CURRENT STATUS OF RIPARIAN BUFFERS IN WASHINGTON STATE: PUBLIC AND PRIVATE LAND COVER WITHIN RIPARIAN MANAGEMENT ZONES BASED ON BEST PRACTICE GUIDELINES

by Danielle Lazarus

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By

Danielle Lazarus

has been approved for

The Evergreen State College

by

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John Withey

Member of the Faculty

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Date

ABSTRACT

Current status of riparian buffers in Washington State: public and private land cover within riparian management zones based on best practice guidelines

Danielle Lazarus

Riparian management is a crucial and controversial policy area in Washington State that is affected by and impacts many stakeholders. Using three riparian buffer prescriptions (50 ft, 100 ft, and site potential tree height at 200 years or '$SPTH_{200}$', which can range from 100 to 240 ft), land use/land cover compositions were calculated within each buffer distance from Washington streams using the 2021 Cropland Data Layer, as well as change over time from National Land Cover Datasets (2001 to 2019). In Western Washington, 80% of lands within the $SPTH_{200}$ buffer is woody vegetation (i.e. considered potential riparian habitat), and in Eastern Washington 40% is woody vegetation with a large gap between coverage on public (62%) vs. private (23%) lands. In Eastern Washington 26% of lands within the $SPTH_{200}$ buffer are shrublands and herbaceous wetlands, of which the quantity of native riparian vegetation is unknown. There are very strong negative correlations between higher amounts of agricultural land cover compared to woody vegetation inside riparian buffers in Eastern Washington, and higher amounts of development land cover compared to woody vegetation inside buffers in Western Washington, and in both regions, there is often higher concentrations of agriculture or development within 50 or 100 ft of streams compared to the $SPTH_{200}$. Woody vegetation has increased substantially from 2001 to 2019 in Western riparian buffers, signaling progress in conservation and preservation. A high percentage of the riparian buffer prescriptions is conserved, but only 1% of conserved lands within the buffers are privately owned, which calls into question the capacity for habitat improvements based on a voluntary system. Maps, policy, restoration funding, and research in riparian management would benefit greatly by addressing restoration and protection in the closest areas of streams, regional differences, operation on watershed levels rather than political boundaries, development as a dominant obstacle in improving riparian habitats, and including floodplain connectivity as a core mitigation and restoration practice.

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ANOVA – Analysis of Variance

BLM – Bureau of Land Management

CAO – critical area ordinance

CDL – Cropland Data Layer

CHAMP – Channel Migration Potential

CMZ – Channel migration zone

CREP – Conservation Reserve Enhancement Program

CRP – Conservation Reserve Program

CWA – Clean Water Act

DEM – Digital Elevation Model

DNR – Department of Natural Resources

EPA – Environmental Protection Agency

ESA – Endangered Species Act

ESRI – Environmental Systems Research Institute

FEMA – Federal Emergency Management Agency

FEMAT – Forest Ecosystem Management Assessment Team

FERC – Federal Energy Regulatory Commission

FPHCP – Forest Practices Habitat Conservation Plan

GAP – Gap Analysis Project

GIS – Geographic Information Systems

GMA – Growth Management Act

LIDAR – Light Detection and Ranging

LULC – Land Use and Land Cover

NAIP – National Agricultural Imagery Program

NASS – National Agriculture Statistic Service

NCED – National Conservation Easement Database

NED – National Elevation Database

NGO – Non-governmental Organization

NHD – National Hydrography Dataset

NOAA – National Oceanic and Atmospheric Administration

NRBM – National Riparian Base Map

NWFP – Northwest Forest Plan

NWIFC – Northwest Indian Fisheries Commission

OBIA – Object-based imagery analysis

OHWM – Original High-Water Mark

PAD – Protected Areas Database

RMZ – Riparian Management Zone

SHSTMP – Salmon Habitat Status and Trend Monitoring Program

SMA – Shoreline Management Act

SPTH – Site Potential Tree Height

$SPTH_{200}$ – Site Potential Tree Height at two hundred years

SSI – Soils Site Index

TIGER – Topologically Integrated Geographic Encoding and Referencing

UAV – Unmanned aerial vehicle

USDA – United States Department of Agriculture

USFS – United States Forest Service

USGS – United States Geological Survey

VSW – Visible Surface Water

WAECY – Washington State Department of Ecology

WARCO/WRCO – Washington State Recreation and Conservation Office

WDFW – Washington State Department of Fish and Wildlife

WRIA – Water Resource Inventory Area

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PREFACE: POSITIONALITY OF THE AUTHOR

This thesis work is grounded in subject matter that can be controversial, as well as being emotional for a variety of stakeholders. It is also directly and indirectly related to treaty rights for federally recognized tribes in Washington State for protection of salmon and their habitats. While scientific research and best practices are embedded in policy related to riparian management in Washington State, it cannot be denied that the socio-economic climate impacts policy applications. My goal is to present research, data, and analysis that may aid parties in practical application for policy enactments. However, data can be interpreted differently based on the biases and goals of the user. There is a possibility that the research, data, or analysis I present may support certain stakeholders in ways that would counteract others' goals.

My personal experience makes it difficult for me to represent as a sole researcher the main stakeholders I perceive as participating in making, and most effected by, policy regarding riparian management: tribes, agricultural landowners (especially those using conventional farming practices), policymakers, and nonprofit conservation groups. I am three generations "American" removed from European ancestry, grew up in a small city on the East Coast of the U.S., and have never owned my own land. I have almost exclusively studied and practiced agriculture with small to medium scale sustainable or organic farming methods. I have never extensively participated in riparian restoration or conservation efforts. Finally, I have never participated in government level policy making or collaboration.

It also should be acknowledged that I am a cis female with both an arts and science background doing work in a field that has been culturally dominated by cis males and this does affect my methodological approach. I am drawn to this research because of the intersection of science and policy and the potential for creativity and collaborative problem solving based on macroscale awareness in addition to the microscale which is more often used for scientific analyses. In this sense, I want to apply my wholistic and artistic sensibilities to my ability to synthesize data and have a desire for groups that traditionally have had conflict with each other to find ways to work towards both common and separate goals.

Bias in scientific research is important to recognize with ecological management practices directly impacting Indigenous people (Brook & McLachlan, 2005; Kadykalo et al., 2021; Skroblin et al., 2021; Wheeler & Root-Bernstein, 2020). Washington State tribes have been leaders regarding riparian management policy and ArcGIS mapping analyses and my thesis was inspired by reading the Lorraine Loomis Act and projects like the State of Our Watersheds released by the Northwest Indian Fisheries Commission. That does not preclude the fact that I discuss policy and science that has far different meanings to the tribes than to myself, and this lack of direct experience and perspective on my part should be acknowledged. The tribes are not a monolith and each tribe in Washington has its own sovereignty, of which I have limited knowledge and understanding. When citing sources related to tribes, the default of the reader would be best to review those sources directly for further interpretation.

During my research, I came across written records of tribes' responses to Washington State compiling boundaries of tribal lands for the public land inventory (WRCO, 2014), expressing a strong sense that federal Bureau of Land Management (BLM) records are inaccurate, and landownership by tribes both communally and as individuals is complex. The Centennial Accord signed in 1989 between Washington State and federally recognized tribes in Washington aims to ensure the recognition of tribal sovereignty and a government-to-government relationship to remedy issues as they arise in honoring this sovereignty. Tribes need to be included for all levels of state-sponsored projects related to salmon habitat restoration, and presentation of maps publicly showing prioritizations for this work need to be approved by tribes that are impacted.

Because of the immense level of communication and organization needed at this scale, I was limited from completing a collaborative or community-initiated research project with stakeholders in the time frame of this master's thesis. However, I still wanted to reduce harm or bias to individuals or groups impacted. Based on perspectives shared in reviewed documents I have chosen not to analyze sovereign tribal lands for this project without permission of all nations involved, with the acknowledgement that I am also unable to clarify tribal boundaries fully. I used public conservation data from NCED and PAD in addition to BLM map layers to enhance the boundary data. While it excludes tribal lands, this analysis, methods, and data will be available for tribal use, and methods can be replicated to share data from within sovereign tribal lands with permission of, and for use by treaty tribes if desired. This also in no way implies that riparian land cover on tribal lands is not extremely important or relevant to the findings of this study or should be left out in defining where restoration efforts should be prioritized.

In addition to seeking ways to mitigate harm towards Washington's tribes, many farmers have perceived themselves as being potentially harmed economically by enactment of riparian management regulations, with the possibility of impacting the wider food system in Washington State and nationally. Priorities and livelihoods of individuals or communities may also conflict with priorities for protecting habitat and species, regardless of larger ecosystem benefits. As such, any overall analysis may be weighed towards one priority or another. A way to mitigate bias in this matter was to try to present the research results in different ways, and by breaking the data into important pre-existing ecological and political boundaries.

CHAPTER 1: INTRODUCTION

Washington State has lost over 50% of its natural riparian habitat since the late 1800s (Knutson & Naef, 1997), but it's not too late for conservation action: riparian buffers are considered one of the most effective means of improving the health of salmon, water quality, and flood mitigation (Shaw, 2018; Broadmeadow & Nisbet, 2004; WDFW, 2020). Buffers provide shade to maintain proper temperature for aquatic species, filter pollution, prevent erosion and bank destabilization, and contribute nutrient and woody debris that support both aquatic and land species, including spawning salmon (Knopf et al., 1988; Knutson & Naef, 1997; Naiman & Décamps, 1997). In Washington State, the health of salmon habitat is also intrinsically tied to the heritage, livelihoods, and spiritual practice of its Indigenous people (NWIFC, 2020).

Currently, there are no state-wide standardized regulations for riparian management zones (RMZs) in Washington besides forests in salmon-bearing watersheds (DNR, 2005). This is despite salmon species' protections provided by tribal treaty rights confirmed in the Boldt decision (*The Boldt Decision: United States v. Washington State*, 1975), the Endangered Species Act (Endangered Species Act, 1983), and water quality protection through the Clean Water Act (US EPA, 1977). The debate between voluntary and regulated riparian buffer policy, as well as the science behind it, has been contested for over 40 years in the Pacific Northwest (Chapman et al., 2020; Clauson & Trautman, 2016; *Washington State Legislature*, 2023). In January 2022, the Lorraine Loomis Act, HB 1838, was proposed in the Washington State Legislature to enhance and protect salmon habitat throughout the state. This bill, which died in committee, would have created a standard for defining RMZs and establishing the infrastructure, funding, and regulatory goals in their restoration and management (House Bill 1838, State of Washington, 2022). While it had wide backing from tribes, fisheries, and the governor, it was contested by agricultural groups and private farm landowners (WA State Legislature, 2022).

In 2023, House Bill 1720 was introduced which aimed to provide funding for a completely voluntary program. While some collaboration increased between stakeholders, it did not include multiple tribes at a level of consensus, and it died in the budget committee (*Washington State Legislature*, 2023). Implementation of voluntary riparian habitat restoration is universally complicated by participation levels of private landowners, especially of agricultural land (Clauson & Trautman, 2016; Yu & Belcher, 2011). As such, there is both a perceived need for regulatory consistency, and a great amount of pushback from some members of the private streamside landowner community. Besides the controversy between regulatory versus voluntary buffer restoration, key questions in this policy debate have been whether the problem is a development or agricultural issue, how to counteract negative economic impacts on landowners, and whether the WDFW's guidelines, especially regarding the use of buffer widths based on Site Potential Tree Height at 200 years of age (SPTH, which can vary on average from 100 to 240 feet depending on the location (Fox, 2003)) have a strong basis in science or can be applied on site-specific levels (IEC & Plauché & Carr LLP, 2022; *Washington State Legislature*, 2023).

The Lorraine Loomis Act had recommended an assessment for all of Washington's historically salmon-bearing watersheds and mandating the creation of a publicly accessible mapping system for the analysis of RMZs based on Site Potential Tree Height at 200 years ($SPTH_{200}$), established as the best management standard by the Department of Fish and Wildlife (Lorraine Loomis Act, 2022; WDFW, 2020). Comprehensive reviews of research on riparian buffer size reveals complex findings and recommendations (Wenger 1999; Hickey & Doran 2004) but tend to be relative to desired management goals (Castelle et al., 1994; Wenger, 1999). Creating policy for buffers that is standardized and aims to accomplish multiple ecosystem services, including cultural and socioeconomic goals, seems to be more elusive. Guidelines produced over the decades from Washington's Department of Fish and Wildlife have stated that the best practice standards are based on desired outcomes for fish and wildlife in addition to water quality, but not specifically socioeconomic goals (Knutson & Naef, 1997; WDFW, 2020).

These policy guidelines do not match actual practice in Washington State, other than commercially forested lands protected under the Department of Natural Resources (DNR) by the Forest and Fish Laws of 1999. While progress has been made with enhanced riparian buffers on federal and forested lands, agricultural and developed lands are mostly regulated at local or regional levels under the Growth Management Act and the Shoreline Management Act. In 2022, despite the Lorraine Loomis Act not moving out of committee, legislators were able to secure funding for an in-depth analysis of current riparian management policy with the aid of outside consultants (Plauché & Carr LLP, 2022). They utilized interviews of interested parties and formed roundtables, creating a task force to determine riparian regulatory needs based on best science recommendations, especially those of the Department of Fish and Wildlife, and assessing and improving interagency cooperation and consistency in application of recommendations. This approach recognizes the need to address socioeconomic and political challenges in moving forward with riparian habitat restoration.

Taking this and recent policy-making attempts for standardizing riparian buffers in Washington State into consideration, mapping land cover and land use within riparian zones with geographic information systems (GIS) can provide useful data at a broad landscape scale in relation to both public and private sectors. Using SPTH-defined buffers can demonstrate the application of recent policy guidelines, in addition to examining other buffer prescriptions on hydrologic layers such as the best practice recommendation for 100 ft buffers that mitigate pollution (WDFW, 2020) and flooding (Daigneault et al., 2016). While most research shows the impacts of smaller buffers are short term and only support some end goals, like filtering some types of agricultural runoff (Mayer et al., 2005; Wenger, 1999; WDFW 2020), a buffer of 50 ft can be used as a more conservative buffer prescription. Using GIS and aerial imagery for mapping and analyzing riparian zones improves upon other methods to measure buffers and estimate land use and land cover (Mason & Maclean 2007; Solomons 2015). Many analyses of riparian land cover in Washington State are done on county or watershed scales like those conducted in Skagit County and the Snohomish River Basin (Greenberg & Carson, 2010; Snohomish Conservation District, 2017), and larger scale projects are generally regional, like the in-depth analyses shared in the State of our Watersheds report (NWIFC, 2020) which focuses on Western Washington. However, the context of statewide policy application and debate suggests a need for a broader comparative state-level macro-analysis. Geospatial mapping and analysis also allow for flexible interactivity with the data, which can be a valuable tool for prioritization, funding, and cooperation among stakeholders.

This research explores the ecological and social science, as well as policy history and application of riparian buffers, and how that may intersect with a broad geospatial analysis of land cover within WDFW's recommended buffer widths. Land cover that potentially meets riparian definitions within multiple prescribed riparian management zone (RMZs) widths of 50 ft, 100 ft, and $SPTH_{200}$ was assessed along all hydrologic lines and polygons for perennial, intermittent, and ephemeral streams in public datasets for Washington State. This assessment included delineations by public and private land, Eastern and Western Washington, and by individual Water Resource Inventory Areas (WRIAs). The results were then analyzed to assess associations between riparian land cover and development or agricultural land cover, and land cover composition to buffer size and type of ownership. The amount of riparian buffer land cover in conservation was calculated, and a temporal comparison was also conducted to explore overall land cover change in the buffer zones since 2001.

CHAPTER 2: LITERATURE REVIEW

INTRODUCTION

Spatial analysis of riparian buffer widths and riparian land cover in Washington State is part of a precedent of research and policy since at least the 1960s (Goodwin et al., 1997) and riparian management has become more prevalent as a goal of federal, state, and local governments since the mid-1990s (Knopf et al., 1988; Richardson et al., 2012). Landscape-level analysis for riparian management is becoming increasingly important, especially as ecologists recognize that compartmentalizing watershed habitat interactions based on human sociopolitical boundaries is ineffectual (Basnyat et al., 2000; Fischer et al., 2000; Li et al., 2009). At the same time anthropogenic actions continue to impact habitats and species despite legal protections (Naiman & Décamps, 1997; WDFW, 2020a).

Riparian buffer size, and especially buffer widths, have been researched extensively for a multitude of impacts and ecosystem services along streams (Feld et al., 2018; Knutson & Naef, 1997; Mayer et al., 2005; WDFW, 2020a; Wenger, 1999). Further, other factors like length (Hilary et al., 2021; S. Li et al., 2009), connectivity (Fogel et al., 2022; Kiffney et al., 2023; Stahl et al., 2013), slope (Nava-López et al., 2016; Wenger, 1999), tree height (DeWalle, 2010), and vegetative composition (González et al., 2015; S. Li et al., 2009) have been identified as having a relation to management outcomes.

There is a very specific and strong historical legal background for protecting salmon habitat in Washington State, stemming from federal tribal treaty rights and the Boldt decision (*The Boldt Decision: United States v. Washington State*, 1975), the Endangered Species Act, federal and state regulatory protections in Washington's forested lands through the Fish and Forests Law (1999); large rivers, the sound, and ocean coasts through the Shoreline Management Act (1971), and higher populated areas through the Growth Management Act (1990). Outside of forested lands, most regulatory enforcements have been on a local level under the Growth Management Act and the Shorelines Management Act in relation to "critical area ordinances" (CAOs), flooding, and pollution prevention or cleanup effecting water quality issues and covered as protection by the Clean Water Act.

Riparian regulatory policy cannot be considered without looking at and comparing the effectiveness of voluntary conservation measures through non-governmental organizations (NGOs), private individuals or organizations, local zoning laws, and federally and state-funded conservation programs on agricultural lands. Agricultural groups and private farm owners on acreage next to streams have testified during recent legislative sessions and in workgroups (Plauché & Carr LLP, 2022; WA State Legislature, 2022; *Washington State Legislature*, 2023) against the potential impacts on their livelihoods and under compensating loss of high-value farmland in voluntary programs, as well as in relation to stronger regulations and fines. Research on economics, values, and education in the adoption of riparian management and conservation practices on private and agricultural lands lends insight into these debates. Further, non-timber commercial agroforestry harvest in the outer riparian zone is an understudied and underutilized management option in the United States, which might increase farmers' willingness to participate. Agroforestry was recently added as an allowed practice in riparian buffer restoration under the 2018 Federal Farm Bill for Conservation Reservation Enhancement Program (CREP) funding.

THE SCIENCE OF RIPARIAN BUFFERS

Riparian buffers: impacts and ecosystem services

Riparian ecosystems are diverse, dynamic, and complex environments that are generally defined from the edge of the channel bank of a stream to the extent of terrestrial interaction with the aquatic into the surrounding uplands and vice versa (Knopf et al., 1988; Naiman & Décamps, 1997; WDFW, 2020a). In Washington State, these ecosystems support about 75% of all terrestrial wildlife species, in addition to aquatic species who intrinsically benefit from the edge environment of earth and water (WDFW, 2020a). Natural disturbances are key parts of this system (Everett et al., 1994; Naiman & Décamps, 1997), but anthropogenic disturbances like development, water re-channelization/obstruction, fire suppression, clear cutting, agriculture, and invasive introduction create a high level of unpredictability for species in the environment that makes adaptation difficult in riparian management zones (RMZs) (K. Li et al., 2018a; Naiman & Décamps, 1997; WDFW, 2020a).

"Riparian buffer" and "riparian management zone" (RMZ) are terms devised for management purposes to protect and restore rivers and streams from anthropogenic disturbance (Knutson & Naef, 1997; WDFW, 2020a). While the phrase was originally used in the Southwest for dry habitats (Elmore & Beschta, 1987), much of the management research in the U.S. has been focused on the forests of the Pacific Northwest. RMZs include floodplains but also provide buffer to upland environments (Knopf et al., 1988; WDFW, 2020a). In management, buffers have been used since at least the 1960s to define areas of protected habitat, often through prescriptive widths (Knopf et al., 1988; Naiman & Décamps, 1997; Richardson et al., 2012). Since that time, hundreds of buffer studies have been conducted and reviewed to define best management practices.

Feld et al. (2018) conducted a review of ecosystem impacts with riparian characteristics, extracting significant results from fifty-five studies (Table 1). Because there were different quantities of studies done in relation to each characteristic, this impacts the weight of the results, but there were strong overall correlations discovered. Buffer width, species composition and abundance (of both riparian vegetation and macroinvertebrate species), and buffer length had the highest beneficial correlations on riparian ecosystems in the studies. More specifically, width had a strong relationship to decreases in erosion and Nitrogen (N) and Phosphorous (P), and in fewer studies a decrease in stream temperature and an increase in woody debris. Length shows a strong correlation to decreasing stream temperature, and composition was more like width, but more often correlating to stream temperature decrease. This would seem to infer that if management goals are to decrease stream temperature, length and species composition are key in addition to width of buffers. Age and density also showed a relationship to decreasing stream temperatures.

In the review, the highest correlations in degrading ecosystems were agriculture, temperature, logging, and high levels of N and P runoff. There were very few studies conducted in urban areas, so this review cannot accurately compare the three main land use types in this research paper: developed, agriculture, and natural or restored riparian habitats. Agriculture relates to an increase in erosion and N and P. Above average stream temperatures were shown in six studies to lead to decreases in fish abundance. Timber harvests had a more one to one correlative relationship of intentional removal of riparian vegetation. Higher anthropogenic N and P inputs simply equal increased N and P in nearby streams. The few studies related to urban development showed increased wastewater entering streams. An outline built around the framework of significant findings from Feld et al. as well as the relationship of development to riparian management will be addressed in more detail by looking at individual studies, starting with buffer size.

Table 1

Significant variables in riparian ecosystems by number of confirmational studies

Supports Ecosystem Health	Studies
Width	44
Composition	35
Length	24
Density	5
Age	6
Woody Debris	5
Light	5
P	1
Degrades ecosystem health	**Studies**
Agriculture	11
Temperature	6
Logging	6
N & P	6
Erosion	4
Density	3
Composition	3
% Erosion	2
Urban	2
Wastewater	2
Width	1

Source: (Feld et al., 2018).

Flood mitigation

Flooding in the Pacific Northwest, a particularly vulnerable area due to snowpacks and glaciers as watershed origination, is predicted to increase dramatically due to climate change (Safeeq et al., 2015). Flood mitigation is an ecosystem service that is often discussed separately from other benefits of riparian buffers, but there is a growing body of research comparing “nature-based solutions” to built infrastructure for flood control (Baldwin et al., 2022; Daigneault et al., 2016). Daigneault et al. (2016) found that planting 30-meter riparian buffers along all streams was the most cost-effective method of flood mitigation, and the most effective regardless of cost was planting native forest in grasslands in upstream areas. Elevating houses was the least cost-effective method overall.

Riparian management zones: buffer size and connectivity

Buffer width

While numerous studies have shown that larger buffer widths that mimic historic conditions support a wide array of ecosystem services, including filtering pollutants and nutrient run-off for better water quality (Anbumozhi et al., 2005; Mayer et al., 2005) providing snags and wood debris that is necessary for many aquatic species’ habitats, including salmon (McDade et al., 1990), reducing stream temperatures (Davies & Nelson, 1994; Fogel et al., 2022; Monohan, 2004), and providing wildlife habitat, some evidence also shows positive impacts with buffers as small as 15 meters (Mayer et al., 2005). Buffer widths are difficult to apply in a generalized sense, as individual riparian sites have many distinct characteristics that impact habitat conditions (Castelle et al., 1994; WDFW, 2020b; Wenger, 1999).

Applying policy regulations to a site-specific level is not very cost-effective or plausible to meet overall goals (Castelle et al., 1994; Tiwari et al., 2016; Wenger, 1999). As a result, those who have reviewed the best available science often recommend a method of guidance or regulation that is adaptable by offering a prescriptive buffer width that can also be site-specific. Site Potential Tree Height (SPTH) is one method that was devised in 1993 by the Forest Ecosystem Management Assessment Team (FEMAT) for managing federal lands in the Northwest, in part to protect endangered species like the spotted owl, as well as the 14 species of salmon currently listed in Washington State (WA Governor's Office, 2020; Reeves et al, 2018). $SPTH_{200}$ is recommended by the Washington Department of Fish and Wildlife as a best-science guideline for buffer widths in riparian management zones (WDFW, 2020b).

Site Potential Tree Height

$SPTH_{200}$ is based on the Site Index (SI) or potential height of a native tree in a specific subset bioregion, soil type, and ground slope, at two hundred years of age (FEMAT, 1993). Using SPTH as a riparian buffer width is largely modeled on slope formulas from research and field data for woody debris entering a stream, that relates distance to tree height (McDade et al., 1990; Sickle & Gregory, 1990), and the work of Chen et al. (1992) researching edge effects of old-growth clear-cuts on microclimate in Western Washington forests.

The ”FEMAT curves” illustrated in the 1993 Forest Ecosystem Management Assessment Team (FEMAT) report are a generalized approach based on research that uses meters and feet widths for buffer sizes, not tree height widths. While a formula might possibly be derived from research on woody debris and tree height/distance from stream, and the WDFW includes quite a few studies (mostly post-1993) with related data in Riparian Ecosystems, Volume I (WDFW, 2020a), the FEMAT report does not include methodology for using tree heights but refers to the curves of distance of SPTH to ecosystem effects as "generalized." It is unclear to this author from the source if this was chosen by the panel as a simplified management method of applying the science of buffer widths or based on a more specific tested methodology, but the WDFW riparian management guidelines do refer to FEMAT assuming old growth tree size as a baseline ecosystem measure (WDFW, 2020a). Chen et al. (1992) also mention a historical precedent for using two to three tree heights to buffer forest edge effects, so it may have been an accepted reference to the foresters involved in the panel. At least two forestry experiments later tested the use of SPTH as a buffer measurement in relation to woody debris contribution (Reid & Hilton, 1998) and riparian vertebrate habitats (Olson & Ares, 2022). Reid and Hilton (1998) concluded that one SPTH would contribute 96% of stream woody debris, but that 3 to 4 SPTH would be needed to buffer the impacts of large tree fall from the vulnerable edge of clearcuts. Olson and Ares (2022) found that one inaccessible "no entry" SPTH supported most vertebrate species, but that a managed/thinned forest that was two SPTH wide was less supportive, pointing to the need for more site-specific management practices.

Most of the studies utilized for FEMAT's management recommendations are based in the Pacific Northwest, but were conducted in coastal range forests, not in dryland areas of Eastern Washington and Oregon, or agricultural restoration buffers. However, the Site Index and SPTH are available for some riparian areas in the drylands region (WDFW, 2021). While some criticism of using SPTH could lump it with overly generalized buffer standards, as heard in legislative hearings for HB1838 (House Bill 1838, State of Washington, 2022; *Public Hearing of the House Rural Development, Agriculture & Natural Resources Committee: HB 1838 - Protecting, Restoring, and Maintaining Habitat for Salmon Recovery.*, 2022; WA State Legislature, 2022), SPTH is based on historical site-specific forest data, and attempts to approximate research findings. Acceptance of SPTH as a management application might increase if analyzed more specifically and rigorously through research, like the Reid and Hilton (1998) or Olson and Ares (2022) experiments, including in dryland and agricultural settings, though buffer widths wider than most Washington SPTHs are recommended in relation to some wildlife habitat goals.

Other buffer width prescriptions

Different management goals require different buffer width size ranges, and this differentiation is seldom acknowledged in policy guidance, including Washington State before 1994 (Castelle et al., 1994). The U.S. Forest Service (USFS) uses site variable methods for buffer application across the U.S., and this method was shown to be effective, and protected 20% more forestlands than individual states' buffers, which often ignored forest species composition in relation to buffer size (Jayasuriya et al., 2022). With federal, state, and local policies, however, the Pacific region of the U.S. has some of the most complex riparian management applications, including buffer size (Lee et al., 2004). The WDFW adjusted their guidelines for 2020 to offer a separate 100 ft buffer width minimum as an alternative to SPTH where it was not possible to apply based on geography, or in places where historical native vegetation and old growth tree heights were unknown (WDFW, 2020b). SPTH is largely related to research in heavily forested areas (FEMAT, 1993), but the 100 ft buffer minimum is based on over 30 years of research on pollutant and runoff filtration (Castelle et al., 1994; Lee et al., 2004; Mayer et al., 2005; Wenger, 1999; Zhang et al., 2010), and helps address water quality issues throughout the state in areas with different land use types or habitats (WDFW, 2020b).

The WDFW did a meta-analysis of buffer widths from several reviews related to water pollution, reanalyzing original data for more consistency across the studies as needed. While filtering by 80% of some pollutants seem to require smaller buffers, if management goals are to get close to full filtration, the buffer width correlated to 99% makes the most sense. The WDFW's weighted means for filtration of surface N required buffers at a minimum of 169 ft (95% filtration), and 200 ft (99% filtration) (Mayer et al., 2005; WDFW, 2020a; Zhang et al., 2010). Phosphorous was filtered by 95% at 87 ft, and by 99% at 101 ft, and pesticides were filtered by 95% at 59 ft, by 99% at 68 ft (WDFW, 2020a; Zhang et al., 2010); and sediment in streams was decreased by 95% at 101 ft, and by 99% at 153 ft (Liu et al., 2008; Sweeney & Newbold, 2014; Yuan et al., 2009; Zhang et al., 2010). The conclusion is that to improve water quality in relation to all these contaminants by 95%, the minimum buffer width should be 169 ft, or by 99%, 200 ft. A minimum of 153 ft might offer 99% filtration for all but surface N.

Because of the immense breadth of research on riparian buffer widths, this literature review is unable to be comprehensive without conducting a full meta-analysis, which would be its own project and has also already been done repeatedly. In summary, while some ecosystem services and water quality improvements can be made at smaller buffer sizes, 100 feet (or 30 meters) does seem to align with the minimum needed width to meet multiple management goals (Sweeney & Newbold, 2014), though meeting the needs for species diversity and habitat on average may be closer to a 100 meter minimum buffer width (Fischer et al., 2000), and much higher widths of 200m to 8000m combined with length may be needed to address issues in riparian areas adjacent to industrial agriculture (Gene et al., 2019) and urban environments (S. Li et al., 2009; Nava-López et al., 2016). In many ways, the WDFW's guidelines are actually conservative and practical to meet more immediate baseline goals for water quality, habitat, and wildlife protection.

Length, height, connectivity, slope

Length

More recent studies have started to look at the impact of length of habitat on riparian ecosystems. On a large river in China, landscape geospatial qualities of length and width had stronger correlations to water quality than land cover composition, but there were strong correlations between urban or forest land cover and length or width to water quality (K. Li et al., 2018b). The longer and closer the strips of urban development along the river, the lower the water quality, while inversely, wider buffers of forested land, with less length, showed stronger correlations to higher water quality. 2000 to 5000 m lengths of large rivers were shown in one study to be more explanatory for effects of land cover on aquatic species than riparian width (Knehtl et al., 2021). Another in Costa Rica showed a strong relationship between buffer length and water quality, and less correlation to buffer width over 15m. The results pointed to a recommendation for a minimum length of 500m, and an ideal prescription of 1000m long by 15m wide (Hilary et al., 2021). The buffer widths in the Costa Rica study were 15m, 50m, and 100m which contrasts to the study in China (K. Li et al., 2018b), which was done at a different scale, and showed that 300m wide and 8km long had the highest correlative value to water quality.

Height

Dewalle (2010) created a model to replicate stream shade on the summer solstice at 40 degrees latitude and found that 80% of shade could be met on streams smaller than 6m if 1) tree height was 30m or higher (or a ratio of 5x or greater height to stream width), 2) there was high density of trees, and 3) buffer width was 12m. Larger buffer widths were unnecessary in the model. While it makes sense that older or taller trees would provide better shade, in an on-site study in

Oregon pastureland, plantings of alder in grassland provided significant stream shade, even with a single row after 4-7 years, though shade outcomes were far better with 36 ft wide tree buffers, and after only 2-6 years (Bishaw et al., 2002). The average height of trees in the study was 3m after 3 years, and 5.6-8.4m after 5 years, with trees being significantly taller in the wider buffer. The authors also point out the importance of location of shade trees, which in the Pacific Northwest is south for streams flowing east-west. Besides shading, tree height and distance is also related to the quantity of woody debris entering a riparian ecosystem (McDade et al., 1990; WDFW, 2020a).

Connectivity and channelization

Floodplain connectivity is another factor that has been researched since at least the 1990s (Goodwin et al., 1997) but has been more recently examined in Washington State. One model looking at habitat change in the Chehalis River Basin estimated a 91% loss of side channel length since the mid-1800s (Beechie et al., 2021). In this study Beechie et al. concluded that awareness of levels of floodplain modification could help create models for salmon habitat restoration. A 20-year study examining the effects of dam removal in Cedar River, WA, found that three salmonid species populations were able to reestablish healthy populations after about 10 years, though different species reacted differently (Kiffney et al., 2023).

Species-specific effects were also found in a study in a model of the Chehalis River Basin, concluding that floodplain connectivity restoration in relation to stream temperatures was more significant than riparian restoration for Chinook and steelhead, who inhabit large rivers and streams, but riparian restoration was more important for coho, who spend more time in smaller tributary streams (Fogel et al., 2022). Restoring both led to significantly greater positive impacts for Spring-run Chinook salmon. Floodplain reconnection in the Columbia River Basin could also potentially support a 25% increase in side-tributary habitat, and 9% increase in Chinook abundance

(Bond et al., 2019). Due to the significance of these multiple findings, watershed-based assessment and plans to remove anthropogenic obstructions for returning channels to their natural paths could have a significant impact on stream temperatures and salmon abundance, especially when coupled with riparian restoration along smaller streams. Fogel et al. (2022) pointed out that many habitats are limited naturally for width of riparian vegetation buffers, and in those cases, floodplain connectivity was still effective.

Slope

The slope of the land in a riparian management zone (RMZ) may seem like an obvious contributor to erosion and pollutants to streams, but not all studies show a statistical relationship. A literature review of riparian buffers summarizes the relevance as being well-studied and suggests buffers should be wider with increased slope or an increased likelihood of erosion at a site (Wenger, 1999). However, slope was found to have a moderate to strong negative correlation to water pollutants in one watershed of Mexico City (Nava-López et al., 2016), though the authors of the study concluded it is likely related to very high slopes in the area studied, which were less accessible for anthropogenic land uses. This seems further confirmed as elevation had the strongest negative correlation to water pollutants. In Tasmania, Australia, clearcut slope angles had no correlation to aquatic species abundance or quality of stream habitat (Davies & Nelson, 1994). In that study, only buffer widths greater than 30m showed significant mitigation effects on clearcuts.

Riparian management zones: vegetation composition and impacts of land use/land cover

Previous studies illustrated how the width and other geospatial qualities of vegetative buffers impact streams. However, different types of vegetative land cover have also been shown to impact the quality or quantity of riparian habitat, though it seems to have a weaker correlation than geospatial qualities until assessment at larger watershed-level scales (Li et al., 2009; Nava-López et al., 2016; Wenger, 1999). Developed land, agricultural land (herbaceous, bush, tree crops, or bare soil), and other vegetated land (which has the potential to be defined as riparian if it contributes to the health of a riparian management area (EPA et al., 2015)), are the major categories researched and reviewed in this paper. While developed land often includes intentionally planted vegetation, including trees, it is generally sparse or disconnected, so land cover classification datasets like the National Land Cover Dataset classify it based on computationally weighted scales (Wickham et al., 2021).

Without vegetation in a riparian area, erosion is substantial (Beeson & Doyle, 1995; Chaney et al., 1990). In a study of a large river basin in China, vegetated land versus bare land (rocks, gravel, or soil) within 100 meters of a river basin had the highest positive correlations with water quality during dry seasons, and forested land most significantly in the rainy/monsoon season, as compared to agricultural, developed, and shrubland land use/land cover (S. Li et al., 2009). All land cover types besides forest (developed, agriculture, perennial agriculture/orchards) have been shown to have a negative relationship to water quality (Basnyat et al., 2000), and land use/land cover lacks variability in impacts until extension beyond 100 meters of a stream (Nava-López et al., 2016).

Grasses, especially native, have some beneficial impacts on aquatic habitats, especially for water filtration (Chaney et al., 1990) but their impact is substantially less overall than forested riparian buffers (Sargac et al., 2021). Vegetation composition in riparian management zones (RMZs) can also change in response to re-channelization (Camporeale et al., 2013; Chaney et al., 1990; Shafroth et al., 2002; Tabacchi et al., 2000) and invasive species introduction (D. M.

Richardson et al., 2007), and this change can have strong cultural impacts, especially on indigenous groups, in addition to ecological services (Stumpff et al., 2020).

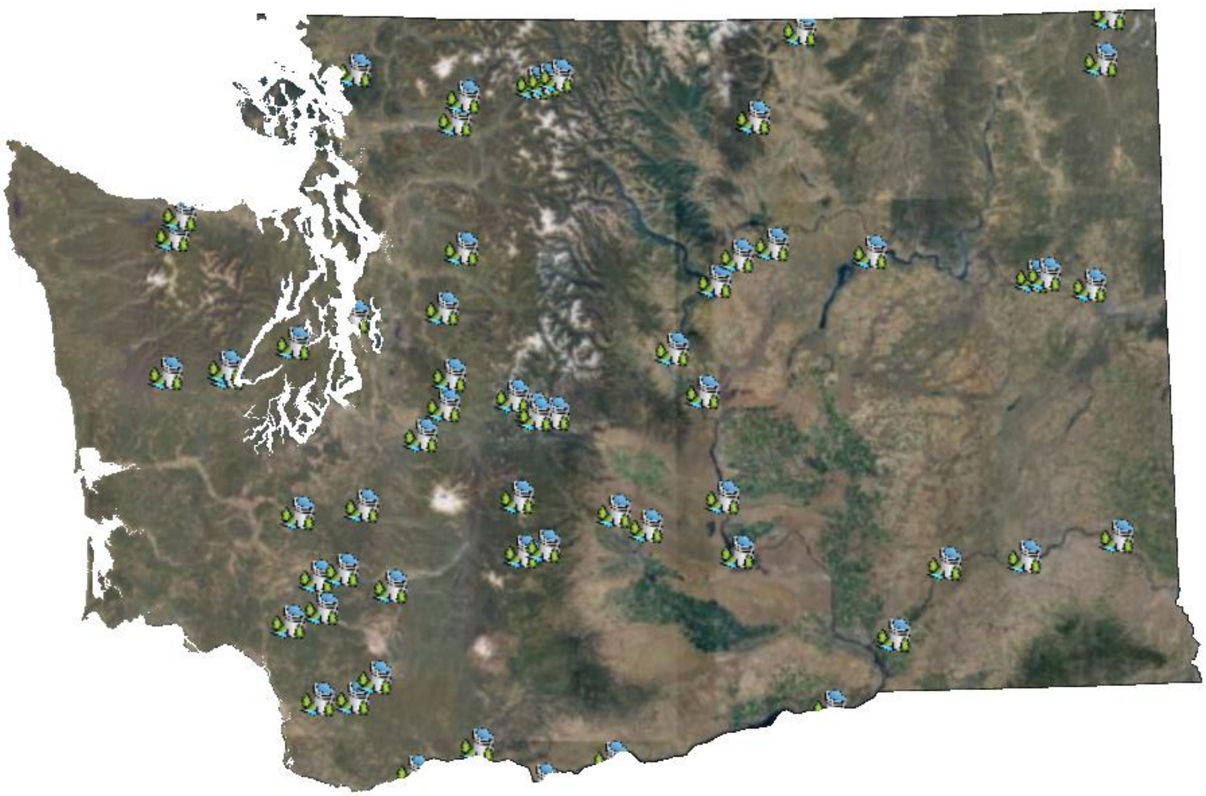
Long-term assessment of riparian restoration projects is lacking globally (González et al., 2015), and recognized as a problem at the state level in Washington (IEC & Plauché & Carr LLP, 2022), including research into understanding the impacts of vegetation composition on aquatic conditions both over time and in comparison, to unrestored and reference sites. Gonzalez et al. (2015) also determined that riparian restoration projects in the Northwestern United States have been predominantly focused on grazing lands, while globally most research on riparian vegetation has been on impacts of channelization restoration like dam-removal. Dams impact vegetation composition in the riparian zone by decreasing natural disturbance for native plant communities that thrive in periodic flooding and creating ecological openings for invasive species to become dominant, and dam-removal has been shown to be one of the most cost-effective methods to restore healthy riparian vegetation (González et al., 2015; Shafroth et al., 2002; Smith et al., 1998).

