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Research

Exploring restoration efforts from a social lens: statistical models reveal relationships between salmon habitat restoration efforts and ecological and social characteristics of the Puget Sound basin, USA

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ABSTRACT. Habitat restoration is an important tool for promoting the conservation and recovery of imperiled species and is motivated by both environmental and social factors. As new restoration efforts are considered, it is important to look back and see what can be learned from past efforts, including how restoration benefits are distributed across communities through an equity lens. Focusing primarily on the Puget Sound basin in the state of Washington, this study investigates correlations between environmental and social factors and the spatial distributions of past restoration efforts. We specified statistical models to explain the variation in the number of restoration worksites undertaken in subwatersheds as a function of environmental and social variables. Using a common set of explanatory variables, we fit four models to examine the distribution of worksites associated with particular types of restoration actions (instream, riparian, land acquisition, and fish passage) and a fifth model to examine the distribution of all aquatic-based restoration worksites across action types. The results reveal statistically significant relationships between the number of worksites and several environmental characteristics, including elevation and species richness number of the Salmon Evolutionary Significant Units. Among the social explanatory variables, the percentage of non-Hispanic white residents in a subwatershed was the most prominent predictor of the number of restoration worksites across models, producing positive and statistically significant estimated coefficients in the instream, riparian, and total worksite models. We also estimated the specified models using data from other populated drainage basins in the region and found corroborating results for some patterns revealed in the Puget Sound basin. Our results provide insight for consideration when planning future restoration effects. With the knowledge of potential past social inequalities and inequities, restoration managers can, moving forward, take appropriate steps to account for these disparities.

Key Words: *habitat restoration; salmon; Puget Sound; environmental justice; equity; Pacific Northwest*

INTRODUCTION

As research continues to expand our understanding of the roles that environmental and social factors play in ecological restoration, increasing attention is being placed on understanding how concepts of equity and environmental justice factor into management objectives, decisions, and outcomes (Moran 2010, Lave 2016, Cottet et al. 2021). Beyond targeting ecological benefits to natural systems, it is important to also examine how human communities benefit from where planners decide to allocate resources, including how benefits are distributed across communities, and how decisions potentially result in disproportionate impacts across social demographics (Leach et al. 2018, Dade et al. 2022). With this in mind, this study analyzes data on past salmon habitat restoration within the Pacific Northwest region of the United States to identify potential environmental and social drivers of the distribution of restoration efforts.

Habitat restoration is an important tool for promoting conservation and recovery of imperiled species and ecosystems (Miller and Hobbs 2007, Hale et al. 2019), and is typically motivated by a variety of environmental, social, and cultural factors (Hagger et al. 2017). Habitat restoration planning involves developing strategies to determine where and when to allocate available resources. This process requires consideration of available resources (e.g., funding), restoration goals (e.g., ecological, social, or both), and project alternatives (e.g., project types, project locations, project timings, project intensities) with the objective of maximizing the effectiveness and overall benefit of the project (Wilson et al. 2007, Fonner et al. 2021). Restoration priorities may differ depending on overarching goals and the environment. For example, Suding et al. (2015) suggest that a broad commitment to ecological restoration requires efforts to find a balance between ensuring that they are sustainable, promoting ecological integrity, and are informed by temporal changes (past and future), all while providing benefits to society.

Although habitat restoration objectives are typically focused on reversing anthropogenic impacts and meeting the needs of target species (Hale et al. 2019), restoration efforts also have the potential to produce co-benefits to the surrounding ecosystems (e.g., improving habitat quality and suitability for other species) and human communities (e.g., improved water quality, recreational opportunities, human health, and intrinsic value; Barbier et al. 2011, Sutton-Grier et al. 2015, Bratman et al. 2019, Keeler et al. 2019). One approach to understanding the societal benefits of restoration efforts involves examining how the ecological and social-political context can influence the management of natural systems and resources (McGinnis and Ostrom 2014, Martinez-Fernandez et al. 2021). The field of urban ecology, for example, focuses on exploring these connections and highlights the importance of centering the human dimension of an environment (Zipperer et al. 2011) when exploring ecological restoration in urban settings (Standish et al. 2013).

However, not all human communities value, have access to, or benefit from natural environments and restoration efforts in the same way or have the ability and opportunity to participate in

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environmental decision-making processes. These differences are often the result of social inequality existing within various communities (Moran 2010, Wolch et al. 2014). Schell et al. (2020) refer to social inequality as the unequal distribution or allocation of resources and/or wealth, often to specific social and/or cultural groups within a community. As a result, prioritization of restoration efforts may unintentionally, or intentionally, result in inequitable distributions of resources and benefits throughout various communities. For example, previous research has explored the "luxury effect" that suggests a positive correlation between affluence and biodiversity in the urban community (Hope et al. 2003, Schell et al. 2020) as well the concept of "ecological gentrification" that explores the potential for ecological restoration and planning efforts to result in the displacement or exclusion of socially vulnerable communities (Dooling 2009). This highlights the importance of exploring the social dimensions of habitat restoration that are often overlooked but are important components of efforts to promote environmental justice.

Environmental justice, similar to the concept of equity, is centered on the idea of fair and just treatment. The United States Environmental Protection Agency defines environmental justice as "the just treatment and meaningful involvement of all people... with respect to the development, implementation, and enforcement of environmental laws, regulations, and policies" (U. S. Environmental Protect Agency 2023). The primary goals of environmental justice are to ensure that communities are not disproportionately impacted by environmental policies and hazards (just treatment), and that potential impacted communities are considered and have the opportunity to participate in the decision-making process (meaningful involvement; U.S. Environmental Protection Agency 2023). Numerous studies have explored the connections between environmental justice and different management strategies (Moran 2010, Sanchez et al. 2014, Hill et al. 2018). Moran (2010) explored the connections between stream restoration and environmental justice, highlighting the importance of applying principles of environmental justice to ecological restoration. Sanchez et al. (2014) and Hill et al. (2018) both used a watershed analysis approach to exploring environmental justice concerns throughout communities with a focus on utilizing spatial approaches to exploring the importance of environmental justice.

Along these lines, Stanford et al. (2018) examined the spatial distribution of stream habitat restoration in central California and found that restoration efforts were the highest in areas with wealthy, white (non-Hispanic), highly educated, highly pro-environmental voting populations. These findings suggest that using a spatial lens to explore the human dimension allows for analysis of differences across various social factors, which has the potential to shed light on social inequality and inequities that may arise during or as a result of conservation planning efforts. Whereas the aforementioned study focused on stream habitat restoration in California, we explore whether similar methods could be applied to analyzing past salmon habitat restoration efforts in the Pacific Northwest region of the United States.

