Evaluation of potential habitat breaks (PHBs) for use in delineating end of fish habitat in forested landscapes in Washington State

Study Design prepared for the Washington Forest Practices Board

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Submitted by:

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Preface

In 2018, the PHB Science Panel convened by The Forest Practices Board (FPB) developed a study design to validate potential habitat breaks (PHBs). The study design (PHB Science Panel 2019) was reviewed and approved by Independent Scientific Peer Review (ISPR), however there were varying levels of comments and criticisms from all caucuses participating in the forest practices adaptive management program to particular aspects of the study design and the review process. In 2019, the Forest Practices Board remanded the project to the Department of Natural Resources' adaptive management science program, tasking the Cooperative Monitoring, Evaluation and Research (CMER) committee with revising the study design following CMER's protocols and standards (referenced in Forest Practices Board Manual Section 22). CMER assigned the study design revision to the Instream Science Advisory Group (ISAG). This revised study design was developed by a project team formed within ISAG.

Summary

The upstream extent of both fish distribution and fish habitat in forested watersheds is influenced by many factors including channel gradient, channel size, channel condition, nutrients, flow, barriers to migration, history of anthropogenic and natural disturbance, and/or fish abundance. The Washington Forest Practices Board has proposed three sets of criteria to be considered in determining potential habitat breaks (PHBs) between fish (Type F) and non-fish bearing waters (Type N) across the state. These criteria are based upon data that can be collected during a single Washington Department of Natural Resources (DNR) protocol electrofishing survey and include channel gradient, bankfull width, and both vertical and non-vertical non-deformable natural barriers to upstream migration. To evaluate which physical criteria best define the end of fish (EOF) habitat (the uppermost stream segments that are actually or potentially could be inhabited by fish at any time of the year based on habitat accessibility and suitability), detailed information is needed on the uppermost fish location and associated habitat in small streams across Washington State. While some data on habitat conditions at last detected fish locations are available (e.g., from existing water type modification forms [WTMFs] submitted to DNR), these data were found to be insufficient to determine PHBs that defined last detected fish locations and associated habitat.

Potential Habitat Breaks Study Plan

The purpose of this study is to develop criteria for accurately identifying PHBs and to evaluate the utility of PHB criteria selected by the Board for use in the Fish Habitat Assessment methodology (FHAM) as part of a water typing rule. The study is designed to assess combinations of gradient, channel width, barriers to migration, and other physical habitat and geomorphic conditions associated with uppermost detected fish locations. This will 1) inform which Board identified PHB criteria most accurately identify the upstream extent of fish habitat in an objective and repeatable manner as applied in the FHAM and 2) evaluate whether an alternative set or combination of empirically derived criteria more accurately achieves this goal. Additionally, this study is intended to provide insight into how last detected fish points and associated stream characteristics may vary across geography, seasons, and years.

The study will be conducted across two sampling seasons (spring and fall/winter) in each of three years at 350 sites statewide; 160 in Eastern and 190 in Western Washington. Upstream last detected fish locations will be determined during each season at each site following modified DNR protocols for electrofishing surveys. Once the uppermost fish is located during each sampling event, the last detected fish location will be flagged, GPS coordinates will be recorded, and a longitudinal profile habitat survey will be conducted to characterize habitat and geomorphic conditions 660 ft (200 meters) downstream and 660 ft upstream of the last detected fish location. To evaluate seasonal changes in the location of the last detected fish, the sites that can be accessed in the fall/winter high-flow season will be sampled on a rotating panel basis. One quarter of the sites will constitute the fixed portion of the panel and will be surveyed every fall/winter, and the remainder will constitute the rotating portion. One third of the rotating portion will be sampled each year in addition to the fixed portion such that every accessible site will be sampled at least once during the fall/winter. If a last detected fish location changes during any subsequent survey, additional longitudinal profile survey data will be collected to ensure that there are channel data 660 ft above and 660 ft below last detected fish locations for all seasons and years. Data will be analyzed to determine the combinations of gradient, channel width, and other geomorphic features associated with the furthest upstream last detected fish locations across all seasons and years at each site, which will define PHBs and EOF habitat, and whether these vary across Eastern and Western Washington. The results of this study will be used to evaluate the effectiveness of PHB criteria in determining the regulatory break between fish (Type F) and non-fish bearing (Type N) waters.

Table of Contents (Not updated. Complete after CMER /ISAG review)

List of Acronyms

AMP	Adaptive Management Program
BFW	Bankfull Width
CMER	Cooperative Monitoring, Evaluation & Research Committee
DNR	Washington State Department of Natural Resources
eDNA	Environmental DNA
EOF	End of Fish (Last detected fish following a Protocol Survey)
F/N Break	Regulatory break between fish and non-fish bearing waters
FHAM	Fish Habitat Assessment Method
GIS	Geographic Information System
HCP	Habitat Conservation Plan
ISPR	Independent Scientific Peer Review
PHB	Potential Habitat Break(s)
TFW	Timber, Fish & Wildlife
Type F	Fish Bearing Streams
Type N	Non-Fish Bearing Streams
WTM	Water Type Modification
WTMF	Water Type Modification Form

Introduction

In Washington State, forest practices are regulated by the Forest Practices Act established by the legislature, with rules established by the Washington Forest Practices Board (Board). The goals of the rules include protecting public resources (water quality, fish, and wildlife) and maintaining an economically viable timber industry. Rules pertaining to aquatic and riparian habitats are specifically included in the Forest Practices Habitat Conservation Plan (HCP), which provides coverage for approximately 9.3 million acres of forestland in Washington (6.1 million acres west of the Cascade Crest and 3.2 million acres in eastern Washington). Specific prescriptions (rules) are applied to waters containing fish to protect fish and their habitats.

The Board is responsible for rulemaking and overseeing the implementation of forest practice rules. The evaluation of the effectiveness of these rules is directed by the Adaptive Management Program of the Washington Department of Natural Resources (DNR). Water typing is an important part of applying contemporary forest practice rules since prescriptions in riparian areas are based in part on whether streams are or potentially could be used by fish. Streams identified as having fish habitat are classified as Type F waters, defined in the water typing rule (WAC 222-16-030), and have specific riparian buffer prescriptions and fish passage requirements. Fish habitat is defined in WAC 222-16-010 as "…habitat, which is used by fish at any life stage at any time of the year including potential habitat likely to be used by fish, which could be recovered by restoration or management and includes off-channel habitat." Currently, an interim rule allows for the delineation of Type F waters through the use of either default physical criteria or a protocol electrofishing survey. DNR provides a map showing stream segments of modeled fish habitat. The Forest Practice Rules require forest landowners to verify, in the field, the type of any regulated waters as identified within proposed harvest areas prior to submitting a forest practices application/notification. Landowners may use the default physical criteria or the results from protocol survey electrofishing to identify the regulatory F/N break. Landowners are encouraged to submit a Water Type Modification Form (WTMF) to the DNR to make permanent changes to the water type maps. Thousands of WTMFs have been submitted to DNR to modify water types and modify the location of the break between Type F and Type N waters.

The Board is currently in the process of establishing a permanent water typing rule. Ultimately, the rule must be implementable, repeatable, and enforceable by practitioners and regulators involved in the water typing system. An important part of the permanent rule will be guidance on a specific protocol to determine the regulatory break between Type F and Type N waters. The Board is considering the use of a fish habitat assessment method (FHAM) that incorporates known fish use with potential habitat breaks (PHBs) to identify fish habitat. The Board recommended that PHBs be based on permanent physical channel characteristics such as gradient, stream size, and/or the presence of natural non-deformable vertical and non-vertical obstacles as potential barriers to upstream fish movement.

Study Purpose

The purpose of this study is to develop criteria for accurately identifying PHBs and to evaluate the utility of PHB criteria selected by the Board for use in the Fish Habitat Assessment methodology (FHAM) as part of a water typing rule. The study is designed to assess which combinations of gradient, channel width, barriers to migration, and other physical habitat and geomorphic conditions are associated with uppermost detected fish locations. This will 1) inform which Board-identified PHB criteria most accurately identify the upstream extent of fish habitat in an objective and repeatable manner as applied in the FHAM and 2) evaluate whether an alternative set or combination of empirically derived criteria more accurately achieves this goal (CMER 2020). Additionally, this study is intended to provide insight into how last detected fish points, EOF habitat, and PHBs proposed by the Washington Forest Practice Board may vary across geography, seasons, and years.

It is important to note that this study is not intended to evaluate the current water typing system or the FHAM; or to describe how the regulatory Type F/N break should be determined. Other factors such as temperature, flow, water quality, population dynamics, and biological interactions are important covariates that might influence the distribution of fishes but do not affect PHBs. Therefore, they are not being evaluated in this study.

Project Research Questions

The following project-specific research questions were developed to address certain aspects of the CMER Workplan Rule Group critical questions listed in Appendix A.

UPSTREAM-MOST FISH LOCATIONS

1. **How do the locations of the last detected fish vary interannually?**
2. **How do the locations of the last detected fish vary seasonally?**
3. **How do the locations of last detected fish vary geographically across the state of Washington?**

HABITAT ASSOCIATED WITH UPSTREAM-MOST FISH LOCATIONS

4. **How do the physical channel and basin characteristics (e.g., bankfull width; average gradient, basin size) associated with the identified end of fish habitat vary geographically across the state of Washington?**
5. **Where the location of the last detected fish changes (seasonally or interannually), how does that influence the PHB that is associated with the F/N break and how frequently does that occur?**
6. **Do the physical channel features at the locations initially identified as PHBs change in time?**
7. **Do similar features appear to limit upstream fish distributions in some contexts but not others (e.g., further into the headwaters vs. downstream; different flow levels)?**

PHB PERFORMANCE ANALYSES

8. **Which combinations of physical channel features and basin characteristics (for example, gradient, channel width, barriers to migration) best identify the end of fish habitat relative to the location of the last detected fish?**
9. **Can protocols used to describe PHBs be consistently applied among survey crews and be expected to provide similar results in practice?**
10. **How well do the PHB criteria provided by the Washington Forest Practices Board accurately identify the EOF habitat when applied in the Fish Habitat Assessment Methodology (FHAM)?**

We will use data from electrofishing and physical habitat channel surveys in a spatially balanced sample of 350 streams across Eastern and Western Washington to address these study questions and evaluate proposed criteria to be used as potential habitat breaks in the FHAM.

Background

Over the past 20 years, protocol electrofishing surveys have been conducted under WAC 222-16-031 with guidance provided by Board Manual Section 13 to determine the upper extent of Type F waters. These surveys often incorporate additional stream length upstream of the uppermost detected fish to include habitat "likely to be used by fish" (defined in WAC 222-16-010). Throughout Washington, the uppermost fish detected during protocol electrofishing surveys is most often a salmonid, and in around 90% of cases the uppermost fish is a cutthroat trout *Oncorhynchus clarki* (D. Collins, Washington Department of Natural Resources, unpublished data; Fransen et al. 2006). Other salmonid species that have been documented at uppermost fish locations on water type modification forms across Washington include rainbow trout *O. mykiss*, brook trout *Salvelinus fontinalis* (an introduced non-native that has become established in many Washington streams), and (rarely) bull trout *S. confluentus*. In headwater reaches that are accessible to anadromous fishes, coho salmon *O. kisutch* juveniles have been reported on occasion as the uppermost fish. Of the non-salmonid species documented at uppermost fish sites on WTMFs in western Washington, sculpins *Cottus* spp. were most prevalent, followed by brook lamprey *Lampetra* spp., and less commonly dace *Rhinichthys* spp., three-spine stickleback *Gasterosteus aculeatus*, and Olympic mudminnow *Novumbra hubbsi*. The only uppermost non- salmonid fish species recorded in east-side Washington streams were sculpins.

Many factors can limit the distribution of fishes including barriers to migration, stream gradient, and flow/channel size. Understanding the current science on how these factors influence fish distribution is important when discussing how they can be used to most accurately define the upstream limits of fish habitat in forested streams of Washington State.

Barriers to Migration

Natural stream habitat breaks that might obstruct or completely block upstream fish movement to apparently suitable habitat include: vertical drops, steep cascades, bedrock sheets, and trench/chutes (Hawkins et al. 1993; Figure 1).