According to the Washington Department of Wildlife (WDFW, 2020), dryland areas of the state in the Columbia Plateau Ecoregion have been highly impacted by large dams built up until 1939 (Figures 1 and 2) that are still used to irrigate 1.17 million acres of farmland converted from shrub steppe. The native ecology of this region has been altered to the point that there are many areas where original plant and animal communities are unknown, and the native dam-building experts, beavers, have been decimated since Eastern Washington was colonized in the 1800s (WDFW, 2020). Improving riparian vegetation in locales with beavers has led to increased beaver activity, supporting additional sediment filtration and increased streamflow (Chaney et al., 1990). The National Oceanic and Atmospheric Administration’s (NOAA) Columbia Basin Historical Ecology Project has been working to investigate historical documents and photos and find reference sites that can help with their identification in riparian habitats (Figure 3) (NOAA Fisheries, 2023). The WDFW (2020) says that historic native plant species in this area are mostly deciduous and more diverse than in conifer forests, and the tallest trees only grow to about 20 ft. While native sedges and shrubs are the dominant species in some dryland riparian habitats, tree species were much more prevalent historically, and stream and river channels described as being much more dynamic than they are today (WDFW, 2020).

Research is sparse on interactions between vegetation composition and aquatic health in Eastern Washington, but recognition of this need has led the U.S. Forest Service (USFS) (Cupp & Lofgren, 2014), NOAA Fisheries Program (NOAA Fisheries, 2023), and the Washington Department of Fish and Wildlife and the Arid Lands Initiative (Arid Lands Initiative, 2023; WDFW Habitat Program, 2023a) to initiate studies or projects related to dryland ecologies in riparian habitats. Compared to Western Washington, Eastern Washington has few federally protected lands, and is mostly privatized and agricultural, making it far more difficult to make progress in terms of historical knowledge, identifying research sites, and initiating restoration efforts using ideal plant communities (NOAA Fisheries, 2023; WDFW, 2020b). There is evidence that diverse vegetation in drylands is important for protection from flooding and erosion, wind, and radiation, reducing evaporation and cooling soil temperatures (Chaney et al., 1990).

Figure 1

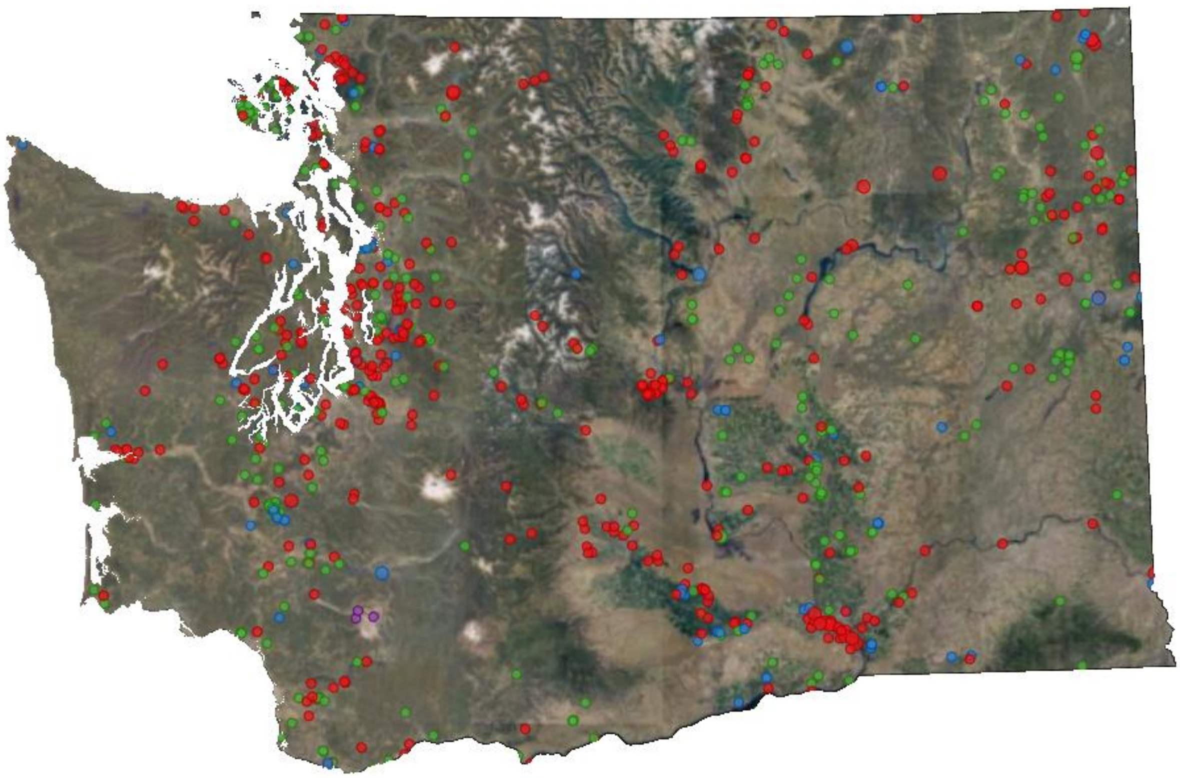
Map of large dams over 50 feet high in Washington State



Note: Original symbology on the NAIP Imagery Base map (US Army Corps of Engineers, FEMA, ESRI, USDA).

Figure 2

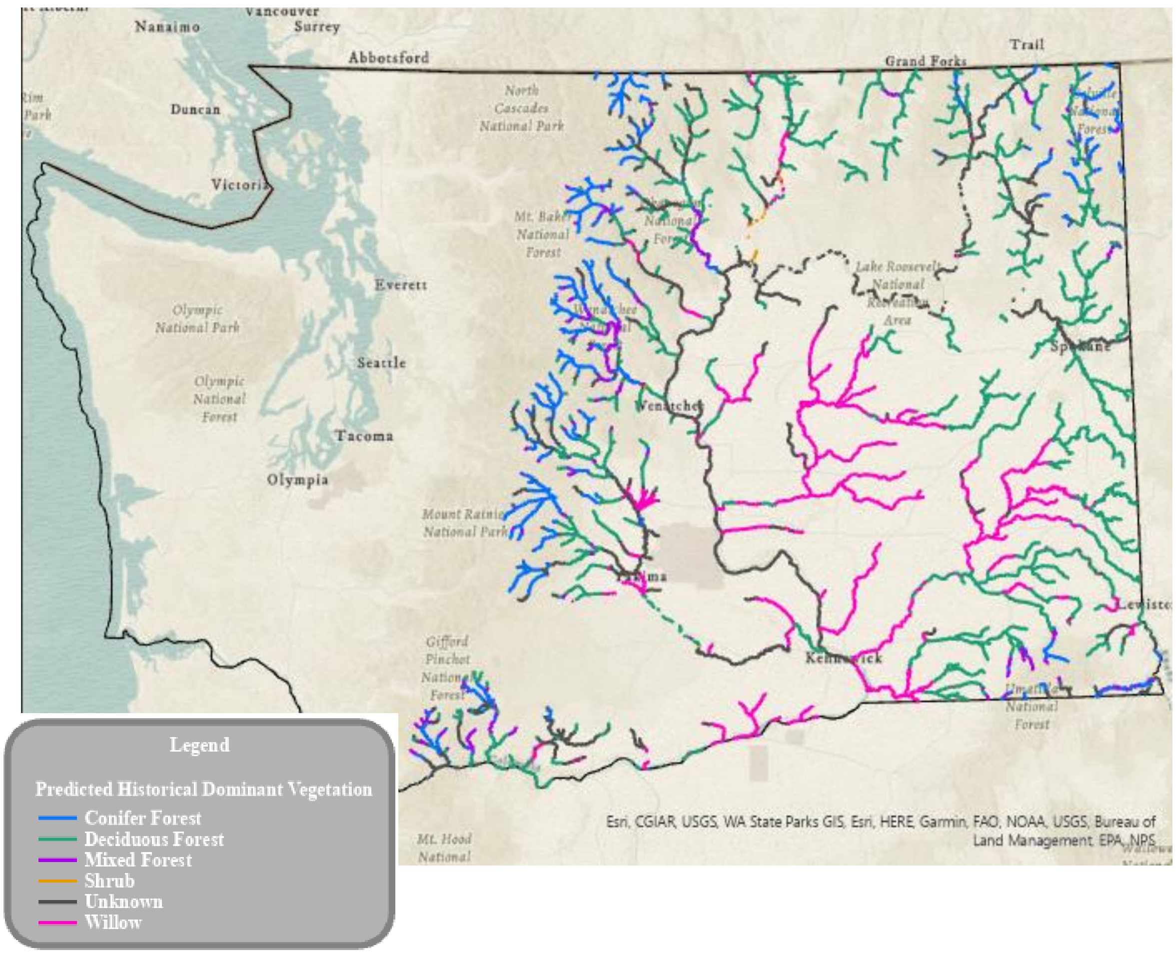
Map of all dams in Washington State from the National Dam Inventory dataset.



Note: Original symbology on the NAIP Imagery base map (US Army Corps of Engineers, FEMA, ESRI, USDA). Color coding and symbol size is based on maximum flow volume, but legend is not included to focus on visualization of quantity of dams.

Figure 3

Map of the NOAA Fisheries' Columbia Basin Historical Ecology Project showing dominant plant types in major riparian areas.



Note: Layer re-symbolized by color coding to accentuate differences.

Agricultural Vegetation

Research on buffers in agricultural lands often focuses on buffer "strips" of different types of vegetation. For example, a study in Iowa on agricultural lands compared a tree-shrub-native grass buffer (with the trees being closest to the stream) to monocrop buffers of cold-season grass, soybeans, corn, and pastureland for water infiltration, a signifier of soil quality (Bharati et al., 2002), performing best (multi-crop) to worst (pasture) in that order. Also in Iowa, a similar study showed that multi-crop strips of native trees and switchgrass sequestered carbon and immobilized nitrogen significantly better than nonnative fall/winter forage grasses and annual soybean-corn plantings (Tufekcioglu et al., 2003). Agroforestry is an interesting management tactic for riparian buffers in agricultural areas that is now supported within the Conservation Reserve Enhancement Program (CREP) and can actually improve species diversity beyond these multi-crop experiments, which impacts carbon sequestration and nitrogen-cycling further in a managed forest (Buchanan et al., 2020).

Some reviews show no significant difference between vegetation types for filtering nitrates and N from groundwater, though woody vegetation still shows a 10-15% increase over grasses (Mayer et al., 2005; Valkama et al., 2019; Wenger, 1999). Still, the ratio of forest to agricultural vegetation combined with buffer sizes of 45-175m may significantly improve water quality by as much as 40% (Pissarra et al., 2019). Additionally, forested areas with an open canopy and dense undergrowth as opposed to a dense canopy and sparse undergrowth may have substantial impacts on habitat quality (Broadmeadow & Nisbet, 2004).

Establishment of riparian buffers of 10.5-90m through CREP in agricultural areas in the Chesapeake area of Virginia led to habitat improvements for fish within a year in highly degraded areas (Teels et al., 2006). An interesting statistical finding was that fish habitat quality had a higher negative correlation to cropland than to pasture, and also a greater magnitude than a positive correlation to forested land. Regardless of success in vegetative establishment in the buffer areas, all areas showed improvement in habitat quality. One key element is that all areas were fenced off, so animal and human interference was reduced. This finding confirms some of the federal work done with grazing management in the West, where several case studies that used more passive management strategies, especially the use of fencing, led to major riparian habitat improvements (Armour et al., 1994; Kauffman et al., 1993).

According to a review in 1990 by the Environmental Protection Agency of livestock grazing, pasturelands may have had the largest negative impact on dryland riparian areas in the western United States, starting with overgrazing of lands in the late 1800s/early 1900s when native grasses were replaced by invasive grasses and shrubs or native plants with shallow roots (Chaney et al., 1990). With less substantial vegetation in riparian areas, combined with dams, streamflow decreased or dried up seasonally or permanently, caused more extreme stream temperatures seasonally, and became poor habitat for many aquatic and wildlife species. Livestock grazing also became a source of nonpoint water pollution (Chaney et al., 1990).

These long-term restoration projects on public lands in the dryland West have demonstrated several key vegetation observations:

1. Rotational grazing combined with "dormant" seasonal forage grasses significantly improves riparian habitat and forage (saving money for ranchers), but upland deterioration prevents full recovery in more arid lands. Seasonal timing is also important in some soils (planting earlier in the spring and leaving land to rest 10 months of the year), but unlikely to work in high rain areas due to soil compaction by the animals.
2. Some areas need long term restriction from grazing for restoration purposes, fencing off areas to prevent livestock from entering riparian areas. At several sites, ten years of rest resulted in dramatic improvement in native vegetative growth, streamflow, and erosion

control. Herding works equally well as fencing to prevent livestock access to riparian areas but is labor intensive.

3. Instream structures treat symptoms and cause more damage than aid riparian areas when grazing improvements are not made or they are poorly designed.
4. Fire Suppression also increased brushlands and invasives, which decreased surface water levels.
5. It may take centuries to restore riparian habitat in some ecosystems, and in glacial areas with little soil, it could take thousands of years. The longer it takes to start, the higher the economic and ecological loss.

(Armour et al., 1994; Belsky et al., 1999; Chaney et al., 1990; Elmore & Beschta, 1987)

Urban/development

There is significantly less recent research directly addressing riparian buffer characteristics in urban environments (Groffman et al., 2003). This may be partially related to a cultural viewpoint that built environments are “permanent” or provide an immense obstacle for regulation and policy change (Knutson & Naef, 1997). Urban streams also tend to be researched from the perspective of storm water drainage of impervious surfaces and non-source point pollution rather than specifically by mitigation methods (Basnyat et al., 2000). In many cities there is substantial interest in urban stream daylighting (or de-culverting) but published research in this field is not focused on riparian buffer size (Khirfan et al., 2020). Policy regulation related to residential lands/development or small businesses is also intrinsically different from corporate-owned development and businesses (Edwards et al., 2015).

While stormwater runoff from impervious surfaces concentrated in urban areas has a known impact on salmon habitat, in addition to other water quality issues, it is one of the least regulated pollution sources, and combined with climate change, has an exponential effect on stream ecosystems and species (Nelson et al., 2009; NWIFC, 2020). A direct negative correlation between the amount of impervious surface area and macroinvertebrate diversity has been found, showing that urban riparian environments are far less species rich than some agricultural areas that use riparian buffers and no-till practices adjacent to streams (C. W. May & Horner, 2000; Moore & Palmer, 2005).

Some studies have supported the significant scale of restoration of riparian areas needed in urban environments to improve ecosystem indicators. In one study in Germany, health indicators for macroinvertebrates were considered with the land use variables of agriculture, urban, and woody vegetation, and correlations showed that woody vegetation had a higher impact in agricultural and rural spaces within near-upstream habitats, but that distant upstream woody vegetation had a very significant relationship to health in urban environments (Palt et al., 2023). Impacts were greater in mixed use environments, and near stream woody vegetation in urban environments was often degraded, which may have impacted its significance on macroinvertebrate communities. This is congruent with studies mentioned in relation to buffer sizes for different land uses which showed water quality impacts of woody vegetation in urban environments required woody buffers as wide as 5000m and 8km long (Knehtl et al., 2021; K. Li et al., 2018b; Nava-López et al., 2016).

In urban areas of the Puget Sound lowlands, management of riparian management zones (RMZs) in developed areas has been inconsistent (May & Horner, 2000) and the number of intact buffers larger than 30m decreases dramatically the more developed the watershed (C. May & Geist, 2007). Watershed health indicators in the Puget Sound region have been linked directly to increased forest vegetation or wetlands and decreased road crossings in stream environments (McBride & Booth, 2005). If at least 35% of habitat within 100m of streams was forested, there was a strong correlation to improved habitat quality, and even higher if 50% was forested. As few as three road crossings within 1km of each other negatively impacted stream health (McBride & Booth, 2005).

Salmon abundance and causal relationships

According to the 2022 State of Salmon Report's interpretation of the "WDFW Adult Abundance Status and Trends Analysis" dataset for 2020-2022 (WA Governor's Office, 2022; WDFW, 2022; WDFW et al., 2022), only two endangered salmon species are close to meeting population goals in Washington State: Snake River Chinook and Hood Canal Summer Run Chum. Two more species are "making progress," but ten are "not keeping pace" or "in crisis." The United States National Marine Fisheries Service in their 5-year reviews of Endangered Salmon species of the Northwest most often associate problems with species abundance to channelization and lack of connectivity, especially in side tributaries to the mainstem rivers, due to dams, roads, culverts, levees, and development; high stream temperatures and poor water quality; degradation of habitat along tributaries; and waterflow decreases due to irrigation or other withdrawals. They additionally mention beaver removal, grazing, agriculture, mining, and silviculture in riparian areas (U.S. National Marine Fisheries Service. West Coast Region, 2022).

Dams built in the 1930s and 1940s contributed to the over 4000 miles of fish habitat loss and spawning blockage on the Columbia and Snake Rivers that started in the 1850s and continued through the mid-1990s (Wissmar et al., 1994). Wild runs were isolated and overfished, and large amounts of downstream hatchery fish from programs starting in 1949 altered the salmon gene pool on these rivers. Several management strategies to improve fish stocks in the Pacific Northwest have compounded the problem, often related to additional anthropogenic instream structures or channelization, or even adding logs and boulders in natural environments where it would be atypical (Kauffman et al., 1993).

While it is clear from looking at Figure 4 in the next chapter on policy that polluted waters are especially concentrated in highly developed watersheds, the impact on shellfish in less populated regions is substantial as highlighted in the State of Our Watersheds Report (NWIFC, 2020). While traditional pollutants, including bacteria, toxins, acidic pH changes, and algal blooms all impact shellfish harvests, increased stream temperatures is one of the most significant factors affecting salmon abundance, and is associated with pollution in addition to anthropogenic climate change, and habitat degradation (decreased shade on streams) (Barnowe-Meyer et al., 2021; Fogel et al., 2022; Fuller et al., 2022; McCullough, 1999; NWIFC, 2020).

In one recent climate change modeling simulation, researchers concluded that riparian restoration that maintained or increased forested buffer areas to 150m or more and other mainstem areas to 20-40m could lead to a decrease in the Snoqualmie River's summer stream temperatures by 10%, and improve Chinook mass and abundance (Fullerton et al., 2022). Under the model, if already managed forested areas remained a width of 150m, but all other buffer areas along the mainstem were 5-10m, stream temperatures would still increase with climate change. Done on a watershed scale to consider important regional characteristics, the authors recommend their model for use in other basins. Another model based on data from the Chehalis River in Western Washington shows that stream temperature increases could lead to salmon abundance losses as high as 95% (Spring-run Chinook) by the end of the century, but mitigation by floodplain re-connectivity (for salmon that spawn in larger rivers and streams) and habitat restoration (for salmon who tend to spawn in smaller stream tributaries and are more impacted by stream temperature) would have significant effects on mitigating stream temperature and salmon abundance (Fogel et al., 2022). Assessments and management of land use/land cover on salmon and other aquatic species may be needed on a scale as wide as 5000m, and as discussed earlier, length of riparian buffers on large rivers may be more significant (Knehtl et al., 2021).

THE POLICY OF RIPARIAN BUFFERS

Federal riparian management

The Clean Water Act and the Endangered Species Act

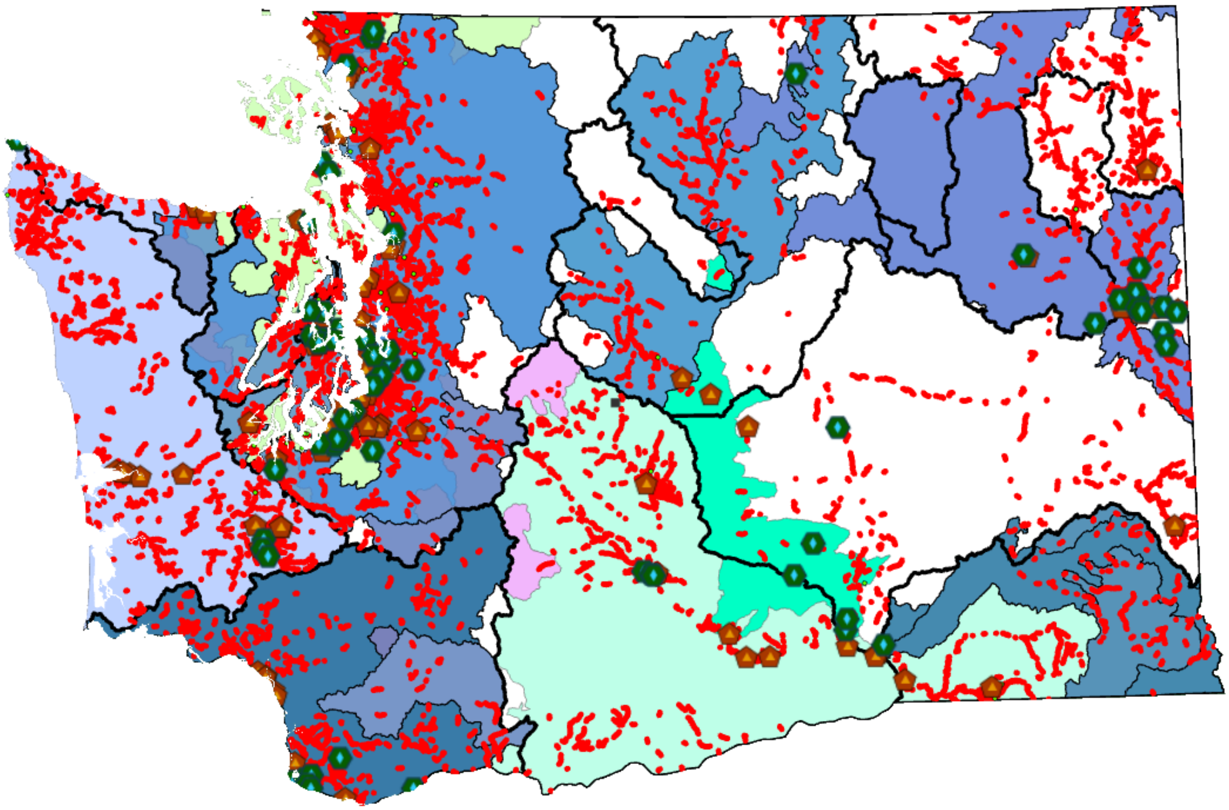
Emerging around the same time as the environmental movement and the newer scientific field of ecology, several key pieces of federal legislation were passed which have had a lasting impact on national and state riparian management. The Clean Water Act of 1972 (CWA) was an update on the Federal Water Pollution Control Act of 1948 (The Clean Water Act, 1972) and in 1973, the first iteration of the Endangered Species Act (ESA) was passed, and then amended in 1983 (Endangered Species Act, 1983). In practice, these two acts have the most substantial impact on both federal lands and state policies regarding riparian policy.

The Clean Water Act regulates polluters by permitting the amount and location of pollutant entry into waters nationwide (US EPA, 1978). It also monitors pollutants in waters and funds their cleanup when found to be at unsafe levels (US EPA, 2013). Permitted polluters must meet the minimum of localized standards for water quality in addition to federal guidelines, and this can include establishing riparian buffers (US EPA, 2005). Research has thus often focused on water quality in relation to riparian management and buffers. While the Clean Water Act addressed pollution discharge sites, the Water Quality Act of 1987 expanded to include nonpoint water pollution sources. However, this act is voluntary and nonregulatory, providing funding, and more interested in states meeting goals of water quality than "how" (Chaney, 1990).

The Endangered Species Act often operates more as a funnel for funding and protection guidelines than it does as a set of regulations (Fischman, 2005) but protection of species typically leads to protection of their habitats. Riparian habitat is especially vulnerable and shown to have a strong relationship to affected species' abundance and traits (Lind et al., 2019). An interesting picture emerges when overlaying maps of Washington's endangered salmon species' geographic range with water pollution monitoring by the Environmental Protection Agency (EPA) (EPA, 2023; WAECY & NOAA Fisheries, 2014; WRCO, 2017) (Figure 4). The extent of water pollution is immense in the salmon runs (Figure 4) (NWIFC, 2020), and is concentrated in higher population areas, especially along Puget Sound.

Figure 4

EPA Superfund sites, facilities of interest, and polluted waters, overlayed on ranges of endangered salmon species runs



Note: Source map layers were symbolized for clarity in overlay where able. Red lines are 2023 updated EPA water-quality assessed streams that are considered "polluted". Green hexagons are on the EPA's Superfund National Priorities List, and red hexagons are on the EPA's Facility of Interest list as potential pollution sources. Salmon species ranges overlap and are symbolized to show scope rather than specifics. Boundaries are RCO/GSRO Salmon Recovery Regions (EPA, 2023; WAECY & NOAA Fisheries, 2014; WRCO, 2017).

The Conservation Reserve Program and the Northwest Forest Plan

Major federal policies attempt to address these major land use types in relation to riparian management: urban/development, agriculture, and managed forests. While the Endangered Species Act (ESA) and Clean Water Act (CWA) potentially address issues in riparian habitats in all these land use types, the Conservation Reserve Program and the Northwest Forest Plan address riparian areas in agricultural and silvicultural land use areas (Barbarika, 2020; Reeves et al., 2018). The Conservation Reserve Program (CRP) has been administered by the U.S. Department of Agriculture since 1985 and is funded by federal legislation during Farm Bill cycles (Barbarika, 2020). The Forest Ecosystem Management Assessment Team (FEMAT) of 1993 created guidelines for riparian management in federal forested lands of the Northwest to address the effects of clearcuts in managed federal forests (FEMAT, 1993) and were implemented through the Northwest Forest Plan (NWFP) of 1994 (Reeves et al, 2018).

The Conservation Reserve Program (CRP) offers funding, resources, and support for voluntary participants in conservation measures on private lands, mostly farms and rangelands. Overall, acreage participating in the Conservation Reserve Program has decreased incrementally since 2007 (Barbarika, 2020). As of 2017, 1,195,638 acres in WA were enrolled in the CRP. This is about 8% of all agricultural land in Washington State (USDA, 2019). Riparian buffers have become a key action for the CRP, but the size of buffers recommended is not standardized to federal forest management recommendations and can be smaller than state or local guidelines. The 2018 Farm Bill updates to the program require a minimum 35-foot buffer or the minimum for state regulation, and funding is provided up to a maximum 180 feet width (Littlefield & Henrietta, 2019). In a state like Washington, where the state has provided guidelines but not regulations aside from established forests, CRP funding does not automatically support the 100 ft minimum for pollution control recommended by the WDFW, and in some cases, because of the maximum, would not provide funding for a buffer at SPTH width. However, it is essentially the only large-scale program addressing riparian buffers on agricultural lands in Washington State.

Some of the largest continuous areas of undisturbed natural riparian habitats are on federal lands, but the federal perspective until recently was to view forests as commodities with only small sections fully protected. The executive branch has recently attempted to shift policy goals and protect more forest lands (Biden, 2022; Vilsack, 2022). Regardless of this driving policy perspective of extractivism throughout the history of the United States Government, the FEMAT guidelines and NWFP considered the importance of species covered by the Endangered Species Act. As a result, within two years of implementation, the Northwest Forest Plan (NWFP) improved protections by identifying twenty-six genetic families of salmon and bull trout that qualified to be listed under the ESA, as opposed to only 3 listings prior (Reeves et al., 2018). The original NWFP prescribed riparian buffers of two times SPTH.

Treaty rights and salmon protection

Riparian management policy in Washington State has historically been intertwined with federal policy and treaty rights. Starting in the mid-1800s after the passing of the United States' Donation Land Act, non-Indigenous farmers took over native lands (Carpenter et al., 2008), often farming or grazing sheep in native prairies and wetlands, and along waterways in salmon spawning habitat (Wilkinson et al. 2005). A decrease in salmon population abundance and tribes' ability to fish for their livelihood, subsistence, and cultural and spiritual ceremonies was compounded by overfishing by settlers and the building of dams in the 1930s and 1940s (Wissmar et al., 1994). Dams, and fish-blocking culverts, as well as other impacts on habitat loss explored in this paper, impede the salmons' ability to spawn and run (NWIFC, 2020).

Fishing rights for salmon were restored to tribes by the treaties of Washington State after the Boldt decision in the U.S. Court of Appeals in 1975 (Boldt, 1975). This decision empowered tribes to use 50% of all salmon caught, and since then, with the listing of many species of salmon under the Endangered Species Act, the issue of habitat loss is now one of the biggest factors negatively impacting fishing rights (Fogel et al., 2022; NWIFC, 2022). Wild native salmon in Washington State have become rare or extinct in many cases (Crozier et al., 2021; Norman et al., 1988; Sedell & Luchessa, 1981). This problem is likely irreversible in terms of quantity ever meeting demand for salmon, so hatcheries have become important in maintaining tribes' ability to fish (NWIFC, 2020; Waples et al., 2017).

The relationship among the tribes and the federal and state governments is complex. Since states are not a sovereign nation, they are subject to "political Federalism" in their relationships to tribes and are also indebted or supported by the Federal Government through "fiscal Federalism" since many aspects of state funding are through Federal funds (Fischman, 2005). "Fiscal Federalism" is often a large chunk of funding for state or local projects, and funding for habitat restoration and salmon hatcheries for tribes has involved many different groups. The Federal Energy Regulatory Commission (FERC) negotiates between cities and tribes regarding dams, which have a major impact on riparian habitats (Blumm, 1986; Curtis & Buchanan, 2019).

Washington State riparian management policy and practice

2022 Washington state riparian program review

A comprehensive preliminary report on all riparian related state programs was submitted to and released in October 2022 by the Office of Financial Management and the Office of the Governor (IEC & Plauché & Carr LLP, 2022). Overall, there were thirty-one riparian programs identified in nine agencies, with ten programs operated by the Department of Ecology.

Of these, eighteen are voluntary, eight are regulatory, and three are scientific or technical assistance. The report assessed that only the Forest and Fish Law specifically regulates riparian management in a direct fashion, and that none of the programs use the WDFW's SPTH recommendation. The Forest and Fishes law integrated SPTH into its regulatory Habitat Conservations Plan in 2005, but to one hundred years (DNR, 2005).

Other State regulatory laws aim to protect riparian areas, through "critical area ordinances" (CAOs), including the Growth Management Act, the Shoreline Management Act, the Department of Ecology's Water Quality Program, the Department of Fish and Wildlife's Hydraulic Project Approval, and the Shorelands and Environmental Assistance Program (Plauché & Carr LLP & IEC, 2022). However, only occasionally do these include prescriptions of riparian buffers, with no consistent regulation as to width or size, and most are established on a county rather than watershed level recommended by reviews of riparian science (Lee et al., 2004; Mayer et al., 2005). This inconsistency, as well as the lack of coordination and funding for voluntary or regulated projects, may be a major impediment in making progress for endangered salmon population growth.

Additionally, working with the Office of the Governor pursuant to ESSB 5693 Sec. 130 (22), Plauché & Carr LLP & Industrial Economics, Incorporated (2022) found that few programs were funded well enough to fully implement their programs or assess their own effectiveness on-the-ground (though there were administrative effectiveness measures in place), and data was sparse. There also appears to be a lack of cooperation among agencies, as there are few standard approaches in place, and there are big goals, but underperformance meeting those goals. Guidelines offered differ in documents, especially from the actual regulations for forested riparian areas, though many concepts and their scientific basis are consistently mentioned.

Washington Department of Fish and Wildlife Guidelines

In 1997, the Washington Department of Fish and Wildlife created guidelines for riparian habitats as a priority and suggested riparian management zones (RMZs) that were a minimum of 150 feet, and up to 250 feet (more if it was necessary to match 100-year floodplains width) (Knutson & Naef, 1997). They also suggest the importance of connectivity and managing on a watershed level. Key factors besides width and connectivity for management were plant diversity that is predominantly native, canopy height diversity, allowing natural disturbance while minimizing human disturbance, presence of dead trees (snags) and other vegetative debris, irregular edges (shape), stabilized stream banks, and maintaining connection to nearby wetlands. The guidelines were based on a scientific review of 1500 articles and considered to be scientific best practice for the time (Knutson & Naef, 1997). The main goal of the guidelines was:

> *Maintain or enhance the structural and functional integrity of riparian habitat and associated aquatic systems needed to perpetually support fish and wildlife populations on both site and landscape levels.* (Knutson & Naef, 1997; p.78)

It is explicitly stated that these are generalized guidelines and do not take into consideration the needs of landowners or site-specific characteristics.

The Washington Department of Fish and Wildlife (WDFW), for its Priority Habitats and Species Program, recently updated their guidelines for riparian management in 2020, in the two-volume series, "Riparian Ecosystems" (WDFW, 2020). Their base recommendation for buffer zone width adopted the Forest Ecosystem Management Assessment Team (FEMAT) federal guidelines for Site Potential Tree Height at two hundred years ($SPTH_{200}$), and like the 1997 guidelines, emphasize the importance of connectivity and managing on a watershed level (WDFW, 2020). These policy guidelines do not match current actual practice in Washington State, other than forested lands protected under the Department of Natural Resources (DNR) by the Forest and Fish Laws of 1999. The DNR integrated SPTH into its regulatory Habitat Conservations Plan in 2005, but to one hundred years (DNR, 2005).

Salmon Recovery Act

In 1999, the Salmon Recovery Act, or "Forest and Fish Laws" created rules and regulations for protection of forests and fish on non-federal, non-tribal forest lands in Washington State, based on recommendations in the Forest and Fish Report. They emphasized protections required by the Endangered Species Act and the Clean Water Act (WA House Committee on Natural Resources, 1999). These rules were in effect until 2001, and the Forest Practices Habitat Conservation Plan (FPHCP) was not approved and implemented until 2006, in cooperation as a 50-year plan with the federal government (DNR, 2005). The plan offers specifics for different habitats and stream types, forest density, and assigns RMZ buffer widths based on categorization. For priority stream types, they include a core zone of 50 feet, with an inner zone and outer zone varying based on stream width, equaling between 90 to 200 feet. A key regulatory element embedded in the Act is the concept of "Adaptive Management," which allows for regulations to change as science-based best practices improve.

State legislative debates 2022-2023

Two major bills were written in 2022 and 2023 that attempted to address improving riparian habitat. House Bill 1838 (the Lorraine Loomis Act) in 2022 aimed to establish consistent regulations for all land use types throughout Washington State (House Bill 1838, State of Washington, 2022), and was supported by the Office of the Governor, the Northwest Indian Fisheries Commission and related tribes, the Department of Fish and Wildlife and Department of Ecology, and independent fishing interests (WA State Legislature, 2022). House Bill 1720 in 2023

(House Bill 1720, State of Washington, 2023) was a direct response to the debate around the Lorraine Loomis Act, establishing funding for a completely voluntary program to establish and maintain riparian buffers on private lands and would be managed by the State Conservation Commission. There was support from some members of the original group involved in the Lorraine Loomis Act after collaborative meetings with different stakeholders were held in late Fall and Winter of 2022, however it was not fully supported by members of several tribes and other stakeholders. The Lorraine Loomis Act never left committee, and HB 1720 never left the budget committee after initial changes were made. The public legislative meetings for both bills offered insight into different perspectives regarding riparian guidelines, regulations, and voluntary involvement.

Supporters of HB 1838 (2022) expressed that climate change is increasing water temperatures and with a lack of riparian cover, salmon populations which are already struggling may never respond to recovery efforts without taking widespread regulatory action (WA State Legislature, 2022). They also expressed trust in the science behind the act, and that voluntary participation by farmers in restoration was not working. Opposers believed that voluntary efforts have not worked because they have been chronically underfunded, and neither voluntary or regulatory funding to farmers will truly match the value of their land or economic losses in production. Some participants believed they would lose most or all their farms, even those that currently work with state agencies and in restoration efforts at some level. Some expressed they believed this would lead to cumulative negative impacts on the strong Washington agricultural economy, and the national food system.

There was also a thread of expression that the guidelines are not science based or best practice, and had not been peer reviewed, though one supporter responded accurately that the guidelines by the WDFW were peer-reviewed by the Washington State Academy of Sciences. Like some voices heard during the public hearings for the Lorraine Loomis Act (2022), social scientists Chapman et al. (2020) criticized the elevation of the WDFW's policies as science-based on the claim that the science behind riparian buffer widths is more values-based than admitted. Specifically, they note that the prescribed buffer widths are built on historical management decisions in the context of forest preservation (as opposed to buffer restoration on agricultural lands) yet apply the same guidelines to all lands (Chapman et al., 2020). While SPTH specifically was devised in relation to forest management and preservation in response to logging, the WDFW's guideline chapters were written by a panel of both internal and contracted scientists who are experts in the field and reviewed and edited with feedback by other scientists and included a review of over 1500 research articles and other comprehensive reviews (WDFW, 2020a).

Some opposing HB 1838 (2022) expressed that the bill and historic restoration efforts have targeted farmers and rural areas, while urban areas have a larger impact on stream temperatures and destruction of salmon habitat, and that rural dwellers are expected to pay for environmental issues that urban dwellers have exacerbated. Some even suggested an urban property tax that would help fund restoration efforts. The bill in fact included all riparian areas, even urban areas, but because of its exception for already built environments, it may have done little for restoration efforts in some urban locations. However, it specifically mentioned application to urban growth areas delineated in Comprehensive Plans completed under the Growth Management Act.

What was clear in the hearing was that there were strong feelings on both sides, but also there seemed to be some level of misunderstanding of what the bill said and how it might impact private landowners. For example, those that were worried they would lose most of their farm may not have known about the exception for smaller areas where buffers would take more than 50% of the acreage. Additionally, while the most current federal Farm Bill (2018) included wording allowing for harvest of certain agricultural products within a forested riparian buffer funded through the Conservation Reserve Program, there was no wording related to this in the Lorraine Loomis Act, nor in the WDFW's guidelines. Adaptability for allowing some economization of the outer riparian buffer might increase support by some farmers.

The debate continued in 2023 during the public hearing for House Bill 1720 ("WA State Legislature Public Hearing for HB 1720," 2023), though many who supported the Lorraine Loomis Act also supported this bill, or the intent of the bill as a way to compromise and move forward with increasing investment in riparian buffers in agricultural areas. The Washington Farm Bureau, the Chairman of the Jamestown S'Klallam Tribe, and others mention how it provides a region-specific (Eastern and Western Washington) focus. However, those who opposed in its current iteration, including representatives of Puget Sound Partnership (which helps aid voluntary restoration efforts), the Department of Ecology, and some tribal chairpersons including those of the Skokomish and Nisqually tribes, felt the bill would not do enough in terms of participation, oversight, or technical expertise, and the goal to improve salmon habitat, and collaboration should continue to come up with a sounder piece of legislation that applies to all land use types in Washington.

Agriculture: voluntary versus regulated participation in riparian restoration

Research on landowners' attitudes and willingness to participate in voluntary riparian management programs highlights longstanding conflicts. Attitudes are largely knowledge and value-based, more so than economic reasoning or awareness of programs that support funding for riparian restoration on private lands (Liebert et al., 2022; Yu & Belcher, 2011). Buffer guidelines are based on science with end goals to protect fish and wildlife (Belcher et al., 1997; WDFW, 2020), water quality and human health, or prevent flooding (Daigneault et al., 2016; Safeeq et al., 2015). In practice, however, the amount of land required is often more than private landowners are willing to take out of agricultural or other use. Many Washington state farmers and their advocates have expressed unwillingness to follow a regulation of SPTH-based buffers, for this reason. Interestingly, a nationwide research survey of small, medium, and large organic farms, found that farms less than 40 acres were the most likely to participate in riparian buffer restoration (Liebert et al., 2022). This reinforces that lack of participation is based more on values, knowledge, and perceptions than actual impacts on land.

While cultural differences are important to consider in research that discusses human perceptions, one study from Ireland seemed to reflect similar concerns by participants as has been mentioned in the policy debate in Washington. The majority (53%) of farmers in the study said they would not be willing to participate in riparian buffer restoration, with their biggest fears being related to the inconvenience of interference in their regular farming systems (45%) and taking land out of production (22%), but the major attitudes as having significant relationship to whether farmers participated was a) whether they had previously participated in an environmentally focused incentive program, and b) general attitudes towards environmental issues (Buckley et al., 2012). Similar to the Irish study, a 1999 study in Oregon to estimate willingness to participate in the Conservation Reserve Enhancement Program (CREP) found that 59% would not choose to participate (Kingsbury & Boggess, 1999). Significant factors affecting participation were also similar, with the most significant being the lack of flexibility in their farming system, especially to adapt to economic need, and fear of unknown restrictions at the end of a 15-year contract. Interestingly, the amount of compensation or effect of taking land out of production were not key factors. Education about riparian buffers, in addition to general attitudes and values around environmental issues, have been shown to have significance in other studies, while economic factors like compensation are insignificant (Valdivia & Poulos, 2009). Age is also a factor in some studies, with older participants showing more reluctance (Valdivia & Poulos, 2009; Yu & Belcher, 2011).

Experience, related education, and values seem to be the driving factors, but the description in public hearings of the 2023 Washington State legislation for HB 1720 for a voluntary riparian compensation program seemed to specifically ask for a limited to no budget for "outreach and education", and was emphasized by the reader of the legislation (WA State Legislature, 2023). While there was more buy-in from agricultural interests in the concept of a voluntary program, in practice, CREP in Washington, while one of the largest conservation and voluntary compensation programs for riparian buffers has had an average of 51 new enrollments between 2004 to 2022, but has been declining in enrollment since 2015 and is at an all-time low (Cochrane, 2022). Additionally, only 10% of eligible farms participate, and tend to be concentrated in a small portion of conservation districts (Plauché & Carr LLP & IEC, 2022).