Throughout the Pacific Northwest, salmon are of great ecological, cultural, and economic significance to many communities (Garibaldi and Turner 2004, Chapman et al. 2020). The societal importance of salmon recovery and conservation in the region is reflected in the hundreds of millions of dollars invested each year on research and habitat restoration efforts (Barnas et al. 2015). For example, from 1999 to 2019, over $740 million were spent on habitation restoration salmon recovery efforts in the state of Washington (State of Washington Governor's Salmon Recovery Office 2020). Despite these restoration efforts, many salmon runs continue to decline, with multiple species listed under the Endangered Species Act (ESA) and not keeping pace with recovery goals (State of Washington Governor's Salmon Recovery Office 2020). Thus, major salmon habitat restoration efforts are ongoing. Although conservation goals typically revolve around utilizing available resources and tools to protect and conserve salmon species, it is also important to understand how ecological and social variables influence how and why resources are allocated (Barnas et al. 2015).

As new salmon recovery efforts are considered, it is prudent to look back and see what can be learned from past restoration efforts. Therefore, we designed our study to examine where past restoration efforts occurred with an ecological and social lens. We focused on past restoration projects that were undertaken, at least in part, to support salmon recovery. Therefore, we hypothesized that habitat restoration projects tend to occur where salmon species are present and where there is an ecological need. We investigated this hypothesis, and added a social lens, by examining how environmental landscape and social variables are related to the locations of past restoration activities. This study contributes to the literature by highlighting the importance of social equity and environmental justice considerations associated with large-scale watershed restoration efforts. By exploring past restoration efforts from a social lens, we seek to identify past social inequality and inequities that are important for planners and managers to consider when deciding on future restoration efforts.

METHODS

Study region and restoration context

This study primarily focused on the Puget Sound basin, which spans 13 counties within the state of Washington and offers a rich setting for analysis given its highly varied human and natural landscapes and the large number of habitat restoration projects undertaken there in the past several decades. The Puget Sound basin and its watersheds have been the focus of a large and multifaceted effort to restore habitat for declining runs of salmon and steelhead. Between the years 2000 and 2015, there were at least 8500 salmon habitat restoration actions undertaken at 3232 worksites as a part of 2302 restoration projects (Barnas and Diaz 2020). This timeframe follows the ESA listing of various evolutionarily significant units (ESU) of Pacific salmon populations in the 1990s, which subsequently resulted in high densities of habitat restoration efforts (Barnas et al. 2015). Reported expenditures on salmon habitat restoration during this period from the subset of 1331 projects reporting cost data totaled $674M in 2019 USD (Barnas and Diaz 2020). The Puget Sound's human landscapes range from highly urbanized locations surrounding the Seattle-Tacoma metropolitan area to sparsely populated rural areas, whereas the physical landscapes span marine shorelines to high alpine zones.

Study design

The objective of this analysis was to explain the spatial distribution of past salmon habitat restoration efforts in our study area as a function of environmental and social landscape features. To characterize past habitat restoration, we divided our study area into subwatershed units at the USGS 12-digit Hydrologic United Code (HUC12) level (Seaber et al. 1987) and measured restoration efforts as the total number of restoration worksites within each subwatershed unit in years 2000 to 2015. The model results yield insights into the relative contribution of ecological and social landscape features in explaining the spatial distribution of past habitat restoration efforts. Comparing results against a priori expectations, salmon habitat needs, and community investment objectives can help inform future restoration planning strategies.

Data and variables

The Puget Sound region study area contains 423 subwatersheds. The final sample excluded 16 areas that did not include Endangered Species Act–listed salmon populations, and an additional 14 areas because of incomplete data. The final sample of 393 subwatersheds is depicted in Figure 1. The sample subwatersheds averaged 109 km^2 in area. The maximum elevation within subwatersheds ranged widely, from 63 to 4362 m. We characterized the spatial distribution of past restoration efforts in our study area using data from the Pacific Northwest Salmon Habitat Project (PNSHP) database (https://www.webapps.nwfsc.noaa.gov/apex/f?p=409:13). The PNSHP database contains information on both public and privately funded projects through the region that aim to improve the conditions of threatened and endangered salmon species.

Fig. 1. The Puget Sound Basin study area with subwatershed boundaries.

The PNSHP data included information about completed restoration projects, including project types and worksite(s) associated with each project. The data provided geographic coordinates describing the approximate location of each worksite and a list of one or more restoration action types undertaken at each worksite. To narrow our focus to actions that directly restore aquatic habitats, we excluded restoration actions that occurred outside of aquatic environments or surrounding riparian areas (e.g., sediment reduction typically decommissioning or repairing unpaved roads, upland agricultural and livestock improvements, upland vegetation restoration, and project maintenance). The restoration action types in our sample included instream restoration, riparian restoration, land acquisitions and easements, fish passage improvements, instream flow supplementation, water quality improvements, estuary and nearshore restoration, and fish screening. The total number of worksites within each subwatershed during the study period that involved at least one of these action types served as one model dependent variable. We also defined action-type specific dependent variables to investigate how associations between landscape factors and restoration efforts differ across restoration types. In our sample instream restoration (e.g., channel reconfigurations and connectivity, plant removal and control, spawning gravel placement), riparian restoration (e.g., riparian planting, riparian plant removal, fencing), land acquisition and easements, and fish passage improvements (e.g., blockage removal/alterations, culvert removal/replacement, fish ladder installation/alteration) were the most common restoration action types. For each of these four types, we specified a dependent variable equal to the total number of worksites within each subwatershed that included at least one action of the respective type (Fig. 2).

We identified four categories of landscape features expected to influence the location of salmon habitat restoration efforts: watershed characteristics, access/human impact, ecological value, and social characteristics. For each category, we compiled data and variables representing ecological and/or social characteristics that potentially influence salmon habitat restoration efforts. Watershed characteristics are the descriptive biophysical features of a subwatershed. These features may be indirectly linked with potential habitat value, accessibility, or other factors that influence the distribution of restoration efforts. We represented this category with measures for maximum stream order, mean slope, maximum elevation, and percentage of natural cover (an aggregation of forest, shrublands, and wetlands; Homer et al. 2015) for each subwatershed (Table 1).

