WRIA 8 Multi-Species Salmon Recovery Synthesis Report

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King County

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1 Introduction

Since the 1999 listing of Puget Sound Chinook salmon (*Oncorhynchus tshawytscha*) as threatened under the Endangered Species Act, the Lake Washington/Cedar/Sammamish Watershed (WRIA 8) Salmon Recovery Council has worked to recover sustainable, harvestable populations of the watershed's two Chinook salmon populations – Cedar River and Sammamish River. The WRIA 8 Chinook Salmon Conservation Plan (Plan) establishes the science-based conservation strategy and goals, identifies priority implementation actions, and provides a monitoring and assessment plan for salmon recovery (WRIA 8 Steering Committee 2017). While the Plan focuses on recovering Chinook salmon, actions taken to improve conditions for Chinook are assumed to improve conditions for other salmon species and contribute to improving overall watershed conditions. However, areas of shared versus Chinook-centric benefits are often not explicit or well understood.

The purpose of this report is to: (1) identify areas of species overlap in space and time in WRIA 8; (2) provide a framework for evaluating assumptions that Chinook salmon recovery actions benefit other salmon species; and (3) summarize where, when, and at what life stages Chinook recovery actions are anticipated to benefit other salmon species in the WRIA 8 watershed.

This report describes the life cycles of key non-Chinook salmonid species within WRIA 8 and whether we expect recovery strategies and their associated actions specified in the WRIA 8 Plan to benefit these species. We organized the report into individual sections for the following five salmon species and life histories: sockeye salmon (*O. nerka*), kokanee (non-anadromous *O. nerka*), coho salmon (*O. kisutch*), chum salmon (*O. keta*), and steelhead/rainbow trout (*O. mykiss*). While pink salmon (*O. gorbuscha*) are occasionally observed within the freshwater portion of WRIA 8, there does not appear to be a viable population within the basin, and little is known about this species within WRIA 8. Therefore, we did not include a section on pink salmon. Additionally, we did not include a section on cutthroat trout (*O. clarkii*) because the population within WRIA 8 appears to be thriving and is not a focus of conservation efforts. Each species section provides the following information:

- Overview of species abundance and distribution in WRIA 8.
- Summary of life stages and habitat use at each stage within WRIA 8.
- Description of the primary factors currently understood to be limiting species productivity and viability within WRIA 8.
- Description of how the priority Chinook salmon recovery strategies in the WRIA 8 Plan are expected to benefit species for the following WRIA 8 habitat areas: Lake Washington, Lake Sammamish, Ship Canal/Lake Union, Cedar River, Sammamish River, Sammamish River tributaries (Bear Creek/Cottage Lake Creek, Little Bear Creek, Swamp Creek, North Creek), Issaquah Creek, other small tributaries (e.g., Kelsey Creek, Coal Creek, May Creek), and the

nearshore/marine shoreline (Figure 1). For each species, we assigned expected benefits to four qualitative categories under each combination of habitat area and recovery strategy: 'No benefit/benefit unlikely', 'Modest benefit', 'Substantial benefit', or 'Strategy not applicable to this location/habitat'.

- Map of species distribution within WRIA 8 and a summary table of expected benefits from priority Chinook salmon recovery strategies.
- In addition to the individual sections, the timing of life stages for the five salmon species/life histories, plus Chinook salmon, is summarized in Appendix A.

We determined that implementation of a recovery strategy within a specific habitat area would provide a 'substantial benefit' to a certain species if the combination of strategy and habitat addressed a key limiting factor for that species within WRIA 8. We determined that implementation of a recovery strategy within a specific habitat area would provide a 'modest benefit' to a certain species if the combination of strategy and habitat did not address a key limiting factor but was still expected to provide some benefit to that species within WRIA 8.

The species profiles are based primarily on published reports and peer-reviewed journal articles. To be considered, documents had to be publicly accessible or available upon request. When written documentation was not available for specific topics, unpublished data were considered if the data were available and readily interpretable. Unpublished data were provided by Aaron Bosworth (Washington Department of Fish and Wildlife [WDFW]), Eric Warner and Jason Schaffler (Muckleshoot Indian Tribe [MIT]), Dave Beauchamp (U.S. Geological Survey [USGS]), Roger Tabor (U.S. Fish and Wildlife Service [USFWS]), Todd Zackey (Tulalip Tribes), Jim Bower (Kokanee Work Group [KWG]), and Aaron David (King County).

Species distribution maps are based on a combination of data from the Washington Department of Fish and Wildlife fish distribution database (apps.wdfw.wa.gov/salmonscape/map.html), fish distribution maps developed for the original WRIA 8 Chinook salmon conservation plan (WRIA 8 Steering Committee 2005), various unpublished fish distribution datasets, the numerous reports referenced in the individual species profiles, and the professional judgement of the authors. These maps are only intended to represent the approximate recent distribution of species within WRIA 8. Due to the inherent challenges in defining the exact distribution of a species and the absence of consistent surveys in many of the watershed's small streams, these maps should not be considered definitive and should not be used for regulatory or restoration and protection decision making.

Finally, this report is intended to be a resource for local and regional salmon recovery partners. This is a first step toward a multi-species assessment in WRIA 8, providing a broad overview of Chinook recovery strategies that may benefit other salmon species and life histories. We continue to refine our understanding of the primary factors limiting species productivity and viability and the effectiveness of Chinook recovery strategies to address these factors cumulatively and at the project or implementation level. To that end, we expect this assessment will evolve as new information becomes available.

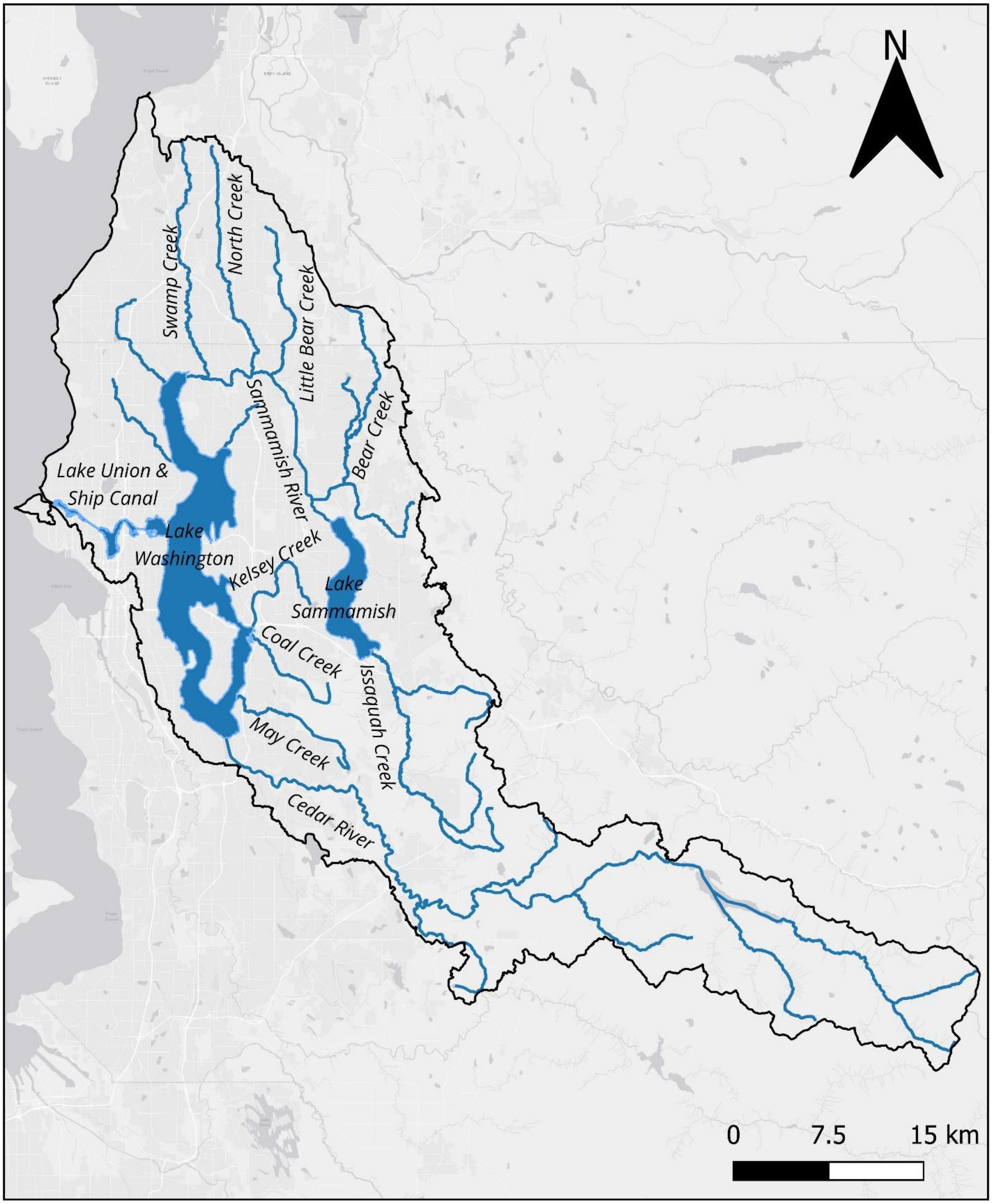

Figure 1. the Lake Washington/Cedar/Sammamish Watershed (WRIA 8), with key waterbodies identified.

2 Sockeye Salmon

2.1 Overview

Sockeye salmon are the anadromous life history variant of *O. nerka*. The history of *O. nerka* (both sockeye and the freshwater resident life history variant kokanee) within WRIA 8 is complex and, as with other salmonid species, influenced by a legacy of large-scale hydrologic modification and habitat alteration in the watershed. The Lake Washington population of sockeye was, for a period, the largest run of sockeye in the lower 48 states (SPU & USACE 2008). The run is also unique as one of the southernmost sockeye populations in North America and because it exists in a highly urbanized setting. Extant sockeye populations within WRIA 8 reflect both a native sockeye population and extensive introductions of Baker Lake sockeye to the watershed during the early and mid-20th century (Hendry et al. 1996; Gustafson et al. 1997; Ames 2006; Spies et al. 2007).

Sockeye salmon are distributed throughout much of WRIA 8 (Figure 2) and have supported extensive recreational and tribal fisheries in the past (Ames 2006). The abundance of sockeye within WRIA 8 has declined dramatically from its peak in the 1980s. Under current regulations, the Lake Washington sockeye fishery occurs when managers forecast at least 350,000 sockeye to return to the Ballard Locks. No Lake Washington sockeye fishery has occurred since 2006 when over 450,000 sockeye returned to Lake Washington. On average, surveyors counted just 29,956 sockeye annually at the Ballard Locks between 2018 and 2022.

In addition to naturally spawning sockeye, production is supported by a hatchery program on the Cedar River that began in 1991, with a permanent hatchery facility constructed by the City of Seattle in 2011. The hatchery produces thermally-marked fry that are released into the Cedar River each spring. Hatchery production is intended to mitigate for the exclusion of sockeye from the Cedar River upstream of the Landsburg diversion dam, which provides drinking water for the greater Seattle area. The City of Seattle typically exclude sockeye from the Cedar River above Landsburg because of risks to drinking water quality from mass-spawning events (Landsburg Mitigation Agreement 2000). However, in 2020 and 2023 the City of Seattle allowed sockeye to pass above Landsburg because low returns did not pose a risk to drinking water quality.

2.2 Adult Migration

Most adult sockeye salmon return to WRIA 8 through the Ballard Locks between early June and late August, with peak migration typically occurring between late June and mid-July (Hodgson and Quinn 2002; Newell et al. 2007; Tillotson et al. 2019; WDFW 2023a). The age at return varies from year to year, but sockeye typically return to spawn within WRIA 8 at age four (~74%) or age five (~23%), and less commonly at age three (~3%) or age six (<1%) (Unrein 2023a; MIT and WDFW unpublished data for 2005-2021). In contrast to more northerly and interior sockeye populations, most WRIA

8 sockeye return to freshwater two to four months before spawning (Hodgson and Quinn 2002; Newell and Quinn 2005; Newell et al. 2007).

After passing through the Ballard Locks, sockeye tend to migrate rapidly through the Ship Canal and reside for extended periods in Lake Washington (on average 85 days; ranging from 60 to 132 days), generally below the thermocline (Newell and Quinn 2005). In Lake Washington, sockeye primarily hold in waters between 9°C and 11°C until they initiate their final spawning migration (Newell and Quinn 2005). The extended duration between migration to freshwater and commencement of spawning appears to be an adaptation to avoid peak surface water temperatures within Lake Washington and the Ship Canal during late summer (Hodgson and Quinn 2002).

Mortality of adults after returning to freshwater but prior to completion of spawning is a limiting factor for sockeye salmon in WRIA 8 (Barnett et al. 2020; Kendell et al. 2023). Fewer sockeye are observed on the spawning grounds than at the Ballard Locks (Kendall et al. 2023) and many sockeye that make it to their spawning grounds die before spawning (Barnett et al. 2020). The causes of sockeye pre-spawn mortality are not fully understood, but high water temperatures, along with temperature-mediated diseases, appear to be contributing factors (Newell et al. 2007; Barnett et al. 2020; Urgenson et al. 2021; Kendall et al. 2023). Disease vectors in Lake Washington include *Parvicapsula minibicornis* and *Flavobacterium columnare* (Barnett et al. 2020). Low dissolved oxygen concentrations, limited thermal refugia, and abrupt transitions in salinity and temperature also negatively impact adult sockeye migrating through the Ballard Locks and Ship Canal (Urgenson et al. 2021 and references therein). Furthermore, predation by pinnipeds is an increasing source of stress and mortality for sockeye and other salmon species as they traverse the Ballard Locks (WSAS 2022; Mulvihill-Kuntz et al. 2024).

2.3 Spawning

The Cedar River supports the largest sockeye salmon spawning aggregation within WRIA 8, but sockeye spawn in many other locations throughout the watershed, including Bear Creek and other tributaries to the Sammamish River (e.g., Little Bear and North creeks), Issaquah Creek, and small streams that drain directly to Lake Sammamish and Lake Washington (Ames 2006; Heller 2023; WDFW 2023b). Sockeye also spawn on beaches within Lake Washington, although these beaches have not been surveyed in recent years (WDFW 2023c). After the Cedar River, Bear Creek typically supports the largest number of spawners.