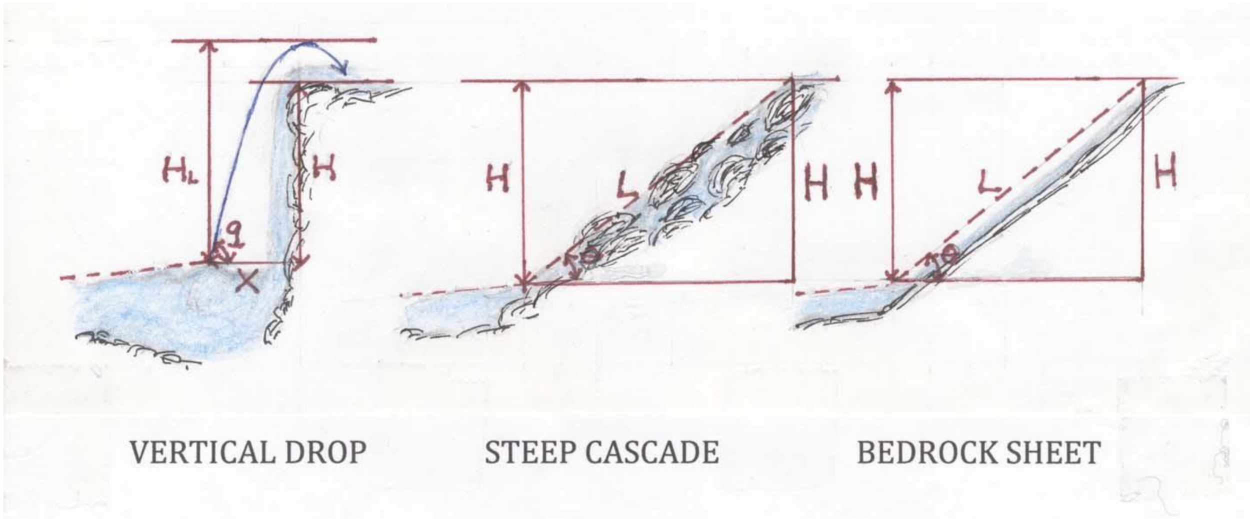

Figure 1. Three types of habitats that could pose obstacles or barriers to upstream movement of headwater fishes. (PHB Science Panel 2019)

The ability of fishes to pass such obstacles is associated with the interactions between their swimming and leaping abilities, environmental factors such as flow and temperature and the dimensions of the obstacles. The swimming ability of fishes is typically described in terms of cruising, prolonged, and burst speeds, which are measured in units of body lengths per second (Watts 1974; Beamish 1978; Webb 1984; Bell 1991; Hammer 1995). Body form also affects swimming ability, with more fusiform body shapes being advantageous for stronger burst speeds in fishes such as cutthroat and rainbow trout (Bisson et al. 1988; Hawkins and Quinn 1996) in comparison to some other fishes, such as sculpin (*Cottus* spp.), commonly found at EOF locations. Cruising speed is the speed a fish can sustain essentially indefinitely without fatigue or stress, usually 2–4 body lengths per second. Cruising speed is used during normal migration or movements through gentle currents or low gradient reaches. Prolonged speed (also called sustained speed) is the speed a fish can maintain for a period of several minutes to less than an hour before fatiguing, typically 4–7 body lengths per second. Prolonged swimming speed is used when a fish is confronted with more robust currents or moderate gradients. Burst speed is the speed a fish can maintain for only a few seconds without fatigue, typically 8–12 body lengths per second. Fish typically accelerate to burst speed when necessary to ascend short, swift, steep sections of streams; to leap obstacles; and/or to avoid predators.

When leaping obstacles, fish come out of the water at burst velocity and move in a parabolic trajectory (Powers and Orsborn 1985). Relationships for the height attained in the leap, and the horizontal distance traversed to the point of maximum height are often used to assess barriers. Depth at the point of takeoff is important for enabling fish to reach burst velocity. Stuart (1962) found water depth of at least 1.25 times the height of an obstacle to be required for successful upstream barrier passage. More recently, however, Kondratieff and Myrick (2006) reported that small brook trout (size range 100-150 mm) could jump vertical waterfalls as high as 4.7 times their body length from plunge pools only 0.78 times the obstacle height, and larger brook trout (size ranges 150-200 mm and 200 mm+) could jump waterfalls with heights 3 to 4 times their body length if the plunge pool depth was at least 0.54 times the obstacle height.

To successfully ascend 4.7 body lengths in height, a back-calculation from the Powers and Orsborn (1985) trajectory equation yields a burst speed of 22 body lengths per second (11.7 feet per second) for the 100-150 mm body-length brook trout reported by Kondratieff and Myrick (2006). If it is assumed that other salmonids (e.g., cutthroat, rainbow trout or coho salmon) could perform as well as brook trout in the size range typically found at uppermost fish locations in Washington (Sedell et al. 1982; Fransen et al. 1998; Liquori 2000; Latterell et al. 2003; Peterson et al. 2013), then a burst speed of 22 body lengths per second (11.7 feet per second) would allow the largest fishes in the size range typical of headwater-dwelling salmonids (6.3 in, 160 mm) to leap a vertical obstacle 2.6 feet high, whereas a vertical obstacle of 3 feet high would be impassable.

When leaping is not required, fishes may ascend steep cascades and other high-velocity habitat units (Hawkins et al. 1993) by seeking pockets of slow water interspersed in areas with turbulent flow (e.g., boundary layers near rocks or logs). For example, Bisson et al. (1988) reported the average water velocity was only 24.8 ± 3.2 cm/s (0.8 ft/s) in shallow (10.0 ± 1.4 cm; 4 inches) cascade habitat units of small western Washington streams. It is possible that fish may ascend streams during periods of elevated flow by moving along the channel margins where water velocities are reduced relative to mid-stream and small falls and boulder cascades are partially or completely submerged.

Although studies examining fish migration through potential non-vertical obstacles are rare, some studies have examined brook trout movement through steep cascades and reported fish ascending cascades of more than 20% gradient (Moore et al. 1985; Adams et al. 2000; Björkelid 2005). For example, Adams et al. (2000) reported that adult brook trout ascended cascades with slopes of 13% that extended for more than 67 m, and 22% for more than 14 m as well as adult brook trout ascending a waterfall 1.2m high. Similarly, Björkelid (2005) reported invasive brook trout colonizing 18 headwater streams in Sweden and found they ascended stream segments with slopes of 22% (measured with a clinometer) and 31% (measured with GIS).

Gradient

In Washington streams, fish (not necessarily the uppermost fish) have been observed in headwater segments with overall slopes as steep as 31% (S. Conroy, formerly Washington Trout [now Wild Fish Conservancy], unpublished data), 35% (J. Silver, Hoh Indian Tribe, unpublished data; D. Collins, Washington Department of Natural Resources, unpublished data), and in reach gradients of 25% and steeper in Oregon streams (C. Andrus, Oregon Department of Forestry, unpublished data; Connolly and Hall 1999). This range of channel steepness is consistent with other observations in western North America (e.g., Leathe 1985; Fausch 1989; Ziller 1992; Kruse et al. 1997; Watson and Hillman 1997; Dunham et al. 1999; Hastings et al. 2005; Bryant et al. 2004, 2007) and Europe (Huet 1959). In the “trout zones” of European rivers (headwaters), brown trout *Salmo trutta* predominate and reach gradients may be 10 to 25% or steeper (Huet 1959; Watson 1993). In Washington, it is important to note that fish presence in streams steeper than 15% accounted for only 10% of reported occurrences in forested streams (Cole et al. 2006; J. T. Light, Plum Creek Timber, unpublished data). Kondolf et al. (1991) reported that often the water surface slopes where fish occur in step-pool habitats have much lower local gradients than the overall reach gradient and may range from only 0.4 to 4%, even where overall reach gradients may be as high as 35% (Figure 2). These observations indicate that in some cases fish habitat in headwater streams can extend into the types of steep step-pool and cascade reaches described by Montgomery and Buffington (1993).

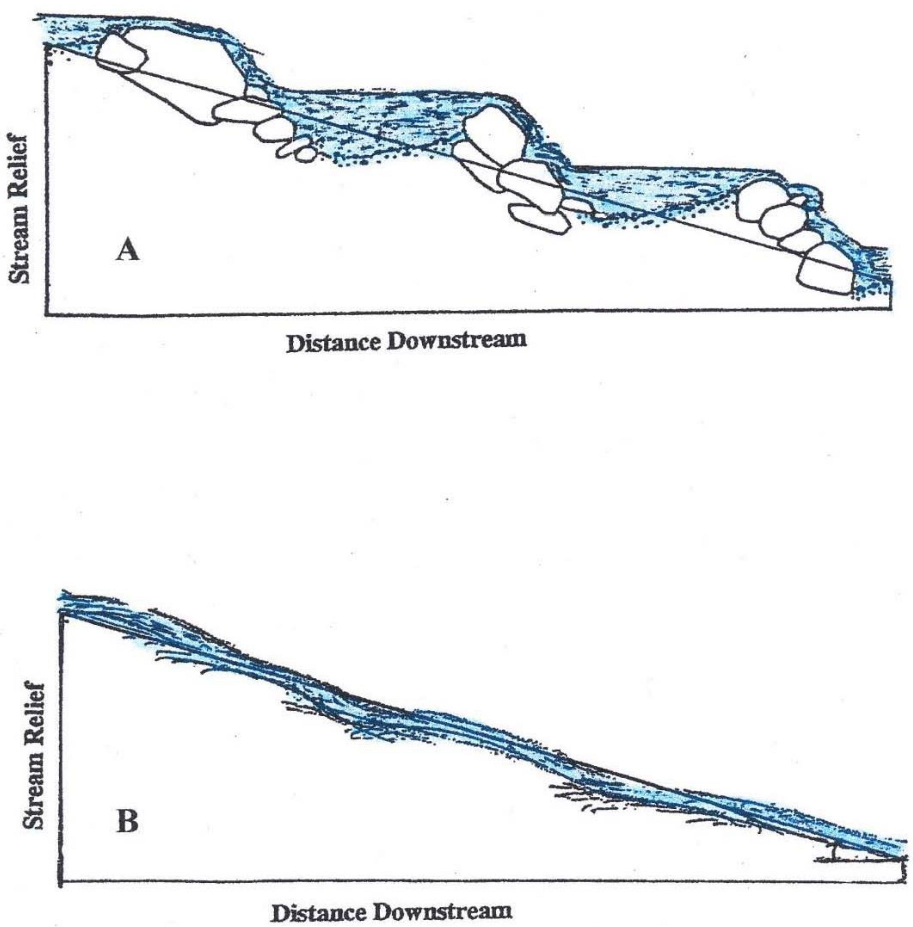

Figure 2. Two very different profiles of a headwater reach with the same overall reach gradient. Illustration (A) demonstrates how roughening elements create local gradients that are lower than the overall reach gradient, while reaches without such features (B) do not. (PHB Science Panel 2019)

Flow and Channel Size

Bankfull width (BFW) has been found to reflect the stage of discharge at which a stream does its habitat-building work (Andrews 1980; Leopold 1994; Rosgen 1996). Studies have shown that BFW is correlated with drainage area and varies with climate, geology, and topography of the basin (Castro and Jackson 2001). For example, Beechie and Imaki (2014) developed an equation for BFW for Columbia Basin streams based on annual precipitation and catchment (drainage) area. Although that equation was developed for larger streams, the PHB Science Panel (2019) tested it using empirical BFW data from multiple smaller streams across Washington State and found that it accurately predicted BFW in headwater streams. However, Castro and Jackson (2001) found that while BFW and drainage area relationships worked well in areas of similar lithology/geology and precipitation regimes to those for which they were developed, they were less useful in the pacific coastal areas of western Washington where the geology and precipitation patterns are highly variable. Researchers continue to work on developing accurate and usable relationship models for highly variable headwater streams, which may become useful as more precise information and mapping of lithology, topography, and precipitation becomes available.