Access/human impact refers to a subwatershed's ecological degradation due to human activity and the accessibility of potential restoration sites. We defined variables for percentage impervious cover, percent public land, and an indicator variable for the presence of impaired waterbodies listed under section 303 (d) of the U.S. Clean Water Act to reflect accessibility and impairment by subwatershed. For ecological value, variables for fish species richness, the maximum number of Evolutionary Significant Units of ESA-listed salmon populations among streams in the subwatershed, and the presence of bull trout final critical habitat in each subwatershed were included to reflect the ecological value and habitat potential of subwatershed areas.

Finally, for social characteristics, we compiled standard measures of social characteristics of each subwatershed unit, including population density (per km^2), median annual income, percentage of the population over 25 with a college degree, percentage of owner-occupied housing units, and percentage of the population that is non-Hispanic white for each subwatershed unit, which

Fig. 2. Number of salmon habitat restoration worksites in Puget Sound subwatersheds years 2000-2015 by action type.

represented social variables commonly used in research on environmental justice and equity (Sanchez et al. 2014). The social characteristic measures were derived from the U.S. Census Bureau data (Table 1). Subwatershed social characteristics were calculated as population-weighted means. Census area boundaries (blocks for decennial census data, block groups for American Community Survey data) were overlaid on each watershed area to create a jigsaw-like collection of polygons, each associated with different census areas, which together comprise the watershed area. We calculated the shares of the entire watershed population area in each of these intersected subwatershed-census polygons and used those shares as weights when calculating mean social characteristics for the watershed areas from the census polygons. This population-based weighting approach is preferred to area-based weighting because the latter imposes the non-plausible assumption that a population is distributed evenly in space. We created five measures of restoration efforts to serve as dependent variables in the models. The first four dependent variables were associated with a single action type: instream, riparian, land acquisition, and fish passage. The fifth dependent variable equals the total number of restoration worksites, regardless of type. Descriptive statistics for the dependent and independent variables are presented in Table 2.

Statistical model

We specified five different empirical models to explain the variation in the number of restoration worksites undertaken in subwatershed areas as a function of the subwatershed-level ecological and social variables described above. The five models differed in their specification of the dependent variable, the number of past restoration worksites, but shared common explanatory variables. Statistical tests revealed overdispersion in each of the dependent variables. Thus, we specified negative binomial statistical models to accommodate overdispersion in the restoration worksite counts (Cameron and Trivedi 1990). The negative binomial models were run by using the *glm.nb* function in the statistical program R (Ripley et al. 2013). To facilitate comparisons across estimated coefficients, each explanatory variable was standardized by subtracting the mean and dividing by two standard deviations. This standardization allows for a direct comparison of the magnitude of estimated coefficients across binary and continuous variables (Gelman et al. 2020).

Comparison across regions

The PNSHP database includes restoration project data across the Pacific Northwest, providing an opportunity to compare spatial patterns of restoration efforts in other drainage basins with those in Puget Sound. Although the primary focus of this study was the Puget Sound basin, we expanded our analysis to two additional regions within the Pacific Northwest region of the United States: the Yakima and Willamette Basins in Washington and Oregon, respectively (Appendix 1). Because of differences in environmental and social characteristics, and in salmon recovery needs and objectives, we chose not to combine these regions with the Puget Sound data, but instead to compare results for worksites actions models across regions.

RESULTS

Estimates for the subwatershed characteristics and ecological value variables are presented in Figure 3, and the access/human impact and social variable estimates are presented in Figure 4 for the Puget Sound basin. Overall, the ecological value and access/

Table 1. Environmental and social explanatory variables.

Category	Variable	Selected metric	Year	Source
Subwatershed characteristics	stream_order	Maximum stream order in subwatershed	2012	National Hydrography Dataset NHDplusV2 (USGS)
	mean_slope	mean slope (degrees)	2012	National Hydrography Dataset NHDplusV2 (USGS)
	max_elevation	Maximum elevation in subwatershed (m)	2022	Amazon Web Services Terrain Tiles
	natural_cover	% of subwatershed	2011	National Land Cover Database, Multi-Resolution Land Characteristics consortium
Access/human impact	impervious	% of developed imperviousness in subwatershed	2011	National Land Cover Database, Multi-Resolution Land Characteristics consortium
	pct_public	% of Public land in subwatershed	2014	Washington State Department of Natural Resources
	impaired	Presence/absence of 303(d) listed waters	2015	Environmental Protection Agency
Ecological value	species_rich	Max count of fish species in subwatershed	2019	Streamnet (Washington Dept. of Fisheries & Wildlife)
	esu_count	Max # of Salmon Evolutionarily Significant Units (ESUs) in subwatershed	Various[†]	NOAA, Northwest fisheries Science center
	bull_trout	Presence/absence of bull trout final critical habitat	2010	U.S. Fish and Wildlife Service
Social characteristics[‡]	pop_density	population per Squared km[‡]	2010	US Census Bureau, Decennial Census (2010)
	household_inc	Median annual income (USD)[‡]	2013	US Census Bureau, American Community Survey, 5-year estimates (2009–2013)
	edu_degree	% of population over the age of 25 with a college degree	2013	US Census Bureau, American Community Survey, 5-year estimates (2009–2013)
	Owner_occ	% of owner-occupied units in subwatershed	2010	US Census Bureau, Decennial Census (2010)
	white_non_hisp	% of population that is White (non-Hispanic) in subwatershed	2010	US Census Bureau, Decennial Census (2010)

[†] Puget sound ESA listings occurred between 1999 and 2007.
[‡] Population weighted subwatershed means.

human impact and watershed characteristics variables tended to produce estimated coefficients with larger magnitudes compared to the social characteristics, indicating their relative prominence in explaining the worksite counts.

Subwatershed characteristics

Across all project types, elevation was the most prominent predictor of the number of salmon habitat restoration worksites in each subwatershed. In particular, the maximum elevation in a subwatershed was negatively related to the number of worksites at a 95% significance level, indicating that high elevation subwatersheds tended to have fewer restoration projects. Likewise, total stream length in a subwatershed was significantly positively related to the number of worksites across the estimated models. Natural cover was positively related to the number of restoration worksites within each subwatershed for total worksites and for instream, land, and fish passage worksites at the 95% significance level. For these models, the number of restoration actions was higher in areas with a higher percentage of natural cover (Fig. 3, Table 3).

Ecological value

Fish species richness was positively related to the number of restoration actions for all project types. The number of salmon ESUs was positively related to the number of worksites for instream, riparian, and total actions but not for land or fish passage worksites. The presence of bull trout's final critical habitat was negatively related to the number of instream worksites (Fig. 3, Table 3).