Sockeye primarily spawn from September through November within WRIA 8. However, the timing of sockeye spawning in the Cedar River has steadily shifted earlier since the mid-1990s, potentially due in part to inadvertent selection for early spawners by the Cedar River hatchery (Tillotson et al. 2019). This earlier spawn timing, coupled with climate change, has resulted in sockeye spawning during warmer water temperatures and may contribute to the rise in pre-spawning mortality observed in recent years (Barnett at al. 2020). Earlier spawning may also align with lower stream flows, which

can limit where sockeye spawn (Ames 2006). Despite low-flow constraints, the quantity or quality of spawning habitat do not appear to be primary limiting factors for sockeye in WRIA 8 (Ames 2006; McPherson and Woodey 2009).

2.4 Incubation and Emergence

Once deposited in the gravel, sockeye salmon eggs incubate until emerging as fry generally between January and May (Beauchamp et al. 2004), although emergence timing depends on both the timing of egg deposition and water temperature. Egg-to-fry survival in the Cedar River is positively correlated with minimum flows during spawning but is negatively correlated with peak flows during incubation (McPherson and Woodey 2009). Low flows during spawning can force sockeye to build redds in the center of the channel where eggs will be more vulnerable to scour from winter high flows (Ames 2006 and references therein). However, while river flows during spawning and incubation can affect egg-to-fry survival, mortality at this life stage does not appear to be a key constraint on sockeye productivity in WRIA 8 (McPherson and Woodey 2009; Kendall et al. 2023).

2.5 Stream Rearing and Downstream Migration

After emerging from the gravel, sockeye salmon fry rapidly migrate downstream at night to the lake environment. In the Cedar River, sockeye fry emigrate from January through early July, although most emigration occurs February through April (e.g., Lisi 2019, 2022). The median emigration date of sockeye fry in the Cedar River has shifted earlier since the 1990s (Lisi 2022), possibly due to the concurrent shift to earlier spawn timing in the Cedar River (Tillotson et al. 2019). In Bear Creek, sockeye fry primarily emigrate from February through May, with peak emigration March through April (e.g., Lisi 2019, 2022). Stream channelization, bank armoring, riparian degradation, and other human alterations to rivers and streams in WRIA 8 likely have a negative impact on sockeye fry survival during stream residence. However, given the short period of time that sockeye fry typically reside within streams, these alterations may have less of an impact on sockeye than on other salmonids with extended stream-rearing life histories (e.g., Chinook salmon or coho salmon).

Piscivorous fishes such as rainbow trout/steelhead, cutthroat trout, coho salmon, and sculpins (*Cottus* spp.) can consume a significant number of outmigrating sockeye salmon fry within the Cedar River, particularly in the lower reaches of the river (Beauchamp 1995; Tabor and Chan 1996; Tabor et al. 2004, 2014). Predation by these fishes may be an important source of mortality for sockeye fry within the Cedar River and presumably other WRIA 8 tributaries. These piscivores are all native species, but human alterations to habitat conditions or streamflow in the Cedar River may exacerbate predation risk to sockeye fry (Tabor and Chan 1996; Tabor et al. 2004).

2.6 Lake Rearing

Sockeye salmon spend a significant portion of their life cycle within lakes, making conditions within lake environments critical to the viability and productivity of sockeye populations. The progeny of sockeye that spawn in the Cedar River rear within Lake Washington, as do presumably the progeny of sockeye that spawn in Bear Creek and other tributaries to the Sammamish River. However, it is unclear if the progeny of sockeye that spawn in Issaquah Creek rear in Lake Sammamish or in Lake Washington. After emigrating from the Cedar River and other tributaries in late winter and spring, sockeye fry are initially closely associated to the lake shore, but rapidly move offshore into deeper water as they grow and spring progresses (Beauchamp et al. 2004). Lake Washington sockeye fry feed primarily on crustacean zooplankton, particularly cladocerans such as *Daphnia* and *Bosmina*, and copepods such as *Cyclops*, *Diaptomus*, and *Epischura*, but also consume chironomids and other aquatic invertebrates (Doble and Eggers 1978; Beauchamp et al. 2004).

Mortality during lake rearing appears to be a primary constraint on the productivity of sockeye salmon in WRIA 8. In-lake survival is often low (average 3% 2000-2018) compared to other sockeye populations (McPherson and Woodey 2009; Kendall et al. 2023). Evidence suggests in-lake mortality is primarily due to top-down effects (predation) and not bottom-up effects (food limitation). Sockeye fry in Lake Washington typically consume a small fraction of the available zooplankton prey (Beauchamp et al. 2004; Ames 2006). Additionally, yearling sockeye smolts in Lake Washington are among the largest in the world (McPherson and Woodey 2009), suggesting foraging and growth conditions are not limiting the population. However, zooplankton abundance and bloom timing in Lake Washington do influence the survival and growth of lake-rearing sockeye (Hovel et al. 2018). Foraging by sockeye fry may temporarily deplete zooplankton prey during certain seasons or in certain locations within Lake Washington (Beauchamp et al. 2004). Additionally, competition with other zooplanktivores such as longfin smelt (*Spirinchus thaleichthys*) and three-spine stickleback (*Gasterosteus aculeatus)* may affect sockeye growth and survival (McPherson and Woodey 2009). Climate change may also create mismatches between the timing of sockeye emigration to the lake and blooms of their zooplankton prey (Winder and Schindler 2004; Hovel et al. 2018). Recent dramatic increases in the abundance of American shad (*Alosa sapidissima*) in Lake Washington (NWS 2022) could also affect the food webs that support juvenile sockeye (Haskell et al. 2013). Thus, while bottom-up processes have not appeared to be primary factors limiting sockeye survival during lake rearing in the past, these processes may be relevant in some years or locations and could become more limiting in future.

Predation on lake-rearing sockeye by native and non-native fishes appears to be a primary driver of low in-lake survival (Kendall et al. 2023). Native cutthroat trout and northern pikeminnow (*Ptychocheilus oregonensis*) are significant predators of lake-rearing sockeye in pelagic habitats of WRIA 8 (Nowak et al. 2004; Beauchamp et al. 2007; Clark 2017). Smallmouth bass (*Micropterus dolomieu*), largemouth bass (*Micropterus salmoides*), and other non-native piscivores such as yellow perch (*Perca flavescens*), rock bass (*Ambloplites rupestris*), and black crappie (*Pomoxis nigromaculatus*) also prey on lake-rearing sockeye, particularly as sockeye fry enter

Lake Washington and as sockeye smolts leave Lake Washington through the Ship Canal (Fayram and Sibley 2000; Tabor et al. 2007; USFWS unpublished data). More recent unsanctioned introductions to the Lake Washington and Lake Sammamish fish assemblages, such as walleye (*Sander vitreus*) and northern pike (*Esox lucius*), are voracious predators which may also consume lake-rearing sockeye. The relative impacts of various predator species on sockeye populations across time and space is a subject of ongoing investigation.

Artificial lighting at night (ALAN) exacerbates predation risk by slowing or stopping sockeye salmon migration and attracting them in rearing habitats, making them more susceptible to predation (Tabor et al. 2004a, 2017), and by extending the diel period during which predatory fishes can effectively feed (Mazur and Beauchamp 2006; USGS unpublished data). In addition to predation, high water temperatures and low dissolved oxygen are stressors for sockeye that may rear within Lake Sammamish (King County 2018). Armoring, overwater structures, and other alternations to lake shorelines likely impact lake-rearing sockeye by creating preferred habitats for predators and disrupting food webs that support sockeye. However, because sockeye fry rapidly shift to the pelagic environment of Lake Washington, restoration of more natural shorelines would likely only provide a modest benefit to lake-rearing sockeye.

2.7 Migration to Puget Sound

Within WRIA 8, most sockeye salmon rear for one year in lake environments before emigrating to Puget Sound (Kendall et al. 2023). However, some sockeye emigrate to the marine environment during their first spring or summer as subyearlings. Others spend two years in freshwater before emigrating to the marine environment (SPU & USACE 2008; WDFW and MIT unpublished data). Predation along with high water temperatures in Lake Union, the Ship Canal, and around the Ballard Locks are likely primary limiting factors for outmigrating sockeye smolts (SPU & USACE 2008 and references therein; Urgenson et al. 2021 and references therein). Additionally, predation by pinnipeds in Salmon Bay may be a source of mortality for sockeye smolts as they exit the Ballard Locks, although the level and extent of pinniped impacts is uncertain (Mulvihill-Kuntz et al. 2024).

2.8 Nearshore Foraging

Little is known about the ecology and behavior of sockeye salmon smolts after they leave the freshwater portion of WRIA 8 (SPU & USACE 2008). Since sockeye rear to a relatively large size within lakes prior to outmigrating, they tend to spend little time foraging and rearing in estuarine or nearshore habitats and instead migrate rapidly to the open ocean (Quinn 2018).

2.9 Maturation (marine waters)

As with nearshore foraging, we know little about sockeye salmon from WRIA 8 during their maturation in marine waters. However, the marine survival of sockeye from WRIA

8 appears to be similar to marine survival rates of other regional sockeye populations and is not considered a primary limiting factor for the population (Ames 2006; Kendall et al. 2023).

2.10 Limiting Factors and Relevance of Chinook Recovery Strategies

Current understanding of the ecology and population dynamics of WRIA 8 sockeye salmon suggest the most important factors limiting sockeye productivity are: (1) low survival rates for lake-rearing sockeye, likely due to predation and factors that exacerbate predation risk (e.g., ALAN); and (2) low survival rates for adult salmon after returning to freshwater, likely due to high water temperatures and temperature-mediated diseases (McPherson and Woodey 2009; Barnett et al. 2020; Kendall et al. 2023).

The WRIA 8 Chinook salmon recovery strategy most likely to improve low survival rates for lake-rearing sockeye salmon fry and presmolts is to **reduce predation of juvenile migrants and lake-rearing fry** (Table 1). Implementation of this strategy would be most relevant in Lake Washington, Lake Sammamish, Lake Union/Ship Canal, and the Sammamish River. ALAN can exacerbate predation risk and is identified in the WRIA 8 Chinook recovery plan as a priority research and data need. Substantial effort and resources are focused on developing a recovery strategy and management goals to reduce effects of ALAN on salmon, including quantifying nighttime light levels across the watershed and associated predation impacts and developing policy and public outreach to address this key issue. Invasive aquatic vegetation in the littoral zones of Lake Washington and Lake Sammamish may also exacerbate predation risk by providing cover and rearing habitat for non-native piscivores (Kyle 2021), but more information is needed on this topic to refine and prioritize potential management actions. If aquatic invasive vegetation is determined to be a significant contributing factor to predation on sockeye and other salmonids in the basin, removal of invasive aquatic weeds and establishment of native aquatic vegetation could be added as a relevant action for the recovery strategy to protect and restore shallow-rearing and refuge habitat. Additionally, the WRIA 8 Chinook recovery plan does not currently include a strategy to address pinniped predation on sockeye and other anadromous salmon at the Ballard Locks. Recovery strategies focused on reducing the effects of predation on adult and juvenile salmon as they migrate through the Locks may be needed as additional information and management recommendations become available.

The two Chinook salmon recovery strategies most likely to address low survival rates for adult sockeye salmon that have returned to freshwater to spawn are to **improve water quality** and to **protect and restore cold-water sources and reduce thermal barriers to migration**. Implementation of these strategies would be most relevant in Lake Union/Ship Canal/Ballard Locks, Lake Sammamish, and the Sammamish River. Actions that improve water quality and reduce water temperatures will likely reduce disease impacts to sockeye returning to freshwater. However, other strategies to mitigate disease impacts may also be needed due to the complex interplay between disease, water temperature, river flows, and habitat conditions. Given recent analyses suggesting that inadvertent hatchery selection has resulted in earlier spawn timing

which coincides with higher water temperatures (Tillotson et all 2019; Barnett et al. 2020), adjustment of hatchery practices may warrant consideration to reduce enroute and pre-spawning mortality, a topic that is not addressed by the Chinook recovery strategies.

Because sockeye salmon are distributed throughout much of WRIA 8, most Chinook salmon recovery strategies should provide at least modest habitat benefits to sockeye. Implementation of the strategies: protect and restore floodplain connectivity; protect and restore functional riparian vegetation; and protect and restore channel complexity should all benefit the spawning, incubation, and stream rearing life stages of sockeye in WRIA 8. However, the magnitude of benefit is expected to be modest given survival during these life stages does not appear to be a primary limiting factor for sockeye.

Table 1. Matrix of priority WRIA 8 Chinook salmon recovery strategies (row headers) and different locations within WRIA 8 (column headers). The matrix cells are colored according to the expected benefit to sockeye salmon of that strategy implemented in that location. Codes: strategy not applicable to this location/habitat, no benefit/benefit unlikely, modest benefit, and substantial benefit.

