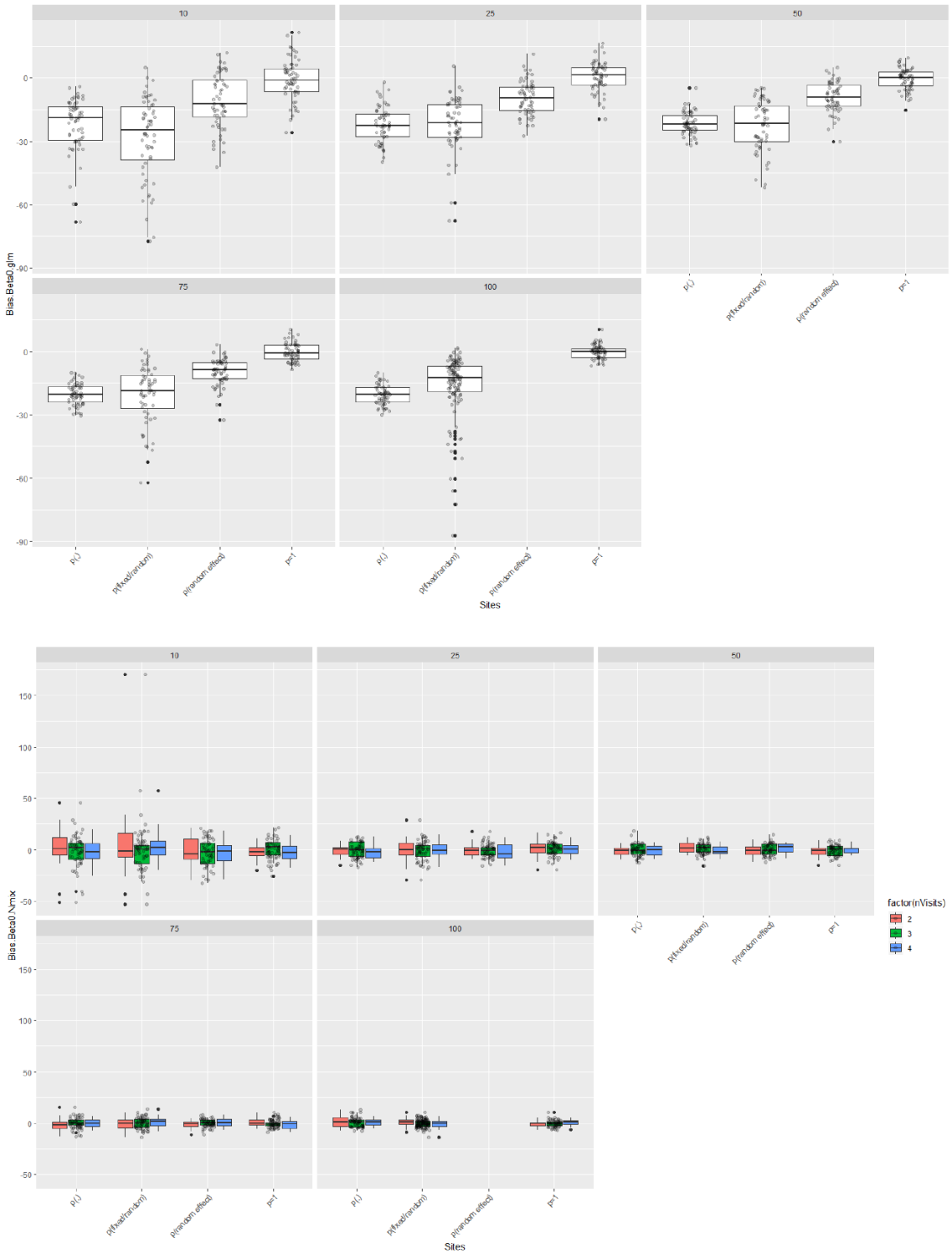

Figure 5. The upper panel shows uncertainty and bias for the model intercept at probability of detection estimates (p) for simulated multiple pass fish observation data at a range of sample sizes

using a generalized linear model, while the lower panel shows the same using a hierarchical N-mixture model.