Access/human impact

The presence of impaired waterbodies was a positive and significant predictor of the number of restoration actions across the estimated models (Fig. 4, Table 3).

Social characteristics

The estimated coefficient on population density was positive for all models except the fish passage specification. However, only the land acquisition model found a statistically significant relationship between population density and the number of worksites. The rate of home ownership in a subwatershed was negatively associated with the number of worksites in the instream, fish passage, and total worksites models, and statistically significant at the 95% level in the latter two. Household incomes were negatively related to the number of restoration project actions across models but none at a statistically significant level. Finally, the percentage of non-Hispanic white residents in a subwatershed was positively related to the number of restoration worksites across models. The magnitude of this relationship, which implies that more worksites were established in areas with a higher percentage of non-Hispanic white residents, was fairly consistent across models and statistically significant in the instream, riparian, and total worksite models (Fig. 4, Table 3).

Comparison to other basins in the Pacific Northwest

Several of the relationships found between subwatershed characteristics, ecological value variables, and the number of worksites in Puget Sound were robust across the Yakima and Willamette models (Table 4). This included a negative association between maximum elevation and the number of worksites, and a positive relationship between stream length and natural cover and worksites. In the Willamette Basin riparian model, significant positive relationships were found between the percentage of the non-Hispanic white population and the percent with a college degree and the number of worksites, and a significant negative relationship was found between average household income and the number of worksites (Appendix 2). In the Yakima Basin, a

Table 2. Descriptive statistics of Puget Sound subwatersheds in sample.

Variable	Units	Mean	Median	Std. dev.	Min	Max	N
instream	worksites	2.453	0	7.619	0	101	393
riparian	worksites	2.509	0	7.282	0	93	393
land	worksites	1.606	0	4.053	0	42	393
passage	worksites	1.583	0	3.261	0	33	393
n_worksites	worksites	6.835	1	12.863	0	141	393
stream_length	KM	77.538	67.166	48.12	5.772	353.631	393
max_elevation	M	1339.331	1411	890.699	63	4362	393
mean_slope	Degrees	0.078	0.068	0.059	0	0.266	393
stream_order	Stream order	3.321	3	1.111	1	6	393
natural_cover	percentage	0.796	0.884	0.221	0.041	0.999	393
species_rich	Species	5.463	6	2.586	1	10	393
bull_trout	indicator variable	0.603	1	0.49	0	1	393
esu_count	Number of salmon ESUs	4.812	5	1.591	0	6	393
impaired	indicator variable	0.382	0	0.486	0	1	393
impervious	percentage	4.563	1.423	8.084	1	49.173	393
pct_public	percentage	0.092	0.023	0.154	0	0.874	393
household_inc	2010 USD	52051.93	55826.18	27054.77	0	131980.1	393
white_non_hisp	percentage	0.776	0.891	0.3	0	1	393
owner_occ	percentage	0.66	0.777	0.317	0	1	393
edu_degree	percentage	0.326	0.312	0.189	0	0.768	393
pop_density	population per square KMs	506.389	72.253	970.56	0	8098.87	393

Fig. 3. Model results for the subwatershed characteristics and ecological value variables with 95% confidence intervals.

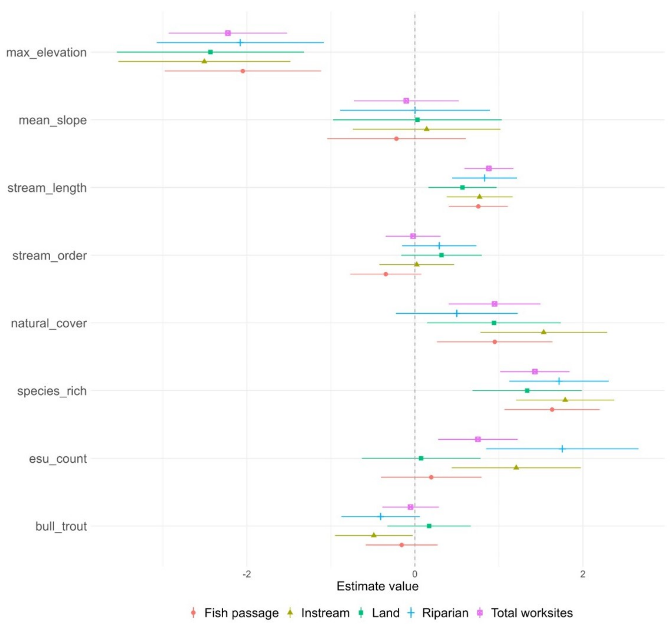
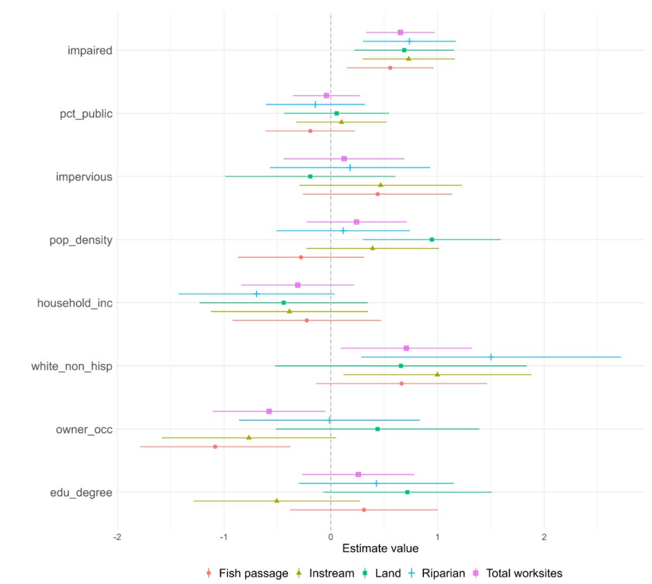


Fig. 4. Model results for access/human impact and social variables with 95% confidence intervals.



significant positive relationship was found between the percentage of white non-Hispanic residents and the number of instream worksites (Appendix 3). Overall, the cross-basin comparison of results suggests that some relationships are consistent across basins whereas others are basin dependent.

DISCUSSION

As the fields of conservation science and habitat restoration planning continue to evolve to ensure that both ecological and societal needs are met, this study set out to explore potential social inequality and inequities in habitat restoration efforts. Focusing on salmon habitat efforts in the Puget Sound region of Washington State, our models reveal robust and statistically significant relationships between habitat restoration efforts and both ecological and social characteristics of the region. The results yield insights that can inform future decision-making processes and habitat restoration efforts, and highlight the value of exploring equity and environmental justice during the planning process.