Recovery Strategies	Lake Union/Ship Canal	Lake Washington	Lake Sammamish	Cedar River	Sammamish River	Sammamish River tribs (Bear, Little Bear, North, Swamp)	Issaquah Creek	Other tributaries*	Marine nearshore	Notes
Protect and restore floodplain connectivity				Modest benefit	Modest benefit	Modest benefit	Modest benefit	Modest benefit		Modest benefits to spawning, incubation, and stream rearing in sockeye spawning streams.
Protect and restore functional riparian vegetation	Modest benefit	Modest benefit	Modest benefit	Modest benefit	Modest benefit	Modest benefit	Modest benefit	Modest benefit	Modest benefit	Modest benefits to spawning, incubation, and stream rearing in sockeye spawning streams, and may provide a small benefit to lake-rearing sockeye.
Protect and restore channel complexity				Modest benefit	Modest benefit	Modest benefit	Modest benefit	Modest benefit		Modest benefits to spawning, incubation, and stream rearing in sockeye spawning streams.
Restore shallow-water rearing and refuge habitat	Modest benefit	Modest benefit	Modest benefit							Small benefit to lake-rearing sockeye by improving conditions for sockeye fry that recently emigrated from their natal streams.
Reconnect and enhance creek mouths	Modest benefit	Modest benefit	Modest benefit	Modest benefit	Modest benefit	Modest benefit	Modest benefit	Modest benefit	Modest benefit	Small benefit to spawning sockeye by increasing the amount of accessible, quality spawning habitat.
Protect and restore cold-water sources and reduce thermal barriers to migration	Substantial benefit	Modest benefit	Substantial benefit	Modest benefit	Substantial benefit	Modest benefit	Modest benefit	Modest benefit		Substantial benefits to lake-rearing sockeye fry and adult sockeye that are returning to spawn, particularly in Lake Union, Lake Sammamish, and the Sammamish River.
Improve juvenile and adult survival at the Ballard Locks	Modest benefit									Modest benefit to sockeye.
Reduce predation of juvenile migrants and lake-rearing fry	Substantial benefit	Substantial benefit	Substantial benefit	Modest benefit	Substantial benefit	Modest benefit	Modest benefit	Modest benefit		Substantial benefits to sockeye fry and lake-rearing sockeye, particularly in the lakes and Sammamish River.
Remove or reduce impact of overwater structures	Modest benefit	Modest benefit	Modest benefit		Modest benefit				Modest benefit	Small benefit to lake-rearing sockeye by improving conditions for fry that recently emigrated from their natal streams.
Remove fish passage barriers				Modest benefit	Modest benefit	Modest benefit	Modest benefit	Modest benefit	Modest benefit	Modest benefits to spawning sockeye by increasing the amount of accessible, quality spawning habitat.
Protect and restore forest cover and headwater areas				Modest benefit	Modest benefit	Modest benefit	Modest benefit	Modest benefit		Modest benefits to spawning, incubation, and stream rearing in sockeye spawning streams.
Provide adequate streamflow				Modest benefit	Modest benefit	Modest benefit	Modest benefit	Modest benefit		Small benefit to spawning and incubation life stages in sockeye spawning streams.
Restore sediment processes necessary for key life stages				Modest benefit	Modest benefit	Modest benefit	Modest benefit	Modest benefit		Modest benefits to spawning, incubation, and stream rearing in sockeye spawning streams.
Restore natural marine shorelines									Modest benefit	Small benefit to sockeye smolts as they leave freshwater and migrate through Puget Sound.
Reconnect backshore areas and pocket estuaries									Modest benefit	Small benefit to sockeye smolts as they leave freshwater and migrate through Puget Sound.
Protect and restore marine water and sediment quality									Modest benefit	Small benefit to sockeye smolts as they leave freshwater and migrate through Puget Sound.
Improve water quality	Substantial benefit	Modest benefit	Substantial benefit	Modest benefit	Substantial benefit	Modest benefit	Modest benefit	Modest benefit		Substantial benefits to sockeye rearing in lake Sammamish and returning adults as they traverse Lake Union and the Sammamish River.

*'Other' tributaries that sockeye salmon use within WRIA 8 include small streams that drain directly to Lake Sammamish and Lake Washington.

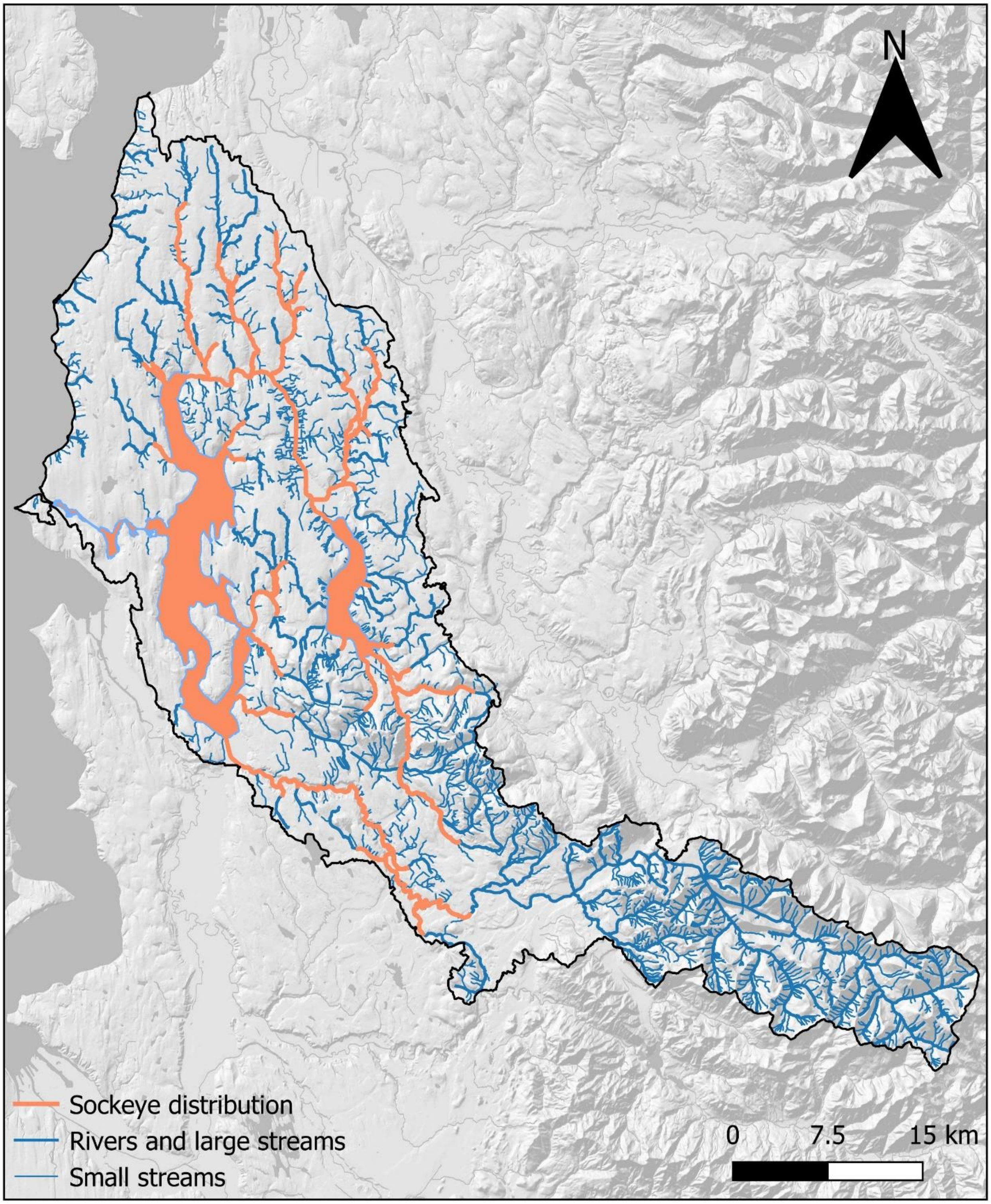

Figure 2. The distribution of sockeye salmon within WRIA 8. This distribution is approximate and may not represent the full distribution of sockeye salmon within WRIA 8. Due to the inherent challenges in defining the exact distribution of a species and the absence of consistent surveys in many of the watershed's small streams, this map should not be considered definitive and should not be used for regulatory or restoration/protection decision making.

3 Kokanee

3.1 Overview

Kokanee are the freshwater resident life history variant of *O. nerka*. In contrast to anadromous sockeye, kokanee do not migrate to the ocean and instead feed and mature within lakes. Early fishery surveys and historical accounts indicate that kokanee were abundant and widely distributed throughout the Lake Washington basin prior to large scale hydrologic modification of the basin in the early 1900s (Bean 1891; Gustafson et al. 1997 and references therein; Conner et al. 2000 and references therein). Historically, the Lake Washington Basin supported at least three separate kokanee runs distinguishable based on spawn timing ('early', 'middle', and 'late') and spawning location (Berge and Higgins 2003 and references therein).

Like other Pacific salmonid species within WRIA 8, the abundance and distribution of kokanee salmon has declined precipitously. Early-run kokanee, which spawned from early August through late September in Issaquah Creek and nearby tributaries, are presumed to be extinct (Jackson 2006). Middle-run kokanee historically spawned during fall within the Sammamish River, tributaries to the Sammamish River, and tributaries to Lake Washington (Conner et al. 2000 and references therein; Berge and Higgins 2003 and references therein). The current abundance and distribution of middle-run kokanee is uncertain. However, recent genetic assessments indicate some native middle run kokanee likely persist in the Sammamish River and tributaries to the Sammamish River (Louden and Seamons 2022). Late-run kokanee, which spawn in tributaries to Lake Sammamish during late fall and early winter (Figure 3), are the focus of extensive conservation efforts due to the low abundance of this run. Lake Sammamish late-run kokanee are the most well-documented kokanee run in WRIA 8, therefore, this profile focuses on the late-run. Current information available on extant middle-run kokanee are also described at the end of this chapter.

3.2 Adult Migration

Little is known about the migration of mature late-run kokanee from foraging within Lake Sammamish to spawning in lake tributaries. Kokanee likely hold near stream mouths in September and October, prior to entering the streams to spawn. Kokanee primarily enter their spawning streams at night, likely to reduce their vulnerability to predators.

3.3 Spawning

Late-run kokanee primarily spawn in small- to medium-sized tributaries to Lake Sammamish and, like most Pacific salmonids, die after spawning. The late-run spawning streams with the highest consistent returns are Lewis Creek, Laughing Jacobs Creek, and Ebright Creek. Other Lake Sammamish tributaries also support late-run kokanee spawning, particularly during years of high spawner abundances. These other streams include North Fork Issaquah, East Fork Issaquah, Pine Lake, Tibbetts, Vasa, Idylwood, Schneider, Zackuse, and George Davis creeks (KWG unpublished

data). Remote stream incubators are currently being used to expand the distribution and consistency of kokanee spawning in these tributaries. Late-run kokanee spawn from early November through the end of December but can be present in streams for a few weeks on both ends of this timeframe. On average, most (more than 80%) late-run kokanee spawn at age three with fewer spawning at age two and four and occasionally at age five.

Key limiting factors during spawning appear to be insufficient quantity or quality of spawning habitat due to stream channel alteration, fish passage barriers, and low stream flows. Habitat is likely sufficient during years of low spawner abundance. However, during years of high abundance, spawning habitat is likely insufficient, leading to superimposition of kokanee redds and spawning in sub-optimal habitat. Late-run kokanee spawner abundances above 2,000 individuals in each of Lewis, Laughing Jacobs, and Ebright creeks have been associated with reduced egg-to-fry survival rates (Lake Sammamish Kokanee Work Group 2016).

3.4 Incubation and Emergence

Late-run kokanee eggs generally incubate between November and March, emerging from stream gravels between early March and late May. The emergence timing of kokanee is affected by stream temperature, which can vary across systems. Mortality of eggs and fry during incubation and emergence is a limiting factor for the late-run kokanee population during years with high winter flows. High stream flows during winter storms can scour redds or cover redds with fine sediments. The flashiness of kokanee spawning streams is magnified due to conversion of natural vegetation to impervious surfaces, stormwater runoff, confinement of stream channels, and disconnection of stream channels from their floodplains.

3.5 Stream Rearing and Downstream Migration

After absorbing their yolk sac, late-run kokanee fry emerge from the stream gravels shortly after sunset and emigrate to the lake environment within several hours. Emigration typically occurs between early March and late May, with peak emigration between late March and late April. Stream channelization, riparian degradation, and increased hydrologic flashiness likely impact kokanee fry survival during stream rearing and migration. However, given the short period of time kokanee reside within streams, these stream alterations presumably impact kokanee less than other salmonids with extended stream-rearing life histories (e.g., Chinook salmon or coho salmon).

3.6 Lake Rearing

Kokanee spend most of their life-cycle within lakes, making conditions within lake environments critical to the viability and productivity of kokanee populations. Late-run kokanee that spawn in tributaries to Lake Sammamish rear and mature within Lake Sammamish. Here they feed extensively on the cladoceran *Daphnia*, copepods, and

other aquatic invertebrates, and to a lesser extent on the mysid *Neomysis mercedis* and small fishes (Berge 2009; HDR Engineering 2009).

Lake Sammamish conditions are a key limiting factor for late-run kokanee. From late spring through fall, only a small fraction of the total lake volume may be usable by kokanee due to high water temperatures and low dissolved oxygen. Lake Sammamish stratifies beginning in spring. The upper portion of the lake becomes too warm while the bottom portion has insufficient dissolved oxygen, leaving only a narrow middle layer with temperatures and dissolved oxygen concentrations tolerable to kokanee. This condition, termed the ‘water temperature-dissolved oxygen squeeze’, typically begins in April, peaks in September or October, and diminishes in November. The water temperature-dissolved oxygen squeeze can cause 80% or more of the lake volume to be unusable by kokanee and other fishes. Additionally, the water temperature-dissolved oxygen squeeze can increase predation risk by concentrating piscivorous fishes in the same narrow band with kokanee and can separate kokanee from their planktonic prey (Berge 2009; King County 2018).

Predation by native and non-native piscivores is likely a critical limiting factor for productivity of lake-rearing kokanee. Cutthroat trout and yellow perch appear to be primary predators of kokanee in Lake Sammamish (Berge 2009), with the population of nonnative yellow perch expanding substantially over the past two decades (King County 2023). Northern pikeminnow, largemouth bass, smallmouth bass, brown bullhead (*Ameiurus nebulosus*), black crappie, and rock bass also likely prey on kokanee. Artificial lighting at night presumably exacerbates predation risk of kokanee by extending the diel period during which visual-based predators can effectively hunt. Recent pilot studies suggest invasive aquatic vegetation including Brazilian elodea (*Egeria densa*) and Eurasian milfoil (*Myriophyllum spicatum*) may provide cover for predatory fishes and potentially exacerbate predation risk (Kyle 2021).

Evidence of pathogens and parasites has been observed for lake rearing and spawning kokanee. Diseases, particularly those caused by myxospore parasites, may be associated with low spawner abundances from at least 2019 through 2022 (Bower et al. 2023). Additional evidence is needed to better understand the impacts of parasites and disease on kokanee. Many diseases are exacerbated by crowding, low dissolved oxygen concentrations, and high water temperatures, common conditions in Lake Sammamish during late spring through early fall. Finally, bycatch during recreational fishing in Lake Sammamish is suspected to be an important threat to kokanee but the level and extent of this impact is currently unknown.