Because of the perceived relationship between channel width and discharge, BFW is often used as a surrogate for stream discharge (area, depth, and velocity), which is often important for determining the uppermost fish and extent of fish habitat (Harvey 1993). Fransen et al. (1998) estimated mean annual flow rates at the upstream extent of fish distribution for 79 streams in the western Cascade foothills and Willapa Hills in Washington and found that 90% of these streams had mean annual flows of ~3.5 cfs or less at the upper boundary of fish presence; 80% had mean annual flows of ~2 cfs or less at the upper boundary; 65% had mean annual flows of ~1 cfs or less at the upper boundary; and approximately 25% of the sites had mean annual flows of 0.5 cfs or less at the upper boundary (Figure 3).

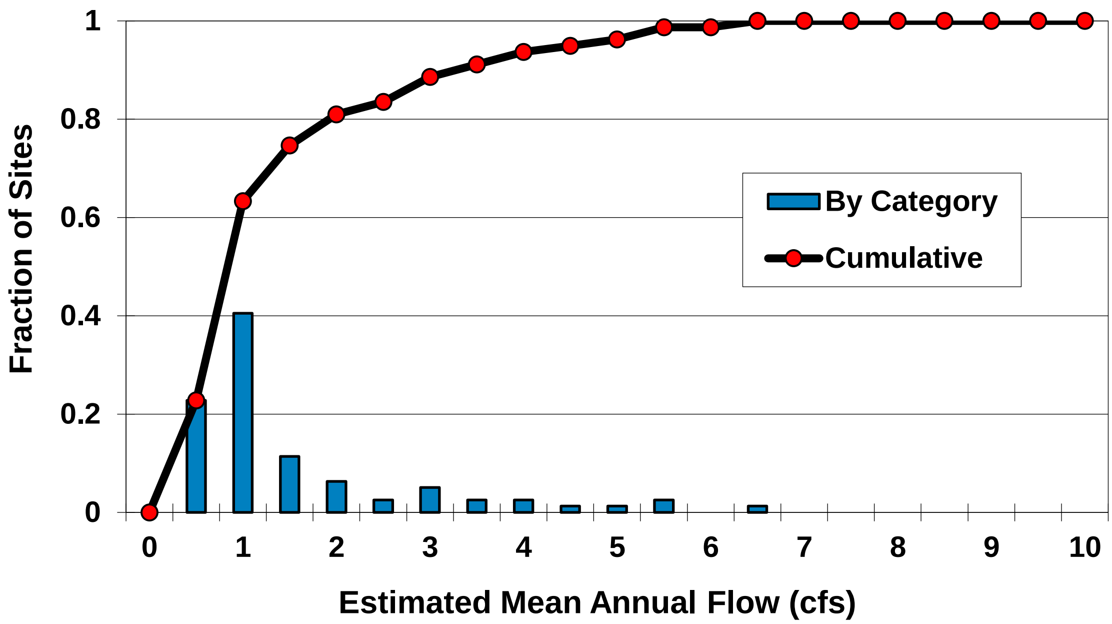

Figure 3. Estimated mean annual flows at uppermost fish locations in 79 streams in western Washington (Cascade foothills and Willapa Hills; Fransen et al. 1998).

Food Availability

Many studies, particularly in Pacific Northwest streams, have demonstrated strong food limitations for fish inhabiting (using) small streams (Warren et al. 1964; Mason 1976; Naiman and Sedell 1980; Bisson and Bilby 1998). Headwater segments are often characterized by closed forest canopies, requiring primary energy sources from allochthonous inputs of coarse particulate organic matter (CPOM). Shredder organisms occur in these reaches and feed on this CPOM. These aquatic organisms, along with any terrestrial invertebrates that fall into the stream, comprise the food base for trout and other predators (Vannote et al. 1980; Hawkins and Sedell 1981; Triska et al. 1982; Wipfli 1997). The total production of macroinvertebrate organisms is substantially lower in small headwater stream reaches than in the larger, lower-gradient reaches further downstream (Northcote and Hartmann 1988; Haggerty et al. 2004). As a result, resident fishes in small headwater stream reaches tend to be small bodied, which limits their ability to negotiate obstacles to upstream movement and migration.

Fish Habitat Assessment Method (FHAM)

Water typing surveyors have used professional judgment to estimate "habitat likely to be used by fish" when proposing regulatory fish bearing/non-fish bearing water type (F/N) breaks. Stream segments that are accessible to fish and exhibit the same characteristics to those of fish-bearing reaches are typically assumed to be fish habitat, whether or not fish are present at the time of a survey. Surveyors have assessed barriers and measurable changes in stream size and/or gradient to estimate the EOF habitat (Cupp 2002; Cole et al. 2006). Although research is somewhat limited, the upstream extent of fish distribution in forest lands appears to be strongly influenced by stream size, channel gradient, and access to suitable habitat (Fransen et al. 2006; PHB Science Panel 2018). In response to these findings, the Board embraced the concept of a Fish Habitat Assessment Methodology (FHAM) developed by a diverse group of AMP technical stakeholders intended to be repeatable, implementable, and enforceable (WA Forest Practices Board 2018; WA DNR, 2019). The FHAM will utilize PHBs that reflect a measurable change in the physical stream characteristics at or upstream from a detected fish point, above which a protocol electrofishing survey would be undertaken (Figure 4). The first PHB located at or upstream from the last detected fish would serve as the end of fish habitat (F/N Break) when no fish are detected above this PHB.

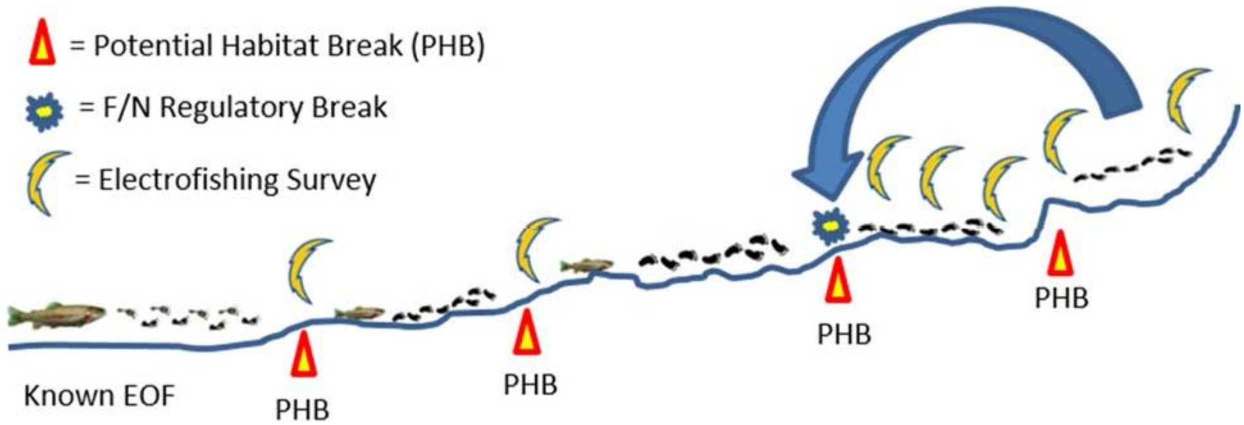

Figure 4. Example of how the PHB criteria and Fish Habitat Assessment Methodology (FHAM) will be applied in the field. The first step is to identify the last detected fish (end of fish) location. Once the point is identified, the survey team would begin to measure bankfull width, gradient, and barrier (obstacle) criteria while moving upstream. Once a point in the stream meeting one of the PHB criterion (gradient, barrier, change in channel width) is identified, the survey team would apply a fish survey (e.g., electrofishing) upstream of the PHB to determine if fish are present upstream. If sampling yields no fish ¼ mile upstream, then the F/N break would occur at the location where the survey commenced (see arrow in the figure). If fish are encountered above any PHB, the process of measuring and moving upstream would repeat until fish are not encountered. (PHB Science Panel 2019)

Per FHAM, PHBs are based on stream size, gradient, and access to fish habitat. The PHB Science Panel reviewed the available science and data on PHBs and provided recommendations to the Board for specific PHB criteria for eastern and western Washington (PHB Science Panel 2018). The Panel considered a variety of potential PHB attributes, including the physical features of a stream channel, water quality and quantity parameters, and other factors that might contribute to measurable habitat breaks. These attributes were evaluated for the ability to simply, objectively, accurately and repeatably measure them in the field, as well as the amount and relevance of existing scientific literature pertaining to each. The Panel concluded that it was possible to identify PHBs based on stream size, channel gradient, and non-deformable obstacles. These three attributes satisfied the objectives of simplicity, objectivity, accuracy, ease of measurement, and repeatability, that can be consistently identified in the field and can be incorporated into a practical survey protocol. The Board then selected three combinations of stakeholder-proposed PHB criteria for these attributes at their 14 February 2018 meeting (WA FPB 2018) and instructed the PHB Science Panel to develop a field study to evaluate the performance of these proposals (Table 1). It was important to the Board to determine which of the proposed criteria most reliably identify PHBs in eastern and western Washington. The Board also instructed the Science Panel to stratify sampling by ecoregion and to examine crew variability in identifying PHBs, especially evaluating aspects of field measurement practicality and repeatability (WA FPB August 2017).

Table 1. Three combinations of barrier, gradient, and width PHBs selected for evaluation by the Washington Forest Practices Board.

Type/	Description of criteria
Criteria 1	
Barrier	Gradient >20%, and barrier elevation difference is greater than BFW
Gradient	10% gradient threshold (Upstream Grad>10% and downstream Grad<10%)
Width	2 ft upstream threshold (Upstream BFW <2ft)
Criteria 2	
Barrier	Gradient >30%, and barrier elevation difference is greater than twice BFW
Gradient	Gradient difference >= 5% (upstream grad - downstream grad >=5) and Downstream gradient >10%
Width	2 ft upstream threshold (Upstream BFW <2ft)
Criteria 3	
Barrier	Gradient >20%, and barrier elevation difference is greater than BFW
Gradient	Gradient difference >= 5% (upstream grad - downstream grad >=5)
Width	20% reduction in bankfull width (upstream to downstream width at tributary confluences ratio <=.8)

Methods

Sample Frame and Study Sites

To evaluate the accuracy of PHB criteria as a method to identify EOF habitat, a representative sample of study sites must be obtained for applying the criteria. The target population is defined as the set of all fish habitat breaks in streams on forested land in Washington. A sampling frame that matches the target population as closely as possible is needed for unbiased inference. Fish/non-fish stream type break points extracted from the current DNR water type GIS map layer (DNR hydro, watercourses; https://data-wadnr.opendata.arcgis.com/datasets/wadnr::dnr-hydrography-watercourses-forest-practices-regulation/about) is an accessible source of possible study sites. Some of these points are based on field surveys that were concurred through the WTM review process while others are modeled points obtained from a logistic regression model that predicts F/N points based on basin area, upstream and downstream gradients, elevation, and precipitation (Conrad et al. 2003, Duke. 2005). Modeled F/N breaks are distributed across the entire state, but modeled points do not necessarily reflect the actual fish distribution and will require additional effort to locate the extent of fish distribution. Furthermore, the 10m digital elevation model (DEM) on which the hydrolayer is based is subject to frame undercoverage (omitted units of the target population) and frame overcoverage (non-target sites erroneously included in the sampling frame). Frame error was found to vary by region, with more undercoverage occurring in western Washington and more frame overcoverage occurring in eastern Washington. To provide the broadest basis for inference, the F/N break points on the DNR hydrolayer, which includes a combination of concurred (survey based) and modeled points, will serve as the sampling frame. This hybrid approach to the sampling frame incorporates existing information while allowing a broader scope of inference than if only the WTM data were used.

