Nanaimo River Watershed Wild Salmon Policy Fish Habitat Status Report

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By

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DFO	Fisheries and Oceans Canada
DO	Dissolved oxygen
GIS	Geographic Information Systems
LWD	Large woody debris
MCW	MC Wright and Associates Ltd.
MFLNRORD	Ministry of Forests, Lands, and Natural Resources Operations and Rural Development
MOECCS	Ministry of Environment and Climate Change Strategy
NETF	Nanaimo Estuary Fish Habitat and Log Management Task Force
WSP	Wild Salmon Policy

INTRODUCTION

In 2005, Canada introduced the Wild Salmon Policy (WSP) to lay out a framework for the conservation and sustainable use of wild Pacific salmon. It identifies six strategies to incorporate habitat and ecosystem considerations into salmon management and to establish local collaborative planning and management efforts throughout British Columbia. Strategy 2 of the WSP is to use indicators and benchmarks of habitat status to evaluate and monitor habitat condition, the results of which will identify four key points of information to guide management: 1) high-value salmon habitats that require protection; 2) habitat constraints that are adversely affecting productivity; 3) areas where habitat restoration or rehabilitation could restore or enhance productivity; and 4) data gaps that may be investigated.

For the last decade, Fisheries and Oceans Canada (DFO) has been funding detailed assessments of watershed habitat status on Vancouver Island, in accordance with Strategy 2 of the WSP. This report presents the results of the Strategy 2 habitat status assessment for the Nanaimo River watershed.

1.1 Objectives

This report is intended to identify the state or quantity of habitat characteristics that are potentially limiting salmon production in the Nanaimo River watershed (by species and life stage), as well as habitats that require protection. There are six specific objectives of this report:

1. To document existing habitat characteristics in the Nanaimo River watershed;
2. To compare existing and historical habitat characteristics, where information exists;
3. To summarise the results of the DFO Risk Assessment Methodology for Salmon workshop held to identify which factors are most limiting Chinook Salmon production in the watershed;
4. To select habitat indicators and compare the state of the indicators to risk benchmarks;
5. To identify data gaps requiring further assessment or monitoring; and
6. To recommend enhancement, rehabilitation, and monitoring activities within the watershed that would have positive effects on salmon species within the Nanaimo River watershed.

1.2 Nanaimo River Watershed

1.2.1 General Description

The Nanaimo River watershed is located on the east coast of Vancouver Island near the city of Nanaimo (Map 1), within the traditional territories of the Snuneymuxw and Stz'uminus First Nations. With its tributaries, the 78 km Nanaimo River drains a total area of approximately 830 km^2. The headwaters of the river originate near Mount Hooper (Butler et al. 2014), approximately 44 km southwest of downtown Nanaimo (straight distance). From Mount Hooper, the river flows eastward to the town of Cassidy, and then northward into the Strait of Georgia via an estuary at the southern end of the Nanaimo Harbour (Bell and Kallman 1976).

The Nanaimo River estuary is the largest on Vancouver Island, and the fifth-largest in BC (Bell and Kallman 1976). In addition to the Nanaimo River, Chase River, Wexford Creek, and Beck (Hong Kong) Creek discharge into the west side of the Nanaimo River estuary, and Holden Creek discharges into the east side of the estuary (Bell and Kallman 1976). The Chase River originates along the southern slopes of Mount Benson and Holden Creek drains the Quennell lake system. For the purposes of discussion in this assessment, MCW has divided the watershed and the watersheds that drain into the estuary into coarse "sub-basins" (Map 1). These sub-basins correspond to areas of land that drain into various sections of the Nanaimo River or estuary.

1.2.2 Geology and Hydrology

The Nanaimo River lies in a low elevation area (<600 m) that was formed by the retreat of the last ice sheet that blanketed Vancouver Island (Bell and Kallman 1976). It is underlain by the Upper Cretaceous Nanaimo Group sedimentary deposits. The sedimentary deposits are comprised of conglomerates, sandstones, shales, and coal, which supported the Nanaimo coal mining industry for over 100 years between 1849 to the mid-1900s (Bell and Kallman 1976).

The Nanaimo River is joined by three major tributaries—North Nanaimo River (also known as Deadwood Creek), South Nanaimo River, and Haslam Creek—and also connects a series of lakes—First, Second, Third and Fourth Lakes (Bell and Kallman 1976, Butler et al. 2014). Fourth Lake is a reservoir on Sadie Creek created by the Fourth Lake Dam that supplies water to Harmac's Northern Bleached Softwood Kraft pulp mill, located outside the watershed at Duke Point. The City of Nanaimo also operates dams on South Nanaimo River (the South Fork Dam) and Jump Creek to supply water to the City of Nanaimo, Snuneymuxw First Nation, and the South West Extension Improvement District. Approximately 28% of the watershed or 230 km^2 is upstream of the dams (Butler et al. 2014).

Despite the presence of three storage reservoirs in the upper watershed, the annual distribution of flows in the Nanaimo River in Cassidy varies closely with precipitation (Butler et al. 2014). High flows generally occur in November, December, or January. Low flows occur in July to September. The lower Nanaimo River watershed is underlain by the Cassidy, South Wellington, and Cedar/Yellow Point North Oyster Aquifers. The groundwater inflow from the Cassidy Aquifer (Aquifer 161) may be a significant component of the base flow in the lower reaches of the Nanaimo River during low flows in late summer and early fall (Butler et al. 2014).

1.2.3 Climate

The Nanaimo River watershed is comprised of four Biogeoclimatic Zones. The lower Nanaimo River and estuary fall within the Coastal Douglas-fir zone (MFLNRORD 2016), which extends from tidewater to approximately 80 m above sea level. It is the warmest and driest zone of the watershed. The forests in this zone range from dry, open woodlands dominated by garry oak (*Quercus garryana*) and arbutus to more closed-canopy forests dominated by Douglas-fir. Understory vegetation is typically comprised of salal (*Gaultheria shallon*), dull Oregon-grape (*Mahonia nervosa*), ocean-spray (*Holodiscus discolor*) and Oregon beaked moss (*Eurhynchium oreganum*).

The majority of the watershed falls within the Coastal Western Hemlock biogeoclimatic zone (MFLNRORD 2016), which is characterized by a wet, humid climate with cool summers and mild, wet winters. The river channel falls within the Eastern variant of the Very Dry Maritime subzone, which extends up to 700 m in elevation. The mid-valley slopes in the watershed fall into the Western variant. Higher up the slopes, the watershed falls within the Montane variant of the Moist Maritime subzone, which extends to approximately 1000 m in elevation. The watershed's mountain ridges typically fall into the Mountain Hemlock zone. This subzone experiences long, wet, and cold winters with significant snowfall accumulation. Summers are typically short and cool.

The forests in the Coastal Western Hemlock and Mountain Hemlock zones are dominated by western hemlock (*Tsuga heterophylla*), but the plant community varies with elevation and wetness. Drier, lower elevation areas may have Douglas-fir (*Pseudotsuga menziesi*) and arbutus (*Arbutus menziesii*); wetter areas may have western redcedar (*Thuja plicata*), amabilis fir (*Abies amabilis*), and, at higher elevation, mountain hemlock (*Tsuga mertensiana*).

The highest peaks in the watershed fall into the Coastal subzone of the Alpine Tundra zone. This region has no trees, but supports a few low-growing shrubs, herbs, bryophytes and lichens. In this zone, vegetation grows between ice, rock, and snow.

Being in the rain shadow of the Vancouver Island Ranges, the region is drier than most of the mainland and the West Coast of Vancouver Island. Between 1981 and 2007, the mean monthly precipitation at the Nanaimo Airport climate station ranged from 25 mm in July to 197 mm in November; however, daily maxima infrequently reached 70–97 mm in winter and 24–76 mm in summer. Mean monthly snowfall peaked at 21 cm in January. Mean daily temperatures over this time ranged from 3.1°C in December (daily minimum and maximum of -0.2°C and 6.3°C) to 18.2°C in August (daily minimum and maximum of 12.1°C and 24.3°C).

With climate change, precipitation is becoming increasingly concentrated during winter, resulting in more severe storms and runoff events, decreased snowpack and snowpack contribution to late spring flows (Butler et al. 2014 and references therein). Staff at the Nanaimo River hatchery have observed longer summer droughts occurring into October (Banks B. and B. Herman, Nanaimo River Hatchery, pers. comm. 2019).

1.2.4 Historical Watershed Use

The Nanaimo River watershed has been extensively altered by human activities. The city of Nanaimo was established in the mid-1800s to develop the Nanaimo coalfields, and between then and 1953, when the last mine was closed, coal mining was the main industry in the area (Bell and Kallman 1976). In the mid-1900s, sand and gravel were mined from pits in the Nanaimo River Valley from the mouth of the river to approximately 16 km upstream for a variety of commercial uses, such as road building. The present downtown area of Nanaimo was created by infilling the natural coastline in the mid-to-late 1800s (Bell and Kallman 1976).

MacMillan Bloedel Ltd. opened the pulp mill at Harmac in 1950 and as coal was depleted in the 1950s, the economy became dependent on the forestry industry (Bell and Kallman 1976). The Nanaimo River watershed has been logged since the late 1800s and by the 1970s was largely comprised of second growth forest (Bell and Kallman 1976). First Lake was historically used for log booming (Figure 1). Historical clear-cut logging and burning eliminated riparian forest, increased erosion and sedimentation in the river and its tributaries, altered stream flow and channel morphology, and increased stream temperatures, all of which adversely impacted fish habitat and decreased fish production (as reviewed by Bell and Kallman 1976). For instance, in one of the first studies of the impacts of logging on BC streams, Narver (1972) found the number of trout in Jump Creek, a tributary to the South Nanaimo River, was twice as high in a forested section as in a recently clearcut and burned section. The logged section had a highly unstable channel with eroded banks, fewer pools, and very few remaining undercut banks with overhanging vegetation due to removal of all riparian vegetation (Figure 2). The impacted stream section was also ~2°C warmer than the forested section.

The Nanaimo River has been impacted since the 1930s by damming and water extraction (reviewed by Bell and Kallman 1976, Brahniuk et al. 1993). In the late 1800s, the Chase River provided the city of Nanaimo's water supply. In 1931, the City of Nanaimo constructed a dam and a 2 million m³ water reservoir on the South Nanaimo River to act as the city's water supply. The dam blocked upstream migration of salmon and trout (Brahniuk et al. 1993), and no provision was made for the dam to maintain flow into the river except during the wettest months when water would spill over the dam (Bell and Kallman 1976). In 1954, MacMillan Bloedel Ltd. built a dam at the outlet of Fourth Lake on the North Nanaimo River to store water during the summer for operation of the Harmac pulp mill. The reservoir may hold 34.5 million m^3 of water (Hop Wo et al. 2005). The dam released water as necessary during the summer months to maintain flow. The pulp mill extracted 265,000 m^3 from the Nanaimo River watershed per day (Bell and Kallman 1976). The water was sourced both from groundwater in the Cassidy area, and later, directly from the river using two pump houses. In 1976, a dam was built on Jump Creek to increase water supply to the Nanaimo area (Bell and Kallman 1976). The dam can store 60 million m^3 of water.

The estuary has also been directly impacted by anthropogenic activities. Raw sewage was discharged directly onto the estuary mudflats until the late 1950s (Bell and Kallman 1976). The Chase River pump station had many wastewater discharges into the estuary during storm events until station upgrades were completed in 2001 (Andrew McNaughton, pers. comm. 2021). Occasional discharges still occurred after this point, though upgrades to have been completed this year should eliminate discharges during storm events (Andrew McNaughton, pers. comm. 2021).

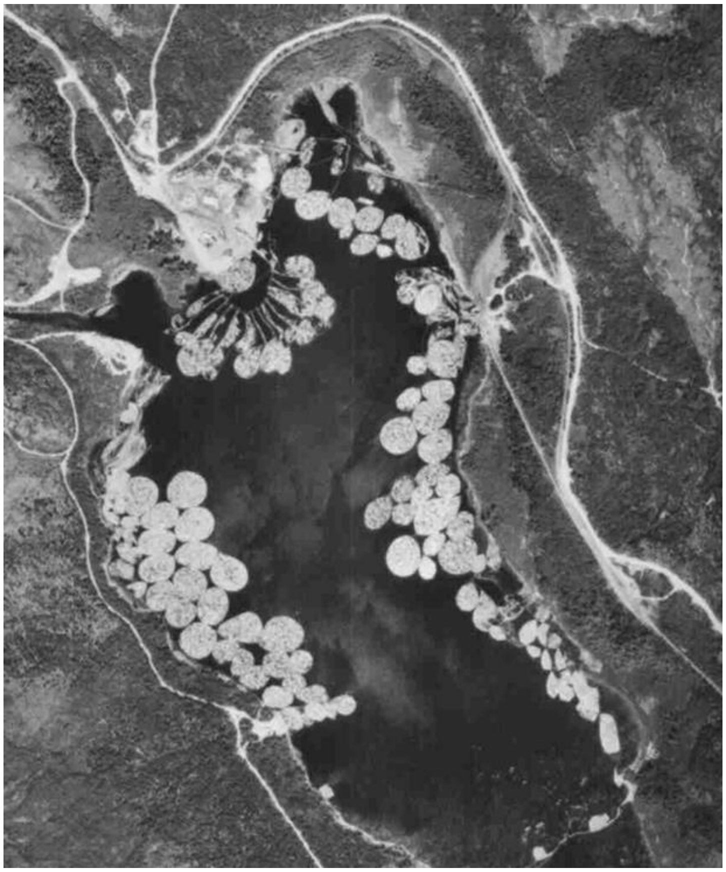

Figure 1. Aerial view of First Lake in 1975 when the lake was used as a log dump and storage area for forestry operations (photo taken from Komori Wong Environmental 2002).

Figure 2. Looking downstream Jump Creek, a tributary to the South Nanaimo River, in May 1970 (photo taken from Narver 1972).

By the 1970s, it was observed that increased sedimentation due to logging had altered the substrate of the estuarine mudflats and raised the elevation of the mudflats in various areas, making it less suitable or unsuitable for eelgrass growth (Bell and Kallman 1976). Additionally, the estuary has been used as a log booming ground for sawmills and the Harmac pulp mill since 1950 (R.G. Fuller & Associates Ltd. 2000). The most intensive use of the estuary was in the early-1970s, when approximately 2,584,646 m^2 (638.68 acres) or somewhere between 25% and over 30% of the estuary was leased for log storage and booming to MacMillan Bloedel Ltd., H.R. MacMillan Export Company, and Eureka Sawmills Ltd. (Bell and Kallman 1976, R.G. Fuller & Associates Ltd. 2000; area from Bob Colclough, Nanaimo River Estuary Log Storage Association). In 1980, it was estimated that approximately 73% of the total estuary area was subject to direct physical impact from log storage and towing activities (NETF 1980a). Approximately 55% of the lease area was first leased between 1950–1956, an additional 38.5% was leased between 1960–1965, and the remaining 6.4% was first leased between 1968–1973 (NETF 1980a). The estuary was regularly dredged in the mill log pockets to maintain depth for log storage.

The river was historically valued most by recreational fishers for its winter Steelhead Salmon runs, and less so for its other salmon species (Bell and Kallman 1976). Anglers would typically fish Chinook, Coho, and Steelhead Salmon within the first 16 km of the river (reaches 1 and 2), and First, Second, and Forth Nanaimo Lakes also experienced high angling effort by boat. The Steelhead Salmon population declined significantly by the late 1990s and has been intensely managed with a combination of fishery closures and a hatchery program. The Nanaimo River salmon populations have also historically contributed to commercial and recreational fisheries in the Strait of Georgia and elsewhere. Bell and Kallman (1976) stated that Nanaimo River Chum Salmon were caught in the commercial gillnet and purse seine fisheries in the Strait of Georgia and Johnstone Strait. Coho and Chinook Salmon contributed to the Strait of Georgia and West Coast of Vancouver Island troll and recreational fisheries, and to commercial gillnet fisheries in Johnstone Strait and the Straits of Georgia and Juan de Fuca. A small Indigenous food fishery operated in the Nanaimo River. Between 1961 and 1971, the mean annual catch in this food fishery was approximately 1,400 Chum, 400 Coho, and 157 Chinook Salmon, as well as small but unknown numbers of Steelhead Salmon (Aro 1972). Steelhead Salmon catch was likely incidental as they were not targeted by the Snuneymuxw First Nation (Andrew McNaughton, pers. comm. 2021). Snuneymuxw First Nation historically harvested 40 MT of clams annually (Andrew McNaughton, pers. comm. 2021).

The abovementioned activities all had adverse effects on fish production in the Nanaimo River watershed; however, these effects were poorly documented or monitored. Studies on juvenile salmon habitat use in the watershed did not begin until the 1970s (Bell and Kallman 1976).

1.2.5 Current Watershed Use

Presently, ~85% of the watershed is private forest land owned by Islands Timberlands LP and Timberwest, which are managed by Mosaic Forest Management Corp. (Map 2) and jointly owned by public service pension investment managers British Columbia Investment Management Corporation, the Public Sector Pension Investment Board, and Alberta Investment Management Corporation. In 2020, it was publicly announced that an agreement was reached between Snuneymuxw First Nation and the province of B.C. to transfer ~30 km^2 of Crown land in the watershed to the Snuneymuxw First Nation (Map 2). The Nation intends to manage the land largely for forestry production. The land transfer process is expected to take a few years to complete because of the need for consultation with neighboring First Nations and public engagement. The lower watershed consists primarily of rural developments, agricultural land, low density residential developments, and some light industrial development (Butler et al. 2014).

The Nanaimo River flow is fully allocated from July to September, which means that no future water withdrawal licenses will be issued except for domestic use, unless additional storage is created (Butler et al. 2014). Harmac Pacific, a division of Nanaimo Forest Products Ltd., and the City of Nanaimo are the largest consumptive water users in the watershed. Harmac draws water from the watershed to supply its Northern Bleached Softwood Kraft pulp mill. The water is drawn from surface water intakes in the Nanaimo River and a series of groundwater wells near the Trans-Canada Bridge that access the Cassidy Aquifer. From there, the water is pumped through an above ground pipeline to the pulp mill. Harmac stores water in its Fourth Lake Reservoir during the winter and spring and releases water to the Nanaimo River during periods of low flow, typically from early July to early October (Butler et al. 2014). The City of Nanaimo continues to supply drinking water to city residents, the Snuneymuxw First Nation, and the South West Extension Improvement District from its Jump Creek and South Fork Dam reservoirs (Butler et al. 2014). When the City releases water from the Jump Creek Dam reservoir, it flows down the South Nanaimo River to the South Fork Dam reservoir. The water level in the South Fork Dam is maintained at full capacity, and water is released to the South Nanaimo River either over the crest of the dam or through a low-level fisheries release point (Butler et al. 2014).

Water withdrawals adjacent to the lower Nanaimo River have increased with time as the South Nanaimo and Cedar area have been developed; much of this area obtains water from wells (Brahniuk et al. 1993). In 2013, there were approximately 2,600 wells in the Nanaimo River watershed listed in the MOE Well Database. Prior to February 2016, there were no regulatory requirements in BC to submit wells logs to the Ministry of Environment for capture in the provincial Wells Database; therefore, this number of wells may only represent as little as 50% of the water wells in operation (Regional District of Nanaimo Phase 1 Water Budget Project report, in Butler et al. 2014). As of February 2016, the new *Water Sustainability Act* (WSA) requires a water licence to use groundwater for non-domestic purposes; however, under the WSA, domestic groundwater usage remains unregulated.

The Port of Nanaimo and the forest products industry remain the principal users of the Nanaimo waterfront and Nanaimo River estuary.

1.2.6 Past Management, Conservation, and Restoration Actions

1.2.6.1 Pacific Salmon Fisheries Management

Due to Chinook Salmon declines in the 1980s, DFO initiated the Lower Georgia Strait Chinook Rebuilding Program in 1988 (Brahniuk et al. 1993). The rebuilding program involved stock enhancement, habitat management, and harvest restrictions. Catch restrictions were imposed in 1988, and a new size restriction was implemented in 1989 for the Strait of Georgia recreational fishery, increasing the Chinook Salmon retention size from >45 cm to >62 cm (Brahniuk et al. 1993). In the early 1990s, spot closures were instituted around the Nanaimo River estuary and Five Finger Island to protect adult Chinook Salmon returning to spawn in the Nanaimo River. Sportfishing for Chinook and Coho Salmon in the Nanaimo River was closed from May 1 to October 20, and after October 20, fishers were only permitted to retain Chinook Salmon jacks that were 30–50 cm in length. In 1992, a non-retention fishery was imposed from Dodd's Narrows north to Newcastle Island from July 15 to October 20.

In the 2019 season, sport fishing of Chum Salmon and hatchery marked Coho Salmon was permitted in the Nanaimo River only from November 1 to December 31 (DFO 2019a). Two hatchery marked Coho Salmon (≥25 cm) could be retained per recreational fisher per day, and only from the area between the upstream side of the Cedar Road Bridge, upstream to the downstream side of the Trans-Canada Highway Bridge. Chum salmon could also be fished within this area but could not be retained due to low returns in the Strait of Georgia. In tidal waters (Area 17), sport fishers could keep two Chinook Salmon per day and the total annual limit for Chinook Salmon was 10 from all tidal waters (DFO 2019b). Only Chinook Salmon >62 cm in length could be retained. Four Chum Salmon, two hatchery marked Coho Salmon, and four Pink Salmon could be retained per day (all species had to be >30 cm in size). Tidal hatchery marked Coho Salmon fishing was only open until December 31.

1.2.6.2 Water Management

Chinook Salmon migration up the Nanaimo River below the Island Highway and at the White Rapids Falls is frequently challenged by low flows. White Rapids Falls, located at km 13.6, consists of a two-step bedrock jump located in a river bend, and is challenging for fish to pass at low and high flows (Brahniuk et al. 1993). Between 1954 and 1989, fishery officers would informally request the Harmac Mill to release additional water into the Nanaimo River in the fall, dependant on water reserves. In 1989, after the success of a similar initiative in the Cowichan River, the Regional Water Manager co-ordinated pulse releases from the Jump Creek and Fourth Lake reservoirs of approximately 10 m^3/s and 11.3 m^3/s, respectively, to trigger Chinook Salmon holding in the Nanaimo River estuary to migrate up the river to spawn (Carter and Nagtegaal 1997). In the early 1990s, the *Nanaimo River Water Management Plan* was created to formalize the seasonal instream flows required to meet the life history requirements of salmon and trout in the Nanaimo River. The plan recommended that river flow at the Water Survey of Canada hydrometric Station 08HB034, upstream of the Harmac intake, be maintained at 7.8 m^3/s (20% of mean annual discharge) from April to June and 3.9 m^3/s (10% of mean annual discharge) from July to October, with a single pulse flow in early October to bring the flow up to 14 m^3/s (Ministry of Environment, Lands and Parks 1993).

Enumeration of adult Chinook Salmon during fall pulse flows was completed 200 m upstream of the Cedar Road Bridge in South Nanaimo during the 1995–2003 seasons (Carter and Nagtegaal 1997, 1998, 1999, 2000, Carter et al. 2003, 2004, Hop Wo et al. 2005). The purpose of the enumeration was to assess the impact of water releases on the upstream migration of Chinook Salmon and to better inform pulse flow ramping rates, discharge rates, and the length of the release. Based on the results of the study, it was identified that the minimum discharge rate from Fourth Lake should be at least 14.87 m^3/s and that the pulse should be maintained over 3 to 4 days, given that peak fish movement generally does not occur until the second day of water release. A minimum two day ramping down period is required to minimize impacts to juvenile fish. In 2017, for example, Harmac (Nanaimo Forest Products) and the City of Nanaimo together released water from the Fourth Lake and Jump Creek reservoirs to generate a week long pulse flow of 16 m^3/s in the Nanaimo River (City of Nanaimo 2017). A flow of 10 m^3/s was released from Fourth Lake and a flow of 6 m^3/s was released from the Jump Creek Reservoir.

It was identified that changing the Fourth Lake water release mechanism so that it releases higher temperature water would provide an additional 15 km of rearing habitat for trout in the Nanaimo River downstream of the lake outlet pipe (Blackman 1981, in Butler et al. 2014). Flow release options for Fourth Lake were examined to determine if water temperatures could be increased to benefit trout rearing in the Nanaimo River downstream of the lake outlet pipe (Gaboury and McCullough 2002). The 2014 Nanaimo River Baseline Report recommended that Harmac have an engineer conduct a detailed feasibility assessment to install a multi-port outlet structure with valved inverts at a range of elevations to take advantage of the warmer surface waters in the lake over the withdrawal period (Butler et al. 2014). MCW is not aware if any further assessments were completed.

1.2.6.3 Log Storage Management

In 1980, the Nanaimo Estuary Fish Habitat and Log Management Task Force (NETF) identified the extent of the alteration of the Nanaimo River estuary due to log storage operations and the impacts from this industry on salmon populations. Specifically, the task force identified that log storage in the Nanaimo River estuary had resulted in loss of eelgrass beds through several mechanisms (NETF 1980a):

- shading, which prevented eelgrass growth and decreased primary production;
- grounding of logs at low tide, which destroyed eelgrass, epifauna and infauna, compacted sediment, and altered drainage patterns;
- reducing current and wave action, which increased sediment deposition and reduced tidal flushing;
- introducing debris and leachate, which adversely affected the health of flora and fauna and decreased substrate oxygen levels; and
- causing tugboat prop damage and wash, which impacted flora and fauna.

The task force recognized the need for an immediate reduction in log storage lease area in the estuary, and the removal of leases from the east side of the estuary, where juvenile fish were observed at highest abundance (NETF 1980a). A cost-benefit analysis was completed to estimate the extra log handling costs of various options to reduce log storage in the estuary versus the financial benefits associated with increased fish catch (NETF 1980b). It was determined that a redistribution of leases rather than a substantial reduction in in-water storage was the most cost-effective option. The task force recommended that the lease area from the east side of the estuary be largely reallocated to the lease areas on the west side of the estuary. It was expected that this change would allow for 75% recovery of highly productive fish habitat on the east side of the estuary that was negatively impacted by log storage activities over the previous 30 years. However, increasing the size of the lease areas on the west side of the estuary by extending them seaward increased overlap with the remaining western eelgrass bed. As of 2002, and after 20 years of recovery time, impacts of past log storage in the east estuary have persisted, including a shallow anoxic layer and wood debris (Komori Wong Environmental 2002).

In 2001, with the expiry of the log storage leases in existence at the time, a Log Storage Working Group was convened to review options for continued log management in the estuary. Three options for log storage were prepared, each proposing varying levels of immediate lease area reduction (Log Storage Working Group 2002): 1) The Forest Industry User's Group proposed a 17% reduction to 410 acres, with a 20 year lease and review of the terms every 5 years; 2) Snuneymuxw First Nation proposed a 46% reduction to 266 acres, with a 5 year lease; and 3) the Nanaimo Community Estuary Support Coalition proposed a 50% reduction, with a 5 year lease. In 2002, the provincial government announced that they had agreed to a 20% reduction of the log storage lease area in the estuary, with the renewal of the lease for another 20 years (Ministry of Sustainable Resource Management 2002). Over the span of 40 years between 1972 and 2012 (the last year of data presently available to MCW), the total log storage area was reduced by 44% to 1,439,871.5 m^2 (355.8 acres) (values from Bob Colclough, Nanaimo River Estuary Log Storage Association).

1.2.6.4 Land Conservation

Little land in the Nanaimo River watershed has been protected from forestry or development (Map 2). The 0.04 km^2 Morden Colliery Historic Provincial Park was established in 1972 and the 0.93 km^2 Hemer Provincial Park on the western shores of Holden Lake was established in 1981. In 1999 and 2000, The Land Conservancy purchased the last remaining intact riparian area on the lower Nanaimo River, which is now the Nanaimo River Regional Park. The park contains 0.56 km^2 of mature Coastal Douglas-fir forest. The site was transferred to The Nature Trust of BC in 2016. The BC Ministry of Forests, Lands, and Natural Resource Operations and Rural Development (MFLNRORD) manages a 19 km^2 McKay Lake Ungulate Winter Range and 0.04 km^2 Haslam Ungulate Winter Range, which include wetland, riparian, terrestrial herbaceous and second-growth Sensitive Ecosystem Inventory (SEI) units (Butler et al. 2014) and have several no harvest zones. The McKay Ungulate Winter Range includes the largest freshwater wetland in the watershed and a rare bog ecosystem. The land to be transferred to the Snuneymuxw First Nation from the Crown includes the McKay Lake Ungulate Winter Range. Haley Lake Ecological Reserve (8.9 km^2) protects Vancouver Island Marmot (*Marmota vancouverensis*) habitat in the upper part of the watershed.

1.2.6.5 Enhancement

Hatcheries

The Nanaimo and Cowichan River Chinook Salmon populations are the largest remaining natural spawning populations of the Lower Strait of Georgia Chinook Salmon stocks, and both are augmented with hatchery releases. The Nanaimo River Hatchery was opened in 1979 on the Nanaimo River near km 8 to enhance summer and fall run Chinook, Chum, Coho, and most recently Pink Salmon stocks by taking broodstock and releasing fry (Lam and Carter 2010, Butler et al. 2014). Hatchery staff is also involved in counting spawners for stock assessment. Summer run Chinook Salmon fry are released into First Lake whereas the fall run Chinook Salmon fry are released into the Lower Nanaimo River (Nagtegaal and Carter 2000). Over the years, fry production has increased. In May 2011, a total of 436,769 fall run Chinook Salmon fry and 226,193 First Lake summer run Chinook Salmon fry from the 2010 brood year were released into the Nanaimo River and First Lake, respectively (Watson et al. 2015). There was a small captive brood project in the 1980s to enhance what has until recently been referred to as spring run Chinook Salmon (see Section 2.1 for run naming history; Nanaimo River Hatchery published data, Steve Baillie, DFO Stock Assessment Biologist, pers. comm. 2021).

Incubators

Sites in the Nanaimo River where Jordan incubation chambers could potentially be installed to try to increase Chinook Salmon egg to fry survival rates have previously been identified (Burt 2002). To MCW's knowledge, no incubators have been installed.

1.2.6.6 Stream Rehabilitation

In 1989, blasting significantly improved fish passage up the White Rapids Falls and in 1992–1993 a cement fishway was constructed at the falls (Carter and Nagtegaal 1997). Limited work has been completed by DFO to improve summer Chinook Salmon passage at the "Borehole", another area of the river's lower canyon that can act as a barrier to fish at low flows (Map 1; Butler et al. 2014).

Potential off-channel habitat construction sites have been identified on the lower Nanaimo River (Griffith 1992), Haslam Creek, and North Nanaimo River (Gaboury and McCullough 2002). No detailed investigations or prescriptions were completed because of the anticipated high costs. Gaboury and McCullough (2002) additionally proposed several spawning enhancement and instream restoration projects for the Nanaimo River watershed. The projects included improving spawning habitat for Rainbow Trout and Steelhead Salmon by placing spawning gravels in the outlet of Second Lake (at an estimated cost of $20,960); improving rearing habitats by installing rock-ballasted large woody debris (LWD) at 51 sites along Haslam Creek ($139,595), and at another 60 sites in the North Nanaimo River ($168,210).

In summer 2003, the BC Conservation Foundation (funded by the Habitat Conservation Trust Fund) added 150 m^3 of gravel in the Second Lake outlet channel to create approximately 240 m^2 of spawning habitat between First and Second Lakes, and 250 m^3 of gravel in three locations immediately downstream of the South Fork Dam to create a total of approximately 425 m^2 of spawning habitat (Smith 2004). Fall monitoring surveys after high water events indicated that there was significant movement of the gravel. Only ~30% of the gravel remained in place at the Nanaimo River site, with displaced gravel deposited as far as 250 m downstream. In the South Nanaimo River, the gravel at two of the three sites had been displaced up to 300 m downstream; ~70% of the gravel remained at the third site.