The models produced estimated coefficients with expected signs for variables capturing fish species richness and the number of ESA-listed salmon populations in subwatersheds. Because the analyzed restoration projects were undertaken, at least in part, to support the recovery of salmon, we expected that habitat restoration efforts would prioritize improving the habitat conditions in areas where

Table 3. Results Puget Sound Basin Negative binomial statistical models for each action type and total worksites. Coefficients with standard errors in parentheses. Bold estimates have 95% confidence or greater.

	Instream	Riparian	Land	Fish passage	Total worksites
(Intercept)	**−0.280 (0.131)**	**−0.583 (0.172)**	**−0.702 (0.162)**	**−0.380 (0.115)**	**0.913 (0.084)**
max_elevation	**−2.505 (0.522)**	**−2.079 (0.507)**	**−2.433 (0.568)**	**−2.048 (0.475)**	**−2.226 (0.360)**
stream_length	**0.770 (0.200)**	**0.830 (0.197)**	**0.567 (0.207)**	**0.755 (0.180)**	**0.881 (0.149)**
mean_slope	0.140 (0.448)	0.001 (0.455)	0.031 (0.512)	−0.219 (0.421)	−0.102 (0.319)
stream_order	0.022 (0.227)	0.290 (0.226)	0.317 (0.244)	−0.346 (0.216)	−0.020 (0.167)
natural_cover	**1.533 (0.385)**	0.499 (0.370)	**0.942 (0.406)**	**0.951 (0.351)**	**0.949 (0.279)**
impervious	0.467 (0.389)	0.181 (0.383)	−0.192 (0.407)	0.439 (0.357)	0.124 (0.289)
species_rich	**1.789 (0.298)**	**1.717 (0.302)**	**1.336 (0.332)**	**1.633 (0.289)**	**1.428 (0.211)**
bull_trout	**−0.488 (0.236)**	−0.408 (0.238)	0.169 (0.238)	−0.157 (0.218)	−0.051 (0.171)
esu_count	**1.207 (0.392)**	**1.755 (0.463)**	0.075 (0.360)	0.195 (0.305)	**0.750 (0.242)**
impaired	**0.730 (0.220)**	**0.737 (0.221)**	**0.688 (0.238)**	**0.557 (0.208)**	**0.652 (0.164)**
pct_public	0.101 (0.216)	−0.144 (0.236)	0.055 (0.250)	−0.192 (0.214)	−0.041 (0.160)
household_inc	−0.387 (0.375)	−0.697 (0.373)	−0.442 (0.402)	−0.225 (0.355)	−0.310 (0.269)
white_non_hisp	**0.999 (0.449)**	**1.502 (0.621)**	0.657 (0.602)	0.664 (0.408)	**0.708 (0.314)**
owner_occ	−0.767 (0.416)	−0.013 (0.432)	0.438 (0.486)	**−1.083 (0.359)**	**−0.579 (0.270)**
edu_degree	−0.506 (0.399)	0.428 (0.370)	0.718 (0.403)	0.311 (0.354)	0.258 (0.268)
pop_density	0.392 (0.317)	0.116 (0.319)	**0.948 (0.329)**	−0.279 (0.302)	0.242 (0.240)
Num.Obs.	393	393	393	393	393
Log.Lik.	−589.730	−574.204	−495.876	−528.770	−905.567
F	11.307	11.325	9.532	10.021	23.438

species are present and where there is environmental and ecological need. However, a previous study found that the placement of restoration projects may not always align solely with ecological needs (Barnas et al. 2015). Although these findings suggest that past restoration efforts have aligned to some degree with the expected environmental characteristics, it is also important to consider how these characteristics translate to ecological needs and to consider other factors that influence which projects are prioritized (e.g., funding available), and the needs of human communities in the region.

The correlations between several of the environmental variables support the placement of salmon habitat restoration efforts to advance recovery objectives; however, human impacts also play a large role in the need for habitat restoration. The estimated models reveal a positive correlation between restoration efforts and subwatersheds containing impaired waterbodies. According to the State of Washington Department of Ecology, impaired waterbodies require development plans to determine which water quality improvements are most needed, which includes working with local governments and communities to identify pollution sources and to reduce or eliminate that pollution (State of Washington Department of Ecology 2022). Our study focuses specifically on the presence or absence of impaired waterbodies within the subwatershed and its correlation to salmon habitat restoration. Although restoration efforts may have taken place in or along impaired waterbodies, how habitat restoration efforts and resource allocations have aligned with water quality improvement efforts merits further investigation (e.g., whether specific impairments influenced restoration decisions and efforts).

The most prominent social predictor of the number of worksite actions within a subwatershed area in our analysis was race and ethnicity, specifically the percentage of the population within the subwatershed that identified as non-Hispanic white. On average more projects tend to occur in areas that are less racially and ethnically diverse. This finding is congruent with previous findings related to stream restoration in California (Stanford et al. 2018), and studies that suggest unequal distribution or allocation of resources tends to favor communities with wealth and/or specific cultural groups within a community (Schell et al. 2020). However, although our study reveals this trend in past restoration efforts, it does not examine the funding sources of these projects, how project distribution changed over time, and whether or not underserved racial/ethnic communities were actively engaged and provided opportunities for meaningful involvement in the restoration allocation decision-making process. Future studies may benefit from exploring potential inequity in funding, project size, outreach and engagement, and decision-making structures surrounding the allocation of restoration resources and efforts. Our results suggest that income was not a significant predictor of the number of worksite actions within our study area. However, we do note that though not significant, the model suggested a negative association between income and restoration sites.

Although the recovery of salmon populations may be the ultimate driver of salmon habitat restoration efforts, our findings suggest the need for a multi-objective planning approach that considers both ecological and social benefits of restoration efforts. Previous research suggests that a multi-objective planning approach that considers several benefits of the project (e.g., ecological and social) has the potential to result in greater overall benefits and allows for the inclusion of equity and justice into the prioritization process (Almeter et al. 2018, Hegeman and Levin 2023). For example, Hegeman and Levin (2023) explored various prioritization strategies for green stormwater mitigation in the Puget Sound region by including addressing human health disparities and maximizing benefit to salmon as two objectives. Their research included scenarios where they prioritize each objective on its own, as well as two scenarios that combined the two objectives, highlighting how planners can achieve multiple goals by tailoring their efforts toward specific environmental and social needs (Hegeman and Levin 2023).