The study design will incorporate spatially balanced sampling. A spatially balanced sample provides a sample that is geographically diverse, which generally means outcomes exhibit less spatial correlation across units (Olsen et al. 2015). When outcomes are less correlated, outcomes are more spatially independent of one another, thus increasing effective sample sizes. Several types of spatially balanced samples exist, including two-dimensional systematic (or grid) samples, balanced acceptance sampling (BAS; Robertson et al. 2013), Halton iterative partitioning (HIP; Robertson et al. 2018), and generalized random tessellation stratification (GRTS; Stevens and Olsen 2003, 2004). This study will use GRTS sampling approach over the other two approaches, because the R package used to draw the other two types of spatially-balanced sampling (BAS & HIP) is currently not being maintained on the CRAN server for R packages whereas the GRTS package, spsurvey, is maintained by the EPA (Appendix B).

The spatially balanced sample of F/N points will be selected within each regional stratum (eastern or western Washington). The western region of Washington consists of about one-third of the state but twice the stream density. Given the differences in stream distribution across the state and the different sources of frame error in each region, east-west stratification will be applied to ensure that spatial balance is maintained within each region.

Sampling effort will be apportioned among mapped terminal or lateral F/N break point type (Figure 5) with “soft stratification.” In this approach, the point types are not available for each site before the survey, so no sampling frame is available to identify each subpopulation for a priori stratification. Survey crews will record the point type at the time of the survey and, when the desired sample size for a point type is satisfied, survey data from this point type will not be collected at subsequent points of this type. Because soft stratification cannot be planned in advance, employing this technique will require some adherence to the spatially-balanced ordered list of sites to ensure that the obtained sample of sites within each point type is also spatially balanced. The point type should be recorded for each site so that inclusion probabilities for each site may be calculated prior to analysis for any design-based summaries such as means and totals. This apportionment will only occur during the initial site surveys. If a site changes from a lateral to a terminal stream over the course of the study, we will not add any study sites to accommodate that change.

Based on an analysis of observed variability in channel gradient and width upstream of last detected fish points from previous CMER studies and existing water type modification forms (Appendix B) we propose to determine the location of last detectable fish at 160 sites in forested watersheds in eastern Washington and 190 sites in forested watersheds in western Washington[1], and measure the habitat characteristics (gradient, channel width, barriers) using a long-profile survey 660 ft (200 m) above and 660 ft below the last detected fish. The last detected fish locations will be determined during each sampling event via electrofishing surveys. The corresponding habitat surveys surrounding the located last fish point are expected to provide the data necessary to evaluate differences among PHB criteria across the state and within the eastern and western Washington regions. Data collected with consistent methods and crews might have lower variability than the data we used to estimate sample size.

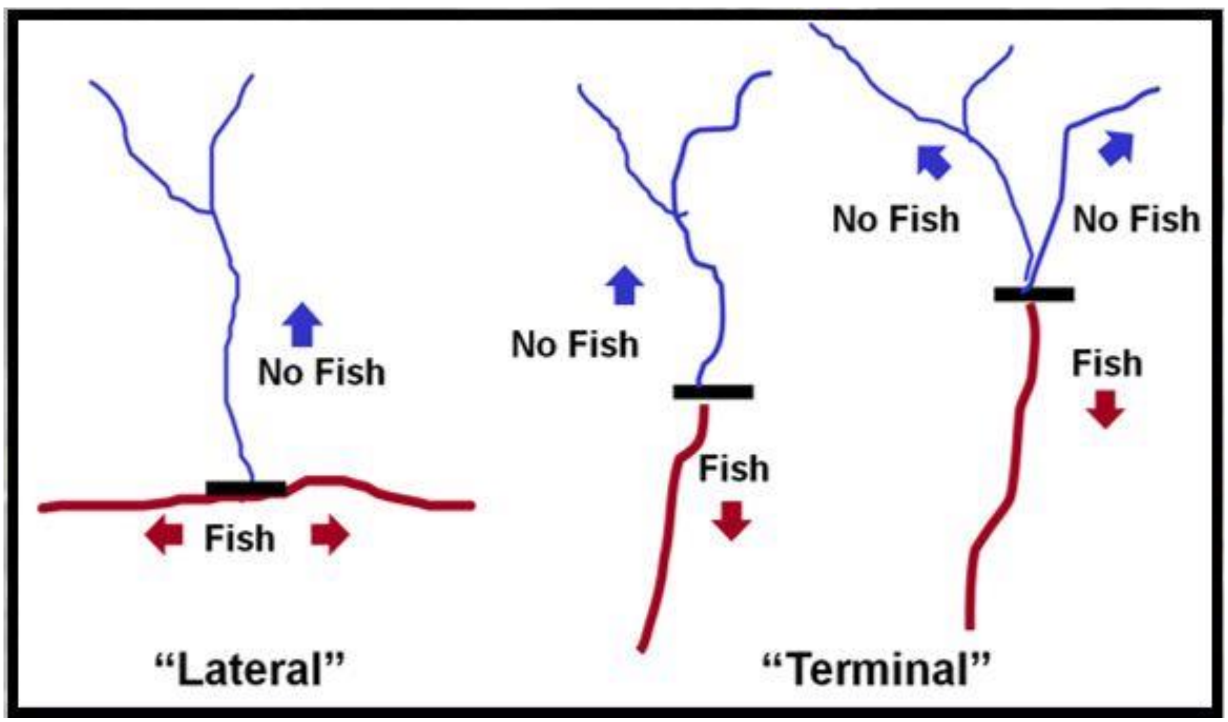

Figure 5. Schematic diagram of lateral versus terminal upstream limits of fish occurrence within streams. The black bar(s) indicate the location of the uppermost fish (Fransen et al. 2006).

Site Identification

[1] The recommended sample size includes sites in addition to the minimum number calculated to meet the specified statistical requirements. This allows for site attrition over life of the project.

The DNR Hydro Watercourses hydrography data layer contains stream channel locations across the state. Stream lines are kept as segments with properties about each segment stored as attributes. Segments are divided at intersections with other stream segments and any place where their recorded properties change (e.g. - fish use/non-fish use). The points at which this classification changes from fish (Type F) to non-fish (Type N) will be extracted from this hydro layer. The properties of the fish use segment below the break are retained with those data points and stored in the new point layer. The attributes (properties) of interest for this study include the bases of the fish use determination, such as whether it was a segment modeled as likely fish habitat, a concurred legacy determination, from a water type modification form, etc. Another attribute is whether that determination was based on biological information (fish observation or electroshocking findings) or on habitat assessment. Such information will be important for locating the optimum survey starting location but will not be used for the purposes of selecting sample streams.

The F/N break points are intersected with the East/West Washington polygons to assign them an East/West attribute. (Points will also be intersected with the DNR Ecoregions polygon layer to assign them an Ecoregion attribute. However, that attribute will be used as a covariate in post-hoc analyses rather than as a stratification variable.) The point layer will be subjected to the GRTS spatial randomization procedure, which will assign a sequence number to each point. The points to be inspected for this study will be selected from each side of the state in the sequence assigned. As points are discarded according to our rejection criteria (below), the next sequential point will be added to the sample population. In this way, spatial balance and random validity should be maintained. This will be verified visually by tracking the current sample selection on a map.

In practice, batches of points will be selected and assessed for suitability, access permission, and field inspection to facilitate the sample set delineation. These batches will ensure that more points (streams) are ready to be sampled (and even perhaps initially sampled) than are actually needed in case selected points are rejected during the first study season. However, the points will always be sampled and analyzed with the priority of their sequence in order to preserve the randomness and spatial balance of the selection

The F/N break point will identify the stream to be sampled, not necessarily the sample starting point. The starting points will be the highest known fish location for that stream based on any available information that can be obtained about that stream. The GIS layer contains some information, such as the typing basis. Other information may be obtained from landowners, tribal entities that monitor that stream area, and other local experts. In the case of tributary streams that have no reliable fish observations, the electrofishing survey will start at the confluence of the subject stream with the known fish-bearing mainstem stream. The initial survey will determine lateral versus terminal status of the selected tributary for site allocation purposes during site selection.

Site Rejection Criteria

Some potential study sites will be excluded from the sample population due to unforeseen circumstances. During the site selection and field validation task, study sites may be dropped as follows:

- Sites where the last upstream fish is associated with a man-made barrier;
- Streams showing evidence of recent (e.g., within three to five years) debris flows through the subject stream;
- Sites where we cannot obtain landowner permission for the full survey length;
- Sites that we do not have safe access to;
- Other reasons determined by project team.

In every case that a site is excluded from the sample, the reasons will be thoroughly documented.

Sampling Frequency and Season

Field surveys (electrofishing and habitat) will be conducted during the spring/early summer and the late fall/early winter sampling periods (seasons). These two high flow periods were chosen because they represent the most likely time periods for fish to be found at their highest point in the stream network, and therefore should be adequate to evaluate seasonal differences in the upper extent of fish use. While summer sampling may be beneficial to compare seasons, due to the low flows typical of summer, it is unlikely that fish would move higher into the system in that season (Cole and Lemke, 2006).

All sites will be surveyed every year during spring/early summer (current protocol electrofishing survey window of March 1 to July 15) for three years to examine inter-annual changes in last detected fish. To evaluate seasonal changes in the location of the last detected fish, the sites that can be accessed in the fall/winter high-flow season will also be sampled on a rotating panel basis. One quarter of the sites will constitute the fixed portion of the panel and will be surveyed every fall/winter, and the remainder will constitute the rotating portion. One third of the rotating portion will be sampled each year in addition to the fixed portion. The fixed portion of the panel will consist of the full count of sites from Table 2, while the rotating portion counts will vary depending on site accessibility. The survey timing within both sampling periods will be determined through consultation with regional experts to optimize the timing based on local hydrology and fish life history and resurvey timing will be consistent (within two weeks of the original survey date) across years.

Table 2. Overall sampling schedule by calendar year and season 2024 to 2026. All sites will be sampled in spring to early summer (March 1 to July 15) with the seasonal fixed and rotating panel being resampled in fall to early winter high flow period (dates determined through consultation with regional experts). A pilot study sampling 15 sites in eastern and 12 sites in western Washington was completed in September of 2018.

Sampling Event	Pilot year (2018)	Year 1 (2024)	Year 2 (2025)	Year 3 (2026)
Spring to early summer		160 eastern Washington 190 western Washington	160 eastern Washington 190 western Washington	160 eastern Washington 190 western Washington
Late Fall/Winter Fixed Panel Sampled All Years (same sites)	27 to test methods	40 E WA 48 W WA	40 E WA 48 W WA	40 E WA 48 W WA
Late Fall/Winter Rotating panel, Sampled Only in Single Season		40 E WA 48 W WA	40 E WA 47 W WA	40 E WA 47 W WA

Reporting	Pilot study report	Annual report	Annual Report	Final Report

Protocol Electrofishing and Habitat Surveys

The protocol electrofishing and habitat survey will provide a complete data set to inform the PHB and associated analyses. Protocol electrofishing surveys will be conducted to determine the location of the last fish at each survey event. We will then conduct channel habitat surveys up- and downstream of that last fish point to provide data for addressing the study questions. The channel survey data will be used to partition the study reach into variable-length stream segments that are scaled to lengths of homogeneous habitat features within the long-channel profile. The length of segments will be based on changes in gradient and channel width that are associated with inflection points and/or changes in habitat features (e.g., vertical and non-vertical obstacle). Vertical and near-vertical obstacles will be captured as individual segments, as such features will have some segment length associated with them.

Prior to sampling a site, the project team will review existing information from any available sources on access, previous location of last detected fish and habitat data, and obtain landowner permission for access and sampling. In determining the upstream extent of fish distribution, multiple upstream segments may be available for survey. When this situation occurs, the selected surveyed segment will be the mainstem channel, defined as the stream segment with the largest contributing basin area upstream from a tributary junction (should have largest bankfull width, most flow, etc.). Where basin area upstream from a junction appears approximately equal, rely on additional on-site metrics such as bankfull width and/or flow to determine upstream direction of survey. Stream segments not included in the hydrolayer may be encountered when moving upstream. These stream segments will be included in the survey process in accordance with the above criteria.