3.7 Migration to Puget Sound

This life history stage is not relevant to kokanee.

3.8 Nearshore Foraging

This life history stage is not relevant to kokanee.

3.9 Maturation (marine waters)

This life history stage is not relevant to kokanee.

3.10 Limiting Factors and Relevance of Chinook Recovery Strategies

Implementation of recovery strategies in Lake Sammamish and its tributaries are most relevant for recovering late-run kokanee in the basin. Lake Sammamish is a shared high priority habitat for recovery of both kokanee and Chinook salmon. However, the WRIA 8 Plan does not currently list most kokanee spawning streams (e.g., Lewis, Laughing Jacobs, and Ebright creeks, among others) as priority recovery areas aside from the lower reaches and stream mouths used by juvenile Chinook as non-natal rearing and refuge habitats.

Current understanding of the ecology and population dynamics of kokanee in WRIA 8 suggest key factors limiting kokanee productivity and survival fall into four categories: (1) insufficient quality and quantity of spawning habitat due to fish passage barriers and stream channelization and confinement; (2) low egg-to-fry survival due to scouring and sedimentation of redds by high winter flows in streams with altered hydrology; (3) increasing annual peak surface and whole lake temperatures, which compounds the seasonal water temperature-dissolved oxygen squeeze in Lake Sammamish; and (4) predation on lake-rearing kokanee and factors that exacerbate predation risk. Disease from myxospore parasites, recreational fishing bycatch, and invasive aquatic vegetation are emerging issues that may also limit kokanee recovery, although their roles and impacts are not yet fully understood.

The WRIA 8 Chinook salmon recovery strategies most likely to address limited spawning habitat include: **protect and restore floodplain connectivity**; **protect and restore functional riparian vegetation**; **protect and restore channel complexity**; **reconnect and enhance creek mouths**; and **remove fish passage barriers** (Table 2). These strategies are also likely to address low egg-to-fry survival in addition to **protect and restore forest cover and headwater areas** and **restore sediment processes necessary for key life stages**.

Two Chinook salmon recovery strategies address high water temperatures and low dissolved oxygen concentrations during lake rearing: **improve water quality** and **protect and restore cold-water sources and reduce thermal barriers to migration**. The Chinook recovery strategy to **reduce predation of juvenile migrants and lake-rearing fry** would also address predation on kokanee rearing in Lake Sammamish. WRIA 8 Chinook recovery strategies not relevant to kokanee include those focused on marine shorelines and the Ballard Locks.

Artificial lighting at night and its effects on predation is identified in the WRIA 8 Plan as a first-tier priority research and data need. Substantial effort and resources are focused on developing a recovery strategy and management goals to reduce the effects of

nighttime lighting, including quantifying light levels across the watershed and associated predation impacts, and developing policy and public outreach to address this issue.

WRIA 8 Chinook salmon recovery strategies appear to address many of the key threats and limiting factors for kokanee in WRIA 8. However, as noted above, much of the late-run kokanee spawning habitat does not overlap with priority Chinook habitat under the WRIA 8 Plan. Therefore, increased implementation of recovery strategies within kokanee spawning streams would likely require an expansion of what is considered priority habitat within the Lake Sammamish watershed under the WRIA 8 Plan. Additionally, two emerging concerns, disease from parasites and recreational bycatch, are not addressed by the Chinook recovery strategies. The WRIA 8 Plan also does not explicitly mention removal of invasive aquatic vegetation as a strategy to address a key pressure in salmon recovery. If these emerging concerns are determined to be significant limiting factors for kokanee, focused strategies to address these issues could be considered to advance kokanee recovery. For example, '*removal of invasive aquatic weeds and establishment of native aquatic vegetation'* could be added as a relevant action in the priority recovery strategy to restore shallow-rearing and refuge habitat.

An additional risk factor not addressed by the suite of Chinook salmon recovery strategies is the small and highly variable size of the kokanee population in WRIA 8, which has made the population vulnerable to inbreeding depression and other Allee effects. Therefore, recovery of kokanee currently requires artificial propagation and rearing. Strategies such as hatchery spawning and rearing, cryopreservation of milt, a captive broodstock program, experimentation with different rearing and release strategies, and off-site rearing of kokanee fry have been implemented for several years and will need to continue for at least the near future.

3.11 Extant Middle Run Kokanee

Recent genetic analysis discovered extant native middle-run kokanee spawning in the Sammamish River and its tributaries including Bear Creek, Little Bear Creek, and North Creek (Louden and Seamons 2022). These kokanee may also spawn in neighboring Swamp Creek. Middle-run kokanee historically spawned within these tributaries, and in the Sammamish River and small tributaries to Lake Washington (MacAleer, Lyon, Thornton, Juanita, Coal, and May creeks) from mid-October through early December. Currently, there is little information available on the abundance, distribution, and habitat needs of middle-run kokanee in the basin.

Prioritizing relevant recovery actions in the Sammamish River and tributaries would likely have substantial benefit for extant middle-run kokanee. Kokanee that spawn in the Sammamish River and tributaries are suspected to rear and mature in Lake Washington. However, assumptions regarding rearing of kokanee in Lake Washington have not been validated. The status of *O. nerka* spawning in Lake Washington tributaries other than the Cedar River is uncertain and a focus of ongoing investigation.

Table 2. Matrix of priority WRIA 8 Chinook salmon recovery strategies (row headers) and different locations within WRIA 8 (column headers). The matrix cells are colored according to the expected benefit to kokanee salmon of that strategy implemented in that location. Codes: strategy not applicable to this location/habitat, no benefit/benefit unlikely, modest benefit, and substantial benefit.

Recovery Strategies	Lake Union/Ship Canal	Lake Washington	Lake Sammamish	Cedar River	Sammamish River	Sammamish River tribs (Bear, Little Bear, North, Swamp)	Issaquah Creek	Other tributaries*	Marine nearshore	Notes
Protect and restore floodplain connectivity				No benefit	Substantial benefit	Substantial benefit	Substantial benefit	Substantial benefit		Substantial benefits to spawning, incubation, and stream rearing life stages in kokanee spawning streams.
Protect and restore functional riparian vegetation	No benefit	Modest benefit	Modest benefit	No benefit	Substantial benefit	Substantial benefit	Substantial benefit	Substantial benefit	No benefit	Substantial benefits to spawning, incubation, and stream rearing in kokanee spawning streams and may provide a small benefit to lake-rearing kokanee.
Protect and restore channel complexity				No benefit	Substantial benefit	Substantial benefit	Substantial benefit	Substantial benefit		Substantial benefits to spawning, incubation, and stream rearing life stages in kokanee spawning streams.
Restore shallow-water rearing and refuge habitat	No benefit	Modest benefit	Modest benefit							May provide a small benefit to lake-rearing kokanee by improving conditions for kokanee fry that recently emigrated from their natal streams.
Reconnect and enhance creek mouths	No benefit	Modest benefit	Substantial benefit	No benefit	Substantial benefit	Substantial benefit	Substantial benefit	Substantial benefit	No benefit	Substantial benefits to spawning kokanee by increasing the amount of accessible, quality spawning habitat.
Protect and restore cold-water sources and reduce thermal barriers to migration	No benefit	Modest benefit	Substantial benefit	No benefit	Substantial benefit	Modest benefit	Modest benefit	Modest benefit		Should benefit lake-rearing kokanee and mature kokanee that are preparing to make their spawning migration, particularly in Lake Sammamish and the Sammamish River.
Improve juvenile and adult survival at the Ballard Locks	No benefit									This strategy is not relevant to kokanee.
Reduce predation of juvenile migrants and lake-rearing fry	No benefit	Modest benefit	Substantial benefit	No benefit	Substantial benefit	Substantial benefit	Substantial benefit	Substantial benefit		Substantial benefits to kokanee fry and lake-earing kokanee wherever kokanee spawn and rear.
Remove or reduce impact of overwater structures	No benefit	Modest benefit	Modest benefit		Modest benefit				No benefit	May provide a small benefit to lake-rearing kokanee by improving conditions for kokanee fry that recently emigrated from their natal streams.
Remove fish passage barriers				No benefit	Substantial benefit	Substantial benefit	Substantial benefit	Substantial benefit	No benefit	Substantial benefits to spawning kokanee by increasing the amount of accessible, quality spawning habitat.
Protect and restore forest cover and headwater areas				No benefit	Substantial benefit	Substantial benefit	Substantial benefit	Substantial benefit		Substantial benefits to spawning, incubation, and stream rearing life stages in kokanee spawning streams.
Provide adequate streamflow				No benefit	Modest benefit	Modest benefit	Modest benefit	Modest benefit		May provide a small benefit to spawning and incubation life stages in kokanee spawning streams.
Restore sediment processes necessary for key life stages				No benefit	Substantial benefit	Substantial benefit	Substantial benefit	Substantial benefit		Substantial benefits to spawning, incubation, and stream rearing life stages in kokanee spawning streams.
Restore natural marine shorelines									No benefit	This strategy is not relevant to kokanee.
Reconnect backshore areas and pocket estuaries									No benefit	This strategy is not relevant to kokanee.
Protect and restore marine water and sediment quality									No benefit	This strategy is not relevant to kokanee.
Improve water quality	No benefit	Modest benefit	Substantial benefit	No benefit	Substantial benefit	Modest benefit	Modest benefit	Modest benefit		Substantial benefits to kokanee rearing in lake Sammamish and migrating through or spawning in the Sammamish River. May also provide a small benefit to other life stages wherever kokanee occur.

*For kokanee ‘other’ tributaries that are important habitats include small streams draining to Lake Sammamish (Lewis, Laughing Jacobs, Ebright, Pine Lake, Tibbetts, Vasa, Idylwood, Schneider, Zackuse, and George Davis creeks).

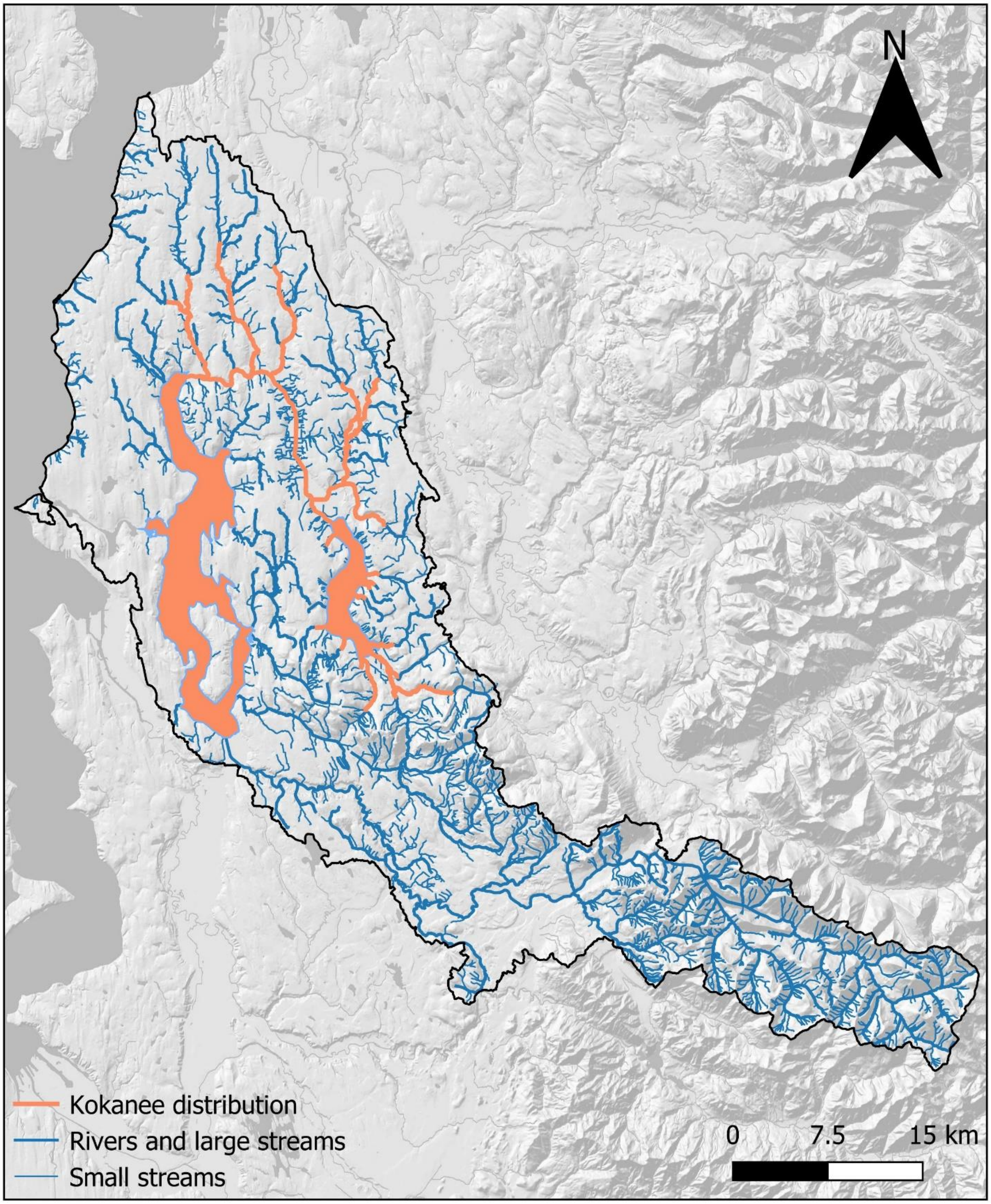

Figure 3. The distribution of kokanee within WRIA 8. This distribution is approximate and may not represent the full distribution of kokanee within WRIA 8. Due to the inherent challenges in defining the exact distribution of a species and the absence of consistent surveys in many of the watershed's small streams, this map should not be considered definitive and should not be used for regulatory or restoration/protection decision making.