As of 2014, the remaining recommendations made by Gaboury and McCullough (2002) had not been implemented due to lack of funding (Butler et al. 2014). Consequently, as part of preparing the 2014 Nanaimo River Baseline Report (Remillard and Clough 2014, in Butler et al. 2014), D.R. Clough Consulting was contracted by the Nanaimo and Area Land Trust to update the enhancement and restoration projects and costing identified by Gaboury and McCullough (2002). D.R. Clough Consulting found that most of the LWD described in the original assessment had been washed away or had moved elsewhere. The firm recommended the following restoration activities:

- adding spawning gravel at the outlet of Second Lake;
- investigating 15 potential Haslam Creek off-channel restoration sites;
- installing LWD at many sites in the lowest reaches where fish use is high; and
- conducting a follow-up inspection of the North Nanaimo River prior to further activities.

Since 2002, the Haslam Creek sub-basin experienced significant flood events in 2006, 2007, 2009, and 2010, which eroded hundreds of meters of stream bank, deposited large volumes of sediment on the lower 2 km of the stream channel, and removed most functional LWD (Butler et al. 2014). The Nanaimo Airport Commission, in partnership with the Nanaimo Fish and Game Protective Association and Nanaimo River Stewardship Society, had installed some LWD in the lower reach of Haslam Creek prior to these floods (Butler et al. 2014). This LWD helped hold the bank together during the floods, though the areas in between the restoration sites continued to degrade. Consequently, the estimated updated costs of all restoration works in the Nanaimo River, North Nanaimo River, and Haslam Creek proposed in 2002 significantly increased (based on 27% inflation in addition to 50% more habitat damage since 2006), from a total cost of $349,765 to $620,854 (Remillard and Clough 2014, in Butler et al. 2014).

1.2.6.7 Estuary Rehabilitation

In 1979, eelgrass was planted on the east side of the estuary following a reduction in log storage activity in this area (Catherine Berris Associates Inc. 2006). The transplantation was not successful, and it was determined that the transplant sites were at elevations that did not support eelgrass growth. Precision Identification transplanted eelgrass to the west shore of the estuary in 2007 but it did not survive. In 2011, the Nanaimo River Estuary Committee began planning a 10–15 year eelgrass planting program in the estuary, funded by the Log Storage and Industry Association and the Nanaimo Port Authority, with student involvement from Vancouver Island University (VIU; Butler et al. 2014). In 2013, a VIU student identified three areas in the estuary for potential eelgrass transplantation: the northeast side of the estuary parallel to Nanaimo Port Authority land; the east side of the estuary adjacent to the Duke Point ferry terminal; and the west side of the estuary just south of the Nanaimo Port Authority main office (Bonar and Zamora 2020). Aquaparian Environmental Consulting Ltd. (in collaboration with VIU students) completed a 1,250 m^2 transplantation project in one of these areas—the northeast end of the estuary—in 2013/2014, again with poor success. As of 2016, there were only sparse patches of low-density eelgrass.

In 1987, the Pacific Estuary Conservation Program (a partnership between Ducks Unlimited Canada, The Nature Trust of BC, Habitat Conservation Trust Foundation, Canadian Wildlife Service, DFO and BC MOE) began purchasing land in the Nanaimo Estuary. As of 2011, a total of eight parcels of land had been acquired, covering 1.8 km^2 of estuarine marsh, farmland, and riparian areas (Butler et al. 2014). The program began restoring portions of the purchased estuarine marsh in 1988 by removing sections of dikes to restore natural tidal flows and vegetation. In 2006, 0.22 km^2 of estuarine marsh was restored by breaching the northern dike on Holden Creek, funded by conservation partners, the Ministry of Transportation, BC Ferries, and the BC Transmission Corporation. In 2008/2009, tide gates were installed on the north dike and east dike at York Creek during dike repairs (Andrew McNaughton, pers. comm. 2021). The dikes protect the Snuneymuxw First Nation, while the tide gates allow water exchange and fish access into the tidal channels. The most recent small estuarine marsh rehabilitation trial in 2018 involved dike removal and estuarine marsh construction (Andrew McNaughton, pers. comm. 2021).

In 2006, the Nanaimo Estuary Management Committee (NEMC)—a collaboration between a number of organizations (federal, provincial, and municipal government agencies, Snuneymuxw First Nation, NGOs)—completed two years of discussion and public consultation to produce a Nanaimo Estuary Management Plan (Catherine Berris Associates Inc. 2006). The purpose of the plan was to guide management and restoration within the estuary, though it did not legislate or regulate activities of the document collaborators. The management plan included a commitment to prepare a comprehensive estuarine monitoring plan. NEMC contracted Nautilus Environmental (2008) to prepare a water and sediment quality and invertebrate monitoring plan; and Streamline Environmental Consulting Ltd. to prepare a terrestrial monitoring plan to monitor estuarine plant communities as well as other wildlife indicator species (Smith and Meggs 2009). These monitoring plans are discussed further in Sections 0 and 4.2.14.2. MCW has been unable to find a record of which, if any, restoration and research priorities identified in the Nanaimo Estuary Management Plan have been completed or whether the sampling programs proposed by Nautilus Environmental (2008) and Streamline (Smith and Meggs 2009) have been carried out.

1.2.6.8 Enrichment

In 2003 and 2004, surplus hatchery salmon carcasses were distributed in the Nanaimo River with assistance from volunteers (Ministry of Water, Land and Air Protection and BC Conservation Foundation 2004). Another nutrient enrichment project to benefit Steelhead Salmon discussed by Butler et al. (2014) was to apply fertilizers from the outlet of First Lake, downstream to White Rapids Falls in the lower canyon, including lower reaches of the North and South Nanaimo Rivers. At the time of Butler et al. (2014)'s report, provincial fisheries agencies, in conjunction with Trout Unlimited Canada, had compiled background water chemistry and stream flow data for this section, so that fertilizer loading rates could be calculated for the late May to August period. MCW has not found any documentation about the end result of this nutrient enrichment project.

2 WILD PACIFIC SALMON OF THE NANAIMO RIVER WATERSHED

The Nanaimo River watershed has historically supported a biodiverse fish community. Among other species, it supports Chinook, Coho, Chum, Pink, and Sockeye Salmon (*Oncorhynchus tshawytscha, O. kisutch, O. keta*, O. *gorbuscha*, and *O. nerka* respectively), Steelhead Salmon (*O. mykiss*), Dolly Varden (*Salvelinus malma*), Coastal Cutthroat Trout (*O. clarkia clarkii*) (e.g., Carter and Nagtegaal 1997, Butler et al. 2014), and Kokanee (Aro 1972, Burt 2006). Dolly Varden and Coastal Cutthroat Trout are species at risk in BC (BC List – Blue), and the Nanaimo River spring run Chinook Salmon population was recently assessed as Endangered by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC 2018). The status of the Nanaimo River Steelhead Salmon population is also of conservation concern because it has significantly declined, though it is not formally listed as a species at risk (Lill 2002, MFLNRO 2016). The focus of this report will be on the status of Chinook, Coho, Chum, Pink, and Sockeye Salmon and their associated habitats in the watershed.

2.1 Chinook Salmon

The Nanaimo River watershed has until recently been considered to support three genetically unique Chinook Salmon populations that exhibit different life-history strategies and juvenile body morphologies (Carl and Healey 1984). Holtby and Ciruna (2007) assigned the three populations to three Conservation Units under the Wild Salmon Policy: the Spring, Summer, and Fall Conservation Units. The fall and summer run Chinook Salmon populations have been relatively well monitored since 1988 so much more is known about these two populations. The spring run Chinook Salmon was historically believed to be a small population that had unique run timing, genetics, and spawning sites in the upper Nanaimo River. The spring run was understudied, having been only intermittently assessed between 1979 and 2008 (Watson et al. 2015).

The designation of the Nanaimo River spring run population as Endangered by COSEWIC in 2018 triggered the need for DFO to complete a Recovery Potential Assessment—a report to help inform the Minister of Fisheries, Oceans, and the Canadian Coast Guard’s decision as to whether to list the population for protection under the *Species at Risk Act*. As part of the Recovery Potential Assessment, DFO Stock Assessment evaluated existing life history, run timing, and genetic evidence for the existence of the three populations. DFO concluded that the spring and summer runs have overlapping freshwater entry timing, are not meaningfully genetically different, and both exhibit stream-type and ocean-type life-history strategies (Luedke 2021). As such, DFO Stock Assessment has recommended that the spring run population be included in the summer run Conservation Unit (Luedke 2021). The remainder of this report reflects this change by referring only to two Chinook Salmon populations in the watershed—a summer and fall run population. Any life-history data obtained from the literature review completed for this report that was attributed to the spring run has been merged with that of the summer run.

2.1.1 Distribution and Timing

2.1.1.1 Holding

Snuneymuxw First Nation oral history indicates that adult Chinook Salmon were present in the river throughout the year (Andrew McNaughton, pers. comm. 2021). The summer run Chinook Salmon population enters the river from Feb to July and holds in the tidally influenced reach (Cedar Bridge area) and in several large pools upstream, awaiting suitable spawning migration flows to pass White Rapids Falls (Brahniuk et al. 1993). Beyond this point, they hold in the deep pool at the confluence of the South Nanaimo River and in First Lake and Second Lake (Healey and Jordan 1982, Hardie 2002, Burt 2006 and references therein). A subset of the population spawns above Second Lake (previously referred to as the spring run) and holds in the deep canyon pools between Tepee Bridge (or TP Bridge) and Bridge 2, and in the deep pool at the confluence of Green Creek (Burt 2006, as reviewed by Watson et al. 2015). The fall run Chinook Salmon population enters the lower river in late August and September (Healey and Jordan 1982, Carl and Healey 1984).

Chinook Salmon were also historically present in the Chase River (Bell and Kallman 1976), the first few kilometres of Green Creek, and sporadically in Haslam Creek up to the Falls at the 7.5 km mark (Ministry of Environment and Climate Change Strategy 2019a (MOECCS)).

2.1.1.2 Spawning

Chinook Salmon spawning begins in September, reaches a peak in October and ends in November and December (Aro 1972). Summer run Chinook Salmon spawn primarily in a two kilometre stretch of the Nanaimo River from Wolf Creek up to First Lake (Healey and Jordan 1982); this is the best quality Chinook Salmon spawning habitat in the river (Hardie 2002). Just below First Lake, there are two important spawning sites for summer run Chinook Salmon (Burt 2002):

- First Lake Outlet – An approximately 450 m² area (50 m wide by 30 m long) at the top of a riffle located at the confluence of the lake outlet with the North Nanaimo River
- Transverse riffle 950 m below First Lake Outlet – An approximately 500 m² area (50 m wide by 10 m long).

Some summer run fish also spawn in the vicinity of the South Nanaimo River confluence (Burt 2006), and a small proportion spawn between Second and Fourth Lakes, but may also spawn in tributaries to the Nanaimo River such as Green Creek (Map 3; Hardie 2002, Watson et al. 2015).

The fall run spawns within the lower reaches of the Nanaimo River, mainly from the Trans-Canada Highway Bridge to the Cedar Road Bridge (Healey and Jordan 1982, Carl and Healey 1984, Banks B. and B. Herman, Nanaimo River Hatchery, pers. comm. 2019). There are two important spawning sites for fall run Chinook Salmon (Burt 2002):

- Bridge Pool – An approximately 1000 m² area (25 m wide by 40 m long) in a pool tailout about 75 m below the Trans-Canada Highway Bridge crossing. Fall Chinook Salmon also spawn in an approximately 300 m² area (6 m wide by 50 m long) in the side channel on the left side of the river in years where there is sufficient flow to access the side channel.
- Log Jam –An approximately 1500 m² area (25 m wide by 60 m long) at the top of the riffle along the left side of the river and adjacent to the top of a log jam. Fish can access this area from the side channel on the other side of the log jam and are able to pass under the log jam. This area receives about 250–300 spawners, which would mean that each spawning pair has an approximately 10 m² spawning area.

The spawning distributions of the two Chinook Salmon runs do overlap, with some fall Chinook Salmon spawning as far upstream as First Lake (Burt 2006).

2.1.1.3 Freshwater Rearing

Both the summer and fall Chinook Salmon populations produce mainly ocean-type fry that do not overwinter in freshwater but out-migrate to the estuary shortly after emergence from the gravel. A portion of the summer run population exhibits a stream-type juvenile life history where fry rear in the river for up to one year before smolting and then out-migrating to the estuary (Watson et al. 2015 and references therein, Luedke 2021).

Summer run stream-type fry rear in various locations. Some spend the winter in freshwater in the middle reaches of the river below First Lake (Carl and Healey 1984, and as reviewed by Watson et al. 2015). Those that hatched above Second Lake may drift down to First and Second Lakes after emerging from the gravel, or rear in the upper river for up to 2 months before migrating to the lakes, and some rear and overwinter in the upper river before emigrating from the system as smolts (Burt 2006 and references therein). Gill netting in First Lake during July and August of 1979 confirmed that juvenile summer Chinook Salmon rear and likely overwinter in First and Second Lakes (McKay 2001, as cited by Burt 2006). The timing of emergence of Chinook Salmon fry is unknown, but fry migrate to First and Second Lakes in March through June (Burt 2006 and references therein).

2.1.1.4 Estuarine Rearing

Individual juvenile Chinook Salmon tend to remain in the estuary for at least a few weeks, and juvenile Chinook Salmon may be found in the estuary for at least four months, though tagged populations out-migrating from the Nanaimo River, specifically, were only found in the estuary at least two and half months (Sibert 1974).

In 1975 and 1976, a trapping study found fry rearing in the intertidal area at the river mouth where salinity was commonly above 20% (Healey 1980). Few Chinook Salmon fry were captured at other sampling sites within a 10 km radius of the river mouth. Juvenile Chinook Salmon were present in the intertidal area of the estuary from March to July each year, but peak numbers occurred in April and May. The peak number of Chinook Salmon fry in the estuary was estimated to be 40,000–50,000 in 1975 and 20,000–25,000 in both 1976 and 1977 (Healey 1980). Departure of smolts from the estuary for all runs appears to occur at ~70 mm fork length (Healey 1980). In 1975 and 1976, Chinook Salmon were found to have increased their bodyweight by 5.8% per day while in the estuary (Healey 1980). Individual fish probably spent an average of about 25 days rearing in the estuary and left the estuary when about 70 mm in fork length.

2.1.2 Habitat Requirements by Life-History Stage

The following sections describe the general biology and critical habitats of Chinook Salmon in the Nanaimo River watershed by life-history stage.

2.1.2.1 Terminal Migration and Spawning

Chinook salmon require unimpeded access throughout their migration corridor to their home spawning grounds. Access to upstream spawning habitats in the Nanaimo River can be challenged by waterfalls, river aggradation, and low flows. Delays in migration due to these factors are known to reduce survival by increasing risk of predation and decreasing energy reserves (Diewert 2007a). Successful terminal migration of adult Chinook Salmon can be attributed to a lack of barriers to fish passage, appropriate flows to facilitate migration, and availability of holding habitats such as deep pools, cut banks, and LWD (Groot and Margolis 1991). Pools, cut banks, and functional LWD are considered critical habitats.

The spawning beds chosen by Chinook Salmon vary considerably in physical characteristics, and can occur in water ranging from a few centimetres to several metres in depth (Groot and Margolis 1991). These fish typically spawn in deeper, higher velocity zones than other species. The BC generalized depth and velocity habitat suitability index curves for Chinook Salmon suggest that the optimum Chinook Salmon spawning habitats would have depths ≥ 70 cm and velocities ranging from 40–150 cm/s (Burt 2006). Chinook salmon eggs have the largest surface area to volume ratio in pacific salmon species; therefore, their eggs are particularly sensitive to reduced oxygen levels. Successful spawning is dependent on the availability of spawning grounds with adequate sub-gravel flows and, typically, coarse gravels (Diewert 2007a).

2.1.2.2 Incubation

Egg to fry survival rates of Chinook Salmon in the river have been estimated from trapping studies to range between approximately 1–12% (Nagtegaal and Carter 1997, 1998, 2000). Survival during the incubation phase varies widely and is influenced by stream flow, dissolved oxygen, gravel composition, water temperature, spawn timing, and spawner density. Studies have shown that spawning grounds with a slightly larger gravel size (and therefore higher permeability for oxygen delivery and waste removal) consistently generate higher egg to fry survival rates (Diewert 2007a). Floods, which scour the bottom or result in heavy siltation, are generally associated with high egg mortality, as are low flows that dewater redds (Groot and Margolis 1991). Successful Chinook Salmon incubation is also dependent on stream temperatures falling between 5.0°C and 15.0°C, and good water quality (i.e., absence of waste water, pesticides, toxic chemicals, petroleum products, and organic compounds) (Groot and Margolis 1991). Note that healthy riparian vegetation is critical to incubation as it helps moderate temperatures (Diewert 2007a).

2.1.2.3 Freshwater Rearing

Critical habitats associated with the early freshwater rearing phase of Chinook Salmon are those that have complex river or lake margin habitat (i.e., back eddies, undercut banks, woody debris, and other areas of cover), and a healthy riparian zone that provides cover, insect subsidies, and that regulates stream temperature. The BC generalized depth and velocity habitat suitability index curves for Chinook Salmon suggest that the optimum Chinook Salmon stream rearing habitats would have depths ≥ 18 cm and velocities ranging from 15–50 cm/s (Burt 2006).

2.1.2.4 Estuarine Rearing

The Nanaimo River estuary is considered critical habitat. It provides an environmental transition zone where fish acclimate between freshwater and saltwater and between waters of different temperatures. Estuaries also provide structural cover and refuge from predators, and substantial foraging opportunities, and are highly productive relative to adjacent ocean or freshwater areas (Diewert 2007a). Estuarine rearing habitats are of particular importance to summer and fall Chinook Salmon run juveniles, which typically arrive in the estuary as sub-yearling fry and smolt before dispersing seaward in June and July (Carl and Healey 1984, and as reviewed by Watson et al. 2015).

In 1975 and 1976, juvenile Chinook Salmon fed on harpacticoid copepods, amphipods, insect larvae, decapod larvae, and mysids while in the estuary. After leaving the estuary, they fed mainly on juvenile herring. The stomach content of Chinook Salmon captured in the estuary averaged 5% of body weight or less, and varied seasonally and between years (Healey 1980).

2.1.3 Escapement

Escapements have been recorded for Nanaimo River Chinook Salmon since 1939; however, early estimates were obtained only for the larger fall run, and it was not until 1979 that separate estimates were obtained for the summer run (Burt 2006). For this reason, it is difficult to determine the historical abundance of the Chinook Salmon populations in the Nanaimo River watershed prior to the development of Nanaimo's coal fields. In 1979, the then spring, summer, and fall runs are estimated to have once numbered 264, 1,126, and 2,520 adults, respectively (Figure 3).

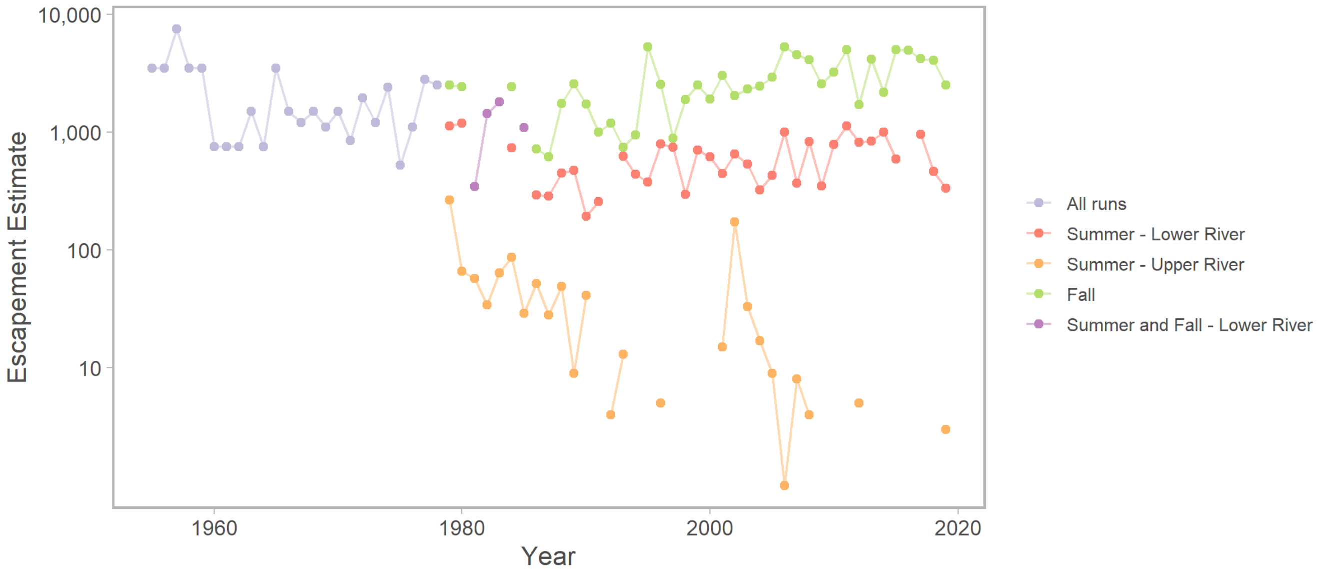

Figure 3. Escapement estimates for summer run and fall run Chinook Salmon (data from the New Salmon Escapement Database System (NuSEDS; DFO (2019c)) and corrected by Steve Baillie, Stock Assessment Biologist). Summer run adults may spawn in the upper river (these were previously referred to as spring run fish), but most spawn in the lower river.

The hatchery-enhanced summer and fall runs have had mean escapements of 776 (range of 333–1,125) and 3,743 (range of 2,169–5,023), respectively (Figure 3). The number of Chinook Salmon that spawn in the upper river above Second Lake has been in decline since the 1960s due to impacts from marine and freshwater anthropogenic stressors. Over the last decade, yearly Chinook Salmon escapement to the upper river has been fewer than 10 spawners.

Historical numbers are less accurate than more recent numbers because the methods used to estimate escapement prior to the mid-1990s may be less reliable. For instance, historical surveys did not fully cover the available summer run spawning area above Second Lake so most historical estimates of the number of salmon that spawned in that area should be considered as minimum estimates (Watson et al. 2015). Further, the raw swim counts were not expanded for observer efficiency and percent population coverage as is done at present (Watson et al. 2015). Annual abundance of spawners in the upper river remained poorly understood at least as of 2006 due to inconsistencies in geographic coverage and timing of upper river snorkel surveys (Burt 2006).

2.2 Coho Salmon

2.2.1 Distribution and Timing

2.2.1.1 Holding

Coho salmon enter the river in early October (Butler et al. 2014). In-migration appears to occur later than it did historically because Aro (1972) stated that Coho Salmon start arriving in the Nanaimo River in late August and September. Coho salmon may be found in the Nanaimo River up to the anadromous barrier near Fourth Lake, Haslam Creek up to the falls at the 7.5 km mark, the North Nanaimo River up to ~11.5 km (including Blackjack Creek), and the first few kilometres of Green Creek (MOECCS 2019a).

2.2.1.2 Spawning

Coho salmon peak spawning occurs from November to early December (Butler et al. 2014). The precise spawning areas are unknown, though Coho Salmon are thought to spawn throughout the Nanaimo River and its tributaries upstream as far as Fourth Lake (Map 3; Butler et al. 2014). In the North Nanaimo River, the spawning habitat is above the first 3.6 km (MOECCS 2019a). They may also spawn in the other rivers that drain into the Nanaimo River estuary—Chase River, Beck Creek, and Holden Creek (Aro 1972).

2.2.1.3 Freshwater Rearing

MCW found little information about the distribution of juvenile Coho Salmon rearing habitats in the Nanaimo River. It can be assumed that they rear throughout their natal rivers, tributaries, and available off-channel habitat. Juvenile Coho Salmon commonly rear in Polkinghorne's Slough that connects to the Nanaimo River near 4.5 km in reach 2 (MOECCS 2019a). In the North Nanaimo River, the rearing habitat is found within the first 3.6 km (MOECCS 2019a).

2.2.1.4 Estuarine Rearing

MCW was unable to find information about the timing of juvenile Coho Salmon entry and exit from the Nanaimo River estuary. Bell and Kallman (1976) reported that Nanaimo River Coho Salmon smolts prefer to use the eelgrass beds of the outer estuary, where they feed primarily on larval and juvenile fish.

2.2.2 Habitat Requirements by Life-history stage

The following sections describe the biology and critical habitats of Coho Salmon in the Nanaimo River watershed by life-history stage.

2.2.2.1 Terminal Migration and Spawning

As with Chinook Salmon, Coho Salmon require unimpeded access throughout their migration corridor to their home spawning grounds. Delays in migration due to obstacles such as dams and low flows are known to reduce survival by increasing risk of predation and decreasing energy reserves (Diewert 2007b). Successful terminal migration of adult Coho Salmon can be attributed to a lack of barriers to fish passage, appropriate flows to facilitate migration, and availability of critical holding habitats such as deep pools, cut banks, and LWD (Groot and Margolis 1991). Coho salmon typically migrate later in the season than other salmon species, therefore, access issues due to low flows are less common. However, future hydrologic regime changes due to climate change may increase this risk. Pools, cut banks, and functional LWD in the Nanaimo River are considered critical habitats.

Coho salmon are both mainstem and tributary spawners, and typically use habitats further upstream than other Pacific salmon species. They have been described as the least particular of all salmon in their choice of spawning areas. On the spawning grounds, they appear to seek out sites where there is groundwater seepage and favour areas where the stream flow is 0.30 to 0.55 m/s (Diewert 2007b). Females generally select a redd site at the head of a riffle area where there is good oxygen circulation through the gravel. The typical gravel size at redd sites is less than 15 cm; however, gravel size selection is largely dependent on spawner size (Groot and Margolis 1991).

2.2.2.2 Incubation

Egg to fry survival during the incubation phase varies widely and is influenced by stream flow, dissolved oxygen, gravel composition, water temperature, spawn timing, and spawner density. Floods, which scour the bottom or result in heavy siltation, are generally associated with high egg mortality, as is dewatering of redds (Groot and Margolis 1991). Successful Coho Salmon incubation is also dependent on good water quality. Healthy riparian vegetation is again critical to incubation as it helps moderate temperatures (Diewert 2007b).

2.2.2.3 Freshwater Rearing

Coho salmon have an extended juvenile rearing phase, spending an additional year in the freshwater environment following emergence. During this life stage, they may use a variety of freshwater rearing habitats.

Immediately following emergence from the gravel, juvenile Coho Salmon fry migrate downstream with high river flows. These flows serve to disperse smaller fry into habitat along the margins of the river, particularly back eddies, behind fallen trees, undercut tree roots, or other areas of bank cover. As fry grow larger, they tend to move away from shore into midstream and higher velocity areas (Groot and Margolis 1991).

During the summer months, low flows have the potential to reduce the overall wetted area and strand juveniles in isolated pools. River aggradation from unstable channel banks and slides can also negatively impact juvenile Coho Salmon by infilling pools and cutting off access to tributary habitats. In addition, high summer water temperatures can negatively impact fish by increasing metabolic rates and lowering dissolved oxygen levels. Access to both mainstem and off-channel rearing habitat with suitable water quality, cover to avoid predation, low sedimentation levels, and adequate flow is critical to juvenile Coho Salmon survival. In addition, healthy streamside riparian vegetation is necessary for temperature regulation, and channel stability, LWD recruitment into the system, and insect production (Diewert 2007b).

The amount of suitable winter habitat is known to be one of the major limiting factors to Coho Salmon production. During the winter, juvenile Coho Salmon seek refuge from high water velocities in areas such as side channels, back waters, beaver ponds, deep river pools, pools formed by debris and root wads, and smaller tributary habitats.

2.2.2.4 Estuarine Rearing

Migration downstream to the estuary typically occurs in the spring, and is dependent on fish size, flow conditions, water temperature, dissolved oxygen levels, day length, and the availability of food (Groot and Margolis 1991). While juvenile Coho Salmon do not typically spend long periods of time in the estuary, studies have indicated that Coho Salmon smolts may move more slowly through the estuary than other stream or river environments. The Nanaimo River estuarine environment remains critical habitat for this species for osmoregulation, feeding, and refuge from production.

2.2.3 Escapement

In the 1930s, the estimated mean Coho Salmon escapement was between 15,500 and 100,000, depending on the report (Bell and Kallman 1976, NETF 1980a). Mean Coho Salmon escapement to the river declined during the 1930s to 1970s (Figure 4). Over the last decade, the mean yearly Coho Salmon escapement has increased to 4,151 (range of 1,013–11,683; Figure 4). Historical numbers may again be less accurate than more recent numbers because the methods used to estimate escapement prior to the mid-1990s may be less reliable. Coho also enter the Nanaimo River later than the other fish and can be difficult to count due to higher water levels.

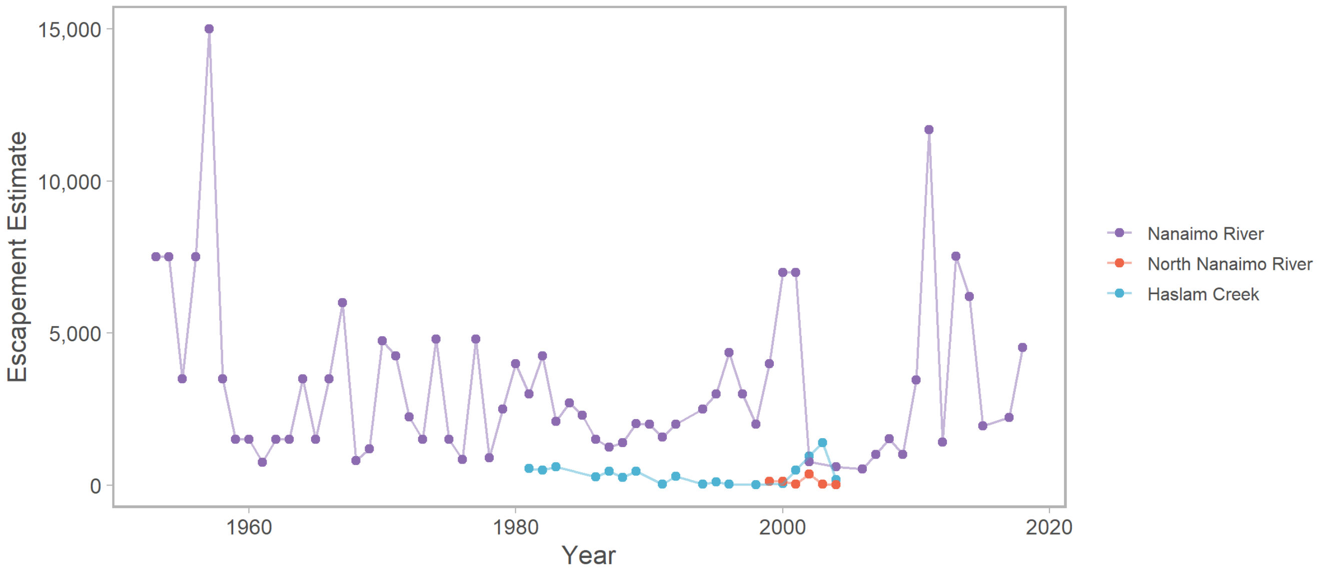

Figure 4. Coho salmon escapement estimates (data from NuSEDS; DFO (2019c)).

2.3 Chum Salmon

2.3.1 Distribution and Timing

2.3.1.1 Holding

Chum Salmon begin arriving in the Nanaimo River from mid-August to late September (Aro 1972). No information was found on critical Chum Salmon holding locations.

2.3.1.2 Spawning

Chum Salmon spawning begins shortly after they arrive in the river, peaking in mid to late October and ending by late November or early December (Aro 1972). Chum Salmon spawn in the lower 7 km of the Nanaimo River and in the lower reaches of Haslam Creek (Map 3; Aro 1972, Catherine Berris Associates Inc. 2006, Butler et al. 2014). Most of the spawning occurs in the mainstem up to and adjacent to Indian Reserve No. 3 and above the Cedar Road Bridge in Polkinghorne's Slough and Side Channel and in Maffeo's Side Channel. Chum Salmon also spawn in the lower reaches of Chase River (Bell and Kallman 1976) and Beck Creek (MOECCS 2019a).

According to staff from the Nanaimo River Hatchery, in the last five years, Chum Salmon have been spawning further upstream in the watershed than historically, and now use the same spawning sites as fall Chinook Salmon (Banks B. and B. Herman, Nanaimo River Hatchery, pers. comm. 2019). Chum Salmon arrive in the river later than the Chinook Salmon, so Chum may dig up Chinook Salmon redds.