Field crews will use modified DNR protocol electrofishing surveys with the intensity consistent with methods being developed for FHAM to determine last detected fish (Figure 6a). Water temperature (to the nearest 0.1 °C), conductivity (micro-Seimens), and electrofishing setting (e.g., voltage, frequency, pulse width) will be recorded at the beginning of each electrofishing survey. The GPS coordinates of each last detected fish location will be recorded, and the location will be flagged and monumented with a marker including the survey date on an adjacent tree. The fish species and approximate sizes will be recorded. Electrofishing surveys will continue from the last detected fish point upstream to the end of default physical fish criteria (end DPC point). In the event the last detected fish is found at the end of default physical criteria, electrofishing will continue 660 feet (upstream) to align with the extent of the detailed habitat surveys. We will also record electrofishing survey time (shock seconds). Coarse scale habitat data will be collected on the full extent of the e-fishing survey. These data will include channel gradient, bankfull width, wetted width and confinement within unequal length segments of relatively uniform habitat character.

An intensive longitudinal thalweg and water surface profile habitat survey will be used to assess key habitat attributes (i.e., gradient, bankfull and wetted width, water depth, substrate size composition, and height of channel steps) below and above last detected fish (Figure 6b). A previous study of variability on the upper limits of fish distribution in headwater streams suggested that over 90% of the interannual variation in the last detected fish location occurred in less than 200 m upstream and downstream of the last detected fish location (Cole et al. 2006). Therefore, we will use a distance of 660 feet (200 m) below and 660 feet above the last detected fish as our intensive habitat survey reach. The crew will measure 660 feet (horizontal distance) downstream from the last detected fish point to determine the beginning point for the intensive stream habitat survey.

The intensive habitat survey involves surveying the streambed elevation along the deepest portion of the stream (the thalweg), yielding a two-dimensional longitudinal profile of streambed elevations. This has been shown to be a reliable and consistent method for measuring change in stream morphology and fish habitat independent of flow (Mossop and Bradford 2006). We will also be recording water surface heights because surface levels are what are important to fish with regard to obstacle heights. Survey measurements will be taken every ten feet, and at any significant inflection points in topography or planform to be sure we capture all changes in thalweg topography and gradient. A laser range finder mounted on a monopod and a target on a second monopod will be used to collect distance and elevation data. All data will be entered into a computer tablet in the field. Measurements and observations at each point will include horizontal distance and slope between survey points, water depths, wetted widths, bankfull width, dominant substrate (e.g, sand, gravel, cobble), large wood, habitat feature (e.g., pool, riffle, cascade), and general characterization of flow and water conditions. Water surface elevation will be calculated after the survey from the bed elevation plus the measured water depth. For steps and potential migration barriers, the crew will record whether the step is formed by wood, bedrock, or another substrate. The presence of wood is particularly important because wood-formed barriers are considered deformable barriers and are not PHBs. Crews will also note whether flow is continuous or intermittent, the presence of beaver dams, groundwater inputs, and any other unusual features (e.g., tunneled or sub-surface flow) that could influence fish distribution. Because sites will generally be in small, constrained streams that are unlikely to change significantly throughout the sampling year, it is likely that the habitat survey data for each stream will only need to be collected once each year with the spring sampling effort. The survey will be repeated annually to ensure we have a complete survey 660 feet above and 660 feet below the last detected fish found during each sampling event (Figure 6c). A similar protocol based on Mossop and Bradford (2006) has been used to survey barrier removal projects on small streams throughout the Columbia River Basin.

Evaluations of various regional stream habitat survey protocols have demonstrated that with *well-trained* field crews, measurement error is small relative to naturally occurring variability amongst sites (Kershner et al. 2002; Roper et al. 2002; Whitacre et al. 2007). Therefore, all crews will participate in a three to five-day training course each year prior to initiation of spring sampling to ensure consistency among crews in determining last detected fish, surveying habitat features (long-profiles), and data collection. Moreover, to quantify variability among crews in conducting longitudinal surveys, we propose that 10% of all sites sampled each spring should be resampled by other crews every year (i.e., 10% of the sites will have three replicate surveys). Since variation in stream flow during subsequent surveys should not affect the longitudinal bed profile, we don't expect flow changes to contribute to variability observed among crews in these resurveys.

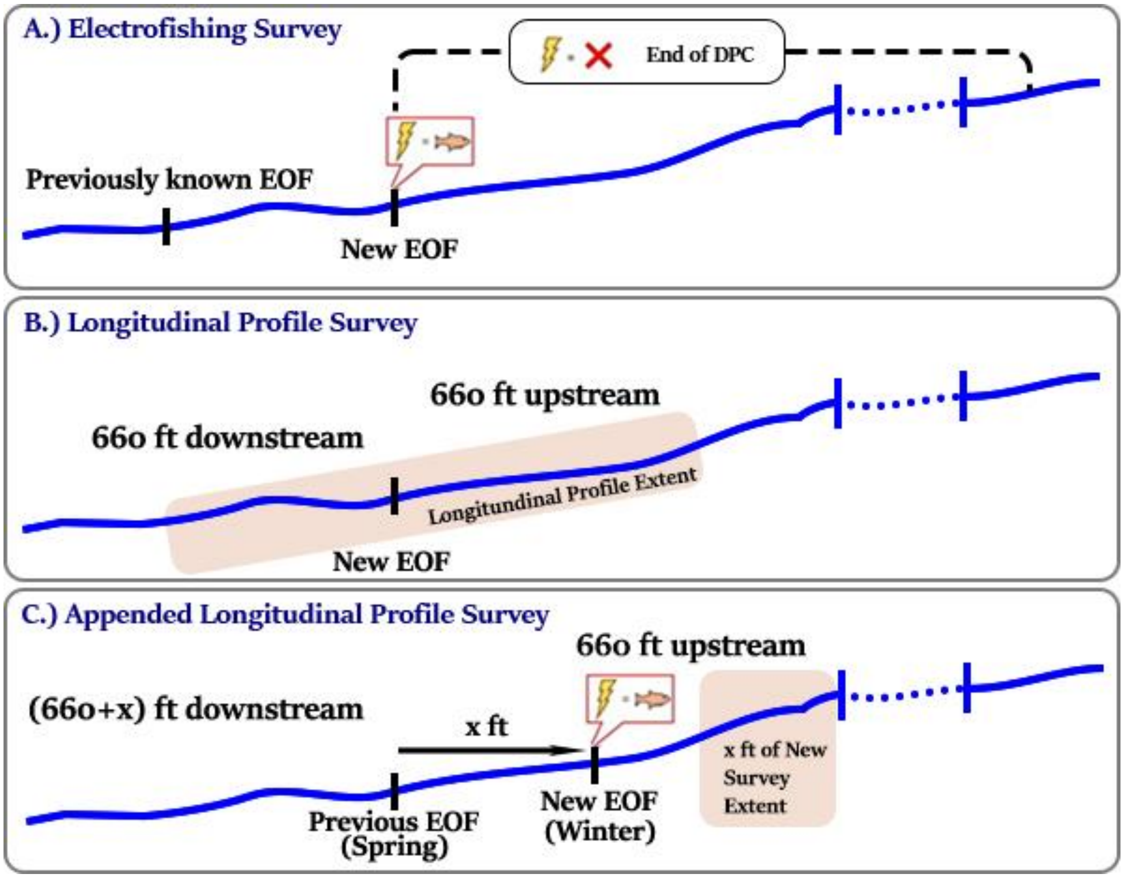

Figure 6. Components of field surveys demonstrating: (A) the extent of the protocol electrofishing survey to determine end of fish (EOF) point, (B) the range of the initial longitudinal profile habitat survey associated with the initial EOF point, and (C) an example of how the longitudinal profile survey would be appended if follow up protocol electrofishing surveys identify a new EOF point (adapted from PHB Science Panel 2019).

Reach- and Basin-Scale Explanatory Variables Derived From Office and Remote Sources

We will also collect data on several other factors that are thought to play a role in last detected fish point and identification of PHBs from sources other than field data. These include: elevation, aspect, drainage area, distance to divide[2], valley width, annual precipitation, channel type[3], riparian stand condition[4], whether last detected fish and PHB is at a mid-channel point (mainstem or terminal) or confluence (tributary or lateral tributary), dominant drainage area geologic competence category[5], stream order, and whether a stream is accessible to anadromous fish or only resident fish. Many of these variables will be derived from existing GIS data layers. Drainage area, distance to divide, and valley width are important because they, combined with annual precipitation, are related to flow and stream size. The local geology around the stream determines whether stream substrate tends to consist of hard, resistant, larger particles or friable, fine-grained substrates, which have been shown to influence fish distribution (Gresswell et al. 2006; Torgersen et al. 2008).

Data Preparation

Physical attribute and fish presence data will be organized by site and variable-length segment. To prepare data for analysis, the stream profile will be divided into variable-length homogeneous segments, and each segment will be populated with a suite of segment-scale physical attributes and fish presence or absence. Variable-length segments will also be populated with associated basin-scale attributes that will be derived from GIS. Other basin-scale characteristics will be included for each site. Measures such as gradient and channel width can also be used to form threshold variables that can be assessed as predictors of segment-level fish presence.

Additional data sets to assess changes in distribution over time will be developed. The variation across seasons will be assessed by examining the maximum distance among last fish points observed across seasons within a year for each site. Similarly, the range of last fish points for each of the two seasons will be calculated across years to examine variation across years within each season.

[2] Palmquist (2005) found distance to divide to be less variable and more reliably calculated than basin area
[3] Montgomery & Buffington, 1993
[4] Watershed Analysis categories, WA DNR 1997
[5] Competent/Incompetent, per McIntyre et al. 2009

Data Analyses

Data Exploration, Summary Statistics, and Initial Tests

After data preparation is complete, initial data exploration will include graphical examination of habitat metrics for segments within a site and for segment means of physical characteristics for each site (Figure 7). Distributions of physical attributes for variable-length segments at a site can be compared for segments with and without fish by and across sites. The length of segments will be based on changes in gradient and channel width that are associated with inflection points and/or changes in habitat features (e.g., vertical [falls] and non-vertical obstacle [steep cascade]). Criteria for classifying variable-length segments and obstacles will be derived during post-hoc data analysis using linear regression methods similar to those described by Tompalski et al. (2017). For seasonal data, physical attributes at each site may be summarized by region (east or west), point type (lateral or terminal), and by season (spring or fall/winter).

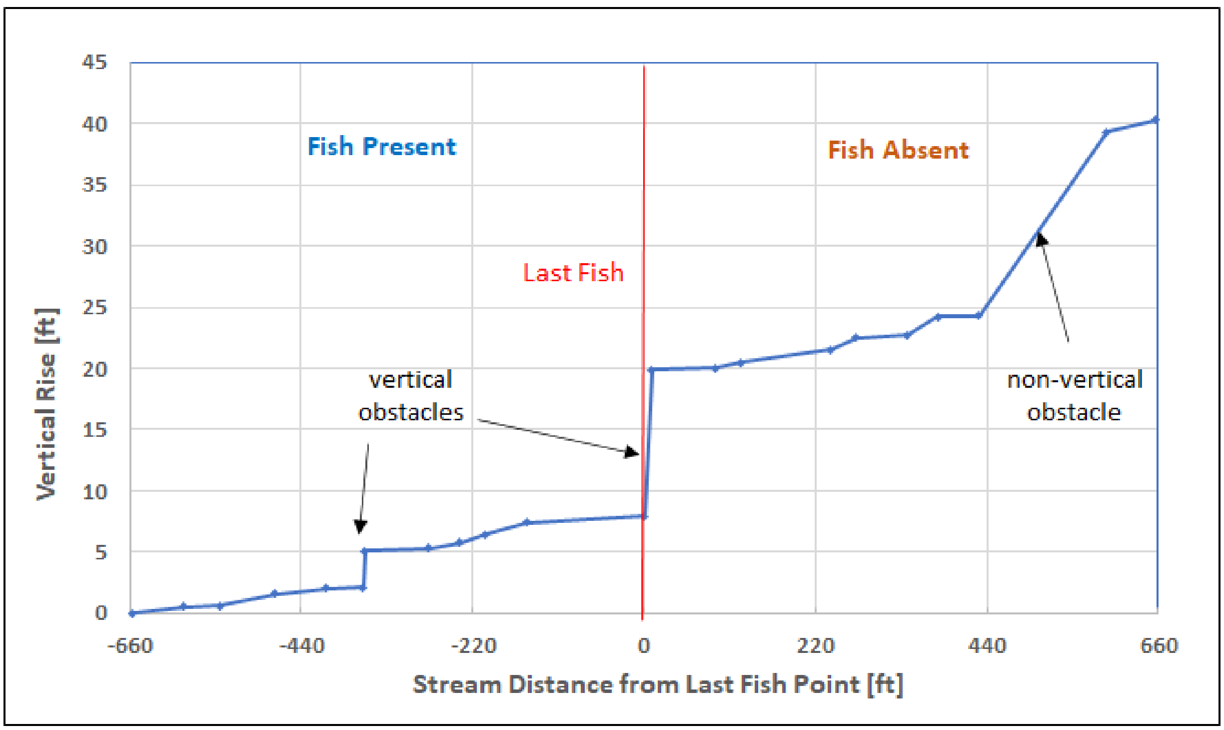

Figure 7. Schematic of channel long-profile survey showing variable-length segments (i.e., distance between inflection points) and associated vertical and non-vertical obstacles.