A review of case studies in 1990 by the Environmental Protection Agency (EPA) of pasturelands in Western drylands evaluated long-term relationships to livestock owners and improvements (or lack of) in riparian areas and found that clear, realistic site-specific riparian goals and cooperation between individuals and entities were key for successful riparian restoration (Chaney et al., 1990). Even major habitat and forage land improvements as evidence shown at long-term demonstration sites had no impact on rancher grazing methods if they were uninterested in cooperation. This lack of cooperation in the 1970s to 1990s (and in some cases still today) was located on leased public lands, and still could not be enforced. Cost-sharing (including fishers) was one reason cooperation occurred and using funds for quicker restoration rather than research with “obvious” results was helpful in public/private relationships (Chaney et al., 1990).

These programs and studies all specifically address riparian restoration in agricultural areas, but there are very few programs in Washington State that fund restoration on private lands in urban areas unless they are managed forests covered under the Fish and Forests Law. The Stormwater Financial Assistance Program offers some funding in urban areas to individuals as well as nonprofits and businesses but there are few if any other resources available (Plauché & Carr LLP & IEC, 2022). This could be an important missing policy and funding piece.

Riparian land in conservation

Riparian land is protected or conserved through federal, tribal, and state programs, county and municipal protection and zoning, conservation easements and land trusts through private, public, and nonprofit ownership, and through some newer innovations like community forests (Nisqually Land Trust, 2023). Research is often divided between studying traits of already long-established riparian buffer areas, and comparing or measuring success of restored areas, but policy regulations, protections, and funding are mostly focused on preservation (like the Forests and Fish Law), rather than restoration in urban or agricultural areas. Because government sponsored funding is often lacking, non-governmental organizations (NGOs) have become major funders themselves, or managers of government funds, for restoration projects. The “Study Design and Methodologies” chapter includes information on publicly available datasets of protected and conserved lands by many of the listed owner types, and the Gap Analysis Project (GAP) status codes used to define levels of protection (Table 5).

Connectivity of wildlife corridors is a difficult goal to accomplish nationally, due to the fragmented nature of landownership and land use in the United States, but some researchers believe it may be accomplished through a focus on protection of riparian corridors coordinated at a larger scale using already established networks (Fremier et al., 2015; Gregory et al., 2021). One research question that is not readily apparent, even on public lands which may have various levels of protection based on GAP status, or due to historical land uses, is how much riparian habitat is already being conserved, including through voluntary programs? An answer is provided based on the research in this paper in the results section (Tables 14 and 15).

CONCLUSION

Determining the size of riparian buffers is a controversial point in creating policy regulations. Research shows the strongest correlations with floodplain connectivity (Bond et al., 2019; Fogel et al., 2022; Kiffney et al., 2023), size of buffers (Castelle et al., 1994; Davies & Nelson, 1994; Mayer et al., 2005; Nava-López et al., 2016; Sweeney & Newbold, 2014; Wenger, 1999; Zhang et al., 2010), and land use type/vegetative composition (Basnyat et al., 2000; Li et al., 2009; Sargac et al., 2021) to water quality, aquatic habitats, and stream temperature, including better outcomes for salmon species (Fogel et al., 2022; Fullerton et al., 2022; Kiffney et al., 2023). However, size is often related to length of buffers (Hilary et al., 2021; Knehtl et al., 2021; K. Li et al., 2018b), and qualities like age and proper density levels of canopy are also significant (Feld et al., 2018a). These latter qualities are likely to be interconnected to tree height and undergrowth present in old growth forest habitat (Broadmeadow & Nisbet, 2004), and tree height and distance from the stream, including $SPTH_{200}$ as a buffer size, have been shown to have significant impact on woody debris entering a riparian system (Fox, 2003; McDade et al., 1990; Olson & Ares, 2022; Reid & Hilton, 1998; Sickle & Gregory, 1990). There is also evidence that much larger buffers than $SPTH_{200}$ may be needed for some management outcomes, especially to filter water pollution from developed areas (Fischer et al., 2000; Gene et al., 2019; S. Li et al., 2009; Nava-López et al., 2016).

While agricultural areas may need smaller buffers than developed areas, the research shows that substantial ≥30m diverse multi-crop buffers with a high forest to agriculture ratio closest to streams are needed to meet most riparian management goals (Basnyat et al., 2000; Mayer et al., 2005; Pissarra et al., 2019; Wenger, 1999). Additionally, while crops can have a more negative impact on water quality compared to grasses, pasturelands are often close to streams, especially in the dryland West (Armour et al., 1994; Belsky et al., 1999; Chaney et al., 1990). Long-term management observation of these habitats concludes that exclusion of livestock from riparian areas, native tree, shrub, and grass restoration, and the practice of rotational grazing, are all necessary to restore riparian areas. In the Eastern drylands, this restoration may take hundreds if not thousands of years to reach pre-colonial riparian habitat and water quality (Chaney et al., 1990).

While the need to act to support salmon recovery is pressing, the lack of clear information for how the application of statewide standards for riparian management would behave economically or impact farmers may need to be clarified to gain more support for applying any regulations or voluntary restoration policy. Different factions support regulatory policy, while others support voluntary participation and funding (WA State Legislature, 2022, 2023). Federal programs and land management have the largest scope, within public lands and through the Clean Water Act (CWA), Endangered Species Act (ESA), Northwest Forest Plan (NWFP), Conservation Reserve Enhancement Program (CREP), and the National Oceanic and Atmospheric Administration (NOAA) Fisheries program in conjunction with Washington states' sovereign tribes, followed by the States' Fish and Forests Act, the Growth Management Act (GMA), and the Shoreline Management Act (SMA) on a state and local level, as well as federally mandated salmon barrier removals. While there are substantial efforts by non-governmental organizations (NGOs) in Washington State in addition to CREP funding for conservation and restoration efforts based on voluntary participation and funding in riparian areas, participation in programs like CREP are at an all-time low (Cochrane, 2022; Plauché & Carr LLP & IEC, 2022). Research shows that a minority of farmers are willing to participate in these types of programs, but the reasoning is related to reluctance to change production systems, flexibility to adapt to farm needs during a contract, and attitudes and experience with environmental values and programs, more so than economics (Kingsbury & Boggess, 1999; Liebert et al., 2022; Valdivia & Poulos, 2009; Yu & Belcher, 2011). Further, outside of regulation by the Growth Management Act, applicable only in larger counties (and not delineated by watershed), there is little funding for private land restoration or research on the impacts of riparian buffers in developed or urban environments (Plauché & Carr LLP & IEC, 2022), despite its much wider (up to thousands of meters) reach on water quality.

A broad state-wide analysis to assess the current status of land use and land cover in riparian areas using the Washington Department of Wildlife's riparian management guidelines for buffers offers more insight for all sides of this issue. The research in this thesis aimed to address this need, by considering variables of stream buffer size, private versus public landownership, and Western versus Eastern Washington in relation to land cover composition using the broad categories of development, agriculture, and potential riparian, as well as more specific differentiations between low/open and medium/high development, crops and pastureland, and woody or shrub or barren land cover. Additionally, considering temporal changes since 2001 helps assess broader progress made by both regulatory and voluntary efforts using the same variables in relation to land composition. Lastly, quantifying percentages of conservation of public versus private landowners within the riparian buffers can help determine how much land is already protected, and one measure for the level of participation in voluntary efforts by private parties versus public regulatory efforts.

CHAPTER 3: STUDY DESIGN AND METHODOLOGY

OVERVIEW

The goal of this research was to attempt to answer the following questions:

1. What percentage of riparian management zones in Washington State, as defined by the Department of Fish and Wildlife's guidelines, are in riparian habitat land cover versus other land cover types on both private and public lands?
2. How much land in these zones is currently protected from development by federal, state, county, or municipal mandates, as well as private or NGO conservation easements?
3. How has land cover in the riparian management zones changed temporally (2001-2019)?

To perform the analyses for these research questions in ESRI's ArcGIS Pro, it was necessary to create (or edit source files for) state and Water Resource Inventory Area (WRIA) boundary layers, a public land layer, a tribal lands layer, a Site Potential Tree Height (SPTH) layer, base hydrological layers representing all streams in Washington State, three sizes of stream buffer layers, clipped land cover rasters, conservation layers clipped inside the buffer polygons, as well as table results for multiple raster calculations. Most layers required editing and adding fields to attribute tables of source layers, as well as joins, merges, unions, and dissolves to get the final analysis products.

The Department of Fish and Wildlife's riparian management best practice science guidelines for salmon spawning and water quality (WDFW, 2020) include a stream buffer width based on Site Potential Tree Height at two hundred years ($SPTH_{200}$) or a 100 ft minimum buffer to filter pollution where SPTH is less than 100 feet (or not available). To answer the first research question, percentages of potential riparian land cover (as defined below) were compared to other land cover types within three prescribed buffer widths: two fixed-width of 50 ft and 100 ft, and one variable width, the maximum of either 100 ft or Site Potential Tree Height ($SPTH_{200}$). For simplicity, the anacronym "SPTH" for this buffer prescription is used throughout the research methods and results is referring to $SPTH_{200}$. The smaller 50 ft width was included in the analysis for a more conservative comparison to the WDFW's recommended buffer widths that is closer to some minimum recommendations in the literature.

After stream buffer polygon layers were created based on modified national and state hydrological layers (listed in the section "Map features and datasets"), land cover raster layers from the U.S. Department of Agriculture's (USDA) 2021 Cropland Data Layer (CDL) (USDA-NASS, 2021) were then clipped to the shape of each of the buffer widths using the "Extract by Mask" tool, and the modified public land layer (US Census Bureau, 2021; USGS GAP, 2022; WA Parcels Working Group et al., 2014; WRCO, 2019) was also used to "Clip Raster" for each CDL raster buffer prescription layer. From these map layers, cell counts of each classification of land cover within each buffer prescription were exported or transcribed into Excel files, and the "Tabulate Area" and "Summarize" tools were used to create tables for export by WRIA or other variables. Statistical comparisons using derived percentages of land cover classifications in each buffer prescription were conducted between all, public, and private lands in aggregate and by subregion. To honor tribal sovereignty, known tribal lands were excluded, as recommended in Washington and tribal policy documents unless requested or permission is granted (Lorraine Loomis Act, 2022; WRCO, 2019; WDFW, 2020b). This information was presented for the whole state, by Western and Eastern Washington, by public and private landownership, as well as by individual WRIA.

To answer the second research question, which was inspired by an earlier study in Skagit County (Greenberg & Carson, 2010), two authoritative publicly available conservation datasets, the National Conservation Easement Dataset (NCED) (U.S. Endowment for Forestry and Communities et al., 2022) and the Protected Areas Database (PAD) (USGS GAP, 2022) were edited and clipped within the three buffer prescriptions to calculate the percentage of total, public, and private land protected from development based on a Gap Analysis Project (GAP) status of 1-3 (Table 5). The polygon layers were spatially joined to the WRIA data using "closest match" and a field was added to calculate geometry in U.S. survey acres for each extracted polygon, then summarized by geographical region and public or private/NGO ownership. They were measured as a percentage of total acreage (also "calculated by geometry" and with a WRIA spatial join) of each polygon buffer layer ("all WA" and "public") and from derived "private" land percentages.

The third research question asking how land use and land cover (LULC) in Washington State has changed over time was assessed using the federal LULC rasters from the 2001 and 2019 National Land Cover Datasets (NLCDs) (Dewitz & U.S. Geological Survey, 2003, 2021). Analyses were repeated for each raster as with the original 2021 CDL raster, calculating cell counts within buffers, by public land, deriving "private" land data from the "all WA" and "public" land layers, by WRIA and Western and Eastern Washington, and by two levels of classification, the "simple" and "reclass" categories. Percentages were calculated in Excel, and 2001 data was subtracted from 2019 data, and statistical analyses were conducted with the percentage change data based on WRIA.

Mapping standards and parameters

The main method of data collection for this project was using available "authoritative" ArcGIS mapping layers and publicly available datasets (shapefiles, geodatabases, and associated data and metadata) from state and federal agencies, as well as non-governmental organizations (NGOs) and ESRI where applicable. Coordinate systems used were based on Washington State geographic information systems (GIS) mapping standards (*Standard 161.01 - Geodetic Control Data Standard*, 2020). All layers were projected to the NAD HARN 83 Washington State Plane South projected coordinates, with NAVD 88 coordinates for vertical reference, run through analyses using the same overall extent, and raster layers used the same cell size based on a 30-meter raster cell (98.4252 U.S. survey feet) which was reduced to half that size (approximately 49.2126 U.S. survey feet) to accommodate measurements within the 50 ft buffer polygon. Consistency was maintained by using the same base layers throughout the analysis. While maps are based on the best data publicly available, this does not guarantee a high level of accuracy in "authoritative" data. Some limitations to the research are addressed in the final section of this chapter.

Final analysis products include associated map layers, plots from specific analyses, output tables of percentages by land cover types at different classification levels in the three buffer prescriptions, by public and private land, by West and East, by individual Water Resource Inventory Area (WRIA), currently conserved lands, and temporal changes, and tables and figures of statistical results from correlative analysis (Pearson's *r*) and two-way analyses of variance (ANOVA) supported by analytical and graphing tools in Excel and R (Microsoft, 2023; R Core Team, 2023).

Map Features & Datasets

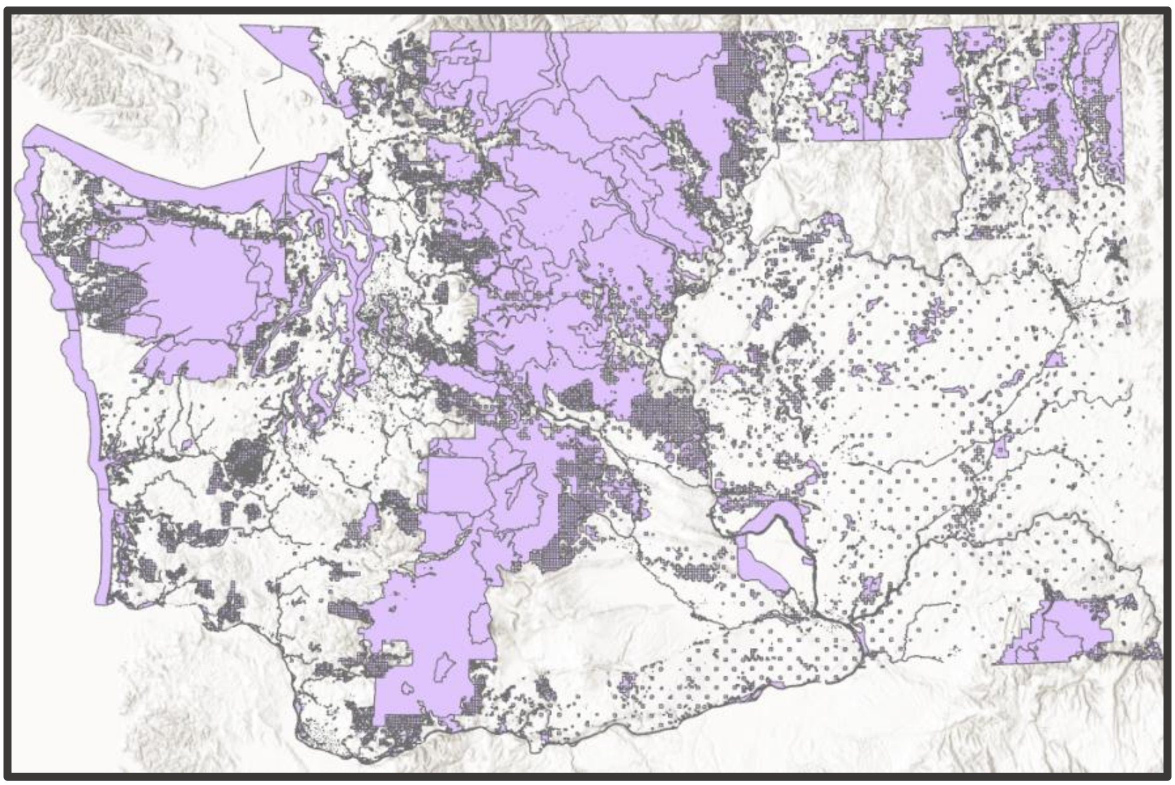
Boundary layers

The first step in the analysis was to modify existing authoritative polygon boundary datasets to clip or analyze all other feature and raster layers. All boundary layers were projected to the State geodesic standards. There were four major boundary layers: Washington State, a sovereign nations land layer, a public lands layer (Figure 5), and a Water Resource Inventory Area (WRIA) layer (Figure 6). The Washington State boundary layer was created from the U.S. Census Bureau's Tiger shapefiles (US Census Bureau, 2021). The same dataset was then used in combination with derived data from the Public Lands Inventory (WRCO, 2019) and Protected Areas Database (PADUS 3.0) (USGS GAP, 2022) to define a sovereign nations layer which was clipped to the Washington State boundary layer. The "Erase" tool was then used on the Washington State boundary layer to create a mask layer that would not include sovereign nations based on the extent of publicly available data (to honor sovereignty until permission is granted to run a similar analysis).

A public lands layer was created by clipping (to Washington State) and merging (erasing overlap) of these datasets: the Public Lands Inventory (WRCO, 2019), federal lands delineated in the US Census' Tiger database (US Census Bureau, 2021), the Protected Areas Database (PADUS 3.0) (USGS GAP, 2022), and the Washington State Parcel Database (WA Parcels Working Group et al., 2014) (Figure 5). The layer was then clipped to remove some small amounts of overlap with known native lands. Finally, the Washington State Water Resource Inventory Area (WRIA) dataset layer (WAECY, 2022) was clipped to also remove sovereign lands. All layers were based on the most recent version of datasets updated up to February or June 2023, and these base polygon layers were used to extract all raster layers, despite temporal changes in boundaries that may exist between 2001-2023, as it was out of the scope of this research and accessibility of data to determine historical differences in boundaries. Additionally, some lands have multiple levels of mutual or disputed multi-ownership or management and may not always be depicted accurately. Finally, public lands also include lands that are leased to private farmers, ranchers, timber companies, and mining companies, and private lands often have public easements that were not determined in this analysis to that level of detail.

Figure 5

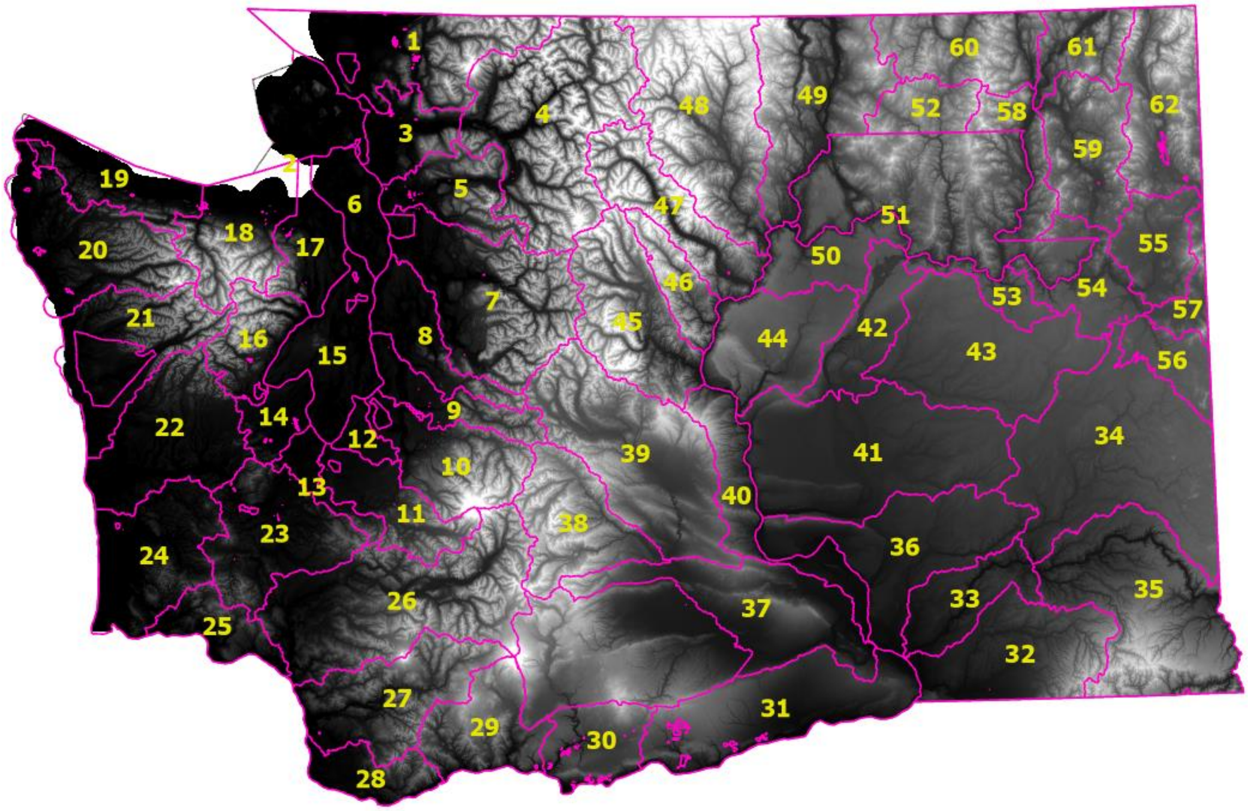
Public Lands Layer for Washington State used to extract public data from all "public" layers.



Source: ESRI, WA RCO, US Census.

Figure 6

Symbolized WRIA layer for Washington State.



Note: WRIA Layer was used to extract data from each buffer layer. Background raster is a clipped, projected, and re-stretched mosaic of the NHD Plus National Elevation Database (NED) digital elevation models (DEMs) of the hydro DEM for WUC 2s: 17b, 17c, and 17d (source: ESRI, WA DNR, USGS).

Watershed level mapping

Mapping related to policy is often associated with political and cultural/economic boundaries. However, natural ecosystems related to our hydrological systems are best assessed in relation to watersheds (Edwards et al., 2015; J. R. Cooper, 1987; C. W. May & Horner, 2000; Nava-López et al., 2016; Shaw & Cooper, 2008; WDFW, 2020a). Planning for watersheds is often a collaborative effort with multiple stakeholders and supports the tendency for broader policy versus that of Growth Management Act planning and regulations that apply to local municipalities which are smaller than watersheds and may have political boundaries that intersect several watersheds. Water Resource Inventory Areas are the most similar political boundary to natural watersheds, and because of the intersection of policy with natural environment in this research, were chosen as an effective subregion delineator. The choice to breakdown data by watershed in addition to the overall political boundary by state is based on the ecological nature of the impact of riparian buffers. GIS analyses of riparian buffers that have been conducted in Washington State and published for the public have been done on both the watershed and county level (Greenberg & Carson, 2010; NWIFC, 2020; Snohomish Conservation District, 2017).

Hydrologic line and polygon layers, active flood zones, and CMZs

The next step in the analysis was to edit, modify, and merge hydrologic stream data from the high resolution National Hydrography Dataset (NHD) (USGS, 2023), Washington Department of Natural Resources watercourse hydrological lines and polygons datasets (DNR, 2021b), Washington State Department of Fish and Wildlife's Visible Surface Water (VSW) data derived from high resolution 2017 National Agricultural Imagery Program (NAIP) imagery (WDFW Habitat Program, 2023b), ESRI's USA Flood Hazard Reduced Set map layer derived from the

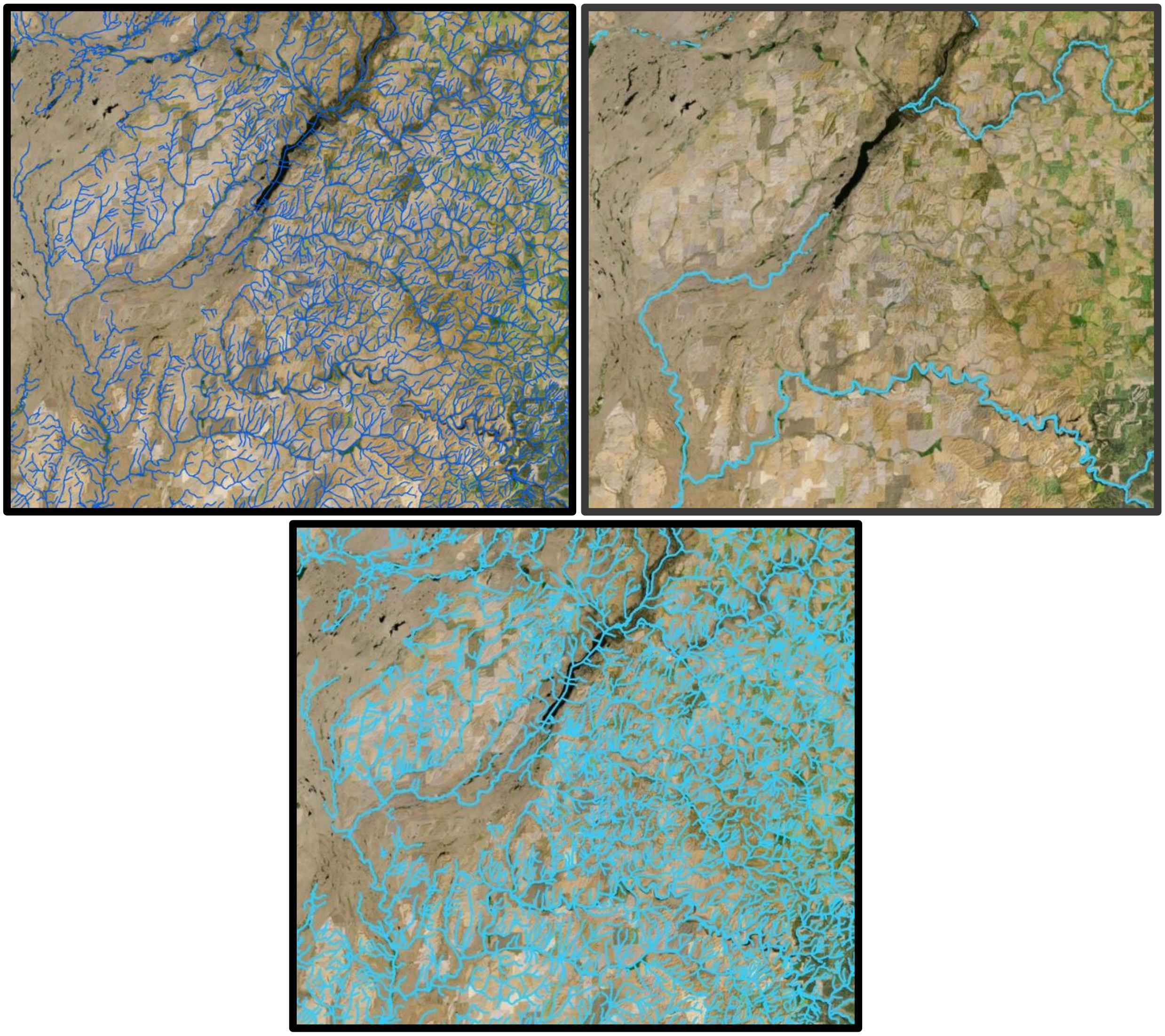
Federal Emergency Management Agency's (FEMA) flood hazard maps (FEMA & Esri, 2022), the National Oceanographic and Atmospheric Agency Fisheries Program's Salmon Habitat Status and Trend Monitoring Program hydroline layer (NOAA Fisheries, 2018), and the Washington Department of Ecology's Channel Migration Potential (CHAMP) feature layer that projects channel migration zones (Legg & Olson, 2015) within Washington.

The WDFW specifies that stream buffers should include active floodplains, channel migration zones, and be measured from the channel bankfull width (the lateral extent of the water surface perpendicular to the channel, if the water 'completely fills' the channel (DNR & Forest Practices Board, 2000)) or ordinary high-water mark (along bodies of water, a noticeable differentiation from upland areas in soil and vegetation creating a line or mark from regular water flow (Anderson et al., 2016)). The availability of data and mapping layers related to these variables is discussed in the section on sources of error. For this research, they were included where data was publicly available. However, the definition of active floodplain varies depending on government agency, and the WDFW chose not to create a definition in their guidelines. As a result, the floodplain polygons used for this analysis were reduced to only "regulatory" and relevant "special" floodplains to address the most frequently flooded riparian areas. The WDFW's guidelines also suggest that all streams regardless of Strahler order (Strahler, 1957) need riparian buffers to maintain ecological health in waterways and the riparian management zones (RMZs) (WDFW, 2021). The multiple datasets were used to address data that was lacking in two ways. First, to use the detailed hydrologic line datasets from multiple sources to address the lack of smaller, ephemeral, and intermittent streams available from polygon datasets, and second, to include the width of streams not available from the more comprehensive line datasets but that were present in polygon layers and the attribute table of the channel migration zone (CMZ) line layer.

All datasets were modified as needed to only include streams and rivers and were clipped and projected based on the Washington State boundary and geodesic standards. To reduce processing times and overlap in data, the “Erase” tool was used to delete any overlapping sections between line or polygon layers. Merged and dissolved layers were created for mapping visualization (Figures 7 to 9), but individual feature layers were used for further analysis (SPTH spatial joins and buffer polygon creation) due to processing times and accuracy. In addition to these steps, the CMZ line layer was converted into a polygon layer using the measurements for channel bankfull width in its attribute table. It was also necessary to retroactively divide the NHD flowline layer into two datasets, West and East, and the VSW layer into three datasets, East, West inland, and West coastal, for processing buffer layers, due to the size and complexity of the datasets. Some hydrologic line data had Strahler stream order numbers in their attribute tables, but only half overall, and while they can theoretically be used for stream widths (Stahl et al., 2020), this methodology was not known or considered until late in the project, after the layers had already been processed.

Figure 7

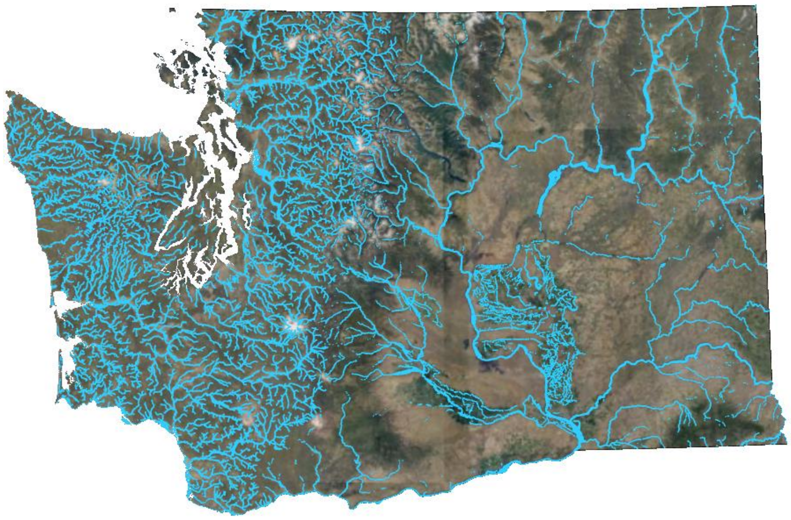
Map excerpts of merged hydrologic line and polygon layers for streams in WRIA 34.



Note: Basemaps are from NAIP imagery in the same area of WRIA 34 in Eastern Washington (ESRI, USDA, 2023). Hydrologic line layers (left) include known major, ephemeral, and intermittent streams (USGS NHD, WA DNR, NOAA SHSTMP). Hydrologic polygon layers (right) include larger known perennial streams with measured width dimensions (USGS NHD, WA DNR, WDFW, ESRI, FEMA). Bottom map includes all hydrologic stream layers.

Figure 8

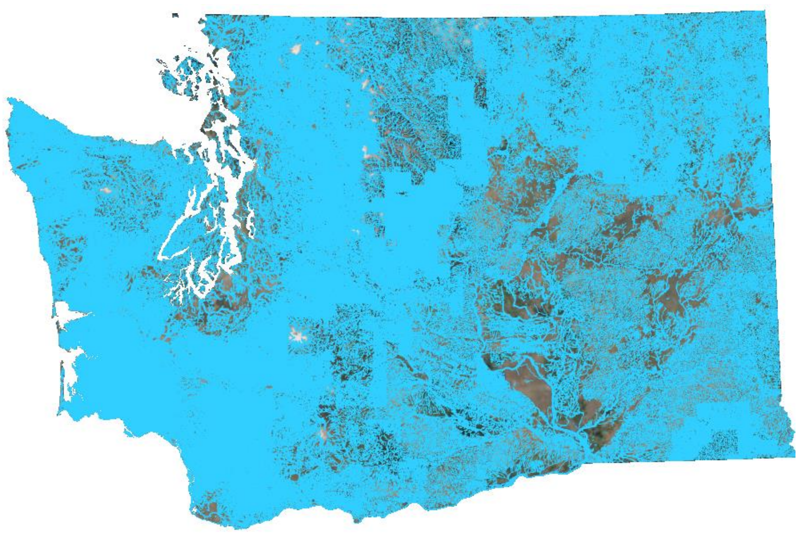
Merged hydrologic polygon feature layers for all streams in WA.



Sources: ESRI, FEMA, USDA NAIP, USGS NHD, WDFW, WA DNR.

Figure 9

Merged line and polygon feature layers for all streams in Washington.



Sources: USGS NHD, WA DNR, NOAA SHSTMP, USGS NHD, WDFW, ESRI, FEMA

$SPTH_{200}$ and the pollution zone: joins and defaults

Site potential tree height at 200 years ($SPTH_{200}$) data was used from the "Priority Habitats and Species: Riparian Ecosystems and the Online SPTH Map Tool" layer created by the WDFW using the National Resource Conservation Association's soil polygons and site index information, as well as the Soils Site Index (SSI) geospatial data for Washington State (Soil Survey Staff, USDA NRCS, 2022; WDFW, 2021; DNR, 2001, 2021a). Additionally, a formula was sourced from Clark County to calculate $SPTH_{200}$ for any location that did not already have an associated SPTH in areas where Douglas Fir was the dominant or secondary species based on the Site index (Davis, 2023). Some modifications for the SPTH Map dataset and the attribute tables for the hydrologic base layers were necessary for a SPTH buffer polygon layer. The WDFW's SPTH layer does not cover the whole state, and some site index values were less than the 100 ft minimum recommended by the WDFW. Several steps were necessary to get the best possible SPTH buffer layer for this study (Figure 10):

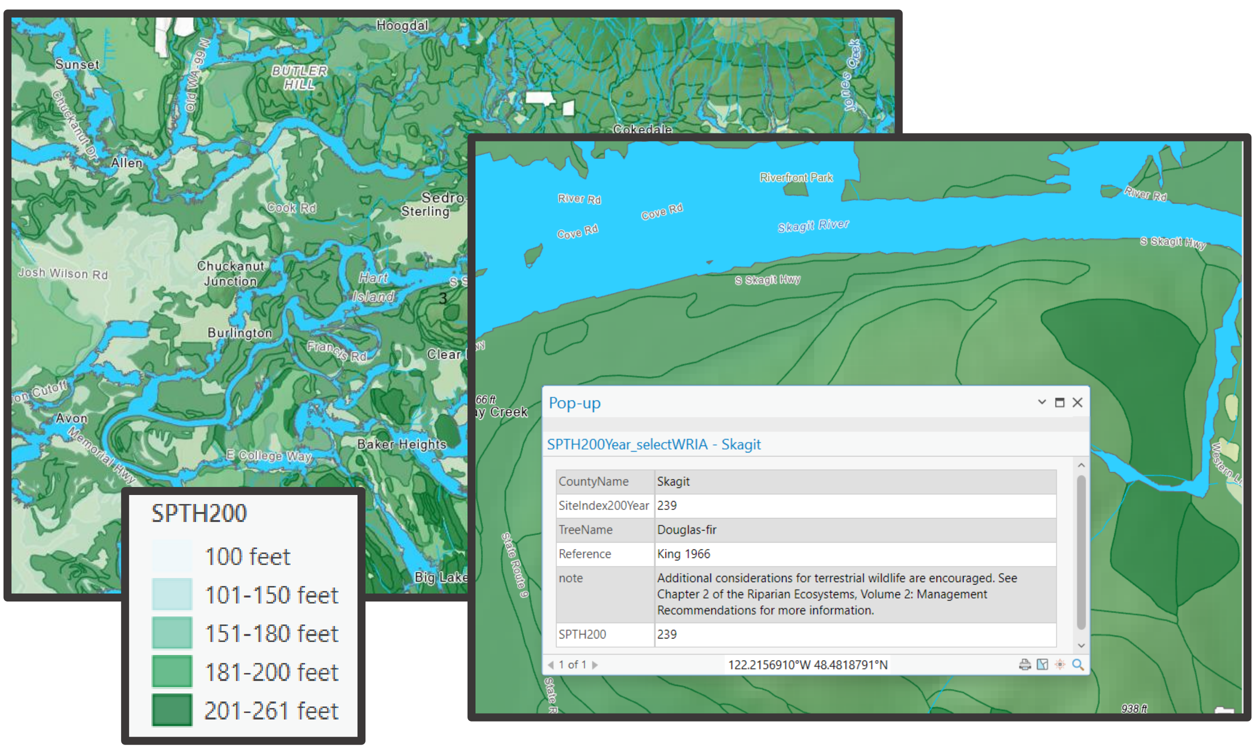
1. "Erase" SPTH layer from the SSURGO layer (clipped to Washington State).
2. Modify the SSURGO attribute table to use Clark County formula for calculating $SPTH_{200}$ on any data row that has Douglas Fir as a primary dominant species ($SPTH_{200} = 2.0436\ SPTH_{50} - 27.364$). $SPTH_{50}$ is the default used in the SSURGO soil index.
3. "Export Data" tool is used to create a new layer from the selected data and attribute table then edited for only relevant information.
4. Append the new Soil Site Index layer to the $SPTH_{200}$ layer.
5. Modify the SPTH layer attribute table by adding a new field, copying the SPTH column into a new default 100 ft column, then using the selection and calculation

tools to change any values below 100 to a 100 ft minimum.

6. Perform "Spatial Joins" between hydrologic layers and the SPTH layer using the parameter of joining the SPTH with "closest" match within 100 feet to stream and river features. The join layers are then exported as new feature layers.
7. In the new SPTH join field on the hydrologic layers, "null values" were changed to 100 feet to account for all parts of Washington state that were not included in the original SPTH layer. A new field calculates a conversion of the SPTH feet to meters to avoid a glitch in ESRI's Buffer tool that always defaults to meters.

Figure 10

Excerpt in WRIA 3 of the modified and re-symbolized SPTH layer with pop-up information from the WDFW Priority Habitats and Species Program.



Sources: WDFW, ESRI, DNR, USGS, USFS

Buffer Widths and the ArcGIS Buffer Tool

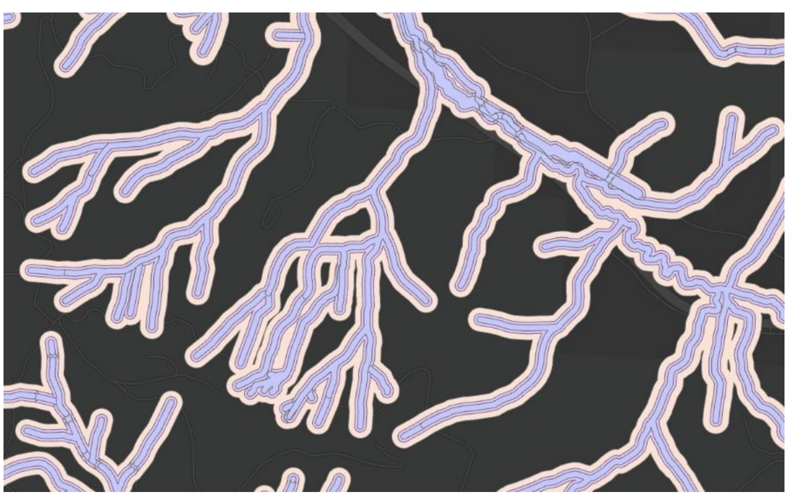
The next step was to delineate riparian management zone (RMZ) buffer width prescriptions and create buffer polygons along streams in Washington State using the hydrologic map layers. Measurements, to remain consistent with current Washington State and federal practice, are in U.S. survey feet. A field was added to the hydrologic line layer attribute tables that added a default of 2.5-foot width to SPTH buffer widths. Since many ephemeral streams can get much wider, this was a very conservative measure to account for the lack of stream width data and assumes a width of 5 feet (the assumption being it would be better to assume a 5-foot stream width than no buffer at all, and the impact to data for smaller width streams would be minimal). Measuring stream widths by ground-truthing, merging, and joining non-spatial datasets into geospatial tables, or measuring from high resolution imagery would take an extremely long time. Towards the end of the research, it became known that Strahler stream order numbers can be used to estimate stream widths (Stahl et al., 2020; Strahler, 1957), but were only available for half of all hydrologic lines, and are not able to estimate channel bankfull width or other more precise measurements, so the original layers are included in the final results. On the other hand, the hydrologic polygon layers inherently include widths around the streams. As these layers included most of the perennial streams and rivers, the hydrologic data seemed robust enough to run the analysis, especially considering the lack of use of intermittent and ephemeral stream data in larger scale riparian assessments like the National Riparian Base Map (NRBM) produced by the U.S. Forest Service.