2.3.1.3 Freshwater Rearing

After emergence, Chum Salmon fry migrate immediately downstream to the estuary, with peak fry out-migration in early May (Butler et al. 2014).

2.3.1.4 Estuarine Rearing

Pacific Biological Station surveys conducted in the 1970s observed juvenile Chum Salmon in the Nanaimo River estuary mudflats from March to May and in the nearshore environment from March to June (Bell and Kallman 1976). The average juvenile Chum Salmon residence time in the nearshore environment was 24 to 28 days. Chum fry use tidal creeks cutting through estuarine marsh as well the marsh itself when the tide is high enough (NETF 1980a). In the 1970s, fry were noted to concentrate in the east side of the estuary, particularly in the east branch of the Nanaimo River. The relatively small numbers of fry in channels through the central and western part of the intertidal mudflats suggested that these habitats were for some reason unsuitable, possibly due to the log storage and tugboat activities in those areas (NETF 1980a). Although, at that time log storage activity occurred on the eastern side as well.

2.3.2 Habitat Requirements by Life-history Stage

2.3.2.1 Terminal Migration and Spawning

For a successful terminal migration, Chum Salmon require unimpeded access throughout their migration corridor to their spawning grounds. Access can be limited by obstacles restricting connectivity to upstream habitats. Delays in migration due to these obstacles are known to reduce survival through increased exposure to predation and loss of energy reserves (Diewert 2007c). Successful terminal migrations of adult Chum Salmon can be attributed to a lack of barriers to fish passage, appropriate flows to facilitate migration, and critical holding habitats such as deep pools, cut banks, and LWD. Pools, cut banks, and functional LWD in the Nanaimo River are considered critical habitats.

Chum salmon generally spawn immediately upstream of turbulent flow or where there is a source of upwelling water (Groot and Margolis 1991).

2.3.2.2 Incubation

Egg to fry survival during the incubation phase varies widely and is influenced by stream flow, dissolved oxygen, gravel composition, water temperature, spawn timing, and spawner density. Floods are generally associated with high egg mortality, as is dewatering of redds (Groot and Margolis 1991). Successful incubation is also dependent on good water quality (i.e., absence of waste water, pesticides, toxic chemicals, petroleum products, and organic compounds). Healthy riparian vegetation is critical to incubation as it helps to moderate temperatures (Diewert 2007c).

2.3.2.3 Freshwater Rearing

During out-migration, Chum Salmon fry do not school as strongly as other species (i.e., Pink or Sockeye Salmon), and predation rates are typically higher than in other species (20–85% over a 2.6 km path) (Diewert 2007c). During downstream migration, fry are dependent on habitats along the margin of the river for refuge, food, and particularly on cover from predation. As such, early rearing Chum Salmon depend on complex river margin habitat (i.e., back eddies, undercut banks, woody debris, and other areas of cover), and a healthy riparian zone for cover, insect production, and temperature regulation.

2.3.2.4 Estuarine Rearing

The Nanaimo River estuary is considered critical habitat for Chum Salmon juvenile migration and rearing. Chum salmon are highly dependent on estuaries for rearing and spend more time in this environment than the other species (Diewert 2007c). Estuarine habitats used by Chum Salmon include tidal creeks, sloughs, and side channels. This period of estuarine residence appears to be the most critical life-history stage of Chum Salmon, and plays a major role in determining the size of the adult return (Aitkin 1998). Benthic copepods were found to be the dominant food type consumed by juvenile Chum Salmon in the Nanaimo estuary mudflats (Bell and Kallman 1976).

2.3.3 Escapement

In the 1930s, the estimated Chum Salmon escapement was around 100,000 (NETF 1980a). Mean Chum Salmon escapement to the river declined during the 1930s to early 1960s, at which point it slowly began to recover (Figure 5). Over the last decade, the mean yearly Chum Salmon escapement has increased to 72,140 (range of 14,176–129,000).

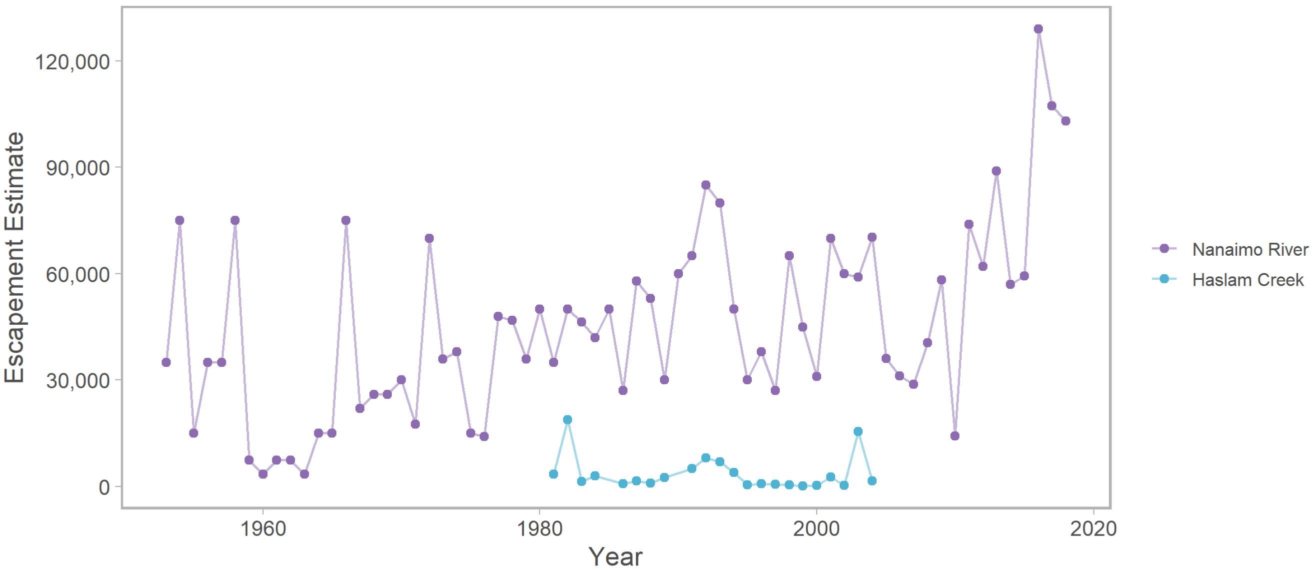

Figure 5. Chum salmon escapement estimates (data from NuSEDS; DFO (2019c)).

2.4 Pink Salmon

2.4.1 Distribution and Timing

Pink salmon have historically spawned in the lower 5 km of the Nanaimo River and lower 0.4 km of Haslam Creek (Map 3; Bell and Kallman 1976). MCW was unable to find any further information about the sites in the Nanaimo River or Haslam Creek used by Pink Salmon for holding during terminal migration, spawning, early freshwater rearing, or estuarine rearing.

2.4.2 Habitat Requirements by Life-history Stage

2.4.2.1 Terminal Migration and Spawning

For a successful terminal migration, Pink Salmon require unimpeded access throughout their migration corridor to their home spawning grounds. Delays in migration to upstream habitats reduce survival through increased exposure to predation and loss of energy reserves (Groot and Margolis 1991). Successful terminal migration can be attributed to lack of barriers, physiological state, habitat quality, water level and temperature (Groot and Margolis 1991). Pink salmon have a high metabolic scope and wide range of inter-individual swimming capabilities. This diversity within populations provides increased survival potential during the variable conditions of upstream migration (MacNutt et al. 2006).

Pink salmon tend to remain in the lower reaches of river systems to spawn, within intertidal zones or along the mouths of streams. Pink salmon spawn within riffle habitat or just below riffles along the edge of pools. These areas are selected for their shallow waters (30–100 cm) with moderate flows (Groot and Margolis 1991). Shallow and fast flowing habitat selection provides aeration for developing eggs during incubation.

2.4.2.2 Incubation

Successful incubation can be attributed to intra-gravel dissolved oxygen levels, temperature stability, low red superimposition, and effective egg deposition. Egg mortalitities occur during high flow events that cause eggs to move into suspension and become subject to predation (Groot and Margolis 1991).

2.4.2.3 Freshwater Rearing

The majority of Pink Salmon fry emerge from the gravel at night once stream bed temperatures have become favourable. Pink Salmon fry exhibit strong schooling behaviour, which leaves them more susceptible to predation as large schools are more visible to predators (Groot and Margolis 1991). Downstream migration of most Pink Salmon stocks occurs earlier than other species. This early migration allows fry to exit the shallow, exposed riffle habitat and seek more cryptic nursery grounds within estuaries (Groot and Margolis 1991).

2.4.2.4 Estuarine Rearing

Schools of Pink Salmon follow the shoreline, remaining in shallow waters throughout their first weeks in the marine environment. Estuarine nursery grounds preferred by Pink Salmon are comprised of irregular shorelines and complex eddies which provide an influx of zooplankton, and shelter from strong currents and wind (Groot and Margolis 1991). This is not true for all populations as some schools move to offshore habitats sooner than others (Groot and Margolis 1991).

2.4.3 Escapement

Historically, a large number of Pink Salmon spawned in the Nanaimo River and Haslam Creek, with runs of over 50,000 fish (Catherine Berris Associates Inc. 2006). The Haslam Creek run is said to have crashed in large part due to years of pollutants being discharged into the stream from nearby coal mines (Aro 1972). By the mid-1950s, only a small number of Pink Salmon (25–750) spawned in the Nanaimo River in both even and odd years, and no Pink Salmon were observed between 1961 and 1978 (Figure 6).

Over the last decade, Pink Salmon have been reared and released from sea net pens off Jack Point for a sport fishery, which has dramatically increased the abundance of Pink Salmon within the river (Steve Baillie, DFO Stock Assessment Biologist, pers. comm. 2019). Over the last decade, the mean yearly escapement has increased to 46,331 spawners (range of 1,643–125,490; Figure 6).

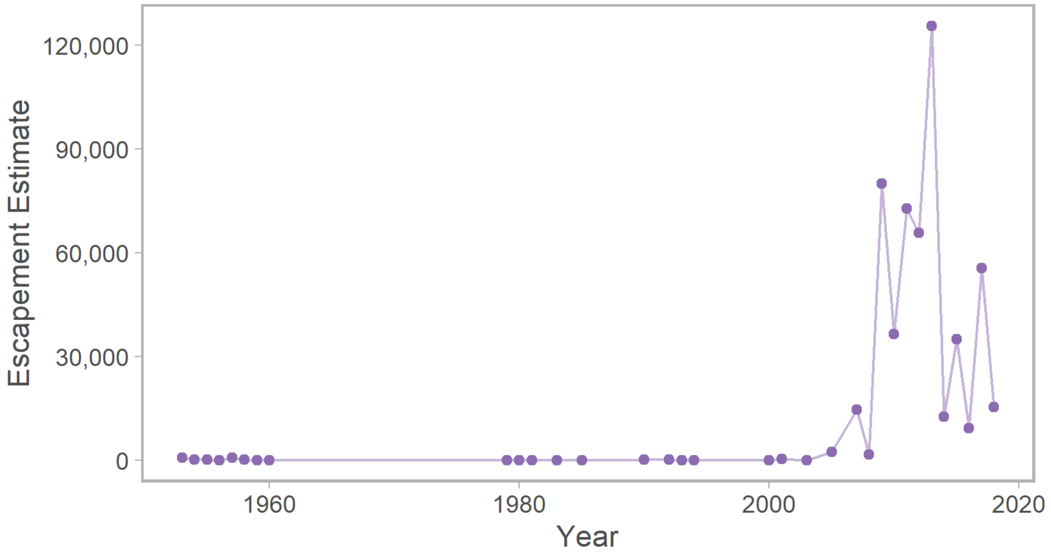

Figure 6. Pink salmon escapement estimates in the Nanaimo River (data from NuSEDS; DFO (2019c)).

2.5 Sockeye Salmon

Sockeye salmon have been intermittently observed in the Nanaimo River since the 1950s. It is not known whether they represent a persistent population (Steve Baillie, DFO Stock Assessment Biologist, pers. comm. 2019). They are believed to be strays either from other rivers such as the Fraser River or perhaps descendants of Sockeye Salmon eggs and fry that were introduced to the Nanaimo River in as early as 1886 and as late as 1933 (Aro 1972, Bell and Kallman 1976).

2.5.1 Distribution and Timing

The Sockeye Salmon that enter the Nanaimo River spawn in the mainstem (Steve Baillie, DFO Stock Assessment Biologist, pers. comm. 2019). MCW was unable to find any information about the specific habitats in the Nanaimo River used by Sockeye Salmon for holding during terminal migration, spawning, early freshwater rearing, or estuarine rearing.

2.5.2 Habitat Requirements by Life-history Stage

2.5.2.1 Terminal Migration and Spawning

Successful terminal migrations of adult Sockeye Salmon can again be attributed to a lack of barriers to fish passage, appropriate flows to facilitate migration, and critical holding habitats such as deep pools, cut banks, and LWD (Groot and Margolis 1991).

For river spawning Sockeye Salmon, most selected spawning sites are located in fast flowing riffles with gravel sizes suitable for favourable egg incubation (i.e., adequate flow-through to deliver oxygen and remove waste from the eggs) (Diewert 2007d). Like other salmon species, the size of the gravel upon which Sockeye Salmon deposit their eggs is related to the size of the spawner and its ability to move material by digging. Successful spawning is largely dependent on the quantity and quality of suitable spawning grounds.

2.5.2.2 Incubation

Egg to fry survival during the incubation phase varies widely and is influenced by stream flow, dissolved oxygen, gravel composition, water temperature, spawn timing, and spawner density. Floods, which scour the bottom or result in heavy siltation, are generally associated with high egg mortality, as is dewatering of redds (Groot and Margolis 1991). Successful Sockeye Salmon incubation is also dependent on good water quality. Healthy riparian vegetation is critical to incubation as it helps to moderate extreme high and low temperatures (Diewert 2007d).

2.5.2.3 Freshwater Rearing

Early stream-rearing Sockeye Salmon depend on complex river margin habitat (i.e., back eddies, undercut banks, woody debris, and other areas of cover), and a healthy riparian zone for cover, insect production, and temperature regulation.

2.5.2.4 Estuarine Rearing

Juvenile Sockeye Salmon typically migrate to the estuary as water temperatures increase in the spring (Diewert 2007d). The specific timing is dependent on fish size, flow conditions, water temperature, dissolved oxygen levels, day length, and the availability of food (Groot and Margolis 1991). While juvenile Sockeye Salmon are not known to spend long periods of time in the estuary, it remains critical habitat for osmoregulation, feeding, and refuge from predation.

2.5.3 Escapement

In the late 1930s to early 1940s, Sockeye Salmon escapement reportedly ranged from 25–2,105 fish (NETF 1980a). There is currently no reliable index of annual Sockeye Salmon return for the Nanaimo River watershed because Sockeye Salmon escapement is only opportunistically monitored (Steve Baillie, DFO Stock Assessment Biologist, pers. comm. 2019). Since 2010, fewer than 15 Sockeye Salmon have been counted in the Nanaimo River (Figure 7).

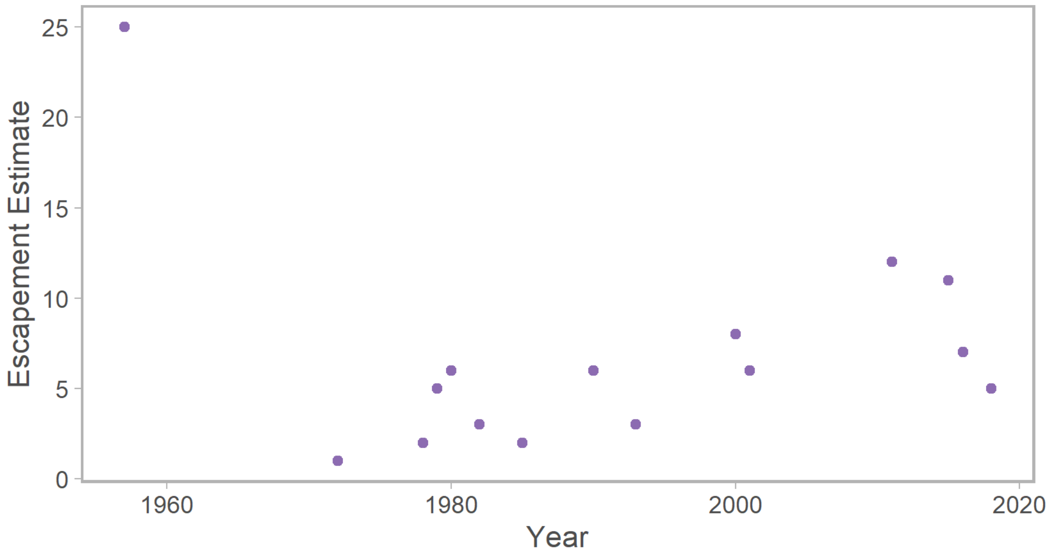

Figure 7. Sockeye salmon escapement estimates in the Nanaimo River (data from NuSEDS; DFO (2019c)).

3 FRESHWATER RISK ASSESSMENT METHOD FOR SALMON WORKSHOP

3.1 Methods

On January 28–29, 2020, DFO held a Risk Assessment Methodology for Salmon (RAMS) workshop attended by stakeholders and Nanaimo River salmon and salmon habitat experts. The RAMS is a methodology developed by DFO to support the assessment of salmon Conservation Units and population status and their habitats in accordance with WSP Strategy 2. It was designed to evaluate what factors, linked to man-made and natural stressors, are most limiting the production of Pacific salmon populations in freshwater, estuarine, and marine environments. While the RAMS process is generally focused on identifying the limiting factors to population persistence and growth, it can also be applied to assess limiting factors to production within a single life stage or multiple populations comprising a wild salmon Conservation Unit.

During this RAMS workshop, attendees reviewed a list of limiting factors to spring run Chinook Salmon production (prior to DFO Stock Assessment recommending that the spring run fall under the summer run Conservation Unit) in the Nanaimo River. The list of limiting factors was prepared by DFO by life-history stage. Attendees then ranked the risk to which spring run Chinook Salmon are exposed by the limiting factors (Very Low, Low, Moderate, High, Very High, as a function of severity of impact, and spatiotemporal scale of impact). Risk rankings were assigned for both current and future watershed states, the latter accounting for the potential impact of climate change (e.g., changing hydrological patterns). A draft of the watershed habitat indicator assessment was used to inform risk rankings and so the rankings are based not solely on attendee perceptions, but the results of the literature review and spatial analyses conducted as part of the habitat indicator assessment. The limiting factors assessed for each life-history stage are listed below.

3.1.1 Terminal Migration and Spawning

LF1: Predation of adults in the estuary and lower river by pinnipeds
LF2: Limited or delayed spawner access
LF3: Potential delays in upstream migration due to physical barriers (natural or anthropogenic)
LF4: Aggradation creates a migration barrier in the lower river
LF5: Loss of safe migration route through the lower river due to channelization, loss of habitat complexity and instream cover features

LF6: High water temperatures in the lower river and estuary during the late summer/early fall migration period can increase mortality and sublethal stress
LF7: Poor water quality conditions during migration period (low dissolved oxygen (DO), high coliform levels, deleterious substances)
LF8: Mortality due to unsanctioned fishing
LF9: Lack of high quality and quantity of spawning habitat
LF10: Disturbance to natural spawning activity due to anthropogenic impacts
LF11: Pre-spawn mortality due to disease
LF12: Mortality due to predation at spawning grounds

3.1.2 Incubation

LF13: High suspended sediment loads and low dissolved oxygen (DO) that reduce egg to fry survival and emergence of alevins
LF14: Non-optimal water temperatures that reduce fry survival by changing emergence time in relation to food availability
LF15: Lower low flows that dewater redds and reduce incubation survival
LF16: More frequent and higher peak flows over winter can scour/disturb redds
LF18: Reduced egg to fry survival due to chum overspawn
LF19: Predation of eggs and alevins by fish (sculpins, trout) and birds (mergansers)
LF20: Egg/alevin mortality due to redd disturbance by invasive or expanding endemic species (e.g., didymo)
LF21: Egg mortality due to redd disturbance by humans

3.1.3 Freshwater Rearing

LF22: Mortality or fitness impacts due to poor water quality (e.g., temperature, TSS, dissolved oxygen levels, pH, hardness, supersaturation)
LF23: Mortality or fitness impacts due to inadequate instream complexity, and riparian complexity
LF24: Increased stranding in isolated off-channel habitat and tributaries can occur with rapid decreases in flow
LF25: High flows impacting fry and smolts
LF26: Mortality or fitness impacts due to lack of food
LF27: Mortality or fitness impacts due to competition with alien invasive species
LF28: Mortality or fitness impacts due to competition, interaction with other species/hatchery fry
LF29: Mortality due to high levels of predation
LF30: Mortality or fitness impacts due to anthropogenic disturbance
LF30.5 Aquifer drawdowns, direct mortality through pumping, domestic use
LF31: Mortality or fitness impacts due to disease
LF32: Mortality or fitness impacts due to hatchery introgression

3.1.4 Estuarine Rearing

LF33: Low early marine survival of chinook fry and smolts in the estuary/nearshore marine due to the lack of adequate food supply (particularly in first four months of marine life)
LF34: Predation of smolts in the lower river and estuary
LF35: Mortality of fry and smolts due to predation and competition from invasive species
LF37a: Loss of good quality marine riparian habitat
LF37b: Loss of good quality intertidal habitat (i.e., loss of natural abundance and composition of benthic communities, associated ecological communities)
LF37c: Loss of good quality subtidal habitat (i.e., Loss of natural abundance and composition of benthic communities, eelgrass habitat, kelp forests and associated ecological communities)
LF38: Reduced survival due to decreased water quality from ballast dumping, industrial discharge, etc in the estuary
LF39: Mortality or reduced fitness due to direct anthropogenic interference, not covered by previous LFs

3.1.5 Marine

LF40: Low marine survival due to inadequate food supply (abundance or value)
LF41: Low marine survival (<1%) in the Strait of Georgia due to low marine productivity, poor water quality, increased mean water temperature
LF42: Low marine survival due to competition for food
LF43: Low marine survival due to high rate of predation by orcas, pinnipeds
LF44: Low marine survival due to high rate of predation in nearshore environments
LF45: Mortality or fitness impacts due to competition with aquatic invasive species
LF46: Mortality due to impacts related to offshore habitat destruction
LF47: Mortality or sub-lethal effects due to pollutants
LF48: Mortality or fitness impacts due to disease
LF49: Mortality or fitness impacts due to HABS
LF50: Mortality due to fishing

3.2 Results

Four limiting factors to spring run (now summer run) Chinook Salmon terminal migration and spawning were assigned a risk ranking of 'High' or 'Very High' by the attendees of the RAMS workshop (detailed results of the 2019 limiting factor risk assessment workshop are attached in Appendix 1). The attendees agreed that successful in-migration of adult salmon is highly threatened by the inability to access spawning habitats due low flows (LF2), particularly at the Bore Hole and White Rapids Falls, which are physical barriers during low flows (LF3). Safe migration through the lower river is further challenged by a lack of habitat complexity and instream cover features due to loss of riparian forest cover and large woody debris with logging as well as artificial channelization (LF5). Once in the river, spawners have little spawning habitat, and even less high-quality spawning habitat (LF9).

Two limiting factors to spring run (now summer run) Chinook Salmon incubation were assigned a risk ranking of 'High' or 'Very High'. Eggs and alevins are at high risk of mortality due to high suspended sediment loads and low DO (LF13) and due to peak flows over winter that can scour or disturb redds (LF16). Extreme peak flows have increased in frequency and magnitude due to logging and climate change, which has also increased the frequency of high turbidity events.

During freshwater rearing, spring run (now summer run) Chinook Salmon fry survival is most limited by five 'High' or 'Very High' limiting factors (Appendix 1): mortality or fitness impacts due to inadequate instream and riparian complexity (LF23); limited off-channel habitat and stranding in isolated off-channel habitat and tributaries during low flows (LF24); high fall and winter flows (LF25); mortality or fitness impacts due to lack of food (LF26); and mortality due to high levels of predation (LF29). The rankings of these limiting factors reflect impacts primarily due to logging but also due to urbanization and agriculture in the lower watershed, such as loss of mature conifer riparian forest to supply cover, nutrients, LWD, and regulate temperatures, loss of pool habitat due to aggradation, and peak flows that exceed natural variation in flow in magnitude and frequency.

All but three estuarine rearing limiting factors were assigned a risk ranking of 'High' or 'Very High'. Low early marine survival of chinook fry and smolts is driven by historical loss of high quality intertidal estuarine marsh, intertidal and subtidal eelgrass in the estuary and kelp forests in the Strait of Georgia to provide refuge and food (LF33, LF37a,b,c). as well as direct or indirect effects of exposure to poor water or sediment quality (LF38).

The risk ranking of most limiting factors was assessed as likely to increase in the future due to increasing water consumption and land conversion to impervious surfaces with population growth and climate change. In the freshwater environment, these stressors will interact to exacerbate summer low flow events and high water temperatures and cause more frequent and extreme high flows in winter that can destabilise stream habitats. In the estuary, eelgrass and estuarine marsh refuge and foraging habitat will be lost if vegetation distribution change cannot keep pace with changes in sea level, if vegetation communities do not have suitable substrates and elevations to shift to, or if urban development blocks landward retreat.

4 HABITAT INDICATOR ASSESSMENT

4.1 General Methods

Strategy 2 of the WSP requires that the risk to the Nanaimo River watershed be assessed using the habitat pressure-state indicator approach developed by Stalberg et al. (2009). With this approach, habitat pressure indicators represent landscape-level anthropogenic stressors. The magnitude or spatial extent of the stressors is often evaluated through spatial analysis of remotely sensed data. Pressure indicators include natural resource extraction activities and land development, for example, and are upslope contributors to downslope impacts. State and quantity indicators act as signs or signals of the physical condition of aquatic habitat, which is generally evaluated through field studies (this assessment focuses on freshwater and estuarine habitats, not marine). A negative change in a state indicator is typically linked to one or more pressure indicators and can impact the critical habitats of one or more salmon life-history stages. Impacts to critical habitats limit salmon production as per the mechanisms described in Sections 3.1.1 to 3.1.5 (Figure 8).

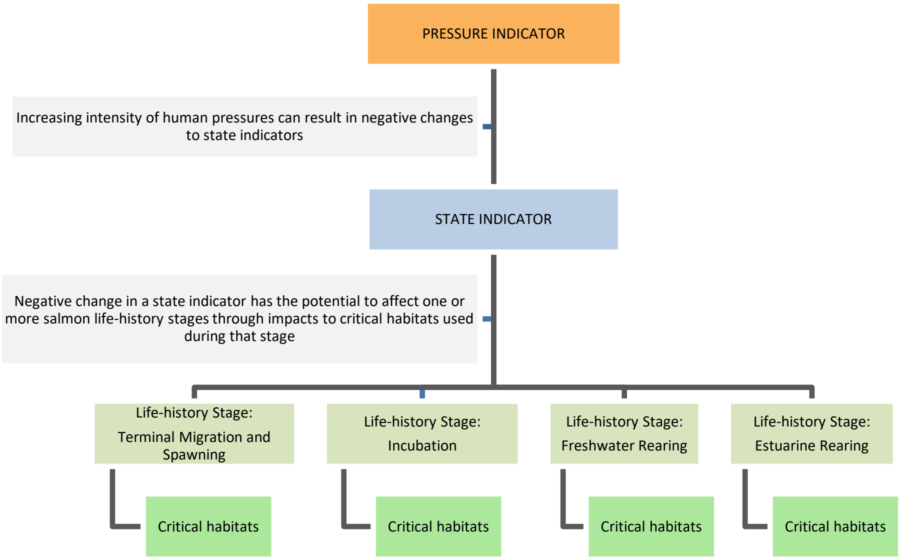

Figure 8. Relationships between pressure indicators, state (or quantity) indicators, life-history stages, and critical habitats.

Six stream, lake, and estuary pressure indicators and eight state/quantity indicators were evaluated in this assessment (Table 1). Metrics—typically quantitative variable(s) measured to determine the status of an indicator—were compared against risk benchmarks outlined by Stalberg et al. (2009) or other sources (Table 1). Risk benchmarks indicate marked changes in the condition of a metric that may signify a change in risk posed to salmon and salmon habitat. MCW assigned risk rankings of ‘Low’, ‘Moderate’ or ‘High’ to the indicators based on these risk benchmarks. In some cases, more than one metric was used for a given indicator, when multiple metrics better captured the diverse mechanisms by which the status of the indicator might be altered. For example, total land cover alteration was evaluated using two metrics, one capturing change due to forestry, and the other due to land development. An overall risk ranking was assigned in these cases that considered both sets of metrics/benchmarks and their cumulative (additive or multiplicative) adverse impacts on fish habitat condition. For some of the indicators, the literature did not provide clear guidance on benchmarks, and so in those cases risk rankings were assigned using MCW’s professional judgement and considering available data.

Preventing impacts to fish habitat from pressure indicators is best achieved at policy and management levels through development and implementation of evidence-based policy, best management practices, and industry standards. Addressing deficiencies in habitat state and quantity indicators is typically done through habitat restoration, which is a reactive approach to fish habitat degradation.

Table 1. Pressure and state indicators assessed in this report.

Habitat Type	Indicator Type	Indicator	Metric	Benchmark	Benchmark Reference
Stream/Lake	Pressure	Total land cover alteration	% of the forested land base ≤40 years old	Low: ≤20% Moderate: >20–30% High: >30%	Created for the assessment based on the *Standard for Terrestrial Ecosystem Mapping in British Columbia* (1998) and typical Equivalent Clearcut Area limits
			% agriculture, industrial, highway, or rural or urban land	Low: ≤18% Moderate: >18–40% High:>40%	Based on thresholds in Plewes et al. (2018)
Stream/Lake	Pressure	Road development	Density of paved	Low: <1.8 km/km^2 Higher risk: >1.8 km/km^2	Based on thresholds in Plewes et al. (2018)
			Density of unpaved roads	Low: <0.4 km/km^2 Higher risk: >0.4 km/km^2	Adapted from Stalberg et al. (2009)
Stream/Lake	Pressure	Riparian disturbance	% forest cover within a 100 m buffer that is ≤40 years old or converted to anthropogenic or agricultural use	Low: ≤5% Moderate: >5–10% High: >10%	Adapted from Stalberg et al. (2009)
Stream/Lake	Pressure	Water extraction	Number of water rights licences and permitted extraction volumes	Ranking based on professional judgement and the degree to which literature and data indicate the watershed can support additional extraction with its present storage infrastructure	
Stream/Lake	Pressure	Permitted waste discharge	Number and type of MOECCS Authorization Management System permitted waste discharge authorizations	Ranking based on professional judgement	
Stream/Lake	State	Water quality	Temperature, dissolved oxygen, turbidity, primary productivity, and nutrient levels (total N, organic N, NH4, NO3, NOx, total P, organic P, particulate P, and ortho-PO4), fecal coliforms	Upper Optimum Temperature Range and Impairment Temperatures for juvenile rearing and adult in-migration	Stalberg et al. (2009)
				BC Approved Water Quality Guidelines	MOECCS (2019b)
Stream	State	Stream discharge	The 1 in 2 year 30-day duration summer mean minimum flow at Cassidy WSC station 08HB034 from 2009 to 2018	Low: >20% of the mean annual discharge Higher risk: <20% of the mean annual discharge, if unregulated 30-day duration summer minimum flow was typically >20% mean annual discharge	Stalberg et al. (2009)
			Minimum flow during July to October recorded at Cassidy WSC station 08HB034 from 2009 to 2018	Low: >3.9 m^3/s from July to October Higher risk: <3.9 m^3/s from July to October	1993 *Nanaimo River Water Management* Plan

			Trend in number of extreme low and/or high flows readings taken hourly at Cassidy WSC station 08HB034 from 1965 to 2018	Low: no trend or declining number Higher risk: increasing number	
Stream/Lake	Quantity	Key spawning areas	Length of stream used for spawning by each Pacific salmon species	Ranking based on professional judgement following a literature review	
Stream	State	Habitat composition	% pool habitat area by reach	Based on Johnston and Slaney (1996) and professional judgement Higher risk: If a low gradient reach (i.e., <2%) contained <40% pool habitat by area, if a moderate gradient reach (i.e., 2–5%) contained <30% pool habitat by area, if a higher gradient reach (i.e., >5%) contained <20% pool habitat by area.	Johnston and Slaney (1996)
Stream	State	Channel stability	Instability of channel morphology, channelization	Ranking based on professional judgement	
Stream	State	Large woody debris	LWD abundance per kilometre, with LWD being >15 m in length	Low: >50 pieces/km, with the pieces being longer than 15 m. Moderate to High: <50 pieces/km	Stalberg et al. (2009)
Estuary	Pressure	Estuary habitat disturbance	Area of estuarine disturbance due to log storage leases, diking, etc. Trends in spatial extent of industrial activities	Ranking based on professional judgement	
Estuary	State	Estuary water and sediment quality	Water contaminant levels, temperature, dissolved oxygen, turbidity, primary productivity and nutrient levels (total N, organic N, NH4, NO3, NOx, total P, organic P, particulate P, and ortho-PO4), fecal coliforms Sediment contaminant levels, dissolved oxygen	Ranking based on professional judgement, as well as the Canadian Council of Ministers of the Environment Canadian Water and Sediment Quality Guidelines for the Protection of Aquatic Life, where applicable	https://ccme.ca/en/summary-table
Estuary	State	Estuarine habitat condition	Area, continuity (degree of patchiness), and condition (density in no. shoots/m^2) of estuarine marsh and eelgrass beds Area and vegetation community composition (i.e., site associations) of estuarine marsh and meadow (in accordance with wetlands of BC handbook)	Ranking based on professional judgement given trends revealed by literature review and spatial analyses	

4.1.1 Literature Review

In summer/fall 2019, the BC Conservation Foundation (Isaac Anderton) compiled all available peer-reviewed and grey literature about the Nanaimo River Watershed. MCW reviewed the literature for this assessment. Topics of interest included general watershed descriptions, history of resource use in the watershed, fish habitat condition, Pacific salmon distribution and population dynamics, and records of restoration activities in the watershed. Additional literature was shared with MCW in early 2020 by attendees of the January 2020 RAMS limiting factor risk assessment.

