PROJECT NARRATIVE

1. Background

In 2001, Washington State was sued on behalf of 21 Northwest tribes for violating treaty fishing rights. The plaintiff argued that state-owned culverts block salmon and steelhead from accessing historical upstream spawning habitat, violating the Stevens Treaties granting tribes protections of off-reservation fishing rights [1]. The lawsuit resulted in a 2013 federal court injunction requiring the state to remove the culverts under its jurisdiction, that are blocking salmon and steelhead from their historical habitat, by 2030. After nearly two decades of legal battles, in 2018, the U.S. Supreme Court ruled in favor of the tribes, upholding the 2013 federal injunction.

As of 2020, the Washington State Department of Transportation (WSDOT), the owner of the vast majority of state-owned culverts within the case area, has corrected 87 injunction barrier culverts opening up an estimated 383.3 miles of habitat at a cost of over $159 million. Since the ruling, WSDOT has replaced an average of 12.4 culverts per year, including 13 in 2020. To satisfy the federal injunction, the rate of culvert replacements must ramp up dramatically. Despite increasing investment in culvert improvement within the case area since the injunction, WSDOT still owns an estimated 998 culvert barriers in the case area as of the end of 2020, and will need to increase the rate of culvert improvement almost ten-fold to meet the 2030 deadline.

Importantly, the 2013 injunction strictly applies to state-owned culverts whereas there exist an estimated 3,000 and 1,300 additional barrier culverts owned by counties and cities respectively, along with barrier culverts on private lands, often on the same streams as state-owned culverts [2]. Individual cities and counties, lacking the financial resources for strategic planning and culvert barrier removal, primarily depend on state and federal grant funds.

Currently WSDOT prioritizes barrier culverts for removal based on factors such as: amount of habitat blocked and habitat quality, tribal input, project cost, traffic detour management during construction, maintenance issues, partnership opportunities, the presence and number of ESA listed species, and permitting constraints. Counties, cities, and other actors have developed their own prioritization frameworks with limited resources and data to inform prioritization [Is this true? Can we say something more here].

Our proposed research will develop a data-driven framework for project prioritization, within the injunction area, that synthesizes multiple geospatial datasets with statistical economic and ecological models to identify restoration plans that maximize ecological, social, and economic objectives at a given funding level. Our framework will be used to assess the tradeoffs between objectives (e.g. tradeoffs between maximizing salmon habitat and ensuring equity in restoration) as well as gains from coordinating barrier culvert replacement across key actors (the state, counties, and cities) and alternative funding streams. We will make the framework accessible to users through an online tool similar to FISH*Pass* developed for California [3].

2. Project Summary

Our restoration planning framework will consider multiple factors identified and defined in an initial phase of the project where we elicit important real-world objectives and constraints from key user groups (see Section 3). For purposes of illustration, here we describe potential factors to be included and the data and models to support their inclusion.

First, we will estimate the cost of culvert restoration for all existing fish passage-blocking culverts within the US vs. Washington injunction area. Culverts in need of restoration will be identified using the Washington State Fish Passage database maintained by the Washington Department of Fish and Wildlife (WDFW). Cost estimates will utilize predictive models of culvert restoration cost estimated using PNSHP data from 2001-2015 with several predictor variables, including stream slope (%), bankfull width, road class, elevation, etc. Parametric cost models are currently being finalized by our research team. For the proposed project, we will leverage the datasets and code we have already compiled and produced to explore the predictive performance of several parametric and non-parametric cost models, selecting the model that provides superior out-of-sample predictive power in the injunction area.

Second, for each culvert restoration plan, defined as a combination of multiple culverts restored, we will quantify the expected increase in habitat for the five species of Pacific salmon. Habitat increases will serve as a proxy for the economic benefits of a restoration strategy. Spatial dependence will drive restoration benefits, because the culvert restoration downstream determines the benefits from culvert restoration upstream. The benefit proxies will be calculated using the USGS National Hydrography Dataset, NDHPlus High Resolution, and the WDFW fish passage dataset, which contains information about fish species affected by culvert blockages. Our team has developed code to estimate similar benefit proxies for culvert restoration projects in the PNSHP database, which can be leveraged to estimate upstream habitat gained by removing barriers cataloged in the Washington State Fish Passage database.