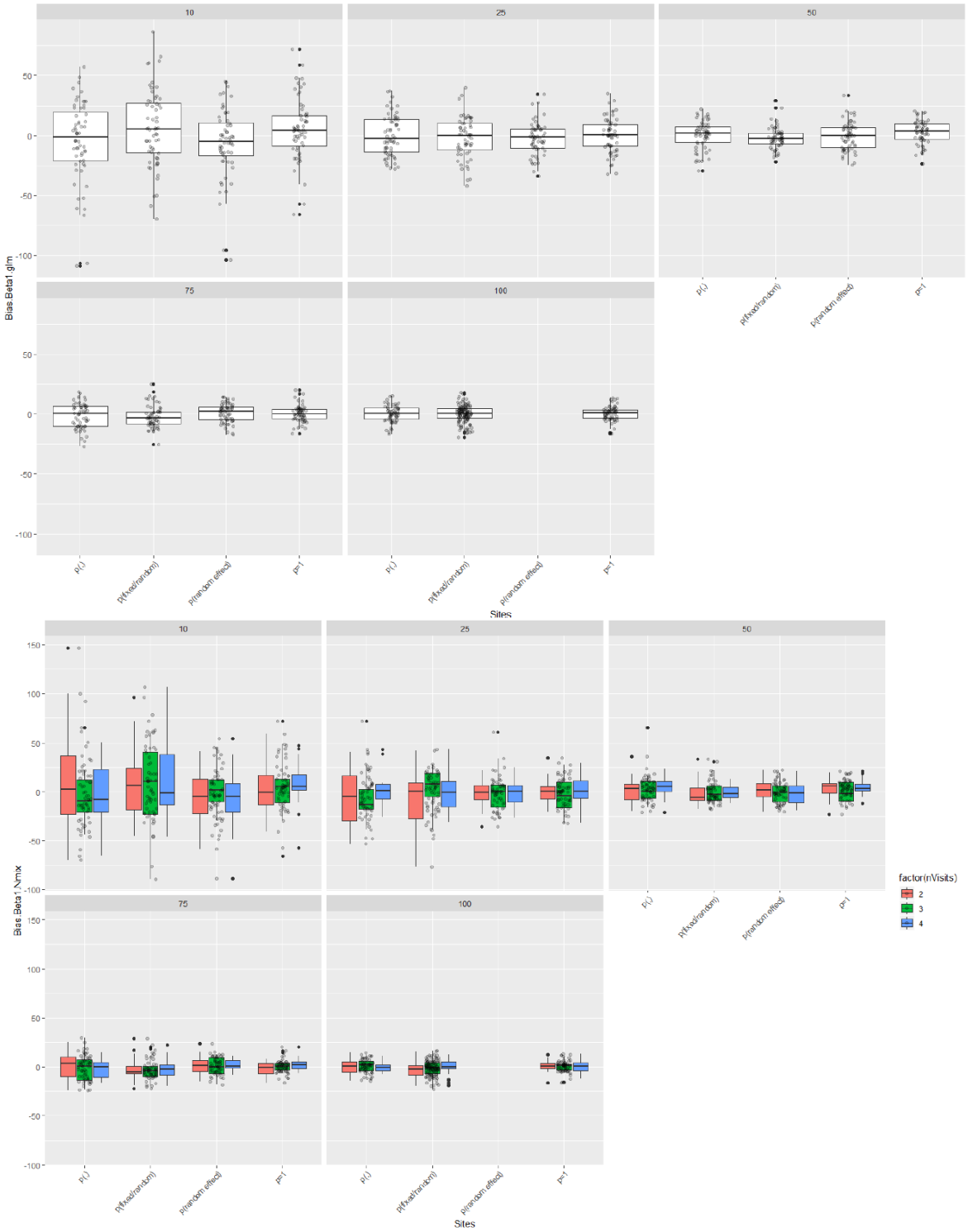

Figure 6. The upper panel shows uncertainty and bias for the model slope at probability of detection estimates (p) for simulated multiple pass fish observation data at a range of sample sizes using a generalized linear model, while the lower panel shows the same using a hierarchical N-mixture model.

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