PROJECT NARRATIVE

1. Background In 2001, Washington State was sued by the United States Department of Justice on behalf of 21 Northwest tribes for violating treaty fishing rights. The plaintiff argued that state-owned culverts are barriers to salmon and steelhead accessing historical upstream spawning habitat, violating the Stevens Treaties [1]. The lawsuit resulted in a 2013 federal court injunction requiring the state remove barrier culverts under its jurisdiction 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), responsible for 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.

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]. Cities and counties are relatively resource constrained and depend on state and federal grant funds for barrier culvert removal and related strategic planning.

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. Strategic planning is therefore complicated by the dispersed responsibility for interconnected barriers, heterogeneous prioritization frameworks, and the cost of acquiring information needed for decision making.

2. Project Summary Our proposed research will develop a data-driven framework for project prioritization, within the injunction area of Washington state, 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 key objectives (e.g. increasing salmon habitat, an equitable distribution of habitat gains, and mitigating investment risk) 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 data, models, and framework accessible to users through an online decision support tool (DST) similar to FISH*Pass* developed for California [3] and Fishwerks developed for the Great Lakes [4]. To our knowledge, our fish passage prioritization framework is the first to include objectives of equity and risk mitigation. In what follows we describe our framework and DST in more detail.

The utility of our framework and DST critically depends on how well real-world priorities and constraints are reflected. Thus, in the initial phase of the project we will organize a series of workshops where we elicit 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.

Barrier removal is costly and managers are budget constrained. To incorporate this constraint, we will estimate the cost of culvert restoration for all known 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 (WSFP) database maintained by the Washington Department of Fish and Wildlife (WDFW). Cost estimates will utilize predictive models developed from over 1,200 culvert projects in the Pacific Northwest Salmonid Habitat Projects (PNSHP) dataset, from 2001-2015, along 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 developed 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.

A primary objective in barrier culvert removal is increased salmon habitat. 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. Estimated habitat gains 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 will be leveraged to estimate upstream habitat gained by removing barriers cataloged in the WSFP database.

Equity is another important dimension to consider. A prioritization framework that simply maximizes expected salmon habitat given a budget constraint could potentially lead to a culvert restoration plan that only benefits a single user group. We will explore alternative equity strategies that prioritize restoration plans that provide an equitable distribution of habitat gains across user groups, e.g. across the 21 tribal nations involved in the 2001 lawsuit. We will explore various equity metrics, e.g. a Gini coefficient, using geospatial data on all salmon runs in the injunction area together with geospatial data delineating user groups, e.g. the usual and accustomed fishing areas for each tribe.

Risk mitigation is yet another important factor to consider when selecting portfolios of barrier culverts to remove. Returns to investments in barrier culvert removal are risky driven by the possibility of low salmon returns to habitat, population extinction driven by both environmental shocks, and future human impacts including impacts to water quality through urbanization [5]. Drawing from the literature on restoration portfolio diversification, we will estimate the degree to which the risk in returns to barrier culvert removal plans can be mitigated through diversification. We will explore risk metrics ranging in complexity from a simple measure of the spread of investments across all salmon runs with habitat in the injunction area to increasingly complex risk metrics that utilize information on the potential negative covariance in expected returns to multiple salmon populations to exploit opportunities for portfolio diversification [6, 7, 8].

As an illustrative example, suppose Lewis County wants to define a restoration plan (a package of culverts to be restored) that balances habitat increases for Chinook salmon in the injunction area with equity and risk mitigation. Further suppose Lewis County had a budget of B dollars to invest in the restoration plan and does not want to restore any culverts outside of its jurisdiction. Our framework would solve the following problem (blue text represents manager inputs):

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

$$\text{subject to: total cost} \leq B \text{ and } \boldsymbol{c} \in \{\boldsymbol{c}_{lewis}\},$$

where $\boldsymbol{c}$ are culverts included in the restoration plan, $\boldsymbol{c}_{lewis}$ are the subset of barrier culverts owned by Lewis county, B is total amount of funding that can be spent, and $w_1 - w_3$ are the weights that managers place on each objective. The problem will be additionally constrained so that benefits from upstream culvert removal cannot be captured without first removing downstream blockages.

The problem will be solved using R, a free software environment that supports integer programming. The user interface to the prioritization framework, or DST, will be an online app created with the Shiny package for R and hosted on the Shiny Server. Similar tools have been built using various proprietary software programs [3, 4, 9]. Through using an open-source optimization framework coupled with an open-source user interface we maximize accessibility and customizability.

3. Engagement Plan In the beginning of YR1, in the initial phase of the project, 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, WDFW, 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 (e.g. tradeoffs between various objectives) 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 our equity metric. 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 DST.

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. In preparation for this workshop, we will develop a video tutorial that will present content from the DST user guide in a way that is accessible and engaging. 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 return on investment. Each workshop participant will be provided with a laptop computer to participate in the exercises.

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. We are actively working to construct a Scientific Advisory Board that has representation from individuals who have worked for and with the tribes, WSDOT, cities and counties, the Fish Barrier Removal Board, and an outreach specialist.

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 can equity be accounted for in in fish passage problems? (Note, to our knowledge equity has not been accounted for in the fish passage prioritization literature.)
2. How can project risk be accounted for in fish passage problems? (Note, to our knowledge risk has not been accounted for in the fish passage prioritization literature.)
3. What are the gains in habitat, equity, and risk avoidance associated with coordination across actors (state agencies, local government, private landowners) and which of these multiple objectives is most affected by a lack of coordination across actors?
4. Where in Washington injunction area (sub-basins/watersheds) are culvert restoration plans associated with tradeoffs between potentially competing priorities (e.g., risk versus total habitat, equity versus total habitat), and where can ”win-wins” occur (i.e., plans that meet multiple objectives without reducing others)?

Second, our project will produce publicly-available, well-documented, open-source prioritization DST for barrier culvert removal in the Washington injunction area. The DST can serve a coordinating function by providing a framework to evaluate restoration plans across various actors regardless of whether the restoration plan is one identified by our optimization framework. The DST can also support planning for cities and counties with limited access to data and quality cost estimates. Finally, the source code behind our open-source DST will be made widely available to users outside of the state of Washington to facilitate the adoption of and customization by 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 information guiding the process of prioritizing culverts for replacement in Washington has the potential to increase realized returns on 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 maximize habitat gains for salmon for a given budget prioritize the equitable distribution of habitat improvements across numerous tribes affected by barrier culverts in the injunction area.

References

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