The attribute field data for default SPTH converted to meters was used as the measurement basis with the hydrologic lines layer to run the ArcGIS Pro “Buffer” tool for the SPTH buffer prescription, while the 50 ft and 100 ft buffers were calculated inside the tool, using the measures of “52.5” and “102.5” U.S. Survey Feet. Layers were checked to ensure proper measurement processing due to an earlier glitch that processed all buffer layers in meters. For the hydrologic polygon layers, the 50 ft and 100 ft buffers could be created in the tool, and the "fields" option was used for SPTH, without adding extra width. The buffer tool was also run for all layers as "geodesic" rather than "planar" for improved accuracy, with "round" ends, set to "dissolve," and on both sides of the line or polygon. The "full" option was used for the lines layer, and for the polygon layer the "exclude the polygon input from the buffer" option was used. Since all hydrologic line and polygon layers had to be processed individually and, in some cases, divided geographically to process, this part of the research was very time-consuming, which should be expected at this scale. The hydrologic layers combined had over two million rows of data.

Finally, the three buffer prescription layers (Figure 11) from the hydrologic lines and polygon layers were combined using the "Union" tool at each buffer width. The "Dissolve" tool was then used for visual fluidity for the 100 ft and SPTH buffer layers, but after several attempts, the 50 ft layer would not "dissolve". This had no bearing on using the layer as a "mask" for other geospatial data and can be seen in Figure 11.

Figure 11

An overlay of the 50 ft, 100 ft, and SPTH200 buffer width polygons in Capitol Forest (WRIA 14).



Map Rasters & Datasets

CDL and NLCD raster data extraction

For the overall riparian management zone (RMZ) land cover analysis, the 2021 U.S. Department of Agriculture's (USDA) National Agriculture Statistic Service's (NASS) Cropland Data Layer (CDL) was used, and for the temporal analysis, the 2001 and 2019 National Land Cover Datasets (NLCD) were used (Dewitz & U.S. Geological Survey, 2003, 2021). Initial extraction from CDL and NLCD rasters required reprocessing using the same mapping standards as other layers mentioned in the Overview. The raster layer cell size was also reduced from the base 30m raster cell (98.4252 U.S. survey feet) to half that size (49.2126 U.S. survey feet) to accommodate measurements in the 50 ft buffer prescription. The "Extract by Mask" tool was then used multiple times to get base raster layers for the analysis. First, for Washington State boundaries without sovereign nation lands, then for public land layers, and finally by using the three buffer prescription feature layers.

Land Use/Land Cover classification definitions

The Cropland Data Layer (CDL) was used because it allowed for the ability to analyze the agricultural impacts on the riparian zones in more detail. The CDL uses the same basic classifications and base layer as the NLCD (Figure 12) for non-crop categories with the exception that it breaks down the agricultural land cover into specific crops and includes grasslands and herbaceous classifications in the same agricultural category as pastures. The NLCD is rigorously assessed for accuracy after each release, and in the most recent research based on the 2016 dataset (Wickham et al., 2021), the grasslands category has one of the lowest accuracies of the classification categories and 50% of misidentified cropland was identified as pasture. There was a

6-9% misclassification rate between shrublands and grasslands (the highest of all categories), but overall, most misclassifications occurred within the same generalized categories: developed lands, agricultural lands, or forest types including woody wetlands. Broader categories tended to have higher levels of accuracy, as much as 90%, which gives credence to using a simple classification method. However, at the basic level of classification provided in the NLCD, there is closer to 84% accuracy in the 2016 dataset. The 2001 dataset was estimated to be between 79-80% accurate.

Figure 12

NLCD Land Cover Classification legend and descriptions

Class\ Value	Classification Description
Water	
11	**Open Water**- areas of open water, generally with less than 25% cover of vegetation or soil.
12	**Perennial Ice/Snow**- areas characterized by a perennial cover of ice and/or snow, generally greater than 25% of total cover.
Developed	
21	**Developed, Open Space**- areas with a mixture of some constructed materials, but mostly vegetation in the form of lawn grasses. Impervious surfaces account for less than 20% of total cover. These areas most commonly include large-lot single-family housing units, parks, golf courses, and vegetation planted in developed settings for recreation, erosion control, or aesthetic purposes.
22	**Developed, Low Intensity**- areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 20% to 49% percent of total cover. These areas most commonly include single-family housing units.
23	**Developed, Medium Intensity** -areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 50% to 79% of the total cover. These areas most commonly include single-family housing units.
24	**Developed High Intensity**-highly developed areas where people reside or work in high numbers. Examples include apartment complexes, row houses and commercial/industrial. Impervious surfaces account for 80% to 100% of the total cover.
Barren	
31	**Barren Land (Rock/Sand/Clay)** - areas of bedrock, desert pavement, scarps, talus, slides, volcanic material, glacial debris, sand dunes, strip mines, gravel pits and other accumulations of earthen material. Generally, vegetation accounts for less than 15% of total cover.
Forest	
41	**Deciduous Forest**- areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. More than 75% of the tree species shed foliage simultaneously in response to seasonal change.
42	**Evergreen Forest**- areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. More than 75% of the tree species maintain their leaves all year. Canopy is never without green foliage.
43	**Mixed Forest**- areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. Neither deciduous nor evergreen species are greater than 75% of total tree cover.

(Figure 12 continued)

Shrubland		
	52	**Shrub/Scrub**- areas dominated by shrubs; less than 5 meters tall with shrub canopy typically greater than 20% of total vegetation. This class includes true shrubs, young trees in an early successional stage or trees stunted from environmental conditions.
Herbaceous		
	71	**Grassland/Herbaceous**- areas dominated by gramanoid or herbaceous vegetation, generally greater than 80% of total vegetation. These areas are not subject to intensive management such as tilling, but can be utilized for grazing.
Planted/ Cultivated		
	81	**Pasture/Hay**-areas of grasses, legumes, or grass-legume mixtures planted for livestock grazing or the production of seed or hay crops, typically on a perennial cycle. Pasture/hay vegetation accounts for greater than 20% of total vegetation.
	82	**Cultivated Crops** -areas used for the production of annual crops, such as corn, soybeans, vegetables, tobacco, and cotton, and also perennial woody crops such as orchards and vineyards. Crop vegetation accounts for greater than 20% of total vegetation. This class also includes all land being actively tilled.
Wetlands		
	90	**Woody Wetlands**- areas where forest or shrubland vegetation accounts for greater than 20% of vegetative cover and the soil or substrate is periodically saturated with or covered with water.
	95	**Emergent Herbaceous Wetlands**- Areas where perennial herbaceous vegetation accounts for greater than 80% of vegetative cover and the soil or substrate is periodically saturated with or covered with water.

Note: Legend with descriptions is taken directly from the Multi-Resolution Land Characteristics Consortium (2023) and is based on the Level II Anderson Land Cover Classification System. Alaska-only categories were removed since they were not related to this research.

Grassland/Herbaceous versus Pasture and Hay classification definitions

While the Cropland Data Layer (CDL) uses the NLCD land classifications for non-agricultural land, the classifications related to grassland and hay/pasture are very different. When considering whether to use the NLCD or the CDL categories for the final land use and land cover (LULC) analysis, the differences in what was considered “potential riparian” versus “agriculture” impacted the “Shrubs and Herbaceous” and “Hay/Pasture” categories dramatically. To determine if the category “Herbaceous” from the NLCD, which includes grasslands, should be used, versus the lack of that category and the inclusion of grasslands as pasture in the CDL, statistics for

Washington State 2017 US Census of Agriculture was used as a comparison.

Total acres of non-water or perennial/ice snow land cover from the CDL was analyzed in ArcGIS for all of Washington and used as the base acreage, at 39,061,708 acres. The acres listed in the census were then compared between relevant agricultural categories (Table 2). Because the grassland categories' statistics from the CDL and NLCD were so similar to the agriculture census, the conclusion was that not only did it make more sense to include the grasslands or herbaceous categories as agricultural pastureland, but there may also be an underestimate of agricultural lands in the CDL and NLCD layers. It is hard to determine from these datasets what percentage of potential riparian land cover is native prairie or grasses, but two things are likely: some are included in shrublands, and many if not most native prairie and grasslands are used as pasture (Belsky et al., 1999)

After comparing land cover compositions in several reclassifications in both the CDL and NLCD layers, it is apparent that while the grasslands and herbaceous categories being adjusted does change the absolute percentages of agricultural and potential riparian vegetation, it does not change the overall patterns among the simple classifications dramatically but does impact compositions in the East more than the West. While there are native prairies and pastures on the Western side of Washington, it is still dominated by "woody" vegetation in the riparian zone. The challenge with land cover classification at this scale is identifying vegetation in the drylands of Eastern Washington more accurately.

Table 2

Comparison of agricultural land percentage statistics to the 2021 CDL in Washington

	2017 Census of Agriculture	2021 CDL
Total Farmland	37.6%	28.7%
Harvested Crops	11.5%	10.6%
Hay, Alfalfa	1.0%	1.4%
Hay (not alfalfa)	0.8%	0.7%
Fallow	3.4%	3.9%
Permanent pasture and rangeland	11.9%	unknown
Other pasture and grazing	0.3%	unknown
Total pastureland without woodlands	12.2%	12.2%
Pastured Woodland	2.8%	unknown
Total pastureland	15.0%	unknown

Note: Based on acreage statistics from the 2017 Census of Agriculture for Washington and those extracted from the 2021 CDL. Does not include the land cover categories for water or ice/snow from the CDL (USDA, 2019; USDA-NASS, 2021).

Reclassification and erasures of land cover types

For analysis, all land cover rasters were modified to remove water and perennial ice categories, as well as any unclassified cells. A further step was taken to "erase" overlap with the visible surface water (VSW) layer (WDFW Habitat Program, 2023b). The National Agricultural Imagery Program (NAIP) images the VSW layer is based on are from the dry season, and are much higher resolution images, so they offered a conservative but more accurate classification of water land cover beyond the NLCD layer. The other land use/land cover classes were then reclassified at two additional levels to the original layers (Tables 3 and 4), the "simple" and "reclass" categories.

Reclassification of land cover categories was originally done using the "Reclassify" tool in ArcGIS Pro, but discrepancies in the data led to manual reclassification in added columns of the attribute tables and Excel documents instead. The first level of reclassification, the “reclass” level, was created to reclassify these in ways that made more sense for a riparian analysis, so all forest land and woody wetlands were combined into the class “Woody”; Shrubs/Scrubs, and Emergent Herbaceous Wetlands were combined into “Shrub or Herbaceous”; and developed land was put into two categories: “Developed, Medium and High” and “Developed, Low and Open”. Agricultural land cover was categorized into the two main categories of “Hay/Pasture/Fallow/Grass” and “Crops.”

The “simple” level further reclassified land cover into just three categories: “developed,” “agriculture,” and “potential riparian” (Tables 3 and 4, Figure 13) and truncated codes were used in some analyses and results tables (shown in Table 3). For the “simple” classification level, all four developed categories were reclassified as “developed,” and all crops, hay, pasture, grassland, and fallow categories were included in the category “agriculture.” In the Environmental Protection Agency’s (EPA) “riparian habitat” land cover classifications (EPA et al., 2015), “natural” land cover types across Cropland Data Layer (CDL) and NLCD land cover types include forests, wetlands, shrub/scrub, and barren lands (often rocky outcrops, etc.) (Tables 3 and 4). They also include the “herbaceous” category. These guidelines were followed for defining the “simple” classification of “potential riparian” land cover with an exception for the “herbaceous” category, which is largely composed of grasslands, and as stated previously, is mostly pastureland, or agricultural, in Washington State. The herbaceous category is already reclassified as pasture in the CDL. Since barren land is included in the EPA’s classification of land cover identified as “riparian” for analysis, it was used in that way for the simple reclassification but was kept separate at the “reclass” level.

In many cases the vegetation defined here as “potential riparian” land cover can refer to landscapes that are anthropogenically altered, like planted forests and timber, but they still meet the basic requirements for conservation or restoration in the riparian zone. In Washington State many forested lands are managed for timber, but because of the Fish and Forests Law, managed forests in the riparian zone are highly regulated. However, because regulation enforcement is prioritized based on Strahler order (DNR, 2005; DNR & Forest Practices Board, 2000), ephemeral and intermittent streams, especially non-fish bearing, may not have as much oversight, despite their significance to overall watershed health (Barnowe-Meyer et al., 2021; Fogel et al., 2022; WDFW, 2020a). As such, the difference between managed and unmanaged forests for commercial timber harvest is not within the scope of this analysis. There is also no way to determine through this particular analysis the quality of “potential riparian” habitat, which is why the word “potential” is used as a descriptor. Despite this challenge in highly accurate land use/land cover analysis, for a broad scale analysis to be accomplished in a relatively short time frame, using the CDL and NLCD was the most practical choice.

Table 3

"Simple" and "reclass" land cover reclassifications and analysis codes for the 2021 CDL

CDL LULC class	"Reclass"	CODES	"Simple"	CODES
Developed, High Intensity	Developed, Med to High	DEVMH	Developed	DEV
Developed, Medium Intensity	Developed, Med to High	DEVMH	Developed	DEV
Developed, Low Intensity	Developed, Low or Open Space	DEVLO	Developed	DEV
Developed, Open Space	Developed, Low or Open Space	DEVLO	Developed	DEV
Grassland/Pasture	Hay/Pasture/Fallow/Grass	PAST	Agriculture	AG
Alfalfa	Hay/Pasture/Fallow/Grass	PAST	Agriculture	AG
Other Hay/Non-Alfalfa	Hay/Pasture/Fallow/Grass	PAST	Agriculture	AG
Fallow/Idle Cropland	Hay/Pasture/Fallow/Grass	PAST	Agriculture	AG
Christmas Trees	Crops	CROP	Agriculture	AG
Sod/Grass Seed	Crops	CROP	Agriculture	AG
All other agricultural crops	Crops	CROP	Agriculture	AG
Barren Land	Barren	BAR or BARREN	Potential Riparian	RIP
Shrub/Scrub	Shrubs or Herbaceous	SHRUB or SHRB	Potential Riparian	RIP
Emergent Herbaceous Wetlands	Shrubs or Herbaceous	SHRUB or SHRB	Potential Riparian	RIP
Woody Wetlands	Woody	WOOD or WOODY	Potential Riparian	RIP
Deciduous Forest	Woody	WOOD or WOODY	Potential Riparian	RIP
Mixed Forest	Woody	WOOD or WOODY	Potential Riparian	RIP
Evergreen Forest	Woody	WOOD or WOODY	Potential Riparian	RIP

Note: Because there were 80 classes, crops with about 1000 acres or less in the SPTH zone were left off the list, but all crops not listed were included in the reclassifications as "Crops" or "Agriculture" (Dewitz & USGS, 2021; USDA-NASS, 2021).

Table 4

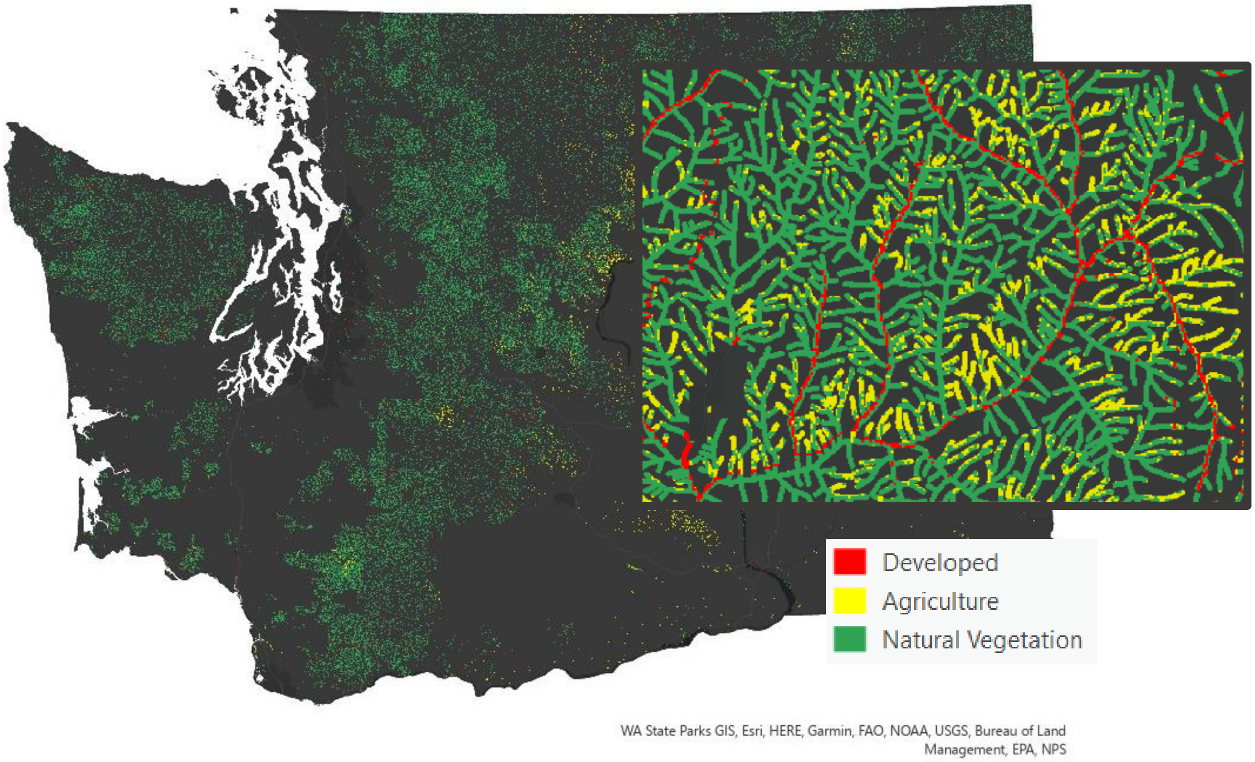
"Simple" and "reclass" land cover re-classifications for the 2001 and 2019 NLCDs

NLCD land use/land cover class	“Reclass”	"Simple"
Developed, High Intensity	Developed, Med to High	Developed
Developed, Medium Intensity	Developed, Med to High	Developed
Developed, Low Intensity	Developed, Low or Open Space	Developed
Developed, Open Space	Developed, Low or Open Space	Developed
Cultivated Crops	Crops	Agriculture
Hay/Pasture	Hay/Pasture/Fallow/Grass	Agriculture
Herbaceous	Hay/Pasture/Fallow/Grass	Agriculture
Barren Land	Barren	Potential Riparian
Shrub/Scrub	Shrub or Herbaceous	Potential Riparian
Emergent Herbaceous Wetlands	Shrub or Herbaceous	Potential Riparian
Woody Wetlands	Woody	Potential Riparian
Deciduous Forest	Woody	Potential Riparian
Mixed Forest	Woody	Potential Riparian
Evergreen Forest	Woody	Potential Riparian

Note: Analysis codes used were the same as listed for the CDL (Table 3).

Figure 13

100 ft buffer prescription extraction of public lands from the 2021 Cropland Data Layer raster.



Note: Inset photo is of public lands in WRIA 46. Source data on image.

Analysis Methodologies

Public and private land aggregation

Percentages of different land covers based on their location on public or private land were calculated by extracting the land cover overall and within buffers using the polygon map layer for extracting public lands (Figure 5) within the Cropland Data Layer (CDL) and National Land Cover Dataset (NLCD) land cover rasters (Figure 13). Private landowner data was determined in Excel by subtracting the public cell counts from the total cell counts within the RMZs. While the methodological process may include sensitive private information in the research when raster layers are viewed in close proximity and in conjunction with tax parcel data, all maps shared in the presentation of this data either focus on public areas or overviews that make it difficult to delineate individual or tribal boundaries. The analytical data of percentages or area precludes the need for personal data.

It is also important to recognize that ownership of land may change, and public data may not always be 100% accurate. This is especially true in relation to tribal lands, which may be unintentionally included in both private and public data where federal maps are inaccurate, or land may be managed by public entities and not accurately ascribed to tribal (or private) entities in the datasets. The Public Lands Inventory was also based on data from 2013-14 and has not been recently updated.

Delineation by Eastern and Western WRIAs

The Water Resource Inventory Area (WRIA) boundary layer (Figure 6) was used to analyze data from the land cover datasets. Initial WRIA data for all of Washington was separated into WRIAs 1-29 for Western Washington and WRIAs 30-62 for Eastern Washington, based on their location draining either to the west or the east of the Cascade Mountains. This was done due to major differences in ecosystems and vegetation (rainforest versus dryland habitats), as well as socioeconomic differences (urban and forested versus more rural and agricultural). These delineations were used for multiple analyses in the results.

CDL and NLCD raster data initial analysis

To obtain WRIA data, the "Tabulate by Area" Tool was used on each raster layer in conjunction with the WRIA polygon layer, which was output in tables and processed using the

“Summarize” tool as needed for quick calculations. Using the “Tabulate by Area” tool did modify overall cell counts slightly, but it was beyond the scope of this project to determine how or why this happened. The differences were calculated and did not impact overall land cover percentages in the broader categories of overall Washington, and Eastern and Western Washington, however some smaller land cover categories, like “barren” may have been impacted on a WRIA scale. There were also some slight discrepancies in cell counts between the 100 ft and SPTH buffers (higher cell counts in the 100 ft versus SPTH buffer) related to the barren land cover category that were specific to a few WRIAs, but were hard to identify visually, even on the WRIA level, and therefore were left uncorrected as they had little impact on overall compositional percentages.

Cell counts for each classification at the original, “simple”, and “reclass” levels were divided by total cell count of all land cover types to get a percentage for each individual land cover type in Washington state overall, public lands, and by Water Resource Inventory Area (WRIA) not inclusive of those exclusively on sovereign nation lands (and thus able to be divided into Western (WRIAs 1-29) and Eastern (WRIAs 30-62) Washington) in each buffer prescription. The base analysis required a minimum of six raster layers for each dataset (18 total), and an additional 6 WRIA tables per raster layer, though some additional raster layers and tables were created for ease of summarized calculation totals. Acreage data was calculated using a formula manually as an added field in ArcGIS Pro, or in excel, as the raster layers could not be processed for area using the “calculate geometry” tool in ArcGIS Pro.

Conserved Lands analysis

The percentages of public or private conservation land were calculated using merged layers of the Protected Areas Database (PAD) and the National Conservation Easement Database (NCED) and extracted by each buffer prescription. Gap Analysis Project (GAP) status codes

(Table 5) are included in both dataset's attribute tables. Categories 1 to 3 could apply to riparian management zones that still follow the WDFW's guidelines and are aligned with the Fish and Forests Law in managed forests. Because category 4 is not appropriate for managing riparian zones, only entries in the attribute tables with GAP codes of 1-3 were selected and exported into new feature class layers to be considered as "conserved" for a riparian management area.

Fields related to ownership type were used to delineate public and private conservation lands and, in some cases, needed to be inferred and entered when they had a "null" value, if the ownership seemed based on other information in multiple other attribute fields. The ownership domain categories were then used for selection filters on the table to extract new private and public feature layers. These layers were then modified to not include tribal lands or properties, though it should be noted (if not very apparent) that tribes make major contributions to conserving natural habitat lands in Washington. If lands were managed by tribes and not on known tribal lands, but "owned" by an NGO or privately, they were left in the analysis. The public, private, and combined conservation feature layers from each database were then merged into single layers and extracted by mask inside the three stream buffer polygons.

There was overlap in the data in two cases which were rectified. First, both public and private owners were listed separately for some overlapping polygons. This data is included and aggregated separately, as it is unknown whether there are multiple owners, a change in ownership, or a mistake in the datasets. It was extracted by using the "Erase" tool between public and private lands in multiple iterations to obtain the overlap and remove it from the public and private layers. Second, some data of conserved land was property acreage within other larger conserved acreage areas. In order to rectify this for summary acreage, the "Dissolve" tool was used on all of the conservation polygon layers to remove overlap.

Because the conservation polygon datasets included water, etc., it made the most sense to compare to the total area of the overall Washington and buffer polygons for the whole state and for public lands, rather than the land cover dataset's raster cell count data. To do this, a field was added to the buffer prescription and conservation layers attribute tables for acreage, then calculated using the "Calculate Geometry" tool. Further, to delineate by Western or Eastern Washington, the WRIA layer was divided into 2 feature layers, West (WRIAs 1-29) and East (WRIAs 30-62), the buffer prescription layers were clipped to these layers, and the conservation layers were then clipped to the West and East buffer layers. Private overall and buffer prescription acreage was determined by subtracting the public acreage from overall Washington acreage, and then used to convert the public and private/NGO conservation layer data to percentages to create an overall Washington percentage for total conserved land, public versus private overall, the same for each buffer width, and between East and West.

Table 5

USGS "GAP Status Code" and descriptions

GAP Status Code	Description
1	An area having permanent protection from conversion of natural land cover and a mandated management plan in operation to maintain a natural state within which disturbance events (of natural type, frequency, intensity, and legacy) are allowed to proceed without interference or are mimicked through management. Examples of Status 1: Wilderness Areas, Several National Parks
2	An area having permanent protection from conversion of natural land cover and a mandated management plan in operation to maintain a primarily natural state, but which may receive uses or management practices that degrade the quality of existing natural communities, including suppression of natural disturbance. Examples of Status 2: National Wildlife Refuges, Conservation Areas, The Nature Conservancy Preserves
3	An area having permanent protection from conversion of natural land cover for the majority of the area, but subject to extractive uses of either a broad, low-intensity type (e.g., logging, Off Highway Vehicle recreation) or localized intense type (e.g., mining). It also confers protection to federally listed endangered and threatened species throughout the area. Examples of Status 3: National Forests, BLM Lands, State Forests, some State Parks
4	There are no known public or private institutional mandates or legally recognized easements or deed restrictions held by the managing entity to prevent conversion of natural habitat types to anthropogenic habitat types. The area generally allows conversion to unnatural land cover throughout or management intent is unknown. Examples of Status 4: Unknown areas, private lands, developed or agriculture areas

Note: Descriptions and examples are exact wording from the USGS 2022 Gap Analysis Project (USGS GAP, 2022) and used in the Protected Areas Database (PAD) and National Conservation Easement Database (NCED).

Temporal LULC analyses

Data extracted from the land cover rasters as described previously was used to assess temporal changes in land cover between the 2001 and 2019 NLCD, using the same variables as the 2021 Cropland Data Layer (CDL) (public/private, individual WRIAs, West/East, the three buffer prescriptions, and the "simple" and "reclass" categories). The 2001 percentages of land cover were subtracted from 2019 percentages to determine overall temporal changes. This is different than the land change index, which analyzes change by specific cell. A quick analysis to determine loss versus gain is not possible with the regular NLCD land change index, which simply expresses cell count changes and not whether there is a gain or loss. It would be ideal to do this sort of analysis, looking at specifics as to how much of each type of change (from this class to that class) was made. The analysis conducted was broader but makes the most sense in staying consistent with analysis of the CDL and can be observed more specifically at the WRIA level.

Statistical analyses

Besides general presentation of percentage and acreage data, the cell counts and percentages of different land cover at the "simple" and "reclass" levels within all of Washington and the prescribed buffer widths for all variables (overall, public/private, East/West, and individual WRIA) were analyzed using statistical tests in R (R Core Team, 2022) and Excel (Microsoft, 2023). Feature map layers were also created in ArcGIS Pro and symbolized to illustrate the "simple" classification across WRIAs based on percentages of different land cover (Figure 15). Pearson's chi square test was used to determine overall residuals and test statistics for total cell counts for each land cover dataset (2021 CDL, 2001 NLCD, and 2019 NLCD). Mosaic plots were created for the broad cell count data and the chi square data.

Because the WRIA data was nonlinear due to some outliers (Western Washington WRIAs had more outliers than Eastern for all raster layer data), it was necessary to use a nonparametric analysis method for correlations between land covers in the buffers. Barren land cover had many outliers on its own in both geographic regions but is a very small percentage of land cover overall, so is not included in the description of correlative results. Spearman's nonparametric ρ (rho) rank order correlation coefficients and related p-values were calculated using WRIA-specific data for both the "simple" and "reclass" classifications on the 2021 Cropland Data Layer (CDL), including within public/private and West/East delineations. It also made sense to analyze the CDL data for all four development types in the correlated buffer prescriptions. Crop-specific information is interesting, but less relevant to this research because most agriculture in the riparian buffer prescriptions is hay and pasture, so deeper statistical analysis was not conducted for these specific land classes. These statistical tests were also conducted on the temporal change data for the NLCD for just the "reclass" classification level without development specific information, which was also within public/private and West/East categories.

To consider potential differences more closely by ownership and the three buffer prescriptions, a two-way repeated measures ANOVA was performed for the 2021 CDL percentage data, with WRIAs as replicates, separately for each "simple" and "reclass" land cover type and by Western and Eastern Washington. In each analysis, ownership was a fixed effect (public v. private), and buffer prescription was the repeated measure (50 ft, 100 ft, and SPTH). Pairwise differences were also estimated using a Bonferroni correction for multiple comparisons.

Sources of Error

A major example of sources of error for the source and output datasets is the accuracy of the hydrography layers. According to the U.S. Geological Survey (USGS), standards for positional accuracy of the high-resolution National Hydrography Dataset (NHD) are 90% within 40 ft at a 1:24,000 scale (USGS, 2023). Considering the scale of the buffers, this could lead to some statistical inaccuracy in land cover data in buffer widths. Multiple layers were included to counterbalance this, and the Visible Surface Water layer is much higher resolution, so large rivers and streams are likely more accurate. However, "stream permanence classifications" (SPC) by the NHD have been linked to climate at time of stream data collection, and the lower the Strahler order, the less likely the NHD depicts them accurately (Hafen et al., 2020). The more ephemeral and intermittent the stream, the less likely it is accurate.

WDFW guidelines say to use floodplains and channel migration zones (CMZs), the channel bankfull width, or Original High-Water Mark (OHWM) as the outer edge of a stream from which to measure buffers. However, the Washington Department of Natural Resources (DNR) mentions that the hydrologic datasets available federally and statewide, while the most authoritative, are not always accurate. In 2022, the Washington State legislature passed a bill that included funding to work on improving statewide hydrological data.

There is also a lack of strong data related to floodplains and channel migration zones. The WDFW guidelines say that there is no clear agreement on modeling for floodplain prediction and some sources mention using a 100-year floodplain, but available datasets like the U.S. Forest Service's (USFS) National Riparian Base Map (NRBM) use 50-year floodplains (Abood et al., 2012; Maclean, 2021). The NRBM also intentionally does not include intermittent and ephemeral streams, though the WDFW guidelines include maintenance of buffers along these smaller and more sporadic streams. While the WDFW recommends using floodplains, they have no specific recommendation and defer to on-the-ground riparian management decisions. In addition, the DNR's Channel Migration Potential (CHAMP) CMZ prediction map is not all-inclusive (the bulk of the data available is for the Northwest part of the state). Lastly, because most smaller streams in the hydrologic datasets had no stream width information available in table or geospatial dataset formats, in addition to the lack of inclusion of accurate floodplain and CMZ data that would more than likely create wider stream paths, it could be deduced that while actual locations of streams, floodplains, and CMZs may vary slightly from the data, the default buffers would tend to be wider than in the buffer width prescription results layers.

As stated earlier in the land use and land cover (LULC) classification section, the CDL and NLCD rasters have differing accuracy levels for different land cover types, especially in relation to grasslands (Wickham et al., 2021), and use Landsat data at a scale of 30m (though the CDL incorporates additional input data, including National Agricultural Imagery Program (NAIP) imagery that is accurate to 1 meter as well as agriculture-specific parcel data). However, Sentinel-2 satellite imagery is higher resolution than Landsat imagery, at 10m as opposed to 30m, and has high accuracy levels over 80% when identifying LULC, though many classification systems use pixel-based classification, which is less accurate than the high-resolution compatible object-based imagery analysis (OBIA) (Phiri et al., 2020). Cloud cover is also a major challenge in land classification on imagery but can be reduced using the thermal bands available from Landsat which can then be fused with the Sentinel-2 data. Land classification can also be improved by fusing Light Detection and Ranging (LiDAR) data and Unmanned Aerial Vehicle (UAV) imagery. The NLCD, however, is still one of the most consistent, accessible, and rigorously tested datasets for a broad land cover analysis.

Tribes have requested and published in various state documents and legislation, not to include mapping data related to them, including riparian assessment, without their collaboration. The sovereign nations land layer used for extraction to avoid analyzation without representation, also likely lacks consensual accuracy. A review of the Washington State Recreation and Conservation Office's Public Lands Inventory Report (WRCO, 2014) cites multiple direct written responses from tribes who said the federal and state designation of tribal lands is inaccurate and ownership or management of lands by the tribes is complex. As such, tribal lands may have been inadvertently included in this analysis. It should also be noted that all this data is relevant to the tribes of Washington State, as a major goal of riparian management is to protect and restore the salmon.

CHAPTER 4: RESULTS

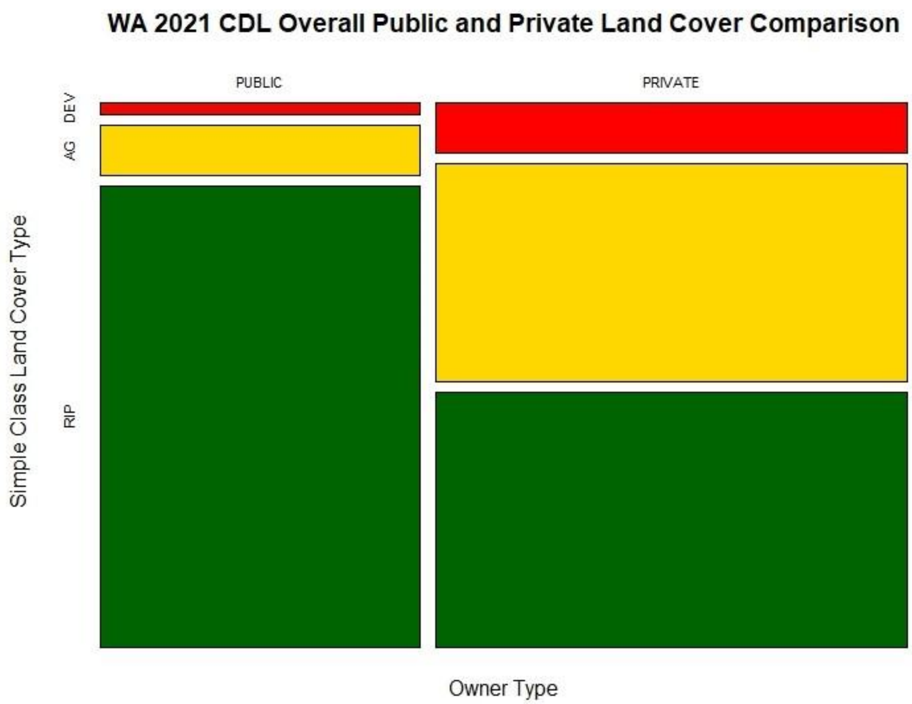
RELATIONSHIP OF LAND COVER TYPE TO BUFFER WIDTH

Riparian land cover percentages in overall Washington

The overall land cover composition using the simple reclassification land use categories is different for private and public lands in Washington (Figure 14). As of 2021, 40.4% of Washington State lands are publicly owned and 59.6% are privately owned (not including Sovereign Nation lands, or any open water or perennial land/ice). On public lands, 2.2% is developed, 9.5% is agricultural, and 88.3% is woody vegetation, wetlands, or shrublands (see Table 2 for land cover that fall in these categories). This contrasts with private lands in Washington (Figure 14) where 9.6% is developed, 41.7% is agricultural, and 48.7% is woody vegetation, wetlands, or shrublands. From these figures we know that Washington is not a highly developed state, has a lot of publicly owned land, and that most development and agriculture occurs on private lands. Note that on both public and private lands, potential riparian land cover includes forests that are managed for timber sales and does not imply age or canopy size of forests, or health of the habitat.

Figure 14

2021 USDA-NASS CDL "simple" reclassification for all of Washington State by public or private ownership.



Note: RIP= "Potential Riparian," AG= "Agriculture," and DEV= "Developed."

Land cover composition percentages by buffer width and public versus private

In Washington State overall (with previously noted exceptions), 20.5% of lands fall within the SPTH buffers, 15.8% falls within the 100 ft buffers, and 8.7% falls within the 50 ft buffers. 16.7% of developed land falls within the SPTH boundaries and 10.0% of agricultural lands fall within the SPTH buffer. The riparian buffer prescriptions have on average 1.5% less development, 13.3% less agriculture, and 14.8% more potential riparian land cover compared to all land cover in Washington State (Table 6). Within the riparian buffer prescriptions, the magnitude of the differences between public and private lands is less than in Washington overall. Private lands are 7% more developed, 32% more agricultural, and have 40% less woody vegetation, barren land, shrubland, and herbaceous wetlands than public lands in all of Washington State. Within the buffer prescriptions, on average, private lands are 5% more developed, 18% more agricultural, and 16.3% less potential riparian land cover than public lands. Potential riparian land cover is less than 81% in each buffer type considering public and private lands together. However, public lands have over 91% potential riparian land cover in all buffer widths.

Table 6

Total Percentage composition of each "simple" land cover classification from the 2021 CDL

	Developed	Agriculture	Potential Riparian
All WA	6.6%	28.7%	64.7%
Public	2.2%	9.6%	88.3%
Private	9.6%	41.7%	48.7%
50 ft	4.9%	15.9%	79.2%
Public	2.4%	5.4%	92.2%
Private	7.3%	25.2%	67.5%
100 ft	4.9%	16.3%	78.7%
Public	2.4%	5.8%	91.8%
Private	7.2%	25.8%	67.0%
SPTH	5.4%	14.0%	80.6%
Public	2.5%	5.2%	92.3%
Private	7.6%	20.6%	71.9%

Division between Eastern and Western Washington

Dividing the state into East and West is a logical step in analyzing riparian buffer compositions because of important differences in ecological and socioeconomic factors impacting land cover (Table 7). Within each buffer prescription there are more acres in development in Western Washington compared to the East (e.g., 100,756 developed acres in the Western 50 ft buffer prescription, and 67,292 in the Eastern 50 ft), while there are more acres in agricultural lands in Eastern Washington compared to the West (e.g., 840,517 acres of agricultural land in the Eastern 100 ft buffer, and only 163,029 acres in the Western 100 ft). Western Washington has more land acreage in riparian buffers, with 40% more land in the SPTH width compared to the East (17% more in the 50 ft and 20% more in the 100 ft).

Table 7

2021 CDL estimated acres of "simple" land cover classes in Western and Eastern Washington

TOTAL ACRES		Developed	Agriculture	Potential Riparian	TOTAL
WEST					
50 ft		100,756	107,705	1,751,571	1,960,033
	Public	21,792	11,219	939,619	972,629
	Private	78,965	96,486	811,952	987,403
100 ft		174,335	163,029	3,075,852	3,413,216
	Public	37,547	18,777	1,646,634	1,702,958
	Private	136,789	144,252	1,429,218	1,710,258
SPTH		290,628	253,703	4,457,816	5,002,147
	Public	50,869	25,383	2,034,595	2,110,847
	Private	239,760	228,320	2,423,221	2,891,301
EAST					
50 ft		67,292	431,472	938,288	1,437,052
	Public	16,461	76,308	542,585	635,354
	Private	50,831	355,164	395,703	801,699
100 ft		128,233	840,517	1,757,312	2,726,062
	Public	31,161	148,959	1,013,202	1,193,323
	Private	97,072	691,558	744,109	1,532,739
SPTH		138,697	862,742	1,975,893	2,977,333
	Public	34,131	153,244	1,121,595	1,308,970
	Private	104,567	709,498	854,298	1,668,363

Note: Within buffer prescriptions and based on raster cell size of 48.2125 U.S. Survey Feet. This does not include the land of sovereign nations, or water or perennial ice/snow land cover.

“Simple” land cover percentages by West and East, public and private

Review of the “simple” reclassification percentages clarifies that there is far more potential riparian land cover in the buffer prescriptions in the West, with a much closer gap between public and private lands than in the East (Table 8). In the West, public lands have 12.5% more potential riparian land cover on average than private lands, with the 50 ft buffer prescription having the largest difference, at 14% more. In the East, this gap between public and private increases to 35.6% on average. While development percentages are higher overall in the West, they are slightly higher on public lands in the East (2.6% developed across all buffer widths) and in the 100 ft buffer on private lands. It is also interesting to note that percentages of potential riparian land cover on *public* lands in the East are similar to the percentages on *private* lands in the West (i.e., in the mid-80’s). When looking at percentages by WRIAs (water resource inventory areas), the impact of development in the West and agriculture in the East is apparent (Figure 15). In the West, the WRIAs with the lowest potential riparian habitat are also more developed, while in the East they are more agricultural (and developed).