4.1.2 Spatial Data Gathering and Processing

Geographic Information Systems (GIS) data relevant to this project was obtained by MCW in fall/winter 2019 from several sources:

- DataBC
- Esri – DigitalGlobe Vivid 2016 satellite imagery
- City of Nanaimo – 5 cm resolution 2018 and 30 cm resolution 2009 orthophotos
- InDro Robotics – 5 cm resolution 2019 drone imagery

Spatial analyses and mapping were completed using ArcMap 10.6 with the Spatial and 3D Analyst extensions.

4.2 Indicator-specific Methods and Results

The following sub-sections describe the methods used to assess each of the habitat indicators and present the results of the habitat indicator assessments. As previously stated in Section 1.2.1, for the purposes of discussion in this assessment, MCW divided the watershed and the watersheds that drain into the estuary into coarse “sub-basins” (Map 1). These sub-basins correspond to areas of land that drain into various sections of the Nanaimo River or estuary. Therefore, for several of the habitat indicator assessments, MCW presents results for each of the sub-basins.

4.2.1 Stream and Lake Pressure: Total Land Cover Alteration

Land cover alterations within a watershed include fire disturbance, forestry, mining activity, and forms of land development such as agriculture and urbanization. Land cover alterations may adversely affect the life-history stages of all salmon species by impacting one or more habitat state indicators (Figure 9). In this way, total land cover alteration provides an index of potential cumulative changes in watershed functions or processes that can affect spawning and rearing habitats (Poff et al. (2006), as cited in Stalberg et al. (2009)).

Forestry

Forestry practitioners typically set harvesting rate by setting a limit on Equivalent Clearcut Area (ECA)—the area of a watershed that has been clearcut, with a reduction factor to account for the areas where hydrologic recovery has been achieved. Practitioners typically define a forest as having reached hydrologic recovery when a regenerating forest stand is comparable to a reference stand (typically an old unlogged stand) with respect to rainfall interception, snowpack development and ablation (G. Horel, pers. comm., 2021). This is frequently cited as being when a stand reaches 9 m in height (e.g., Timberline Natural Resource Group 2010, Hocking et al. 2013). ECA can be a problematic metric; however, as the stand characteristics required to achieve hydrologic recovery depend on the hydrologic regime (G. Horel, pers. comm., 2021). For example, though ECAs of 20% are frequently used as a limit in Fisheries Sensitive Watersheds in BC, ECAs exceeding 17.5% have been shown to increase the frequency and magnitude of peak flows in small Vancouver Island watersheds by up to 70% compared to the unlogged state (Hudson 2002), posing a risk to stream structure and function, particularly on erosion-prone terrain (Klein et al. 2012). Further, the forest characteristics and tree sizes needed for hydrologic recovery are different from those required to maintain geomorphic processes (e.g., supply of LWD, bank erosion resistance, bank stability and slope stability) or for ecological function (G. Horel, pers. comm., 2021). For instance, though foresters often cite hydrologic recovery as being when a stand reaches ~9 m in height, under the *Standard for Terrestrial Ecosystem Mapping in British Columbia* (1998) stands typically between 2–10 m in

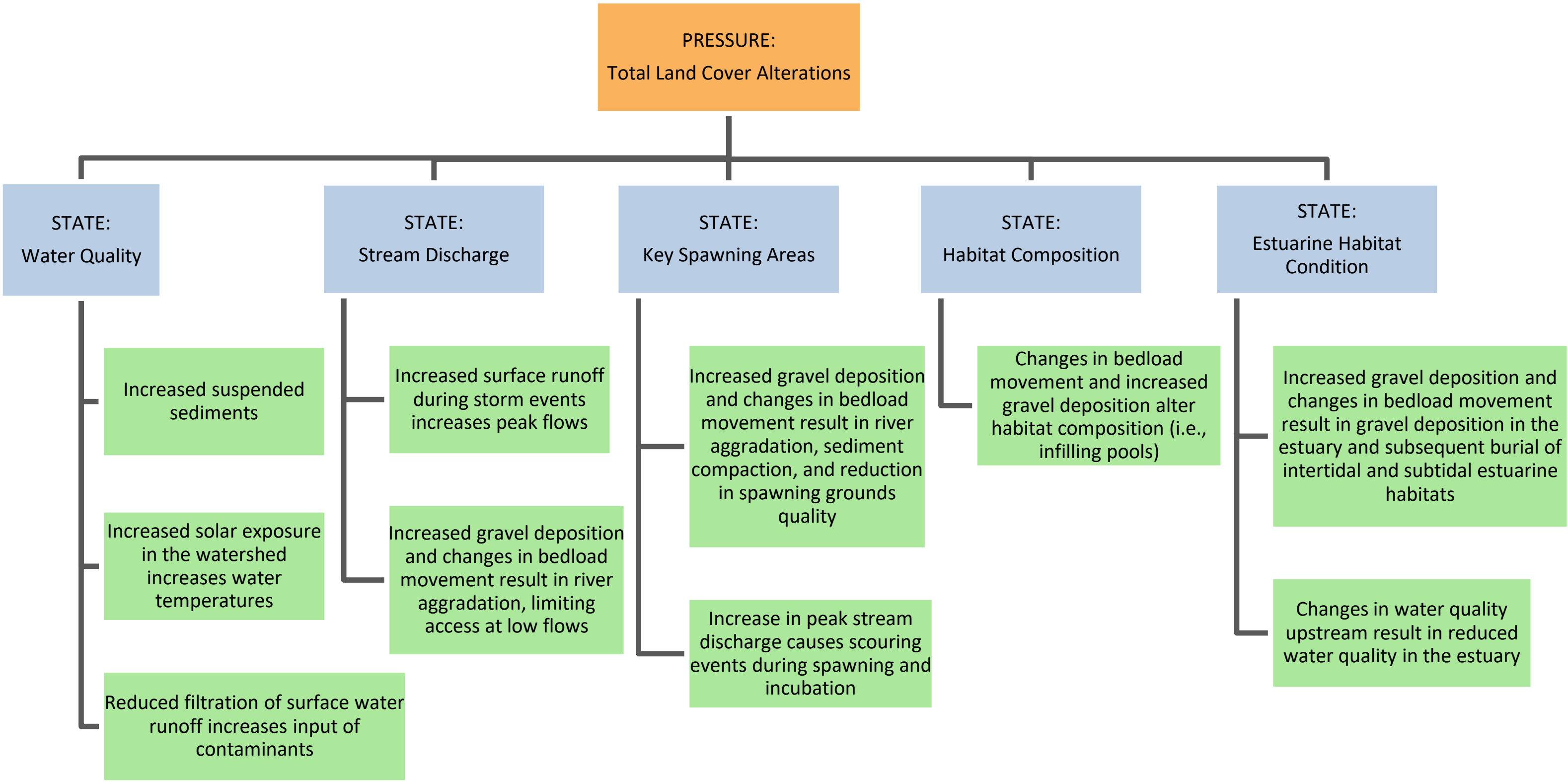

Figure 9. Relationship between total land cover alterations and state indicators.

height are less than 40 years old and are classified as being in the tall shrub stage. Forest stands less than 40 years old do not have the same structure and therefore do not support the same ecological functions as mature (>80 years old) or old-growth forest (>250 years old). Under the *Standard for Terrestrial Ecosystem Mapping in British Columbia* (1998), forest stands less than 40 years and greater than 10 m tall old are in the pole/sapling structural stage of regeneration, where there is no evident vertical canopy structure.

With this information about how ecological and hydrological functions decline with loss of mature and old-growth forest, this assessment assumes that forest stands less than 40 years old are dominated by trees less than 9 m tall, based on the *Standard for Terrestrial Ecosystem Mapping in British Columbia* (1998), and that ecological and hydrological risk increase as the area of forest cover below this age increases beyond 20%.

Land Development
In addition to forestry, land development can alter the hydrology of the watershed. Impermeable surfaces (e.g., roofs and roads) change run-off patterns and decrease detention of rainfall, which increase peak discharge and impact surface and groundwater availability in the area (e.g., Bronstert et al. 2002, Shi et al. 2007). Land development also introduces non-point source pollutants to aquatic systems. Impermeable surfaces and altered surfaces such as lawns accumulate contaminants (e.g., metals) from land-based human activities and shed contaminants more easily and rapidly than natural substrates. Agriculture may introduce pesticides. Septic disposal fields and agriculture introduce nitrates and coliform bacteria that may leach into freshwater systems, stimulate primary productivity, and deplete DO (e.g., Windom 1992, Sanger et al. 2004, Kroon et al. 2016). Analyses of correlations between land use and water quality in watersheds of the Regional District of Nanaimo (RDN) found that stream summer DO levels decreased with increasing percentage agricultural/rural residential land use in a watershed (Plewes et al. 2018).

Agricultural land use also increases stream turbidity through more than one mechanism (Plewes et al. 2018). First, these areas typically have less forest cover and riparian vegetation and so experience increased bank erosion and sedimentation, and warmer water temperatures. Second, warm water temperatures and nutrient enrichment together cause increased turbidity through the growth of algae. Summer turbidity levels across RDN watersheds increased markedly when percent agricultural/rural residential land use in the watershed exceeded a non-linear threshold of ~18% (Plewes et al. 2018).

4.2.1.1 Methods

Total land cover alterations in the Nanaimo River watershed sub-basins, as well as the Chase River and Holden Creek watersheds, were calculated by analyzing the DataBC vegetation resource inventory “VRI - Forest Vegetation Composite Polygons and Rank 1 Layer” within the provincial watershed boundary. This layer was subsequently updated using the Esri DigitalGlobe Vivid 2016 satellite imagery. The forested cover in the layer was classified by age as being 1–20 years, 21–40 years, 41–60 years, and so on, up to older than 250 years. Forested cover classified as older than 120 years was considered unaltered. Non-forested cover types included natural bedrock, alpine areas, wetlands, and urban areas.

Risk ranking was assigned by qualifying risk associated with two metrics that capture impacts to fish habitat driven by the dominant land uses in the watershed—forestry and land development:

1. The percentage of the sub-basin forested land base that is less than 40 years old

   Low: ≤20%
   Moderate: >20–30%
   High: >30%

2. The percentage of the sub-basin that is agriculture, industrial, highway, or rural or urban land (benchmarks informed by the relationship between percent agricultural/rural residential land and summer DO; and non-linear thresholds observed in the RDN in the relationships between watershed percent

agricultural/rural residential land and summer turbidity, and percent forested cover and summer turbidity (Plewes et al. 2018))

Low: ≤18%
Moderate: >18–40%
High:>40%

The greater of the two metric risk rankings was used as the indicator risk ranking for each sub-basin, except where the benchmark for a 'Moderate' risk ranking was exceeded for both metrics. In this case, the overall risk ranking was considered 'High' to account for the fact that forestry and land development may have cumulative (additive or multiplicative) adverse impacts on fish habitat condition.

4.2.1.2 Results

The sub-basins of the Nanaimo River watershed, as well as the Chase River and Holden Creek watersheds, which drain into the Nanaimo River estuary, have experienced near complete land cover alteration (Map 4). Only 0.55%, 2.8%, and 1.4% of what would have historically been vegetated land or wetland (i.e., excluding alpine areas and avalanche chutes) in the Lower Nanaimo River, Middle Nanaimo River, and Haslam Creek sub-basins, respectively, is unaltered (Figure 10). The mountain zones of the South and Upper Nanaimo River still contain old growth forest, covering 15% and 20% of what would have historically been vegetated land or wetland. The remaining forested land is covered by early regenerating forest: 41%, 30%, 41%, 53%, and 44% of forest in the Haslam Creek, and Lower, Middle, South, Upper Nanaimo River sub-basins is under 40 years old, respectively.

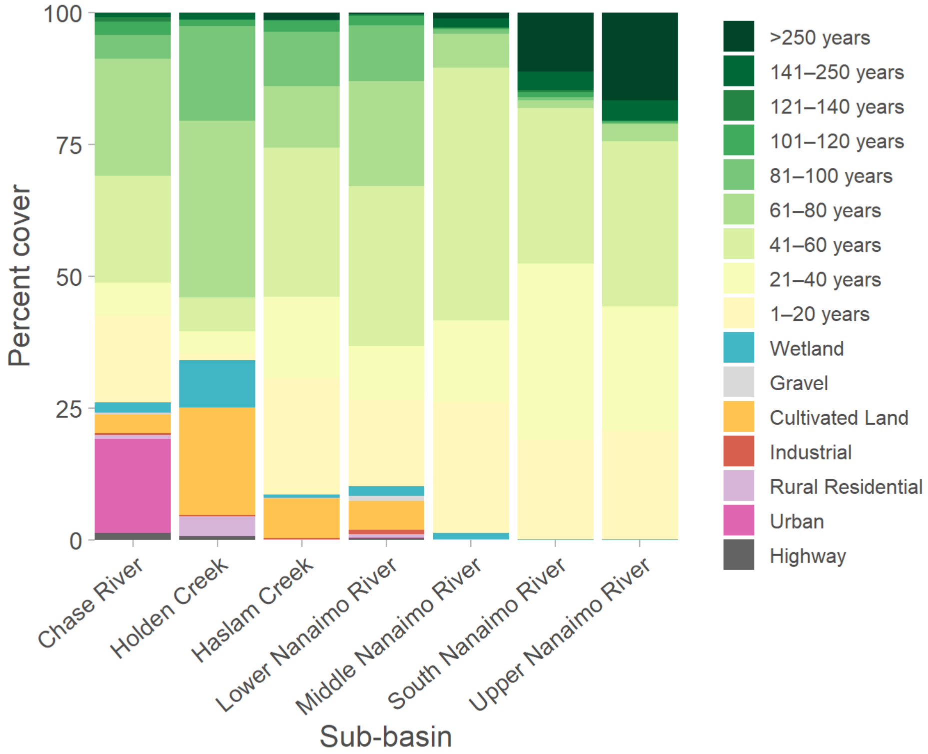

Figure 10. Percent cover of land cover types in the Nanaimo River watershed sub-basins and the Chase and Holden Creek sub-basins, excluding lakes and typically unvegetated land (i.e., bedrock, alpine areas, and avalanche chutes).

The lower elevations of the Lower Nanaimo River, Haslam Creek, Chase River, and Holden Creek sub-basins have been altered by agriculture, industrial, highway, or rural and urban development. These land cover types comprise a low of 7.4% of the Lower Nanaimo River, up to 23.8% of the Chase River sub-basin and 25% of the Holden Creek sub-basin (Figure 10).

The percentage of the forested land base in each sub-basin that is less than 40 years old exceeds the ‘High’ risk ranking benchmark in all sub-basins except Chase River (‘Moderate’), Holden Creek (‘Low’), and Lower Nanaimo River (‘Moderate’). Chase River and Holden Creek exceed the ‘Moderate’ risk ranking benchmark in terms of potential for water quality impacts on fish and fish habitat due to agriculture, and industrial, rural and urban development. Given the high coverage of the lower watershed land area by agriculture and urban land uses, and the young age of the remaining forest in the sub-basins, the risk of cumulative impacts to fish habitat from land cover alteration is ‘High’ in the Nanaimo River, Chase River, Beck Creek watersheds, and ‘Moderate’ in Holden Creek watershed.

4.2.2 Stream and Lake Pressure: Road Development

Road density is positively correlated with land-use within a watershed, and is an indicator of overall watershed development (Stalberg et al. 2009). Gravel forestry road construction in a watershed may increase fine sediment deposition into streams and lakes, reduce aquatic invertebrate diversity, affect aquatic connectivity, and channel morphology (Tschaplinski, 2010; Brown et al, 2013). The extent to which gravel forestry roads impact streams and fish habitat depends on terrain characteristics in the watershed, standards of road construction and maintenance, the degree to which cutslopes and ditchlines are vegetated, and the level of traffic on the roads (G. Horel, pers. comm., 2021). Legacy road issues persist, but standards for stream crossings and forest road construction have markedly improved from historical practices.

Paved roads have different effects on watershed fish habitats. Paved road density increases with residential development and is positively correlated with poor water quality because, as stated in Section 4.2.1, impervious surfaces shed and transport non-point source pollutants (e.g., fertilizers, metals, and other contaminants from agricultural, residential, and industrial land uses) to aquatic systems more easily that natural substrates. Non-point source pollutant levels are positively and non-linearly correlated with stream conductivity, in that there is little increase in conductivity until some threshold road density is reached (Plewes et al. 2018 and references therein). In RDN watersheds, this threshold effect on stream conductivity was observed when paved road density exceeded ~1.8 km/km^2.

Both paved and gravel road stream crossings may additionally reduce the total amount of habitat available to salmonids in a watershed by limiting or blocking fish access to upstream spawning or rearing habitats if the stream crossing structures are poorly installed or maintained (Harper & Quigley, 2000). Watershed road development and stream crossing density can affect the life-history stages of all species by adversely affecting several habitat state indicators (Figure 11). Negative relationships between road densities and salmon production have been observed at road densities as low as 0.4 km/km^2 (Stalberg et al. 2009).

4.2.2.1 Methods

The extent of road development in each sub-basin in the Nanaimo River, Chase River, and Holden Creek watersheds was evaluated by calculating the lineal length of road per square kilometre of sub-basin. MCW obtained the Digital Road Atlas layer and manually digitized any additional roads not captured in the layer using Esri DigitalGlobe Vivid 2016 satellite imagery of the watershed. MCW evaluated the cumulative risk posed to the sub-basin by road development for forestry and urban development using two sets of metrics/benchmarks.

First, gravel road development density in each sub-basin were determined by dividing the total length of gravel roads in each sub-basin by the sub-basin area. The risk posed by gravel road densities was then evaluated using the benchmark proposed by Stalberg et al. (2009):

Low: <0.4 km/km^2
Higher risk: >0.4 km/km^2

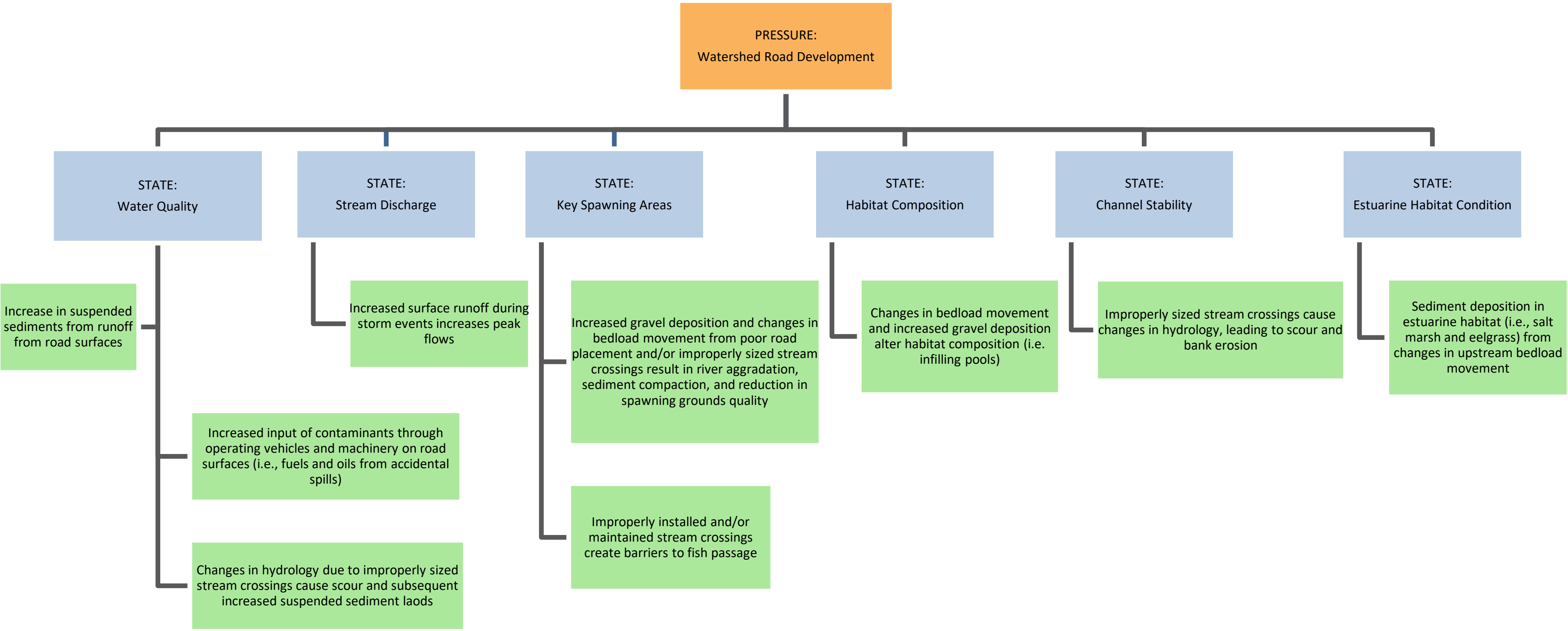

Figure 11. Relationship between watershed road development and selected state indicators.

Note that this gravel road density calculation could not distinguish between roads that are overgrown relative to those that are in active use, roads that have been deactivated or remediated and roads that have not. MCW contacted Mosaic Forest Management (Molly Hudson, Sustainability Director) for spatial road status data that would allow active vs deactivated road density calculations. Mosaic has suggested that drafting a data sharing agreement with DFO for the use of the road data may be possible, but given the timeline to complete this report, such an agreement will need to be drafted following the writing of this report. We also did not have the data to distinguish between roads built before vs after the introduction of forest management legislation. As a result, this metric is not a substitute for field information on road condition and crossing structures. Deactivated roads would be expected to pose little or no risk of being sediment or landslide sources, and roads built after the introduction of forest management legislation would be expected to be lower risk than those built prior to the introduction of this legislation.

Second, MCW evaluated the risk posed to stream water quality in the watershed by paved roads. The risk benchmarks below were based on the threshold paved road density that was correlated with a marked increase in stream conductivity across RDN watersheds (Plewes et al. 2018):

Low: <1.8 km/km^2
Higher risk: >1.8 km/km^2

Stream and lakes were mapped using the DataBC “TRIM Stream Lines - 1:5,000” and “Freshwater Atlas Lakes” layers. The number of modelled fish-bearing crossings was determined for each sub-basin to visualize the number of crossings that intersect fish and fish habitat. The fish-bearing status of the streams was based on observed and inferred fish presence data obtained from the Fisheries Information Summary System.

If both road density metrics fell below the low-risk benchmark, then the sub-basin was assigned an overall risk ranking of ‘Low’. If one or more of the individual metrics exceeded the higher-risk benchmark, then the sub-basin was assigned an overall risk ranking of ‘High’, in recognition of the potential for impacts from gravel roads and paved roads to act additively or multiplicatively on fish habitat condition.

4.2.2.2 Results

Gravel road development densities in each sub-basin greatly exceeded the 0.4 km/km^2 benchmark set out in Stalberg et al. (2009). Paved road densities exceeded the 1.8 km/km^2 benchmark in the Chase River and Holden Creek sub-basins. The Chase River and Lower Nanaimo River sub-basins had the highest road densities, with 3.08 and 3.44 km of gravel road/km^2, respectively, and 3.56 and 1.17 km of paved road/km^2, respectively (Map 5, Table 2). The risk to fish habitat in the watershed sub-basins from road development and stream crossings is therefore ranked as ‘High’ for all sub-basins.

The Lower and Upper Nanaimo River and the Chase River sub-basins have approximately 380 m to 3.1 km more gravel road per square kilometer than eight of the nine actively logged Clayoquot and Nootka Sound watersheds that MCW has assessed using this Wild Salmon Policy framework and in which road densities exceeded the 0.4 km/km^2 benchmark.

Most road construction in the Nanaimo River watershed has been done in service of logging operations, which has caused road and hillslope instability in the upper Nanaimo watershed (Butler et al. 2014). In the 1980s, Chinook Salmon fry survival in the Nanaimo River was noted to be low due to siltation and streambed shifting during high flows, presumably caused by road and hillslope instability (Blackman 1981, in Butler et al. 2014). There are over 1.48 fish-stream crossings/km^2 in the Upper Nanaimo River sub-basin. Field investigation is needed to determine the extent of road and crossing effects on streams, and to update the inventory of legacy crossing structures that are affecting fish passage or fish habitat. DFO may ask Mosaic to share sources of instability caused by roads and fish passage inventory data for the purposes of understanding and monitoring ongoing effects on fish habitat and fish passage.

Table 2. Stream crossing density and fish-bearing status in the Nanaimo River, Chase River, and Holden Creek sub-basins. The two metrics used in assigning risk rankings are highlighted in grey.

	Chase River	Holden Creek	Haslam Creek	Lower Nanaimo River	South Nanaimo River	Middle Nanaimo River	Upper Nanaimo River
# of crossings	52	24	56	88	129	96	365
# of fish-bearing crossings	52	24	43	88	74	78	123
# of non-fish-bearing crossings	0	0	13	0	55	18	242
Gravel road density (km of road/km^2)	3.08	1.72	2.90	3.44	3.30	3.29	3.44
Paved road density (km of road/km^2)	3.56	2.12	0.56	1.17	0	0.14	0.04

4.2.3 Stream and Lake Pressure: Riparian Disturbance

Riparian disturbance is a commonly used pressure indicator for both streams and lakes (Stalberg et al. 2009). Riparian vegetation has many critical functions in aquatic habitats, including, but not limited to, temperature regulation, provision of cover and LWD, nutrient input, insect subsidies, and channel stabilization. Today, while forestry operators are generally required to preserve some amount of riparian vegetation adjacent to fish-bearing streams, this was not the case when much of the Nanaimo River was first logged. The impacts from historical loss of riparian forest on fish habitat persist in the absence of intervention and compound present-day impacts from riparian forest loss (Figure 12). When lost, restoring riparian habitats to a functioning condition can require intervention through conifer release and bank stabilization practices.

4.2.3.1 Methods

The extent of riparian disturbance along the Nanaimo River, including First and Second Lakes, and the South Nanaimo River (up to the South Fork Dam) was determined by classifying riparian vegetation types, by reach, within 100 m of the high water mark. MCW used the DataBC vegetation resource inventory "VRI - Forest Vegetation Composite Polygons and Rank 1 Layer" (subsequently updated using the Esri DigitalGlobe Vivid 2016 satellite imagery) to classify forest stand types into seven categories consistent with the *Standard for Terrestrial Ecosystem Mapping in British Columbia* (1998):

- Mature conifer (>80 years old, >90% mature coniferous stand)
- Mature mixed (>80 years old, mixture of mature coniferous and deciduous vegetation)
- Young (40–80 years old)
- Early regenerating (<40 years old)
- Wetland
- Agricultural
- Anthropogenic (i.e., roads, residential and industrial buildings, gravel pits)

The VRI layer does not always capture the most recent cutblocks and can miss finer details in the riparian zone so MCW also used the following imagery to visually verify that the cover types were classified as accurately as possible: 5 cm resolution 2018 orthophotos (estuary and reach 1) and 30 cm resolution 2009 orthophotos (half of reach 2, reaches 5–7, reaches 9–14, South Nanaimo River) obtained from the City of Nanaimo; 5 cm resolution drone imagery collected in 2019 by InDro Robotics (reaches 18–24); and Esri DigitalGlobe Vivid 2016 satellite imagery.

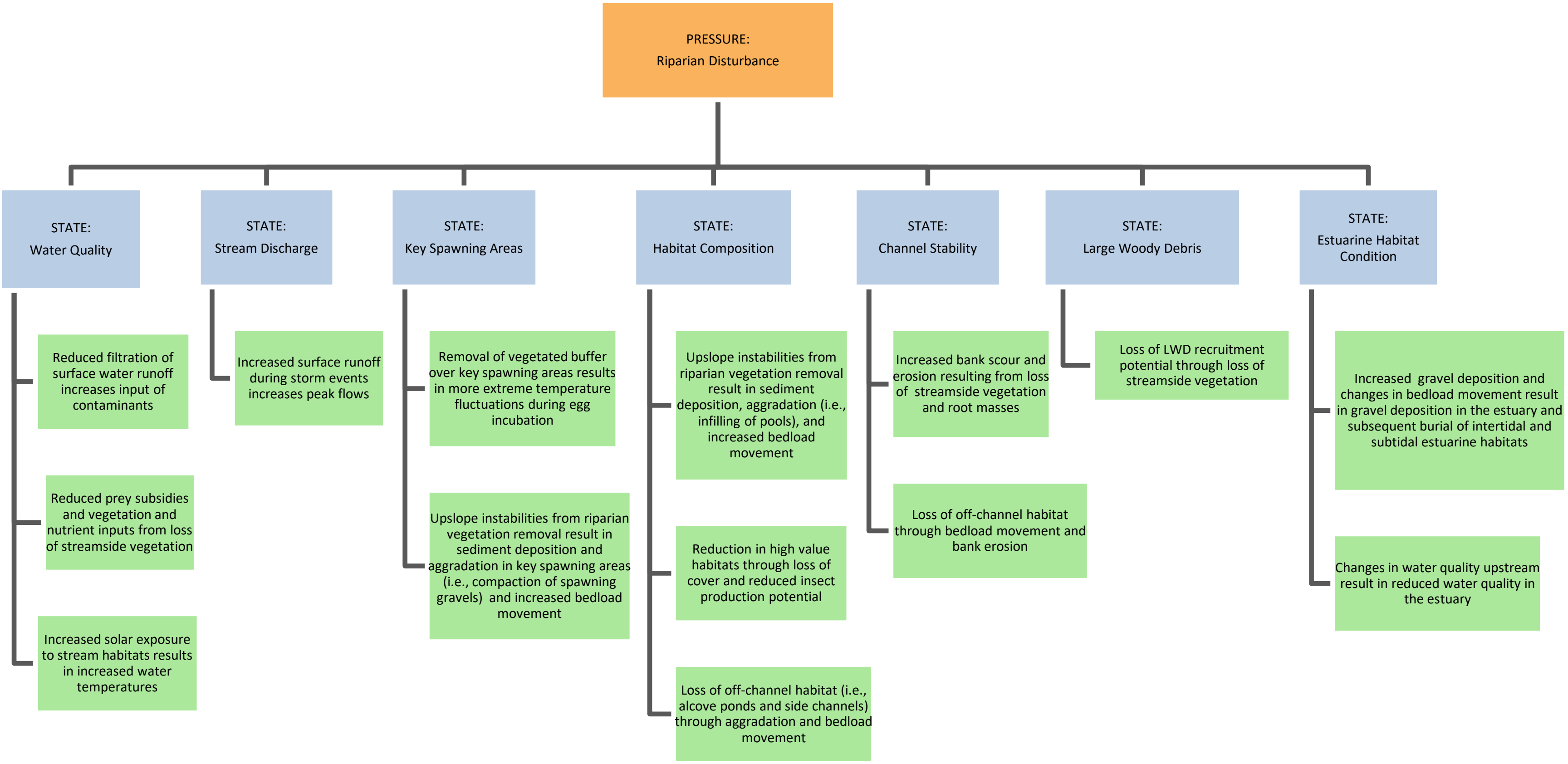

Figure 12. Relationship between riparian disturbance and state indicators.