Changing demographics

Our analysis focused on past restoration efforts and utilized social data that was collected within our study timeframe (2000–2015). During that period the Puget Sound region was less diverse than

Table 4. Negative binomial statistical results for the Yakima and Willamette Basin models for each action type and total worksites. Coefficients with standard errors in parentheses. Bold estimates have 95% confidence or greater.

	Yakima Basin					Willamette Basin				
	Instream	Riparian	Land	Fish passage	Total worksites	Instream	Riparian	Land†	Fish passage	Total worksites
(Intercept)	**−0.655 (0.205)**	−0.090 (0.159)	**−1.740 (0.313)**	**−1.894 (0.349)**	**1.073(0.115)**	0.168 (0.104)	**0.544 (0.085)**	-	0.143 (0.105)	1.593 (0.059)
max_elevation	0.980 (0.872)	0.394 (0.694)	1.415 (0.989)	0.571 (1.285)	**1.368 (0.525)**	0.086 (0.586)	**−1.241 (0.522)**	-	−0.682 (0.646)	−0.603 (0.353)
stream_length	1.045 (0.556)	**1.432 (0.424)**	0.990 (0.578)	1.227 (0.765)	0.441 (0.309)	0.453 (0.236)	**0.902 (0.186)**	-	**0.672 (0.215)**	**0.652 (0.134)**
mean_slope	**−2.487 (0.803)**	−0.584 (0.593)	**−3.514 (1.020)**	**−2.708 (1.251)**	**−1.895 (0.480)**	−0.473 (0.398)	0.050 (0.348)	-	−0.604 (0.401)	−0.215 (0.236)
stream_order	−0.393 (0.630)	0.049 (0.484)	0.947 (0.761)	0.172 (0.928)	0.403 (0.365)	0.197 (0.298)	−0.061 (0.238)	-	−0.431 (0.274)	−0.171 (0.169)
natural_cover	1.126 (0.845)	0.327 (0.598)	0.755 (0.881)	−0.084 (1.118)	−0.196 (0.460)	**2.415 (0.491)**	0.407 (0.387)	-	**3.665 (0.464)**	**1.873 (0.274)**
impervious	**1.107 (0.549)**	**1.249 (0.434)**	−2.192 (1.145)	−0.046 (1.387)	0.475 (0.341)	**1.456 (0.334)**	**0.758 (0.240)**	-	**0.936 (0.314)**	**0.691 (0.176)**
species_rich	−0.234 (0.705)	−0.163 (0.521)	0.700 (0.770)	0.305 (0.969)	0.138 (0.399)	**0.719 (0.300)**	0.150 (0.243)	-	**0.893 (0.275)**	**0.466 (0.171)**
bull_trout	1.085 (0.674)	0.908 (0.545)	−0.579 (0.846)	−0.694 (1.006)	0.549 (0.413)	−0.149 (0.240)	0.337 (0.196)	-	**−0.539 (0.264)**	0.021 (0.141)
esu_count	0.470 (0.587)	−0.016 (0.374)	−0.026 (1.356)	0.200 (1.228)	0.422 (0.299)	**−0.666 (0.259)**	0.031 (0.216)	-	0.059 (0.237)	−0.127 (0.149)
impaired	**1.091 (0.440)**	−0.395 (0.343)	0.784 (0.509)	1.179 (0.649)	0.086 (0.267)	−0.060 (0.218)	0.054 (0.176)	-	0.053 (0.198)	0.096 (0.123)
pct_public	0.351 (0.396)	−0.313 (0.334)	**1.050 (0.462)**	1.010 (0.533)	**0.513 (0.242)**	**−1.133 (0.434)**	0.120 (0.381)	-	**−2.736 (0.408)**	**−1.345 (0.256)**
household_inc	0.336 (0.623)	−0.154 (0.553)	−0.241 (0.884)	−1.274 (1.000)	0.126 (0.382)	0.069 (0.539)	**−0.887 (0.436)**	-	−0.838 (0.500)	−0.549 (0.308)
white_non_hisp	**1.631 (0.793)**	−0.698 (0.604)	0.282 (0.842)	2.387 (1.373)	0.079 (0.473)	−0.232 (0.431)	**0.965 (0.357)**	-	0.098 (0.463)	0.422 (0.249)
owner_occ	−0.272 (0.550)	**1.985 (0.578)**	**1.922 (0.904)**	−0.075 (0.988)	**0.886 (0.374)**	0.000 (0.425)	−0.084 (0.347)	-	0.930 (0.478)	−0.273 (0.246)
edu_degree	**−1.657 (0.701)**	−0.408 (0.546)	**−2.036 (0.816)**	−0.280 (0.999)	−0.527 (0.423)	0.248 (0.418)	**0.702 (0.329)**	-	0.113 (0.379)	**0.579 (0.235)**
pop_density	−0.562 (0.766)	−1.165 (0.599)	0.705 (0.796)	−1.666 (1.276)	−0.663 (0.432)	−0.651 (0.449)	−0.429 (0.267)	-	**−0.880 (0.447)**	−0.328 (0.195)
Num.Obs.	131	131	131	131	131	387	387	-	387	387
Log.Lik.	−141.532	−185.971	−97.395	−78.716	−299.551	−571.640	−700.460	-	−637.985	−1050.228
F	2.326	2.598	2.299	1.341	4.245	4.268	7.304	-	13.648	11.972

† Land statistical model for the Willamette Basin did not converge.

it is today, as demonstrated in demographic results from the most recent decennial census in 2020. In fact, the state of Washington's census diversity index, which reflects the "chance that two people chosen at random will be from different racial/ethnic groups" increased from 45.5% in 2010 to 55.9% in 2020 (U.S. Census 2021). In each of the three largest counties in our study region (King, Pierce, and Snohomish) diversity indices also increased by roughly 10% in the ten-year time span, with King County's (the largest and most populated county) diversity index being the highest for the state at 64.6% (U.S. Census 2021). Future research could explore changes in trends and explore whether demographic shifts influence where restoration efforts are occurring in subwatersheds.

Comparison to other basins

We extended our analysis to two additional populated basins within the Pacific Northwest (Yakima and Willamette) and found that some relationships are consistent across basins whereas others are basin dependent. This highlights the importance of understanding social and environmental dynamics that exist at different scales within regions and communities. Although this study primarily focused on the Puget Sound basin, future research could benefit from further exploring similarities and differences across basins. Future research on equity could also benefit from inclusion of smaller regional or community-level assessments to capture differences that may be overlooked when comparing at a larger regional scale.

