Riparian Buffer Zones Management for Improving British Columbia's Salmon Habitat

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Executive Summary

This project addresses the challenges faced by British Columbia and Pacific Northwest salmon-bearing streams as the result of urbanization and climate change. The project focuses on understanding the factors that influence riparian functionality and how these factors are monitored within a forested ecosystem where most salmon-bearing streams occur most. By conducting a systematic literature review, the project evaluates and compares riparian management plans implemented in different regions, namely Maine, Seattle's Olympic Experimental State Forest, and British Columbia. These case studies have management framework based on different premises, by providing management based on land uses, monitoring guidelines and the particular focus on forested ecosystems.

The research highlights the ecological functions of riparian buffer zones and their potential for mitigating the negative impacts of human activities on salmon habitats. Through the analysis of various management plans, the project identifies specific indicators used to assess riparian systems and discusses the advantages and disadvantages of different management practices.

The findings emphasize the need for effective riparian management to conserve and restore salmon habitat. The project highlights available options for riparian management in British Columbia and provides recommendations for optimizing riparian regulations. These recommendations are based on the successful practices observed in the examined regions and aims to enhance the resilience of riparian buffer zones in British Columbia, thus benefiting salmon populations.

By shedding light on the importance of riparian buffer zones in supporting salmon habitat, the project contributes to the broader understanding of sustainable ecosystem management. The results can guide policymakers, land managers, and conservation organizations in developing strategies and implementing effective riparian management practices.

Overall, this project provides insights into riparian buffer zones management and their role in improving British Columbia's salmon habitat. It serves as a resource for stakeholders involved in salmon conservation efforts, offering recommendations to enhance riparian regulations and protect the long-term sustainability of salmon populations in the region.

Introduction

Freshwater habitat alterations and water temperature rise in response to ubiquitous land use changes threaten cold-water salmonids (Bradford & Irvine, 2000; Justice et al.,2017). As the transitioning interface, riparian buffer zones play a vital role in connecting the aquatic and terrestrial ecosystems (Collins et al., 2010). Riparian buffer zones possess diverse environmental processes and functions that result in variable flooding regimes, unique channel processes, as well as upland influences on the fluvial corridor (Naiman & Decamps, 1997).

Benefits of Riparian Buffer Zones

While riparian buffer zones exhibit numerous ecological benefits, including flood control, nutrient cycling, altitudinal climate regulations, energy-matter exchange, and biodiversity (Pal et al., 2020), their significance is particularly pronounced in forested ecosystems where most salmonid-bearing streams occur. In the context of British Columbia, forested ecosystems represent a crucial habitat for cold-water salmonids and play a key role in supporting their populations. Additionally, riparian buffer zones significantly contribute to biodiversity richness (Wentzel & Hull, 2021). In the U.S, riparian systems accommodate one third of plant species and 60% of vertebrate species. Despite their insignificant land coverage (>2%), they are responsible for supporting 70% of endangered and threatened species (Wentzel & Hull, 2021). Riparian buffer zones are also crucial as they play a role in altering hydrological processes and water regimes that directly impact the aquatic ecosystem (Klapproth & Johnson, 2009).

In addition, riparian systems are valuable as they bring recreational and economic benefits beyond the ecosystem. For instance, riparian buffer zones can maintain surrounding water quality for recreational purposes, such as hiking, fishing and camping (Wentzel & Hull, 2021). Riparian zones aid in minimizing the effects of anthropogenic activities on terrestrial land, including urbanization, dam construction, and agriculture, which can negatively influence watershed quality and stream health. Urban watersheds present higher concentrations of nutrients, sediments, bacteria, and metals in comparison to a forested watershed (Chelsea Nagy et al.,2012). The issues of urbanization are commonly associated with increased imperviousness, runoff volumes, and velocities. More importantly, the increased discharge of pollutants such as oil, grease, and other substances results in urban pollution (Barrios, 2000). Human and livestock waste may lead to fecal

contaminant runoff to adjacent water bodies (Chelsea Nagy et al.,2012; Mallin et al.,2009). Riparian buffer zones effectively reduce water velocity, capture sediments, and filter pollutants, including pesticides and heavy metals, resulting in cleaner water and improved habitat conditions (Wentzel & Hull, 2021). Moreover, the productive vegetation and clean water in riparian zones can also benefit neighboring foraging and agricultural activities (Wentzel & Hull, 2021).

Factors Influencing Riparian Buffer Zones

While a healthy riparian buffer system can protect and even enhance water bodies, a degraded system may have a compromised capacity to perform its functions. Although riparian buffer systems usually exhibit a certain extent of resiliency towards natural processes, prolonged stresses may irreversibly damage the riparian and aquatic ecosystem (Wu et al.,2023; Sabater, 2008). Factors such as erosion, wildfire risks and increasing air temperatures all pose threats to the well-being of a riparian buffer (Wentzel & Hull, 2021). Severe water erosion may degrade a riparian ecosystem if the surface layer of the soil is removed by runoff, rainfall and irrigation. Similarly, intense wildfires could severely impact riparian vegetation and result in more fuel accumulation (Wentzel & Hull, 2021).

Increasing Temperature and Cold-Temperature Fish Species

Increasing air temperature may lead to an increase in water temperature, which creates a serious problem for cold-water salmonid species (Wentzel & Hull, 2021; Justice et al., 2017). Salmonid populations inevitably decrease sharply when they are exposed to a temperature that exceeds their range for survival (Barrios, 2000; Justice et al., 2017). Anadromous fish populations rely on freshwater bodies to carry out their juvenile and reproductive stages (Grunblatt et al., 2019). Specifically, salmonids return to swim from the ocean to the headwaters of their home river to spawn and complete their life cycle (Fullerton et al., 2006). Young hatches also begin their initial stages in the freshwater before returning to the ocean (Emmingham et al.,2005). Successful spawning, hatching and survival is dependent on the conditions of the **entire migration route** (Emmingham et al.,2005). Riparian buffer vegetation enables favorable salmon habitats by providing shading that lowers water temperature. In addition, tree litters act as coverage for juvenile salmon that protects them from predators (Emmingham et al.,2005). A well-restored

riparian system even has the potential to offset climate change impacts on the salmon population (Justice et al., 2017).

As a keystone species in British Columbia, salmon is a vital part of the food chain and contributes to a significant portion of BC's aquaculture income (Pacific Salmon Foundation, 2011). Salmon has a great spiritual value to many First Nations communities as they are commonly regarded as a gift from the creator (Smithsonian. 2018). In addition, salmonids' spawning process is considered to be a sacrifice of their own life for the next generation, thus they are the symbol of regeneration and perseverance (Artina, 2023). Due to the importance of salmon to BC's culture, ecology, and economy, it is critical to investigate how riparian buffer zones can be maintained, or restored to accommodate salmon, given the accelerating land-use changes, urban and agriculture contamination, as well as climate change unpredictability.

Riparian Indicators and Design

While studies support the positive role of riparian buffer zones in pollutant and sediment control, there is a need for investigations of riparian buffer zone indicators and how they would benefit salmon habitats. This research provides information on ideal riparian characteristics to specific streams, to understand if the riparian habitats in the selected areas provide a high stream quality for salmon to carry out their lifecycle, as land use surrounding the streams and the riparian areas have a large impact on the stream quality (Fullerton et al., 2006). Hence, the type of land use surrounding the stream is an indicator of the quality of the stream. Research has determined that the width of riparian buffers greatly impacts multiple stream factors (Fullerton et al., 2006). There are additional riparian buffer factors that impact riparian efficacy, these include slope, soil quality and the types, quantity and structure of vegetation (Haberstock et al., 2000). As the vegetation can be easily impacted by nearby land use and the riparian buffers (Haberstock et al., 2000). Having poor riparian vegetation along streams can impact functions within the streams (Fullerton et al., 2006). The type of vegetation and density can impact shade and in turn, the temperature of the stream itself. Nutrient levels, invertebrate diversity and drift are also heavily tied to tree and vegetation cover and quality (Erős et al., 2012).