Those river reaches that exceeded a benchmark level of riparian disturbance of 5% of the riparian area were assigned a risk ranking of 'Moderate', and those that exceeded a benchmark level of riparian disturbance of 10% of the riparian area were assigned a risk ranking of 'High' (adapted from Stalberg et al. 2009). Riparian disturbance was defined as riparian forest in the early regenerating stage (<40 years old) plus land conversion to agricultural and anthropogenic substrates/structures. In rain-dominated catchments, immediately following loss of forest vegetation, groundwater tables in logged areas are elevated and summer runoff can increase for five years to two decades (Moore et al. 2020, Coble et al. 2020). This initial increase in flow is followed by a long-term decline in summer stream flow and increased stream temperature that can last for several decades and is caused by increased transpiration by streamside vegetation (Winkler et al. 2010, Moore et al. 2020, Coble et al. 2020). Increased transpiration by second growth stands relative to old forests typically occurs when the stands are 20 to 50 years old (Moore et al. 2020, G. Horel, pers. comm. 2021) and would be most likely to affect streams in the immediate vicinity of such stands (G. Horel, pers. comm. 2021). This process is observed with shifts from old forest to young forest and from conifers to deciduous species. Loss of riparian vegetation can also lead to a decline in functional riparian LWD in streams because maturing forests have less senescence than old-growth forest (Brayshaw 2018).

Note that Stalberg et al. (2009) recommended that the assessment area for the riparian disturbance analysis be limited to riparian forest within 30 m, not 100 m, of the stream bank. For reasons unpacked in the following paragraphs, MCW considered a 100 m buffer to be a more appropriate assessment area boundary for this metric of risk to stream functions and fish habitat condition.

Stalberg et al. (2009) explained that they recommended a 30 m buffer because it had become a commonly used riparian reserve zone width (a "de facto standard") in forestry and private land management. A 30 m riparian buffer became a standard along streams of larger width with the implementation of the province's earliest forest management legislation in the late 1990s. MCW found this rationale for the selection of the metric for WSP reports to be problematic because forestry legislation and forestry practice standards are not set purely with consideration for the protection of fish and fish habitat; they also consider timber supply and socioeconomic factors. In contrast, the purpose of a WSP watershed habitat status report is to characterize salmon habitat condition and habitat constraints that are adversely affecting salmon productivity for the conservation and sustainable use of wild salmon. To do so, the indicators, metrics, and benchmarks selected for the assessment must evaluate risk to fish habitat based on best available science, uninfluenced by economic considerations.

As an example, to better illustrate the discrepancy between forestry practice standards and the science that informed MCW's use of a 100 m assessment area, the Forest Planning and Practices Regulation of the *Forest and Range Practices Act* does not require a riparian reserve zone buffer along fish-bearing streams of width <1.5 m or along non-fish bearing streams. Even along small streams <3 m wide in BC and Europe, 30 m wide reserve zone buffers are required to ensure that relative air humidity, air temperature and canopy openness remain at similar levels as in unlogged sites (e.g., Oldén et al. 2019, Kuglerová et al. 2020), and much wider to maintain biodiversity (Semlitsch and Bodie 2003, Kuglerová et al. 2020). Buffer strip widths of 15 m along streams of 0.2 to 4.2 m are not enough to maintain windthrow to a natural background level or to prevent microclimatic changes (Oldén et al. 2019, Mäenpää et al. 2020). Simulation modeling of harvest strategies in an Oregon watershed dominated by Douglas fir found that removal of all trees within riparian management areas around streams <4 m wide permitted under existing private forest land regulation was likely to produce stream temperature warming in exceedance of the amount permissible under the state criterion (Groom et al. 2018). A buffer of 30.5 m was necessary to prevent unacceptable stream temperature change, which was in line with a review of 18 papers that examined the relationship between buffer width and stream temperature that stated that buffers ≥30 m were necessary to protect stream temperatures (Sweeney and Newbold 2014).

Public and private forestry management legislation has set objectives to conserve water quality, fish habitat, wildlife habitat and biodiversity associated with riparian areas. And while many hydrologic and geomorphic functions of a riparian forest can be maintained along small tributaries with a 30 m buffer, 30 m buffers have repeatedly been shown to be the *minimum* required to preserve physical and ecological functions of even the smallest streams—those that presently receive little to no riparian protection through application of existing legislation and forestry practice standards. Far greater than 30 m is required to protect the quality and functions of larger streams such as the mainstem Nanaimo River. Having a highly fragmented surrounding landscape (Mäenpää et al. 2020), and increasing amount of forest loss as a percentage of the sub-basin and watershed (Tschaplinski and Pike 2010), particularly on erosion-prone terrain over too short a time period (Klein et al. 2012), further increase risk to stream habitat condition for a given buffer size. So, too, does increasing slope, a southern aspect, and changes in species composition and density (e.g., more pools are formed by wood in streams with a greater proportion of conifers rather than deciduous trees in the riparian zone (Ross et al. 2019)), which is why it is not possible to say that one buffer width alone is sufficient for riparian protection of a given stream size (Richardson and Béraud 2014, Oldén et al. 2019). Caution should be used in drawing conclusions about risk posed to fish populations due to riparian alteration when an analysis is limited to 30 m from the stream bank without knowing more about stream size, riparian vegetation composition, and landscape condition. For these reasons, MCW selected a 100 m buffer as the assessment area boundary because it would capture deficits in riparian functions that impact fish habitat.

During revision of this report, MCW was asked by DFO to repeat the analysis for this indicator using a 30 m buffer. MCW has done this for the purposes of comparison, though the final risk rankings remain based on the 100 m buffer assessment area. Regardless of buffer size, this assessment will not fully capture cumulative risk associated with riparian forest loss or alteration given that it is restricted to the mainstem Nanaimo River and anadromous South Nanaimo River. The watershed’s small streams receive limited riparian protection in practice, as explained above, but do transport water, nutrients, sediment, and debris to downslope fish-bearing waters (as reviewed by Tripp et al. (2017)). For example, if stream temperatures become elevated in small streams without adequate riparian buffers, there will be cumulative impacts on mainstem stream temperature.

4.2.3.2 Results

Lower Nanaimo River

Almost no mature conifer riparian forest remains in reaches 1–6 of the Lower Nanaimo River (Maps 6 and 7), whether one restricts the assessment area to a 30 m buffer or a 100 m buffer. A large proportion of the riparian zone of the Lower Nanaimo River in reaches 1 and 2 (40.6% and 37.9%, respectively within 100 m; or 30.8% and 21.9%, respectively within 30 m) is comprised of agriculture and anthropogenic substrates and development (Figure 13). Reaches 6–8, and 10–12 of the Lower Nanaimo River have primarily young riparian forest (40–80 years old). Within 100 m of the stream bank, nine of the 12 reaches exceed the high-risk benchmark in that more than 10% of the riparian zone is early regenerating forest (<40 years old) or has been converted to agricultural or other anthropogenic uses (Maps 7 and 8; Figure 13). Within 30 m of the stream bank, three of the 12 reaches (reaches 1, 2, 12) exceed the high-risk benchmark and reach 3 exceeds the moderate-risk benchmark. Reaches 1–3 contain the spawning grounds for fall run Chinook, Chum, and Pink Salmon, but along much of this section of the river there is little to no mature conifer forest and areas with buffers that are less than 30 m wide (Map 9). Given the extent of riparian alteration within 100 m of the stream bank relative to the benchmark, this indicator has been assigned a risk ranking of ‘High’ in this sub-basin.

Middle Nanaimo River

The Middle Nanaimo River riparian zone has been altered by forestry and road construction (Map 10, Figure 13). Within 100 m of the stream bank, all reaches exceed the high-risk benchmark, with 11.1–45.1% of the riparian zone being early regenerating forest or gravel road. Reach 14 has been the most altered by riparian logging—41% of it is early regenerating forest. Half of reach 14 has a riparian forest buffer less than 30 m wide (Map 9). This is a concern because reach 14 contains the summer run Chinook Salmon spawning grounds, and what was identified as the best quality Chinook Salmon spawning habitat remaining in the river (Burt 2002, Hardie 2002). Within 30 m of the stream bank, reach 16 exceeds the high-risk benchmark, with 15.5% being early regenerating forest or anthropogenic substrates, and reach 17 exceeds the moderate-risk benchmark. On the basis of the extent of riparian alteration within 100 m of the stream bank relative to the benchmark, this indicator has been assigned a risk ranking of ‘High’ in this sub-basin.

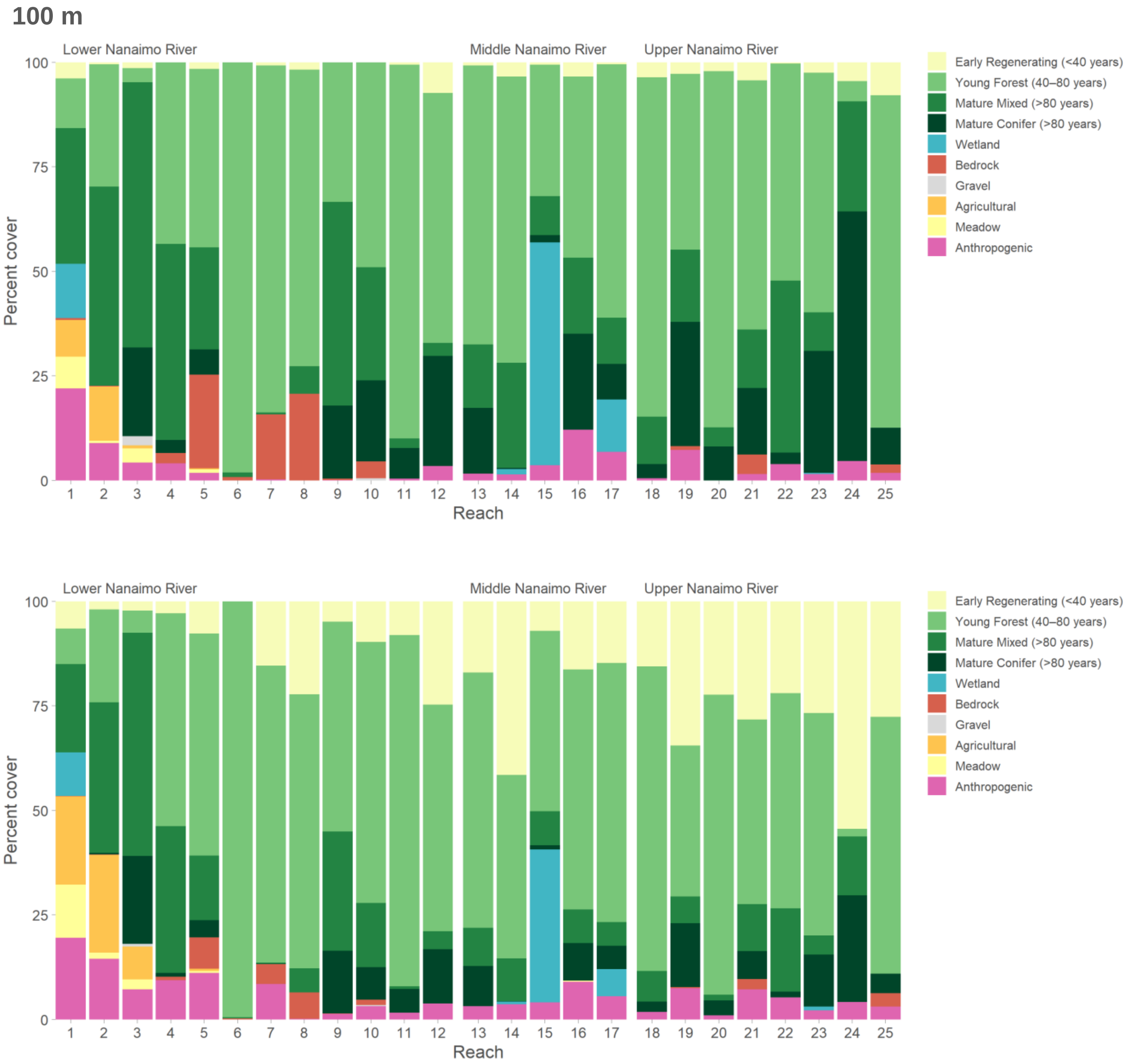
100 m

Figure 13. Riparian vegetation types along the Lower, Middle, and Upper Nanaimo River, within 30 m and 100 m of the stream banks.

Upper Nanaimo River

The Upper Nanaimo River riparian zone has been the most impacted by forestry and road construction (Maps 11 and 12). Within 100 m of the stream bank, 15.5–54.4% of the riparian zone around the reaches is in an early regenerating age class (Figure 13). Roads or other anthropogenic impacts comprise another 1–7.4% of the riparian zone, depending on the reach. Within 30 m of the stream bank, reach 19 just exceeds the 10% high-risk benchmark and reaches 21, 24, and 25 exceed the moderate-risk benchmark, with 5.8–9.7% of the riparian zone being comprised of road or forest <40 years old. Many sections of the mainstem have riparian forest buffers less than 30 m wide (Map 9). At the same time, these reaches contain the historical spawning habitats of the declining portion of summer run Chinook Salmon that spawn in the upper river (previously referred to as spring run). This indicator has been assigned a risk ranking of 'High' in this sub-basin.

South Nanaimo River

The South Nanaimo River has, like the Nanaimo River, lost a significant portion of its riparian zone to forestry and road construction. 21.8% of the riparian zone around the river is early regenerating forest or has been altered by road construction (Map 10). Consequently, this indicator has been assigned a risk ranking of 'High' in this sub-basin. Within 30 m of the stream bank, this value drops to just over 5%, which would place this river it into a moderate-risk category.

In sum, the riparian disturbance indicator has been assigned a risk ranking of 'High'. If one were to assess impacts strictly within 30 m of the streambank using the selected benchmarks, the ranking would be 'Moderate'.

4.2.4 Stream and Lake Pressure: Water Extraction

Water extraction in the watershed has the potential to impact spawning and rearing habitats by reducing stream flows (Porter et al. (2013); Figure 14).

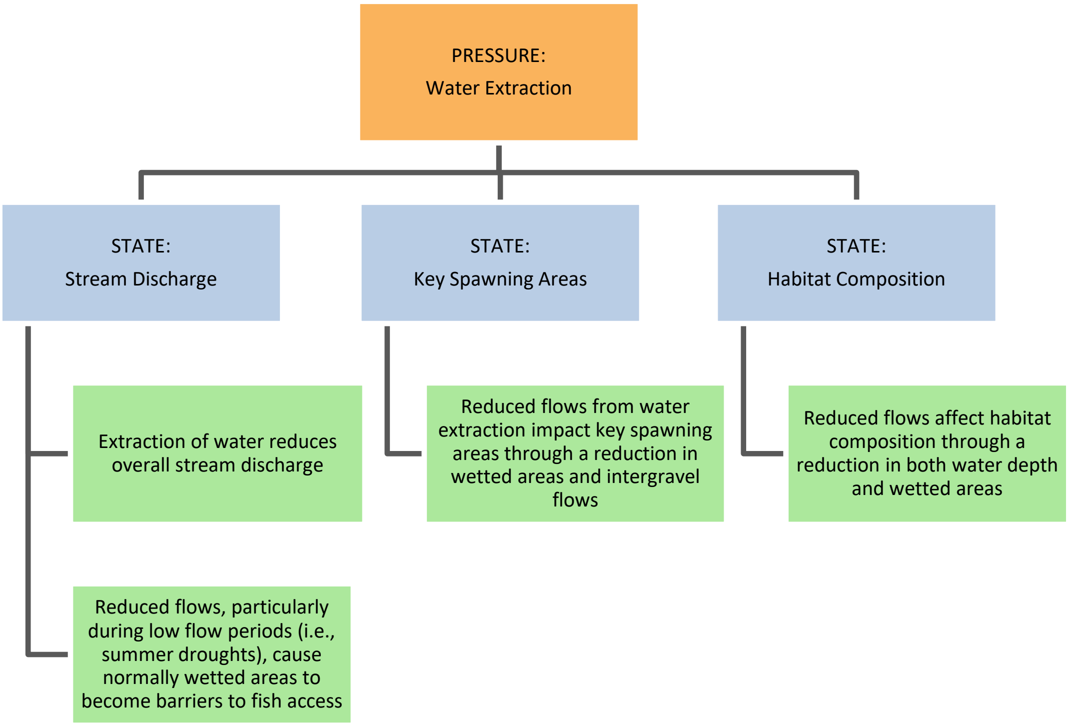

Figure 14. Relationship between water extraction and state indicators.

4.2.4.1 Methods

Water licence information, including licence types and permitted extraction volumes, was obtained from the BC Water Rights Databases' Water Licence Search tool and DataBC in December 2019. The indicator risk ranking was assigned using professional judgement and founded on the degree to which literature and data indicate the watershed can support additional extraction with its present storage infrastructure.

4.2.4.2 Results

There are 201 active water rights licences for groundwater and surface water withdrawal within the study area, which permit extraction from 181 points of diversion across the Nanaimo River, several of its main tributaries, including Haslam Creek, South Nanaimo River, Jump Creek, and Sadie Creek, and the watershed aquifers (Map 13, Table 3 shows select licences). The total licensed surface water withdrawal in the watershed is 193,855,104.9 m^3/year, which represents 10% of the watershed mean annual discharge. The natural unregulated mean annual discharge and volume for the Nanaimo River (1971 to 2000) including all tributaries was 58.3 m^3/s and 1,839 million m^3 (RDN Phase 1 Water Budget Project report, in Butler et al. 2014). The mean summer discharge and volume was 7.83 m^3/s and 62.2 million m^3 (the months included in the summer discharge and volume calculation are not reported in the RDN Phase 1 Water Budget Project report).

Table 3. Select active surface water licences within Nanaimo, Chase, and Holden Creek Watersheds.

Purpose	Quantity (m^3/y)[1]	Stream	License	Licensee
Consumptive				
Domestic	1,659.29	Nanaimo River	C055161	1819 Wilkinson Road, Nanaimo
Domestic	829.65	Nanaimo River	C063962	31 River Terrace, Nanaimo
Domestic	829.65	Nanaimo River	C065841	2165 Holden Corso Rd, Nanaimo
Private irrigation	37,000	Nanaimo River	C130065	Arbor Memorial Inc.
Pulp mill	22,327,488	Nanaimo River	F124213	Nanaimo Forest Products Ltd.[2]
Pulp mill	53,579,664	Nanaimo River	F124215	Nanaimo Forest Products Ltd.
Pulp mill	35,730,288	Nanaimo River	F124216	Nanaimo Forest Products Ltd.
Camps & Public	829.68	Dixon Creek	C109318	Timberwest Forest I Limited
Local waterworks	7,466,952.825	South Nanaimo River	C007001	City of Nanaimo
Local waterworks	15,763,567	South Nanaimo River	C022272	City of Nanaimo
Local waterworks	41,483,071	South Nanaimo River	C041112	City of Nanaimo
Private irrigation	23,645.812	Haslam Creek	C054220	3150 Frost Road, Nanaimo
Pulp mill	8,924,688	Haslam Creek	F124214	Nanaimo Forest Products Ltd.
Local waterworks	829,661.425	Chase River	C022585	City of Nanaimo
Land Improvement	172,687.2	Chase River	C061423	City of Nanaimo
Land Improvement	92,511	Chase River	C061424	City of Nanaimo
Private irrigation	3,700.44	Chase River	C048543	874 Park Avenue, Nanaimo
Private irrigation	111.013	Chase River	F049556	395-7th Street, Nanaimo
Private irrigation	10,731.276	Holden Creek	C128687	3088 Haro Road, Nanaimo
Non-consumptive				
Stream Storage	43,171,800	Sadie Creek/Fourth Lake	F124217	Nanaimo Forest Products Ltd.
Stream Storage	1233.48	Blake Creek	C111992	Timberwest Forest I Limited
Stream Storage	3,034,361	South Nanaimo River	C022273	City of Nanaimo
Stream Storage	123,348	South Nanaimo River	C022587	City of Nanaimo
Power	8,514,720	South Nanaimo River	C126285	City of Nanaimo
Stream Storage	17,885,460	Jump Creek	C100838	City of Nanaimo
Stream Storage	61,674	Chase River	C022586	City of Nanaimo

Notes: [1] The licences authorize a maximum amount of water that can be obtained from one or several points of diversion along the stream/waterbody specified in the table. The permitted extraction volumes obtained through the Water Rights Databases' Water Licence Search tool were converted to m^3/y. [2] Nanaimo Forest Products Ltd. is Harmac Pacific.

The largest consumptive water user from the Nanaimo River watershed continues to be Harmac Pacific, with a licensed withdrawal rate of 120,562,128 m^3/year (3.823 m^3/s). Note that Harmac's groundwater wells are licensed as surface water withdrawal and so their groundwater withdrawal is included in this licensed surface water withdrawal rate. The second largest consumptive user is the City of Nanaimo (City), with a licensed withdrawal rate for waterworks of 64,713,590.8 m^3/year from the South Nanaimo River and another 829,661.425 m^3/y from the Chase River. Both Harmac and the City use less than their allocated amounts. In 2010, Harmac withdrew 39.8 million m^3 (9.95 million m^3 in the summer) and the City withdrew 15.7 million m^3 (5.3 million m^3 in the summer) (Butler et al. 2014). Recorded withdrawals are not publicly posted and so the 2018 withdrawal volume was not available to MCW at the time of writing. The City also has a non-consumptive licence for power production, at a withdrawal rate of 8,514,720 m^3/year. Together, these two users withdraw 99% of the total licensed surface water withdrawal in the watershed (Butler et al. 2014).

As stated in Section 1.2.5, the Nanaimo River flow is fully allocated from July to September, which means that no future water rights licenses will be issued except for domestic use, unless additional storage is created (Butler et al. 2014). The groundwater aquifers in the area are under high stress and the continuing development and population increase in the Cassidy and Cedar area will increase groundwater demand and extraction through private wells (RDN Phase 1 Water Budget Project report, in Butler et al. 2014). The altered and low flows during summer and fall due to water extraction from the Nanaimo River, its tributaries, and groundwater have been an important contributor to the decline in salmon populations in the watershed (Brahniuk et al. 1993). For these reasons and given the increasing demand on surface and aquifer water sources, this indicator has been assigned a risk ranking of 'High'.

4.2.5 Stream and Lake Pressure: Permitted Waste Discharges

Permitted waste discharges provide insight into potential pressures on water quality in streams, lakes, and estuaries (Figure 15). Permitted waste discharges affecting streams may be associated with agricultural operations, aquaculture, commercial waste management, contaminated sites management, mining, municipal sewage management, and effluent (pulp, paper, wood processing, household, etc.).

4.2.5.1 Methods

MCW downloaded the BC MOECCS Authorization Management System permitted waste discharge authorizations excel spreadsheet (updated to October 19, 2021) on October 21, 2021 to obtain a list of authorizations in the watershed issued under the Waste Discharge Regulation. After downloading the AMS authorizations excel data, MCW filtered the data to all authorizations where State = "Active", Waste Type = "Effluent" OR "Refuse" OR "Hazardous Waste", where Nearest Municipality = "Nanaimo", and where Facility Address contained "Nanaimo" OR "Cassidy" OR "Duke Point". This left 15 records. From there, MCW confirmed whether the facility addresses were located with the Nanaimo River watershed or could feasibly impact the Nanaimo River estuary's water quality through proximity (e.g., properties on the west side of Duke Point).

4.2.5.2 Results

There are five active waste discharge authorizations held by two private companies, the Nanaimo Airport, and the Regional District of Nanaimo for facilities located within the Nanaimo River watershed or along the west side of Duke Point (Table 4). Because of these facilities, the surface water, aquifers, and estuary of the Nanaimo River watershed may be exposed to more sources of contamination than the typical Vancouver Island watershed. However, as there is presently no direct effluent discharge to rivers or to the Nanaimo River estuary this indicator has been assigned a risk ranking of 'Low'.

Table 4. Active waste discharge authorizations in the Nanaimo River, Chase, or Holden watersheds.

Authorization Type	Company	Waste Type	Description	Facility Address
Municipal Wastewater Regulation	The Nanaimo Airport Commission	Effluent	Disposal to septic tank	3350 Spitfire Road, Cassidy
Hazardous Waste Regulation	Revolution Evolution Environmental Solution Acquisition GP Inc. Terrapure	Effluent	Storage of hazardous waste	1080 Maughan Road, Nanaimo
Hazardous Waste Regulation	Revolution Evolution Environmental Solution Acquisition GP Inc. Terrapure	Hazardous Waste	Storage of hazardous waste	1080 Maughan Road, Nanaimo
Operational Certificate	Regional District of Nanaimo	Refuse	Municipal solid waste landfill	1105 Cedar Rd, Nanaimo
Operational Certificate	Nanaimo Organic Waste Ltd.	Refuse	Composting Facility	981 Maughan Road, Nanaimo

4.2.6 Stream and Lake State: Water Quality

Water quality metrics of interest include temperature, dissolved oxygen (DO), contaminant, nutrient, and turbidity levels in stream or lakes within the watershed sub-basins. Poor water quality has the potential to impact the life-history stages of all species of pacific salmon by reducing aquatic primary production, increasing biochemical oxygen demand, and causing physiological stress (Figure 16). High water temperatures during the summer and fall also have the potential to delay migrating adults salmonids (Sauter et al. 2001).

During the terminal migration phase, those species that migrate earlier in the season (i.e., Chinook and Sockeye Salmon) are more susceptible to higher water temperatures than those that migrate later in the season (i.e., Chum and Coho Salmon). Stalberg et al. (2009) defines the maximum daily Upper Optimum Temperature and Impairment Temperatures for in-migrating and spawning Chinook and Coho Salmon as 14°C and 20°C, respectively; 15°C and 21°C, respectively, for Pink and Chum Salmon; and 15°C and 18°C for Sockeye Salmon.

Water temperature also impacts incubation and juvenile rearing and migration. The Upper Optimum Temperature and Impairment Temperatures for the juvenile life stage of salmonids were defined in Stalberg et al. (2009) as a maximum weekly average water temperature of 15°C and 20°C, respectively. Because Coho and stream-type summer run Chinook Salmon have a protracted freshwater rearing phase, these fish are more susceptible to higher water temperatures during the summer months. Warm water temperatures affecting downstream estuarine habitats have the biggest potential impact on Chum Salmon as they are known to rely heavily on foraging in the estuary prior to their migration to sea.

4.2.6.1 Methods

MCW conducted a search for water quality data collected within the Nanaimo River watershed and neighbouring watersheds. Hourly turbidity data (2013–May 2019) collected at the Harmac intake in the lower Nanaimo River was obtained from Harmac. Hourly water temperature data was obtained from Water Survey of Canada (WSC) hydrometric monitoring station 08HB034, located on the Nanaimo River in Cassidy. MCW was unable to find public data pertaining to water quality in the Nanaimo Lakes.

MCW also reviewed a recent analysis of trends in turbidity, temperature, and DO data collected by the Community Watershed Monitoring Network (Plewes et al. 2018). The Network is supported by the RDN's Drinking Water and Watershed Protection program, the MOECCS, Mosaic Forest Management, and community watershed stewardship groups and has been sampling water quality at six sites in the Nanaimo River Water Region since 2011 to 2017, depending on the site. All sites are in the lower watershed:

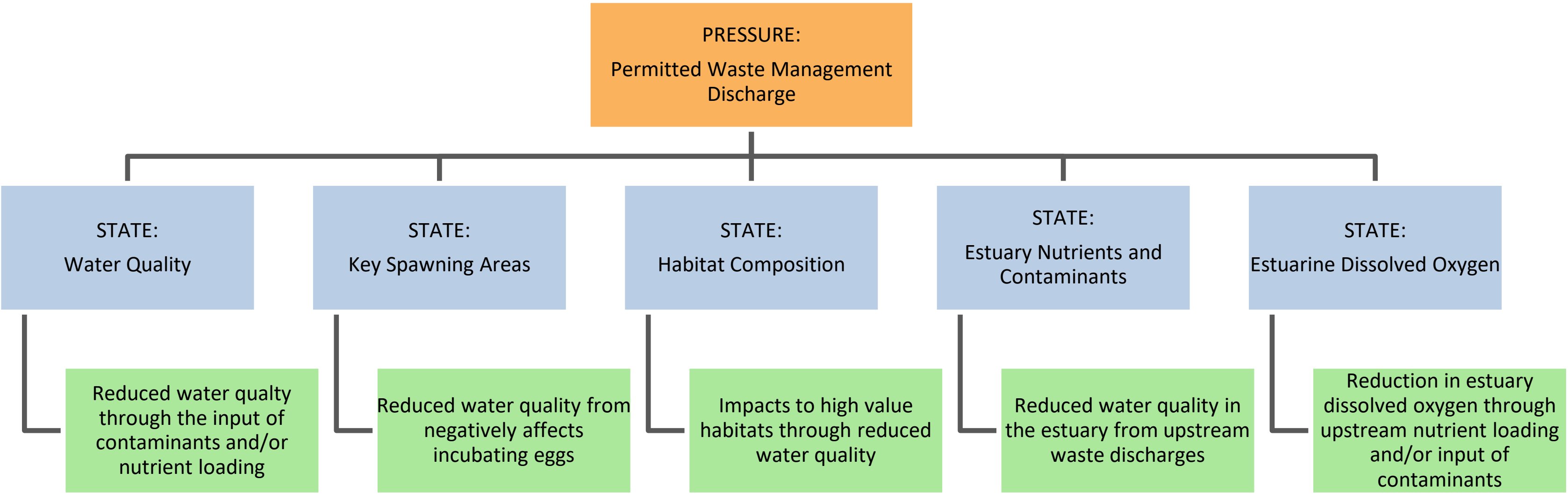

Figure 15. Relationship between permitted waste management discharge and state indicators.