Table 8

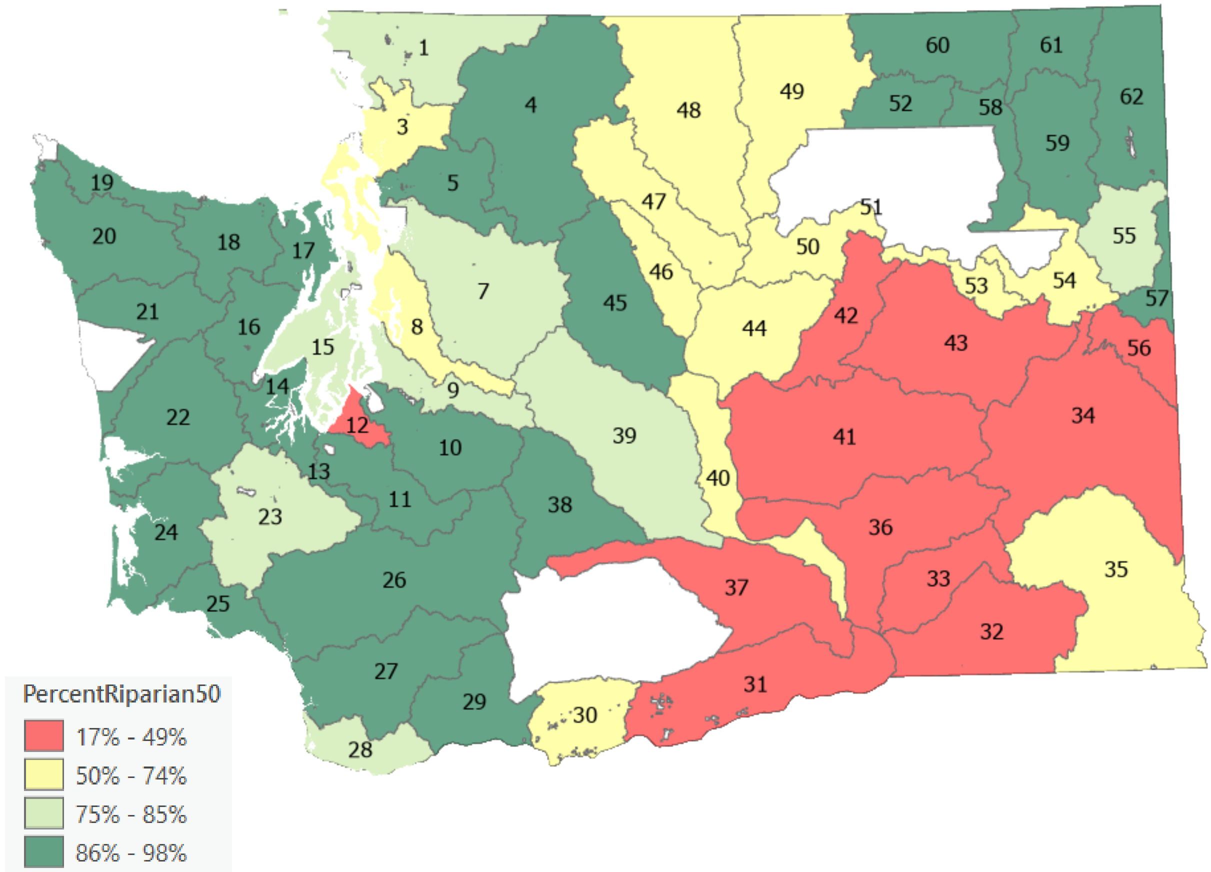
2021 CDL "simple" reclassification of LULC percentages in Western and Eastern Washington

WEST	Developed	Agriculture	Potential Riparian
50 ft	5.1%	5.5%	89.4%
Public	2.2%	1.2%	96.6%
Private	7.6%	9.8%	82.6%
100 ft	5.1%	4.8%	90.1%
Public	2.2%	1.1%	96.7%
Private	5.5%	8.7%	85.8%
SPTH	5.8%	5.1%	89.1%
Public	2.4%	1.2%	96.4%
Private	8.3%	7.9%	83.8%
EAST	Developed	Agriculture	Potential Riparian
50 ft	4.7%	29.8%	65.5%
Public	2.6%	12.0%	85.4%
Private	6.3%	44.3%	49.4%
100 ft	4.7%	30.8%	64.5%
Public	2.6%	12.5%	84.9%
Private	6.3%	45.1%	48.5%
SPTH	4.7%	29.0%	66.4%
Public	2.6%	11.7%	85.7%
Private	6.3%	42.5%	51.2%

Note: LULC compositional percentages of total within riparian buffer width prescriptions.

Figure 15

Map of the WRIAs of Washington State, color coded by percentage of potential riparian land cover (as an estimate of riparian habitat) in the 50 ft stream buffer prescription



Note: Empty areas are sovereign lands not analyzed.

<u>"Reclass" land cover percentages by West and East, public and private</u>

In order to consider finer-scale distinctions such as rural versus urban development, agricultural crops versus hay/pasture/fallow/grass land and differentiating woody vegetation versus shrub and herbaceous wetlands land cover, the "reclass" land cover percentages were also calculated for Western and Eastern Washington in the three buffer prescriptions (Table 9). Eastern Washington has substantially more shrubland and hay/pasture/fallow/grass, as well as crops in the buffers, with less woody vegetation. While the crops percentage on Eastern public lands is higher than the West, it is still under 1.0% of all land cover in each public buffer. In other categories the public lands of the East have substantially higher amounts of shrubland and hay/pasture/grass/fallow than public lands in the West. These three categories all have slightly higher percentages in the 50 ft and 100 ft buffers than the SPTH.

Table 9

2021 CDL "reclass" LULC percentages for Eastern and Western Washington

WEST	**50 ft**	**Pub**	**Pvt**	**100 ft**	**Pub**	**Pvt**	**SPTH**	**Pub**	**Pvt**
Developed, Med to High	0.7%	0.1%	1.2%	0.7%	0.1%	1.2%	0.7%	0.1%	1.2%
Developed, Low or Open Space	4.5%	2.1%	6.8%	4.4%	2.1%	6.8%	5.1%	2.3%	7.1%
Crops	1.0%	0.1%	2.0%	0.7%	0.0%	1.4%	0.6%	0.0%	1.0%
Hay/Pasture/Fallow/Grass	4.5%	1.1%	7.8%	4.0%	1.1%	7.0%	4.5%	1.2%	6.9%
Barren	1.3%	2.5%	0.2%	1.3%	2.5%	0.1%	0.9%	2.1%	0.1%
Shrubs or Herbaceous	8.1%	7.3%	9.0%	8.1%	7.1%	9.1%	8.2%	6.6%	9.3%
Woody	79.9%	86.9%	73.1%	80.7%	87.1%	74.4%	80.0%	87.7%	74.4%
EAST	**50 ft**	**Pub**	**Pvt**	**100 ft**	**Pub**	**Pvt**	**SPTH**	**Pub**	**Pvt**
Developed, Med to High	0.7%	0.3%	1.0%	0.7%	0.3%	1.1%	0.7%	0.3%	1.0%
Developed, Low or Open Space	4.0%	2.3%	5.3%	4.0%	2.3%	5.3%	4.0%	2.3%	5.2%
Crops	9.9%	0.7%	17.1%	10.2%	0.7%	17.6%	9.5%	0.6%	16.4%
Hay/Pasture/Fallow/Grass	20.1%	11.3%	27.2%	20.6%	11.8%	27.5%	19.5%	11.1%	26.1%
Barren	0.4%	0.9%	0.0%	0.4%	0.9%	0.0%	0.3%	0.8%	0.0%
Shrubs or Herbaceous	26.6%	23.6%	29.0%	26.6%	24.0%	28.7%	26.1%	23.0%	28.4%
Woody	38.3%	60.9%	20.4%	37.4%	60.1%	19.8%	40.0%	61.9%	22.8%

Note: LULC compositional percentages of total within riparian buffer width prescription.

Statistical analysis of land cover composition within the riparian buffer prescriptions

ANOVA analysis of buffer size significance

Considering Washington State overall, there was little difference in amounts of “simple” land cover composition by buffer prescription on public lands but some apparent differences in the SPTH buffer on private lands (Figure 16). Figure 16 also demonstrates the overall difference in public versus private lands shown in Figure 14 and Table 6. However, there were several significant differences among buffer widths when considering Western and Eastern Washington separately using a two-way repeated measures ANOVA and *post hoc* pairwise tests using a Bonferroni adjustment for multiple comparisons (Tables A1 and A2 in Appendix A).

Within the “simple” land cover classes there was a statistically significant difference between buffer sizes for public and private agriculture and riparian land cover in the East, and private development in the West (Appendix A, Table A1). There was no statistically significant difference for buffer sizes for development in the East, or agriculture and potential riparian land cover in the West. Significant differences were found between the 50 ft and 100 ft and 100 ft and SPTH buffers for all significant categories. For the “reclass” potential riparian land cover classes, there were additional statistically significant differences between buffer sizes in the West besides development (Appendix A, Table A2), but only medium and high development was different between the private 50 ft and 100 ft buffer in the East (with an increased mean in the 100 ft buffer).

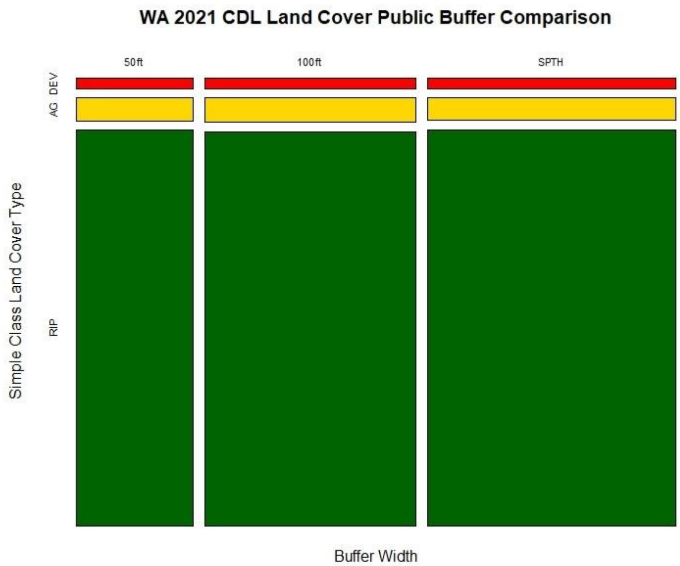
The West “reclass” buffer comparisons for development show the same pattern on private lands as the “simple” comparisons for both development classes, but the difference in means is higher between the buffers in the low and open development class than the high and medium development class. Additionally, public lands show significant difference between the 50 ft and 100 ft buffers for high and medium development and show that the mean is actually higher in the

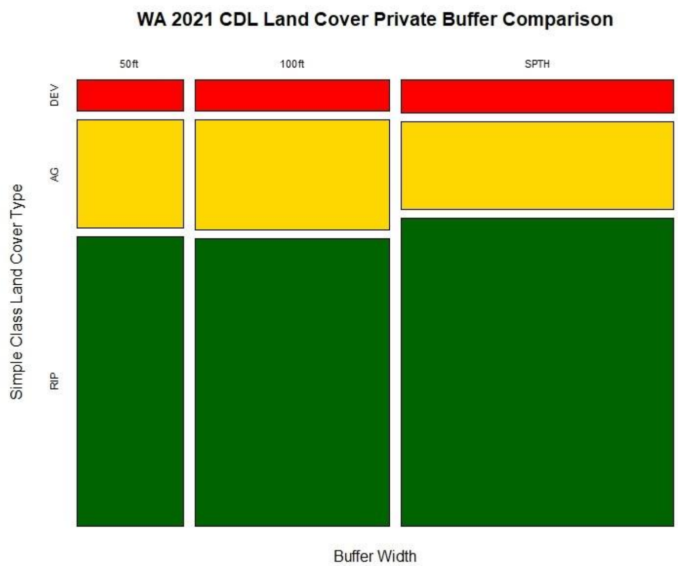
50 ft. Barren lands showed significance in most variables, but as a small percentage of all land cover, did not impact overall “simple” results (Tables A1 and A2). Croplands also showed significant differences not affecting the overall “simple” category, because they are a much smaller percentage of agricultural lands than pasturelands. On both public and private lands, the means were higher in the 50 ft buffer than the 100 ft buffer, and on private lands the means were also higher in the 100 ft buffer than the SPTH buffer.

In the East “reclass” ANOVA analysis, both croplands and hay and pasture showed significantly higher means in the 100 ft buffer than the SPTH buffer, and aside from crops in the public 50 ft to 100 ft buffer comparison which showed no significant difference, they also showed significantly lower means in the 50 ft buffer compared to the 100 ft buffer. There are significant differences for both public and private woody vegetation, but significance of buffer size in relation to shrublands only occurs on private lands. The land cover compositions in the 50 ft buffer compared to the SPTH buffer, and the 100 ft to the SPTH were significant for private shrublands in the East with higher means in the smaller buffer sizes, while the 50 ft to 100 ft comparison was insignificant. In the East, decreased composition of the potential riparian land cover classes on public and private lands in the 100 ft buffer versus the 50 ft and SPTH buffers was simultaneously occurring with an increase in crops and hay and pastureland cover compositions in the 100 ft compared to the SPTH and the 50 ft buffers.

Figure 16

2021 CDL “simple” land cover for each buffer prescription on public and private land.





Note: RIP= “Potential Riparian,” AG= “Agriculture,” and DEV= “Developed.”

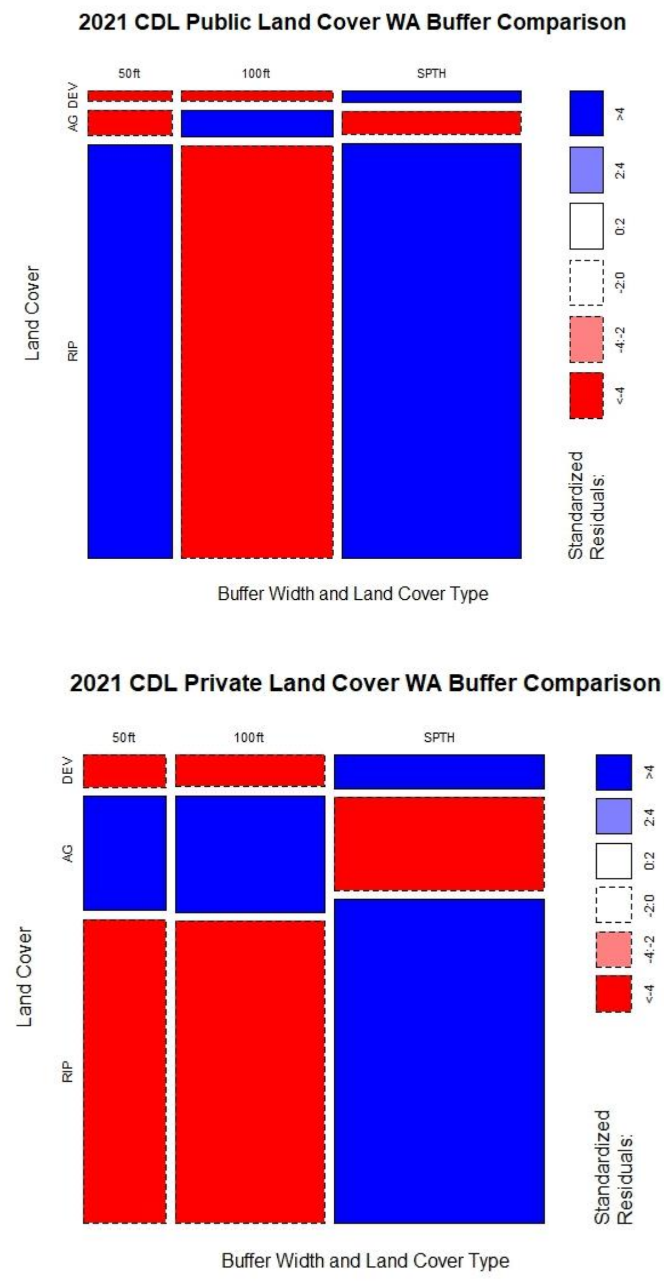
Pearson’s Chi-Square Test

<u>“Simple” land cover reclassification</u>

Residuals from the Pearson’s Chi Square Test on the cell counts for each “simple” buffer classification confirm that on private lands (χ^2 = 614258, *df* = 4, p-value = <0.001), there is more potential riparian and developed land cover than expected, and less agricultural land cover, in the SPTH buffer size as compared to 50 ft and 100 ft buffers (Figure 17). On public lands (χ^2 = 19129, *df* = 4, p-value = <0.001), there is more potential riparian land cover than expected in the 50 ft and SPTH buffers, and less than expected in the 100 ft buffer, where there is more than expected agriculture compared to the 50 ft and SPTH buffers. There is more than expected development in the SPTH compared to the 50 ft and 100 ft buffers. The most notable variation between public and private lands is for the agriculture classification, within all buffer sizes, as well as the difference between potential riparian land cover in the SPTH buffer width (Figure 17). On private lands, there is higher-than-expected agriculture in the 50 ft and 100 ft buffers than in the SPTH.

Figure 17

"Simple" land cover chi-square results for public and private riparian buffers in Washington



Note: Mosaic plot represents Pearson chi square residual comparisons of 2021 CDL LULC cell counts.

“Reclass” land cover reclassification

Residuals from the Pearson’s Chi Square Test on the cell counts for each “reclass” land cover classification were also calculated for all of Washington State by public (χ^2 = 74862, *df* = 12, p-value = <0.001) and private (χ^2 = 964575, *df* = 12, p-value = <0.001) landownership. With the exception of barren and medium and high development LULC, the residuals of the cell counts are of greater magnitude on private lands than on public lands (Table 10). Perhaps the most important pattern noticeable in the residuals is that there is less than expected woody vegetation on both public and private lands in the 50 ft and 100 ft buffer prescriptions compared to the SPTH, which has more than expected. This is confirmed by the overall percentages for the potential riparian classification by shrublands and herbaceous wetlands class versus woody (Table 11).

On private lands, shrubland, pastureland, and crop LULC amounts are all higher than expected in the 50 ft and 100 ft buffers, and lower in the SPTH buffer. Medium and high development is higher than expected in the 50 ft private buffer. Public lands in comparison follow the same residual patterns with a few exceptions, and to a lesser magnitude. The differences are that there is more public pastureland than expected in the 100 ft buffer, and less than expected in the 50 ft and SPTH buffers, and medium and high development are higher than expected in the 100 ft and 50 ft buffers. Barren land is also different between public and private land, with more than expected in the 50 ft and 100 ft buffers, and less than expected in the SPTH on public land but having no significant difference from expected amounts in the 100 ft buffer on private lands.

Table 10

2021 CDL "reclass" land cover residuals for public and private buffer prescriptions

PUBLIC	50 ft	100 ft	SPTH
Developed, Med to High	9.13	3.22	-9.22
Developed, Low or Open Space	-18.37	-26.00	35.78
Crops	18.64	24.00	-34.86
Hay/Pasture/Fallow/Grass	-12.07	94.43	-78.62
Barren	49.64	59.22	-88.54
Shrubs or Herbaceous	31.96	110.18	-123.31
Woody	-16.17	-76.90	81.85

PRIVATE	50 ft	100 ft	SPTH
Developed, Med to High	2.97	-1.19	-0.86
Developed, Low or Open Space	-29.92	-51.33	62.03
Crops	180.56	323.12	-385.63
Hay/Pasture/Fallow/Grass	166.74	270.23	-332.36
Barren	33.38	-6.85	-15.13
Shrubs or Herbaceous	87.18	194.92	-219.01
Woody	-202.34	-366.50	435.85

Table 11

2021 CDL potential riparian land cover percentages for each riparian buffer width prescription

	Shrubland and Herbaceous Wetlands	Woody	TOTAL Potential Riparian
50 ft	15.9%	62.3%	79.2%
Public	13.7%	76.6%	92.2%
Private	17.9%	49.5%	67.5%
100 ft	16.3%	61.5%	78.7%
Public	14.1%	75.9%	91.8%
Private	18.4%	48.6%	67.0%
SPTH	14.8%	65.1%	80.6%
Public	12.9%	77.8%	92.3%
Private	16.3%	55.5%	71.9%

Note: "TOTAL Potential Riparian" percentages include barren land cover.

Significant correlations between land cover types

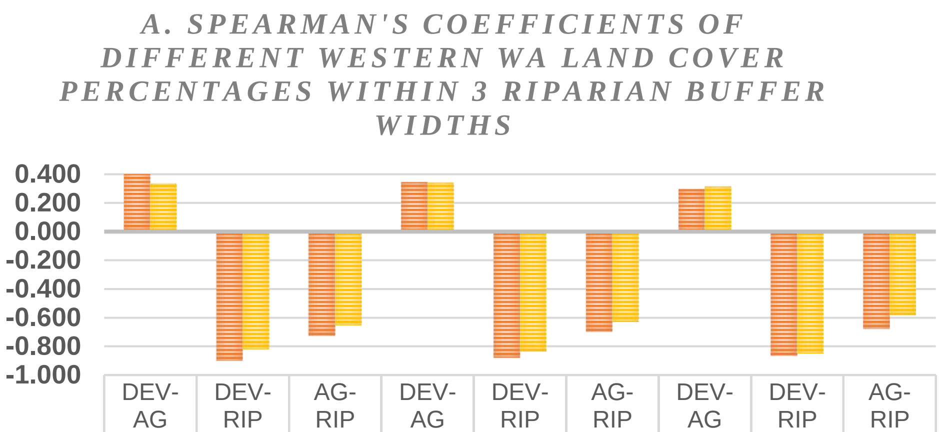
<u>"Simple" land cover reclassification</u>

Spearman's nonparametric ρ (rho) rank order correlation coefficients were calculated for the % cover of the three "simple" land cover types from the 2021 Cropland Data Layer (CDL) data, using individual WRIA data separated into Western and Eastern Washington. The sample size was 28 for Western Washington WRIAs (1 and 3-29) and Eastern (WRIAs 30-50 and 52-62). Missing WRIAs are due to the lack of inclusion of sovereign nations land designations in the data. There were very strong negative correlations between both agriculture and developed land cover types with potential riparian land cover, but the magnitude of the correlations was different between Eastern and Western Washington (Figure 18). The three buffer prescriptions had only slight differences when comparing correlations for the same land cover/location combinations. Correlations for public and private lands (Figure 19), supported by small p-values also show similar direction of the correlations (positive or negative) to those seen overall in Western versus Eastern Washington (Figure 18).

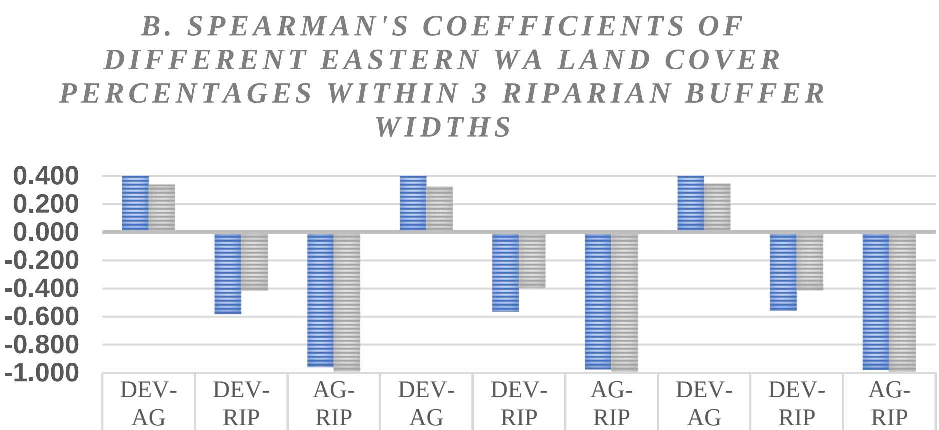
Both developed and agricultural land cover have very strong negative correlations to potential riparian land cover in the West and East, but agriculture in the East has the highest correlations, close to -1, and has slightly higher ρ on private lands versus public (p-value = <0.001) (Figure 19). Development in the West has the second strongest correlation, with relationships of ρ>0.81 to potential riparian land cover on both public and private lands (p-value = <0.001). There is additionally a strong negative correlation between agriculture and potential riparian land cover across all West public and private buffer sizes (p-value = <0.001). In the East, development has a strong negative correlation to potential riparian land cover on public lands (p-value = <0.001) and more moderate negative correlation on private lands (50 ft p-value = 0.018, 100 ft p-value = 0.024, SPTH p-value = 0.018). To put the impacts into perspective, there is between 15-17.5 times more riparian acreage than development land cover in the buffer prescriptions in the West, but only about two times more than agriculture in the East. The “simple” development and agriculture classes have non-significant relationships in the West except in the public 50 ft buffer (p-value = 0.021), and all public buffers in the East (p-value = 0.007), but the relationship is also negative on private lands in the East. These relationships are all positive, meaning that they increase together.

Figure 18

Graph of Spearman's ρ (rho) rank order correlation coefficients r for "simple" LULC by Western (A) and Eastern (B) Washington and by public and private ownership in riparian buffer prescriptions



	50ft			100ft			SPTH		
	DEV-AG	DEV-RIP	AG-RIP	DEV-AG	DEV-RIP	AG-RIP	DEV-AG	DEV-RIP	AG-RIP
PUBLIC	0.434	-0.902	-0.729	0.346	-0.879	-0.700	0.295	-0.866	-0.680
PRIVATE	0.333	-0.821	-0.655	0.341	-0.839	-0.629	0.313	-0.851	-0.583



	50ft			100ft			SPTH		
	DEV-AG	DEV-RIP	AG-RIP	DEV-AG	DEV-RIP	AG-RIP	DEV-AG	DEV-RIP	AG-RIP
PUBLIC	0.464	-0.582	-0.961	0.471	-0.567	-0.977	0.465	-0.561	-0.980
PRIVATE	0.339	-0.416	-0.991	0.326	-0.399	-0.993	0.345	-0.415	-0.993

Note: Spearman's ρ values are in the chart below each bar.

“Reclass” land cover reclassification

Since there is such strong correlation between development and potential riparian land cover in the three buffer prescriptions in Western Washington, and agriculture in Eastern Washington, the “reclass” classifications were assessed to clarify more specific factors affecting riparian land cover in the different regions (Tables 12, 13, and Appendix A, Tables A3 to A8). Further, because development overall shows low percentages of land cover compared to both the potential riparian and agricultural categories, yet has a substantial negative correlation, it was analyzed for all four development types in the correlated buffer prescriptions. While not assessed for correlations, condensed tables of East and West crop-specific land cover (Tables A3 and A4), and one reclassifying based on perennial versus annual crops (Table A5), is included in Appendix A for the buffer prescriptions divided by West and East. Additionally, tables showing specific land cover percentages by public landowner East and West (Tables A6 and A7) are also in Appendix A.

The development land cover analysis using Spearman’s nonparametric ρ (rho) rank order correlation coefficients clarifies several things. First, the strong negative correlations are more often related to the woody land cover category than the shrubland category (Table 12). The correlation between development categories and shrublands only show strong negative correlation in the West with open development on public lands and in the private SPTH buffer to high, medium, and low development land covers. In the Western public lands, the correlation to open development is negative where other developments were weak but positive, while the private land correlations between development and shrublands are all negative. On Eastern public lands there are strong positive correlations for all developments categories in relation to shrublands in the 50 ft buffer, high and medium development in the 100 ft buffer, and flips to a negative correlation in the high development category in the SPTH. All other shrubland categories have non-significant relationships, notably with no Eastern private development land cover types being in correlation to shrublands (Table 12).

Private lands in Western Washington show the highest strong negative correlations between all development categories and woody land cover class across all buffers, followed by western public lands, which show a negative correlation to all but open development in all buffers (Table 12). On the East side, all four separated development types show a moderate or strong negative correlation to woody vegetation on public lands in the 50 ft and SPTH buffers, but only to the high development category in the 100 ft buffers, confirming the stronger influence of pastureland on overall composition percentages in that buffer (Tables 9 and 13). Private lands in the East show the littlest correlation between development and woody vegetation, with only medium development showing a strong negative correlation in all buffers.

There are a few strong positive correlations in the "reclass" Spearman's analysis that reveal relationships beyond what is shown through the "simple" analysis (ρ and p-values for all correlations are in Appendix A, Table A8), or concurring land cover types. Eastern public lands show positive correlations between all land class categories (excluding barren lands as a variable) except woody vegetation, with the strongest relationships being between pasturelands and shrublands, and crops in relation to pasturelands and shrublands, followed by high and medium development in relation to low and open development. In all buffers on both East and West, public and private lands, there are positive correlations between the two development types, between croplands and pasturelands, and high and medium development to crops (except in the 100 ft private buffers in the East). High and medium development has a strong positive correlation to pasturelands on Western public lands in all buffers, and crop and pasturelands have strong correlations to shrublands in the West in the 50 ft and 100 ft buffers, and between pasture and shrublands on public lands in the SPTH buffer and on private lands in the 50 ft buffer. In summary, within riparian zones, development and agriculture often increase together while woody vegetation decreases, and there is mostly a strong concurrent relationship between shrublands and agriculture on public lands and sometimes on private lands.

Strong negative Spearman's ρ correlations exist between woody vegetation and all other land cover classes in all buffers, East and West, public and private, with these non-significant exceptions (ρ and p-values are in Table 13): Medium and high development in the 50 ft and 100 ft buffers on private lands in the East (the correlation is significant in the SPTH), low and open development in all West public and East private buffers, and with crops on Western public lands in the 100 ft and SPTH buffers (it is significant in the 50 ft buffer). Additionally, there are strong negative correlations between both development classes and shrublands on private lands in the West within the SPTH buffer size.

In terms of the magnitude of land cover relationships with strong negative ρ, they tend to be highest in private lands in the West, and public lands in the East (Table 13). In the West, on public lands, the highest correlations with woody vegetation are similar and flip between shrublands and pastureland, depending on the buffer size, with ρ between -0.702 and -0.774. On private lands in the West, the negative correlations with both development types are the most significant, increasing in magnitude with buffer size increasing with ρ between -0.760 and -0.824. In public lands of Eastern Washington, the most significant negative correlation to lower percentage of potential riparian land are shrublands, pasturelands, and croplands, in that order, with *r* between -0.857 and -0.924. On private lands in the East, the most significant relationships are first between pasturelands, then by cropland in relation to woody vegetation, with ρ between -0.742 and -0.792.

Table 12

Spearman's ρ (rho) rank order correlation coefficients and p-values for different development land cover types of the 2021 CDL in relation to potential riparian land cover on public and private lands in Western and Eastern Washington.

PUBLIC		WEST				EAST			
		Shrublands		Woody		Shrublands		Woody	
		ρ	p-value	ρ	p-value	ρ	p-value	ρ	p-value
50 ft	HI	0.263	NS	-0.677	<0.001	0.662	<0.001	-0.628	<0.001
	MED	0.250	NS	-0.665	<0.001	0.713	<0.001	-0.683	<0.001
	LOW	0.149	NS	-0.566	0.002	0.523	0.002	-0.531	0.002
	OPEN	-0.205	NS	-0.182	NS	0.456	0.009	-0.492	0.005
100 ft	HI	0.307	NS	-0.650	<0.001	0.421	0.016	-0.376	0.034
	MED	0.246	NS	-0.606	<0.001	0.359	0.043	-0.275	NS
	LOW	0.113	NS	-0.457	0.015	0.021	NS	0.051	NS
	OPEN	-0.395	0.037	0.167	NS	-0.034	NS	0.050	NS
SPTH	HI	0.201	NS	-0.604	<0.001	-0.376	0.034	-0.636	<0.001
	MED	0.175	NS	-0.539	0.003	-0.275	NS	-0.699	<0.001
	LOW	0.062	NS	-0.426	0.024	0.051	NS	-0.535	0.002
	OPEN	-0.210	NS	-0.099	NS	0.050	NS	-0.483	0.006
PRIVATE		WEST				EAST			
		Shrublands		Woody		Shrublands		Woody	
		ρ	p-value	ρ	p-value	ρ	p-value	ρ	p-value
50 ft	HI	-0.180	NS	-0.789	<0.001	0.085	NS	-0.232	NS
	MED	-0.259	NS	-0.770	<0.001	0.148	NS	-0.352	0.049
	LOW	-0.272	NS	-0.783	<0.001	-0.124	NS	0.014	NS
	OPEN	-0.132	NS	-0.664	<0.001	-0.136	NS	-0.185	NS
100 ft	HI	-0.291	NS	-0.806	<0.001	0.100	NS	-0.260	NS
	MED	-0.343	NS	-0.804	<0.001	0.157	NS	-0.358	0.044
	LOW	-0.363	NS	-0.822	<0.001	-0.155	NS	0.009	NS
	OPEN	-0.206	NS	-0.768	<0.001	-0.168	NS	-0.170	NS
SPTH	HI	-0.438	0.020	-0.817	<0.001	0.082	NS	-0.269	NS
	MED	-0.050	0.007	-0.807	<0.001	0.151	NS	-0.372	0.037
	LOW	-0.543	0.003	-0.825	<0.001	-0.157	NS	-0.003	NS
	OPEN	-0.353	NS	-0.771	<0.001	-0.172	NS	-0.177	NS

Table 13

Spearman's ρ (rho) rank order correlation coefficients and p-values for all significant negative land cover relationships of the 2021 CDL in relation to public and private lands in Western and Eastern Washington.

			WEST				EAST			
	variable1	*variable2*	**PUBLIC**	*p-value*	**PRIVATE**	*p-value*	**PUBLIC**	*p-value*	**PRIVATE**	*p-value*
50 ft	DEVMH	WOOD	-0.681	<.001	-0.771	<.001	-0.665	<.001	NS	*ns*
	DEVLO	WOOD	NS	*ns*	-0.760	<.001	-0.520	0.003	NS	*ns*
	CROP	WOOD	-0.449	0.017	-0.589	0.001	-0.871	<.001	-0.750	<.001
	PAST	WOOD	-0.734	<.001	-0.620	0.001	-0.887	<.001	-0.766	<.001
	SHRUB	WOOD	-0.734	<.001	NS	*ns*	-0.924	<.001	-0.391	0.028
100 ft	DEVMH	WOOD	-0.586	0.001	-0.801	<.001	-0.688	<.001	NS	*ns*
	DEVLO	WOOD	NS	*ns*	-0.817	<.001	-0.513	0.003	NS	*ns*
	CROP	WOOD	NS	*ns*	-0.600	0.001	-0.857	<.001	-0.742	<.001
	PAST	WOOD	-0.702	<.001	-0.604	0.001	-0.893	<.001	-0.760	<.001
	SHRUB	WOOD	-0.774	<.001	NS	*ns*	-0.917	<.001	-0.359	0.044
SPTH	DEVMH	WOOD	-0.558	0.002	-0.814	<.001	-0.692	<.001	-0.361	0.043
		SHRUB	NS	*ns*	-0.484	0.010	0.715	<.001	NS	*ns*
	DEVLO	SHRUB	NS	*ns*	-0.430	0.023	0.477	0.006	NS	*ns*
		WOOD	NS	*ns*	-0.824	<.001	-0.497	0.004	NS	*ns*
	CROP	WOOD	NS	*ns*	-0.562	0.002	-0.857	<.001	-0.751	<.001
	PAST	WOOD	-0.760	<.001	-0.529	0.004	-0.893	<.001	-0.792	<.001
	SHRUB	WOOD	-0.731	<.001	NS	*ns*	-0.917	<.001	-0.373	0.036

CONSERVED LANDS INSIDE BUFFER PRESCRIPTIONS

The results of combining data from the National Conservation Easement Database (NCED) and the Protected Areas Database (PAD) within the different buffer prescriptions are in Table 14. While data only includes lands with a Gap Analysis Project (GAP) code of 1, 2, or 3, and private or NGO data is assumed underestimated by the sources, the results show that a very high percentage of conserved lands in Washington State are public (98.54% overall average) and a very low percentage is private or NGO (1.33% overall average). Divided by Western and Eastern Washington (Table 15), the results demonstrate differences as in the other analyses. Across the board, all buffers in the West have a higher percentage conserved, with a higher percentage of private ownership conserved (1.75% on average in the West compared to 0.72% in the East). Comparing differences between buffers,the percentage between the SPTH and 100 ft in the West is 7.14%

It is notable that 168,921 acres within the SPTH buffers in the public conservation datasets do not overlap with the public land inventory polygon layer. Whether these lands are public easements on private lands, have changed ownership over time, have a mixed ownership agreement, or there are geospatial inaccuracies in the datasets, is unknown. If all of this acreage was included in the private conservation acreage (though it is very unlikely all private), it would increase its percentage to 5.9% overall, 5.1% in the West, and 6.4% in the East.

Table 14

Percentages of public and private conserved lands in Washington State extracted from the NCED and PAD datasets within three riparian buffer width prescriptions

All WA	50ft	100ft	SPTH
Percent conserved of buffer	47.24%	47.64%	43.84%
Public percent of conserved	98.43%	98.66%	98.53%
Private percent of conserved	1.43%	1.22%	1.34%
Overlap pub/pvt percent of conserved	0.14%	0.12%	0.13%

Table 15

Percentages of public and private conserved lands in Western and Eastern Washington extracted from the NCED and PAD datasets within three riparian buffer width prescriptions

WEST	50ft	100ft	SPTH
Percent conserved of buffer	50.30%	50.88%	43.74%
Public percent of conserved	97.86%	98.25%	98.08%
Private percent of conserved	1.94%	1.57%	1.74%
Overlap pub/pvt percent of conserved	0.20%	0.18%	0.18%
EAST	50ft	100ft	SPTH
Percent conserved of buffer	43.51%	43.81%	44.01%
Public percent of conserved	99.25%	99.21%	99.24%
Private percent of conserved	0.70%	0.74%	0.71%
Overlap pub/pvt percent of conserved	0.05%	0.05%	0.05%

TEMPORAL LAND USE CHANGES IN BUFFER WIDTHS 2001-2019

Comparison of the data from the National Land Cover Dataset (NLCD) for 2001 and 2019 (Table 16) shows an overall pattern in Washington of both development and potential riparian land cover increasing, while agriculture is decreasing. However, within the buffer prescriptions, agriculture is increasing on both public and private lands, while development is increasing on private lands and decreasing on public lands. Land cover that is potentially riparian is decreasing in all categories of buffer besides private lands in the SPTH, where it is increasing. Table 16 shows the actual change in composition percentages, but to put things in perspective, we can consider the rate of change. In Washington overall, there has been a 5.1% increase in development (5.7% on public lands, and 5.0% on private), a 6.9% increase in potential riparian land cover (5.1% public, 7.2% private), and a decrease of 15.6% in agriculture (-21.8% public, and -14.6% private). The average changes in the three buffer prescriptions for public lands is -3.2% development, +35.7% agriculture, and -30.6% potential riparian land cover. On private lands it is +4.2% development, +2.7% agriculture, and -5.6% potential riparian land cover.

Table 16

Change from 2001 to 2019 NLCDs in land cover composition percentages (above) and in acres (below) in Washington overall and within three riparian buffer width prescriptions

2001-2019 NLCD difference		Developed	Agriculture	Potential Riparian
All WA		0.32%	-0.98%	0.43%
	Public	0.12%	-0.45%	0.11%
	Private	0.45%	-1.34%	0.66%
50 ft		0.10%	0.62%	-0.63%
	Public	-0.13%	0.77%	-0.60%
	Private	0.30%	0.48%	-0.65%
100 ft		0.12%	0.69%	-0.75%
	Public	-0.06%	0.95%	-0.83%
	Private	0.28%	0.46%	-0.67%
SPTH		0.15%	0.11%	-0.24%
	Public	-0.03%	0.82%	-0.75%
	Private	0.28%	-0.42%	0.14%

2001-2019 NLCD difference in acres		Developed	Agriculture	Potential Riparian
All WA		124007	-381962	168875
	Public	18349	-70767	16652
	Private	105658	-311195	152222
50 ft		3336	21027	-21292
	Public	-2065	12367	-9707
	Private	5401	8660	-11585
100 ft		7330	42300	-45989
	Public	-1872	27433	-24106
	Private	9202	14867	-21883
SPTH		11770	9288	-17493
	Public	-1172	28180	-25404
	Private	12936	-18905	7876

Temporal changes within the buffers by "reclass" categories

As with the USDA Cropland Data Layer (CDL), delineating the data by East and West, and a comparison of land class within the "reclass" categories gives more insight into the potential amount of riparian land cover. The West has increases in the "woody" category across all buffers, public and private, with a higher increase on private lands (Table 17). There is also a pattern of increase in "woody" vegetation in the West where there is a decrease in "shrublands and herbaceous wetlands" for each buffer width. The East has decreases in potential riparian cover, with a higher percentage change on public lands.

The details related to the natural cover loss in the buffer zones necessitate a comparison of land cover differences in all "reclass" categories between Western and Eastern Washington from 2001 to 2019 as shown in Table 18. When compared to the overall differences, the most notable regional differences are that both medium and high development and the agricultural categories are increasing across all buffers in the East at a higher rate than in the West, where pastureland is also decreasing. One noticeable difference between buffer sizes is that crops are increasing in the 50 ft buffer at a higher rate than the 100 ft and SPTH in the West.

Table 17

Change in composition of land cover from 2001 to 2019 NLCDs for Eastern and Western Washington and riparian buffer width prescriptions for potential riparian land cover by percent woody vegetation versus shrublands and herbaceous wetlands.