Investments in equity and environmental justice

In recent years there have been increases in efforts focused on exploring equity in restoration (Villarreal-Rosas et al. 2021), and how investments impact individuals from traditionally underserved communities, which include communities of color and tribal communities. Since 2021, the Biden Administration has signed multiple executive orders focused on equity and environmental justice (Executive Order 13985 [2021], Executive Order 14008 [2021], Executive Order 14096 [2023]) that direct federal agencies to pursue approaches to advancing equity for all, make achieving environmental justice part of their missions, and to revitalize the nation's commitment to environmental justice for all (Executive Order 13985 [2021], Executive Order 14008 [2021], Executive Order 14096 [2023]). As a result, many federal agencies, in alignment with other funding partners, are dedicating funding for conservation projects, including habitation restoration, which promote equity and environmental justice for underserved communities. For example, in 2024, NOAA awarded nearly $25 million in funding for projects throughout the United States, including multiple projects in the Pacific Northwest, which advance the coastal habitat restoration priorities of underserved communities through funding provided by the Bipartisan Infrastructure Law and Inflation Reduction Act (National Oceanic and Atmospheric Administration 2024).

The State of Washington has also implemented numerous policies and laws, including establishing the Healthy Environmental for All Act (Heal Act, https://ecology.wa.gov/About-us/Who-we-are/Environmental-Justice/HEAL), which is the state's first environmental justice law. Regionally, the Puget Sound Partnership, a state agency leading the region's collective effort to restore and protect the Sound, recently released its 2022–2026 Action Agenda that outlines goals and approaches that support environmental and ecological recovery and incorporates human well-being equity and environmental justice (Puget Sound Partnership 2022).

This study supports these calls for equity in restoration efforts by highlighting the inequities that exist in previous restoration efforts. Although the results do not suggest that these inequities were intentional or provide insight into underlying drivers of the relationships identified, they do provide a space to begin intentional conversations on the need to have restoration efforts consider equity concerns and create opportunities that target benefits to underserved communities.

CONCLUSION

Habitat restoration efforts have the potential to not only improve ecological communities, but also to benefit the surrounding human communities. Planners and resource managers, along with the input of stakeholders, are tasked with making decisions on how to allocate resources. In many scenarios, planners may have clear ecological goals, objectives, and outcomes in mind. However, without taking a step back and assessing human impacts, it is easy to make decisions that may disproportionately impact or disadvantage communities that have been traditionally underserved resulting in inequality and inequity. The purpose of this study was to explore relationships between environmental and social characteristics of regions and past restoration efforts from an equity lens to shed light on some potential social equity issues and blind spots that may have existed in the past. As community demographics continue to shift and investment in conservation, habitat restoration, and equity continue to grow, it is important to create planning processes that are inclusive of the ecological and social needs of surrounding communities. With the knowledge and acknowledgment of potential past oversight in the restoration planning process, decision makers can take steps to avoid or minimize inequity in future planning efforts.

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Data Availability:

Data used for this study were derived from resources available in the public domain. See Appendix 4 for a list of resources and URLs. The code that supports the findings of this study is available in where_restoration_occured at https://github.com/robby-fonner/where_restoration_occured. The dataset that supports the findings of this study (compiled from the public resources/data listed in Appendix 4) are available on request.

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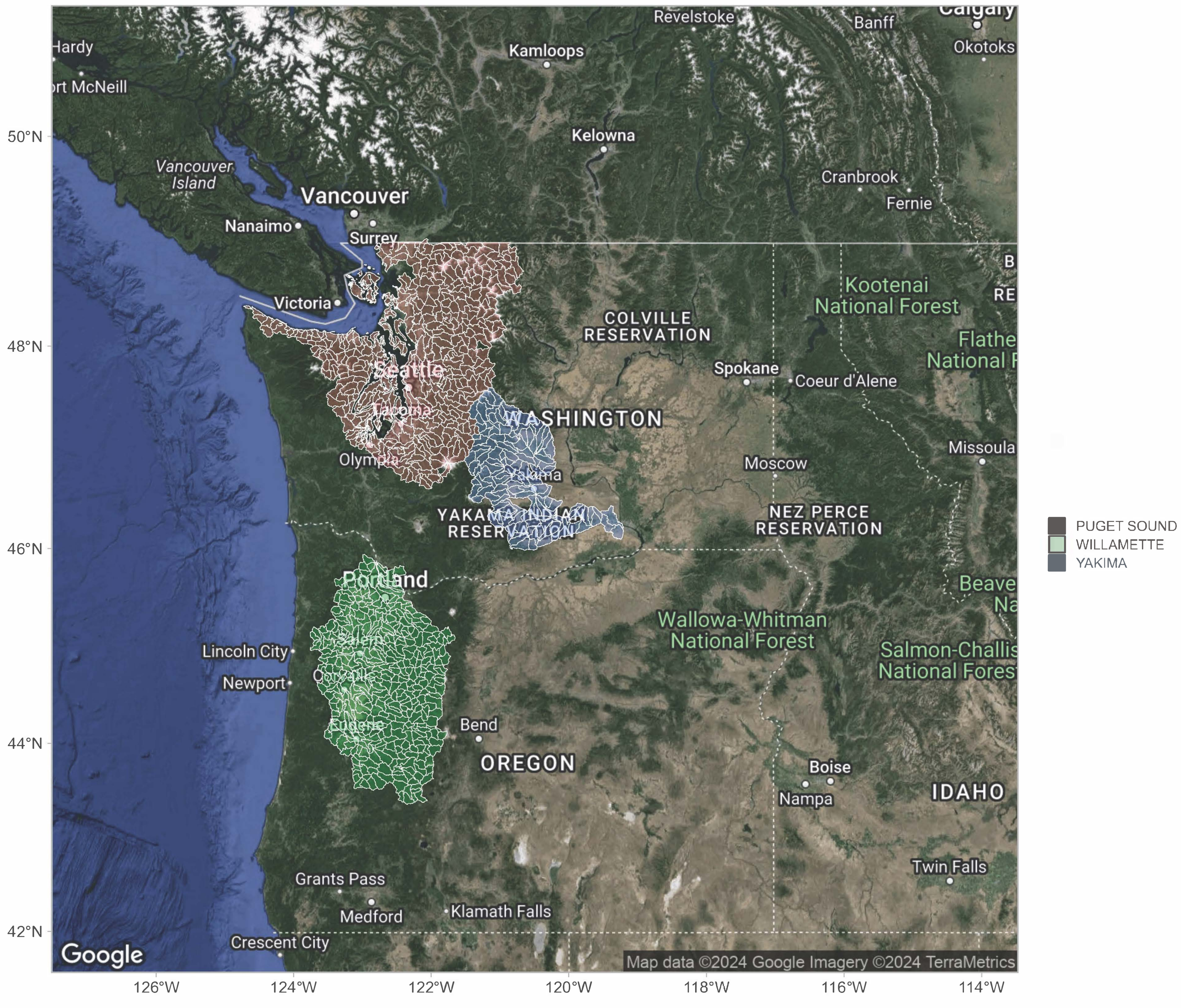
Appendix 1