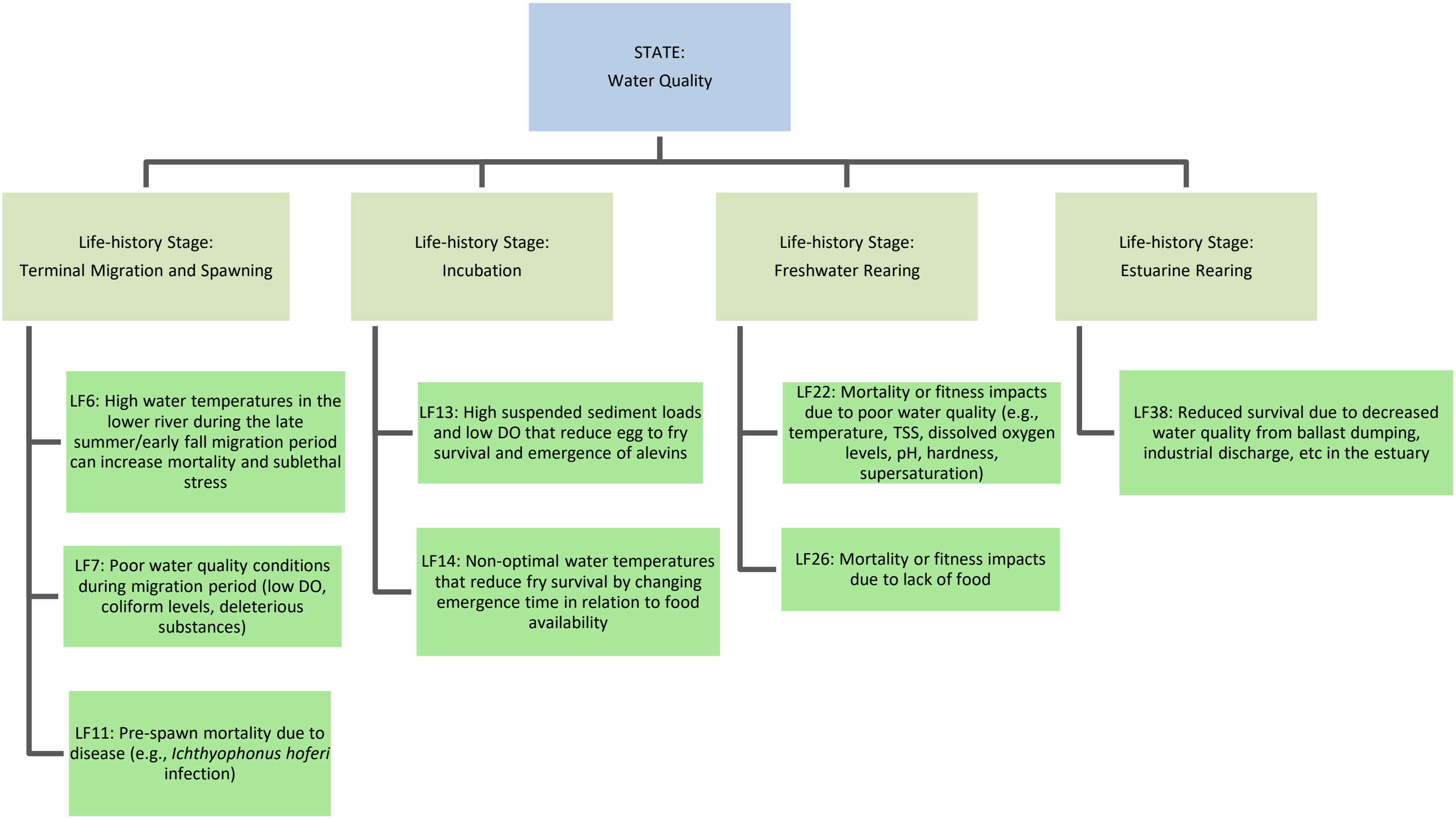

Figure 16. Relationship between water quality, life-history stages, and limiting factors.

- Nanaimo River (~500 m downstream of Hwy 1 bridge [E287699]; at the Cedar Road bridge [E215789]),
- Beck Creek (E290487),
- Haslam Creek (E287700)
- Holden Creek (E310147), and Lower Holden Creek (E309281).

In assigning a risk ranking, MCW considered the degree to which the Stalberg et al. (2009) temperature Upper Optimum Temperature Range and Impairment Temperatures for juvenile rearing and adult in-migration have been exceeded through time at station 08HB034 as well as how DO levels compared to BC Approved Water Quality Guidelines (MOECCS 2019b).

4.2.6.2 Results

Turbidity

Turbidity levels are high following heavy rainfall events and, in the lower Nanaimo River, turbidity levels at the Harmac intake have exceeded 10 NTUs with increasing frequency over the last six years (Figure 17). The analysis of the first six years of water quality data from CWMN Nanaimo River site E287699 likewise revealed that mean summer and fall turbidity had increased over time (Plewes et al. 2018). These data align with anecdotal observations from the Nanaimo River Hatchery that sediment loading has notably increased over the past decade (Banks B. and B. Herman, pers. comm. 2019). Higher turbidity levels across the RDN CWMN sampling sites were correlated with a high density of paved roads, residential development, agriculture, and total forest cover loss, as exist in the Nanaimo River watershed (Plewes et al. 2018). As discussed in Sections 4.2.1, 4.2.2, and 4.2.3, total forest cover loss is positively correlated with increased suspended sediment in streams and streams with less riparian vegetation due to urbanization, agriculture, and forestry operations tend to experience increased bank erosion and sedimentation.

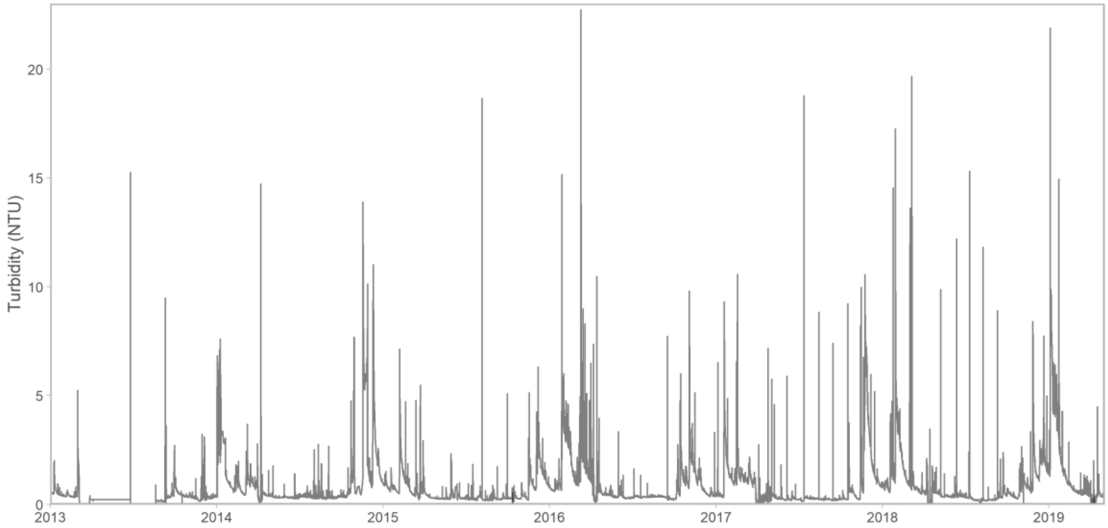

Figure 17. Hourly turbidity data collected at the Harmac water intake in the lower Nanaimo River (obtained from Harmac).

Temperature and DO

In the summer, water temperatures and low DO concentrations in the lower watershed frequently reach levels that may stress or kill fish (Butler et al. 2014). From 2003 to 2018, water temperatures at WSC station 08HB034 consistently exceeded the maximum daily 20°C Impairment Temperature for in-migrating Chinook and Coho Salmon from late June to late August and the 14°C Upper Optimum Temperature for both rearing and spawning from typically late May to late September (Figure 18). Water temperatures during the low flow period have reportedly frequently exceeded 20°C as of the 1990s (Brahniuk et al. 1993, Butler et al. 2014). Fish kills have occurred in the lower Nanaimo River at water temperatures of 21–25°C (Brahniuk et al. 1993). The Nanaimo River hatchery has additionally noted changes to the annual temperature regime in the lakes in recent years, such as early or sudden warming (Banks B. and B. Herman, pers. comm. 2019).

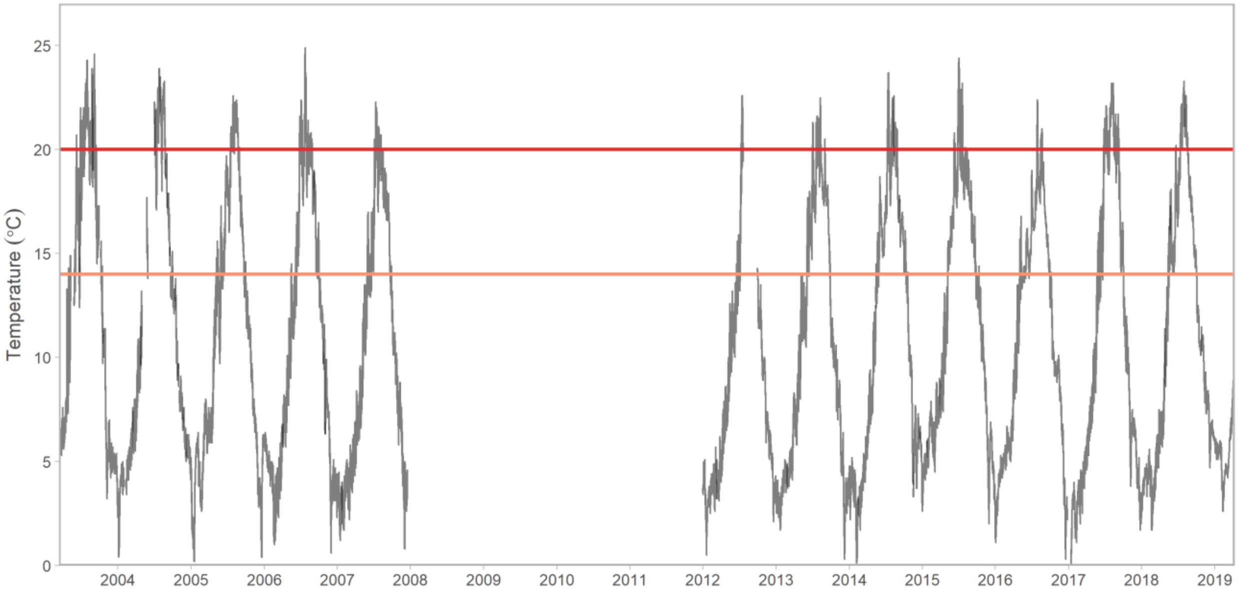

Figure 18. Nanaimo River hourly water temperatures from Water Survey of Canada station 08HB034. The orange and red lines indicate the 14ºC maximum daily Upper Optimum Temperature and 20ºC Impairment Temperatures, respectively, for in-migrating Chinook and Coho Salmon (Stalberg et al. 2009).

At CWMN Nanaimo River site E287699, mean summer river temperature increased from 2011 to 2017, whereas mean summer DO levels decreased over this time (Plewes et al. 2018). All CWMN sampling sites had suitable water temperatures to support aquatic life in the fall; however, water temperatures in the lower Nanaimo River and in Lower Holden Creek consistently exceeded rearing guidelines for fish during summer low flows. In 2018, all CWMN sample sites experienced 30-day average DO levels below 8 mg/L, which is below the BC Approved Water Quality Guidelines for protection of fish: Nanaimo (upstream of Haslam, 7.52 mg/L and Cedar Rd, 7.46 mg/L), Beck (7.03 mg/L), Holden (7.66 mg/L) and Lower Holden (5.08 mg/L). The 30-day average DO levels in Lower Holden Creek were also below 8 mg/L during the fall sample period. Life stages other than buried embryo/alevin should not be exposed to water column DO levels less than 5 mg/L (instantaneous) or 8 mg/L (30-day average); and buried embryo/alevin not lower than 9 mg/L (instantaneous) or 11 mg/L (30-day average) to achieve required interstitial DO levels (MOECCS 2019b).

While fish in the lower watershed may experience high water temperatures and depleted DO due to nutrient loading from agriculture, fish in the upper watershed may experience two different stresses. First, the release of cold water (4°C) from the bottom of Harmac's reservoir may have the unintended effect of reducing the summer growth and subsequent survival of juvenile Coho and stream-type summer run Chinook Salmon downstream of the chilling flows between Forth Lake and Second Lake (Komori Wong Environmental 2002, Butler et al. 2014, and references therein). In July 1986, the water temperature immediately below the release point was 6.5°C, and increased to 8.25°C 1.5 km downstream and 13°C 6 km downstream (Tredger 1986). Tredger (1986) roughly calculated, for example, that the cold water release resulted in a 38% decrease in Steelhead Salmon fry production and approximately 100 fewer adult Steelhead Salmon returning to the system each year. Second, the decline of Nanaimo River salmon populations has resulted in a loss of nutrient subsidies from salmon carcasses, and therefore likely a reduction in overall stream productivity (Butler et al. 2014).

Fecal Coliform

High bacteria counts are also a problem in the lower watershed in the summer. Water quality testing done as part of the 1993 Nanaimo River Watershed Water Management Plan showed that summer bacteria levels had exceeded 12 human health standards downstream of the Island Highway (Butler et al. 2014).

Poor water quality in the lower Nanaimo River watershed during summer is attributed to the cumulative effects of loss of forest cover, inadequate riparian vegetation, low flows, high agricultural use of the land, and urbanization (Plewes et al. 2018). Data indicate that low summer DO and high summer temperatures in the lower watershed, high fall/winter turbidity levels, and potentially low temperatures in the upper watershed below the Harmac reservoir can limit the survival of embryonic wild fall run Chinook, Coho, Chum, and Pink Salmon, and juvenile Coho Salmon. Low DO and high temperatures in the lower river may impede the successful spawning migration of all Pacific salmon species. Poor water quality also elevates the risk of pre-spawn mortality due to disease, such as ichthyophoniasis caused by the protozoan *Ichthyophonus hoferi*. Pre-spawn mortality due to this protozoan has been as high as 30% (Banks B. and B. Herman, Nanaimo River Hatchery, pers. comm. 2019). Given these factors, this indicator has been assigned a risk ranking of ‘High’.

4.2.7 Stream State: Discharge

The carrying capacity of streams and the suitability of streams for use by different salmonid species and life-stages are related to the annual hydrograph and mean annual discharge of the stream. Stalberg et al. (2009) suggests that impacts to fish are likely when the 1 in 2 year 30-day duration summer minimum flow is less than 20% of the mean annual discharge. Stalberg et al. (2009) states flows ≥20% of the mean annual discharge are sufficient to maintain riffle widths, depths, and velocities needed for production of benthic invertebrates for salmon. This 20% benchmark is intended for application to small to medium sized streams. Some river systems naturally drop below 20% MAD benchmark during summer low flows, and so in these systems additional benchmarks (e.g., instream flow thresholds for fish and fish habitat) can be applied in determining whether flows are limiting fish production, where local/system-specific data allow.

Lower than normal discharges have the potential to affect all species throughout various stages of their life history (Figure 19). Adults migrating earlier in the season (i.e., Sockeye and Chinook Salmon) are more susceptible to access issues to their spawning grounds during low flows (particularly in heavily aggraded systems). Low flows during the winter months have the potential to dewater redds and cause desiccation or freezing of eggs, and the dispersal of emergent fry to critical river margin habitat may be delayed if there are inadequate flows upon emergence. Summer low flows may have the largest impact on Coho Salmon fry. The fish can become stranded in pool habitats where there is limited food resources and increased risk of mortality due to predation.

Higher than normal discharges also affect all species throughout various stages of their life cycle (Figure 19). In-migrating adults may be delayed by velocity barriers in more confined sections of the river. Flood events during the winter season may cause egg mortality, and high flows during emergence can result in unfavourable dispersal of fry throughout the system. High discharge events are related to increased suspended sediment loads, which can negatively impact fry by clogging or abrading the gills. Flood events may also impact estuarine habitat through sediment deposition or scouring, which can in turn reduce the area of foraging and rearing habitat available for juvenile salmonids in the estuary.

4.2.7.1 Methods

There are three active Water Survey of Canada (WSC) and one PacFish hydrometric monitoring stations in the watershed (Map 13). WSC Station 08HB034, located on the Nanaimo River in Cassidy, has hourly data from 1965. WSC Station 08HB092, located on the South Nanaimo River upstream of its confluence with the mainstem, has data from 1997. WSC Station 08HB041, at the mouth of Jump Creek, has data from 1970. The PacFish station has been operational on Haslam Creek since 2016. The WSC stations are located downstream of the reservoirs and therefore measure regulated (i.e., influenced by storage management) water flows. There are also data from three discontinued WSC hydrometric stations. The data from the discontinued Extension WSC station (08HB005) is valuable because it provides a record of daily natural flows from 1913 to 1927, prior to the construction of the

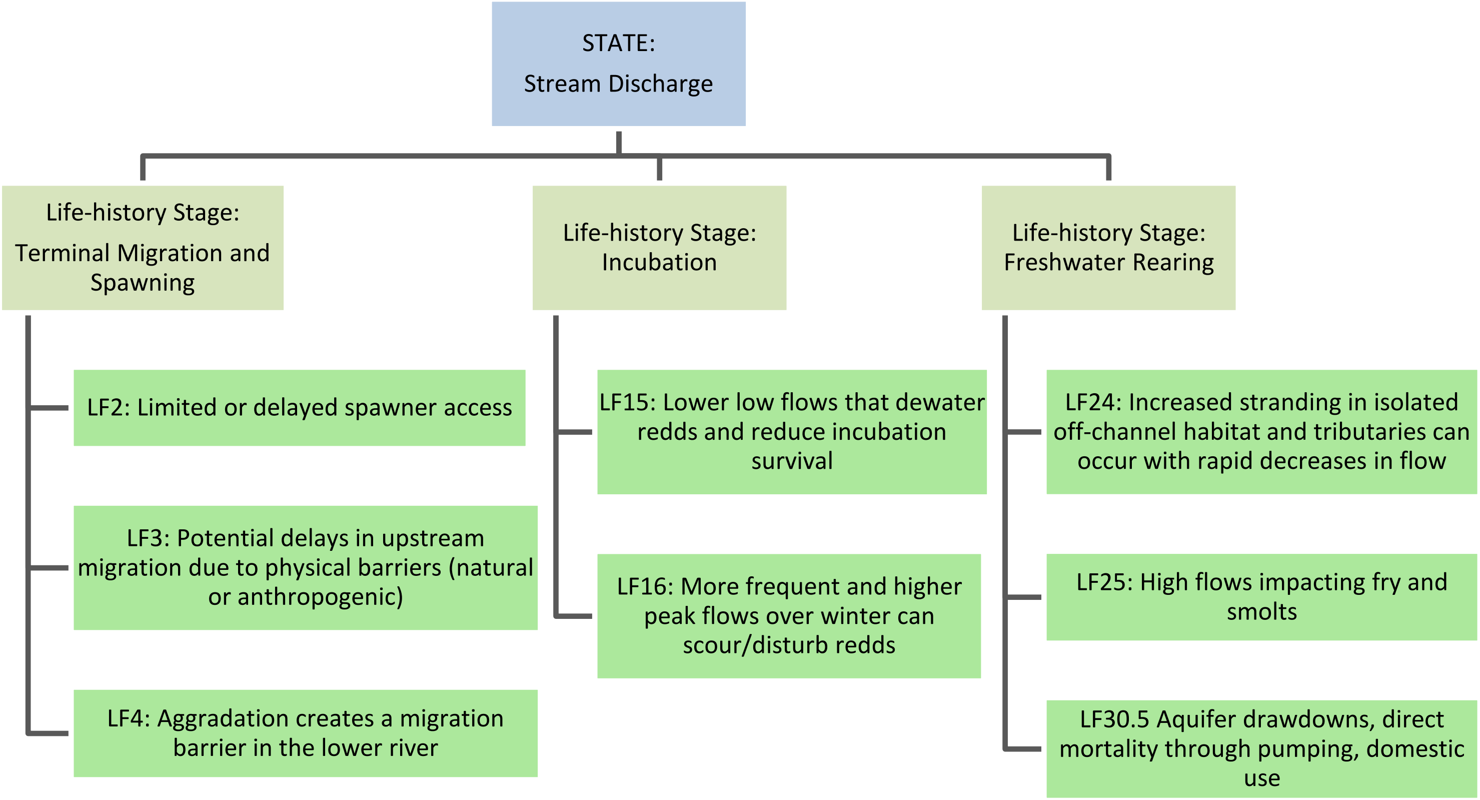

Figure 19. Relationship between discharge, life-history stages, and limiting factors.

South Fork Dam (Butler et al. 2014). In December 2019, MCW requested and obtained the hourly discharge data from 1965 to 2018 (1996 was missing) for WSC station 08HB034 from the National Hydrological Services, Environment and Climate Change Canada (ECCC). Daily mean discharges at WSC station 08HB005 were extracted from the ECCC Historical Hydrometric Data website (https://wateroffice.ec.gc.ca/search/historical_e.html).

MCW calculated the long-term mean annual discharge for the period between 1914 and 1926 (1913 and 1927 data were excluded due to incomplete sampling) at the Extension WSC station 08HB005 and took it to be the natural pre-dams mean annual discharge for the system at this location (this assumes that logging during this time did not materially affect river flow). MCW then calculated the 1 in 2 year 30-day duration summer mean minimum flow at this station during this time period and took it to be the natural 1 in 2 year 30-day duration summer mean minimum flow for the system at this location.

With this data, MCW evaluated the risk posed to salmon from low or high discharge by evaluating three metrics and comparing the results to their respective benchmarks. The first metric is the general metric recommended by Stalberg et al. (2009), the second is a system-specific metric relating to the Nanaimo River instream flow thresholds for protection of salmon and trout, and the third captures how extremes in flow have been changing over time due to land cover alteration and climate change:

1. The 1 in 2 year 30-day duration summer mean minimum flow at Cassidy WSC station 08HB034 from 2009 to 2018

   Low: >20% of the mean annual discharge
   Higher risk: <20% of the mean annual discharge, if unregulated 30-day duration summer minimum flow was typically >20% mean annual discharge

2. Minimum flow during July to October recorded at Cassidy WSC station 08HB034 from 2009 to 2018

   Low: >3.9 m^3/s
   Higher risk: <3.9 m^3/s

As first explained in Section 1.2.6.2, Harmac and the City have an agreement with DFO and MOECCS to release water from their reservoirs to maintain the minimum flows identified in the 1993 *Nanaimo River Water Management Plan* required to protect salmon and trout. The plan recommended that river flow at the Water Survey of Canada hydrometric Station 08HB034, upstream of the Harmac intake, be maintained at 3.9 m^3/s from July to October.

3. Trend in number of extreme low and/or high flows readings taken hourly at Cassidy WSC station 08HB034 from 1965 to 2018

   Low: no trend or declining number
   Higher risk: increasing number

If one of the metrics exceeded the higher risk benchmark, the indicator was assigned a risk ranking of 'Moderate', if two exceeded the higher risk benchmark, the indicator was assigned a risk ranking of 'High'.

4.2.7.2 Results

Between 1914 and 1926, the long-term mean annual unregulated discharge of the Nanaimo River at Extension station 08HB005 was 39.3 m^3/s (range 28.6–58.3 m^3/s). The long-term mean maximum and minimum discharges over this time were 567 m^3/s (274–1160 m^3/s) and 1.59 m^3/s (1.12–3.34 m^3/s), respectively. The 1 in 2 year 30-day duration summer mean minimum flow typically occurred in August to October and ranged from 1.24 to 1.68

m^3/s. So, the 1 in 2 year 30-day duration summer mean minimum flow historically fell below 5%, well below 20% of the mean annual discharge.

At station 08HB034, the long-term mean annual regulated discharge from 1965 to 2018 was 40.8 m^3/s. Between 2009 and 2018, the 1 in 2 year 30-day duration summer mean minimum flow ranged from 2.88 to 6.24 m^3/s or 7% to 15% of the mean annual discharge. Given 1 in 2 year 30-day duration summer mean minimum flow has always fallen below the 20% benchmark, this benchmark is not particularly informative on its own. It is necessary to look at the second and third metrics to assign a ranking.

Since the introduction of the minimum 3.9 m^3/s instream flow limit for salmon and trout in the 1993 *Nanaimo River Water Management Plan*, the 30-day duration summer mean minimum flow fell below 3.9 m^3/s in three of the 10 years in the 2009–2018 time period and two years out of the 1999–2008 time period. Between 2009 and 2018, the daily mean flow fell below 3.9 m^3/s for an average of 20.2 (range: 0–61 days) consecutive days. This is a marked increase from the 1999–2008 time period, where the daily mean flow fell below 3.9 m^3/s for an average of 5.4 (range: 0–27 days) consecutive days. The exceedance of the 3.9 m^3/s instream flow limit places salmon at higher risk of impact. In general, the range of flows observed at station 08HB034 between 1965 to 2018 was not greatly different from that observed at station 08HB005 between 1914 and 1926; however, the frequency of high flow and low flow events has increased from 1965 to 2018 (Figure 20). The number of readings (recorded hourly) where winter flows exceeded 300 m^3/s or 500 m^3/s increased by approximately 235% and 190% between the periods of 1969–1978 to 2009–2018. The number of readings where flows were less than 5 m^3/s or 3 m^3/s increased by approximately 175% and 185%, respectively, between the periods of 1969–1978 to 2009–2018. These changes are attributed to a combination of forestry, urbanization, water extraction, and climate change.

High flows due to frequent and intense precipitation events are a major limiting factor for fish populations in many Vancouver Island systems. These events may cause significant egg mortality if there is high bedload movement and a reduction in habitat complexity. Logging and increasing the area of impervious surfaces exacerbate high flows. Low flows also limit salmon migration and spawning in the watershed. Low flows delay or limit access to upstream spawning habitats, increase stream temperatures, increase stress, and increase risk of mortality due to predation. Aggradation of stream channels due to sedimentation caused by logging contributes to low flows. Adult Chinook Salmon may be impacted during extremely low water events as they travel through the estuary and the river (Banks B. and B. Herman, Nanaimo River Hatchery, pers. comm. 2019). Other adult salmonids (i.e., Chum and Coho Salmon) do not return as early as Chinook and Sockeye Salmon and are less affected by low water events during in-migration. Ocean-type summer and fall Chinook Salmon fry are at low risk for stranding during low flows as they are typically out of the system by the time the dry season arrives. However, juvenile Coho and stream-type summer run Chinook Salmon may be at risk as they rear in the freshwater environment during low flow periods.

In years where there is insufficient water stored in the reservoirs to maintain the required flow, the City is required to maintain a minimum flow of 0.28 m^3/s below its South Fork Dam and Harmac is required to maintain a minimum flow of 1.4 m^3/s below its surface water intake, just downstream of the Trans-Canada Bridge. However, this minimum flow does not capture the impact to river discharge from Harmac's groundwater extraction as Harmac's extraction wells are downstream of the surface water intake and WSC Station (Butler et al. 2014). Calculations completed in 1993 revealed that a significant portion of the groundwater extracted by Harmac would have normally contributed to river base flow during natural low flows in the watershed. For instance, Harmac's average groundwater withdrawal rate in 2010 was 48,000 m^3/day (0.56 m^3/s) or 40% of the 1.4 m^3/s minimum required base flow.

To summarize, available data suggest Nanaimo River salmon population productivity was historically naturally limited to some degree by low water levels in the lower river—a 1 in 2 year 30-day duration summer mean minimum flow of <20% mean annual discharge. To protect salmon population productivity, the *Nanaimo River Water Management Plan* set an instream flow limit of 3.9 m^3/s at station 08HB034, but summer discharge at the station drops not infrequently below the 3.9 m^3/s flow benchmark and has done so over longer durations this last decade, which places salmon populations at ‘higher risk’ of poor spawning success. The frequency of extreme high and low discharge readings has, in general, markedly increased over historical levels, which places salmon at ‘higher risk’ of poor spawning, incubation, and rearing success. Given that two of the assessment metrics for this indicator exceeded the higher-risk benchmark, this indicator has been assigned a risk ranking of ‘High’. The risk to salmon populations posed by extreme flows will continue to increase with climate change. Climate modelling for eastern Vancouver Island and adjusted to the Nanaimo River watershed indicates that annual watershed yield in the Nanaimo River and South Nanaimo River sub-basin will likely decline by approximately 13% in the next 50 years (as synthesized by Butler et al. 2014). Total watershed *low* flow period (June–September) yield is expected to decline by up to 60% in the next 50 years. That is, the watershed is expected to produce slightly less water on an annual basis, but significantly less water during the dry season.

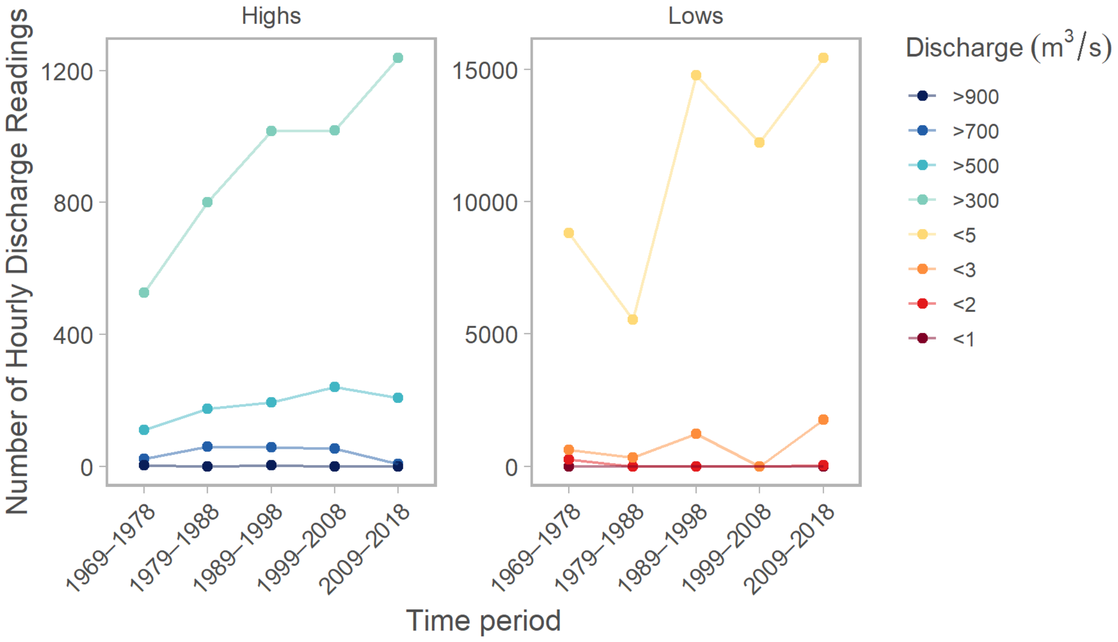

Figure 20. Number of readings (discharge is recorded hourly) at the Cassidy WSC station 08HB034 where Lower Nanaimo River discharge was extremely high or low, by time period.

4.2.8 Stream and Lake State (Quantity): Key Spawning Areas (Length)

Quantification of the length of known spawning areas provides an indicator of the relative productive capacity of a watershed, and a baseline against which changes in spawning habitat may be compared. Additionally, identification and documentation of these key habitats is the first step to protecting them from future industrial activity. Figure 21 describes the relationship between key spawning areas, life-history stage, and limiting factors to production.

4.2.8.1 Methods

MCW conducted a literature search for any information pertaining to Pacific salmon spawning areas in the watershed. Any areas or lengths of key spawning areas identified by previous assessments are specified in the results below. In other cases, information about the general spawning distribution of salmon species was mapped by MCW in ArcMap to provide an approximate estimation of the lengths of the spawning areas. MCW assigned a risk ranking by species as well as overall based on professional judgement after considering the results of the literature review.

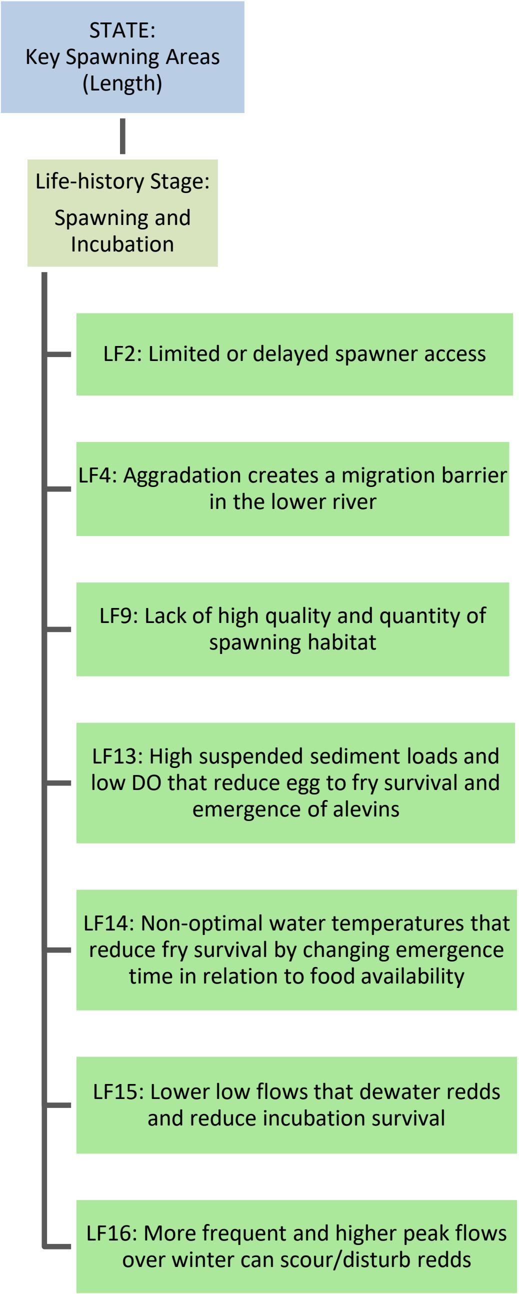

Figure 21. Relationship between key spawning areas, life-history stages, and limiting factors.