To avoid permanent jeopardy to ecological resilience, information on how to evaluate a riparian buffer system's well-being is crucial. The purpose of this study was to understand how different indicators of riparian buffer zones can influence their functionality and capacity to perform ecological services. Because riparian systems in British Columbia are distributed across various land uses, site-specific management guidance is also considered, as management and regulations can not be uniform across agricultural, industrial, and forested landscapes as geographical context and the extent of degradation is distinct.

Objective

The goal of this project was to understand how different indicators influence riparian buffer systems' efficacy, along with land use changes and alterations to the freshwater habitats for cold-temperature salmonid species. Under the stresses of climate change and land use changes, riparian buffer zones that demonstrate significant promise in maintaining water quality and achieving restoration goals are increasingly significant in sustaining salmonid species. The three objectives of this research were to:

1. Understand factors that influence riparian systems' functionality and efficacy,
2. Compare these factors with existing monitoring and management framework for riparian habitats within the forested ecosystem where most salmon-bearing streams occur,and
3. Provide recommendations to improve existing regulations and management to further support riparian restoration and salmonid populations

Methods

A review of existing general and specific literature on the design of riparian buffer zones was conducted on the Atlantic salmon to compare approaches that might aid in assessment for the potential of maintaining salmon habitats in British Columbia and the Pacific Northwest. Riparian buffer systems were studied using literature, government websites, and existing case studies on the salmon population and riparian management. The search term "riparian", was paired with the term "salmon" in the initial UBC library and Google Scholar search engine. Further filtering process involved adding the term "habitat" with "salmon" while keeping the term "riparian". Particular knowledge on salmon habitats and riparian was referenced from field experts who

focused their lenses in the British Columbia context, particularly Dr. Scott Hinch and Dr. John Richardson (UBC Forestry 2023, UBC Forestry 2023a). To achieve the objectives mentioned above, the research will provides an analysis on riparian systems through the following steps:

- Investigate previous case study on Atlantic salmon habitat protection as part of the Atlantic Salmon Conservation Plan for Seven Maine River,
- Understand existing monitoring framework to manage riparian habitats, in Olympic Experimental State Forest of Washington, and British Columbia,
- Compare and contrast riparian management plans for the two different locations, and
- Discuss the results based on available findings to inform riparian buffer zone potential and provide recommendations to improve existing policies on riparian buffers

Results

Atlantic Salmon Conservation Plan for Seven Maine River

The Atlantic Salmon Conservation Plan was the result of an executive order from the State of Maine, USA. Governor King's appointment in 1995. The mission was to prepare a conservation plan for the protection and recovery of the Atlantic Salmon population across seven rivers in Maine. The seven rivers include the Dennys, Machias, East Machias, Narraguagus, and Pleasant Rivers in Washington and Hancock Counties and the Ducktrap and Sheepscot Rivers in Lincoln, Kennebec, Sagadahoc, Knox, and Waldo Counties (The Maine Atlantic Salmon Task Force,1997). The single legislature granted the State Government the authority to manage Atlantic salmon in both saltwater and freshwater environments. For the purpose of this research, the analysis focused on the freshwater habitats for salmonid species.

Salmon Vulnerability and Overall Threats

According to the State Government documents (1997), salmon are of particular interest by the Government as they provide irreplaceable cultural and ecological values. Their lifecycle makes them intricately connected with the freshwater ecosystem: they begin as juvenile hatchlings in freshwater streams, migrate from rivers and streams to the oceanic environments and return as adults 1-3 years later as adults to spawn (The Maine Atlantic Salmon Task Force,1997). Salmon are sensitive to various environmental factors, such as hydrology, seasonal water temperatures, pH, dissolved oxygen, as well as streambed characteristics. Food availability, competition and human

disturbances also influence salmon survival (The Maine Atlantic Salmon Task Force,1997). A well-maintained salmon population is not only the result of a healthy riparian system but they play an integral role in the ecosystem. Atlantic salmon, in particular ,provide nitrogen to riparian vegetation and the decomposition of their carcasses transfers nutrients to the soil (Drake&Naiman,2007).

Ideally, salmon generally requirs cool, well-oxygenated water beds with coarse gravel beds and suitable water depths (The Maine Atlantic Salmon Task Force,1997). Salmonid species are threatened by an array of human activities, both directly and indirectly. Illegal harvesting results in a decrease in the salmon population, while urbanization and agricultural activities introduce a wide range of chemicals that may pollute and become lethal to salmon in freshwater habitats (Coelho et al.,2014), through solid waste management practices, accidental spills and direct discharges, chemicals such as petroleum products, pesticides and heavy metals (The Maine Atlantic Salmon Task Force,1997). To minimize the detrimental effects of anthropogenic activities, the State Government proposed actions to address current threats and enhance salmon protection. These actions were based on the different types of land uses practices: a) agriculture, b) forestry, c) aquaculture and d) other types of land use. The following section will focus agriculture and forestry practices.

A. Agriculture

Prior to the salmon conservation planning initiative, a comprehensive list of agricultural activities across the seven watersheds were identified (Table 1). These agricultural activities and production systems included diary farming, hay, silage corn, horse farming, sheep farming, blueberries, cranberries, landscape and horticultural plants, and peat mining (The Maine Atlantic Salmon Task Force,1997). Major agricultural activities were grouped into three categories:

1. crop and animal production: cultivation, manure and water use,
2. harvest and transport: road construction and maintenance, storage, harvest energy, and
3. processing and management: pest management, waste recycling, process water use, treatment and discharges.

Table 1. Potential threats to Atlantic salmon habitat quantity and quality related to agricultural activities across 7 watersheds.

Source: The Maine Atlantic Salmon Task Force,1997

WATERSHED: PLEASANT RIVER, NARRAGUAGUS RIVER, MACHIAS RIVER, SHEEPSCOT RIVER, EAST MACHIAS RIVER, DENNYS RIVER, DUCKTRAP RIVER		
AGRICULTURAL ACTIVITY	**FACTOR POSING A POTENTIAL THREAT TO HABITAT**	**ISSUE PRIORITY**
Water Use	Irrigation	Low to Moderate
	Cranberry culture	Low
	Land application of processed water	Low
	Process water, Volume, Temperature	Low
Agricultural Practices	Pesticide use (blueberry, cranberry)	Moderate
	Nutrients and sediments	Low to High
	Wetland alteration	Low
	Oil, fuel, and contaminants	Low
	Livestock management	High
	Manure/sludge management	High
Peat Mining	Proposed mine	Moderate

Agricultural activities are associated with an array of concerns for salmon habitats. The adverse effects of direct water withdrawal from salmon-running rivers contributes to bank instability and salmon inaccessibility (Mills,1972). Hydrological influences of surface water withdrawal for irrigation impact in several ways: alter spring and fall runoff, reduce total annual and seasonal peak flows, transport water across watersheds, and reduce summer flows (The Maine Atlantic Salmon Task Force,1997). The reduction of summer base and peak flows may further influence the water quality by reducing habitat areas, changing the quality of the legacy habitats, reducing aeration and the levels of dissolved oxygen, promoting algae growth on substrates, and increasing temperatures (The Maine Atlantic Salmon Task Force,1997).