4 Coho Salmon

4.1 Overview

Like most other salmonid species within WRIA 8, abundances of coho salmon (*O. kisutch*) have declined over time (Fresh 1994; WDFW unpublished data). However, accurate abundance estimates of coho do not currently exist for WRIA 8 due to limited spawning ground surveys within the basin and the challenges of conducting winter surveys (e.g., high flows and turbid water) for coho spawners. Despite suspected low abundances, coho are widely distributed throughout WRIA 8, inhabiting both larger rivers and small tributary streams for spawning and rearing (Figure 4). Coho within WRIA 8 are a mixed-stock population (both hatchery and wild production) and are considered a secondary management unit by the co-managers, meaning that there is no active management to meet a natural escapement target (WDFW 2023c). Issaquah Creek hatchery rears and releases coho smolts.

4.2 Adult Migration

Coho salmon typically return to freshwater at age three, and to a lesser degree at age two and age four (Quinn 2018). Migration of adult coho through the Ballard Locks typically begins in early August and peaks in mid-September (WDFW 2023a; MIT and WDFW unpublished data). Surveyors count salmon at the Ballard Locks until October 2^{nd} of each year and coho are often observed on the last day of this period, suggesting that coho continue migrating beyond the beginning of October. Adult coho that were PIT-tagged as juveniles have been detected migrating through the Ballard Locks between late August and mid-November (SPU & USACE 2008 and references therein).

Coho salmon migrate through the Lake Washington Ship Canal after water temperatures peak and begin to decline. However, high water temperatures and low dissolved oxygen concentrations, along with abrupt gradients in temperature, salinity, and dissolved oxygen, likely harm migrating coho (SPU & USACE 2008; Urgenson et al. 2021). Pinnipeds also predate on adult coho migrating from Puget Sound to the Lake Washington Ship Canal (SPU & USACE 2008), but the magnitude of pinniped predation on coho is unclear.

4.3 Spawning

Coho salmon spawn widely throughout WRIA 8, including within the Cedar River, Issaquah Creek, Bear Creek, and other larger tributaries, but also within numerous small streams that drain to these larger tributaries, directly to Lake Washington and Lake Sammamish, and directly to Puget Sound (King County 2005, 2016; Heller 2023; WDFW 2023b; WDFW unpublished data). Spawners in some smaller tributaries (e.g., Coal Creek) include surplus coho that returned to the Issaquah Creek hatchery and that were outplanted by the Muckleshoot Indian Tribe to supplement low numbers of natural spawners. Coho spawn during fall and early winter, primarily between late October and late December (King County 2005, 2016; Heller 2023; WDFW unpublished data).

However, there appears to be spatial variation in the timing of coho spawning within the basin, with later spawning (through January and February) within the Cedar River basin and earlier spawning within the Issaquah Creek basin (SPU & USACE 2008; Unrein 2023b; WDFW unpublished data).

Extensive pre-spawn mortality of coho salmon has been consistently observed in urbanized streams within WRIA 8 and other Puget Sound watersheds (Scholz et al. 2011; Feist et al. 2017). Rates of pre-spawn mortality are positively associated with impervious land cover, road density, and other measures of watershed urbanization, suggesting that stormwater runoff from impervious surfaces is the cause of mortality (Feist et al. 2011, 2017). Recently, Tian et al. (2021) identified 6PPD-quinone, an oxidative byproduct of an additive to vehicle tires, as the primary toxicant within stormwater runoff that is responsible for coho pre-spawn mortality.

Along with stormwater runoff-induced mortality, human infrastructure creates fish passage barriers that constrain the distribution of coho salmon spawning in many WRIA 8 basins, particularly in small headwater streams. The benefits of remediating fish passage barriers are exemplified in the recolonization of coho in the Cedar River upstream of the Landsburg diversion dam. After the dam was retrofitted to allow fish passage in 2003, coho rapidly recolonized the upper Cedar River and appear to have a productive, self-sustaining population above the dam (Anderson et al. 2015; Kiffney et al. 2023; Unrein 2023b).

In addition to stormwater runoff and fish passage barriers, many rivers and streams in WRIA 8 have been extensively altered through urbanization, removal of riparian vegetation, loss of large wood, altered sedimentation rates, disconnection from floodplains, loss of channel-complexity, and loss of off-channel habitats (Kirwin 2001). These alterations likely impair both the quantity and quality of coho spawning habitat.

4.4 Incubation and Emergence

After spawning, coho salmon eggs incubate until late winter or spring, although there is limited documentation of coho emergence timing within WRIA 8. Within the Cedar River, coho fry are typically observed beginning in mid- to late March (King County unpublished data). Flashy hydrology caused by impervious land cover, along with other instream alterations such as loss of large wood and channel complexity, likely contribute to mortality of incubating coho eggs via increased scouring or sedimentation of redds.

4.5 Stream Rearing and Downstream Migration

Most juvenile coho salmon spend a full year within streams or rivers before out-migrating to Puget Sound, but some also out-migrate during their first spring or summer in freshwater, and occasionally after spending two years in freshwater (DeVries et al. 2005; SPU & USACE 2008; Anderson and Lisi 2023). The primary emigration period spans April to June, with peak emigration occurring during May (Kiyohara 2017; Anderson and Lisi 2023). Juvenile coho feed primarily on aquatic insects during

freshwater rearing but also consume small fishes such as sockeye salmon fry (Tabor et al. 2004b, 2014).

Because most coho salmon spend a full year rearing in freshwater, the productivity of coho populations is strongly influenced by freshwater conditions. The extensive alterations to river and stream habitats within WRIA 8 likely constrain the survival of juvenile coho. Loss of instream and channel complexity, including large wood, native riparian vegetation, beaver dams, pools, and off-channel habitats, along with water withdrawals, anthropogenic pollution, and high summer water temperatures, are some of the major impairments to juvenile coho habitat in WRIA 8's rivers and streams. Floodplain reconnection and off-channel habitat restoration projects implemented in the Cedar River appear to be improving rearing conditions and increasing localized abundances of juvenile coho and other salmonids (Lincoln and Akyuz 2022; David and Stiling 2024; King County unpublished data).

4.6 Lake Rearing

Extensive lake rearing by coho salmon has been observed in British Columbia lakes and a few Washington lakes (Swain and Holtby 1989; Bonar et al. 2005; Arostegui and Quinn 2019). However, juvenile coho do not appear to rear extensively in Lake Washington or Lake Sammamish. After emigrating from rivers or streams, coho smolts pass through Lake Sammamish and/or Lake Washington on their way to Puget Sound. The duration of time between PIT-tagging of coho smolts in the Cedar River or Bear Creek and detection at the Ballard Locks averaged 17.5 days (range of tagging group medians: 10 – 27 days; DeVries et al. 2004). During lake residence, coho are primarily found near shore (SPU & USACE 2008), otherwise little information is available regarding the distribution or behavior of coho smolts within Lake Washington and Lake Sammamish.

Risks to coho salmon smolt survival in the lakes include predation, high water temperatures, lakeshore alteration, and water quality impairments (SPU & USACE 2008; MIT 2016; Urgenson et al. 2021). Largemouth bass, smallmouth bass, and northern pikeminnow prey on coho smolts in the Lake Washington Ship Canal, particularly during June and July, and may consume a significant number of smolts (Tabor et al. 2004b, 2007). However, most of the predation observed by Tabor et al. (2004b, 2007) was on subyearling coho, which were likely from the now inactive University of Washington hatchery. While cutthroat trout and northern pikeminnow occasionally prey on coho smolts in Lake Washington and Lake Sammamish, coho do not appear to make up a significant portion of the diet of these predators (Overman et al. 2009).

High water temperature towards the end of this outmigration period may harm coho salmon smolts or increase their vulnerability to both native and non-native piscivores (DeVries et al. 2005; SPU & USACE 2008). Other factors that may exacerbate predation risk to coho smolts are artificial light at night (ALAN) and non-native aquatic vegetation. ALAN is an active research priority for WRIA 8, but little information is

available about how non-native aquatic vegetation mediates predation risk to juvenile salmonids. ALAN can attract juvenile coho (Tabor et al. 2017), potentially increasing their vulnerability to predators, and can extend the diel period when predatory fishes can effectively feed (Mazur and Beauchamp 2006; USGS unpublished data). The widespread alteration of lake shorelines and nearshore habitats in WRIA 8, along with anthropogenic water quality pollution, may also disrupt the food webs that support coho smolts as they migrate through the lakes.

4.7 Migration to Puget Sound

Coho salmon smolts generally out-migrate through the Ballard Locks between early May and late June (DeVries et al. 2004, 2005). As noted above, predation by non-native fishes, high water temperature (particularly towards the later end of the out-migration season), and extensive development of the Lake Washington Ship Canal are all risks to out-migrating coho smolts.

4.8 Nearshore Foraging

Because most coho salmon smolts emigrate to the marine environment as yearlings, they typically spend less time foraging in nearshore and estuarine environments than do smaller subyearling salmonids. However, coho smolts do forage along the WRIA 8 nearshore as they migrate into Puget Sound (Brennan et al. 2004; SPU & USACE 2008). Juvenile coho are primarily present in the nearshore waters of WRIA 8 during May, June, and July, with smaller numbers observed during late summer and early fall (Brennan et al. 2004).

Opportunities for rearing, foraging, and growth by juvenile coho salmon along the WRIA 8 nearshore have been impaired by the substantial alteration to shoreline and estuarine habitats. Significant impacts to the WRIA 8 nearshore environment include: disruption of flows of sediment and prey items by the Burlington Northern Santa Fe (BNSF) railroad and shoreline armoring; removal of marine riparian vegetation; destruction and isolation of small tidal marshes and pocket estuaries; and overall development of the coastal zone (Kerwin 2001).

4.9 Maturation (marine waters)

After navigating the nearshore environment, many coho salmon smolts from Puget Sound rivers migrate to the continental shelf along the Washington coast, Strait of Georgia, and Vancouver Island (Weitkamp and Neely 2002). However, a significant number of coho appear to stay in Puget Sound for the duration of their marine maturation (Quinn and Losee 2021).

4.10 Limiting Factors and Relevance of Chinook Recovery Strategies

There have been no comprehensive assessments of factors limiting WRIA 8 coho salmon productivity. However, given a general understanding of their biology, coho-

focused studies in the basin, and knowledge of habitat impairments within WRIA 8, reasonable assumptions can be made about primary factors limiting coho in WRIA 8.The primary factors limiting coho productivity in WRIA 8 appear to be: (1) limited access to spawning habitat due to fish passage barriers; (2) high rates of pre-spawn mortality in urbanized watersheds due to toxic stormwater runoff; and (3) low survival rates during freshwater rearing due to degraded stream and river habitats.

The WRIA 8 Chinook salmon recovery strategy most likely to address limited spawning habitat for coho salmon is to **remove fish passage barriers** (Table 3). The recovery strategies most likely to address high rates of pre-spawn mortality are to **improve water quality**, **protect and restore functional riparian vegetation**, and **protect and restore forest cover and headwater areas**. The recovery strategies most likely to address poor freshwater survival and rearing conditions are to **protect and restore floodplain connectivity**, **protect and restore functional riparian vegetation**, **protect and restore channel complexity**, **protect and restore forest cover and headwater areas**, **provide adequate streamflow**, and **improve water quality**.

Overall, there is substantial alignment between the WRIA 8 Chinook salmon recovery strategies and the primary factors limiting coho salmon productivity in the basin. We expect that implementation of each of the existing recovery strategies should provide some benefits to coho salmon within WRIA 8. However, greater focus on ways to mitigate the impacts of 6PPD-quinone on coho may be needed as this chemical has a greater impact on coho than Chinook or steelhead (French et al. 2022). Geographically, implementation of strategies to increase spawning habitat and improve freshwater rearing conditions are relevant to most of WRIA 8's rivers and streams given the widespread distribution of coho spawning and rearing. However, because coho will spawn and rear within smaller streams than Chinook, implementation of these strategies to maximize benefits to coho would likely entail more focus on smaller streams than strategies solely designed to benefit Chinook. Additionally, implementation of strategies to reduce pre-spawn mortality are most relevant in highly urbanized basins but should benefit coho throughout WRIA 8.

Table 3. Matrix of priority WRIA 8 Chinook salmon recovery strategies (row headers) and different locations within WRIA 8 (column headers). The matrix cells are colored according to the expected benefit to coho salmon of that strategy implemented in that location. Codes: strategy not applicable to this location/habitat, no benefit/benefit unlikely, modest benefit, and substantial benefit.