4.2.8.2 Results

Chinook Salmon

The best description of Chinook Salmon spawning habitat in the Nanaimo River remains that by Hardie (2002), who was contracted by DFO to quantify and rank the condition of spawning habitat in each section of the river based on the quality of gravel substrate and gradient:

- High quality – associated with high spawner densities and where spawning is observed at low, medium, and high spawner escapements;

- Intermediate quality – associated with medium spawner densities and where spawning is observed at medium and high spawner escapements, but not at low escapements; and
- Poor quality – associated with infrequent spawning and where spawning is observed only at high spawner escapements.

Assuming that the spawning habitat is relatively unchanged as of 2002, summer run Chinook Salmon have a total of 41,176 m^2 of high quality, 68,792 m^2 of intermediate quality and 64,272 m^2 of poor quality spawning habitat in the upper river from the confluence of Sadie Creek with the Nanaimo River to Second Lake, covering 11.2 km (Table 5). Lower in the river, summer run Chinook Salmon have a total of 12,233 m^2 of high quality and 14,955 m^2 of intermediate quality spawning habitat over 1.9 km. Fall run Chinook Salmon have 79,560 m^2 of high quality, 57,623 m^2 of intermediate quality and 83,199 m^2 of poor quality spawning habitat available for spawning. The section used for fall run spawning is 9.2 km long. Hardie (2002) also produced maps of the spawning habitat; however, they were not attached to the version of the report that MCW found and the location of the maps at DFO is presently unknown (Steve Baillie, DFO Stock Assessment Biologist, pers. comm. 2019).

The low availability of quality spawning habitat in the Nanaimo River is a major limiting factor to Chinook Salmon production (Burt 2002, Hardie 2002) and so a ‘High’ risk ranking has been assigned to this indicator for this species. The riverbed contains fairly high amounts of sand and other fines that make it unsuitable for spawning (Hardie 2002). The lower river is additionally prone to bedload shifting and fluctuating water levels (Hardie 2002).

Table 5. Chinook salmon spawning habitat areas and lengths, by habitat condition category (taken from Hardie 2002).

Run	River Section	Length (km)	Total Area (m^2)		
			High Quality	Intermediate Quality	Poor Quality
Summer	Sadie Creek	5.5 (Sadie Creek to Bridge 2)	936	4,918	
	Sadie Creek to Green Creek		312	1,404	3,432
	Green Creek to Bridge 2		10,476	11,458	31,356
	Tepee Bridge		5,740	17,940	26,832
	to Second Lake	5.7	23,712	33,072	2,652
	First Lake to Wolf Creek	1.9	12,233	14,955	
	Summary	13.1	53,409	83,747	64,272
Fall	Lower Canyon to Hwy	1.8	2,964	9,329	
	Hwy to Haslam Creek	2.2	9,984	16,268	23,244
	Haslam Creek Jct. To 2nd Island	3.6	49,608	29,998	47,475
	Lower Island to Cedar Road	1.6	17,004	2,028	12,480
	Summary	9.2	79,560	57,623	83,199

Note: Burt (2006) noticed some stream distances reported in the literature appeared to be incorrect; therefore, where available, the values in the Length column reflect distances corrected by Burt, which were obtained by digitizing on 1:20,000 TRIM maps in ArcMap.

Coho salmon

The spawning areas used by Coho Salmon in the Nanaimo River and its tributaries are poorly documented, but the length of accessible spawning habitat may be approximately 241 km (214 in Nanaimo River and tributaries, 27 km in Chase River and Beck and Holden Creeks), based on accessible stream lengths (Map 3). To assign a risk ranking, spawning areas would need to be ground-truthed.

Chum salmon

The spawning areas used by Chum Salmon in the Nanaimo River and its tributaries are poorly documented. To assign a risk ranking, spawning areas would need to be ground-truthed. However, based on what is known about the historical general spawning distribution of the species (as described in Sections 2.3.1 and 2.3.2.2; Map 3), the species' spawning grounds cover no more than approximately 27.1 km in the watershed, with ~20.8 km in the Nanaimo River and in Polkinghorne's Slough and Side Channel and in Maffeo's Side Channel and in Haslam Creek (Aro 1972, Butler et al. 2014). Chum also have approximately 6.3 km of spawning habitat, combined, in the lower reaches of Chase River (Bell and Kallman 1976) and Beck Creek (MOECCS 2019a).

Pink salmon
The spawning areas used by Pink Salmon in the Nanaimo River and its tributaries are poorly documented. To assign a risk ranking, spawning areas would need to be ground-truthed. The historical general spawning distribution of the species would indicate that they have up to approximately 5 km of spawning habitat in the lower Nanaimo River and 0.4 km in lower Haslam Creek (Map 3; Bell and Kallman 1976).

Sockeye salmon
The spawning areas used by Sockeye Salmon in the Nanaimo River and its tributaries are undocumented. To assign a risk ranking, spawning areas would need to be ground-truthed.

Previous assessments have concluded that road and hill slope instability in logged areas have been a major source of sediment to the Nanaimo River, negatively impacting fish spawning gravel quality, decreasing the area of suitable spawning habitat, and reducing egg and alevin survival through siltation damage (Komori Wong Environmental 2002, Butler et al. 2014, and references therein). At the same time, the South Fork Dam limits the natural recruitment of spawning substrate below the dam (Smith 2004). Though MCW has not assigned a risk ranking for Chum, Pink, and Sockeye Salmon due to data deficiencies, MCW predicts that the risk rankings would be 'Moderate' to 'High'. The spawning distributions of salmon species in the Nanaimo River watershed often overlap and it is expected that logging and land development have reduced the area and quality of spawning habitat for these species through the same mechanisms that have resulted in loss or degradation of Chinook Salmon spawning habitats.

4.2.9 Stream State: Habitat Composition

A reduction in habitat condition can impact all life stages of Pacific salmon and can largely be attributed to changes in hydrology and bedload movement from upslope impacts (i.e., total land cover alterations and/or riparian disturbances; Figure 22). Johnston and Slaney (1996) state that in streams with widths <15 m and gradients <2%, the stream is considered to be in poor condition to support salmonid summer and winter rearing when there is <40% pool habitat area by reach. Streams with gradients between 2% and 5% provide poor-quality summer and winter rearing habitat when there is <30% pool habitat area by reach, and streams with gradients >5% provide poor-quality summer and winter rearing habitat when there is <20% pool habitat area by reach.

4.2.9.1 Methods

MCW determined the habitat composition of the Nanaimo and South Nanaimo River mainstems by digitizing stream channel mesohabitat types using several imagery sources: 5 cm resolution 2018 orthophotos (estuary and reach 1) and 30 cm resolution 2009 orthophotos (half of reach 2, reaches 5–7, reaches 9–14, South Nanaimo River) obtained from the City of Nanaimo, 5 cm resolution drone imagery collected in 2019 by InDro Robotics (reaches 18–24), and Esri DigitalGlobe Vivid 2016 satellite imagery. The mesohabitat types were riffle, pool, glide, cascade, chute, gravel bar, and vegetated gravel bar (based on Johnston and Slaney (1996) BC Fish Habitat Assessment Procedures). Only the anadromous reaches of the mainstem rivers were classified.

MCW subsequently calculated the total area of each mesohabitat type with ArcMap. The pool areas were then compared against the Johnston and Slaney (1996) benchmarks for adequate pool habitat area. The indicator was assigned a risk ranking of 'High' if a low gradient reach (i.e., <2%) contained <40% pool habitat by area, if a moderate gradient reach (i.e., 2–5%) contained <30% pool habitat by area, and if a higher gradient reach (i.e., >5%) contained <20% pool habitat by area. MCW is aware that the anadromous reaches of the Nanaimo and South Nanaimo River mainstems exceed 15 m in width and the Johnston and Slaney benchmark is for streams with widths <15 m. However, in the absence of another benchmark, this reasonable metric and benchmark was

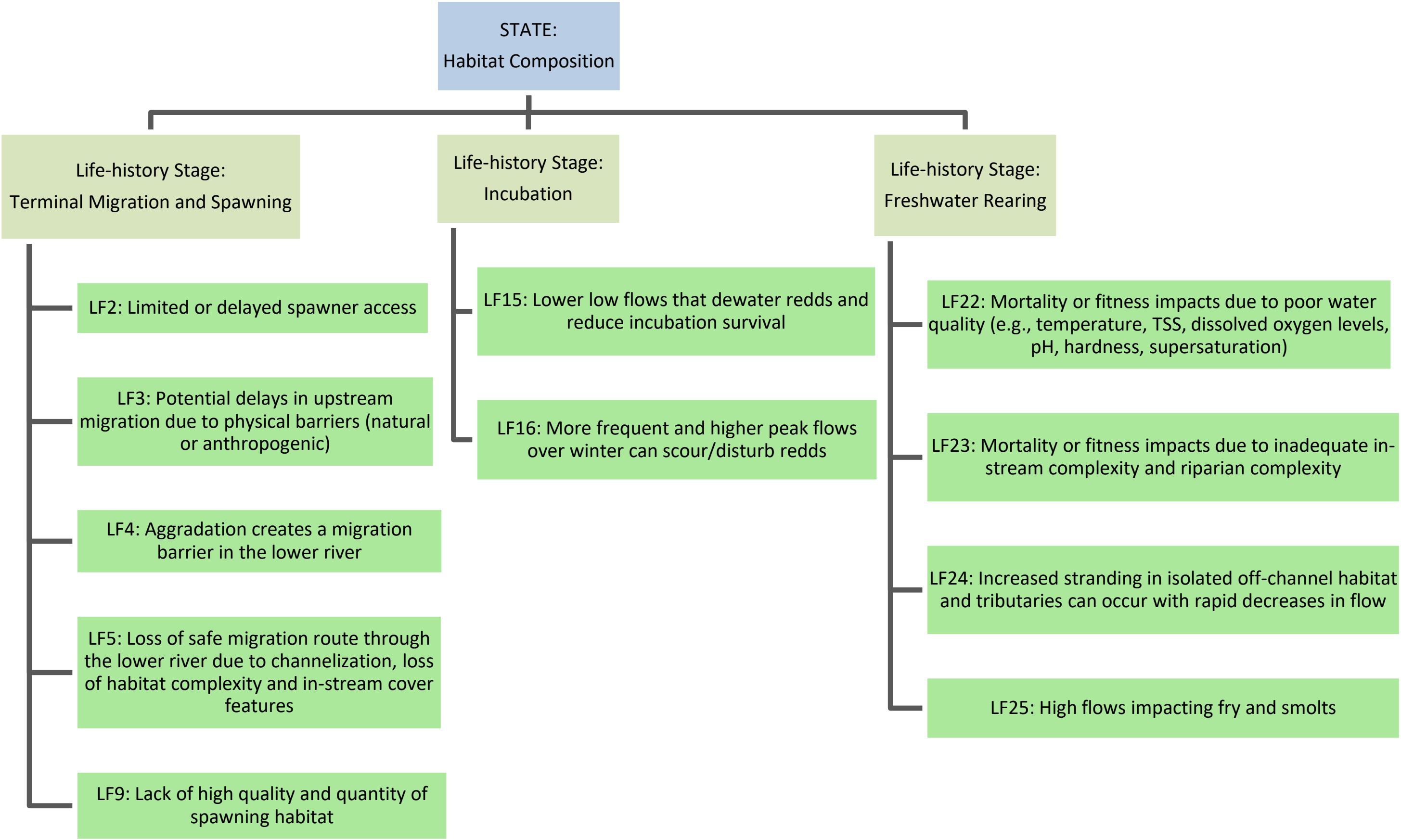

Figure 22. Relationship between habitat composition, life-history stages, and limiting factors.

applied for the purposes of deriving a precautionary ranking. Note that this risk ranking does not account for depth of pool habitat and so does not fully capture risk to fish due to pool infilling from stream aggradation. Additionally, this risk ranking relates primarily to risk of poor juvenile growth and survival and not to risk of poor spawning and incubation success due to lack of quality spawning gravels. For all the above reasons, literature that spoke to instream habitat condition, particularly abundance of pools, LWD, and high-quality spawning habitat was also weighed in assigning a ranking.

MCW did not have high resolution elevation data for the watershed; therefore, reach gradients were estimated using a combination of three sources:

1) The 20 m TRIM contours;
2) The DataBC Macro-Reaches layer, which provides elevation estimates at macro-reach breaks that sometimes lined up with the reach breaks identified by MCW. These elevation estimates were used specifically at the upper ends of reaches 1, 3, 5, 6, 8, 12–14, 17, 18, 21, and 24. Where elevation estimates sometimes conflicted with the 20 m TRIM contours, the TRIM contours were trusted; and
3) Google Earth elevations, which were used in some cases to get a sense of the elevation difference between major landmarks.

4.2.9.2 Results

Lower Nanaimo River
The 12 reaches of the Lower Nanaimo River have gradients less than 1.4%. Reaches 1–3 (the fall run Chinook Salmon spawning grounds) are comprised primarily of glide habitat (32–78%) and large unvegetated and vegetated gravel bars (13–51%) (Map 6, Figure 23). There is little pool habitat; all but four reaches had only 4.23–10.2% pool habitat by area. Reaches 4, 5, 7, and 10 had 25.3–34.6% pool habitat by area (Maps 7 and 8). The absence of pools means that in-migrating spawners are more vulnerable to low flows, high temperatures, and poaching. In Reaches 5, 7, 8, and 10, the channel transitions into cascades, and steep chutes are found in reach 5, 7, and 8. There was no off-channel habitat in the Lower Nanaimo River except for small areas in reaches 1–3. Because there is less than 20% by area pool habitat within any given reach, the Lower Nanaimo River was assigned a habitat composition risk ranking of ‘High’.

Middle Nanaimo River
The three stream reaches of the Middle Nanaimo River have gradients less than 0.5%. The habitat is dominated by glides (34–82%) and riffles (15–51%) (Map 10, Figure 23). There are no pools in reach 16 and reaches 13 and 14 have only 13 and 18% pool habitat by area. Accordingly, the Middle Nanaimo River was assigned a habitat composition risk ranking of ‘High’.

Upper Nanaimo River
The Upper Nanaimo River reaches have gradients of 0.3–1.1%, except reach 25, which has a 4% gradient. This portion of the river is dominated by long shallow glides that provide little water for adult salmon to hold, as previously documented by Hardie (2002). Reach 19 is 37% pool habitat by area; however, the remaining reaches either have no pools (reach 21) or little pool habitat by area (4.3–12.9%) (Maps 11 and 12). Some off-channel habitat is found in reaches 18, 20, and 23 (<2% in each reach). The Upper Nanaimo River was assigned a habitat composition risk ranking of ‘High’.

South Nanaimo River
The South Nanaimo River stream channel has a gradient of less than 1.5% and is comprised primarily of glide (22%) and riffle (64%) habitat (Map 10). Only 3.4% of the entire stream channel is pool habitat, which results in the river being assigned a risk ranking of ‘High’.

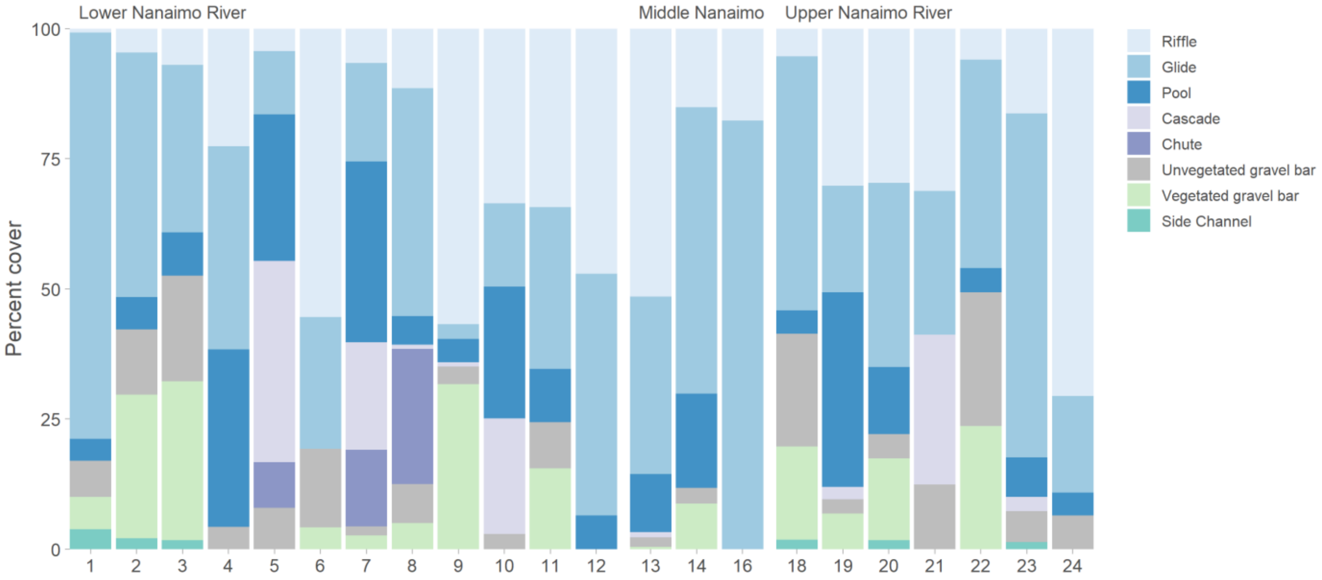

Figure 23. Mesohabitat types in the Lower, Middle, and Upper Nanaimo River.

The risk rankings are based on the Johnston and Slaney (1996) benchmarks for adequate pool habitat area in streams <15 m in width, and so they must be interpreted with some caution as stated in the preceding section; however, a 'High' risk ranking is supported by the results of previous field investigations of the Nanaimo River, which documented a lack of spawning and rearing habitat across the anadromous mainstem reaches. Hardie (2002) described the Nanaimo River as having "poor quality spawning habitat" overall. The first half of the upper river (Sadie Creek to Bridge 2) had little holding habitat and the final reach of the upper river (Teepee Bridge to Second Lake) had marginally better habitat with more holding water and better-quality spawning habitat. Gaboury and McCulloch (2002) found historical logging had resulted in unstable channel morphology, formation of extensive gravel bars, pool-infilling, and reduced pool frequency, with likely adverse impacts on adult spawning and juvenile overwintering. Logging and land development likewise resulted in a loss of off-channel rearing habitats (Gaboury and McCullough 2002), which are particularly important to juvenile Coho Salmon. Coho and stream-type summer run Chinook Salmon will be more vulnerable to loss of pools and off-channel habitats than ocean-type fry that out-migrate upon emergence (Hop Wo et al. 2006).

4.2.10 Stream State: Channel Stability

Forest harvesting and road building in a watershed have the potential to increase peak flows, increase sediment delivery, alter riparian vegetation, and decrease bank stability. These alterations can cause morphological changes to a channel, and may result in aggradation or degradation of the streambed, with subsequent impacts to critical salmonid habitats (Hogan and Ward (1997); Figure 24).

4.2.10.1 Methods

MCW did not have historical imagery with which to determine how bankfull widths, channel length, and channel sinuosity have changed over time. Instead, MCW synthesized available information on channel stability from existing assessment reports and, based on this information, assigned a risk ranking using professional judgement. To quantity the extent of channel migration over time, it would be necessary to acquire and compare high-resolution orthophotos against historical air photos. Historical imagery may not exist for all areas of the watershed.

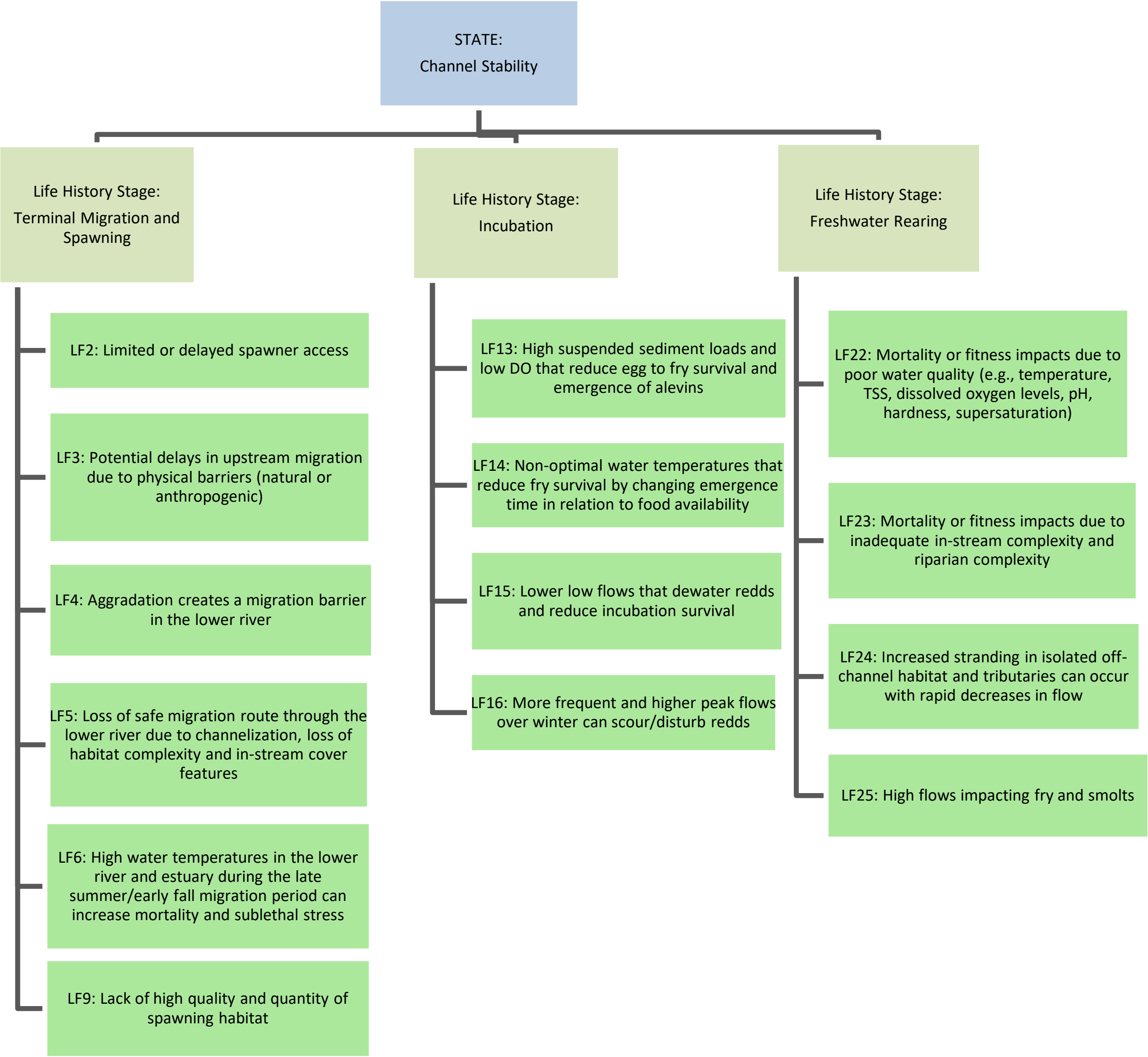

Figure 24. Relationship between channel stability, life-history stages, and limiting factors.

4.2.10.2 Results

Morphological changes to the Nanaimo River and its tributaries are not well documented. Previous field assessments have identified that logging of the Nanaimo River riparian forest has caused channel widening and instability of the river and its tributaries and formed extensive gravel bars—changes which have impacted both adult migration and instream and juvenile off-channel rearing habitat (Gaboury and McCullough 2002, Remillard and Clough 2014, in Butler et al. 2014). Changes to channel morphology have also resulted from agricultural and residential developments, such as seen in the mainstem of Nanaimo River below the Trans-Canada Highway and the lower reaches of Haslam Creek. Fish habitat has been destroyed or damaged due to artificial channelization of the river and removal of riparian vegetation. For example, in 1974, a section of Haslam Creek below the Island Highway Bridge was channelized to prevent the stream for meandering and eroding bordering properties (Bell and Kallman 1976).

Based on this information and the fact that the main drivers of channel instability—high peak flows, high land cover alteration, and riparian forest loss—have been flagged in this assessment as being at high risk of impacting salmon habitat in the Nanaimo River watershed, this indicator has been assigned a risk ranking of ‘High’. A detailed instability risk assessment of the Nanaimo River watershed should be completed to verify the sensitivity of the watershed (e.g., percentage of the sub-basin area comprised of slopes steeper than 60%) and the degree of landscape stability disturbance from forestry operations (e.g., density of landslides from roads and cutblocks).

4.2.11 Stream State: Large Woody Debris

In stream channels, large woody debris (LWD) functions to help form and stabilize pools and gravel bars. LWD further affects channel geomorphology by influencing the storage and release of detritus and sediment and providing natural armour along stream/river banks. LWD provides cover for salmonids, and in the winter, the velocity shadows LWD creates (especially during higher winter flows) are extremely important for overwintering juvenile Coho and stream-type summer run Chinook Salmon (Figure 25).

Decreases in LWD supply occur shortly after forest harvesting (Bilby and Ward, 1991). Changes in riparian stand composition (e.g., a transition from mature coniferous to deciduous) are known to reduce the quality and stability of LWD in a system as deciduous trees, such as red alder, break down in river systems faster than mature conifers.

4.2.11.1 Methods

MCW counted LWD in the Upper Nanaimo River watershed reaches visible from the 5 cm resolution 2019 InDro Robotics drone imagery. The imagery available for the Middle and Lower Nanaimo River was of insufficient resolution to count LWD. The reaches that did not meet a benchmark LWD abundance greater than 50 pieces per kilometre, with the pieces being greater than 15 m in length (Stalberg et al. 2009) were assigned a risk ranking of ‘High’. Any additional information on LWD available from previous assessments in the watershed was considered in assessing the relative risk of this habitat state indicator.

4.2.11.2 Results

In the Upper Nanaimo River, reaches 19 and 21 had no visible LWD. The remaining reaches (18, 20, 22–24) had only 2 to 10 pieces of LWD per kilometre, and the average length of the LWD ranged from 6.6–14 m, except for reach 18, where the average length was 25.2 m. These values reaffirm previous assessments that the river and its major tributaries are deficient in LWD and that removal of riparian vegetation has resulted in a meaningful decrease in large conifer recruitment from the riparian zone to the river and off-channel rearing habitats (Gaboury and McCullough 2002, Remillard and Clough 2014, in Butler et al. 2014). Insufficient LWD is also exacerbated by decreased channel stability and higher peak flows (Stalberg et al. 2009), both indicators of watershed degradation that this report has flagged as being at high risk in the Nanaimo River watershed. For these reasons, this indicator has been assigned a risk ranking of ‘High’.

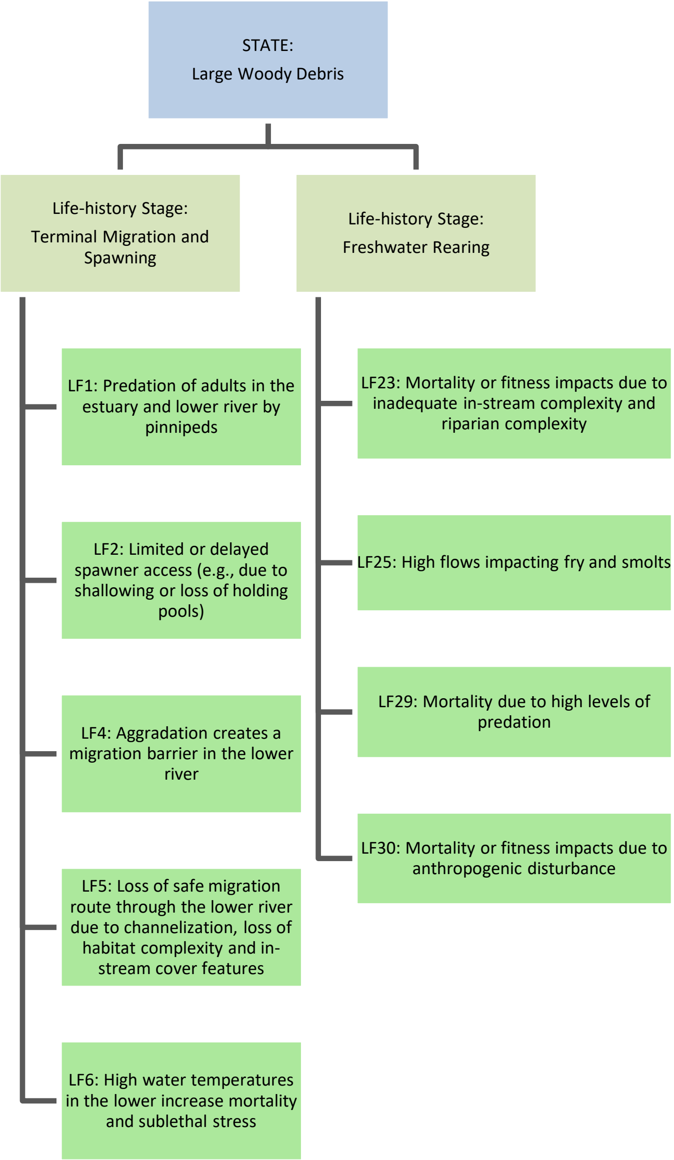

Figure 25. Relationship between large woody debris, life-history stage, and limiting factors.

4.2.12 Estuary Pressure: Estuary Habitat Disturbance

Estuaries are considered critical habitat for all species of salmon for both terminal migration and juvenile rearing, particularly for juvenile Chum Salmon, which have longer residency times in estuaries (Diewert 2007c). Estuaries are important habitats for adult salmon for staging while undergoing the physiological changes needed to transition to the freshwater environment. Estuaries also provide important refuge and rearing habitat for juvenile salmon transitioning to the marine environment (Figure 26).

Anthropogenic impacts within an estuary can have negative effects on both adult and juvenile salmonids through several mechanisms (Aitkin 1998): 1) loss of intertidal rearing habitat due to nearshore development, dredging and filling, and gravel deposition from upstream sediments; 2) decreased DO due to input of sewage, agricultural practices, and dredging of anoxic sediments; 3) water contamination due to chemical spills and discharge of chemical waste from industry and mining; and 4) increased total suspended solids and turbidity due to logging activities upstream, agricultural practices, dredging, and input of sewage and industrial waste. These impacts amplify the physiological stresses fish experience during the transition between the freshwater and marine environments.

4.2.12.1 Methods

MCW conducted a literature search for information about habitat disturbance within the Nanaimo River watershed estuary. Log storage lease areas and maps showing change in the spatial configuration of the lease areas in the estuary over time was provided by Bob Colclough (Nanaimo River Estuary Log Storage Association). MCW assigned a risk ranking based on professional judgement, considering the area of estuarine disturbance due to log storage leases, diking, etc. and trends in the spatial extent of industrial activities.

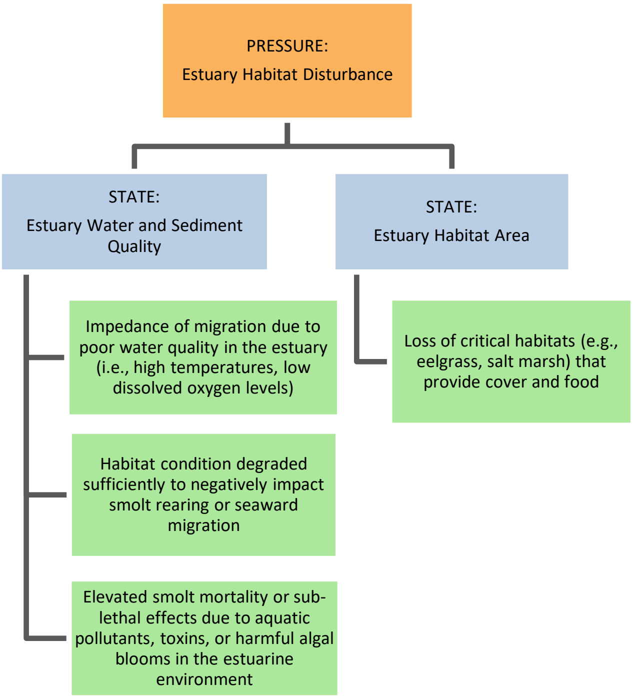

Figure 26. Relationship between estuary habitat disturbance and state indicators.