PHB Classification Methods

The primary goal of this project is to identify PHBs associated with EOF habitat using a suite of physical channel features and basin characteristics (Research Questions #3, #4, #7, and #8). Three sets of classification criteria proposed by the Board will be assessed, and an independent set of criteria will be developed with statistical tools for classification. Possible statistical techniques include classification trees (Breiman et al.1984), generalized linear models (McCullagh and Nelder 2019), linear discriminant analysis (Tharwat et al. 2017), and random forests (Cutler et al. 2007, Trigal and Degerman 2015). Random forest methodology is a nonparametric approach used for classification and prediction and can identify important predictor variables among a large suite of possible covariates even when those covariates are highly correlated (Cutler et al. 2007, Kubosova et al. 2010). Random forest can also bin continuous data into discrete categories as part of the analysis, as opposed to assigning arbitrary bins *a priori*. Cutler et al. (2007) found that random forests had high classification accuracy compared to classification trees, generalized linear models (logistic regression), and linear discriminant analysis. Random forest (RF) classification has been used to classify salmonid habitat in Alaska (Romey and Martin 2021), fish assemblage presence in stream segments in coastal Australia (Rose et al. 2016), and in macroinvertebrate habitat in the Czech Republic (Kubosova et al. 2010). Random forest methods have been extended to boosted random forests (Ko et al. 2015, Mishina et al. 2015) which features more memory-efficient calculations. When classification covariates are impacted by spatial and/or temporal correlation, binary mixed model forest (Speiser et al. 2019) or generalized mixed effects random forest (Fontana et al. 2021, Seibold et al. 2019) can account for these sources of correlation.

Random forest classification will be applied to the binary indicator of fish presence within each of the variable length segments to model PHBs as a function of physical and basin characteristics. Separate random forest classifications may be applied to eastern and western sites and for lateral and terminal points to identify influential variables independently in each system. The data will be split into training and testing data sets to assess the performance of the random forest classification. A random forest model will be developed from the training data set and then applied to the test data set to assess classification. Classification performance metrics will include the overall percentage of PHBs that were correctly classified, sensitivity (proportion of presences correctly classified), specificity (proportion of absences correctly classified), kappa (a measure of agreement computed across presences and absences, Cohen 1960), and the area under the receiver operating characteristic curve (Fawcett 2006). The final model will be applied to the entire sample of points to obtain indices of fish presence.

Board-Proposed PHB Performance Evaluation

Three sets of classification criteria proposed by the Washington Forest Practices Board will be assessed with random forest methodology (Research Question #10). Each proposed criteria set will be assessed by including only the proposed variables in the random forest model. The data will be split into training and testing data sets by randomly selecting EOF points into each group. The training EOF points will be used to develop the random forest model, and the testing data set will be used to assess the performance of the model to classify variable length segments as above or below the last fish point. PHB criteria provided by the Washington Forest Practices Board can be similarly assessed by developing a random forest model for each criteria set and evaluating the performance of each classification.

Interannual and Seasonal Last Fish Variability

Interannual and seasonal variation in the last detected fish locations (Research Questions #1, #2, and #5) will be assessed with linear mixed models or generalized linear mixed models (Bolker et al. 2009). The model may contain classification and continuous covariates that explain seasonal movement, including the season, region (east/west), ecoregion, and point type (lateral/terminal). Random effects for space and time will ensure that standard errors for fixed effects estimates are not underestimated due to correlation. Variance components may also incorporate habitat categories for which variance heterogeneity in seasonal movement is observed (e.g., low vs high elevation).

All statistical analysis will be conducted in the R statistical programming language (R Core Team 2021). Random forest modeling will apply the randomForest package (Liaw and Wiener 2002) and generalized linear mixed modeling will be conducted with the glmmTMB package (Brooks et al. 2017).

Changes in Features Originally Identified as PHBs Over Time (Research Question #6)

Compare physical features measured among sampling events at locations of the various tested PHBs to assess the degree of change in the parameters defining those PHBs.

Effect of Crew Variability on Identification of PHBs (Research Question #9)

Crew-variability testing conducted within this study will provide insight into the ability for multiple survey crews to repeatably identify the same PHBs when implementing FHAM in the field in the future.

Potential Challenges

Although the methods we propose have been widely used to quantify habitat conditions and identify last detected fish, there are some potential challenges. These include location of sites that meet selection criteria, access to initially identified sites, and access to these sites throughout the two seasons and three years. It is possible that we may not have access to selected sample sites due to issues with land ownership, landowner willingness to permit access, or problems with the road networks. Thus, if a site is not suitable due to access or for other reasons a different site (the next consecutive site number from the initial random selection) would be used to replace the non-suitable site, and the reasons the site is excluded will be documented. A more challenging scenario would be if accessibility changes between or among seasons and years. For example, forest fires, heavy early or late snow, or road failures could affect repeat surveys at a site. In such cases, we would continue to sample sites during other seasons and years when possible. The recommended sample size includes sites in addition to the minimum number calculated to meet the specified statistical requirements. This allows for some site attrition over life of the project.

An additional challenge with study implementation will be largely financial and could result from underestimating or overestimating the amount of time and cost needed to adequately sample sites initially and repeatedly. Similarly, we need to ensure that the data collected will allow us to answer the PHB study questions. To proactively assess these critical uncertainties, a pilot (feasibility) study was conducted in August of 2018 to test and refine protocols, and estimate the time needed to conduct a survey and collect data at a site (PHB Science Panel 2018b). The pilot study included conducting longitudinal thalweg profile surveys upstream and downstream of known last detected fish points at 27 sites on private, state, and federal forestlands in western and eastern Washington. The analysis of longitudinal survey data from the pilot study demonstrated that PHBs based on gradient, BFW, and obstacles being examined by the Board could be easily determined from the survey data. The field surveys helped identify several modifications to the initial proposed protocol that are needed to assure the proposed and other potential PHBs can be easily identified (e.g., spacing of the survey points, habitat types, minimum habitat length, and substrate categories). It also provided important information on time needed to conduct surveys, which we have incorporated into the study plan and estimated cost to conduct the full validation study.

Another challenge is that this study does not address long-term changes in small streams that may render them unsuitable for fish occupancy, or conversely, may render previously unsuitable streams habitable for fish. At any point in time, some headwater streams are not used by fish during any season of the year due to a blockage, to invasion, or to unfavorable physical conditions (e.g., gradient) in the channel itself. Factors that determine whether small streams can be used by fish are typically related to disturbances such as exceptionally high discharge, landslides, debris flows, and windstorms. Such episodic disturbances are erratic and can be widely spaced in time (decades to centuries), but their overall effect in drainage systems is to create a mosaic of streams suitable for fish occupancy that changes over long intervals (often hundreds of years) in response to local disturbance regimes (Kershner et al. 2018; Penaluna et al. 2018). An important implication of the notion that the potential use of small tributaries by fish can change over time is that while some stream segments are not now occupied by fish, there is no guarantee that they may not become suitable in the future, or that those which are currently habitable will always remain so. This study, however, does not address the expansion and contraction of fish habitat over long time intervals, because the sample time is limited to three years and the methods cannot predict with certainty where and in what form large disturbances capable of transforming a stream segment's ability to support fish will occur.

Expected Results and Additional Studies

Highly precise measurements of stream channel conditions both upstream and downstream of last detected fish locations will provide a nearly continuous dataset of physical stream characteristics within the surveyed area. Thus, we will be able to objectively identify the physical stream characteristics most closely associated with last detected fish. These data will be used to test the different PHB criteria under consideration by the Board in 2018, and also to identify alternative physical stream characteristics that may function as PHBs. We expect that the study will assess the performance of proposed and/or identify alternative PHB criteria for gradient, channel width, and barriers that are most frequently associated with the uppermost of all the last detected fish points found at each stream across the time period of the study. Seasonal and inter-annual sampling will allow us to examine the variation of last detected fish locations across years and seasons, which will help identify PHBs that are consistently associated with the upper extent of fish habitat across years, seasons, and flow conditions regardless of where fish are found on any given day. Because we will be using some sites for which a WTMF already exists and last detected fish was potentially identified, examining longer-term inter-annual variation in last detected fish may be possible for a subset of sites where last detected fish has been previously identified and monumented. In addition, study sites could be revisited in the future to look at longer-term changes in last detected fish, if desired.

Ultimately, the analysis will provide the distances (upstream and downstream) from last detected fish to the different proposed PHB criteria, if and how that differs among years and seasons, whether one set of criteria performs better in terms of consistently identifying EOF habitat across seasons and years, and whether different PHB criteria should be applied for different regions or should be stratified by other factors. While the focus of the study is to test the three different sets of PHB criteria being considered for adoption by the board, we expect that the analyses will help identify other criteria that might more consistently be associated with the last detected fish and therefore better indicate EOF habitat when integrated with FHAM.

The results should also help inform the protocols for measuring gradient, bankfull width, and obstacles in the field to minimize variability among field crews and assure consistent identification of PHBs. Focus should be placed on specific protocols used to consistently and accurately identify and measure physical stream characteristics, including gradient, bankfull width, barriers, and any other criteria that may be used to identify PHBs in this study.

We will also examine seasonal and inter-annual changes in end of fish locations in headwater streams across the state. For the subset of selected sites where previous WTM data exists we may also be able to assess variability at longer time scales. While this would potentially lay the groundwork for continued monitoring of long-term variability in the upper end of fish distribution, it is not designed as a long-term study on such variability. Depending on results, we may recommend that sites continue to be periodically revisited in the future to examine this longer-term variability, but long-term monitoring is beyond the current scope of this study.

DPC Study Integration

With the electrofishing and habitat surveys for each PHBs study stream continuing up to or beyond the end of current DPCs as described on p 22, the PHBs study will yield a data set that can be analyzed regarding the frequency with which fish are found up to the limits of current DPCs, including how this varies between seasons, years, and geography. The coarse scale data collected during the electrofishing survey will also provide channel profiles and other data for the reaches between EOF/H and end of current default physical criteria that can be analyzed for possible explanations as to what features are limiting fish distributions for those sites where fish use does not extend to end of current DPCs. These data will include channel gradient, bankfull width, wetted width and confinement within unequal length segments of relatively uniform habitat character. The results might suggest appropriate metrics for barriers and NVOs that could be used in conjunction with width and gradient to add an element of accessibility to the DPCs, thereby improving their accuracy and utility - in particular, by reducing the number and rate of "false positives" when using DPCs alone, in the absence of protocol surveys.

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Appendix A. CMER Workplan and prior science panel study questions

CMER Workplan Water Typing Rule Group Critical Questions

The following are the critical questions of the water typing rule group program this study will address:

CQ 1. How can the line demarcating fish- and non-fish habitat waters be accurately identified?

CQ 2. To what extent does the current water typing survey window capture seasonal and annual variability in fish distribution considering potential geographic differences?

CQ 3. How do different fish species use seasonal habitats (timing, frequency, duration)?

CQ 4. How does the upstream extent of fish use at individual sites vary seasonally and annually?

CQ 5. How does the delineation of the upstream extent of fish habitat change seasonally?