Recovery Strategies	Lake Union/Ship Canal	Lake Washington	Lake Sammamish	Cedar River	Sammamish River	Sammamish River tribs (Bear, Little Bear, North, Swamp)	Issaquah Creek	Other tributaries*	Marine nearshore	Notes
Protect and restore floodplain connectivity				Substantial benefit	Substantial benefit	Substantial benefit	Substantial benefit	Substantial benefit		Substantial benefits to juvenile coho rearing in streams and rivers, along with lesser benefits to spawning and incubation life stages.
Protect and restore functional riparian vegetation	Modest benefit	Modest benefit	Modest benefit	Substantial benefit	Substantial benefit	Substantial benefit	Substantial benefit	Substantial benefit	Modest benefit	Substantial benefits to juvenile coho rearing in streams and rivers, along with lesser benefits to spawning, incubation, and lake-migrating life stages.
Protect and restore channel complexity				Substantial benefit	Substantial benefit	Substantial benefit	Substantial benefit	Substantial benefit		Substantial benefits to juvenile coho rearing in streams and rivers, along with lesser benefits to spawning and incubation life stages.
Restore shallow-water rearing and refuge habitat	Modest benefit	Modest benefit	Modest benefit							Modest benefits to coho smolts migrating through Lake Washington and Lake Sammamish.
Reconnect and enhance creek mouths	Modest benefit	Modest benefit	Modest benefit	Modest benefit	Modest benefit	Modest benefit	Modest benefit	Modest benefit	Modest benefit	Modest benefits to both spawning and rearing coho by increasing the amount of accessible, quality stream habitat.
Protect and restore cold-water sources and reduce thermal barriers to migration	Modest benefit	Modest benefit	Modest benefit	Modest benefit	Modest benefit	Modest benefit	Modest benefit	Modest benefit		Modest benefits to adult migration, spawning, and stream rearing coho life stages throughout the basin.
Improve juvenile and adult survival at the Ballard Locks	Modest benefit									Improving juvenile and adult survival at the Ballard Locks should provide modest benefits to the WRIA 8 coho population.
Reduce predation of juvenile migrants and lake-rearing fry	Modest benefit	Modest benefit	Modest benefit	Modest benefit	Modest benefit	Modest benefit	Modest benefit	Modest benefit		Reducing predation risk should provide modest benefits to stream-rearing and lake-migrating coho salmon.
Remove or reduce impact of overwater structures	Modest benefit	Modest benefit	Modest benefit		Modest benefit				Modest benefit	Small benefit to coho smolts as they migrate through the Lakes and Puget Sound.
Remove fish passage barriers				Substantial benefit	Substantial benefit	Substantial benefit	Substantial benefit	Substantial benefit	Substantial benefit	Substantial benefits to spawning coho by increasing the amount of accessible, quality spawning habitat.
Protect and restore forest cover and headwater areas				Substantial benefit	Substantial benefit	Substantial benefit	Substantial benefit	Substantial benefit		Substantial benefits to spawning, incubation, and stream rearing coho throughout WRIA 8.
Provide adequate streamflow				Substantial benefit	Substantial benefit	Substantial benefit	Substantial benefit	Substantial benefit		Substantial benefits to stream rearing coho throughout WRIA 8.
Restore sediment processes necessary for key life stages				Modest benefit	Modest benefit	Modest benefit	Modest benefit	Modest benefit		Modest benefits to spawning, incubation, and stream rearing coho.
Restore natural marine shorelines									Modest benefit	Modest benefits to coho smolts as they leave freshwater and migrate through Puget Sound.
Reconnect backshore areas and pocket estuaries									Modest benefit	Modest benefits to coho smolts as they leave freshwater and migrate through Puget Sound.
Protect and restore marine water and sediment quality									Modest benefit	Modest benefits to coho smolts as they leave freshwater and migrate through Puget Sound.
Improve water quality	Modest benefit	Modest benefit	Modest benefit	Modest benefit	Substantial benefit	Substantial benefit	Modest benefit	Substantial benefit		Substantial benefits to spawning, incubation, and stream rearing coho life stages in the more urbanized basins within WRIA 8 and modest benefits in less-urbanized basins.

*'Other' tributaries that coho salmon use within WRIA 8 are small streams that drain to larger rivers and creeks, drain directly to Lake Washington or Lake Sammamish, and drain directly to Puget sound.

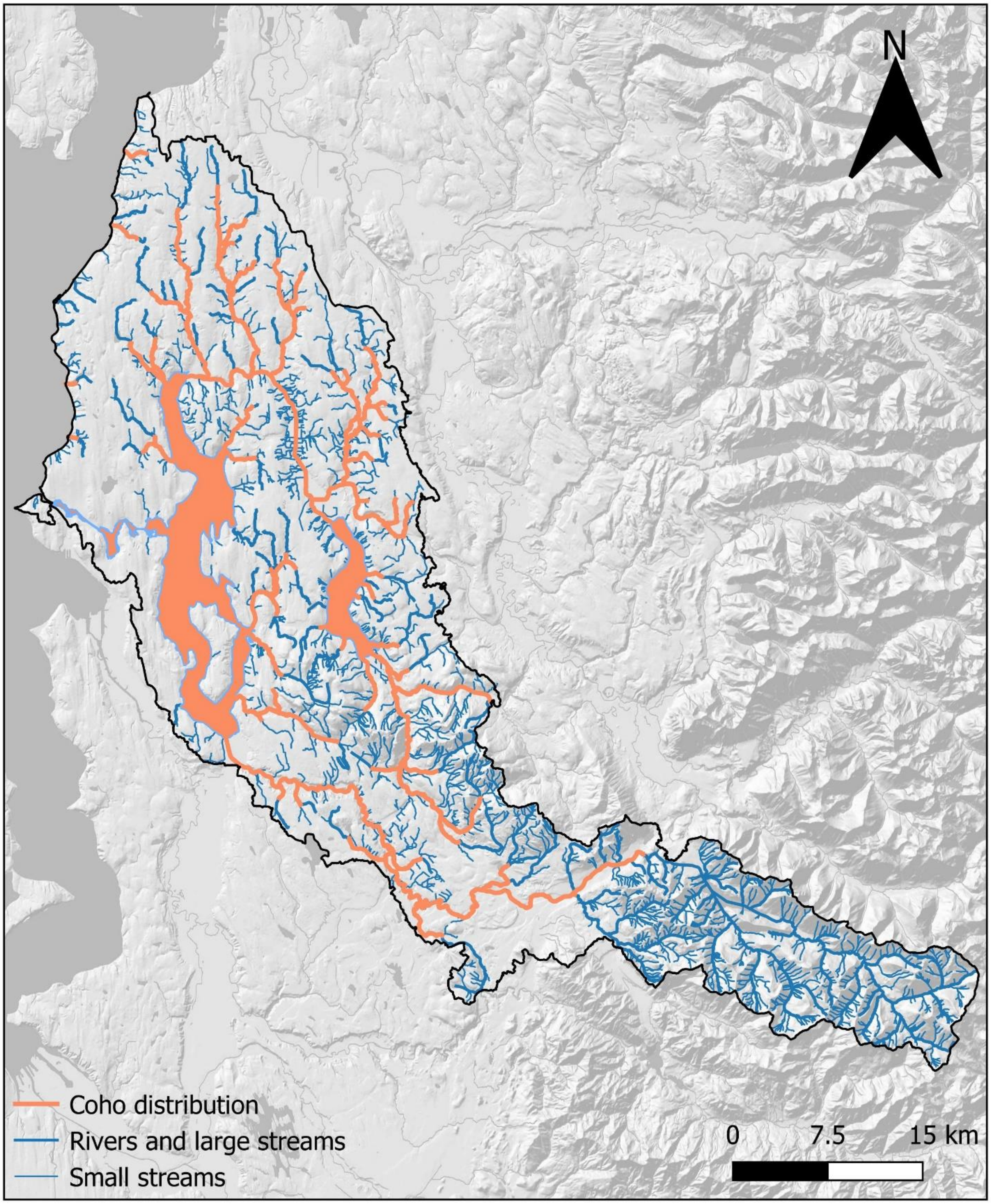

Figure 4. The distribution of coho salmon within WRIA 8. This distribution is approximate and may not represent the full distribution of coho salmon within WRIA 8, particularly within small streams. Due to the inherent challenges in defining the exact distribution of a species and the absence of consistent surveys in many of the watershed's small streams, this map should not be considered definitive and should not be used for regulatory or restoration/protection decision making.

5 Chum Salmon

5.1 Overview

Chum salmon (*O. keta*) were present in the Cedar River prior to its rerouting into Lake Washington in the early 1900s, but while small numbers of chum are occasionally observed in tributaries to Lake Washington, this population subsequently went extinct (Kerwin 2001). Currently, most chum in WRIA 8 spawn and rear within small streams that drain directly to Puget Sound north of the Ballard Locks, including Pipers Creek, Boeing Creek, and Lunds Gulch (Figure 5). These chum are not part of a defined population or management unit and consist of both natural-origin spawners and Grovers Creek hatchery chum that are released in Pipers Creek by the Carkeek Watershed Community Action Project.

5.2 Adult Migration

Mature chum salmon migrate directly from Puget Sound into their spawning streams. Given the small size of the watersheds in which chum spawn and alteration of the natural hydrology due to extensive development of these basins, mature chum may be unable to migrate into these steams until the first fall rainstorms increase flows. Additionally, the Burlington Northern Santa Fe (BNSF) railway runs along most of the WRIA 8 marine shoreline, creating partial or complete fish passage barriers at the mouths of streams draining to Puget Sound.

5.3 Spawning

Chum salmon spawn in Pipers Creek, Boeing Creek, Lunds Gulch, and possibly other small streams in WRIA 8 (King County 2005, 2016). Within Pipers Creek, chum spawn primarily from mid-October to mid-December, with peak spawning in November (CWCAP 2023). Fish passage barriers likely constrain the spawning distribution of chum in WRIA 8 streams draining directly to Puget Sound, including the BNSF railway and other human infrastructure further upstream in these watersheds.

Overall, these small nearshore streams have been extensively developed and altered from natural conditions, impairing both the quantity and quality of chum salmon spawning habitat. Specific habitat impairments that impact spawning and other life stages of chum in these streams include extensive urbanization and impervious land cover, flashy hydrology, high rates of erosion and sedimentation, loss of large wood, loss of pools, loss of channel complexity and connectivity, and loss of native riparian vegetation (Kerwin 2001).

5.4 Incubation and Emergence

After spawning, chum salmon eggs incubate until late winter or spring, although information on chum emergence timing within WRIA 8 is not available. Flashy hydrology and high rates of sedimentation caused by extensive development and impervious land

cover, along with other instream alterations such as loss of large wood and channel complexity, are likely significant sources of mortality for incubating chum eggs.

5.5 Stream Rearing and Downstream Migration

After emerging from the stream gravel, chum salmon fry typically migrate rapidly downstream at night (Quinn 2018). Chum fry have been observed in Pipers Creek, Boeing Creek, Lunds Gulch, Picnic Point Creek, and Big Gulch between March and May (Beamer et al. 2013; Tulalip Tribes unpublished data). Stream rearing habitat for chum is impaired by many of the same factors that impact spawning and incubating life stages: flashy hydrology, high rates of erosion and sedimentation, loss of large wood, loss of pools, loss of channel complexity, loss of native riparian vegetation, and poor water quality due to anthropogenic pollution.

5.6 Lake Rearing

This life history stage is not relevant to chum salmon.

5.7 Migration to Puget Sound

Given the small size of the streams where chum salmon spawn in WRIA 8, the impaired habitat conditions of many of these streams, and the short time that chum fry typically rear within freshwater environments, chum fry presumably migrate quickly to Puget Sound from their natal streams.

5.8 Nearshore Foraging

After subyearling Chinook salmon, chum salmon tend to spend the most time rearing in estuarine and nearshore coastal environments of all Pacific salmonid species (Quinn 2018). Juvenile chum forage and grow extensively in estuarine and other coastal habitats prior to migrating to the open ocean (Sibert et al. 1977; Simenstad et al. 1982; Quinn 2018). Juvenile chum are present in nearshore waters along the WRIA 8 shoreline, with peak abundances in April through June (Brennan et al. 2004). These juvenile chum likely originate from multiple Puget Sound populations.

Substantial alteration to shoreline and estuarine habitats impairs opportunities for rearing, foraging, and growth by juvenile chum in the WRIA 8 nearshore. Significant impacts to the WRIA 8 nearshore environment include: disruption of flows of sediment and prey items by the railroad and shoreline armoring; removal of marine riparian vegetation; destruction and isolation of small tidal marshes and pocket estuaries; and overall development of the coastal zone (Kerwin 2001). For example, nearshore armor and loss of marine riparian vegetation reduce terrestrial insect drift that support juvenile chum and other salmonids along the nearshore (Romanuk and Levings 2003; Sobocinski et al. 2010).

5.9 Maturation (marine waters)

After foraging and growing in the nearshore environment, juvenile chum salmon typically migrate through Puget Sound and the Strait of Juan de Fuca to the open ocean during summer and fall. Chum from Washington tend to migrate to the north and west along the continental shelf, spending most of their ocean residence in the North Pacific Ocean, Gulf of Alaska, or Bering Sea (Urawa et al. 2018). However, some chum appear to stay in Puget Sound for the duration of their marine maturation (Quinn and Losee 2021). Chum mature at a wide range of ages, but primarily at age three or four in the Pacific Northwest (Urawa et al. 2018).

5.10 Limiting Factors and Relevance of Chinook Recovery Strategies

To our knowledge there have been no assessments to identify factors limiting WRIA 8 chum salmon productivity. However, given their biology and impairments to stream habitats draining directly to Puget Sound, reasonable assumptions can be made about primary factors limiting chum in WRIA 8.

The primary factors limiting chum productivity in WRIA 8 appear to be: (1) limited spawning habitat due to fish passage barriers; (2) high mortality of incubating eggs due to flashy hydrology and high sedimentation rates; (3) low survival rates and limited growth opportunities during stream residence due to degraded stream habitat; and (4) poor foraging and growth opportunities in the marine nearshore environment due to altered nearshore and coastal habitats.

The WRIA 8 Chinook salmon recovery strategies most likely to address limited spawning habitat for chum salmon are to **remove fish passage barriers** and to **reconnect and enhance creek mouths** (Table 4). However, within the WRIA 8 Chinook recovery plan the **reconnect and enhance creek mouths** strategy is focused on freshwater tributary stream mouths, not coastal streams. An example of successful implementation of these strategies is the recent replacement of the railroad culvert over Lunds Gulch with a wider bridge that improves fish passage and the flow of water and sediment (Meadowdale Beach and Estuary Restoration project).

The recovery strategies most likely to address high incubation mortality and poor stream rearing conditions are to **protect and restore floodplain connectivity**, **protect and restore functional riparian vegetation**, **protect and restore channel complexity**, **protect and restore forest cover and headwater areas**, **restore sediment processes necessary for key life stages**, and **improve water quality**. The recovery strategies most likely to improve foraging and growth opportunities for juvenile chum salmon in the nearshore environment are to **protect and restore functional riparian vegetation**, **restore natural marine shorelines**, and **reconnect backshore areas and pocket estuaries**. Fish passage barrier removal projects along the shoreline, such as the Meadowdale Beach and Estuary Restoration project, can also help reconnect backshore areas and pocket estuaries. Geographically, implementation of these strategies is relevant to chum in small streams draining directly to Puget Sound along the WRIA 8 marine nearshore.

Table 4. Matrix of priority WRIA 8 Chinook salmon recovery strategies (row headers) and different locations within WRIA 8 (column headers). The matrix cells are colored according to the expected benefit to chum salmon of that strategy implemented in that location. Codes: strategy not applicable to this location/habitat, no benefit/benefit unlikely, modest benefit, and substantial benefit.