Equity is another important dimension to consider. A prioritization framework that simply maximized expected salmon habitat given a budget constraint could potentially lead all barrier culvert replacements in a restoration plan benefiting one tribe. We will explore equity strategies that prioritize restoration plans that generate equity in the benefits (increased habitat) across the 21 tribal nations involved in the 2001 lawsuit. Equity concerns are further complicated by the fact that some tribes have greater pre-existing access to salmon harvest. We will explore various definitions of equity using geospatial data on all salmon runs in the injunction area together with maps of reservations and ceded land for all federally recognized tribes in Washington [does this get at the right to off-reservation fishing? Can we measure which tribes currently have more fish?].

Finally, our analysis will consider risk to returns on investment. Investment risks include the risk of low salmon returns to habitat and/or population extinction driven by both environmental shocks and future human impacts including impacts to water quality through urbanization [4]. We will explore risk metrics ranging in complexity from a simple measure of the spread of investments across salmon runs (e.g. a Shannon Index) to increasingly complex risk metrics that utilize information on the negative covariance in expected returns to multiple salmon populations to exploit opportunities for portfolio diversification.

As an illustrative example, suppose Lewis County wanted to define a restoration plan (a package of culverts to be restored) that balanced habitat increases for Chinook salmon in the injunction area with risk and equity concerns. Further suppose Lewis County had a budget of $B to invest in the restoration plan and did not want to restore any county-owned culverts. Our framework would solve the following problem (blue text represents manager inputs):

$$\max_{\boldsymbol{c}} \quad w_1 \text{miles of Chinook habitat} + w_2 \text{equity metric} + w_3 \text{risk metric},$$

subject to:

$$\text{total restoration cost} \leq B,$$

and

$$\boldsymbol{c} \in \{\boldsymbol{c}_s\},$$

where $\boldsymbol{c}$ is the culverts included in the restoration plan, $\boldsymbol{c}_s$ are the subset of barrier culverts owned by Lewis county, B is the manager's budget constraint, and $w_1 - w_3$ are the weights that managers place on each objective.

The problem will be solved using R, a free software environment that supports integer programming. The user interface to the prioritization framework will be an online app created with the Shiny package for R and hosted on the Shiny Server. Similar tools have been built using Microsoft Windows [3] and OpenSolver, a Microsoft Excel add-in [5].

3. Engagement Plan

In an initial phase of engaging potential users, at the beginning of YR1, we will organize a series of workshops intended to uncover the objectives and challenges in culvert barrier replacement for key user groups including WSDOT, city and county governments, restoration agencies such as the Fish Barrier Removal Board, and representatives from relevant Tribal Nations. The workshops will begin with a presentation of our proposed framework and online tool (described in Section 2) as a straw-man proposal in order to generate discussion and elicit ideas on how to capture fundamental real-world priorities and constraints in barrier culvert removal. We will gather feedback during the workshops and through post-workshop surveys. Ideas coming from the initial series of workshops will be incorporated into our project to the extent possible given data and computational limitations, which will be made clear to workshop participants.

In a second phase, at the beginning of YR2 we will organize a second series of workshops to present preliminary results and demonstrate the functionality of a preliminary working version of the online tool. This second series of workshops will demonstrate how feedback from the initial workshops was incorporated in our framework and tool and provide a more in-depth discussion of our data inputs to the tool, e.g. a demonstration of the quality of our cost estimates and a visual demonstration of our preliminary spatial definition of equity. The second series of workshops will provide stakeholders with a final opportunity to guide key features of the framework and solicit feedback on the usability of the online tool.