50°N
48°N
46°N
44°N
42°N
126°W
124°W
122°W
120°W
118°W
116°W
114°W
PUGET SOUND
WILLAMETTE
YAKIMA
Vancouver
Vancouver Island
Victoria
Seattle
Tacoma
Olympia
Portland
Salem
Corvallis
Eugene
Bend
Spokane
Yakima
WASHINGTON
OREGON
IDAHO
Kamloops
Kelowna
Revelstoke
Banff
Cranbrook
Fernie
Okotoks
Nanaimo
Surrey
Coeur d'Alene
Moscow
Missoula
Boise
Nampa
Twin Falls
Lincoln City
Newport
Grants Pass
Medford
Klamath Falls
Crescent City
COLVILLE RESERVATION
YAKAMA INDIAN RESERVATION
NEZ PERCE RESERVATION
Kootenai National Forest
Wallowa-Whitman National Forest
Google
Map data ©2024 Google Imagery ©2024 TerraMetrics

Appendix 2

Variable	Units	Mean	Median	Std.Dev.	Min	Max	N
instream	worksites	1.687	0	4.486	0	64	387
riparian	worksites	2.54	1	4.898	0	38	387
land	worksites	0.01	0	0.203	0	4	387
passage	worksites	2.943	0	6.885	0	66	387
n_worksites	worksites	6.659	3	9.869	0	69	387
stream_length	KM	68.928	63.165	33.449	18.005	289.048	387
max_elevation	M	984.367	950	618.955	67	3116	387
mean_slope	Degrees	0.05	0.045	0.038	0	0.166	387
stream_order	Stream order	3.791	3	1.178	1	9	387
natural_cover	percentage	0.683	0.875	0.349	0.008	1	387
species_rich	Species	3.721	4	1.655	1	16	387
bull_trout	indicator variable	0.09	0	0.287	0	1	387
esu_count	Number of salmon ESUs	1.778	2	1.042	0	4	387
impaired	indicator variable	0.556	1	0.498	0	1	387
impervious	percentage	4.09	1.349	7.613	1	51.046	387
pct_public	percentage	0.37	0.159	0.402	0	1	387
household_inc	2010 USD	46648.934	52438	23688.066	0	89185.81	387
white_non_hisp	percentage	0.743	0.891	0.332	0	1	387
owner_occ	percentage	0.58	0.721	0.331	0	1	387
edu_degree	percentage	0.259	0.272	0.144	0	0.628	387
pop_density	population per square KMs	664.9	62.049	1290.349	0	14035.965	387
area	square KMs	0.779	0.715	0.306	0.206	2.013	387

Appendix 3

Variable	Units	Mean	Median	Std.Dev.	Min	Max	N
instream	worksites	1.053	0	2.591	0	19	131
riparian	worksites	1.435	0	2.834	0	18	131
land	worksites	0.588	0	1.508	0	9	131
passage	worksites	0.405	0	1.305	0	8	131
n_worksites	worksites	4.855	1	10.283	0	87	131
stream_length	KM	124.971	122.442	51.794	35.998	290.621	131
max_elevation	M	1457.008	1520	521.598	282	2362	131
mean_slope	Degrees	0.059	0.051	0.036	0.001	0.157	131
stream_order	Stream order	4.336	4	1.304	1	7	131
natural_cover	percentage	0.789	0.907	0.238	0.015	0.994	131
species_rich	Species	5.389	5	2.862	1	11	131
bull_trout	indicator variable	0.519	1	0.502	0	1	131
esu_count	Number of salmon ESUs	2.954	3	0.643	0	6	131
impaired	indicator variable	0.389	0	0.489	0	1	131
impervious	percentage	2.227	1.637	2.359	1	23.264	131
pct_public	percentage	0.073	0.014	0.125	0	0.642	131
household_inc	2010 USD	49446.76	51058	15489.64	0	104392.86	131
white_non_hisp	percentage	0.701	0.855	0.325	0	1	131
owner_occ	percentage	0.687	0.745	0.259	0	1	131
edu_degree	percentage	0.261	0.257	0.138	0	0.629	131
pop_density	population per square KMs	303.042	25.029	694.317	0	3130.245	131
area	square KMs	1.06	1.078	0.327	0.419	2.244	131

Appendix 4

Description	URL
Pacific Northwest Salmon Habitat Project Database	https://www.webapps.nwfsc.noaa.gov/apex/f?p=409:13::::::
HUC6 polygons with information about which ESU occupy and habitat type	https://drive.google.com/file/d/1oDV7z1lum00wckm0XjQt3gQQFtxeghxC/view?usp=sharing
High definition NHD data for Puget Sound subbasin	https://viewer.nationalmap.gov/basic/?basemap=b1&category=nhd&title=NHD%20View
Fish data for the PNW	https://www.streamnet.org/home/data-maps/gis-data-sets/
NHD data for puget sound region	https://viewer.nationalmap.gov/basic/?basemap=b1&category=nhd&title=NHD%20View
Watershed boundaries for entire Columbia basin	https://viewer.nationalmap.gov/basic/?basemap=b1&category=nhd&title=NHD%20View
Reach Catchments and Modified Network Routed Upstream Watersheds for the Conterminous United States	https://www.sciencebase.gov/catalog/item/5d2f72f0e4b01d82ce821afa
The National Land Cover Database (NLCD) provides nationwide data on land cover and land cover change at a 30m resolution with a 16-class legend based on a modified Anderson Level II classification system.	https://www.usgs.gov/centers/eros/science/national-land-cover-database
County boundaries for WA state	https://geo.wa.gov/datasets/12712f465fc44fb58328c6e0255ca27e_11
Inventory of pubically owned land with management and acquisition characteristics	https://rco.wa.gov/recreation-and-conservation/maps-and-data/
Integrates data from EPA water programs (e.g. to NHDPlus	https://www.epa.gov/waterdata/waters-geospatial-data-downloads
Census Data (Social Variables)	https://www.census.gov/programs-surveys/acs