In Maine, the annual flow among all the rivers was sufficient to conclude that agricultural-related issues are not the result of the water-shortage problem, but challenges regarding water management (The Maine Atlantic Salmon Task Force,1997). A common issue related to agriculture is the use of pesticides in crop production. Pesticides include chemicals that aim to control biological organisms, such as insects [insecticides], primary producers [herbicides], and fungi [fungicides] (Macneale et al.,2010). As non-point source pollution, agricultural and urban runoff containing pesticide toxins are transported to salmon habitats (Macneale et al.,2010). Figure 1. shows that the measured concentrations of toxins at Atlantic salmon habitats are already exceeding the threshold to kill 50% of the test salmon.

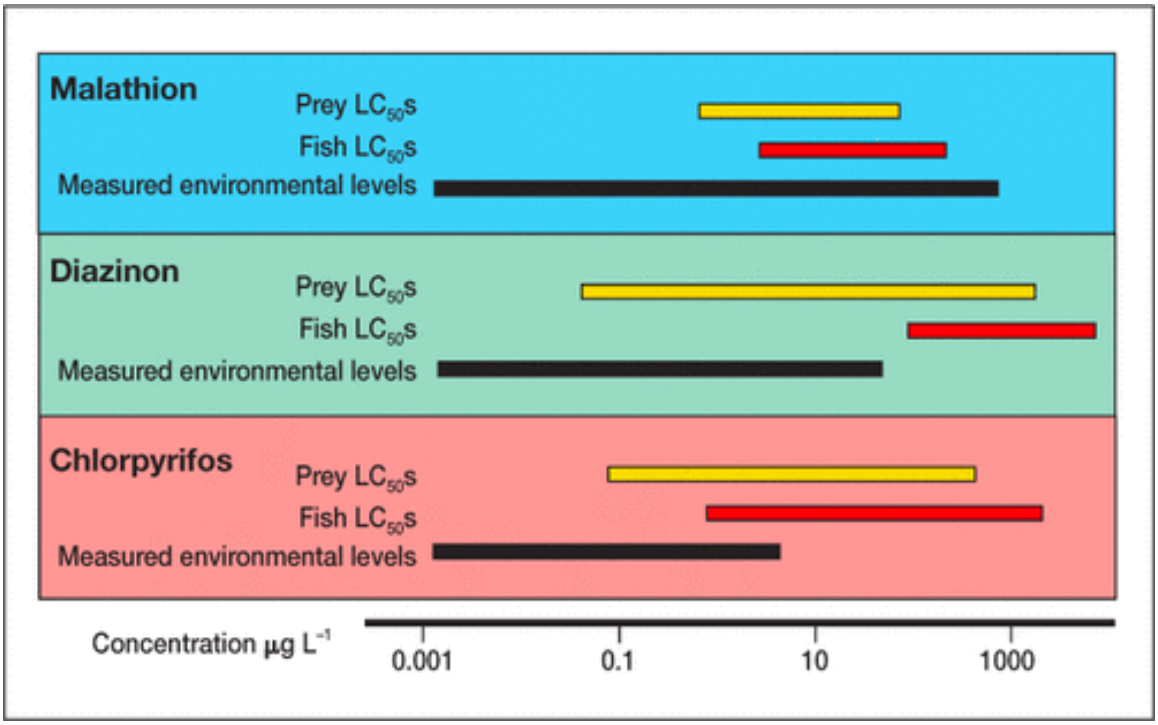

Figure 1. Environmental concentrations of three insecticides (malathion, diazinon, and chlorpyrifos) measured in Pacific salmon habitats and range of concentrations that have been found to kill 50% of tested salmon and prey species after ≤4-day exposures (ie LC50s; US EPA Ecotox Database, http://cfpub.epa.gov/ecotox/).

With existing programs that minimize the negative effects of agricultural runoff, the working group proposed further actions to complete salmon conservation and protection. Some identified current actions to reduce threats are:

- Integrated Crop Management (ICM) and Best Management Practices (BMPs) for blueberry and cranberry production with the leadership of Maine Cooperative Extension, program.

- The Non-point Source (NPS) program and the Coastal Zone Management (CZM) program with BMPs to protect water quality.
- Generic State Management Plan for Pesticides and Ground Water and the Hexazinone State Management Plan for Protection of Ground Water.
- Soil and Water Conservation Districts' technical assistance to farmers with BMPs to reduce NPS pollution.
- Collaboration among the Department of Environmental Protection, the Land Use Regulation Commission, and Worcester Peat Co., the owner of the Denbo Heath Peat Mine (The Maine Atlantic Salmon Task Force,1997).

To ensure protection for salmon habitats, the working group suggests implementing Total Water Use Management Plans for each watershed to meet the needs of both agricultural production and Atlantic salmon. The site-specific non-point source program is also proposed for Sheepscot River, the watershed most vulnerable to agricultural practices. Furthermore, Board of Pesticide Control programs should be enhanced along with knowledge of wetlands functions that are important for maintaining the integrity of Atlantic salmon habitat (The Maine Atlantic Salmon Task Force,1997).

B. Forestry

Forestry practices readily influence small streams, where most salmonid habitats are distributed. According to Murphy (1995), although salmonids occupy streams ranging from first order, salmon spawning and rearing mostly take place in second to fourth-order streams. Small streams affect downstream habitat quality as they are responsible for the transport of water, sediments, nutrients, and woody debris from the upper watershed (Murphy, 1995).

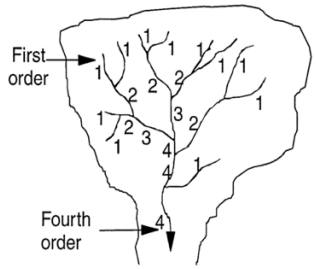

Figure 2. Diagram of a watershed's drainage network, showing stream orders according to the Strahler classification system. First-order streams are headwater streams without tributaries; second-order streams are formed by the

confluence of two first-order streams; third-order streams are formed by the confluence of two second-order streams; and so on.

Forestry practices are crucial considerations for salmon conservation. Timber activities throughout the entire watershed may influence salmonids by altering watershed processes and structures (Murphy, 1995). Temperature increase and fine sediments are the most associated issues with logging activities. The removal of the vegetative canopy can increase the temperature by up to 10 degrees (Beschta et al.,1987). The temperature increase is directly proportional to the area that is exposed to sunlight, thus the smallest streams would be the most influenced. Similarly, soil compaction, as a result of logging machinery also increases the risk of erosion. Erosion increases when disturbed, compacted soils are exposed to rainfall (Murphy, 1995). Road surfaces, landings, and disturbed clear-cut areas are all likely to introduce fine sediments to streams (Murphy, 1995). Landslides associated with roads is 300 times more frequent than in a forest with minimum disturbance and the sediment quantities produced far exceed the sediments from forests (Furniss et al.,1991). While coarse gravels and cobbles can help to shape channel morphology, fine sediments reduce substrate permeability for salmon embryos, decreases available cover by filling interstitial spaces, and can even trigger stream bank slope failures as the soil is saturated (Murphy, 1995).

To minimize the detrimental effects, the Governor's Atlantic Salmon Task Force outlined a list of actions to reduce the threats to Atlantic salmon from forestry-related activities and promote salmon recovery (The Maine Atlantic Salmon Task Force,1997). Research recognizes the critical importance of riparian buffer strips with functional vegetation and the need to separate intensive land use from complex natural systems to sustain larger ecosystems and maintain water quality (The Maine Atlantic Salmon Task Force,1997).