Science Panel document Study Questions

- Do the PHB criteria provided by the Washington Forest Practices Board accurately capture the EOF habitat when applied in the Fish Habitat Assessment Methodology (FHAM)?
- Based on data collected, what is the most accurate combination of metrics for determining PHB by region or ecoregion?
- Are there differences in PHB criteria by Environmental Protection Agency (EPA) Level III ecoregion, eastern vs western Washington, or some other geographic or landscape strata?
- Are there additional variables (e.g., geology, drainage area, valley width, land use, channel type, and stand age) that could improve the accuracy of existing criteria?
- What is the influence of season/timing of survey on PHB identification?

- What is the typical inter-annual variability in last detected fish and PHBs?
- Can protocols used to describe PHB be consistently applied among survey crews and be expected to provide similar results in practice?
- Answering these questions requires identifying the last detected fish and surveying habitat above and below these points in a random representative sample of streams across the state.

Appendix B. Sample Size Estimation Memo of Jan 4, 2022

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MEMO

To: Instream Science Advisory Group
From: Leigh Ann Starcevich (WEST, Inc.)
Date: January 4, 2022
Re: Sample size approximation from Eastern WA and Western WA data

The Instream Science Advisory Group (ISAG) is developing a sampling design for surveys of potential habitat breaks (PHB) for fish use. A sample size approximation is needed to ensure that the data collected to assess criteria defined by the Washington Forest Practices Board (Board) for the Fish Habitat Assessment methodology (FHAM) yield useful covariates for PHB modeling. Cooperative Monitoring, Evaluation, and Research (CMER) data from eastern Washington surveys conducted in 2001, 2002, and 2005 were provided by Chris Mendoza. Stream habitat data associated with uppermost detected fish points from concurred water type modification forms for surveys conducted in western Washington between 2016 and 2020 were provided by Weyerhaeuser. These data were used to approximate sample sizes needed to estimate means of PHB model covariates with desired levels of precision and accuracy.

Eastern Washington Data

The eastern Washington data were collected in 2001 by Terrapin Environmental (Cupp 2002) and in 2002 and 2005 by ABR, Inc. Environmental Research & Services (Cole and Lemke 2003, 2006). Channel characteristic metrics included mean channel widths and means gradients for reaches extending up to 100m above and 100m below the last fish point obtained in the 2001 survey. Data for barriers were collected but inconsistencies in how barriers were classified and recorded prevented sample size evaluation specific to barriers. For surveys conducted after 2001, the last fish distance relative to the 2001 last fish was provided. A metric for the maximum change in distance from the 2001 last fish point was calculated for each site. Using the 2001 point as baseline, the range of distances where the last fish was observed during subsequent surveys was calculated and used to inform the sample size approximation.

Data screening was used to limit the data set to a subset of locations with natural habitat breaks. Unscreened data sets included sites where large woody debris jams were found, no surface flow occurred for at least 100m, and surveys were conducted past July 15. The screened data sets eliminated many of these sites. Sites where fish passage was limited by culverts were removed from all data sets. About 46% of the unscreened points were classified as lateral points.

Western Washington Data

Water type modification form data from western Washington were collected between 2016 and 2021 and included gradient and bankfull width metrics for stream segments upstream and downstream of the last fish point. For many lateral points, only the upstream measurements were provided because the point was located on a river mainstem. At these points, data on gradient and bankfull width metrics downstream of the confluence were not always collected, so these points are omitted for sample size calculations based on the downstream metrics. About 70% of the points were classified as lateral points.

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Sample Size Approximation

Estimated means of channel characteristic metrics and change in last fish locations among years were used as the basis for the sample size approximation. Let z reflect the quantile of a standard normal random variable for a given Type I error rate (α). For $\alpha = 0.10$ we have that $z = 1.645$. Let d be the maximum absolute error (i.e. confidence interval half-width), let r be the relative precision of the estimate, and let γ be the coefficient of variation (CV). The coefficient of variation is a standardized measure of precision calculated as the standard deviation (SD) of the outcome divided by the mean of the outcome (Thompson 2002). The sample size approximation formula below is applied with the mean and standard deviation for each outcome of interest. The sample size needed to obtain an estimate that is within 100*r% of the true mean with probability 1 - α was calculated. In other words, the confidence interval half-width of the mean should be 100*r% of the true mean. The sample size to accomplish this goal is based on a normal approximation and calculated as:

$$n = \frac{z^2\gamma^2}{r^2}.$$

For each outcome of interest from the eastern Washington data sets, the coefficient of variation was computed from the mean and standard deviation of the screened (Tables 1 through 3) and unscreened (Tables 4 through 6) data, and sample sizes were approximated for relative precision values of 0.10, 0.15, 0.20, and 0.30. Variation was slightly higher in the unscreened data set, resulting in slightly larger sample sizes. For the eastern data, the coefficients of variation were higher for terminal points than for lateral points for the upstream reach gradient, reach gradient difference, and maximum change in distance (Tables 2 and 3, Tables 5 and 6). The coefficients of variation were higher for lateral points than for terminal points for downstream reach gradient and downstream bankfull width.

Similar results were observed for the western Washington data. For estimation of mean channel metrics across point types, coefficients of variation ranged from 0.69 to 0.79 for reach gradient metrics and for the bankfull width above the point. However, bankfull width measured below the last fish point was less precise than in the eastern Washington data set with a CV of 1.28 (Table 7). The precision for the gradient difference was similar to that observed for the eastern Washington data with coefficients of variation near or above one. For the western data, the coefficients of variation were higher for terminal points than for lateral points for the reach gradient difference (Tables 8 and 9). The coefficients of variation were higher for lateral points than for terminal points for reach gradient metrics and the downstream bankfull width. The higher variability in these metrics suggest larger sample sizes are needed for precise estimation of means. While mean estimation of channel characteristics is not the ultimate inferential goal, we assume that samples large enough to provide information on the range of values for each of the potential PHB modeling covariates will yield a useful data set for modeling.

The maximum change in distance from the eastern data was highly variable and generated large sample sizes for levels of desired precision. The difference in reach gradient exhibited high variability across both the eastern and western data sets, and sample sizes needed for precise mean estimation are large. To obtain relative precision of 0.15, the required sample size is nearly double that calculated for relative

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precision of 0.20. Note that the sum of the sample sizes calculated for lateral and terminal points generally exceeds the sample size calculated from data pooled across point types. This indicates that overall sample sizes may need to be larger than indicated by the pooled analysis to achieve the same level of precision for means of channel characteristics for lateral and terminal points.

Table 1: Estimates of means, standard deviations, and coefficients of variation from *screened eastern WA data pooled across point types* with sample size approximations for four levels of relative precision.

Outcome	n	Est. Mean	SD	CV	r = 0.10	r = 0.15	r = 0.20	r = 0.30
Reach gradient (%) above LF point	193	21.56	13.98	0.65	114	50	28	13
Reach gradient (%) below LF point	161	10.31	6.73	0.65	115	51	29	13
Reach gradient difference (%)	161	9.96	11.19	1.12	341	152	85	38
Bankfull width (m) above LF point	197	2.14	1.41	0.66	117	52	29	13
Bankfull width (m) below LF point	174	1.84	1.35	0.74	146	65	37	16
Maximum change in distance (m)	121	73.26	186.34	2.54	1751	778	438	195

Table 2: Estimates of means, standard deviations, and coefficients of variation from *screened eastern WA data at lateral point types* with sample size approximations for four levels of relative precision.

Outcome	n	Est. Mean	SD	CV	r = 0.10	r = 0.15	r = 0.20	r = 0.30
Reach gradient (%) above LF point	67	24.03	12.36	0.52	72	32	18	8
Reach gradient (%) below LF point	53	8.30	9.25	1.11	336	149	84	37
Reach gradient difference (%)	53	18.30	10.77	0.59	94	42	23	10
Bankfull width (m) above LF point	74	1.42	0.79	0.55	83	37	21	9
Bankfull width (m) below LF point	64	0.83	0.74	0.89	214	95	53	24
Maximum change in distance (m)	13	72.12	72.49	1.01	273	121	68	30

Table 3: Estimates of means, standard deviations, and coefficients of variation from *screened eastern WA data at terminal point types* with sample size approximations for four levels of relative precision.

Outcome	n	Est. Mean	SD	CV	r = 0.10	r = 0.15	r = 0.20	r = 0.30
Reach gradient (%) above LF point	126	20.25	14.64	0.72	141	63	35	16
Reach gradient (%) below LF point	108	11.30	4.81	0.43	49	22	12	5
Reach gradient difference (%)	108	5.87	8.92	1.52	624	277	156	69
Bankfull width (m) above LF point	123	2.57	1.52	0.59	95	42	24	11
Bankfull width (m) below LF point	110	2.43	1.28	0.53	75	34	19	8
Maximum change in distance (m)	108	73.40	195.84	2.67	1926	856	481	214

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Table 4: Estimates of means, standard deviations, and coefficients of variation from *unscreened eastern WA data pooled across point types* with sample size approximations for four levels of relative precision (recommended eastern WA sample size in bold).

Outcome	n	Est. Mean	SD	CV	r = 0.10	r = 0.15	r = 0.20	r = 0.30
Reach gradient (%) above LF point	268	18.73	13.30	0.71	136	61	34	15
Reach gradient (%) below LF point	227	9.72	6.42	0.66	118	52	29	13
Reach gradient difference	227	8.13	10.23	1.26	428	190	107	48
Bankfull width (m) above LF point	282	2.02	1.47	0.73	143	63	36	16
Bankfull width (m)below LF point	264	1.59	1.30	0.81	179	79	45	20
Maximum change in distance (m)	153	74.21	172.56	2.33	1463	650	366	163

Table 5: Estimates of means, standard deviations, and coefficients of variation from *unscreened eastern WA data at lateral point types* with sample size approximations for four levels of relative precision.

Outcome	n	Est. Mean	SD	CV	r = 0.10	r = 0.15	r = 0.20	r = 0.30
Reach gradient (%) above LF point	104	19.65	12.76	0.65	114	51	29	13
Reach gradient (%) below LF point	83	7.90	8.22	1.04	293	130	73	33
Reach gradient difference (%)	83	13.65	10.92	0.80	173	77	43	19
Bankfull width (m) above LF point	129	1.38	0.81	0.59	93	41	23	10
Bankfull width (m) below LF point	116	0.72	0.71	0.98	261	116	65	29
Maximum change in distance (m)	14	67.89	71.42	1.05	299	133	75	33

Table 6: Estimates of means, standard deviations, and coefficients of variation from *unscreened eastern WA data at terminal point types* with sample size approximations for four levels of relative precision.

Outcome	n	Est. Mean	SD	CV	r = 0.10	r = 0.15	r = 0.20	r = 0.30
Reach gradient (%) above LF point	164	18.15	13.64	0.75	153	68	38	17
Reach gradient (%) below LF point	144	10.77	4.83	0.45	55	24	14	6
Reach gradient difference (%)	144	4.94	8.31	1.68	765	340	191	85
Bankfull width (m) above LF point	153	2.55	1.67	0.65	115	51	29	13
Bankfull width (m) below LF point	148	2.28	1.24	0.55	80	36	20	9
Maximum change in distance (m)	139	74.85	179.75	2.40	1561	694	390	173

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Table 7: Estimates of means, standard deviations, and coefficients of variation from *western Washington WTMF data pooled across point types* with sample size approximations for four levels of relative precision (recommended western WA sample size in bold).

Outcome	n	Est. Mean	SD	CV	r = 0.10	r = 0.15	r = 0.20	r = 0.30
Reach gradient (%) above LF point	1982	17.59	13.97	0.79	171	76	43	19
Reach gradient (%) below LF point	1512	5.96	4.13	0.69	130	58	32	14
Reach gradient difference (%)	1505	10.79	13.39	1.24	416	185	104	46
Bankfull width above LF point	1900	1.00	0.76	0.76	157	70	39	17
Bankfull width below LF point	1502	4.18	5.79	1.38	518	230	130	58

Table 8: Estimates of means, standard deviations, and coefficients of variation from *western Washington WTMF data at lateral point types* with sample size approximations for four levels of relative precision.