WEST	Shrublands & Herbaceous Wetlands	Woody Vegetation	TOTAL Potential Riparian
50 ft	-3.54%	4.63%	1.02%
Public	-3.61%	3.87%	0.30%
Private	-3.48%	5.38%	1.73%
100 ft	-3.48%	4.61%	1.09%
Public	-3.57%	3.76%	0.25%
Private	-3.38%	5.46%	1.93%
SPTH	-3.38%	4.86%	1.43%
Public	-3.58%	3.82%	0.28%
Private	-3.24%	5.62%	2.28%
EAST			
50 ft	-0.45%	-2.61%	-3.04%
Public	1.27%	-3.45%	-2.07%
Private	-1.82%	-1.92%	-3.77%
100 ft	-0.42%	-2.76%	-3.15%
Public	1.52%	-4.10%	-2.48%
Private	-1.93%	-1.71%	-3.67%
SPTH	-0.33%	-2.78%	-3.09%
Public	1.49%	-4.07%	-2.50%
Private	-1.75%	-1.77%	-3.54%

Note: Slight discrepancies in overall percentages are from barren land, which is also included in the "potential riparian" percentages.

Table 18

Change in composition of "reclass" land cover classes by percentage from 2001 to 2019 NLCDs for Eastern and Western Washington and riparian buffer prescriptions.

WEST	DEVMH	DEVLO	CROP	PAST	BAR	SHRUB	WOOD
50 ft	0.11%	0.01%	0.16%	-1.30%	-0.07%	-3.54%	4.63%
Public	0.02%	-0.07%	0.00%	-0.25%	0.03%	-3.61%	3.87%
Private	0.20%	0.09%	0.32%	-2.33%	-0.17%	-3.48%	5.38%
100 ft	0.11%	0.02%	0.11%	-1.33%	-0.04%	-3.48%	4.61%
Public	0.01%	-0.03%	0.00%	-0.23%	0.06%	-3.57%	3.76%
Private	0.20%	0.08%	0.21%	-2.42%	-0.14%	-3.38%	5.46%
SPTH	0.13%	0.03%	0.09%	-1.69%	-0.04%	-3.38%	4.86%
Public	0.02%	0.00%	0.00%	-0.29%	0.04%	-3.58%	3.82%
Private	0.22%	0.06%	0.15%	-2.71%	-0.10%	-3.24%	5.62%
EAST	DEVMH	DEVLO	CROP	PAST	BAR	SHRUB	WOOD
50 ft	0.16%	-0.10%	0.07%	2.91%	0.03%	-0.45%	-2.61%
Public	0.01%	-0.27%	0.01%	2.32%	0.10%	1.27%	-3.45%
Private	0.28%	0.02%	0.10%	3.37%	-0.03%	-1.82%	-1.92%
100 ft	0.17%	-0.07%	0.06%	3.00%	0.03%	-0.42%	-2.76%
Public	0.03%	-0.16%	0.01%	2.61%	0.09%	1.52%	-4.10%
Private	0.29%	0.00%	0.09%	3.29%	-0.03%	-1.93%	-1.71%
SPTH	0.17%	-0.06%	0.07%	2.91%	0.02%	-0.33%	-2.78%
Public	0.03%	-0.14%	0.01%	2.60%	0.08%	1.49%	-4.07%
Private	0.28%	0.00%	0.12%	3.15%	-0.02%	-1.75%	-1.77%

Significant correlations between land cover types

Spearman’s nonparametric ρ (rho) rank order correlation coefficients applied to all variables within the “reclass” classification, except the barren class (Appendix B, Table B1), on the change percentages from the 2001 to 2019 NLCD were again divided into public and private ownership, and by Western and Eastern Washington. The effects of change at the WRIA level may not be reflected in the overall compositional percentages, due to larger WRIAs with larger compositional differences influencing the data. Several positive and negative significant correlative patterns emerge in this analysis.

In the East, there were no concurrent positive significant changes in land cover within the riparian buffer prescriptions (Table B1). On West private lands, there was a positive rho correlation in all buffers between the two development classes, where ρ increases as buffer size increases. There is also a positive correlation between pasturelands and shrublands on public lands in the West in the 50 ft and 100 ft buffers.

Across buffers, and both West and East, the most significant negative ρ correlation is between shrublands and woody vegetation (Table 19). In the West this strong negative correlation is on both public and private lands and is related to an increase in woody vegetation and a decrease in shrublands, but in the East the negative ρ correlation in all buffers on public lands and in the SPTH buffer on private lands seems to show a likely relationship between an increase in shrublands and a decrease in woody vegetation on public lands, however is more difficult to decipher which increases or decreases in the private SPTH buffer where both decrease simultaneously overall. This is likely because the Spearman ρ analysis is on a WRIA level, but the overall regional data is compared to all land cover.

The next most significant negative relationship was a ρ correlation between pasturelands and woody vegetation in all Western buffers on both public and private lands and on Eastern private lands in the 50 ft and SPTH buffers. However, they have a reverse relationship. In the West, there is a decrease in pasturelands while woody vegetation increases. In the East, there is an increase in pasturelands concurrent with a decrease in woody vegetation, but on private lands pastureland increased at a higher magnitude than on public lands, and woody vegetation on public lands decreased at a higher magnitude than on private lands. The next highest ρ correlation was a negative correlation between the low and open development class and woody vegetation in all private buffer sizes of the East, the private 50 ft and 100 ft buffers and the public 100 ft buffer in the West. Again, this relationship is hard to determine without examining on the WRIA level, as the low and open development class overall has a very small increase to neutral change while woody vegetation decreased at a much higher degree in the East, and in the West on private lands there is only a small decrease in low and open development in the public buffers, but an increase in private buffers, with an increase in woody vegetation in both buffers. Finally, in the East, there was a negative correlation in all buffers and both public and private lands between pastureland and shrubland. This appears to be related to an increase in pasturelands and a decrease in shrublands.

Table 19

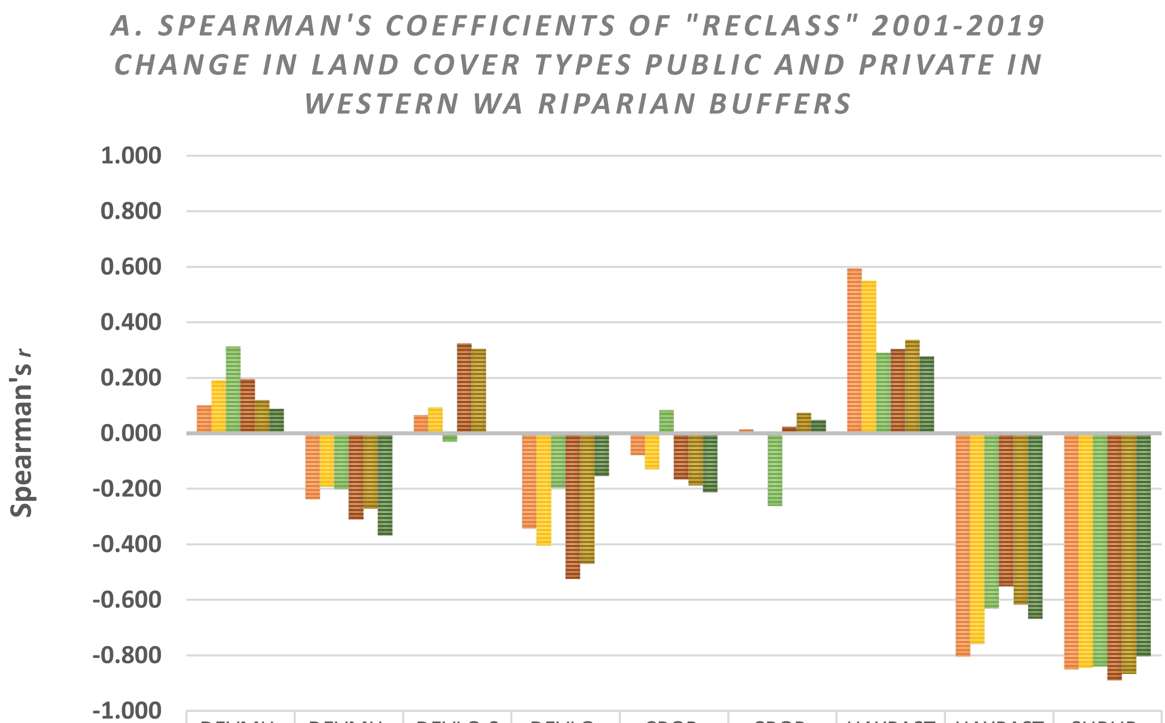
Spearman's ρ (rho) rank order correlation coefficients and p-values for significant negative land cover relationships of the 2021 CDL on public and private lands in Western and Eastern Washington.

			WEST				EAST			
	variable1	*variable2*	**PUBLIC**	*p-value*	**PRIVATE**	*p-value*	**PUBLIC**	*p-value*	**PRIVATE**	*p-value*
50 ft	DEVLO	WOOD	-0.343	*ns*	-0.524	0.005	-0.229	*ns*	-0.731	<0.001
	PAST	SHRUB	0.593	0.001	0.303	*ns*	-0.477	0.006	-0.550	0.001
		WOOD	-0.805	<0.001	-0.551	0.003	-0.313	*ns*	-0.392	0.027
	SHRUB	WOOD	-0.851	<0.001	-0.891	<0.001	-0.527	0.002	-0.309	*ns*
100 ft	DEVMH	SHRUB	0.190	*ns*	0.118	*ns*	-0.406	0.022	-0.274	*ns*
	DEVLO	WOOD	-0.405	0.033	-0.471	0.012	-0.185	*ns*	-0.680	<0.001
	CROP	WOOD	-0.006	*ns*	0.073	*ns*	-0.228	*ns*	-0.420	0.017
	PAST	SHRUB	0.548	0.003	0.336	*ns*	-0.516	0.003	-0.552	0.001
		WOOD	-0.760	<0.001	-0.619	<0.001	-0.307	*ns*	-0.315	*ns*
	SHRUB	WOOD	-0.846	<0.001	-0.868	<0.001	-0.502	0.004	-0.297	*ns*
SPTH	DEVMH	WOOD	-0.201	*ns*	-0.368	*ns*	-0.420	0.017	0.156	*ns*
	DEVLO	WOOD	-0.196	*ns*	-0.155	*ns*	-0.168	*ns*	-0.530	0.002
	CROP	WOOD	-0.261	*ns*	0.048	*ns*	-0.181	*ns*	-0.414	0.019
	PAST	SHRUB	0.289	*ns*	0.277	*ns*	-0.518	0.003	-0.530	0.002
		WOOD	-0.632	<0.001	-0.667	<0.001	-0.296	*ns*	-0.360	0.044
	SHRUB	WOOD	-0.840	<0.001	-0.804	<0.001	-0.484	0.006	-0.350	0.050

Note: Tests were run on a WRIA level for land cover composition percentage change data, with a sample set N=28 for the West, and N=31 for the East. P-values are included if p-value<0.05. The "shrublands" land cover classification includes herbaceous wetlands.

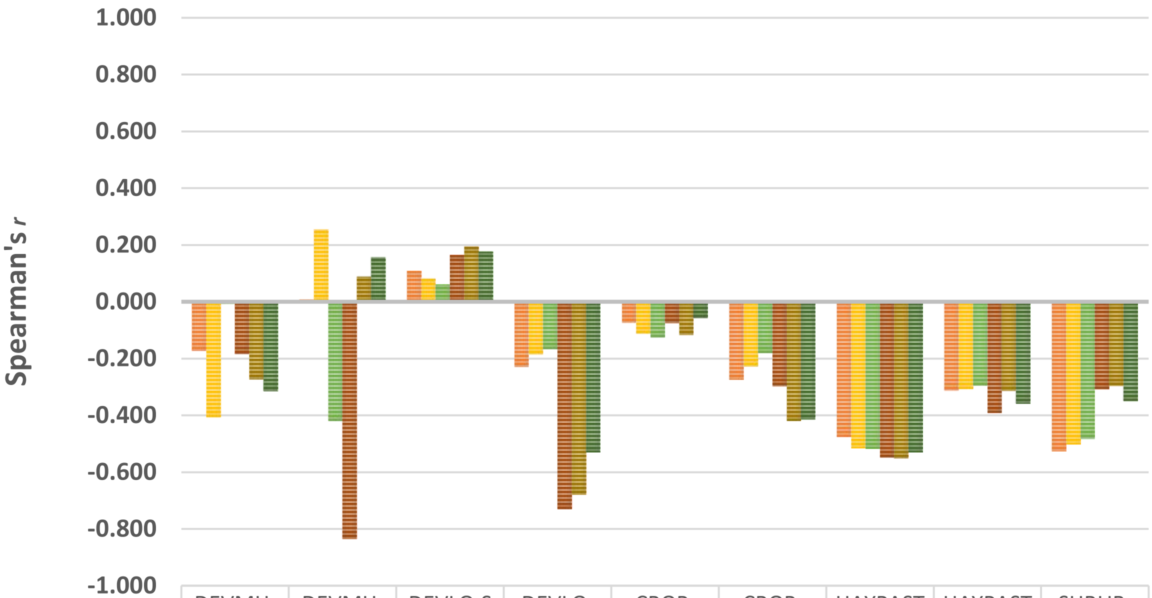
Figure 19

Significant negative Spearman's ρ (rho) correlations in relation to change of the NLCD from 2001 to 2019 for potential riparian "reclass" land cover categories within three buffer prescriptions on Western (A) and Eastern (B) public and private lands.



	DEVMH: SHRUB	DEVMH: WOODY	DEVLO:SHRUB	DEVLO: WOODY	CROP: SHRUB	CROP: WOODY	HAYPAST:SHRUB	HAYPAST:WOODY	SHRUB: WOODY
PUBLIC 50ft	0.100	-0.238	0.066	-0.343	-0.078	0.014	0.593	-0.805	-0.851
PUBLIC 100ft	0.190	-0.193	0.093	-0.405	-0.130	-0.006	0.548	-0.760	-0.846
PUBLIC SPTH	0.312	-0.201	-0.030	-0.196	0.083	-0.261	0.289	-0.632	-0.840
PRIVATE 50ft	0.195	-0.310	0.323	-0.524	-0.166	0.023	0.303	-0.551	-0.891
PRIVATE 100ft	0.118	-0.272	0.303	-0.471	-0.188	0.073	0.336	-0.619	-0.868
PRIVATE SPTH	0.088	-0.368	0.002	-0.155	-0.214	0.048	0.277	-0.667	-0.804

B. SPEARMAN'S COEFFICIENTS OF "RECLASS" 2001-2019 CHANGE IN LAND COVER TYPES PUBLIC AND PRIVATE IN EASTERN WA RIPARIAN BUFFERS



	DEVMH: SHRUB	DEVMH: WOODY	DEVLO:S HRUB	DEVLO: WOODY	CROP: SHRUB	CROP: WOODY	HAYPAST :SHRUB	HAYPAST :WOODY	SHRUB: WOODY
PUBLIC 50ft	-0.174	0.007	0.108	-0.229	-0.074	-0.275	-0.477	-0.313	-0.527
PUBLIC 100ft	-0.406	0.254	0.082	-0.185	-0.112	-0.228	-0.516	-0.307	-0.502
PUBLIC SPTH	-0.007	-0.420	0.060	-0.168	-0.126	-0.181	-0.518	-0.296	-0.484
PRIVATE 50ft	-0.185	-0.836	0.165	-0.731	-0.076	-0.298	-0.550	-0.392	-0.309
PRIVATE 100ft	-0.274	0.088	0.194	-0.680	-0.117	-0.420	-0.552	-0.315	-0.297
PRIVATE SPTH	-0.315	0.156	0.175	-0.530	-0.059	-0.414	-0.530	-0.360	-0.350

CHAPTER 5: DISCUSSION

Buffer width size significance

The results show that land cover composition inside different buffer width prescriptions has more significant differences in the Eastern half of the state than in the West. In the West, agriculture and potential riparian land cover have very similar compositions no matter the buffer size, and only development in the “simple” classes on private lands is significantly different between buffer sizes in the West (Appendix A, Table A1). However, the “reclass” analysis is useful to discover patterns at finer scales. In the West, both medium and high development on public lands (50 ft to 100 ft), and crops on both public and private lands have higher mean compositions in some smaller buffer sizes (Appendix A, Table A2) . In the East, on the other hand, development was mostly similar across buffers. Agricultural land cover was significantly different on both public and private lands between buffers in the East, showing a pattern of croplands and pasturelands having higher compositions in the 100 ft buffer than both the 50 ft and SPTH buffer (Appendix A, Table A2).. This difference in the East seems related to a lower percentage composition of woody vegetation within the 100 ft buffer.

The WDFW recommendations for $SPTH_{200}$ used as a policy goal are important based on research findings that support similar widths as minimums, but based on this research, within the closest 50 or 100 feet of streams, there is still often higher concentrations of development and agriculture in the smaller buffers than in the SPTH buffer. Further, based on the data from the National Conservation Easement Dataset (NCED) and Protected Areas Database (PAD) conserved lands analyses, there is a lower percentage of lands in the immediate 50 ft buffer protected at a level that meets riparian management guidelines than in the 100 ft and SPTH. The FEMAT curves that the WDFW used as a major basis for its recommendations illustrate that a full SPTH has the most impact on a riparian ecosystem, but the overall efficiency of impact is greater the closer to the stream (FEMAT, 1993).

Impacts of buffer width in several studies have also been greatest at scales much larger than SPTH buffer size (Knehtl et al., 2021; K. Li et al., 2018; Nava-López et al., 2016; Palt et al., 2023), with urban development having the strongest negative impact on water quality in narrow buffer widths, and forests having a greater positive impact in less space. Based on the larger scale landscape studies, impacts on water quality by development, and agriculture (to a lesser degree) change based on length and channel connectivity in addition to width (Bond et al., 2019; Fogel et al., 2022; Knehtl et al., 2021; K. Li et al., 2018), and go far beyond the prescribed buffer widths in this study. Floodplain connectivity also has significant positive results on water quality in areas where riparian buffer widths are limited geographically (Fogel et al., 2022).

Regional riparian buffer LULC compositions

Overall, Western Washington (WRIAs 1-29) has 1.7 times more land within the SPTH buffer width (about 5M acres) than Eastern Washington (WRIAs 30-62, just under 3M acres, Table 7). However, the West has 2.1 times more development, whereas the East has 3.4 times as much acreage in agricultural lands. 80% of the SPTH buffer in the West is woody vegetation, which has been shown repeatedly to be a key factor in an effective riparian buffer (Basnyat et al., 2000; S. Li et al., 2009; Sargac et al., 2021), while in the East, only 40% of the SPTH buffer is woody vegetation. Even accounting for shrublands that may include native plants and contribute to a healthy riparian habitat (in conjunction with woody vegetation; Chaney et al., 1990; Shaw & Cooper, 2008; Tufekcioglu et al., 2003), potential riparian land cover is only 66% in the East (Table 8).

It is also apparent from examining Spearman ρ (rho) coefficients that development and agriculture are not negatively correlated to shrublands, only to woody vegetation, except in relation to development on private lands in the SPTH buffer in the West (Table 13). Shrublands are strongly negatively correlated to woody vegetation on public lands in both the West and the East, and moderately to private lands in the East. Both of these results, combined with the lower identification accuracy in the NLCD data layers (Wickham et al., 2021) calls into question whether shrublands as a broad category should be considered "potential riparian" land cover without more precise characterization of native shrubland and herbaceous wetland plants.

When comparing the land cover composition of Eastern and Western Washington, while it is clear Western Washington has more development in the buffer zone, and Eastern buffers have more agriculture, woody vegetation in Western Washington is also negatively correlated with pasturelands in all three buffer widths, and crops within the 50 ft buffer width (Table 13). Also, woody vegetation on Eastern lands is negatively correlated with development on public lands, and on private lands, by medium development in all buffer widths.

Policy implications

The strong negative correlative relationships shown here between potential riparian habitat to both development and agriculture with stark regional differences between Eastern and Western Washington are in contrast to policy approaches that lack coordination and mainly focus on commercial forest management and voluntary agricultural restoration that currently impacts a very small percentage of all agriculture in the buffers. While some water quality monitoring and habitat protection in the riparian buffers of developed areas occurs through the Clean Water Act, the Growth Management Act, and the Shoreline Management Act, they are focused on highly populated areas and do not apply policy at a watershed level. Further, water pollution (Figure 4), which is known to have a major influence on stream temperatures which in turn impacts salmon populations and other water quality issues (Barnowe-Meyer et al., 2021; Fogel et al., 2022; Fuller et al., 2022; McCullough, 1999; NWIFC, 2020) is an ongoing and immense problem in the state, especially in the Western half which has high levels of woody vegetation in the riparian buffer prescriptions of this study, yet still has declining salmon populations.

Development in the Western riparian buffer prescriptions

While there are many more acres of agricultural land in the Eastern buffer width prescriptions and at a much higher ratio to riparian land cover (with a Spearman ρ (rho) correlation close to -1), than there is development in the West, development presents a major obstacle for riparian restoration and protection. It is difficult to undo built environments next to rivers, and policies to address improvements to the habitat in these spaces could be key to improving the health of streams and rivers in the Western half of the state, where development has a high impact on riparian composition and habitat health, more so than agriculture (S. Li et al., 2009; C. W. May & Horner, 2000; Moore & Palmer, 2005). For western regions where there are high percentages of woody vegetation within 50 ft to $SPTH_{200}$ wide riparian buffers it is important to consider whether the land cover identified as "riparian" actually meets goals for water quality and species habitat, and research like that conducted by McBride and Booth (2005), which identified the exponential impact of roads near streams in Washington, could be utilized to identify reductions in riparian buffer efficiency due to other land cover.

Agriculture in the Eastern riparian buffer prescriptions

In Eastern Washington, the amount of riparian habitat inside buffers is strongly and negatively correlated with the amount of agriculture (Figure 18B). Most state regulation for riparian habitat falls under the Fish and Forests Law, which is interrelated more heavily with forests in the West than the drylands of the East, and the Growth Management Act applies to fewer counties than in the West, including some that are severely lacking in riparian vegetation (Figure 15). Research on riparian buffer composition and buffer widths near dryland streams is lacking in the literature, aside from impacts of pasturelands, and might help contribute to smarter management since the ecology is very different with historic tree heights closer to 20 feet and are more diverse with inclusion of deciduous trees, native grasses, and shrubs than the dominant conifer forests in the West (Chaney et al., 1990; WDFW, 2020a; WDFW Habitat Program, 2023a). Shrublands (and potentially grasslands) constituting a large portion of native riparian land cover makes sense in the native dryland ecology of the Eastside but does not reflect what is known of historic riparian ecosystems endemic to the area, which had more woody vegetation. Increasing research and policy efforts in the Eastern half of the state, as well as rural and agricultural areas in general, may be a key component to improving riparian habitat and water quality throughout the state.

Pasturelands

In the Western half of the state, when we look at crop specifics, most agriculture is pastureland or hay (Appendix A, Table A3). Hay and pastureland cover is the highest agricultural component of riparian land cover in the Eastern half of the state as well, but wheat and fallow croplands are also highly prevalent (Appendix A, Table A4), and there is a higher diversity of crops in the buffer zones. While development has a wider impact in watersheds than agricultural lands (Basnyat et al., 2000; Sargac et al., 2021), and crops are shown to have a higher negative correlation than pasture (Teels et al., 2006), pasturelands that don’t include rotational grazing or native grasses as multi-crop buffers with trees, have repeatedly demonstrated negative impacts on riparian habitats and water quality, and best results in restoration have been to completely fence off or prevent livestock from entering riparian management areas (Armour et al., 1994; Belsky et al., 1999; Chaney et al., 1990; Elmore & Beschta, 1987).

Relationship between development and agriculture in the riparian buffer prescriptions

There is concern in Washington as a whole regarding preservation of farmland. The temporal results of this study showed this impact in the state overall, but this pattern is not prevalent in riparian management areas. While there are some nuances in the temporal study, for the analysis of the 2021 Cropland Data Layer (CDL), the only negative correlation was between development and pasturelands on private lands in the Western SPTH buffer. The development and agriculture simple classes show a lack of strong or even moderate correlation to each other in the buffer prescriptions in the West, but moderate and strong correlations in the East are positive, meaning that they increase together (Figure 18). The results also clearly demonstrate that negative correlations are associated with increases of agriculture and decreases of woody vegetation (shrublands were often increasing alongside agriculture and development as well).

Temporal Changes 2001-2019

Overall, in Washington, agricultural land is decreasing, while development and natural land cover are increasing, based on the temporal changes from 2001-2019 using the NLCD. This pattern is different than what is happening over the same time period in the prescribed buffer widths, especially when broken out into Western and Eastern Washington (Tables 17 and 18). The indication is that the land cover classes constituting shrublands and woody vegetation are not co-occurring, but have a strong negative correlation across buffers, regions, and ownership type, that both development and agriculture are negatively impacting riparian habitat in the East (Figure 19B), while woody vegetation is increasing substantially in the buffers in Western Washington (Table 18).

In the West, this increase in woody vegetation is at higher rates on private lands, and at higher rates overall than other land class categories. This is related to a decrease in shrublands and pasturelands (with evidence from negative correlations, Table 19, and overall compositional percentage changes, Table 18). There is also a strong positive correlation between shrublands and pasturelands (Figure 19), which leads to a question of whether there is some level of classification crossover or miscategorization between the land cover types between 2001 and 2019. However, this assessment, because of its breadth, makes it difficult to conclude the reasoning for this increase. It is possibly due to increased preservation and restoration (especially on private lands) or could also be due to natural processes from areas that were younger forests or clearcut before or around 2001. This still implies a level of preservation since it increased dramatically compared to other categories and could be considered a measure of success.

Crops in the Western buffers increased, even as pasturelands decreased, and most notably, at a higher rate closer to streams by buffer width, but with no strong correlations to other land class categories (Figure 19). Interestingly, and going against overall relationships shown repeatedly in the analysis of the 2021 Cropland Data Layer, croplands grew at a higher rate in the buffers in the West than the East, whereas the development land class categories had less of a correlation in the West than in the East, and high and medium development grew at a higher rate in the East than in the West (Table 18). On public lands, shrublands increased in correlation to pasturelands. Again, this brings into question whether this was due to restoration efforts, natural processes from grassland to shrubland, or whether there was a land cover misclassification.

In contrast to the Western half of the state, the potential riparian land class categories in the East decreased while medium and high development and croplands increased slightly, and pasturelands more substantially, from 2001-2019 (Table 18). Also notable is that woody vegetation in the East has a negative correlation to shrubland, like in the West, but it is only on public lands and in the private SPTH. On public lands there is a decrease of woody vegetation and an increase of shrubland, but in the private SPTH both decrease. Two factors that weren't considered in this analysis is the impact of wildfires or managed silviculture on woody vegetation, and may be related to the increase of shrubland and decrease of woody vegetation, especially on public lands. Low and open development had negative correlations to woody vegetation on private lands as well, and on public lands, there was a negative correlation between high and medium development and shrublands in the 100 ft buffer, and to woody vegetation in the SPTH.

Even though there seems to be progress in high rates of growth of woody vegetation in riparian buffers in Western Washington, there are still increases of development and cropland in the buffers, and in the East there is a continuation of degradation even in drylands, with woody vegetation being the most impacted despite its key importance (Basnyat et al., 2000; Chaney et al., 1990; S. Li et al., 2009; Sargac et al., 2021; WDFW, 2020a). While the general status in land cover lets us understand patterns in how land cover types are interacting and decreasing riparian land cover and implications for restoration, the temporal analysis tells us how Washington is doing in terms of preservation and conservation.

Patterns in the Eastern half of the state show that on both public and private lands, development and agriculture have increased in riparian areas, suggesting a failure to protect riparian habitat, especially woody vegetation. While the Western half of the state is showing progress in riparian habitat, salmon are not (NOAA Fisheries, 2023; NWIFC, 2020; WA

Governor's Office, 2022; WDFW et al., 2022). Development in both regions, which may be anything from aquatic channelization infrastructure like dams to roads to buildings to lawns or golf courses, have a higher negative correlation to water quality and stream temperatures than agriculture (Basnyat et al., 2000; Bond et al., 2019; Fogel et al., 2022; Kiffney et al., 2023; May & Horner, 2000; McBride & Booth, 2005; Nelson et al., 2009), which compounded with pervasive pollution in streams (EPA, 2023) (Figure 4), and research showing that developed areas may need far wider buffers, or are impacted by woody vegetation further upstream (Knehtl et al., 2021; K. Li et al., 2018a; Nava-López et al., 2016; Palt et al., 2023), seems to need far greater focus if riparian habitats and water quality are to be restored in both regions. Since development is actually increasing at a higher rate in the East, and the Growth Management Act is not mandatory in all areas, especially in the East, and only applies to political boundaries, it may be worth it to find ways to address riparian buffers in a different way, especially focused on delineation by watershed or WRIA, as watershed-scale management has been shown to be the most effective (Basnyat et al., 2000; Fischer et al., 2000; S. Li et al., 2009).

Conserved Lands

The amount of land conserved within the buffers is 43.5-50.9% (includes all land cover, including open water and perennial ice, but not sovereign lands, Table 14). The percentage of public lands in the buffers is about 43% (SPTH) to 47% (50 ft and 100 ft) of the buffers (these numbers do not include the open water and perennial ice classes) compared to private lands. This is relevant since about 98.5% of the land conserved within the buffers is public. The amount of private or NGO-managed land in conservation is quite small, though not all privately conserved land is included in the databases. NCED estimates the database includes 60% of all privately conserved lands (NCED et al., 2017). Conservation goals in the riparian management zones are not always aligned specifically with the WDFW's guidelines and may include agricultural conservation as a priority. Since only public lands with Gap Analysis Project (GAP) codes of 1-3 (Table 5) were included, there is some level of conservation associated with higher number GAP codes, but riparian management goals based on WDFW's guidelines seem unlikely without the lower number GAP code assignment.

While restoration and protection of riparian habitat is a major challenge in Washington, close to half are already protected long term, but almost exclusively on public lands. These results, combined with a small percentage participation in the Conservation Reserve Enhancement Program (CREP) (Cochrane, 2022; Plauché & Carr LLP & IEC, 2022), points to a minimal level of participation of private landowners in long-term riparian preservation. Since research confirms this lack of willingness to participate unless personal experience and values are aligned with programs (Buckley et al., 2012; Kingsbury & Boggess, 1999; Liebert et al., 2022; Valdivia & Poulos, 2009; Yu & Belcher, 2011), rather than economic compensation, it pulls into question whether policy based on voluntary participation will be as effective as regulatory policy (public federal lands managed under the Northwest Forest Plan, the Endangered Species Act, and the Clean Water Act are the most substantial percentage of conserved public lands). If voluntary participation and a reliance on NGOs and private landowners to protect riparian management areas is expected or desired, new approaches and a substantial amount of investment in programs may be needed to make up for the massive gap in effectiveness for conservation compared to that at the federal level.

Public versus private

While delineated in relation to other analyses, it is important to point out a few key differences between public and private lands. There is substantially more riparian land cover on public lands in both the Western and Eastern regions within the buffer prescriptions than on private lands, despite having less acreage overall. While this makes sense, it is notable that most of this riparian land cover is on federal lands, followed by the Washington Department of Natural Resources (DNR), and then cities and counties (or local municipalities) (Appendix A, Tables A6 and A7). The public lands reflect the land cover patterns of private lands by region and are closer in magnitude within the buffers than in the state as a whole, though the substantial amount of shrubland and pastureland categorization on public lands in the East reiterates a need to identify what is native shrubs and grasses versus actual pastureland or invasive plant species. It is also notable that woody vegetation is increasing at a higher rate on private lands in the West and decreasing at a higher rate on private lands in the East. While some loss may be related to wildfires in the East, this signals different approaches/attitudes on public lands between regions, and perhaps reflects a strong values difference (and/or depth of policy impact) by private landowners by region. Considering the low percentages in some cases of potential riparian land cover on public lands by some state entities (Table A7), wider application of the WDFW's guidelines to state and locally owned properties could help improve habitats and offer more demonstration sites in both rural and urban settings.

Mapping tools and geospatial datasets

A broad analysis like this is helpful in gaining better understanding of overall patterns and policy gaps, however, it made it apparent that the Geographic Information Systems (GIS) tools and datasets needed to address the WDFW's guidelines on watershed levels for all parts of the state are not yet fully available. Not all datasets used in this research were easy to access or assemble. They required copious amounts of time for editing, reprocessing, and merging.

While several entities in Washington are approaching riparian health assessment on a watershed level using GIS mapping, there is still a need to compile multiple datasets, many of which are lacking data, especially for the Eastern half of the state, as demonstrated in the methodologies section of this paper. Having a comprehensive and adaptable riparian mapping tool that incorporates policy requirements and guidelines for Washington State from all relevant entities (WDFW, Fish and Forests Law/Northwest Forest Plan, GMA, SMA, EPA/CWA, ESA, etc.) could be an excellent start to closing the gap in riparian quality degradation, and consolidate and coordinate in a way that could help improve communication across stakeholders and support less well-funded regions for these types of assessments. As an example, for this aspect of mapping, Stahl et al. (2020) used legal authority/regulatory associations incorporated into a riparian corridor map to aid with riparian conservation prioritization goals. A comprehensive riparian buffer mapping tool was mentioned as an intrinsic part of the Lorraine Loomis Act (2022) that failed to be passed but could still be created with proper funding without passing a full-scale regulatory policy. This sort of tool could help with planning, monitoring, and assessment like in this research, on both micro and macro-scales particular to Washington State and overlapping watershed boundaries. Based on my experience with this research project as an individual, a project to create a comprehensive mapping tool would be a large endeavor, but seems feasible, especially with a small team coordinating with multiple entities.

Many riparian analyses in Washington have a prescriptive or prioritization aspect. The goal of this analysis was to give a broader statistical assessment that might offer perspective on statewide policy needs. To make qualitative habitat assessment or management decisions, it is important to determine site-specific qualities. Using the National Land Cover Database (NLCD) to identify land cover as riparian is helpful on this broader scale, but for management its scale is too broad for site-specific work. Issues related to spatial location of the cover within the buffer area, invasive species or quality of vegetation in the buffer, or water quality problems, are not able to be detected at this broad scale.

While more accurate land use and land cover (LULC) data layers may exist from entities like ESRI or Google using higher resolution imagery, they were not available for downloading or use with the standard ArcGIS tools used in the methodology of this research. Washington State has higher resolution mapping tools that are in progress but do not yet meet the scope of this project. Hydrologic datasets are also constantly improving, but they still focus heavily on larger streams, with minimal data on stream widths for smaller perennial, intermittent, and ephemeral side-channel streams, which are known to be intrinsic to the health of many species, and where riparian buffers may have a larger impact than along larger streams (Beechie et al., 2021; Fogel et al., 2022; Fuller et al., 2022; WDFW, 2020a). This study was conservative in methods due to lack of data or modeling for floodplains, channel bankfull widths or migration predictions, SPTH data for dryland environments, and inclusion of tribal lands. While some "theoretical" hydrologic paths may have been overcompensated by using multiple hydrologic layers simultaneously, and site-specific landscapes could reduce the buffer zone in practice, it is still likely that the true buffer areas based on the broad geometry of this method would be larger.

Some key elements to incorporate into a comprehensive mapping tool that I have identified as lacking in the process of doing this research are:

1. Consistent coordinate systems and measurement scales for all geospatial data at similar levels of accuracy and adaptability to interact with other relevant mapping layers, including federal datasets.
2. Full coordination with sovereign nations.

3. An updated public lands layer.
4. Improved comprehensive hydrological datasets (broken out by watershed and/or WRIA), that include dimensions for smaller streams and use imagery or observation from different times of year or years to identify intermittent and ephemeral streams.
5. Clear floodplain definitions and geospatial data specific to riparian management buffers.
6. Increased coverage by the CHAMP dataset.
7. Increased coverage for $SPTH_{200}$ (and more related reference materials/research).
8. State-wide and watershed level land cover rasters using the NAIP 1m and/or Sentinel-2 10m and/or UAV imagery for more accurate identification of land cover in the riparian buffer width.
9. More specific land cover identification for shrublands, grasslands, pasture, and development that help identify native versus non-native vegetation, protected prairies and shrublands versus pasture, and specific types of development like roads, lawn, buildings, utilities, etc.
10. Habitat quality tools – either compatible or incorporated as separate layers.
11. Preset buffers that include all these elements plus any important 3D geospatial factors like slope and elevation or natural physical barriers like rock.
12. Data layers that are adaptable to external analysis and use on different scales will reduce ArcGIS analysis tool processing times and are accessible to a wide variety of users with different levels of GIS mapping experience.
13. Public access to versions of datasets with a reduction of unnecessary, repetitive, or incomplete data in associated attribute tables.

CONCLUSION

In this analysis, land cover within the SPTH buffers (not including lands of sovereign nations) made up about 21% of all terrestrial land cover in Washington. This contradicts the claim that riparian habitat is about 1% of Western ecosystems (Chaney, 1990; Knopf et al., 1988; Knutson & Naef, 1997; WDFW, 2020a). Source data was not always complete or fully accurate, but the resulting land cover compositions were surprisingly consistent, even among individual WRIAs, within all buffer sizes and types when broken into Eastern and Western Washington.

Assessments made in the 2020 'State of Our Watersheds Report' by the Northwest Indian Fisheries Commission and the recent roundtable initiated by the Governor's Office (Plauché & Carr LLP, 2022) were confirmed by this analysis: there needs to be more focus on the relationship between development to riparian habitat and water quality, especially in the Western half of the state, as it has a much stronger correlation to riparian loss than agriculture, and is growing in riparian buffers in the Eastern half of the state. Based on the temporal assessment, growth of development is occurring within the different buffer sizes, including the narrowest, despite increased application of riparian buffer preservation and restoration through regulations by the Fish and Forests Law and the Growth Management Act. The Eastern half of the state has severely depleted buffer zones, and this is strongly correlated to agriculture, especially pasturelands. There is far less research into dryland riparian zones, and several species are endangered or threatened in this habitat.

While restoration and protection of riparian habitat is a major challenge in Washington, 43% of the buffers are publicly owned, and 45% are already protected long term. Private conservation in the riparian buffers was only about 1% of all conservation, which casts some doubt on the private sectors' ability to match government protections, especially considering the stark difference of woody riparian vegetation on public lands compared to private lands in the Eastern half of the state. The majority of public lands are also federal lands, and it was unclear if the large losses of woody vegetation over time on public lands both West and East is related to managed timber sales and/or natural and anthropogenic disturbance like forest fires. Likewise, it was unclear if an increase in woody vegetation in buffer zones on private lands in the West was a result of increased compliance with buffer recommendations, or representative of natural processes from shrubs on forest edges.

Considering the high percentage of potential riparian land cover in the buffer zones of the West, along with the continued struggle to save salmon and other aquatic species, as well as high levels of pollution in Western waters, suggests several questions to consider for future research and policy. How much riparian land cover is necessary to maintain functioning riparian habitat or mitigate pollution? Is buffer width enough, especially considering research showing the potential importance of length and floodplain connectivity, and does it need to be both wider and longer to mitigate the impacts of development? Is the quality of the “potential” riparian habitat poor due to invasives, canopy height, or other factors, and can this be identified through remote geospatial analysis? What policy changes would be necessary to mitigate the impact of development on riparian zones and incentivize urban riparian buffers, as it seems the Growth Management Act and Clean Water Act have not worked to prevent continued development in these areas as shown in the temporal land cover analysis?

Pasturelands are also predominant in the buffer zones compared to crops, especially in the East, and restoration efforts since the 1970s demonstrate that in most cases exclusion of livestock from riparian areas may be necessary to restore native habitat (Armour et al., 1994; Belsky et al., 1999; Chaney et al., 1990). What policy efforts could be made, especially in the East, to decrease pasture in the buffers, especially closer to streams?

The mapping tools needed to properly plan, monitor, and assess riparian management areas in Washington, while authoritative and standardized, are not yet comprehensive and coordinated with different entities, policies, and guidelines in a way that is easy to use or accessible on a state-wide and watershed scale. There are also discrepancies particular to Washington State from the National Land Cover dataset regarding identification of native shrub and grasslands versus pastures and invasive species that could be improved using higher resolution imagery and accuracy testing. Additionally, based on the literature and results of statistical analyses that demonstrate a negative correlation between shrubland and woody vegetation, limiting the definition of riparian habitat when using land cover datasets to woody categories with only native shrublands and grasslands that are not used as pasture would likely be more accurate than the more inclusive definitions used in this research and even more broadly by federal entities like the Environmental Protection Agency (EPA). The creation of a singular riparian mapping tool could be a key element in improving application of best science guidelines for stakeholders in all regions and watersheds of the state, and supporting policy efforts, whether regulatory or voluntary, and is strongly recommended by the author.

REFERENCES

Abood, S. A., Maclean, A. L., & Mason, L. A. (2012). Modeling Riparian Zones Utilizing DEMS and Flood Height Data. *Photogrammetric Engineering & Remote Sensing*, *78*(3), 259–269. https://doi.org/10.14358/PERS.78.3.259

Anbumozhi, V., Radhakrishnan, J., & Yamaji, E. (2005). Impact of riparian buffer zones on water quality and associated management considerations. *Ecological Engineering*, *24*(5), 517–523. https://doi.org/10.1016/j.ecoleng.2004.01.007

Anderson, P. S., Meyer, S., Olson, Dr. P., & Stockdale, E. (2016). *Determining the Ordinary High-Water Mark for Shoreline Management Act Compliance in Washington State* (Publication no. 16-06-029). Shorelands and Environmental Assistance Program, Washington State Department of Ecology.