1. **Assessment of Forest Cover and Hydrology Dynamics in Watersheds**

   This is the necessary first step to identify the baseline of the watershed and monitor potential abnormal flow, and using remote sensing technologies and modeling hydrology dynamics has proven to be a reliable technique. Using models and existing data from the USDA Forest Service Decennial Forest Inventory and Assessment(1972-1984),managers can predict the potential impacts of harvest on local watersheds. And the watershed flow

dynamics can be observed over a timeframe. For instance, existing data can recorded the timber harvest operations from 1990 to 1994 and computer modeling and remote sensing technologies were helpful for refining the knowledge gaps, but Forest Service experts must still collaborate closely with local landowners and acquire permission.

2. Complete Habitat Mapping and Assessment

The Atlantic authority can complete the mapping on its own. The Maine Department of Inland Fisheries works cooperatively with local landowners to develop salmon habitat protection agreements. Open waters that either provide food or refuge to Atlantic Salmon are evaluated by regulatory agencies, and areas that are classified as significant to Atlantic salmon are recommended to be rezoned to Fish and Wildlife Protection Subdistricts.

3. Voluntary Management of Road Impacts and Enforce Existing Regulation

Cooperating with landowners, resource managers and state agencies can help to update the Best Management Practices (BMP). Local compliance and individual initiatives promoted by educational programs can effectively protect salmon-bearing streams from non-point source pollution. Project SHARE, as an organization, can work with the government, river groups and landowners to manage future access to the rivers. The combined efforts of State agencies and private groups are the key for responsible angling and eliminating illegal fishing.

4. Support Riparian Harvesting Restrictions and Enhance Headwater Protection

Timber harvest activities should be monitored by regulatory agencies and there by increasing enforcement with a strict compliance standard as the best approach to maintaining stream temperature and conserving salmon habitats. Project SHARE should continue education, particularly to local contractors and manage salmonids' sensitivity to shading and the importance of canopy. It is ideal to promote the use of streamside BMP in Atlantic salmon watersheds.

5. Enhance Atlantic Salmon Habitat

The initial activity is to ensure continued support of project SHARE along with local river groups to remove large woody debris that causes blockages for salmon migration. This step should take place after consulting a fishery biologist, since not all woody debris adversely influences salmon. Some trapped logs provide holding pools for juvenile salmon and some may provide organic carbon as energy source for aquatic species. A system approach to assess whether a log is beneficial to the salmon habitat can increase spawning and nursery habitats availability.

6. Comprehensive Management of Forest Chemicals

The forestry industry supports precautionary actions to prevent water quality degradation from pesticide use, acute or chronic effects on Atlantic salmon and habitat changes. The Board of Pesticide Control work closely with the government and experts to update BMPs based on the latest research. Meanwhile, the geographic usage of pesticide should be reviewed and critical regions should be targeted as priorities.

Riparian Habitat in the Olympic Experimental State Forest, Washington State

The Washington State Department of Natural Resources has presented a monitoring protocol for assessing the status of riparian and aquatic habitats in the Olympic Experimental State Forest (OESF). The purpose of this document was to outline the field procedures for sampling riparian and aquatic habitats indicators, quality assurance and control steps, as well as data management procedures for documentation and reporting of trends (Devine et al.,2022). The procedures described in the government document help to record progress toward reaching the conservation objectives of the State Trust Land Conservation Plan (HCP).

The Study Site:

A long-term study was conducted to monitor riparian management through riparian and stream conditions within the OESF – 270,000 acres (110,000 ha) of State trust lands managed by the Washington State Department of Natural Resources. The area has precipitation ranging from 203 to 355 cm, with the majority falling during the winter. Numerous small streams and headwaters are concentrated within a tight network of streams and rivers exceeding 4000 km in length (Devine

et al.,2022). Riparian buffer areas in the OESF provide habitats for nine native anadromous salmonid species: sockeye salmon (*Oncorhynchus nerka*), pink salmon (*O. gorbuscha*), chum salmon (*O. keta*), Chinook salmon (*O. tshawytscha*), coho salmon (*O. kisutch*), steelhead trout (O. mykiss), coastal cutthroat trout (*O. clarkii clarkii*), bull trout (*Salvelinus confluentus*), and mountain whitefish *(Prosopium williamsoni*).

Key indicators are monitored at 50 representative study sites in the OESF. In addition, four ecologically similar watersheds in the adjacent Olympic National Park (ONP) were selected as reference sites. The purpose of the reference sites is to understand riparian habitat complexity without management and consider natural variation (Devine et al.,2022). The monitoring protocols follow nine habitat attributes: **stream temperature, channel morphology, shading, channel substrate, instream Large Woody Debris(LWD), habitat valley and channel classification, stream discharge, riparian microclimate, and riparian vegetation.** The conditions of riparian habitats are monitored at the most downstream section. This is because the transmission of land use disturbances from headwaters through the drainage network results in a downstream section that is most representative of the changes throughout the entire watershed (Devine et al.,2022). The monitoring process is expected to last at least 10 years, thus it is to criticaly clarify quality assurance and quality control procedures to ensure consistency.

Indicator 1: Channel Morphology

The protocols to measure stream temperature are adapted from Stream Channel Reference Sites (Harrelson et al. 1994). The manual is widely accepted in the Pacific Northwest due to its detailed and well-described procedures. Channel morphology ,such as shade, dimension and slope provide critical information about watershed-level ecological processes. Channel morphology is a fundamental narrative for the distribution and abundance for aquatic species. By regulating water flow and stream capacity, channel morphology influences sediment storage and organic matter availability (Bisson et al.,2017; Minkova & Foster, 2017). Geomorphological attributes, such as channel width, confinement and gradients are particularly important for managing and conserving fish habitats (Minkova & Foster, 2017).

Channel morphology information is further employed in environmental impact assessment modeling. For instance, stream gradients are used for understanding stream

reaches and the assignment of reach-scale sensitivity, and channel width are similarly used in the stream model and the microclimate model. Channel morphology measurement begins with bank-full width, which is defined as the horizontal distance between each side of the stream, followed by the bank-full depth while taking account of special circumstances such as the side channel and undercuts (Minkova & Foster, 2017). Furthermore, the percentage of active erosion along with channel confinement are also measured as quantifiable data. It is recommended to take an Azimuth survey and measurement of the channel sinuosity during field procedures (Minkova & Foster, 2017).

Indicator 2: Stream Shade

The OESF Forest Land Plan recognizes stream shade as a major indicator for fish habitats quality, riparian areas and water quality (Martens et al.,2016;Ricklefs et al.,2022) Stream shade is the extent that the stream channel is exposed to sunlight. As mentioned earlier, Stream shade is one of the most important factors in affecting stream temperature (Ricklefs et al.,2022). Stream temperature furthermore influences aquatic organisms as all species have a range within which they can survive. Salmonids, for example, can spawn when the water temperature is between 1-20°C, with stronger performance between 4-17°C (Murphy, 1995). Stream shade can also dictate stream structure such as organic substrate, algae biomass and primary production (Naiman & Decamps, 1997). Empirical stream shade data is not always available and measurable. Fortunately, riparian vegetation inventory data can help to model and project sun paths over streams (Ricklefs et al.,2022).

Indicator 3: Channel Substrate

Channel substrate measures the content of organic and mineral materials that form the stream bottom bed (Horton et al.,2022). The substrate composition determines channel stream roughness, channel hydraulics, including water velocity and thus habitat quality. When salmon begin their migration back to the ocean, they desire streams with adequate flow (Murphy, 1995). Channel substrates provide necessary conditions for other stages of salmonids. For instance, some substrates are favorable during spawning because they adhere to salmon eggs (Horton et al.,2022). Larger substrates can provide ideal living space for macroinvertebrates as food sources for salmon (Mellina & Hinch, 2009). Substrate

composition, stability and embeddedness are also useful indicators of management impact on sediments and hydrologic regimes (Horton et al.,2022). Substrate particles are classified into different types according to their size and their relevant percentages reflect on the sediment delivery that influences salmon habitats. When sediment delivery data is not available, road surfaces and traffic proximity to streams are used to project the level of traffic influences (Horton et al.,2022).