Outcome	n	Est. Mean	SD	CV	r = 0.10	r = 0.15	r = 0.20	r = 0.30
Reach gradient (%) above LF point	1393	19.65	15.45	0.79	167	74	42	19
Reach gradient (%) below LF point	921	4.23	2.81	0.66	119	53	30	13
Reach gradient difference (%)	916	15.13	14.86	0.98	261	116	65	29
Bankfull width (m) above LF point	1318	0.81	0.54	0.67	121	54	30	13
Bankfull width (m) below LF point	913	5.90	6.86	1.16	367	163	92	41

Table 9: Estimates of means, standard deviations, and coefficients of variation from *western Washington WTMF data at terminal point types* with sample size approximations for four levels of relative precision.

Outcome	n	Est. Mean	SD	CV	r = 0.10	r = 0.15	r = 0.20	r = 0.30
Reach gradient (%) above LF point	589	12.71	7.60	0.60	97	43	24	11
Reach gradient (%) below LF point	591	8.65	4.41	0.51	70	31	18	8
Reach gradient difference (%)	589	4.06	6.34	1.56	661	294	165	73
Bankfull width (m) above LF point	582	1.44	0.98	0.68	125	55	31	14
Bankfull width (m) below LF point	589	1.53	0.92	0.61	99	44	25	11

Initial results from the sample size approximation (Tables 1 through 9) suggested to the ISAG subgroup that upstream metrics provided a robust basis for sample size approximation. Upstream gradient and bankfull width metrics were consistently measured and are ecologically meaningful for both point types, were available for both eastern and western WA data, and were the most precise among the channel characteristics examined. Furthermore, the subgroup also decided to use the unscreened data for sample size approximations based on eastern WA data because the metrics were slightly more variable in this data set and provide more conservative sample sizes.

To obtain an overall statewide sample size that accounted for variation across the state, the unscreened eastern data and the western data were pooled. Coefficients of variation for estimates of means of both upstream metrics were computed to generate statewide sample sizes across both point types (Table 10),

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for lateral points (Table 11), and for terminal points (Table 12). From this analysis, a conservative statewide minimal sample size of surveyed sites to provide relative precision of 0.10 is obtained from the upstream bankfull width approximation of 190 sites (Table 10). Assuming that the proportion of sites classified as lateral points is similar to the proportion observed in the eastern WA data set (46%) and western WA data set (70%), we can expect roughly 87 to 133 lateral sites and 57 to 103 terminal sites from this sample of 190 sites. These sample sizes within each point type should be sufficient to obtain means of the two upstream metrics with at least 0.15 relative precision (Tables 11 and 12).

Table 10: Estimates of means, standard deviations, and coefficients of variation from *pooled eastern and western Washington data at all point types* with sample size approximations for four levels of relative precision.

Outcome	n	Est. Mean	SD	CV	$r=$ 0.10	$r=$ 0.15	$r=$ 0.20	$r=$ 0.30
Reach gradient (%) above LF point	2250	17.73	13.89	0.78	166	74	42	18
Bankfull width (m) above LF point	2182	1.13	0.95	0.84	190	84	47	21

Table 11: Estimates of means, standard deviations, and coefficients of variation from *pooled eastern and western Washington data at lateral point types* with sample size approximations for four levels of relative precision.

Outcome	n	Est. Mean	SD	CV	$r=$ 0.10	$r=$ 0.15	$r=$ 0.20	$r=$ 0.30
Reach gradient (%) above LF point	1497	19.65	15.28	0.78	164	73	41	18
Bankfull width (m) above LF point	1447	0.86	0.59	0.69	129	57	32	14

Table 12: Estimates of means, standard deviations, and coefficients of variation from *pooled eastern and western Washington data at terminal point types* with sample size approximations for four levels of relative precision.

Outcome	n	Est. Mean	SD	CV	$r=$ 0.10	$r=$ 0.15	$r=$ 0.20	$r=$ 0.30
Reach gradient (%) above LF point	753	13.90	9.52	0.69	127	56	32	14
Bankfull width (m) above LF point	735	1.67	1.24	0.74	149	66	37	17

This analysis provides guidance for establishing the sample size of sites for PHB surveys in eastern and western Washington. If the data sets that were provided are not representative of the larger population of PHBs in Washington, then variation may be underestimated causing approximated sample sizes to be lower than needed for the desired precision. The unscreened CMER data were used for the sample size approximation because they provided more conservative sample sizes than when the screened data were used. However, this application does not imply a preference for the unscreened data set relative to other analyses. Differences in site selection for eastern and western Washington data sets were not considered when pooling the data, but the combined data set provided an index of statewide variability that was not available otherwise. While the ultimate goal of this project is to identify criteria with which to identify

PHBs, ensuring that the data collected on potential PHB criteria represent the range of conditions in the population will provide a robust basis for PHB modeling when three years of data are available.

Sampling Design Recommendations

Probabilistic selection of the sampling locations from the sampling frame is recommended to avoid selection bias and to provide a basis for inference to the larger population of interest (Lohr 2009). For ecological surveys, spatially-balanced sampling approaches provide methods to obtain probabilistic samples across large areas without risking selection of clustered points that are correlated and provide duplicate information. Several methods for selecting spatially-balanced samples are available and include generalized random tessellation stratified (GRTS) sampling (Stevens and Olsen 2003, 2004), balanced acceptance sampling (BAS; Robertson et al. 2013), and Halton iterative partitioning (HIP, Robertson et al. 2018). Data from samples selected with spatially-balanced sampling can be analyzed with design-based tools available in the *spsurvey* package (Kincaid et al. 2019). All three of the sampling techniques can be implemented in the *SDraw* package (McDonald and McDonald 2020). However, since the *SDraw* package is currently not maintained on the CRAN website (as of 12/6/21 and since 11/16/21), drawing GRTS samples with the *spsurvey* package is recommended.

The sampling design for the PHB surveys will incorporate *a priori* geographic stratification by region (east or west WA) so that spatial balance is obtained for each region. Additionally, sampling effort will be apportioned among point types (terminal or lateral points) with "soft stratification." In this approach, the point types are not available for each site before the survey so no sampling frame is available to identify each subpopulation for a priori stratification. Survey crews will record the point type at the time of the survey and, when the desired sample size for a point type is satisfied, survey data from this point type will not be collected at subsequent points of this type. Because soft stratification cannot be planned in advance, employing this technique will require some adherence to the spatially-balanced ordered list of sites to ensure that the obtained sample of sites within each point type is also spatially balanced. The point type should be recorded for each site so that inclusion probabilities for each site may be calculated prior to analysis for any design-based summaries such as means and totals.

Based on the sample size approximation for data pooled across region, the total sample size should be no less than 190 sites (Table 10) to obtain relation precision of 0.10 for the statewide estimates of mean channel characteristics. ISAG members expressed a desire to obtain estimates of means for channel characteristics with geographic stratum-level relative precision of 0.10. For the two metrics of interest (reach gradient above LF point and bankfull width above LF point), obtaining the more conservative sample size for each region is recommended. Therefore, the eastern WA sample should consist of 143 sites (Table 4) and the western WA sample should consist of 171 sites (Table 7) for a total of 314 sites across the state.

Given the ISAG statement that there are roughly five times more lateral points than terminal points, I examined methods to allocate sampling effort among the two point types. Proportional allocation of effort will favor lateral points since they exist more frequently throughout the landscape. Optimal allocation accounts for the relative precision of lateral and terminal points but is still influenced by the larger

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relative frequency of lateral points as compared to terminal points. The final sample sizes were based on reach gradient above LF point in eastern WA and bankfull width above LF point in eastern WA. The precision in the means for these two sets of estimates were similar between lateral and terminal point types. Therefore, I recommend an equal allocation of sampling effort among the two point types. Based on the sample size approximation of lateral and terminal points for eastern and western WA (Tables 5, 6, 8, and 9), equal allocation of effort between the two point types should still provide channel characteristic means with relative precision between 0.10 and 0.15.

Note that the suggested sample sizes are the numbers of sites where data are successfully collected. To account for inaccessible sites and sites that do not meet the definition of the target population (such as in reaches with no water), a larger sample of sites (perhaps three to five times larger than the desired sample size) should be drawn to successfully collect data at the desired number of sites. There is no penalty for selecting a much larger sample than needed, but the final set of surveyed sites should consist of a contiguous set of sites from the spatially-balanced randomized list of locations to avoid any sort of systematic or geographic bias in the sample locations caused by surveying a disproportionate number of sites in one area. For each site visited, notes on any frame error or nonresponse error should be recorded so that inclusion probabilities for each site can be accurately calculated. For model-based analysis approaches, incorporating design variables such as *a priori* and soft stratification variables such as region and point type (lateral or terminal) may account for the sampling design without directly incorporating inclusion probabilities.

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Appendix C. Potential for a concurrent eDNA study

The original study design (Roni et al. 2019) included a proposed collaborative complementary study with the U.S. Forest service to compare environmental DNA (eDNA) and electrofishing to identify fish habitat. A separate pilot for that proposed complementary study was completed in 2020 (Penaluna 2020).

The project team explored ways to include further eDNA components into this study design. The team determined that the best option would be to recommend that an additional complementary study is developed by the Adaptive Management Program that utilizes the sample sites and the fish location data that are collected in this study. This companion study can further compare electrofishing and eDNA as methods for determining the location of the upper extent of fish use, as well as different methods for eDNA collection and analysis, and can take advantage of the lessons learned from the pilot study. Conducting a complementary study in conjunction with the PHB study might save time, money, and resources.

Appendix D. Budget

Budget estimate from DNR PM Anna Toledo as of February 18, 2022. Estimates are based on figures updated from the FY19 study design, expenditures from the FY19 pilot study, and existing contract budgets for similar work. These estimates may change based on revisions made during CMER, ISAG, and ISPR reviews.

Task	Expenditures FY17-FY21	FY22	FY23	FY24	FY25	FY26	FY27	FY28	FY29	Total
Study design, coordination, site reconnaissance, permitting, crew training		31,247	69,250	163,679	114,167	30,512	30,918	N/A	N/A	439,773
Field sampling – Spring/summer (350 sites)					723,697	723,433	737,901	N/A	N/A	2,185,031
Field sampling – Fall/winter (175 sites: fixed + rotating panels)					N/A	176,389	179,917	183,515	N/A	539,821
Crew variability (10% of sites – all crews)					57,944	55,028	56,129	25,505	N/A	194,606
Data collection equipment					183,600	27,540	27,540	27,540	N/A	266,220
Data analysis and reporting				12,485	39,202	67,832	69,189	94,796	61,229	344,733
Project Management				9,364	15,918	16,236	16,561	10,930	4,460	73,469
Total	**398,702**	**31,247**	**69,250**	**185,528**	**1,134,529**	**1,096,970**	**1,118,155**	**342,286**	**65,689**	**4,442,355**

Budget Comparison

Comparison of original study design and revised study design budgets. Original study design budget and tasks in grey.

Task	Original Study Design Totals	Revised Study Design Totals	Notes
Study design, coordination, site reconnaissance, permitting, crew training	421,900	439,773	Revised budget accounts for a 2% yearly increase for inflation/COLA throughout all line items, which was not accounted for in the original budget.
Field sampling – Spring (245 sites)	1,519,000		Total site visits (original): 529 Total site visits (revised): 525
Field sampling – Spring/summer (350 sites)		2,185,031	
Field sampling – Summer (82+60)	460,151		
Field sampling – Fall (82+60); pilot in FY 19	581,151		
Field sampling – Fall/winter (175 sites: fixed + rotating panels)		539,821	
Crew variability (10% of sites – all crews)	115,000	194,606	
Data collection equipment		266,220	Data collection equipment was not a separate line item in original budget.
eDNA sampling (82 sites 3 times)	50,000		eDNA recommended as a complementary study, removed from revised budget.
eDNA Lab Analysis and reporting	164,000		
Data analysis and reporting	180,163	344,733	Budget updated to reflect updated time estimate for analysis and reporting.
Project Management	72,669	73,469	
Total	3,564,034	4,442,355	