Recovery Strategies	Lake Union/Ship Canal	Lake Washington	Lake Sammamish	Cedar River	Sammamish River	Sammamish River tribs (Bear, Little Bear, North, Swamp)	Issaquah Creek	Other tributaries*	Marine nearshore	Notes
Protect and restore floodplain connectivity				No benefit	No benefit	No benefit	No benefit	Substantial benefit		Substantial benefits to spawning, incubation, and stream rearing in chum spawning streams.
Protect and restore functional riparian vegetation	No benefit	No benefit	No benefit	No benefit	No benefit	No benefit	No benefit	Substantial benefit	Substantial benefit	Substantial benefits to spawning, incubation, and stream rearing in chum spawning streams, along with chum fry as they leave freshwater and migrate through Puget Sound.
Protect and restore channel complexity				No benefit	No benefit	No benefit	No benefit	Substantial benefit		Substantial benefits to spawning, incubation, and stream rearing in chum spawning streams.
Restore shallow-water rearing and refuge habitat	No benefit	No benefit	No benefit							This strategy is not expected to provide benefits to chum because it is focused on lake environments.
Reconnect and enhance creek mouths	No benefit	No benefit	No benefit	No benefit	No benefit	No benefit	No benefit	Substantial benefit	Substantial benefit	Substantial benefits to spawning chum by increasing the amount of accessible, quality spawning habitat.
Protect and restore cold-water sources and reduce thermal barriers to migration	No benefit	No benefit	No benefit	No benefit	No benefit	No benefit	No benefit	Modest benefit		Small benefit to spawning chum and stream-rearing chum fry, although water temperature does not appear to be a limiting factor for chum in WRIA 8.
Improve juvenile and adult survival at the Ballard Locks	No benefit									This strategy is not relevant to chum.
Reduce predation of juvenile migrants and lake-rearing fry	No benefit	No benefit	No benefit	No benefit	No benefit	No benefit	No benefit	Modest benefit		May provide a small benefit to out-migrating chum fry.
Remove or reduce impact of overwater structures	No benefit	No benefit	No benefit		No benefit				Modest benefit	May provide a small benefit to chum fry as they leave freshwater and migrate through Puget Sound.
Remove fish passage barriers				No benefit	No benefit	No benefit	No benefit	Substantial benefit	Substantial benefit	Substantial benefits to spawning chum by increasing the amount of accessible, quality spawning habitat.
Protect and restore forest cover and headwater areas				No benefit	No benefit	No benefit	No benefit	Substantial benefit		Substantial benefits to spawning, incubation, and stream rearing in chum spawning streams.
Provide adequate streamflow				No benefit	No benefit	No benefit	No benefit	Modest benefit		May provide a small benefit to spawning and incubation life stages in chum spawning streams.
Restore sediment processes necessary for key life stages				No benefit	No benefit	No benefit	No benefit	Substantial benefit		Substantial benefits to spawning, incubation, and stream rearing in chum spawning streams.
Restore natural marine shorelines									Substantial benefit	Substantial benefits to chum fry as they leave freshwater and migrate through Puget Sound.
Reconnect backshore areas and pocket estuaries									Substantial benefit	Substantial benefits to chum fry as they leave freshwater and migrate through Puget Sound.
Protect and restore marine water and sediment quality									Modest benefit	Modest benefits to chum fry as they leave freshwater and migrate through Puget Sound.
Improve water quality	No benefit	No benefit	No benefit	No benefit	No benefit	No benefit	No benefit	Substantial benefit		Substantial benefits to spawning, incubation, and stream rearing in chum spawning streams.

*'Other' tributaries that chum salmon use within WRIA 8 are the small streams that drain directly to Puget sound (e.g., Pipers Creek, Boeing Creek, Picnic Point Creek, Big Gulch, and Lunds Gulch).

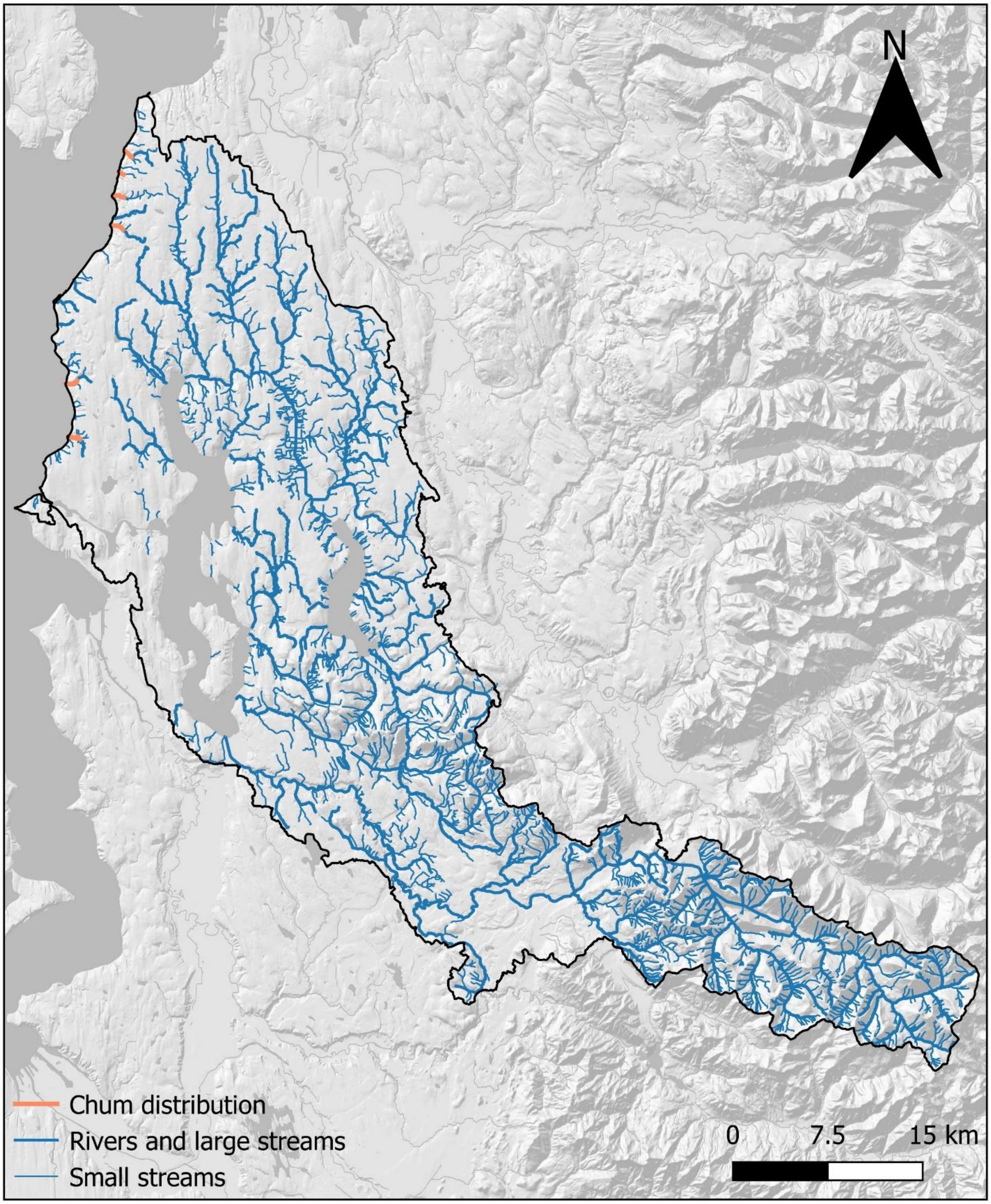

Figure 5. The distribution of chum salmon within WRIA 8. This distribution is approximate and may not represent the full distribution of chum within WRIA 8. Due to the inherent challenges in defining the exact distribution of a species and the absence of consistent surveys in many of the watershed's small streams, this map should not be considered definitive and should not be used for regulatory or restoration/protection decision making.

6 Steelhead

6.1 Overview

WRIA 8 currently supports limited numbers of two demographically independent steelhead (*O. mykiss*) populations, Cedar River Winter Run steelhead and North Lake Washington/Lake Sammamish Winter Run steelhead (Myers et al. 2015; WDFW 2023c). These populations are part of the larger Puget Sound steelhead distinct population segment, which was listed as threatened under the Endangered Species Act in 2007 (Myers et al. 2015). The Cedar River was designated as critical habitat for Puget Sound steelhead, but Lake Washington, Lake Sammamish, the Sammamish River, and their tributaries were not (NOAA 2016). The Cedar River population spawns in the Cedar River and other small tributaries to the south end of Lake Washington (Myers et al. 2015). The North Lake Washington/Lake Sammamish population spawns in small tributaries to the north end of Lake Washington, tributaries to the Sammamish River, and tributaries to Lake Sammamish (Figure 6). Unfortunately, counts of spawners have been extremely low since the early 2000s and both populations appear to be functionally extinct (Myers et al. 2015; Burton 2022; WDFW 2023c). However, WRIA 8, particularly the Cedar River, supports a robust population of rainbow trout (Tabor et al. 2014; Myers et al. 2015), the non-anadromous *O. mykiss* life history variant. Steelhead and rainbow trout within WRIA 8 are closely genetically related and appear to interbreed (Marshall et al. 2006). The existence of resident *O. mykiss* within WRIA 8, along with the capacity of rainbow trout to produce offspring that can become anadromous and vice versa (Kendall et al. 2015), suggest potential exists to restore viable steelhead populations within WRIA 8.

6.2 Adult Migration

Mature steelhead primarily return to WRIA 8 through the Ballard Locks during winter and early spring (SPU & USACE 2008), with most migrating between January and March (Gearin et al. 1988). A significant source of mortality to returning adult steelhead in the past has been predation by sea lions and other pinnipeds in Shilshole Bay and around the Ballard Locks (Gearin et al. 1988; Pfeifer 1990; SPU & USACE 2008). However, it is unclear how much predation by pinnipeds currently impact returning steelhead. In contrast to other anadromous salmonids within WRIA 8, water temperature and dissolved oxygen conditions within Lake Union and the Ship Canal likely have minimal deleterious impact on migrating steelhead because temperatures are low and dissolved oxygen concentrations high during winter and early spring.

6.3 Spawning

The few remaining steelhead primarily spawn within the Cedar River (Burton 2022), but in the past steelhead have spawned in other WRIA 8 tributaries (Kerwin 2001; Myers et al. 2015; WDFW 2023b). Between 2007 and 2022, the estimated number of spawning steelhead in the Cedar River below the Landsburg diversion dam ranged from zero to ten (WDFW 2023c). A total of 29 presumptive steelhead were observed passing above

Landsburg Dam from 2003 to 2022 (Unrein 2023b). Information on the spawning distribution of steelhead within WRIA 8 but outside of the Cedar River is limited (Meyers et al. 2015; WDFW 2023c). Rainbow trout also spawn in the Cedar River (Burton 2022) and presumably spawn in other locations within WRIA 8, including small tributaries to Lake Washington, tributaries to the Sammamish River, and tributaries to Lake Sammamish. In the Cedar River, steelhead spawn primarily from March to May (Burton 2022).

Many of WRIA 8's rivers and streams have been extensively altered through urbanization, removal of riparian vegetation, loss of large wood, altered sedimentation rates, disconnection from floodplains, loss of channel complexity, and loss of off-channel habitats (Kerwin 2001). All of which impact the quantity and quality of steelhead and rainbow trout spawning habitat. Freshwater habitat degradation appears to be a key constraint on the productivity of WRIA 8 steelhead (Cram et al. 2018; NMFS 2019).

6.4 Incubation and Emergence

Steelhead eggs typically incubate between 60 to 90 days after being spawned, depending on water temperatures (Burton 2022). Earlier spawned eggs generally incubate longer, and later spawned eggs incubate for a shorter period. Thus, most steelhead fry emerge between late spring or early summer. Flashy hydrology and high rates of sedimentation caused by extensive development and impervious land cover, along with other instream alterations such as loss of large wood and channel complexity, are likely significant sources of mortality for incubating steelhead eggs. Stream flow during incubation also affects the survival of spawned eggs due to the risk of dewatering of redds, particularly because steelhead often spawn during the descending limb of natural hydrographs in the Pacific Northwest. Therefore, flows are managed in part in the Cedar River to minimize the risk of dewatering steelhead redds (Burton 2022).

6.5 Stream Rearing and Downstream Migration

Juvenile steelhead typically rear for at least a year, if not longer, in freshwater before migrating to the ocean, while rainbow trout complete their entire life cycle in freshwater. Therefore, steelhead and rainbow trout populations are particularly sensitive to freshwater conditions. Most steelhead within WRIA 8 spend between one and three years in freshwater before emigrating to the ocean (Fresh and Lucchetti 2000; Kerwin 2001). Rainbow trout have been observed up to five years old within the Cedar River (Tabor et al. 2014). Given the extensive freshwater residence of steelhead and rainbow trout, loss and degradation of freshwater habitats within WRIA 8 likely constrain the survival of juvenile steelhead and trout (Cram et al. 2018; NMFS 2019). Loss of large wood, native riparian vegetation, pools, channel complexity, and off-channel habitats, along with water withdrawals, anthropogenic pollution, and high summer water temperatures, are some of the major impairments to steelhead habitat in WRIA 8's rivers and streams (Fresh and Lucchetti 2000; Kerwin 2001; NMFS 2019).

In the Cedar River, *O. mykiss* sometimes forage extensively on other fishes, particularly sockeye salmon (Beauchamp 1995; Tabor et al. 2014). Thus, declines in other salmonids that are part of the *O. mykiss* forage base within WRIA 8 may also constrain their freshwater productivity. While spawning steelhead have only been observed in very low numbers in recent years, if at all, outmigrant traps on the Cedar River and Bear Creek typically catch small numbers of *O. mykiss* each year that appear to be steelhead smolts (e.g., Kiyohara 2017; Lisi 2018). Small numbers of juvenile *O. mykiss* tagged in the Cedar River have later been detected at the Ballard Locks, further indicating the persistence of an anadromous *O. mykiss* life history within the Cedar River (Tabor et al. 2014). Most *O. mykiss* smolts emigrate from the Cedar River and Bear Creek during spring, with peak emigration during April and May (Seiler et al. 2003, 2004a, 2004b).