Indicator 4: Instream Large Woody Debris(LWD)

In-stream Large Woody Debris (LWD) refers to pieces of logs, root wads, and a large chunk of wood that are present in the stream channels. LWD plays various roles in stream regulation: trapping and retaining sediment, changing water velocity, diverting streamflow and changing channel gradients (Foster et al.,2022). The condition of LWD also suggests the historical and cumulative recruitment rate over time (Schuett-Hames et al.,1999).

The type and magnitude of ecological functions of LWD depends on the size, species, location, and particular distribution of the pieces. LWD functionality is affected by channel gradient and size. For example, woody debris was once regarded as detrimental to salmon survival as large pieces of wood may impede the migration process. However, later evidence suggests that woody debris can also provide habitats and cover for many aquatic species (Devine et al., 2022). LWD input varies throughout the year, it is recommended that sampling of LWD take place during summer or early fall, when streamflow is typically moderately and the discharge rate is stable (Foster et al.,2022).

Indicator 5: Habitat Units and Valley and Channel Classification

The classification of stream valleys, channels, and habitat units forms the basis for comprehending channel morphology, assessing channel conditions, characterizing the microhabitat of fish and other aquatic organisms, and gaining insights into the response of streams to natural and anthropogenic influences (Minkova& Foster, 2017).

The knowledge of stream response to disturbance relies on resilient systems and procedures for stream classification and assessment. These frameworks facilitate the creation of accurate and replicable reach descriptions, while providing valuable

information on the processes that govern channel structure (Bisson et al.,2017). Valley segments are classified into alluvial, bedrock and colluvial valleys based on sediment types, length of the sample reach, and segment types. The hierarchy classification system also enables comparisons and extrapolation of results to other ecologically similar sites during management (Minkova& Foster, 2017).

Indicator 6: Stream Temperature

Stream temperature influences the survival of aquatic species, as all life forms have a tolerance threshold. As discussed in the previous section, increasing water temperature stresses cold-water salmonids and results in eggs or individual mortality (Foster et al.,2022). Federaly recognized as endangered species, such as trout and salmon, also list temperature as a limiting factor. Warmer water temperature can affect embryonic development, juvenile growth, migration, and susceptibility to diseases (Sullivan et al.,2000).

Water temperature is the product of multiple energy transfer processes. Solar radiation and long-wave input, air convection, stream bed conduction, groundwater flux, hyporheic flux, evaporation, and condensation all contribute to stream temperature. Solar radiation, in particular, is the primary influencer of daily maximum temperature. The input of solar radiation is directly related to riparian canopy removal as a result of logging, wildfires and windthrow (Poole & Berman, 2001). Comprehensive stream temperature is not only a measure of daily maximum temperature, but inclusion of other metrics such as daily and weekly temperature mean and deviation, range of annual temperature, as well as the correlation of air and water temperature when stream water temperature(Foster et al.,2022).

Indicator 7: Stream Discharge

Stream discharge, also known as stream flow, refers to the amount of water that passes through a specific point within a set timeframe. The quantity and timing of stream flow play essential roles in water supply, water quality, and the overall ecological integrity of river systems (LeRoy et al.,1997). Salmon habitat conditions are significantly influenced by stream discharge as it directly influences channel morphology, the concentration of chemicals, dissolved oxygen levels, and the distribution of LWD

(LovellFord et al., 2022). The life patterns of many aquatic species including salmonids are dependent on-stream discharge conditions: adult salmon migration and juvenile salmonids growth. Stream discharge reflects climatic factors and land use practices. For instance, timber harvest increases the fraction of precipitation as available streamflow and thus increase peak flows in headwater catchment (LovellFord et al., 2022). In the Western Oregon Cascades, increased timber harvest is associated with 50% peak discharge increase in small basins and 100% increase peak discharge in large basins (Jones & Grant, 1996). Stream discharges are also influenced by other land use changes such as urbanization (Horwitzet al.,2008). Stream discharge data should be measured year round on a monthly basis, and more records can ensure the establishment of an accurate rating curve for riparian management (LovellFord et al., 2022).

Indicator 8: Riparian Microclimate

Given that the goal of OSEF is to promote suitable habitats for salmonids and other fish taxa in the local region, the consideration for climatic factors should be included during the monitoring process. Preservation of riparian microclimate factors such as moisture, temperature, light, wind speeds, all affect how aquatic species are adapted to the environmental conditions and stream geomorphology (Bigley et al.,2022). Stream microclimates are influenced by adjacent land uses, yet scientists assume that riparian buffers have the capacity to ameliorate the negative consequences of land use changes. Riparian microclimate significantly contributes to mitigating environmental fluctuations and maintaining stable in-stream temperatures, while providing a habitat for wildlife closely associated with riparian zones. Microclimatic variables must be understood and monitored as they are the backbone of high productivity, complex habitat structure, moisture rich conditions and high biodiversity natures of riparian systems (Olson et al.,2007).

Indicator 9: Riparian Vegetation

The observation of riparian vegetation serves as an irreplaceable indicator in understanding the overall riparian system condition. The dynamics of forest structure, including competition, decay, and disturbance, are vital for assessing the influence of

riparian forests on stream temperature, near-stream microclimate, and inputs such as litter, sediment, and woody debris that impact stream habitat. Consequently, the recovery of aquatic communities and their resilience following disturbances is closely tied to the successional process driven by the regeneration of riparian vegetation (Devine et al., 2022).

Effective riparian management practices are essential for protecting riparian areas from the impacts of timber harvesting, with their capacity to maintain water quality, biodiversity, and ecosystem functions dependent on the preservation of near-stream vegetation. However, the effectiveness of different management approaches can vary significantly. In the Olympic Experimental State Forest (OESF), riparian areas have undergone clear-cutting up to the stream edge, resulting in a vegetation composition that consists of a mix of natural regeneration and plantation establishment. Meanwhile, dense riparian vegetation canopy without thinning may also affect salmon stocks negatively (McCormick & Harrison, 2011). Monitoring changes in vegetation structure is crucial for interpreting the recovery of watersheds from past disturbances and assessing the overall success of restoration efforts. It is recommended that sampled trees be measured at the Diameter at Breast Height (DBH). More importantly, understory plantations that influence soil structure and stability should be recorded(Devine et al.,2022).

BC Riparian Buffer Zone Management: Forested Ecosystem

The synthesis from this section was produced from Tschaplinski and Pike's Publication, as it offers a comprehensive review and the historical development of riparian forest management in British Columbia. This publication is used as a case study to exemplify riparian habitats management strategies in forested ecosystems, which are crucial for freshwater salmon habitats. Although the BC provincial government presented general guidelines for Riparian Areas protection, the focus on forested ecosystem through Forest the Forest Practices Code and the Forest and Range Practices Act which aims to target the well-being of riparian systems through vegetation management is worth investigating. The justification for this approach is based on the intention to delve deeply into the specific regulations governing forested riparian habitats, acknowledging that the BC Riparian Areas Protection Act/Regulation may indeed offer complementary measures. Like many other Pacific Northwest jurisdictions, BC also uses fish conservation as a principal foundation for riparian management (Tschaplinski & Pike,2011). Water for domestic use is another most common

objective for riparian management. The framework of BC's riparian management extends beyond conserving fish or tree species. The Forest Practice Code (FPC) was implemented to achieve the following objectives:

1. Minimize impacts of forest and range uses on stream-channel dynamics, aquatic ecosystems, and water quality of water bodies.
2. Prevent impacts of forest and range use on wildlife habitat diversity, productivity, and sustainability in riparian areas.
3. Allow for forest and range use that aligns with the objectives of preserving stream channel dynamics, aquatic ecosystems, water quality, and wildlife habitat.