Arid Lands Initiative. (2023). *Arid Lands Initiative | The Science* [Public/Private Partnership]. Arid Lands Initiative. https://aridlandsinitiative.org/our-projects/the-science/

Armour, C., Duff, D., & Elmore, W. (1994). The Effects of Livestock Grazing on Western Riparian and Stream Ecosystem. *Fisheries*, *19*(9), 9–12. https://doi.org/10.1577/1548-8446(1994)019<0009:TEOLGO>2.0.CO;2

Baldwin, M., Fox, A., Klondike, T., Hovis, M., Shear, T., Joca, L., Hester, M., & Cubbage, F. (2022). Geospatial Analysis and Land Suitability for “FloodWise” Practices: Nature-Based Solutions for Flood Mitigation in Eastern, Rural North Carolina. *Land*, *11*(9), Article 9. https://doi.org/10.3390/land11091504

Barbarika, A. (2020). *The Conservation Reserve Program: A 35 Year History*. United States Department of Agriculture.

Barnowe-Meyer, S., Bilby, R., Groom, J., Lunde, C., Richardson, J., & Stednick, J. (2021). *Review of current and proposed riparian management zone prescriptions in meeting westside Washington State anti-degradation temperature criterion: Prepared for the Timber, Fish, and Wildlife Policy Committee Forest Practices Adaptive Management Program* [Final Report]. Technical Type Np Prescription Workgroup, State of Washington Department of Natural Resources.

Basnyat, P., Teeter, L. D., Lockaby, B. G., & Flynn, K. M. (2000). The use of remote sensing and GIS in watershed level analyses of non-point source pollution problems. *Forest Ecology and Management*, *128*(1), 65–73. https://doi.org/10.1016/S0378-1127(99)00273-X

Beechie, T. J., Fogel, C., Nicol, C., & Timpane-Padgham, B. (2021). A process-based assessment of landscape change and salmon habitat losses in the Chehalis River basin, USA. *PLOS ONE*, *16*(11), e0258251. https://doi.org/10.1371/journal.pone.0258251

Beeson, C. E., & Doyle, P. F. (1995). Comparison of Bank Erosion at Vegetated and Non-Vegetated Channel Bends1. *JAWRA Journal of the American Water Resources Association*, *31*(6), 983–990. https://doi.org/10.1111/j.1752-1688.1995.tb03414.x

Belsky, A. J., Matzke, A., & Uselman, S. (1999). Survey of Livestock Influences on Stream and Riparian Ecosystems in the Western United States. *Journal of Soil and Water Conservation*, *54*, 419–431.

Bharati, L., Lee, K.-H., Isenhart, T. M., & Schultz, R. C. (2002). Soil-water infiltration under crops, pasture, and established riparian buffer in Midwestern USA. *Agroforestry Systems*, *56*(3), 249–257. https://doi.org/10.1023/A:1021344807285

Biden, J. (2022). *Executive Order on Strengthening the Nation's Forests, Communities, and Local Economies* (Executive Order 87 FR 24851; pp. 24851–24855). Executive Office of the President. https://www.whitehouse.gov/briefing-room/presidential-actions/2022/04/22/executive-order-on-strengthening-the-nations-forests-communities-and-local-economies/

Bishaw, B., Emmingham, W. H., & Rogers, W. R. (2002). *Riparian forest buffers on agricultural lands in the Oregon coast range: Beaver Creek riparian project as a case study* (Research contribution: Oregon State University, Forest Research Laboratory). Oregon State University, College of Forestry, Forest Research Laboratory.

Blumm, M. C. (1986). A Trilogy of Tribes v FERC: reforming the federal role in hydropower licensing. *Harvard Environmental Law Review*, *10*, 1.

The Boldt Decision: United States v. Washington State, 520 F.2d 676 (United States Court of Appeals for the Ninth Circuit June 4, 1975), 384 F. Supp. 312 (W.D. Wash. 1974).

Bond, M. H., Nodine, T. G., Beechie, T. J., & Zabel, R. W. (2019). Estimating the benefits of widespread floodplain reconnection for Columbia River Chinook salmon. *Canadian Journal of Fisheries and Aquatic Sciences*, *76*(7), 1212–1226. https://doi.org/10.1139/cjfas-2018-0108

Broadmeadow, S., & Nisbet, T. R. (2004). The effects of riparian forest management on the freshwater environment: A literature review of best management practice. *Hydrology and Earth System Sciences*, *8*(3), 286–305. https://doi.org/10.5194/hess-8-286-2004

Brook, R., & McLachlan, S. (2005). On Using Expert-Based Science to "Test" Local Ecological Knowledge. *Ecology and Society*, *10*(2). https://doi.org/10.5751/ES-01478-1002r03

Buchanan, S. W., Baskerville, M., Oelbermann, M., Gordon, A. M., Thevathasan, N. V., & Isaac, M. E. (2020). Plant Diversity and Agroecosystem Function in Riparian Agroforests: Providing Ecosystem Services and Land-Use Transition. *Sustainability*, *12*(2), Article 2. https://doi.org/10.3390/su12020568

Buckley, C., Hynes, S., & Mechan, S. (2012). Supply of an ecosystem service—Farmers' willingness to adopt riparian buffer zones in agricultural catchments. *Environmental Science & Policy*, *24*, 101–109. https://doi.org/10.1016/j.envsci.2012.07.022

Camporeale, C., Perucca, E., Ridolfi, L., & Gurnell, A. M. (2013). Modeling the Interactions Between River Morphodynamics and Riparian Vegetation. *Reviews of Geophysics*, *51*(3), 379–414. https://doi.org/10.1002/rog.20014

Carpenter, C. S., Pascualy, M. V., & Hunter, T. (2008). *Nisqually Indian tribe*. Arcadia Publishing Library Editions.

Castelle, A. J., Johnson, A. W., & Conolly, C. (1994). Wetland and Stream Buffer Size Requirements—A Review. *Journal of Environmental Quality*, *23*(5), 878–882. https://doi.org/10.2134/jeq1994.00472425002300050004x

Chaney, E., Elmore, W., & Platts, W. S. (1990). *Livestock Grazing on Western Riparian Areas*. U.S. Environmental Protection Agency, Northwest Resource Information Center.

Chapman, M., Satterfield, T., & Chan, K. M. A. (2020). How value conflicts infected the science of riparian restoration for endangered salmon habitat in America's Pacific Northwest: Lessons for the application of conservation science to policy. *Biological Conservation*, *244*, 108508. https://doi.org/10.1016/j.biocon.2020.108508

Clauson, S., & Trautman, L. (2016). *Braided Freshwater Governance: A case study of regulation and stewardship of riparian areas and wetlands in British Columbia and Washington State*. 122. BPRI Research Reports. 2. https://cedar.wwu.edu/bpri_rr/2

The Clean Water Act, Pub. L. No. Title 33, 33 U.S. Code § 1251 et seq. U.S. (1972).

Cochrane, B. (2022). *Implementation and Effectiveness Monitoring for the Washington Conservation Reserve Enhancement Program (CREP) for Federal Fiscal Year 2022*. Washington State Conservation Commission. https://assets-global.website-files.com/5faf8a950cdaa224e61edad9/64cbd8c06468c0de3aac22da_CREP%20-%20Monitoring%20Report%20-%202022.pdf

Crozier, L. G., Burke, B. J., Chasco, B. E., Widener, D. L., & Zabel, R. W. (2021). Climate change threatens Chinook salmon throughout their life cycle. *Communications Biology*, *4*(1), 222. https://doi.org/10.1038/s42003-021-01734-w

Cupp, C. E., & Lofgren, T. J. (2014). *Effectiveness of riparian management zone prescriptions in protection and maintaining shade and water temperature in forested streams of Eastern Washington* (Cooperative Monitoring Evaluation and Research Report CMER #02-212). Washington State Forest Practices Adaptive Management Program. https://file.dnr.wa.gov/publications/fp_cmer_02_212.pdf

Curtis, T. L., & Buchanan, H. (2019). *Basin-Wide Approaches to Hydropower Relicensing: Case Studies and Considerations* (NREL/TP--6A20-71979, 1493695; p. NREL/TP--6A20-71979, 1493695). https://doi.org/10.2172/1493695

Daigneault, A., Brown, P., & Gawith, D. (2016). Dredging versus hedging: Comparing hard infrastructure to ecosystem-based adaptation to flooding. *Ecological Economics*, *122*, 25–35. https://doi.org/10.1016/j.ecolecon.2015.11.023

Davies, P., & Nelson, M. (1994). Relationships between riparian buffer widths and the effects of logging on stream habitat, invertebrate community composition and fish abundance. *Marine and Freshwater Research*, *45*(7), 1289. https://doi.org/10.1071/MF9941289

Davis, B. (2023). *Designating Riparian Habitat Areas Using WAC 222 Site Class and 200-year Site Potential Tree Height* (CPZ2022-00010). Clark County Community Development. https://clark.wa.gov/sites/default/files/media/document/2023-02/Designating%20Riparian%20Habitat%20Areas%20%28CPZ2022-00010%29.pdf

DeWalle, D. R. (2010). Modeling Stream Shade: Riparian Buffer Height and Density as Important as Buffer Width. *JAWRA Journal of the American Water Resources Association*, *46*(2), 323–333. https://doi.org/10.1111/j.1752-1688.2010.00423.x

Dewitz, J., & U.S. Geological Survey. (2003). *National Land Cover Database (NLCD) 2001 Land Cover Conterminous United States* [dataset]. U.S. Geological Survey. https://doi.org/10.5066/P9MZGHLF

Dewitz, J., & U.S. Geological Survey. (2021). *National Land Cover Database (NLCD) 2019 Products* (2.0) [dataset]. U.S. Geological Survey. https://doi.org/10.5066/P9KZCM54

Edwards, P. J., Schoonover, J. E., & Williard, K. W. J. (2015). Guiding Principles for Management of Forested, Agricultural, and Urban Watersheds. *Journal of Contemporary Water Research & Education*, *154*(1), 60–84. https://doi.org/10.1111/j.1936-704X.2015.03188.x

Elmore, W., & Beschta, R. (1987). Riparian Areas: Perceptions in management. *Rangelands Archives, 9*(6), 260–265. http://hdl.handle.net/10150/640262

The Endangered Species Act as amended by Public Law 97-304 (the Endangered Species Act amendments of 1982), Pub. L. No. 97–304 (1983).

Environmental Protection Agency (EPA). (2023). *ATTAINS data related to the Clean Water Act* [Feature Layers; Geodatabase]. Environmental Protection Agency.

Environmental Protection Agency (EPA), Neale, A., Ebert, D., Jahre, J., & Bryce, S. (2015). *EnviroAtlas Fact Sheet: Percent Natural land Cover in Stream Buffer*. U.S. Environmental Protection Agency. https://enviroatlas.epa.gov/enviroatlas/DataFactSheets/pdf/ESN/PercentNaturalLandCoverinStreamBuffer.pdf

Everett, R., Hessburg, P., Jensen, M., & Bormann, B. (1994). *Eastside forest ecosystem health assessment. Volume 1: Executive Summary*. *Forest service general technical report.* U.S. Department of Agriculture, Forest Service Pacific Northwest Research Station. https://www.fs.usda.gov/pnw/pubs/pnw_gtr317.pdf

Feld, C. K., Fernandes, M. R., Ferreira, M. T., Hering, D., Ormerod, S. J., Venohr, M., & Gutiérrez-Cánovas, C. (2018). Evaluating riparian solutions to multiple stressor problems in river ecosystems—A conceptual study. *Water Research*, *139*, 381–394. https://doi.org/10.1016/j.watres.2018.04.014

FEMA, & Esri. (2022). *USA Flood Hazard Reduced Set* [Feature Layer; ESRI Geodatabase]. ArcGIS Pro. https://services.arcgis.com/P3ePLMYs2RVChkJx/arcgis/rest/services/USA_Flood_Hazard_Reduced_Set_gdb/FeatureServer

FEMAT. (1993). *Forest Ecosystem Management: An Ecological, Economic, and Social Assessment*. U.S. Department of Agriculture, U.S. Department of the Interior, and the Environmental Protection Agency. https://www.blm.gov/or/plans/nwfpnepa/FEMAT-1993/1993_%20FEMAT_Report.pdf

Fischer, R., Martin, C., & Fischenich, C. (2000). *Improving Riparian Strips and Corridors for Water Quality and Wildlife*. International Conference on Riparian Ecology and Management in Multi-Land Use Watersheds, American Water Resources Association.

Fischman, R. L. (2005). Cooperative Federalism and Natural Resources Law. *Articles by Maurer Faculty, New York University Environmental Law Journal*, *14*(179), 219. https://www.repository.law.indiana.edu/facpub/219

Fogel, C. B., Nicol, C. L., Jorgensen, J. C., Beechie, T. J., Timpane-Padgham, B., Kiffney, P., Seixas, G., & Winkowski, J. (2022). How riparian and floodplain restoration modify the effects of increasing temperature on adult salmon spawner abundance in the Chehalis River, WA. *PLOS ONE*, *17*(6), e0268813. https://doi.org/10.1371/journal.pone.0268813

Fonseca, A., Ugille, J.-P., Michez, A., Rodríguez-González, P. M., Duarte, G., Ferreira, M. T., & Fernandes, M. R. (2021). Assessing the Connectivity of Riparian Forests across a Gradient of Human Disturbance: The Potential of Copernicus “Riparian Zones” in Two Hydroregions. *Forests*, *12*(6), Article 6. https://doi.org/10.3390/f12060674

Fox, M. J. (2003). *Spatial organization, position, and source characteristics of large woody debris in natural systems* [Doctor of Philosophy]. University of Washington. http://hdl.handle.net/1773/5463

Fremier, A. K., Kiparsky, M., Gmur, S., Aycrigg, J., Craig, R. K., Svancara, L. K., Goble, D. D., Cosens, B., Davis, F. W., & Scott, J. M. (2015). A riparian conservation network for ecological resilience. *Biological Conservation*, *191*, 29–37. https://doi.org/10.1016/j.biocon.2015.06.029

Fuller, M., Leinenbach, P., Detenbeck, N., Labiosa, R., & Isaak, D. (2022). Riparian vegetation shade restoration and loss effects on recent and future stream temperatures. *Restoration Ecology*, *30*. https://doi.org/10.1111/rec.13626

Fullerton, A. H., Sun, N., Baerwalde, M. J., Hawkins, B. L., & Yan, H. (2022). Mechanistic Simulations Suggest Riparian Restoration Can Partly Counteract Climate Impacts to Juvenile Salmon. *JAWRA Journal of the American Water Resources Association*, *58*(4), 525–546. https://doi.org/10.1111/1752-1688.13011

Gene, S. M., Hoekstra, P. F., Hannam, C., White, M., Truman, C., Hanson, M. L., & Prosser, R. S. (2019). The role of vegetated buffers in agriculture and their regulation across Canada and the United States. *Journal of Environmental Management*, *243*, 12–21. https://doi.org/10.1016/j.jenvman.2019.05.003

González, E., Sher, A. A., Tabacchi, E., Masip, A., & Poulin, M. (2015). Restoration of riparian vegetation: A global review of implementation and evaluation approaches in the international, peer-reviewed literature. *Journal of Environmental Management*, *158*, 85–94. https://doi.org/10.1016/j.jenvman.2015.04.033

Goodwin, C. N., Hawkins, C. P., & Kershner, J. L. (1997). Riparian Restoration in the Western United States: Overview and Perspective. *Restoration Ecology*, *5*(4S), 4–14. https://doi.org/10.1111/j.1526-100X.1997.00004.x

Greenberg, J., & Carson, S. (2010). Mapping Riparian Land Use within Agricultural Zones: A Case in Skagit County. *Skagit County Board of Commissioners*. https://www.skagitcounty.net/SalmonStrategy/Documents/White%20Paper%20v23%20booklet-style.pdf

Gregory, A., Spence, E., Beier, P., & Garding, E. (2021). Toward Best Management Practices for Ecological Corridors. *Land*, *10*(2), 140. https://doi.org/10.3390/land10020140

Groffman, P. M., Bain, D. J., Band, L. E., Belt, K. T., Brush, G. S., Grove, J. M., Pouyat, R. V., Yesilonis, I. C., & Zipperer, W. C. (2003). Down by the riverside: Urban riparian ecology. *Frontiers in Ecology and the Environment*, *1*(6), 315–321. https://doi.org/10.1890/1540-9295(2003)001[0315:DBTRUR]2.0.CO;2

Hafen, K. C., Blasch, K. W., Rea, A., Sando, R., & Gessler, P. E. (2020). The Influence of Climate Variability on the Accuracy of NHD Perennial and Nonperennial Stream Classifications. *JAWRA Journal of the American Water Resources Association*, *56*(5), 903–916. https://doi.org/10.1111/1752-1688.12871

Hilary, B., Chris, B., North, B. E., Angelica Maria, A. Z., Sandra Lucia, A. Z., Carlos Alberto, Q. G., Beatriz, L. G., Rachael, E., & Andrew, W. (2021). Riparian buffer length is more influential than width on river water quality: A case study in southern Costa Rica. *Journal of Environmental Management*, *286*, 112132. https://doi.org/10.1016/j.jenvman.2021.112132

Industrial Economics, Incorporated & Plauché & Carr LLP (2022). *Effectiveness of State Programs on Riparian Habitat Protection and Restoration: Analysis and Recommendations* [Final Report][Pursuant to Engrossed Substitute Senate Bill 5693, Sec. 130(22)] (2022). Industrial Economics, Incorporated; Plauché & Carr LLP. https://ofm.wa.gov/sites/default/files/public/publications/RiparianFinalReport.pdf

J. R. Cooper. (1987). Riparian Areas as Filters for Agricultural Sediment (J. R. Cooper, J. W. Gilliam, R. B. Daniels, & W. P. Robarge, Trans.). *Soil Science Society of America Journal, v. 51*(2), 416–420. PubAg. https://doi.org/10.2136/sssaj1987.03615995005100020029x

Jayasuriya, M. T., Germain, R. H., & Stella, J. C. (2022). Applying the "Goldilocks Rule" to Riparian Buffer Widths for Forested Headwater Streams across the Contiguous U.S.—How Much Is "Just Right"? *Forests*, *13*(9), Article 9. https://doi.org/10.3390/f13091509

Kadykalo, A. N., Cooke, S. J., & Young, N. (2021). The role of western-based scientific, Indigenous and local knowledge in wildlife management and conservation. *People and Nature*, *3*(3), 610–626. https://doi.org/10.1002/pan3.10194

Kauffman, J. Boone, Robert L. Beschta, and William S. Platts (1993). *Fish Habitat Improvement Projects in the Fifteenmile Creek and Trout Creek Basins of Central Oregon: Field Review and Management Recommendations* [Technical Report]. Washington, DC, USA: US Department of Energy, Bonneville Power Administration, Division of Fish and Wildlife. https://doi.org/10.2172/10180641

Khirfan, L., Peck, M. L., & Mohtat, N. (2020). Digging for the truth: A combined method to analyze the literature on stream daylighting. *Sustainable Cities and Society*, *59*, 102225. https://doi.org/10.1016/j.scs.2020.102225

Kiffney, P. M., Lisi, P. J., Liermann, M., Naman, S. M., Anderson, J. H., Bond, M. H., Pess, G. R., Koehler, M. E., Buhle, E. R., Buehrens, T. W., Klett, R. S., Cram, J. M., & Quinn, T. P. (2023). Colonization of a temperate river by mobile fish following habitat reconnection. *Ecosphere*, *14*(2), e4336. https://doi.org/10.1002/ecs2.4336

Kingsbury, L., & Boggess, W. G. (1999). *An Economic Analysis of Riparian Landowners' Willingness to Participate in Oregon's Conservation Reserve Enhancement Program*. Annual Meeting of the American Agricultural Economics Association. https://doi.org/10.22004/ag.econ.21641

Knehtl, M., Podgornik, S., & Urbanič, G. (2021). Scale-depended effects of hydromorphology and riparian land-use on benthic invertebrates and fish: Implications for large river management. *Hydrobiologia*, *848*(15), 3447–3467. https://doi.org/10.1007/s10750-021-04589-8

Knopf, F., Johnson, R., Rich, T., Samson, F., & Szaro, R. (1988). Conservation of riparian ecosystems in the United States. *The Wilson Bulletin*, 100(2), 272-284.

Knutson, K. L., & Naef, V. L. (1997). *Management recommendations for Washington's priority habitats: Riparian* (p. 181pp.). Washington Department of Fish and Wildlife.

Lee, P., Smyth, C., & Boutin, S. (2004). Quantitative review of riparian buffer width guidelines from Canada and the United States. *Journal of Environmental Management*, *70*(2), 165–180. https://doi.org/10.1016/j.jenvman.2003.11.009

Legg, N. T., & Olson, P. L. (2015). *Screening Tools for Identifying Migrating Stream Channels in Western Washington: Geospatial Data Layer—SEA_WAT_CHAMP* (Feature Layer Publication: 15-06-003) [Geodatabase]. Washington State Department of Ecology. https://apps.ecology.wa.gov/publications/SummaryPages/1506003.html

House Bill 1215, State of Washington, HB 1215, Washington State House of Representatives, 68th Legislature, Regular Session (2023). https://lawfilesext.leg.wa.gov/biennium/2023-24/Pdf/Bills/House%20Bills/1215.pdf?q=20231130163013

House Bill 1720, State of Washington, HB 1720, Washington State House of Representatives, 68th Legislature, Regular Session (2023). https://lawfilesext.leg.wa.gov/biennium/2023-24/Pdf/Bills/House%20Bills/1720-S.pdf?q=20231130163607

Lorraine Loomis Act. State of Washington, HB 1838, Washington State House of Representatives, 67th Legislature, Regular Session, 22 (2022). https://lawfilesext.leg.wa.gov/biennium/2021-22/Pdf/Bills/House%20Bills/1838.pdf?q=20220114060358

Li, K., Chi, G., Wang, L., Xie, Y., Wang, X., & Fan, Z. (2018a). Identifying the critical riparian buffer zone with the strongest linkage between landscape characteristics and surface water quality. *Ecological Indicators*, *93*, 741–752. https://doi.org/10.1016/j.ecolind.2018.05.030

Li, K., Chi, G., Wang, L., Xie, Y., Wang, X., & Fan, Z. (2018b). Identifying the critical riparian buffer zone with the strongest linkage between landscape characteristics and surface water quality. *Ecological Indicators*, *93*, 741–752. https://doi.org/10.1016/j.ecolind.2018.05.030

Li, S., Gu, S., Tan, X., & Zhang, Q. (2009). Water quality in the upper Han River basin, China: The impacts of land use/land cover in riparian buffer zone. *Journal of Hazardous Materials*, *165*(1–3), 317–324. https://doi.org/10.1016/j.jhazmat.2008.09.123

Liebert, J., Benner, R., Bezner Kerr, R., Björkman, T., De Master, K. T., Gennet, S., Gómez, M. I., Hart, A. K., Kremen, C., Power, A. G., & Ryan, M. R. (2022). Farm size affects the use of agroecological practices on organic farms in the United States. *Nature Plants*, *8*(8), 897–905. https://doi.org/10.1038/s41477-022-01191-1

Lind, L., Hasselquist, E. M., & Laudon, H. (2019). Towards ecologically functional riparian zones: A meta-analysis to develop guidelines for protecting ecosystem functions and biodiversity in agricultural landscapes. *Journal of Environmental Management*, *249*, 109391. https://doi.org/10.1016/j.jenvman.2019.109391

Littlefield, D. A. N., & Henrietta, T. (2019). *Conservation Enhancement Activity E391A*. 5. US Department of Agriculture.

Liu, Y., Yang, W., & Wang, X. (2008). Development of a SWAT extension module to simulate riparian wetland hydrologic processes at a watershed scale. *Hydrological Processes*, *22*(16), 2901–2915. https://doi.org/10.1002/hyp.6874

Maclean, S. A., Linda Spencer, Micheal Wieczorek, Ann. (2021, November 22). *National Riparian Areas Base Map*. ArcGIS StoryMaps. https://storymaps.arcgis.com/stories/8cd69adaaaf541c78f8d867f0ec6b6ef

May, C., & Geist, D. (2007). *Grays River Watershed and Biological Assessment, 2006 Final Report.* (DOE/BP-00000652-38, 961998; p. DOE/BP-00000652-38, 961998). https://doi.org/10.2172/961998

May, C. W., & Horner, R. R. (2000). The Cumulative Impacts of Watershed Urbanization on Stream-Riparian Ecosystems. *Proceedings of the American Water Resources Association International Conference on Riparian Ecology and Management in Multi-Land Use Watersheds*, 6.

Mayer, P. M., Reynolds, S. K., & Canfield, T. J. (2005). *Riparian buffer width, vegetative cover, and nitrogen removal effectiveness: A review of current science and regulations* (EPA/600/R-05/118). US Environmental Protection Agency.

McBride, M., & Booth, D. B. (2005). Urban impacts on physical stream condition: effects of spatial scale, connectivity, and longitudinal trends. *Journal of the American Water Resources Association*, *41*(3), 565–580. https://doi.org/10.1111/j.1752-1688.2005.tb03755.x

McCullough, D. A. (1999). *A review and synthesis of effects of alterations to the water temperature regime on freshwater life stages of salmonids, with special reference to chinook salmon* (Water Resources Assessment EPA 910-R-99-010). Environmental Protection Agency, Water Division; Columbia River Inter-Tribal Fish Commission.

McDade, M. H., Swanson, F. J., McKee, W. A., Franklin, J. F., & Sickle, J. V. (1990). Source distances for coarse woody debris entering small streams in western Oregon and Washington. *Canadian Journal of Forest Research*, *20*(3), 326–330. https://doi.org/10.1139/x90-047

Microsoft. (2023). *Microsoft® Excel® for Microsoft 365 MSO 64-bit* (2308 Build 16.0.16731.20182) [Computer software]. Microsoft.

Monohan, C. E. (2004). *Riparian Buffer Function with Respect to Nitrogen Transformation and Temperature Along Lowland Agricultural Streams in Skagit County, Washington* [Doctor of Philosophy]. College of Forest Resources, University of Washington.

Moore, A., & Palmer, M. (2005). Invertebrate Biodiversity in Agricultural and Urban Headwater Streams: Implications for Conservation and Management. *Ecological Applications*, *15*, 1169–1177. https://doi.org/10.1890/04-1484

Naiman, R. J., & Décamps, H. (1997). The Ecology of Interfaces: Riparian Zones. *Annual Review of Ecology and Systematics*, *28*(1), 621–658. https://doi.org/10.1146/annurev.ecolsys.28.1.621

Nava-López, M. Z., Diemont, S. A. W., Hall, M., & Ávila-Akerberg, V. (2016). Riparian Buffer Zone and Whole Watershed Influences on River Water Quality: Implications for Ecosystem Services near Megacities. *Environmental Processes*, *3*(2), 277–305. https://doi.org/10.1007/s40710-016-0145-3

National Conservation Easement Database, Ducks Unlimited, & The Trust for Public Land. (2017). *Conservation easements and the National Conservation Easement Database* [Storymap]. Conservation Easements and the National Conservation Easement Database. https://site.tplgis.org/NCED/storymap/index.html

Nelson, K. C., Palmer, M. A., Pizzuto, J. E., Moglen, G. E., Angermeier, P. L., Hilderbrand, R. H., Dettinger, M., & Hayhoe, K. (2009). Forecasting the combined effects of urbanization and climate change on stream ecosystems: From impacts to management options. *Journal of Applied Ecology*, *46*(1), 154–163. https://doi.org/10.1111/j.1365-2664.2008.01599.x

Nisqually Land Trust. (2023). *Nisqually Community Forest* [Non-profit]. Nisqually Land Trust. https://nisquallylandtrust.org/our-lands-and-projects/nisqually-community-forest/

National Oceanic and Atmospheric Administration (NOAA) Fisheries. (2018). *Salmon Habitat Status and Trend Monitoring Program Data—Puget Sound Floodplains 2016* [Feature Layer; Geodatabase]. National Oceanic and Atmospheric Administration Fisheries, Salmon Habitat Status and Trend Monitoring Program. https://www.fisheries.noaa.gov/resource/map/salmon-habitat-status-and-trend-monitoring-program-data

National Oceanic and Atmospheric Administration (NOAA) Fisheries. (2023, February 22). *Columbia Basin Historical Ecology Project Data | NOAA Fisheries* (West Coast) [Government]. National Oceanic and Atmospheric Administration Fisheries.

https://www.fisheries.noaa.gov/resource/data/columbia-basin-historical-ecology-project-data

National Oceanic and Atmospheric Administration (NOAA) Fisheries. (2023, July 5). *Salmon Habitat Status and Trend Monitoring Program Data | NOAA Fisheries* (West Coast). National Oceanic and Atmospheric Administration, Salmon Habitat Status and Trend Monitoring Program. https://www.fisheries.noaa.gov/resource/map/salmon-habitat-status-and-trend-monitoring-program-data

Norman, D. K., Cederholm, C. J., & Lingley, W. S. (1988). Flood Plains, Salmon Habitat, and Sand and Gravel Mining. *Washington Geology*, *26*(2/3). https://www.yakimacounty.us/DocumentCenter/View/1073/1996-Department-of-Natural-Resources-Flood-Report?bidId=

Northwest Indian Fisheries Commission (NWIFC). (2020). *2020 State of Our Watersheds: A Report by the Treaty Tribes in Western Washington*. Northwest Indian Fisheries Commission Member Tribes. https://files.nwifc.org/sow/2020/state-of-our-watersheds-sow-2020-final-web.pdf#page=1

Olson, D. H., & Ares, A. (2022). Riparian buffer effects on headwater-stream vertebrates and habitats five years after a second upland-forest thinning in western Oregon, USA. *Forest Ecology and Management*, *509*, 120067. https://doi.org/10.1016/j.foreco.2022.120067

Palt, M., Hering, D., & Kail, J. (2023). Context-specific positive effects of woody riparian vegetation on aquatic invertebrates in rural and urban landscapes. *Journal of Applied Ecology*, *60*(6), 1010–1021. https://doi.org/10.1111/1365-2664.14386

Phiri, D., Simwanda, M., Salekin, S., Nyirenda, V. R., Murayama, Y., & Ranagalage, M. (2020). Sentinel-2 Data for Land Cover/Use Mapping: A Review. *Remote Sensing*, *12*(14), Article 14. https://doi.org/10.3390/rs12142291

Pissarra, T. C. T., Valera, C. A., Costa, R. C. A., Siqueira, H. E., Martins Filho, M. V., Valle Júnior, R. F. do, Sanches Fernandes, L. F., & Pacheco, F. A. L. (2019). A Regression Model of Stream Water Quality Based on Interactions between Landscape Composition and Riparian Buffer Width in Small Catchments. *Water*, *11*(9), Article 9. https://doi.org/10.3390/w11091757

Plauché & Carr LLP, & Industrial Economics, Incorporated (IEC) (2022). *Evaluation of Riparian-Related Programs in Washington State: Summary of Preliminary Findings (Pursuant to ESSB 5693 Sec. 130 (22))*. Plauché & Carr LLP, Industrial Economics, Incorporated (IEC). https://one.ofm.wa.gov/sites/default/files/public/publications/Preliminary%20Report%20on%20Evaluation%20of%20Riparian-Related%20Programs_update.pdf

Plauché & Carr LLP (2022). *Riparian Taskforce Final Report 2022: Facilitation Process and Recommendations (Pursuant to Section 117(12), Chapter 297, Laws of 2022)*. Plauché & Carr LLP. https://ofm.wa.gov/sites/default/files/public/publications/RiparianTaskForceFinalReport2022.pdf

Popescu, C., Oprina-Pavelescu, M., Dinu, V., Cazacu, C., Burdon, F. J., Forio, M. A. E., Kupilas, B., Friberg, N., Goethals, P., McKie, B. G., & Rîșnoveanu, G. (2021). Riparian Vegetation Structure Influences Terrestrial Invertebrate Communities in an Agricultural Landscape. *Water*, *13*(2), Article 2. https://doi.org/10.3390/w13020188

R Core Team. (2022). *R: A language and environment for statistical computing.* [Computer software]. R Foundation for Statistical Computing. https://www.R-project.org

R Core Team. (2023). *RStudio: "Cherry Blossom" Release, Build 446* [Windows]. Posit Software, PBC.

Reeves, G., Olson, D. ("Dede") H., Wondzell, S., Bisson, P., Gordon, S., Long, J. W., & Furniss, M. (2018). Chapter 7: The aquatic conservation strategy of the northwest forest plan—A review of the relevant science after 23 years. *Synthesis of Science to Inform Land Management within the Northwest Forest Plan Area. General Technical Report PNW-GTR-966*. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station: 461-624., 966, 461–624.

Reid, L., & Hilton, S. (1998). *Buffering the Buffer* (General Technical Report PSW-GTR-168; Proceedings of the Conference on Coastal Watersheds: The Caspar Creek Story, p. 25). United States Department of Agriculture, Forest Service, Pacific Southwest Research Station.

Richardson, D. M., Holmes, P. M., Esler, K. J., Galatowitsch, S. M., Stromberg, J. C., Kirkman, S. P., Pyšek, P., & Hobbs, R. J. (2007). Riparian vegetation: Degradation, alien plant invasions, and restoration prospects. *Diversity and Distributions*, *13*(1), 126–139. https://doi.org/10.1111/j.1366-9516.2006.00314.x

Richardson, J. S., Naiman, R. J., & Bisson, P. A. (2012). How did fixed-width buffers become standard practice for protecting freshwaters and their riparian areas from forest harvest practices? *Freshwater Science*, *31*(1), 232–238. https://doi.org/10.1899/11-031.1

Riis, T., Kelly-Quinn, M., Aguiar, F., Manolaki, P., Bruno, D., Bejarano, M., Clerici, N., Fernandes, M. R., Franco, J. C., Pettit, N., Portela, A., Tammeorg, O., Tammeorg, P., Rodríguez-González, P., & Dufour, S. (2020). Global Overview of Ecosystem Services Provided by Riparian Vegetation. *BioScience*, *70*. https://doi.org/10.1093/biosci/biaa041

Safeeq, M., Grant, G. E., Lewis, S. L., & Staab, B. (2015). Predicting landscape sensitivity to present and future floods in the Pacific Northwest, USA: present and future floods in the Pacific Northwest, USA. *Hydrological Processes*, *29*(26), 5337–5353. https://doi.org/10.1002/hyp.10553

Sargac, J., Johnson, R. K., Burdon, F. J., Truchy, A., Rîşnoveanu, G., Goethals, P., & McKie, B. G. (2021). Forested Riparian Buffers Change the Taxonomic and Functional Composition of Stream Invertebrate Communities in Agricultural Catchments. *Water*, *13*(8), Article 8. https://doi.org/10.3390/w13081028

Sedell, J. R., & Luchessa, K. J. (1981). Using the historical record as an aid to salmonid habitat enhancement. *Acquisition and Utilization of Aquatic Habitat Inventory Information: Proceedings of a Symposium Held 28-30 October 1981, Portland, Or.* Western Division, American Fisheries Society.

Shafroth, P. B., Friedman, J. M., Auble, G. T., Scott, M. L., & Braatne, J. H. (2002). Potential Responses of Riparian Vegetation to Dam Removal: Dam removal generally causes changes to aspects of the physical environment that influence the establishment and growth of riparian vegetation. *BioScience*, *52*(8), 703–712. https://doi.org/10.1641/0006-3568(2002)052[0703:PRORVT]2.0.CO;2

Shaw, J. R., & Cooper, D. J. (2008). Linkages among watersheds, stream reaches, and riparian vegetation in dryland ephemeral stream networks. *Journal of Hydrology*, *350*(1–2), 68–82. https://doi.org/10.1016/j.jhydrol.2007.11.030

Sickle, J. V., & Gregory, S. V. (1990). Modeling inputs of large woody debris to streams from falling trees. *Canadian Journal of Forest Research*, *20*(10), 1593–1601. https://doi.org/10.1139/x90-211

Skroblin, A., Carboon, T., Bidu, G., Chapman, N., Miller, M., Taylor, K., Taylor, W., Game, E. T., & Wintle, B. A. (2021). Including indigenous knowledge in species distribution modeling for increased ecological insights. *Conservation Biology*, *35*(2), 587–597. https://doi.org/10.1111/cobi.13373

Smith, S. D., Devitt, D. A., Sala, A., Cleverly, J. R., & Busch, D. E. (1998). Water relations of riparian plants from warm desert regions. *Wetlands*, *18*(4), 687–696. https://doi.org/10.1007/BF03161683

Snohomish Conservation District. (2017). *Action Plan for Riparian Protection and Restoration for the Stillaguamish Confluence, French Creek, and Lower/Middle Pilchuck River*. Integrated Riparian Stewardship in the Stillquamish and Snohomish Basins. https://static1.squarespace.com/static/54933166e4b00173e5357840/t/5a60f6e7c8302582f6c5c37b/1516304111832/Action+Plan+for+Integrated+Riparian+Stewardship+in+the+Stillaguamish+and+Snohomish+basins_Final.pdf

Soil Survey Staff, USDA NRCS. (2022). *Soil Survey Geographic Database (SSURGO)* [Feature Layer; Geodatabase]. United States Department of Agriculture Natural Resources Conservation Service. https://websoilsurvey.nrcs.usda.gov/

Stahl, A. T., Fremier, A. K., & Cosens, B. (2013). *Adaptive governance of riparian lands in Washington State: Coordinating policy and practice to leverage river and floodplain protection benefits*. State of Washington Water Research Center (WRC). https://s3.wp.wsu.edu/uploads/sites/354/2017/06/Fremier_WRC_Report.pdf

Stahl, A. T., Fremier, A. K., & Cosens, B. A. (2020). Mapping legal authority for terrestrial conservation corridors along streams. *Conservation Biology*, *34*(4), 943–955. https://doi.org/10.1111/cobi.13484

Standard 161.01—Geodetic Control Data Standard (Government Standard 161.01). (2020). Office of the Chief Information Officer.

Strahler, A. N. (1957). Quantitative analysis of watershed geomorphology. *Transactions, American Geophysical Union*, *38*(6), 913. https://doi.org/10.1029/TR038i006p00913

Stumpff, L. M., Sanchez-Trigueros, F., Watson, A. E., Mdodi, F., & Teasdale, A. (2020). *Grassland, forest and riparian ecosystems on mixed-ownership federal lands adjacent to the Crow Indian Reservation: Developing a protective shield for sustainability of the environment and culture from the impacts of climate-related disturbance* (RMRS-GTR-410; p. RMRS-GTR-410). U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. https://doi.org/10.2737/RMRS-GTR-410

Sweeney, B. W., & Newbold, J. D. (2014). Streamside Forest Buffer Width Needed to Protect Stream Water Quality, Habitat, and Organisms: A Literature Review. *JAWRA Journal of the American Water Resources Association*, *50*(3), 560–584. https://doi.org/10.1111/jawr.12203

Tabacchi, E., Lambs, L., Guilloy, H., Planty-Tabacchi, A.-M., Muller, E., & Décamps, H. (2000). Impacts of riparian vegetation on hydrological processes. *Hydrological Processes*, *14*(16–17), 2959–2976. https://doi.org/10.1002/1099-1085(200011/12)14:16/17<2959::AID-HYP129>3.0.CO;2-B

Teels, B. M., Rewa, C. A., & Myers, J. (2006). Aquatic Condition Response to Riparian Buffer Establishment. *Wildlife Society Bulletin (1973-2006)*, *34*(4), 927–935.

Tiwari, T., Lundström, J., Kuglerová, L., Laudon, H., Öhman, K., & Ågren, A. M. (2016). Cost of riparian buffer zones: A comparison of hydrologically adapted site-specific riparian buffers with traditional fixed widths. *Water Resources Research*, *52*(2), 1056–1069. https://doi.org/10.1002/2015WR018014

Tufekcioglu, A., Raich, J. W., Isenhart, T. M., & Schultz, R. C. (2003). Biomass, carbon and nitrogen dynamics of multi-species riparian buffers within an agricultural watershed in Iowa, USA. *Agroforestry Systems*, *57*, 187–198.

U.S. Census Bureau. (2021). *TIGER/Line Shapefiles 2021:* [dataset]. United States Census Bureau. https://www.census.gov/cgi-bin/geo/shapefiles/index.php

U.S. Department of Agriculture (USDA). (2019). *2017 Census of Agriculture State Profile: Washington* (2017 Census of Agriculture County Profile). National Agricultural Statistics Service, United States Department of Agriculture. https://www.nass.usda.gov/Publications/AgCensus/2017/Online_Resources/County_Profiles/Washington/cp99053.pdf

U.S. Department of Agriculture National Agricultural Statistics Service (USDA-NASS). (2021). *National Agricultural Statistics Service Cropland Data Layer 2021* [Published crop-specific data layer [Online]]. National Agricultural Statistics Service, United States Department of Agriculture. https://nassgeodata.gmu.edu/CropScape

U.S. Endowment for Forestry and Communities, Ducks Unlimited, The Trust for Public Land, & USGS. (2022). *National Conservation Easement Database (NCED)* [Geospatial Data; Geodatabase]. The Trust for Public Land. https://www.conservationeasement.us/about/

U.S. Environmental Protection Agency (EPA). (2005). *National Management Measures to Protect and Restore Wetlands and Riparian Areas for the Abatement of Nonpoint Source*

Pollution (EPA-841-B-05-003). United States Environmental Protection Agency, Office of Water.