As the project is nearing completion we will develop a video tutorial that will present content from a user guide to the tool in a way that is accessible and engaging. [resources we can leverage here? Looks like UW video would charge $4k]

Finally, at the end of YR2 we will host an interactive workshop to launch our finalized online tool letting stakeholders directly engage with the tool. The workshop will begin with a screening of the video tutorial. Then, we will engage participants with exercises that highlight the tradeoffs between various objectives, gains from coordination, and how alternative budget/funding scenarios (defined by budget levels and their distribution across time) impact the culvert restoration packages with the highest ROI.

At each phase of our engagement plan we will rely on advice from our Scientific Advisory Board. Members of our Scientific Advisory Board will include individuals working directly in the

area of barrier culvert restoration, individuals with a history of engaging with our key stakeholder groups, and individuals generating science relevant to our problem area [?].

4. Expected Outcomes

We anticipate two major research outcomes. First, our research will form the basis of a student thesis, leading to a scientific publication, applying our underlying optimization model to answer important research questions including:

1. How to measure risk associated with portfolio-style restoration plan?
2. Which species would benefit from risk-mitigating vs. habitat-maximizing restoration plans?
3. Where in Washington injunction area (sub-basins/watersheds) are culvert plans associated with tradeoffs between potentially competing priorities (e.g., risk vs. total habitat, equity vs. total habitat), and where can "win-wins" occur (i.e., plans that meet multiple objectives without reducing others)?
4. What are the potential efficiency gains associated with coordination across culvert owner groups (state agencies, local gov't, private landowners)?
5. What are the tradeoffs (i.e. across habitat, risk, equity metrics) associated with such coordination?
6. Who are winners and losers associated with low vs. high coordination settings?

Second our project will produce publicly-available, well-documented, open-source prioritization tool for barrier culvert removal in the Washington injunction area. The tool can serve a coordinating function by providing a framework to evaluate restoration plans across various actors. The tool can support planning for cities and counties with limited access to data and quality cost estimates. Finally, the source code behind our open-source tool will be made widely available to users outside of the state of Washington to facilitate a larger set of potential users.

5. Program Priorities

Our project contributes directly to two of Washington Sea Grant's critical program areas: Healthy Coastal Ecosystems and Sustainable Fisheries and Aquaculture.

Goal # 2 under the Healthy Coastal Ecosystems program area is that "ocean and coastal habitats, ecosystems and living marine resources are protected, enhanced and restored. Our project will directly contribute to the goal of restoring habitat for salmon. Improving the process of prioritizing culverts for replacement ensures that resource managers are able to maximize the returns on their investments in salmon restoration.

Goal # 4 under the Sustainable Fisheries and Aquaculture program area is that "fisheries are safe, responsibly managed and economically and culturally vibrant. Our project contributes to the goal of responsible fisheries management and the economic and cultural vibrancy related to tribal salmon fisheries. We will explore restoration plans that prioritize the equitable distribution of habitat improvements across numerous tribes affected by barrier culverts in the injunction area.

[1] Ryan Hickey. Highway culverts, salmon runs, and the stevens treaties: A century of litigating pacific northwest tribal fishing rights. *Pub. Land & Resources L. Rev.*, 39:253, 2018.

[2] Alex Brown. Coming down the pipe: Saving washington's salmon may require replacing tens of thousands of culverts, and nobody knows where the money will come from. *The Daily Chronicle*, August 2019.

[3] Jesse R. O'Hanley. Optipass: The migratory fish passage optimization tool, Version 1.1. User manual. Technical report, Ecointelligence LLC, 2015.

[4] AK Ettinger, ER Buhle, BE Feist, E Howe, JA Spromberg, NL Scholz, and PS Levin. Prioritizing conservation actions in urbanizing landscapes. *Scientific reports*, 11(1):1–13, 2021.

[5] Ryan A McManamay, Joshuah S Perkin, and Henriette I Jager. Commonalities in stream connectivity restoration alternatives: an attempt to simplify barrier removal optimization. *Ecosphere*, 10(2):e02596, 2019.