These principles align with the Forest Planning and Practices Regulations (FPPR) for water, fish, wildlife and biodiversity within riparian management. It is believed that riparian management will achieve these objectives, while not compromising timber supply in British Columbia (Tschaplinski & Pike,2011).

Since 1995, the province of British Columbia has defined the Riparian Management Area (RMA) as the principal management unit. The RMA zone consists of a riparian management zone (RMZ) and a non-harvest riparian reserve zone located adjacent to the waterbody. The widths of these zones vary by stream attributes and adjacent land uses (Tschaplinski & Pike,2011). Streams are classified from S1 to S6 based on fish abundance, average channel width and status within the community watershed (Table 2). The government guidebook recommends classifying streams, wetlands and lakes prior to riparian management.

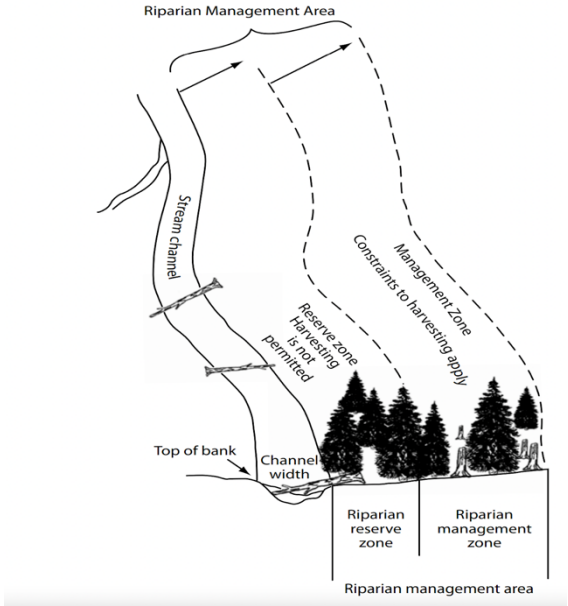

Figure 3. Riparian management area for streams showing a management zone and a reserve zone along the stream channel (B.C. Ministry of Forests and B.C. Ministry of Environment 1995a)

Table 2. Riparian management area classification standards for streams. This classification framework developed for the FPC has been retained under the FRPA.

Riparian class	Average channel width (m)	Reserve zone width (m)	Management zone width (m)	Total width of RMA (m)	Retention in RMZ (%)[a]
S1-large (FPC) = S1-A (FRPA)	> 100 (for > 1 km of stream length)	0	100	100	≤ 70[b]
S1 (FPC) = S1-B (FRPA)	> 20	50	20	70	50
S2	> 5 to ≤ 20	30	20	50	50
S3	1.5 to ≤ 5	20	20	40	50
S4	< 1.5	0	30	30	25
S5[c]	> 3	0	30	30	25
S6[c]	≤ 3	0	20	20	5

a Recommended in the *Riparian Management Area Guidebook* for FPC only as maximum and averaged over large operating areas, not specific to each cutblock (B.C. Ministry of Forests and B.C. Ministry of Environment 1995a).
b Softwood retention = 50% within 20 m of island perimeters and channel banks (see Table 6, B.C. Ministry of Forests and B.C. Ministry of Environment 1995a). Hardwood retention as per active floodplains = 70% (see Table 6, B.C. Ministry of Forests and B.C. Ministry of Environment 1995a).
c Non-fish-bearing streams.

Since the beginning of 1990s, ecosystem-based approaches to riparian management have been recommended and encouraged (Richardson et al.,2005). As a response, two legislative

management schemes emerged: *Forest Practices Code of British Columbia Act* and its successor, the current *Forest and Range Practices Act*(Tschaplinski & Pike,2011). In addition, the Forest Stewardship Council developed a riparian management framework .

I. Forest Practice Codes(FPC)

The prescriptive approach of the FPC establishes minimum widths for riparian management areas, reserve zones, and management zones based on riparian classification. Widths vary depending on channel width, stream gradient, watershed use, and fish presence. The goal is to minimize sediment and woody debris input, protect various riparian values such as wildlife, biodiversity, habitat integrity, and water quality across diverse environments. These schemes are easy to implement and administer, assumed to protect aquatic resources.

Realistically, the FPC approach for riparian management combines rules and results-based elements. Prescribed minimum widths for riparian reserves and management zones served as proxies for desired outcomes due to unknown thresholds for responses to management activities. Regulations such as the Timber Harvesting Practice Regulations are in place to govern activities, aiming to preserve reserve integrity and protect channels and aquatic habitats.

The FPC scheme enabled flexibility in riparian retention and management practices for water bodies without mandatory reserves. Forest licensees had discretion to achieve riparian management objectives within the designated zone. This included streams inhabited by small fish (class S4) and those without fish (classes S5 and S6). Management practices followed objectives outlined in the Riparian Management Area Guidebook, including recommendations for best practices.

The FPC established riparian reserve and management zones to protect streams, lakes, and wetlands of different types and sizes during and after forestry operations. Moreover, the standards aimed to balance riparian tree retention for environmental protection with economic and social values related to timber access. Mandatory, no-harvest riparian reserves were implemented for fish-bearing streams within specific size ranges, while smaller fish-bearing streams, streams without fish, and large rivers did not have legally required reserves. The decision allowed flexibility in managing the diverse population of small streams, while very large rivers were deemed to have minimal ecological and hydrological dependence on riparian areas.

Criticism

The FRC management approach faced two main criticisms. Firstly, concerns regarding the use of timber supply impacts in determining environmental protection standards, including riparian reserves and recommended levels of tree retention. Secondly, critics highlighted the absence of mandatory riparian reserves for small fish-bearing streams and their non-fish-bearing tributaries. Critiques supported more conservative approaches, such as mandatory reserves for certain stream classes.

Best Management Practices corresponding to the FRC do not always result in positive riparian changes. The Stuart–Takla Fisheries–Forestry Interaction Project found that stream temperatures remained four to six degrees warmer even after five years following the completion of the treatments, and diurnal temperature variation were higher than in the control streams regardless of treatment (Macdonald et al.,2013).

Despite criticisms and limitations of the FPC's riparian management standards, the Forest Practices Board concluded that the FPC had significantly improved the protection and maintenance of riparian and stream values compared to pre-FPC conditions, especially for larger fish-bearing streams with no-harvest riparian reserves. Any issues identified were mainly related to small streams being missed or misclassified, leading to improvements in stream identification and classification. Surveys in the central Interior Plateau confirmed that classified S4 streams were generally managed according to FPC standards and achieving objectives outlined in the Riparian Management Area Guidebook. The study found a low level of short-term impacts on stream channels, partly due to higher levels of riparian tree retention (49%) compared to the guidebook's recommended maximum (25% basal area). Full-retention reserves or similar high-retention riparian treatments were commonly implemented.

II. Forest and Range Practices Act

The Forest and Range Practices Act (FRPA) and its regulations took effect on Jan. 31, 2004. It replaced the FRC of British Columbia Act and regulations.