U.S. Environmental Protection Agency (EPA). (2013, February 22). *Summary of the Clean Water Act* [Overviews and Factsheets]. United States Environmental Protection Agency. https://www.epa.gov/laws-regulations/summary-clean-water-act

U.S. Environmental Protection Agency (EPA). (1977, December 28). *Statement by Douglas M. Costle on Enactment of the Clean Water Act of 1977* [Speeches, Testimony and Transcripts]. https://www.epa.gov/archive/epa/aboutepa/statement-douglas-m-costle-enactment-clean-water-act-1977.html

U.S. Environmental Protection Agency (EPA). (1978). *The Meaning of the 1977 Clean Water Act* [Speeches, Testimony and Transcripts]. https://www.epa.gov/archive/epa/aboutepa/meaning-1977-clean-water-act.html

U.S. Geological Survey (USGS). (2023). *National Hydrography Plus High Resolution (NHDPlus HR) Dataset* [Geospatial data; Geodatabase]. United States Geological Survey. https://www.usgs.gov/national-hydrography/access-national-hydrography-products

U.S. Geological Survey Gap Analysis Project (USGS GAP). (2022). *Protected Areas Database of the United States (PAD-US) 3.0 (ver. 2.0, March 2023)* [dataset]. U.S. Geological Survey Gap Analysis Project. https://doi.org/10.5066/P9Q9LQ4B

U.S. National Marine Fisheries Service. (2022). *2022 5-Year Review: Summary & Evaluation of Upper Columbia River Spring-run Chinook Salmon and Upper Columbia River Steelhead*. United States National Marine Fisheries Service, West Coast Region. https://doi.org/10.25923/P4W5-DP31

Valdivia, C., & Poulos, C. (2009). Factors affecting farm operators' interest in incorporating riparian buffers and forest farming practices in northeast and southeast Missouri. *Agroforestry Systems*, *75*(1), 61–71. https://doi.org/10.1007/s10457-008-9129-2

Valkama, E., Usva, K., Saarinen, M., & Uusi-Kämppä, J. (2019). A Meta-Analysis on Nitrogen Retention by Buffer Zones. *Journal of Environmental Quality*, *48*(2), 270–279. https://doi.org/10.2134/jeq2018.03.0120

Vilsack, T. (2022). *Climate Resilience and Carbon Stewardship of America's National Forests and Grasslands* (Secretary's Memorandum 1077–004). U.S. Department of Agriculture, Office of the Secretary.

Waples, R. S., Elz, A., Arnsberg, B. D., Faulkner, J. R., Hard, J. J., Timmins-Schiffman, E., & Park, L. K. (2017). Human-mediated evolution in a threatened species? Juvenile life-history changes in Snake River salmon. *Evolutionary Applications*, *10*(7), 667–681. https://doi.org/10.1111/eva.12468

Washington Department of Ecology (WAECY). (2022). *Washington State Water Resources Inventory Areas (WRIA) dataset* [Polygon Feature Layer]. https://data.wa.gov/Natural-Resources-Environment/Water-Resource-Inventory-Areas-WRIA-Washington-Sta/fwgq-q5ti

Washington Department of Ecology (WAECY), & National Oceanic and Atmospheric Administration (NOAA) Fisheries. (2014). *WAECY Endangered Species Units (ESU) for Salmon based on NOAA National Marine Fisheries Service data* [ArcGIS Feature layers; Geodatabase]. Department of Ecology Geoservices.

Washington Department of Fish and Wildlife (WDFW). (2020a). *Riparian Ecosystems, Volume 1: Science Synthesis and Management Implications*. Habitat Program, Washington Department of Fish and Wildlife.

Washington Department of Fish and Wildlife (WDFW). (2020b). *Riparian Ecosystems, Volume 2: Management Recommendations* (Priority Habitats and Species Document of the Washington Department of Fish and Wildlife). Habitat Program, Washington Department of Fish and Wildlife.

Washington Department of Fish and Wildlife (WDFW). (2021). *Priority Habitats and Species: Riparian Ecosystems and the Online SPTH Map Tool* [Webmap Using: ArcGIS by esri]. Washington Department of Fish and Wildlife. https://wdfw.maps.arcgis.com/apps/MapJournal/index.html?appid=35b39e40a2af447b9556ef1314a5622d

Washington Department of Fish and Wildlife (WDFW). (2022). *Key Links: WDFW Adult Abundance Status and Trends Analysis (2022) | Data.WA | State of Washington* [Raw Data and Reports]. Washington State Department of Fish and Wildlife. https://data.wa.gov/Natural-Resources-Environment/Key-Links-WDFW-Adult-Abundance-Status-and-Trends-A/7xsn-jhyc

Washington Department of Fish and Wildlife (WDFW), Buehrens, T., & Kendall, N. (2022). *Final WDFW Adult Abundance Status and Trends Analysis for 2022 SOS* [Analysis]. Washington Department of Fish and Wildlife.

Washington Department of Fish and Wildlife (WDFW) Habitat Program. (2023a). *Arid Lands Initiative* [ArcGIS Online WebMap]. Washington Department of Fish and Wildlife. https://wdfw.maps.arcgis.com/apps/webappviewer/index.html?id=746b5d1ffb464fbf9228534945e148e8

Washington Department of Fish and Wildlife (WDFW) Habitat Program. (2023b). *Visible Surface Water (VSW)* [Feature Layer; Geodatabase]. Washington State Department of Fish and Wildlife. https://hrcd-wdfw.hub.arcgis.com/pages/vsw

Washington Department of Natural Resources (DNR). (2005). *Forest Practices Habitat Conservation Plan | WA - DNR*. Washington Department of Natural Resources. https://www.dnr.wa.gov/programs-and-services/forest-practices/forest-practices-habitat-conservation-plan

Washington Department of Natural Resources (DNR). (2001). *Forest Practices Site class data layer—Siteclass_poly* [Feature Layer; File Geodatabase Feature Class]. Washington State Department of Natural Resources, Forest Practices Division. https://dnr.wa.gov/publications/fp_data_siteclass_meta.htm

Washington Department of Natural Resources (DNR). (2021a). *WA Soils* [Feature Layer; Geodatabase]. Washington State Department of Natural Resources. https://geo.wa.gov/datasets/wadnr::wa-soils/explore

Washington Department of Natural Resources (DNR). (2021b). *Washington DNR Hydrography—Water Bodies (WB) and Watercourses (WC)—Forest Practices Regulation* [Feature Layers; Geodatabase]. Washington State Department of Natural Resources. https://data-wadnr.opendata.arcgis.com/datasets/wadnr::dnr-hydrography-water-bodies-forest-practices-regulation/explore?location=47.267474%2C-123.895949%2C13.98

Washington Department of Natural Resources (DNR), & Forest Practices Board. (2000). *Forest Practices Board Manual*. Washington Department of Natural Resources.

Washington Governor's Office. (2022). *State of Salmon in Watersheds Executive Summary 2022* (State of the Salmon Report). Governor's Salmon Recovery Office, Recreation and Conservation Office. stateofsalmon.wa.gov

Washington Parcels Working Group, Washington Department of Health (WADOH), National Resource Spatial Informatics Group (NRSIG), U.S. Forest Service (USFS), & Washington Department of Revenue (WADOR). (2014). *2012 Washington State Parcel Database* (9.2) [Geospatial Data; ESRI Geodatabase]. National Resource Spatial Informatics Group.

Washington State Legislature. (2022, January 19). *Public Hearing of the House Rural Development, Agriculture & Natural Resources Committee—TVW: HB 1893—Protecting, restoring, and maintaining habitat for salmon recovery*. TVW. https://tvw.org/video/house-rural-development-agriculture-natural-resources-committee-2022011365/

Washington State Legislature. (2023, February 20). Public Hearing of the House Rural Development, Agriculture & Natural Resources Committee: SHB 1720 [Digital Video]. In *WA State Public Hearings*. TVW. https://tvw.org/video/house-capital-budget-2023021413/?eventID=2023021413

Washington State Recreation and Conservation Office (WRCO). (2014). *Public Lands Inventory Project Final Report* (Public Lands Inventory Project). Washington State Recreation and Conservation Office.

Washington State Recreation and Conservation Office (WRCO). (2017). *WA RCO GSRO Salmon Recovery Regions* [ArcGIS Feature layer; Geodatabase]. Recreation and Conservation Office.

Washington State Recreation and Conservation Office (WRCO). (2019). *Public Lands Inventory Polygon Layer* [ArcGIS]. Recreation and Conservation Office. https://geoduck.maps.arcgis.com/home/item.html?id=d296b58b0eae485fba2c55ab90e5908d

Wenger, S. (1999). *A review of the scientific literature on riparian buffer width, extent and vegetation* (p. 59) [Scientific Review]. Institute of Ecology, University of Georgia.

Wheeler, H., & Root-Bernstein, M. (2020). Informing decision-making with Indigenous and local knowledge and science. *Journal of Applied Ecology*. https://doi.org/10.1111/1365-2664.13734

Wickham, J., Stehman, S. V., Sorenson, D. G., Gass, L., & Dewitz, J. A. (2021). Thematic accuracy assessment of the NLCD 2016 land cover for the conterminous United States. *Remote Sensing of Environment*, *257*, 112357. https://doi.org/10.1016/j.rse.2021.112357

Wissmar, R. C., Smith, J. E., McIntosh, B. A., Li, H. W., Reeves, G. H., & Sedell, J. R. (1994). Ecological health of river basins in forested regions of eastern Washington and Oregon. *Gen. Tech. Rep. PNW-GTR-326. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 65 p. (Everett, Richard L., Assessment Team Leader; Eastside Forest Ecosystem Health Assessment; Hessburg, Paul F., Science Team*

Leader and Tech. Ed., Volume III: Assessment.), 326. https://doi.org/10.2737/PNW-GTR-326

Yu, J., & Belcher, K. (2011). An Economic Analysis of Landowners' Willingness to Adopt Wetland and Riparian Conservation Management. *Canadian Journal of Agricultural Economics/Revue Canadienne d'agroeconomie*, *59*(2), 207–222. https://doi.org/10.1111/j.1744-7976.2011.01219.x

Yuan, Y., Bingner, R. L., & Locke, M. A. (2009). A Review of effectiveness of vegetative buffers on sediment trapping in agricultural areas. *Ecohydrology*, *2*(3), 321–336. https://doi.org/10.1002/eco.82

Zhang, X., Liu, X., Zhang, M., Dahlgren, R. A., & Eitzel, M. (2010). A Review of Vegetated Buffers and a Meta-analysis of Their Mitigation Efficacy in Reducing Nonpoint Source Pollution. *Journal of Environmental Quality*, *39*(1), 76–84. https://doi.org/10.2134/jeq2008.0496

APPENDIX A: Supplemental statistical tables and analysis for 2021 CDL

Table A1

Results of Bonferroni post hoc and pairwise tests for significant ANOVA riparian buffer size comparisons within 2021 CDL "simple" LULC types for Western and Eastern Washington.

	df	Mean Difference (Buffer1-Buffer2)	*F*	*p-value adj.*
WEST				
Development				
Public	2, 27		0.26	*ns*
Private	2, 27		22.50	<0.001
50 ft:100 ft				*ns*
50 ft: SPTH		-4.76		<0.001
100 ft: SPTH		-5.72		<0.001
EAST				
Agriculture				
Public	2, 31		8.83	0.002
50 ft:100 ft		-4.03		0.001
50 ft: SPTH				*ns*
100 ft: SPTH		3.17		0.01
Private	2, 31		17.90	<0.001
50 ft:100 ft		-7.5		<0.001
50 ft: SPTH				*ns*
100 ft: SPTH		4.98		<0.001
Potential Riparian				
Public	2, 31		2.26	*ns*
50 ft:100 ft				*ns*
50 ft: SPTH				*ns*
100 ft: SPTH		-3.29		0.007
Private	2, 31		18.40	<0.001
50 ft:100 ft		7.81		<0.001
50 ft: SPTH				*ns*
100 ft: SPTH		-5.01		<0.001

Note: Sample size of 28 for the West is data from WRIAs 1 and 3-29 and a sample size of 32 for the East is data from WRIAs 30-50 and 52-62 (not including WRIAs of sovereign nations).

Table A2

Results of Bonferroni post hoc and pairwise tests for significant ANOVA riparian buffer size comparisons within 2021 CDL "reclass" LULC types for Western and Eastern Washington.

	df	Mean Difference (Buffer1-Buffer2)	*F*	*p-value adj.*
WEST				
DEVMH				
Public	2, 27		5.75	0.044
Buffers				
50 ft:100 ft		3.55		0.004
50 ft: SPTH				*ns*
100 ft: SPTH				*ns*
Private	2, 27		7.37	0.016
50 ft:100 ft				*ns*
50 ft: SPTH		-2.79		0.029
100 ft: SPTH		-2.84		0.026
DEVLO				
Public	2, 27		0.55	*ns*
Private	2, 27		23.90	<0.001
50 ft:100 ft				*ns*
50 ft: SPTH		-4.74		<0.001
100 ft: SPTH		-6.66		<0.001
CROP				
Public	2, 27		4.88	0.022
50 ft:100 ft				*ns*
50 ft: SPTH		2.76		0.031
100 ft: SPTH				*ns*
Private	2, 27		6.80	0.028
50 ft:100 ft				*ns*
50 ft: SPTH		2.64		0.041
100 ft: SPTH		2.8		0.028
BAR				
Public	2, 27		12.90	<0.001
50 ft:100 ft				*ns*
50 ft: SPTH		3.28		0.009
100 ft: SPTH		5.02		<0.001
Private	2, 27		12.20	0.002
50 ft:100 ft		2.85		0.025
50 ft: SPTH		3.55		0.004
100 ft: SPTH		4.14		<0.001

EAST				
DEVMH				
Public	2, 31		0.47	*ns*
Private	2, 31		7.98	0.004
50 ft:100 ft		-4.35		<0.001
50 ft: SPTH				*ns*
100 ft: SPTH				*ns*
CROP				
Public	2, 31		1.36	*ns*
50 ft:100 ft				*ns*
50 ft: SPTH				*ns*
100 ft: SPTH		2.79		0.027
Private	2, 31		8.77	<0.001
50 ft:100 ft		-3.82		0.002
50 ft: SPTH				*ns*
100 ft: SPTH		3.99		0.001
HAYPAST				
Public	2, 31		8.38	0.004
50 ft:100 ft		-3.75		0.002
50 ft: SPTH				*ns*
100 ft: SPTH		3.23		0.009
Private	2, 31		11.30	<0.001
50 ft:100 ft		-4.53		<0.001
50 ft: SPTH				*ns*
100 ft: SPTH		4.44		<0.001
SHRUB				
Public	2, 31		0.80	*ns*
Private	2, 31		10.20	<0.001
50 ft:100 ft				*ns*
50 ft: SPTH		4.87		<0.001
100 ft: SPTH		2.72		0.032
WOODY				
Public	2, 31		3.48	0.132
50 ft:100 ft		2.53		0.05
50 ft: SPTH				*ns*
100 ft: SPTH		-3.97		0.001
Private	2, 31		24.80	<0.001
50 ft:100 ft		6.94		<0.001
50 ft: SPTH				*ns*
100 ft: SPTH		-6.32		<0.001

Note: Sample size of 28 for West WRIAs 1 and 3-29 and sample size of 32 for East WRIAs 30-50 and 52-62 (not including WRIAs of sovereign nations).

Table A3

2021 CDL detailed agricultural crop classification for Western Washington by acreage and percentage of agricultural total within riparian buffer prescriptions.

WEST	50 ft	Acres	100 ft	Acres	SPTH	Acres
Grassland/Pasture	71.93%	77475	77.04%	125604	81.70%	207272
Other Hay/Non Alfalfa	9.01%	9708	7.26%	11831	5.70%	14450
Corn	8.91%	9601	6.76%	11027	4.99%	12649
Blueberries	4.18%	4503	3.40%	5545	2.67%	6765
Potatoes	1.11%	1193	0.95%	1550	0.76%	1921
Christmas Trees	0.97%	1050	1.06%	1724	1.25%	3162
Caneberries	0.82%	883	0.75%	1228	0.70%	1788
Barley	0.69%	747	0.60%	971	0.45%	1140
Sod/Grass Seed	0.49%	524	0.44%	722	0.35%	883
Alfalfa	0.46%	495	0.40%	652	0.33%	846
Pumpkins	0.20%	213	0.16%	254	0.11%	282
Greens	0.18%	199	0.19%	307	0.16%	397
Cranberries	0.18%	196	0.21%	338	0.15%	382
Apples	0.12%	133	0.11%	172	0.10%	250
Peas	0.11%	115	0.07%	117	0.05%	119
Other Tree Crops	0.10%	103	0.09%	150	0.08%	215
Dry Beans	0.08%	90	0.08%	134	0.07%	173
Rye	0.08%	89	0.08%	129	0.07%	167
Spring Wheat	0.06%	63	0.05%	86	0.04%	108

Note: Only includes crops making up the top two quartiles of acreage for each prescription size.

Table A4

2021 CDL detailed agricultural crop classification for Eastern Washington by acreage and percentage of agricultural total within riparian buffer prescriptions.

EAST	50 ft	Acres	100 ft	Acres	SPTH	Acres
Grassland/Pasture	47.81%	206289	47.64%	400438	47.93%	413486
Winter Wheat	15.09%	65094	15.30%	128604	15.09%	130176
Fallow/Idle Cropland	11.16%	48138	11.39%	95747	11.17%	96393
Alfalfa	5.56%	23988	5.42%	45524	5.58%	48112
Spring Wheat	5.47%	23592	5.54%	46593	5.54%	47825
Apples	3.05%	13154	2.92%	24560	2.86%	24689
Other Hay/Non Alfalfa	2.58%	11151	2.47%	20770	2.55%	22003
Chick Peas	1.17%	5028	1.19%	10003	1.18%	10210
Grapes	1.13%	4890	1.10%	9229	1.07%	9254
Canola	1.09%	4705	1.11%	9316	1.12%	9690
Corn	0.88%	3809	0.92%	7700	0.89%	7717
Cherries	0.75%	3254	0.69%	5782	0.68%	5849
Peas	0.63%	2712	0.64%	5399	0.63%	5466
Potatoes	0.60%	2576	0.62%	5205	0.60%	5215
Barley	0.56%	2403	0.56%	4714	0.57%	4902
Pears	0.48%	2087	0.46%	3825	0.47%	4081
Sod/Grass Seed	0.44%	1884	0.44%	3684	0.46%	3997
Lentils	0.30%	1298	0.31%	2641	0.31%	2715
Dry Beans	0.26%	1133	0.27%	2303	0.27%	2306
Hops	0.23%	973	0.23%	1923	0.22%	1924
Sweet Corn	0.21%	885	0.21%	1766	0.20%	1768
Onions	0.12%	538	0.13%	1084	0.13%	1084
Blueberries	0.09%	392	0.09%	719	0.08%	720
Oats	0.07%	293	0.07%	575	0.08%	654
Mint	0.06%	250	0.06%	491	0.06%	493
Triticale	0.05%	195	0.05%	396	0.05%	414
Dbl Crop Triticale/Corn	0.04%	162	0.04%	344	0.04%	345
Carrots	0.02%	87	0.02%	178	0.02%	178
Other Crops	0.02%	71	0.02%	142	0.02%	172
Sunflower	0.01%	63	0.01%	122	0.02%	136
Christmas Trees	0.01%	55	0.01%	107	0.01%	120
Clover/Wildflowers	0.01%	53	0.01%	101	0.01%	107

Note: Only includes crops making up the top two quartiles of acreage for each prescription size.

Table A5

2021 CDL perennial crops and percentage totals of perennial versus annual crops within the riparian buffer width prescriptions

Perennial Acres	**E 50 ft**	**E 100 ft**	**E SPTH**	**W 50 ft**	**W 100 ft**	**W SPTH**
Apples	13154	24560	24689	133	172	250
Apricots	7	11	11			
Asparagus	14	31	31			
Blueberries	392	719	720	4503	5545	6765
Caneberries	5	8	9	883	1228	1788
Cherries	3254	5782	5849	8	14	24
Christmas Trees	55	107	120	1050	1724	3162
Cranberries	3	5	5	196	338	382
Grapes	4890	9229	9254	35	59	104
Herbs	43	83	84	11	19	28
Hops	973	1923	1924			
Mint	250	491	493			
Other Tree Crops	4	8	9	103	150	215
Peaches	52	95	98	1	2	5
Pears	2087	3825	4081	34	67	128
Plums	1	1	1			
Walnuts	1	3	3	7	13	24
TOTAL Percent						
Perennial	17.8%	16.9%	16.8%	34.8%	37.5%	41.5%
Annual	82.2%	83.1%	83.2%	65.2%	62.6%	58.6%

Note: Perennials on this list includes crops that tend to live at least three years, but it is important to note some growers will harvest whole plants (herbs, mint) in a single year. This is why strawberries are not included.

Public land cover composition statistics specific to public landowner type

Federal lands make up most of the public lands in the riparian management zone by far, in both Eastern and Washington. In Eastern Washington, they are 77% of all public lands inside the three buffer prescriptions, and 71.5% in the 50 ft and 100 ft in Western Washington (but only 62% in the SPTH). The second highest percentage is the Washington Department of Natural Resources (DNR) Uplands program for both East and West, making up 15% of Eastern public lands, and 23-24% in the 50 ft and 100 ft, and 33% in the SPTH on Western lands. State Parks (0.6%), City and County (0.4%), and the DNR Aquatics program (0.2%) are the smallest percentages of public lands in the East. State Parks (0.5%) and DNR Aquatics (0.6%) are also less than 1% in the West. The biggest differences between East and West in terms of ownership are that of City and County and the Washington Department of Fish and Wildlife (WDFW). On average, 6.6% of Eastern Washington public lands in the buffers are owned by WDFW, but only 0.7% of Western lands are owned by the WDFW. In the West, 3% of public lands are city or county lands compared to the 0.4% in the East.

While there are some slight differences between buffers, to simplify variables in the comparisons, only the 100 ft buffer was used in the rest of this public landowner type analysis. First, it is important to understand the major difference in quantity of land cover within each public owner type. Table A6 shows East and West acreage and percentage of each land cover type by owner as a part of the total land cover (rather than as a percentage within that specific land cover type). For example, woody vegetation (51.3%) and shrublands (16.3%) on federal lands make up the highest percentage of land cover on public lands in the East, followed by 7% hay and pasture on Federal lands and 6.8% woody vegetation on DNR Uplands. Only federal, DNR Uplands, and WDFW lands have a contribution greater than 1%.

While these statistics show vast differences in the amounts of riparian buffer land cover on different public land types, for management purposes, it is useful to consider percentages of each land cover type within each owner and land cover type (Table A7). The most relevant statistics to policy or agency usage are probably that on WDFW lands in the East, there is a higher percentage (26.2%) of hay and pasture than there is woody vegetation (22.8%); City and County has the highest percentage of development in the Eastern buffer (DEVMH=3.4% and DEVLO=17.3%) and West (DEVMH=1.3% and DEVLO=8.7%) (Though, again, in acreage, Federal lands are far higher). Deciphering the reasons behind these numbers of specific public landowner types is outside the scope of this analysis, as there are many different factors to consider.

Table A6

2021 CDL "reclass" LULC classes on public lands in West and East Washington by owner in acres and as a percentage of total public land cover within the 100 ft riparian buffer prescription

WEST ACRES	DEVMH	DEVLO	CROP	HAY/PAST	BARREN	SHRUB	WOODY
City and County	598	4113	89	1412	69	3102	37991
DNR Aquatics	263	501	117	633	355	2257	5399
DNR Uplands	95	8411	109	2810	597	14025	383303
Federal	1022	21687	69	11994	41546	98061	1046222
State Parks	29	399	7	235	77	653	6723
WDFW	98	455	379	1007	392	3675	5642
% of all LC	DEVMH	DEVLO	CROP	HAY/PAST	BARREN	SHRUB	WOODY
City and County	0.0%	0.2%	0.0%	0.1%	0.0%	0.2%	2.2%
DNR Aquatics	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.3%
DNR Uplands	0.0%	0.5%	0.0%	0.2%	0.0%	0.8%	22.5%
Federal	0.1%	1.3%	0.0%	0.7%	2.4%	5.7%	61.3%
State Parks	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.4%
WDFW	0.0%	0.0%	0.0%	0.1%	0.0%	0.2%	0.3%
EAST ACRES	DEVMH	DEVLO	CROP	HAY/PAST	BARREN	SHRUB	WOODY
City and County	151	762	151	456	0	1038	1842
DNR Aquatics	95	118	78	148	102	960	688
DNR Uplands	607	5392	5939	34258	31	51172	81001
Federal	2368	17580	1156	83752	10021	194930	612720
State Parks	85	394	98	845	2	2458	3203
WDFW	211	3468	868	21364	12	35970	18248
% of all LC	DEVMH	DEVLO	CROP	HAY/PAST	BARREN	SHRUB	WOODY
City and County	0.0%	0.1%	0.0%	0.0%	0.0%	0.1%	0.2%
DNR Aquatics	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.1%
DNR Uplands	0.1%	0.5%	0.5%	2.9%	0.0%	4.3%	6.8%
Federal	0.2%	1.5%	0.1%	7.0%	0.8%	16.3%	51.3%
State Parks	0.0%	0.0%	0.0%	0.1%	0.0%	0.2%	0.3%
WDFW	0.0%	0.3%	0.1%	1.8%	0.0%	3.0%	1.5%

Note: Acreage is an estimate.

Table A7

2021 CDL "reclass" LULC on public lands in West and East Washington within each owner's total land and within each land class's public land total in the 100 ft riparian buffer prescription

WEST % w/in Owner	DEVMH	DEVLO	CROP	HAY/PAST	BARREN	SHRUB	WOODY
City and County	1.3%	8.7%	0.2%	3.0%	0.1%	6.5%	80.2%
DNR Aquatics	2.8%	5.3%	1.2%	6.6%	3.7%	23.7%	56.7%
DNR Uplands	0.0%	2.1%	0.0%	0.7%	0.1%	3.4%	93.6%
Federal	0.1%	1.8%	0.0%	1.0%	3.4%	8.0%	85.7%
State Parks	0.4%	4.9%	0.1%	2.9%	0.9%	8.0%	82.8%
WDFW	0.8%	3.9%	3.3%	8.6%	3.4%	31.5%	48.4%
% w/in LC	DEVMH	DEVLO	CROP	HAY/PAST	BARREN	SHRUB	WOODY
City and County	28.4%	11.6%	11.6%	7.8%	0.2%	2.5%	2.6%
DNR Aquatics	12.5%	1.4%	15.2%	3.5%	0.8%	1.9%	0.4%
DNR Uplands	4.5%	23.6%	14.1%	15.5%	1.4%	11.5%	25.8%
Federal	48.5%	61.0%	9.0%	66.3%	96.5%	80.5%	70.4%
State Parks	1.4%	1.1%	0.9%	1.3%	0.2%	0.5%	0.5%
WDFW	4.7%	1.3%	49.2%	5.6%	0.9%	3.0%	0.4%
EAST % w/in Owner	DEVMH	DEVLO	CROP	HAY/PAST	BARREN	SHRUB	WOODY
City and County	3.4%	17.3%	3.4%	10.4%	0.0%	23.6%	41.9%
DNR Aquatics	4.4%	5.4%	3.5%	6.8%	4.6%	43.9%	31.4%
DNR Uplands	0.3%	3.0%	3.3%	19.2%	0.0%	28.7%	45.4%
Federal	0.3%	1.9%	0.1%	9.1%	1.1%	21.1%	66.4%
State Parks	1.2%	5.6%	1.4%	11.9%	0.0%	34.7%	45.2%
WDFW	0.3%	4.3%	1.1%	26.7%	0.0%	44.9%	22.8%
% w/in LC	DEVMH	DEVLO	CROP	HAY/PAST	BARREN	SHRUB	WOODY
City and County	4.3%	2.7%	1.8%	0.3%	0.0%	0.4%	0.3%
DNR Aquatics	2.7%	0.4%	0.9%	0.1%	1.0%	0.3%	0.1%
DNR Uplands	17.3%	19.5%	71.6%	24.3%	0.3%	17.9%	11.3%
Federal	67.3%	63.4%	13.9%	59.5%	98.5%	68.0%	85.4%
State Parks	2.4%	1.4%	1.2%	0.6%	0.0%	0.9%	0.4%
WDFW	6.0%	12.5%	10.5%	15.2%	0.1%	12.6%	2.5%

Note: "% w/in Owner" adds up to 100% horizontally by owner, and "% w/in LC" [LC = Land Cover] adds up to 100% vertically by land cover class.

Table A8

Spearman's ρ (rho) rank order correlation coefficients for different land cover types in the "reclass" classifications from the 2021 CDL within three buffer prescriptions.

			WEST				EAST			
	variable1	*variable2*	**PUBLIC**	*p-value*	**PRIVATE**	*p-value*	**PUBLIC**	*p-value*	**PRIVATE**	*p-value*
50 ft	DEVMH	DEVLO	0.660	<.001	0.874	<.001	0.778	<.001	0.672	<.001
		CROP	0.499	0.008	0.404	0.034	0.525	0.002	0.366	0.040
		PAST	0.696	<.001	NS	*ns*	0.500	0.004	NS	*ns*
		SHRUB	NS	*ns*	NS	*ns*	0.695	<.001	NS	*ns*
		WOOD	-0.681	<.001	-0.771	<.001	-0.665	<.001	NS	*ns*
	DEVLO	CROP	NS	*ns*	NS	*ns*	0.421	0.017	NS	*ns*
	DEVLO	PAST	0.400	0.036	NS	*ns*	0.396	0.026	NS	*ns*
		SHRUB	NS	*ns*	NS	*ns*	0.531	0.002	NS	*ns*
		WOOD	NS	*ns*	-0.760	<.001	-0.520	0.003	NS	*ns*
	CROP	PAST	0.531	0.004	0.714	<.001	0.738	<.001	0.501	0.004
		SHRUB	0.554	0.003	NS	*ns*	0.755	<.001	NS	*ns*
		WOOD	-0.449	0.017	-0.589	0.001	-0.871	<.001	-0.750	<.001
	PAST	SHRUB	0.513	0.006	0.407	0.033	0.752	<.001	NS	*ns*
		WOOD	-0.734	<.001	-0.620	0.001	-0.887	<.001	-0.766	<.001
	SHRUB	WOOD	-0.734	<.001	NS	*ns*	-0.924	<.001	-0.391	0.028
100 ft	DEVMH	DEVLO	0.622	0.001	0.878	<.001	0.758	<.001	0.647	<.001
		CROP	0.461	0.014	0.457	0.015	0.553	0.001	NS	*ns*
		PAST	0.638	<.001	NS	*ns*	0.509	0.003	NS	*ns*
		SHRUB	NS	*ns*	NS	*ns*	0.738	<.001	NS	*ns*
		WOOD	-0.586	0.001	-0.801	<.001	-0.688	<.001	NS	*ns*
	DEVLO	CROP	NS	*ns*	0.394	0.039	0.437	0.013	NS	*ns*
		PAST	NS	*ns*	NS	*ns*	0.386	0.030	NS	*ns*
		SHRUB	NS	*ns*	NS	*ns*	0.510	0.003	NS	*ns*
		WOOD	NS	*ns*	-0.817	<.001	-0.513	0.003	NS	*ns*
	CROP	PAST	0.447	0.018	0.708	<.001	0.728	<.001	0.497	0.004
		SHRUB	0.515	0.006	NS	*ns*	0.749	<.001	NS	*ns*
		WOOD	NS	*ns*	-0.600	0.001	-0.857	<.001	-0.742	<.001
	PAST	SHRUB	0.501	0.007	NS	*ns*	0.751	<.001	NS	*ns*
		WOOD	-0.702	<.001	-0.604	0.001	-0.893	<.001	-0.760	<.001
	SHRUB	WOOD	-0.774	<.001	NS	*ns*	-0.917	<.001	-0.359	0.044
SPTH	DEVMH	DEVLO	0.573	0.002	0.877	<.001	0.742	<.001	0.655	<.001
		CROP	0.382	0.046	0.433	0.022	0.562	0.001	0.367	0.040
		PAST	0.568	0.002	NS	*ns*	0.529	0.002	NS	*ns*
		SHRUB	NS	*ns*	-0.484	0.010	0.715	<.001	NS	*ns*
		WOOD	-0.558	0.002	-0.814	<.001	-0.692	<.001	-0.361	0.043

DEVLO	CROP	NS	*ns*	NS	*ns*	0.420	0.017	NS	*ns*
	PAST	NS	*ns*	NS	*ns*	0.387	0.029	NS	*ns*
	SHRUB	NS	*ns*	-0.430	0.023	0.477	0.006	NS	*ns*
	WOOD	NS	*ns*	-0.824	<.001	-0.497	0.004	NS	*ns*
CROP	PAST	0.407	0.032	0.707	<.001	0.727	<.001	0.526	0.002
	SHRUB	NS	*ns*	NS	*ns*	0.753	<.001	NS	*ns*
	WOOD	NS	*ns*	-0.562	0.002	-0.857	<.001	-0.751	<.001
PAST	SHRUB	0.526	0.005	NS	*ns*	0.755	<.001	NS	*ns*
	WOOD	-0.760	<.001	-0.529	0.004	-0.893	<.001	-0.792	<.001
SHRUB	WOOD	-0.731	<.001	NS	*ns*	-0.917	<.001	-0.373	0.036

APPENDIX B: Spearman's Correlations for NLCD change 2001-2019

Table B1

Spearman's rho correlations for compositional change from the NLCD 2001-2019 of land cover types in the "reclass" classifications from within three riparian buffer prescriptions.

			WEST				EAST			
	variable1	*variable2*	**PUBLIC**	*p-value*	**PRIVATE**	*p-value*	**PUBLIC**	*p-value*	**PRIVATE**	*p-value*
50 ft	DEVMH	DEVLO	-0.113	*ns*	0.490	0.009	-0.134	*ns*	0.129	*ns*
		CROP	0.197	*ns*	0.228	*ns*	-0.319	*ns*	-0.051	*ns*
		PAST	0.209	*ns*	0.188	*ns*	0.088	*ns*	0.229	*ns*
		BAR	-0.233	*ns*	0.174	*ns*	-0.367	0.039	-0.252	*ns*
		SHRUB	0.100	*ns*	0.195	*ns*	-0.174	*ns*	-0.185	*ns*
		WOOD	-0.238	*ns*	-0.310	*ns*	0.007	*ns*	-0.836	*ns*
	DEVLO	CROP	0.088	*ns*	-0.641	*ns*	0.044	*ns*	0.202	*ns*
		PAST	0.233	*ns*	0.220	*ns*	-0.163	*ns*	0.319	*ns*
		BAR	0.349	*ns*	0.055	*ns*	0.172	*ns*	-0.500	0.004
		SHRUB	0.066	*ns*	0.323	*ns*	0.108	*ns*	0.165	*ns*
		WOOD	-0.343	*ns*	-0.524	0.005	-0.229	*ns*	-0.731	<0.001
	CROP	PAST	-0.018	*ns*	-0.039	*ns*	0.209	*ns*	0.093	*ns*
		BAR	0.151	*ns*	-0.074	*ns*	0.266	*ns*	-0.059	*ns*
		SHRUB	-0.078	*ns*	-0.166	*ns*	-0.074	*ns*	-0.076	*ns*
		WOOD	0.014	*ns*	0.023	*ns*	-0.275	*ns*	-0.298	*ns*
	PAST	BAR	0.033	*ns*	0.115	*ns*	0.102	*ns*	-0.267	*ns*
		SHRUB	0.593	0.001	0.303	*ns*	-0.477	0.006	-0.550	0.001
		WOOD	-0.805	<0.001	-0.551	0.003	-0.313	*ns*	-0.392	0.027
	BAR	SHRUB	0.054	*ns*	-0.312	*ns*	0.340	*ns*	-0.081	*ns*
		WOOD	-0.226	*ns*	0.158	*ns*	-0.340	*ns*	0.397	0.024
	SHRUB	WOOD	-0.851	<0.001	-0.891	<0.001	-0.527	0.002	-0.309	*ns*
100 ft	DEVMH	DEVLO	0.018	*ns*	0.598	<0.001	-0.048	*ns*	-0.014	*ns*
		CROP	0.142	*ns*	0.185	*ns*	-0.211	*ns*	-0.120	*ns*
		PAST	0.152	*ns*	0.191	*ns*	0.095	*ns*	0.207	*ns*
		BAR	-0.312	*ns*	0.238	*ns*	-0.346	*ns*	-0.266	*ns*
		SHRUB	0.190	*ns*	0.118	*ns*	-0.406	0.022	-0.274	*ns*
		WOOD	-0.193	*ns*	-0.272	*ns*	0.254	*ns*	0.088	*ns*
	DEVLO	CROP	0.368	*ns*	0.005	*ns*	-0.024	*ns*	0.270	*ns*
		PAST	0.173	*ns*	0.202	*ns*	-0.266	*ns*	0.097	*ns*
		BAR	0.395	0.038	0.072	*ns*	0.157	*ns*	-0.424	0.016

		SHRUB	0.093	*ns*	0.303	*ns*	0.082	*ns*	0.194	*ns*
		WOOD	-0.405	0.033	-0.471	0.012	-0.185	*ns*	-0.680	<0.001
	CROP	PAST	-0.593	*ns*	0.057	*ns*	0.193	*ns*	0.136	*ns*
		BAR	0.159	*ns*	-0.102	*ns*	0.321	*ns*	-0.037	*ns*
		SHRUB	-0.130	*ns*	-0.188	*ns*	-0.112	*ns*	-0.117	*ns*
		WOOD	-0.006	*ns*	0.073	*ns*	-0.228	*ns*	-0.420	0.017
	PAST	BAR	0.022	*ns*	0.084	*ns*	0.003	*ns*	-0.215	*ns*
		SHRUB	0.548	0.003	0.336	*ns*	-0.516	0.003	-0.552	0.001
		WOOD	-0.760	<0.001	-0.619	<0.001	-0.307	*ns*	-0.315	*ns*
	BAR	SHRUB	0.054	*ns*	-0.101	*ns*	0.162	*ns*	-0.106	*ns*
		WOOD	-0.268	*ns*	0.050	*ns*	-0.150	*ns*	0.430	0.015
	SHRUB	WOOD	-0.846	<0.001	-0.868	<0.001	-0.502	0.004	-0.297	*ns*
SPTH	DEVMH	DEVLO	-0.070	*ns*	0.702	<0.001	-0.022	*ns*	-0.088	*ns*
		CROP	0.216	*ns*	0.193	*ns*	-0.147	*ns*	-0.101	*ns*
		PAST	-0.093	*ns*	0.285	*ns*	0.059	*ns*	0.191	*ns*
		BAR	-0.267	*ns*	0.216	*ns*	-0.339	*ns*	-0.198	*ns*
		SHRUB	0.312	*ns*	0.088	*ns*	-0.007	*ns*	-0.315	*ns*
		WOOD	-0.201	*ns*	-0.368	*ns*	-0.420	0.017	0.156	*ns*
	DEVLO	CROP	0.239	*ns*	0.230	*ns*	-0.114	*ns*	0.295	*ns*
		PAST	0.114	*ns*	0.147	*ns*	-0.222	*ns*	0.055	*ns*
		BAR	0.465	0.013	0.168	*ns*	0.106	*ns*	-0.349	0.050
		SHRUB	-0.030	*ns*	0.002	*ns*	0.060	*ns*	0.175	*ns*
		WOOD	-0.196	*ns*	-0.155	*ns*	-0.168	*ns*	-0.530	0.002
	CROP	PAST	0.180	*ns*	0.134	*ns*	0.162	*ns*	0.133	*ns*
		BAR	0.081	*ns*	0.140	*ns*	0.295	*ns*	0.000	*ns*
		SHRUB	0.083	*ns*	-0.214	*ns*	-0.126	*ns*	-0.059	*ns*
		WOOD	-0.261	*ns*	0.048	*ns*	-0.181	*ns*	-0.414	0.019
	PAST	BAR	0.083	*ns*	0.101	*ns*	-0.016	*ns*	-0.181	*ns*
		SHRUB	0.289	*ns*	0.277	*ns*	-0.518	0.003	-0.530	0.002
		WOOD	-0.632	<0.001	-0.667	<0.001	-0.296	*ns*	-0.360	0.044
	BAR	SHRUB	0.070	*ns*	-0.011	*ns*	0.155	*ns*	-0.113	*ns*
		WOOD	-0.303	*ns*	-0.082	*ns*	-0.126	*ns*	0.343	*ns*
	SHRUB	WOOD	-0.840	<0.001	-0.804	<0.001	-0.484	0.006	-0.350	0.050