6.6 <u>Lake Rearing</u>

The ecology and behavior of steelhead smolts and rainbow trout within Lake Washington and Lake Sammamish are poorly understood (SPU & USACE 2008). For example, it is unclear if steelhead smolts rapidly migrate through Lake Washington or Lake Sammamish on their way to Puget Sound, or if they actively feed and rear. Hatchery rainbow trout stocked in Lake Washington during the 1980s consumed a mix of zooplankton, insects, and fishes, with zooplankton representing a larger proportion of the diets of smaller trout and fishes representing a larger proportion of the diets of larger trout (Beauchamp 1990). In other watersheds with large lakes, resident *O. mykiss* often adopt an adfluvial life history, meaning that these fish spend a significant portion of their lives within lakes. Within WRIA 8 it is unclear to what extent rainbow trout adopt an adfluvial life history, but rainbow trout are occasionally observed in both Lake Washington (Garrett et al. 2017) and Lake Sammamish (Lantz 2023). The limited understanding of the ecology of *O. mykiss* within Lake Washington and Lake Sammamish is an important area of uncertainty about this species.

6.7 <u>Migration to Puget Sound</u>

Information regarding the migration of steelhead smolts from Lake Washington to Puget Sound is also limited, although most smolts pass through the Ship Canal during May and June (SPU & USACE 2008 and references therein). Risks to steelhead smolt survival during outmigration through the Ship Canal likely include predation, warm water temperatures, lakeshore habitat alteration, and water quality impairments (SPU & USACE 2008; Urgenson et al. 2021).

6.8 <u>Nearshore Foraging</u>

After leaving freshwater, steelhead smolts tend to move offshore and migrate rapidly though Puget Sound (Goetz et al. 2015; Quinn 2018). Therefore, steelhead smolts likely rely less on nearshore food webs than do salmonids that out-migrate as subyearlings such as Chinook or chum salmon. Survival of steelhead smolts migrating through Puget Sound is generally low (Goetz et al. 2015; Moore et al. 2015; Kendall et al. 2017),

suggesting that conditions in this environment constrain productivity of Puget Sound steelhead populations.

6.9 Maturation (marine waters)

Steelhead have an extensive marine distribution, and this distribution varies depending on the age of the fish and time of year (Myers 2018). However, steelhead from North America tend to be concentrated off the coast of British Columbia, in the Gulf of Alaska, or in the central North Pacific Ocean (Myers 2018). The period of marine residence is typically one to three years for steelhead (Myers 2018). Yet, steelhead are notable for their considerable life history diversity and can mature at a variety of ages (Myers 2018; Quinn 2018). Furthermore, some steelhead spawn repeatedly (kelts) and make multiple migrations between the marine and freshwater environments. However, the extent of repeat-spawning within WRIA 8 steelhead is unknown.

6.10 Limiting Factors and Relevance of Chinook Recovery Strategies

Due to the extremely low numbers of steelhead currently within WRIA 8 and lack of understanding of what led to the collapse of the WRIA 8 steelhead populations, little is known about the primary factors limiting the productivity and viability of WRIA 8 steelhead. However, given a general understanding of steelhead biology, steelhead-focused studies in the basin, and regional assessments of steelhead limiting factors and recovery strategies (i.e., Cram et al. 2018; NFMS 2019), reasonable assumptions can be made about primary factors limiting steelhead in WRIA 8.

The primary factors limiting steelhead productivity in WRIA 8 appear to be: (1) predation on mature steelhead as they return to freshwater to spawn; (2) low survival rates during freshwater rearing due to lost and degraded stream and river habitats; and (3) low survival rates during outmigration through Puget Sound due to predation and altered coastal habitats. However, there is considerable uncertainty regarding whether these or other factors are the primary limitations on steelhead productivity in WRIA 8.

The WRIA 8 Chinook salmon recovery strategy most likely to address predation on steelhead returning to spawn is to **improve juvenile and adult survival at the Ballard Locks** (Table 5). This strategy should focus on better understanding and ameliorating predation by pinnipeds on steelhead as they traverse the Ballard Locks. The recovery strategies most likely to address poor freshwater survival and rearing conditions are to **protect and restore floodplain connectivity**, **protect and restore functional riparian vegetation**, **protect and restore channel complexity**, **protect and restore forest cover and headwater areas**, **provide adequate streamflow**, and **protect and restore cold-water sources and reduce thermal barriers to migration**. The recovery strategies most likely to address poor survival during outmigration through Puget Sound are to **restore natural marine shorelines**, **reconnect backshore areas and pocket estuaries**, and **protect and restore marine water and sediment quality**. However, implementation of these strategies along the WRIA 8 shoreline would likely result in only modest improvements to steelhead survival due to poor survival being a Puget Sound-

wide phenomenon. Substantial improvements to the survival of steelhead smolts migrating through Puget Sound will require actions that extend beyond WRIA 8.

Overall, there is strong alignment between the WRIA 8 Chinook salmon recovery strategies and the primary factors limiting steelhead productivity in the basin. Implementation of each of the existing recovery strategies should provide some benefits to steelhead within WRIA 8. Yet, there may be additional factors that limit steelhead productivity that are not addressed by the WRIA 8 Chinook recovery strategies. For example, the dramatic decline of steelhead abundances in the 1990s and early 2000s is suggestive of a disease outbreak. Geographically, implementation of strategies to improve freshwater rearing conditions are relevant to most WRIA 8 rivers and streams given the widespread distribution (at least in the past) of steelhead spawning and rearing. However, given that most of the few observed steelhead spawners in recent years have been within the Cedar River, implementation of these strategies would be particularly beneficial in the Cedar River.

Table 5. Matrix of priority WRIA 8 Chinook salmon recovery strategies (row headers) and different locations within WRIA 8 (column headers). The matrix cells are colored according to the expected benefit to steelhead of that strategy implemented in that location. Codes: strategy not applicable to this location/habitat, no benefit/benefit unlikely, modest benefit, and substantial benefit.

Recovery Strategies	Lake Union/Ship Canal	Lake Washington	Lake Sammamish	Cedar River	Sammamish River	Sammamish River tribs (Bear, Little Bear, North, Swamp)	Issaquah Creek	Other tributaries*	Marine nearshore	Notes
Protect and restore floodplain connectivity				Substantial benefit	Substantial benefit	Substantial benefit	Substantial benefit	Substantial benefit		Substantial benefits to steelhead rearing in streams and rivers, along with lesser benefits to spawning and incubation life stages.
Protect and restore functional riparian vegetation	Modest benefit	Modest benefit	Modest benefit	Substantial benefit	Substantial benefit	Substantial benefit	Substantial benefit	Substantial benefit	Modest benefit	Substantial benefits to steelhead rearing in streams and rivers, along with lesser benefits to spawning, incubation, and lake-migrating life stages.
Protect and restore channel complexity				Substantial benefit	Substantial benefit	Substantial benefit	Substantial benefit	Substantial benefit		Substantial benefits to steelhead rearing in streams and rivers, along with lesser benefits to spawning and incubation life stages.
Restore shallow-water rearing and refuge habitat	Modest benefit	Modest benefit	Modest benefit							Modest benefits to steelhead smolts migrating through Lake Washington and Lake Sammamish.
Reconnect and enhance creek mouths	Modest benefit	Modest benefit	Modest benefit	Modest benefit	Modest benefit	Modest benefit	Modest benefit	Modest benefit	Modest benefit	Modest benefits to both spawning and rearing steelhead by increasing the amount of accessible, quality stream habitat.
Protect and restore cold-water sources and reduce thermal barriers to migration	Modest benefit	Modest benefit	Modest benefit	Substantial benefit	Substantial benefit	Substantial benefit	Substantial benefit	Substantial benefit		Substantial benefits to steelhead rearing in streams and rivers, along with lesser benefits to steelhead smolts migrating through Lake Washington, Lake Sammamish, and the Ship Canal.
Improve juvenile and adult survival at the Ballard Locks	Substantial benefit									Improving survival at the Ballard Locks, particularly for adult steelhead, should provide substantial benefits to the WRIA 8 steelhead population.
Reduce predation of juvenile migrants and lake-rearing fry	Modest benefit	Modest benefit	Modest benefit	Modest benefit	Modest benefit	Modest benefit	Modest benefit	Modest benefit		Reducing predation risk should provide modest benefits to stream-rearing and lake-migrating steelhead.
Remove or reduce impact of overwater structures	Modest benefit	Modest benefit	Modest benefit		Modest benefit				Modest benefit	Small benefit to steelhead smolts as they migrate through the Lakes and Puget Sound.
Remove fish passage barriers				Modest benefit	Modest benefit	Modest benefit	Modest benefit	Modest benefit	Modest benefit	Modest benefits to spawning and stream-rearing steelhead by increasing the amount of accessible spawning and rearing habitat.
Protect and restore forest cover and headwater areas				Substantial benefit	Substantial benefit	Substantial benefit	Substantial benefit	Substantial benefit		Substantial benefits to spawning, incubation, and stream rearing steelhead throughout WRIA 8.
Provide adequate streamflow				Substantial benefit	Substantial benefit	Substantial benefit	Substantial benefit	Substantial benefit		Substantial benefits to stream rearing steelhead throughout WRIA 8.
Restore sediment processes necessary for key life stages				Modest benefit	Modest benefit	Modest benefit	Modest benefit	Modest benefit		Modest benefits to spawning, incubation, and stream rearing steelhead.
Restore natural marine shorelines									Modest benefit	Modest benefits to steelhead as they leave freshwater and migrate through Puget Sound.
Reconnect backshore areas and pocket estuaries									Modest benefit	Modest benefits to steelhead as they leave freshwater and migrate through Puget Sound.
Protect and restore marine water and sediment quality									Modest benefit	Modest benefits to steelhead as they leave freshwater and migrate through Puget Sound.
Improve water quality	Modest benefit	Modest benefit	Modest benefit	Modest benefit	Modest benefit	Modest benefit	Modest benefit	Modest benefit		Modest benefits to spawning, incubation, and stream rearing steelhead life stages, particularly in more urbanized basins throughout WRIA 8.

*'Other' tributaries that steelhead use within WRIA 8 are small streams that drain to larger rivers and creeks or drain directly to Lake Washington or Lake Sammamish.

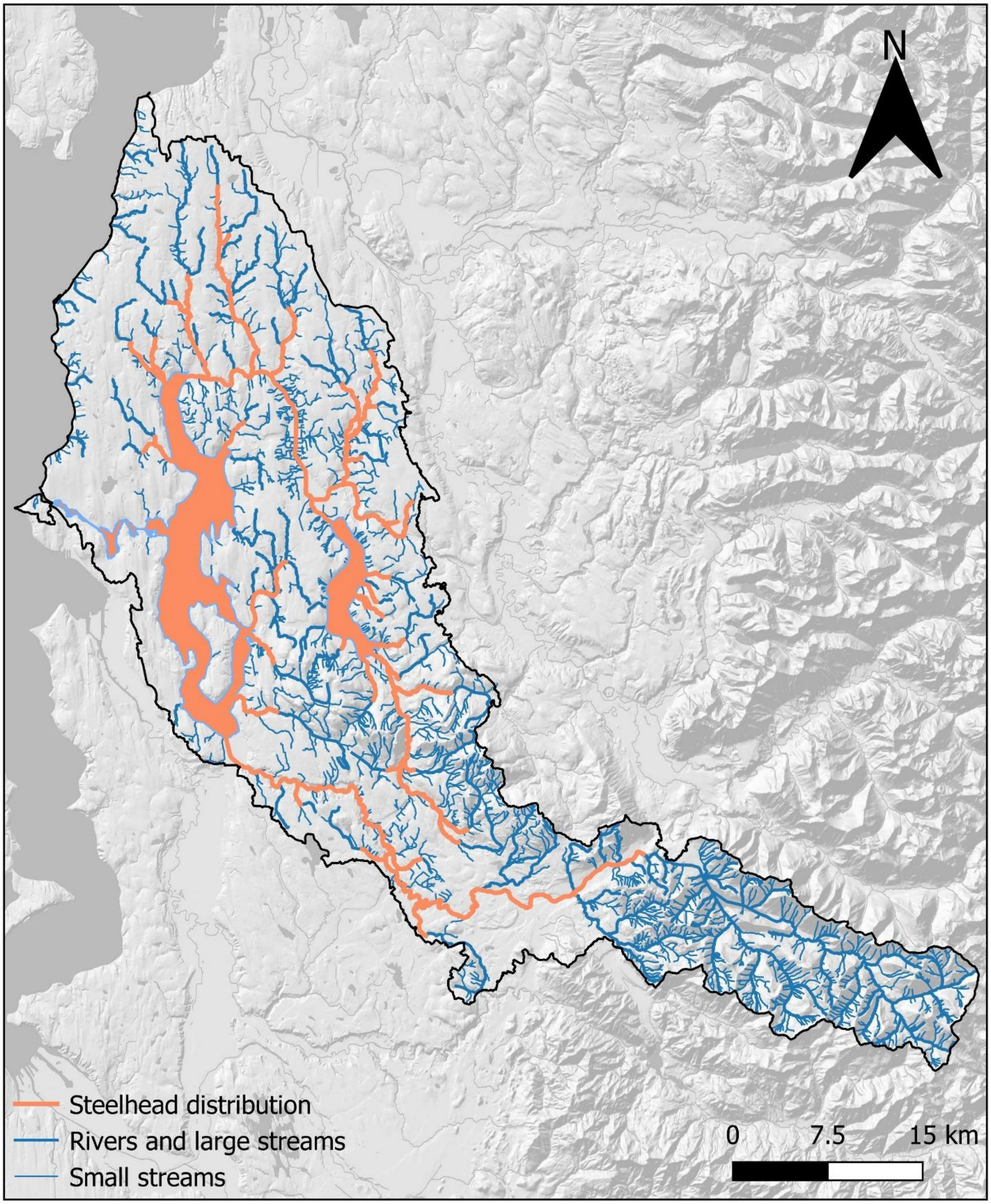

Figure 6. The distribution of steelhead within WRIA 8. This distribution is approximate and may not represent the full distribution of rainbow trout within WRIA 8. Due to the inherent challenges in defining the exact distribution of a species and the absence of consistent surveys in many of the watershed's small streams, this map should not be considered definitive and should not be used for regulatory or restoration/protection decision making.

7 Acknowledgements

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Appendix A. WRIA 8 Salmon Life Stage Timing Summary.