As a results-based approach, FRPA provides greater adaptability in riparian management by considering watershed-scale information and integrated riparian assessments. This approach recognizes the connections between small headwater streams and larger valley-bottom channels, allowing for more ecologically relevant and efficient management compared to rigid prescriptive

regimes. Under the current Forest and Range Practices Act (FRPA), there are two options for riparian management:

1) the default prescriptive approach similar to the Forest Practices Code (FPC), and

2) an alternative approach outlined in a government-approved forest stewardship plan that demonstrates adherence to government objectives for riparian areas.

The first option retains the riparian classification systems from the Forest Practices Code (FPC) and incorporates a mix of rules-based and results-based elements in riparian management zones. Specific tree retention requirements are not regulated, but guidance can be found in the Riparian Management Area Guidebook. The second option allows for flexibility in management. Licensees can deviate from the prescriptive defaults by including results or strategies in a forest stewardship plan that aligns with government objectives for water, fish, wildlife, and biodiversity in riparian areas. The plan must address tree retention in riparian management areas. This approach enables licensees to choose the default prescriptive method or implement alternative riparian management strategies based on their expertise, resources, and willingness to meet the requirements of the results-based regime.

No explicit guidance is provided in the Act for licensees regarding alternative riparian management approaches. The regime envisions that these approaches are implemented by the proponent, based on existing knowledge and information collected at the watershed level. The goal is to have rational and informed riparian retention schemes that integrate hillslope-stream channel linkages and stand-level requirements. This information serves as non-legal background information for licensees' planning process, rather than being included in a forest stewardship plan.

Additional considerations are required regardless of the selected riparian management option. For instance, Licensees are obligated to provide results or strategies to comply with requirements in government-designated, fisheries-bearing watersheds. The aim is to prevent significant negative impacts on fish habitat resulting from the cumulative hydrological effects of primary forest activities. Similarly, Licensees must adhere to water quality objectives in community watersheds and avoid activities in coastal areas that could destabilize alluvial fans. These requirements are outlined in the Forest Planning and Practices Regulation and serve to ensure the protection of sensitive ecosystems and the maintenance of water quality in designated areas.

The Forest and Range Practices Act (FRPA) relies on "professional reliance" to achieve desired management outcomes. Qualified specialists, including geomorphologists, hydrologists, foresters, biologists, assess and plan activities. Riparian management areas and reserve zones are flexible and tailored to local watershed characteristics, ensuring riparian function is maintained. This approach aligns with environmental certification schemes. Post-harvest evaluations are conducted by both licensees and the government for adaptive management.

Advantages of the comprehensive watershed-based approach include ecologically sound riparian protection, licensee-driven planning, and consistency with environmental certification initiatives.

Riparian management assessments evaluate adjacent riparian areas by using 15 primary indicators that reveals their physical and biological characteristics. According to the protocol of riparian management, a list of questions used to determine the functioning conditions of a stream in British Columba (Table 3; Trip et al.,2009).

Table 3. Fifteen main assessment questions that correspond to the 15 indicators of stream riparian function as given in Table 15.13. These questions, ordered in a checklist, are answered "Yes" or "No" or "Not Applicable" (NA). Source: Trip et al.,2009)

Question 1.	Is the channel bed undisturbed?
Question 2.	Are the channel banks intact?
Question 3.	Are channel LWD processes intact?
Question 4	Is the channel morphology intact?
Question 5.	Are all aspects of the aquatic habitat sufficiently connected to allow for normal, unimpeded movements of fish, organic debris, and sediments?
Question 6.	Does the stream support a good diversity of fish cover attributes?
Question 7	Does the amount of moss present on the substrates indicate a stable and productive system?
Question 8.	Has the introduction of fine sediments been minimized?
Question 9.	Does the stream support a diversity of aquatic invertebrates?
Question 10.	Has the vegetation retained in the RMA been sufficiently protected from windthrow?
Question 11	Has the amount of bare erodible ground or soil compaction in the riparian area been minimized?
Question 12.	Has sufficient vegetation been retained to maintain an adequate root network or LWD supply?
Question 13.	Has sufficient vegetation been retained to provide shade and reduce bank microclimate change?
Question 14.	Have the number of disturbance-increaser plants, noxious weeds and/or invasive plant species present been limited to a satisfactory level?
Question 15.	Is the riparian vegetation within the first 10m from the edge of the stream generally characteristic of what the healthy unmanaged riparian plant community would normally be along the reach?

III. Forest Stewardship Council

The Forest Stewardship Council (FSC) has riparian standards for British Columbia that utilize both riparian reserves and high-retention riparian management zones. This approach is similar to the Forest and Range Practices Act (FRPA) in offering both prescriptive-like options and assessment-based alternatives. Both models include post-harvest effectiveness monitoring within an adaptive management framework. However, the FSC's alternative scheme explicitly requires comprehensive riparian assessments and a minimum riparian retention budget at the watershed or landscape level.

The FSC standards, by comparison, offers several benefits compared to the Forest Practices Code (FPC) and Forest and Range Practices Act (FRPA) standards, including:

- Reserves for a greater number of streams, including 30 m wide riparian reserve zones for all fish-bearing classes, including S4 streams and large rivers (S1a).
- Wider reserves and more classes requiring reserves for wetlands and lakes.
- Reserves that are narrower or equal in width to FPC/FRPA stream classes S1 and S2, but with increased tree retention of 65% by basal area in riparian management zones.
- Tree retention levels of 65% by basal area in the riparian management zones of all streams, except for classes S5b and S6b, with 30% retention in the management zones of all lakes and wetlands.
- Wider riparian management zones for certain streams, such as S1b, S2, and S5a, with higher basal area retention for fish-bearing streams.
- Narrower or equal-width management zones for non-fish-bearing streams, with basal area retention increased to 65% in domestic watersheds or within specific distances from fish-bearing streams.

The assessment-based alternative allocates riparian tree retention based on comprehensive watershed-level assessments that integrate hillslope-stream channel linkages and stand-level requirements. However, management freedom is limited by the need to maintain a minimum proportion of riparian area in an unharvested state. Implementing a watershed-based, flexible approach poses challenges due to complexity, data requirements, technical expertise, and costs. Identifying and defining riparian ecotypes and determining appropriate retention levels remain complex tasks. In addition, compliance, enforcement, and interpreting monitoring results within the natural range of variability create challenges. Coordinating activities among multiple licensees or tenures further add to the complexity of the system.

IV. Riparian Management Regulations

The BC Riparian Areas Protection Act/Regulation provides a comprehensive framework for protecting riparian areas in the province. The purpose of riparian system protection moves beyond fish conservation like the FPC or the FRPA by defining and interpreting key terms within this regulation.

Active Floodplain: Defined as an area supporting floodplain plant species adjacent to a stream susceptible to inundation or within a designated boundary.

Assessment Methods: Refers to standardized methods outlined in the Schedule.

Assessment Report: A report prepared by a qualified environmental professional, certifying the potential impact of a proposed development in a riparian assessment area.

Development: Encompasses various activities associated with residential, commercial, or industrial endeavors, including vegetation alteration, construction, and infrastructure development.

Fish: Includes salmonids, game fish, and regionally significant fish.

Floodplain Plant Species: Plants adapted to inundated or saturated soil conditions, distinct from upland species.

High Water Mark: The visible mark where water presence and action differentiate the stream's bed from its banks.

Natural Features, Functions, and Conditions: Encompass various elements such as organic debris, side channels, forests, and permeable surfaces that influence riparian health.

Permanent Structure: A building or structure lawfully constructed on a secure foundation.

Riparian Area: Defined as a streamside protection and enhancement area.

Riparian Assessment Area: Varies based on stream type, generally extending 30 meters from the high-water mark on both sides.

Stream: Includes various water bodies, even if they usually lack water.

Streamside Protection and Enhancement Area: Adjacent to streams, linking aquatic and terrestrial ecosystems.

Wetland: Land inundated or saturated with water supporting vegetation adapted to saturated soil conditions.

The regulation aims to protect riparian areas, ensuring they provide natural features, functions, and conditions supporting fish life processes. Additionally, it promotes intergovernmental cooperation and facilitates agreements with local governments to enforce and monitor riparian protection. The regulation applies to specific regional districts within British Columbia, excluding developments related to permanent structures on existing foundations. To proceed with development in riparian assessment areas, local governments must receive certification from qualified environmental professionals, confirming adherence to assessment methods and the absence of harmful impacts. Strategies for monitoring, enforcement, and education are also emphasized, with local governments responsible for their implementation. The regulation outlines the necessary components of assessment reports and includes transitional provisions for areas previously protected under the former Streamside Protection Regulation (Canlii, 2019).

Discussion

The Atlantic Salmon Conservation presents a pioneer salmon conservation case where riparian systems are monitored based on land use. The management is targeted towards saving salmon population by delineating a land use plan on the broader watershed scale. Agriculture and forestry activities both raise serious concerns for the well-being of salmon and risks for salmon habitats. In the case of Maine, other land use practices such as aquaculture and recreational fishing activities are also problematic. Actions targeting recreational activities and fishing, however, were not as explicit as the management of agricultural and forestry practices (The Maine Atlantic Salmon Task Force, 1997). Other major influencing factors such as urbanization, were not discussed in isolation, but combined with stressors. For instance, traffic and road construction resulting in increasing imperviousness and surface runoff were categorized as part of the forestry practices influences. Without clearly defining urbanization as a type of unique land use practice, monitoring regulations based on land uses remains flawed. This ambiguity in defining urbanization as a unique land use practice highlights the imperfect and ambiguous nature of monitoring regulations based on land uses. The working authority also provided suggestions focused on immediate actions for salmon conservation, and the enhancement of habitat protection over the long-term. While short-term management strategies focused on fixing legal loopholes and strengthening legal enforcement, the enhancement process usually involves multi-stakeholder cooperation, public outreach, and education to raise awareness of riparian buffers' importance. This case can be used as an inspiration to BC Riparian management as the division of land uses are distinct and the potential threats are issued with a priority issue. Although the framework itself focuses on large-scale land use application rather than riparian ecosystems, the identification of potential threats from adjacent land uses to fish population can be applied.

Recent case studies suggest improvement in the riparian management framework. The case study in OSEF of Washington outlined a clear list of indicators to understand the riparian system, including the basic channel morphology, stream temperature, shading, channel substrate, instream Large Woody Debris (LWD), habitat valley and channel classification, stream discharge, riparian microclimate, and riparian vegetation. These indicators are not selected because they present unique information about each individual site but are considered crucial for understanding the health and effectiveness of a riparian system. In fact, these indicators often interact and affect one another. For instance, shading can cause fluctuations in stream temperature, while being affected

by riparian vegetation. The OSEF framework recommended various appropriate frequencies to record the data for each indicator. Some indicators such as bank width are simply easier to measure than other information such as the relationship between air and water temperature. The OSEF guidebook takes into consideration of unusual situations that may cause inconsistency or inaccuracy. For instance, although trees are a significant part of riparian vegetation that provide stream shading, the guidebook also recognizes that understory vegetation that does not have a measurable diameter at breast height plays an equally significant ecological role, if not, a more important one for soil erosion control. The thorough monitoring process is projected to last at least ten years and will be kept consistent with monitoring quality control and assurance (Devine et al.,2022). These guidelines as protocols are crucial for the monitoring of riparian systems, thus can also be enhanced in the assessment aspect in BC's management. The working group also have instructions on how to deal with complex situations when measuring the interactive indicators, which can be informative for qualified professionals as they are answering binary assessment questions for a riparian buffer zone.

In British Columbia, riparian buffer zone management within a forested ecosystem is prescriptive, result-based with some degree of independence, or regulated by the FSC. Riparian management guidelines are not as specified as the OSEF guidebook. The progress of riparian management is still notable as it has advanced from the former FRC due to common criticism. The advanced FRPA enables more individual freedom and better assessment of watersheds through a list of indicator questions. FRPA have high demands for knowledge as the management standards are established, planned, and implemented by qualified experts in biology, forestry, and hydrology. Meanwhile, other types of riparian management that are regulated by non-governmental organizations such as the FSC are also available. They have the potential to provide more flexibility and more specified protection towards small-riparian streams if applied appropriately. Another limitation of BC riparian management is the lack of enforcement on small streams even though they are the most vulnerable to land use change and the most critical for salmon habitats. Future riparian management must consider how to apply specific riparian standards, particularly on little streams where there is minimum enforcement.

Future Management Guidance and Recommendations

Based on the findings from the three case studies, several recommendations are made to enhance existing riparian management policies. First, future riparian management frameworks should incorporate specific indicators that accurately measure the well-being of riparian systems. These indicators, such as channel morphology, stream temperature, shading, and riparian vegetation, provide valuable insights into the health and effectiveness of riparian buffer zones. By implementing a comprehensive set of indicators, policymakers and land managers can obtain a more holistic understanding of riparian conditions and make informed decisions regarding conservation strategies. Outlining the ecosystem by identifying relevant threats to riparian health is also important, especially when there are multiple land use activities that poses different levels of risks.

Second, it is crucial to establish consistent monitoring protocols and address unusual occasions that may affect data accuracy. The case study in the Olympic Experimental State Forest (OSEF) demonstrated the importance of recording data for each indicator at appropriate frequencies and considering potential anomalies that could impact measurement consistency. By implementing robust monitoring protocols and quality control measures, policymakers can ensure that the collected data accurately reflects the true state of riparian systems over time. This consistent monitoring will facilitate the evaluation of management practices and allow for adaptive management approaches that can address changing environmental conditions.

Last, existing policies should include site-specific management measures to prevent the oversight of small streams. While the focus of riparian management often falls on larger water bodies, small streams play a crucial role in supporting salmon habitats and are highly vulnerable to land use changes. To address this, riparian management guidelines should specifically address the protection and restoration of small streams, considering their unique ecological characteristics and potential impacts from adjacent land uses. This targeted approach will help ensure that the conservation needs of small streams are not overlooked and that their contribution to overall salmon habitat health is effectively addressed. This requires the alignment of riparian management regulations standards with FPC and FRPA as they are the primary approaches to manage riparian forests in British Columbia. Communication between different departments to minimize the mismatch between regulations can provide uniform standards and guidelines to follow.

Conclusion

This analysis presented a movement towards a “systems” approach for riparian management in British Columbia. Moving towards a 'systems' approach that integrates the best available information on all human activities is vital for achieving effective riparian management to support BC salmon habitat. Implementing this comprehensive framework would allow for improved communication of the critical importance of riparian ecosystem management to a broader spectrum of stakeholders, including the public. Embracing a systems-based approach acknowledges the interconnectedness of various land uses and their impacts on riparian buffer zones and salmon-bearing streams. This inclusive strategy enables policymakers, land managers, and conservation organizations to holistically address the challenges posed by urbanization and climate change, while also identifying opportunities to enhance riparian functionality. Engaging a wider range of stakeholders in the conversation fosters greater awareness and support for the conservation and restoration of riparian areas. Through collective efforts and informed decision-making, the long-term sustainability of salmon populations and their vital habitats in British Columbia's diverse landscapes can be assured.

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Appendix

Communication Infographic to brief decision makers and inform the public