4.2.12.2 Results

As reviewed in Section 1.2.4 and 1.2.6.3, the Nanaimo River estuary has been significantly altered by historical and ongoing anthropogenic activities. Portions of the estuarine marsh and meadow habitats were diked to create fields for hay production and grazing by domestic animals, altering the plant communities in these areas (Bell and Kallman 1976). Intensive log booming over the intertidal mudflats resulted in widespread loss of eelgrass from the middle portion of the mudflats due to shading, logs grounding at low tide, and damage by prop wash or dragging of logs by tow boats. Logs were stored as flat rafts until the 1980s, after which point they were stored in bundles (G3 Consulting Ltd. 2005). Prior to 1948, when the estuary was relatively undisturbed, eelgrass was reported to have been growing over two thirds of the estuary, primarily in the lower portion of the estuary (Bell and Kallman 1976). The introduction of coal washings from mining operations in the area and increased sedimentation in the estuary due to logging in the watershed were additional causes of eelgrass loss (Bell and Kallman 1976).

The anoxic layer and wood debris caused by log storage has persisted after removal of log storage leases in the east portion of the estuary decades ago (Komori Wong Environmental 2002). In a review of late 1970s research on the biological productivity of the estuary, Sibert (1979) stated that sampling of the standing crop of chlorophyll, as a metric of primary productivity, indicated that primary productivity was generally low in the mudflats but that the sampling station in an area highly disturbed by log storage (on the western side of the estuary) was 7% of that in an undisturbed area, suggesting that benthic microalgae was inhibited by log storage. Harpacticoid copepods, an important invertebrate food for juvenile salmon, were quite abundant under the highly disturbed western estuary site, but as fry were noted to rarely use the region, it was estimated that food production was limiting fry growth in the estuary. There were no noticeable trends in the distribution of meiofauna, but no macrofauna were found under log rafts (as reviewed by Sibert 1979).

Log storage continues in the western half of the estuary; however, the tenure area is approximately 44% of what it was at its peak in the 1970s (based on 2012 value provided by Bob Colclough, Nanaimo River Estuary Log Storage Association; Map 14). Agricultural dikes remain in the eastern estuary (the footprint roughly half of the peak footprint in the late 1980s). Because of these ongoing impacts and the scale of persisting damage caused by historical human activities, this indicator has been assigned a risk ranking of ‘High’.

4.2.13 Estuary State: Estuary Water and Sediment Quality

An analysis of estuarine water chemistry and contaminants (i.e., nutrients, metals, polycyclic aromatic hydrocarbons (PAHs) and polychlorinated biphenyls (PCBs)) can help determine the suitability of water quality for aquatic life. Adequate DO levels and stratification in estuaries are necessary for salmon to successfully transition between the freshwater and marine environments (Stalberg et al. 2009). Beyond having direct effects on fish survival, fish will typically migrate away from areas with low DO levels, which may situate them in areas where they are more vulnerable to predation. As mentioned in Section 4.2.12, the estuary is considered critical habitat for all species of salmon for both terminal migration and juvenile rearing; however, juvenile Chum Salmon are the most dependent on healthy estuarine habitats to complete their life cycle (Figure 27).

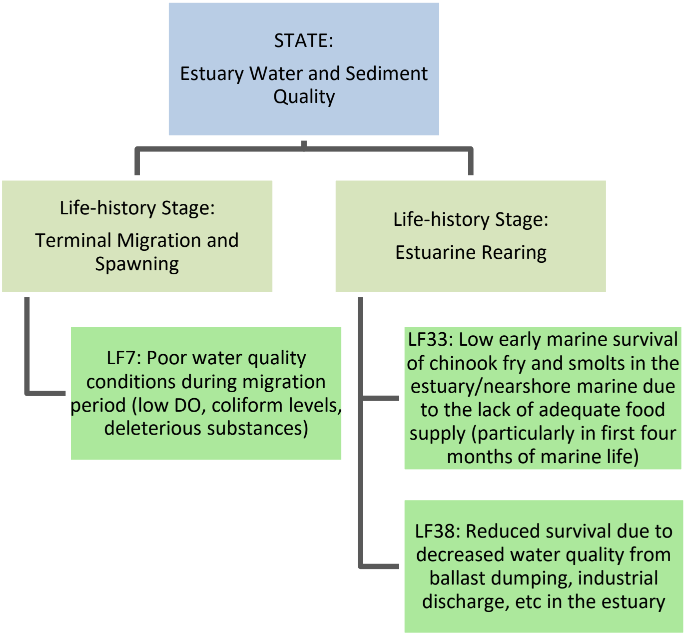

Figure 27. Relationship between estuary water and sediment quality, life-history stage, and limiting factors.

4.2.13.1 Methods

MCW conducted a literature search for information about estuarine water and sediment quality within the Nanaimo River watershed estuary. A risk ranking was assigned using professional judgement and founded on the results of previously conducted water and sediment quality sampling and any information on trends in water and sediment quality parameters.

4.2.13.2 Results

Nearshore marine habitats in the vicinity of the estuary have historically been exposed to multiple sources of pollutants produced by industries in the Nanaimo area that would have impacted both adult and juvenile fish on their migration to and from the river. As mentioned earlier, prior to the late 1950s, raw sewage was discharged into Nanaimo Harbour, leading to elevated levels of fecal coliform. The Harmer pulp mill also discharged untreated domestic sewage into the Northumberland Channel up until 1976. Hooker Chemical Co., one of several chemical plants, was located on Northumberland Channel next to the Harmac pulp mill and produced chlorine and caustic soda chemicals for the pulping process. It was responsible for multiple fish kills throughout the 1960s caused by discharging waste with high chlorine concentrations (Bell and Kallman 1976). Dungeness crab populations near Jack Point support fisheries, but bivalve shellfish harvesting has largely been closed since 1949 due to high fecal coliform (e.g., Environment Canada Environmental Protection Program 1997) and other high contaminant levels, including dioxins, furans, PCBs, PAHs, pesticides, and metals (Catherine Berris Associates Inc. 2006). A limited Snuneymuxw First Nation shellfish depuration harvest was begun in 2003 on the east side of the estuary (Nautilus Environmental 2008) and continues today (Andrew McNaughton, pers. comm. 2021). Dioxins, furans, PCBs, PAHs, and metals generated by industry and shipping may accumulate in estuarine sediments.

Log handling has contributed to decreased DO levels in the estuary due to wood waste deposition (Picard et al. 2003). Presently, water quality in the estuary is also naturally impacted by the water quality of the Nanaimo River and the other rivers that drain into the estuary, which has been flagged of concern during summer due to low DO levels and high fecal coliform levels (Section 4.2.6.2). Low DO in the lower Nanaimo River may exacerbate low DO in the estuary in the summer.

Sibert (1978) investigated the timing and magnitude of carbon and nutrient movements from the Nanaimo River to the estuary mudflat. Every 2 to 3 weeks over one year, water samples were collected below the surface of the Nanaimo River about 1 km upstream of tidal influence. The authors observed distinct seasonal changes in nutrient concentrations in the river. Inorganic nitrogen and phosphorus peaked between January and May, with rainfall causing run-off of agricultural nutrients, but were relatively low the remainder of the year.

In 2004, G3 Consulting Ltd. (2005) conducted water quality and surface sediment sampling for the Nanaimo Log Storage Association. Samples were obtained from four sites, with five replicate samples per site (G3 Consulting Ltd. 2005; Map 14):

S1 – Western estuary log storage site
S2 – Western estuary proposed log storage site, adjacent to existing log storage lease
S3 – Western estuary log storage site
S4 – Eastern estuary reference site

The existing log storage sites (S1 and S3) had dense woody debris layers, whereas a site adjacent to an existing log storage lease (S2) and the reference site (S4) did not. The S1 log storage site had the most pronounced anoxic sediment layer and the reference site the least. The authors indicated that the increased anoxia at the log handling sites was due to compaction of sediments from log grounding causing decreased interstitial water circulation. Arsenic and copper levels in surface sediments were close to or above the Canadian Council of Ministers of the Environment Interim Sediment Quality Guideline (ISQG) at all sites, which suggests these metals may be naturally elevated in the estuary. Given that metal concentrations were below the ISQG, metal levels were unlikely to be high enough to cause acute toxic effects on biota. Bioavailability analyses similarly indicated that the metals were not highly bioavailable.

Benthic invertebrates (food to juvenile Pacific salmon) sampling revealed differences in total species abundance, richness, and diversity between sites, with S1 and S2 being most different from the reference site (G3 Consulting Ltd. 2005). The reference site had a far greater total abundance of benthic invertebrates than the log storage sites or S2, adjacent to log storage areas (S1 had ~25% the abundance of S4). Species tolerant of low DO were present at the S1 log storage site. However, community composition differences could not be entirely explained by log storage activities. Runoff from urban sources and other physical factors (e.g., differences in salinity, hydrology, sediment deposition, etc.) also influence sediment and water quality. For instance, the location of the S2 sampling site appeared to experience greater tidal/freshwater flushing, which possibly helps mitigate anoxification of sediments due to log storage. And the west side of the estuary represents the principal sediment deposition zone of the estuary (G3 Consulting Ltd. 2005). Given the small sample size (with only one reference site) of the G3 Consulting survey, it is not possible to derive robust conclusions or tease apart factors contributing to sediment and water quality.

Following the G3 Consulting survey, Nautilus Environmental was contracted by the Nanaimo Estuary Management Committee to prepare a water and sediment quality and invertebrate monitoring plan. Nautilus Environmental (2008) decided that it would be impractical to try to assess what factors are driving changes in measured parameters because the complexity of the estuary would require many sampling sites. The plan they prepared recommended sampling at five sites (three of them aligning with G3 Consulting Ltd. (2005) sites S1, S3, and S4) according to the following schedule:

- Collect sediment samples every other year for the first five years of the program, in the spring, just after freshet, when run off from urban sources would be greatest. Analyse levels of metals, PAHs, PCBs, pesticides (organochlorine, organophosphate, and pyrethroids), wood extractives (tannins and lignins), and basic sediment properties such as total organic carbon, total organic nitrogen, total volatile solids, particle size distribution and percent moisture;
- Collect benthic macroinvertebrates every other year along with sediment samples to evaluate potential correlations between contaminant levels and invertebrate abundance, and species diversity and richness;
- Collect clam tissue samples and analyse metal and organic compound levels, and lipid/moisture content;
- Collect starry flounder tissue from two sampling stations (one in the east estuary and one in the west estuary) every two years and analyse tissue contaminant levels among other parameters;
- Evaluate differences in measured parameters as a function of whether the sampling site is on the west side or east side of the estuary; and
- Re-evaluate the plan every five years and adapt the protocol as necessary.

As first mentioned in Section 1.2.6.7, there was no information available to MCW at the time of writing that indicates whether the sampling program proposed by Nautilus Environmental (2008) has been carried out.

In 2009, an unrelated Vancouver Island University sediment sampling project collected 18 sediment samples from 9 locations within the estuary, at depths spanning 10 cm to 95 cm, to conduct grain size analysis and describe the contents (Earle et al. 2009). Sediment around the Doman mill area and near the log booms contained abundant wood material relative to the other locations. Fine coal fragments were abundant around the Doman mill area and along the beach fronting the Snuneymuxw First Nation reserve. It was recommended that further sampling, including coring to several metres depth, be conducted to quantify sub-surface coal and wood content.

This indicator has been assigned a risk ranking of ‘Moderate’ given the historical contamination of the estuarine substrates, persistent sediment anoxia in areas long impacted by log storage, the continued agricultural use of the lower estuary, and the increasing area of impermeable surfaces in the lower estuary with urban development.

4.2.14 Estuary State: Estuarine Habitat Condition

The area of riparian, sedge, eelgrass, and mudflat habitats within an estuary is considered an indicator of the productive capacity of an estuary and represents critical rearing and foraging habitat for both returning adults and rearing juveniles (Figure 28). An analysis of estuarine habitat changes over time also provides an indicator of habitat improvement or degradation and may identify critical habitats requiring protection and/or restoration.

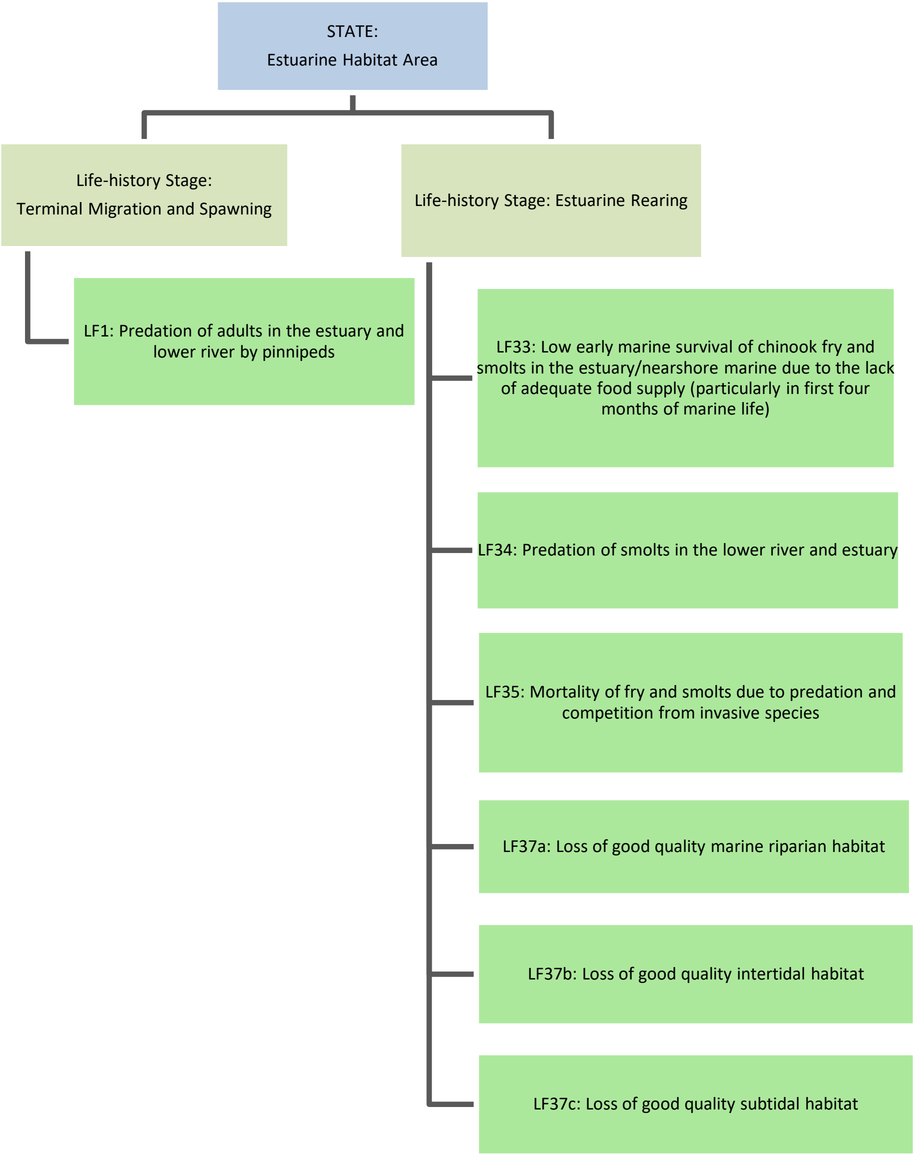

Figure 28. Relationship between estuary habitat area, life-history stage, and limiting factors.

4.2.14.1 Methods

The area of each estuarine habitat type in the Nanaimo River estuary was calculated by digitizing habitat types visible from 5 cm resolution 2018 orthophotos obtained from the City of Nanaimo. The NETF (1980a) provided a map of eelgrass in 1980 derived from aerial photos and the Nanaimo Estuary Management Plan includes a map of eelgrass as delineated by underwater drop camera in 2002 (Catherine Berris Associates Inc. 2006). MCW later obtained the results of eelgrass delineation completed in July 2015 by Aquaparian Environmental Consulting and VIU by boat, kayak, and scuba with a handheld GPS. The field results were used to ground truth aerial photos of eelgrass taken by Bazett Land Surveying in 2015. The southern extent of eelgrass was not fully mapped in 2015 and so this year's data are not discussed further here. Aquaparian returned in July 2020 to delineate the southern extent of eelgrass in the estuary by kayak and on foot. MCW used these data to look at trends in eelgrass area across 1980, 2002, 2018, and 2020. MCW was not able to quantify precisely how much the area and distribution of other habitats has changed over the entire history of resource use in the watershed because there were few historical images against which to assess changes in estuary habitat composition.

4.2.14.2 Results

The Nanaimo River estuary contains 3,876,702 m^2 of mudflat habitat, 1,754,371 m^2 of salt marsh habitat, and between ~1,112,000 m^2 and 1,458,000 m^2 of eelgrass habitat (Map 15). Intertidal benthic algae, covering an unknown area, also provide habitat and contribute to primary production in the estuary (primarily sea lettuce (*Ulva* spp.) and rockweed (*Fucus* spp.) (Sibert 1979).

Estuarine Marsh

Less than half of the original extent of the Nanaimo River estuary marshes exist today due to diking and infilling the marshlands for agriculture and urban development (when the boundary of the estuary includes the area out to Departure Bay; Catherine Berris Associates Inc. 2006).

Streamline Environmental prepared a terrestrial monitoring plan for NEMC, which stated that several indicators of ecological community and vegetation status should be monitored every five years using a combination of permanent plots, elevational transects, and imagery interpretation with ground-truthing (Smith and Meggs 2009). All monitoring results are to feed into an adaptive management framework whereby management actions are adjusted based on status trends to ensure that the objectives of the plan pertaining to vegetation—maintaining the amount, quality, and diversity of vegetation and wildlife habitats—are met. There was no information available to MCW at the time of writing that indicates whether the monitoring program was carried out.

In 2019, MCW mapped the vegetation site associations in the estuary for the Nature Trust of BC using high-resolution imagery coupled with ground-truthing. MCW also collected elevation data throughout the estuary, which together with the vegetation data will be used to help the Nature Trust prepare a monitoring plan to assess risks to estuarine ecological communities from sea level rise. Estuarine marsh site associations—intertidal ecosystems that are flooded with the daily tides and are therefore accessible to juvenile salmon—that match those described in the BC Land Management Handbook, *Wetlands of British Columbia: A Guide to Identification* included the following:

Em02–glasswort – sea-milkwort (*Salicornia virginica – Glaux maritima*),
Em03–seashore saltgrass (*Distichlis spicata*)
Em05–Lyngbye's sedge (*Carex lyngbyei*) Herbaceous Vegetation

All BC estuarine site associations are Red- or Blue-listed ecological communities at risk. MCW created additional community classifications for areas of the estuarine marsh and meadow that did not fall under the established BC site associations, in many cases due to significant spread of non-native plant species. For instance, a large area of the estuarine marsh was covered by saltmarsh rush (*Juncus gerardii*) and small areas of the southeastern estuary by American bulrush (*Scirpus americanus*)-dominated communities.

Eelgrass

Eelgrass grows in the intertidal and subtidal zones in the Nanaimo estuary, including in permanent lower intertidal and subtidal tidal channels. As discussed in Section 1.2.6.3, there was significant loss of eelgrass on the east side of the estuary by 1980 due to 30 years of shading of the eelgrass beds by log booming grounds, grounding of logs, altered current and wave action, deposition of wood waste debris, and damage by tugboats (NETF 1980a). In 1980, eelgrass covered 1,127,900 m^2 and was noted as occurring only in areas that were less than 2 m above the mean lower low water and that were not covered by intertidal log storage (NETF 1980a).

The total area of eelgrass increased 1,369,000 m^2 (886,000 m^2 continuous, 483,000 m^2 patchy) by 2002. The area of eelgrass increase was in the northeast portion of the estuary, following removal of the eastern log storage leases at the NETF's (1980a) recommendation (also noted by G3 Consulting Ltd. 2005 and references therein). However, between 1980 and 2002 there was a loss of eelgrass in the northwest portion of the estuary, which was likely due to the reallocation of the eastern log storage lease area to the west side of the estuary. Increasing the size of the western log storage lease areas increased the northward extent of wood waste debris accumulation and boat damage on the sea bottom (first noted by Catherine Berris Associates Inc. 2006). The upper intertidal zone had a lower density of eelgrass (mostly *Zostera japonica* at a density of 10–20 shoots per m^2) than the lower intertidal and subtidal zone (mostly *Zostera marina*; 30–40 shoots per m^2), and had lesser amounts of epiphytic algae (Catherine Berris Associates Inc. 2006).

The current log storage lease area falls over what would have historically been high to moderately high value fish habitat prior to the use of the estuary for log storage (Catherine Berris Associates Inc. 2006). Analysis of the City of Nanaimo 2018 orthophotos indicated that the area of eelgrass in the estuary was 1,111,859 m^2 (1,017,146 m^2 dense, 94,712 m^2 sparse), 19% less than observed in 2002. This reduction may have been driven by continued log storage activities, climatic changes, and/or it may additionally reflect seasonal or inter-annual differences in eelgrass bed size, which can increase or decrease in size by 11–50% (Harris et al. 2012). Additionally, patchier and deeper subtidal eelgrass beds are less observable from imagery. In 2020, Aquaparian field surveys yielded an eelgrass distribution covering ~1,458,000 m^2, an increase of 31% from 2018 and 6% greater than in 1980. The sparsely colonized areas and deeper subtidal areas not visible from the 2018 imagery were likely captured during the 2020 field surveys. It is also possible to see differences across eelgrass delineation efforts based on how generous one is in designating eelgrass distribution around patchy and sparsely colonized areas. Given the potential for eelgrass area to naturally vary from year to year, MCW recommends the eelgrass area be ground-truthed by dive and/or underwater camera on a regular basis to differentiate year-to-year variation from anthropogenically-driven trends.

Loss of eelgrass and saltmarsh habitat and food resources in the estuary was identified early on as likely limiting the productivity of salmon populations (NETF 1980a). This indicator has been assigned a risk ranking of 'High'.

5 SUMMARY OF HABITAT INDICATOR AND LIMITING FACTOR RANKINGS

Based on the results of the habitat status assessment for the Nanaimo River watershed, there are several indicators with a risk ranking of ‘High’ (Table 6, Table 7).

Table 6. Nanaimo River watershed habitat pressure indicators and related state indicators.

Pressure Indicator	Indicator Risk Ranking	Data Gaps (Y/N) ?	Comments	Related State Indicators and Risk Rankings *Where Risk =* Data Gap / Low / Moderate / High
Total land cover alterations	High	N	The watershed has experienced extensive land cover alteration in the middle and upper watershed due to forest harvesting and road building—Only 0.55%, 2.8%, and 1.4% of what would have historically been vegetated land or wetlands in the Lower Nanaimo River, Middle Nanaimo River, and Haslam Creek sub-basins, respectively, is unaltered forest. The remaining forested land in the watershed is covered by young forest. 30%, 41%, 53%, 44%, and 41% of forest in the Lower, Middle, South, Upper Nanaimo River and Haslam Creek sub-basins is less than 40 years old, respectively. 7.4% of the Lower Nanaimo River, 23.8% of the Chase River, and 25% of the Holden Creek sub-basins has been converted to agriculture, industrial, highway, or rural and urban development. The risk of cumulative impacts to fish habitat from loss of mature forest and land development is ranked as ‘High’ in the Nanaimo River, Chase River, Beck Creek watersheds, and ‘Moderate’ in Holden Creek watershed.	Water Quality Stream Discharge Key Spawning Areas Habitat Composition Large Woody Debris Estuarine Habitat Area
Road development	High	N	The gravel road density in the watershed greatly exceeds the benchmark for protection of salmon habitats and the paved road density exceeds the benchmark in the Chase River and Holden Creek sub-basins. The South and Upper Nanaimo River sub-basins and the Chase River watershed have ~380 m to 3.1 km more gravel road per square kilometer than eight of the nine actively logged Clayoquot and Nootka Sound watersheds that MCW has assessed using this Wild Salmon Policy framework and that also exceeded the higher-risk benchmark.	Water Quality Key Spawning Areas Habitat Composition Channel Stability Estuarine Habitat Area
Riparian disturbance	High	N	Little mature conifer riparian forest remains along the Nanaimo River. Up to 58.6% of the riparian forest in each reach of the Nanaimo River is early regenerating (<40 years old) or has been converted to agricultural or other anthropogenic use (e.g., gravel road, gravel pits, urban development). Harvesting of riparian vegetation can lead to increased transpiration by streamside regenerating vegetation, increased stream temperatures, reduced summer stream flow, bank erosion, introduction of sediments from logging, and loss of mature conifer LWD inputs, among other effects.	Water Quality Stream Discharge Habitat Composition Channel Stability Large Woody Debris Estuarine Habitat Area

Pressure Indicator	Indicator Risk Ranking	Data Gaps (Y/N)?	Comments	Related State Indicators and Risk Rankings *Where Risk =* Data Gap	Low	Moderate	High
Water extraction	High	N	The total licenced water extraction in the Nanaimo River watershed is over 193 million m^3/y, representing ~10% of mean annual discharge. Water extraction in the watershed is fully allocated unless more storage is created. Aquifers are under high stress, though groundwater withdrawal for domestic use remains unregulated. The annual watershed yield in the Nanaimo River and South Nanaimo River sub-basins will likely decline by approximately 13% in the next 50 years. Total watershed low flow period (June–September) yield is expected to decline by up to 60% in the next 50 years.				Stream Discharge
							Key Spawning Areas
							Habitat Composition
Permitted waste management discharges	Low	N	There are five active waste discharge authorizations for facilities located within the watershed. Because of these facilities, the surface water, aquifers, and estuary of the Nanaimo River watershed are exposed to more sources of contamination than less populated Vancouver Island watersheds. However, there is presently no direct effluent discharge to rivers or to the Nanaimo River estuary.				Water Quality
							Key Spawning Areas
						Estuary Water and Sediment Quality	
Estuary habitat disturbance	High	N	The estuary has been significantly altered by historical and ongoing anthropogenic activities. Portions of the estuarine marsh and meadow habitats were diked to create fields for hay production and grazing by domestic animals. Log booming over the intertidal mudflats resulted in widespread loss of eelgrass from the middle portion of the mudflats. The introduction of coal washings from mining operations in the area and increased sedimentation in the estuary due to clearcut logging in the watershed were additional causes of eelgrass loss.				Estuarine Habitat Area
						Estuary Water and Sediment Quality	

Table 7. Summary of assessed Nanaimo River watershed habitat state indicators risk rankings and DFO's related limiting factor risk rankings (under the current climate regime). The values under the column "Related Limiting Factors Risk Ranking" correspond to the limiting factors listed in Section 3.1. For example, LFs 6, 7, and 11, which pertain to terminal migration and spawning, are related to/impacted by water quality.

Indicator	Indicator Risk Ranking	Comments	Related Limiting Factors Risk Ranking: Data Gap	Very Low	Low	Mod	High	Very High
Water Quality	High	High water temperatures and low DO frequently reach levels that may stress or kill fish in the summer. Fish in the lower watershed also experience nutrient loading from agriculture and high turbidity levels in the fall and winter. In the	Terminal Migration and Spawning:					
				7 11		6		
			Incubation:					

Indicator	Indicator Risk Ranking	Comments	Related Limiting Factors Risk Ranking					
			Data Gap	**Very Low**	**Low**	**Mod**	**High**	**Very High**
		upper watershed, rearing fish may be exposed to cold water from the Harmac reservoir that can reduce summer growth and survival. Poor water quality elevates the risk of pre-spawn mortality due to disease, such as ichthyophoniasis caused by the protozoan *Ichthyophonus hoferi*.				14	13	
			Freshwater Rearing:					
					22		26	
			Estuarine Rearing:					
							38	
Stream Discharge	High	To protect salmon population productivity, the *Nanaimo River Water Management Plan* set an instream flow limit of 3.9 m^3/s at station 08HB034, but summer discharge at the station drops not infrequently below the 3.9 m^3/s flow benchmark and has done so over longer durations this last decade, which places salmon populations at higher risk of poor spawning success. The frequency of extreme high and low discharge readings has, in general, markedly increased over historical levels, which places salmon at higher risk of poor spawning, incubation, and rearing success. The number of readings at station 08HB034 where fall/winter flows exceeded 300 m^3/s and 500 m^3/s has increased by approximately 235% and 190% between the periods of 1969–1978 to 2009–2018. The number of station readings where summer low flows were less than 5 m^3/s and 3 m^3/s has increased by approximately 175% and 185%, respectively, between the periods of 1969–1978 to 2009–2018. High flows are exacerbated by logging and conversion of land to impervious surfaces and may cause significant egg mortality if there is high bedload movement and a reduction in habitat complexity. Aggradation of stream channels due to sedimentation caused by logging contributes to low flows in the summer. Adult Chinook Salmon may be impacted during extreme low water events as they travel through the estuary and the river.	Terminal Migration and Spawning:					
				4		3	2	
			Incubation:					
				15				16
			Freshwater Rearing:					
							24 25 30.5	
Key Spawning Areas	High	There is approximately 13.1 km of summer Chinook Salmon spawning habitat and 9.2 km of fall Chinook Salmon spawning habitat in the watershed. Roughly one third of this spawning habitat is considered to be of high quality. The riverbed contains fairly high amounts of sand and other fines that make it unsuitable for spawning. The lower river is additionally prone to bedload shifting and fluctuating water levels.	Spawning:					
				4			2	9
			Incubation:					
				15		14	13	16
Habitat Composition	High	The Nanaimo River has little holding habitat required by adult fish during migration and spawning. Removal of riparian vegetation has destabilized channel morphology and caused channel infilling with sediments, reducing the abundance of pools. Logging and land development have likewise resulted in a loss of off-channel rearing habitats. Coho and stream-type summer run	Terminal Migration and Spawning:					
				4		3	2	5 9
			Incubation					
				15				16
			Freshwater Rearing:					

<table>
<tr><th rowspan="2">Indicator</th><th rowspan="2">Indicator Risk Ranking</th><th rowspan="2">Comments</th><th colspan="6">Related Limiting Factors
Risk Ranking</th></tr>
<tr><th>Data Gap</th><th>Very Low</th><th>Low</th><th>Mod</th><th>High</th><th>Very High</th></tr>
<tr><td></td><td></td><td>Chinook Salmon are more vulnerable to loss of pools and off-channel habitats than ocean-type fry.</td><td></td><td>22</td><td></td><td></td><td>23
24
25</td><td></td></tr>
<tr><td rowspan="6">Channel Stability</td><td rowspan="6">High</td><td rowspan="6">Logging of the Nanaimo River riparian forest has caused channel widening and instability of the river and its tributaries and formed extensive gravel bars—changes which have impacted both adult migration and instream and juvenile off-channel rearing habitat. Changes to channel morphology have also resulted from agricultural and residential developments, such as seen in the Nanaimo River below the Trans-Canada Highway and the lower reaches of Haslam Creek. Fish habitat has been destroyed or damaged due to artificial channelization of the river and removal of riparian vegetation.</td><td colspan="6">Terminal Migration and Spawning:</td></tr>
<tr><td></td><td>4</td><td></td><td>3
6</td><td>2</td><td>5
9</td></tr>
<tr><td colspan="6">Incubation:</td></tr>
<tr><td></td><td>15</td><td></td><td>14</td><td>13
16</td><td></td></tr>
<tr><td colspan="6">Freshwater Rearing:</td></tr>
<tr><td></td><td>22</td><td></td><td></td><td>23
24
25</td><td></td></tr>
<tr><td rowspan="4">Large Woody Debris</td><td rowspan="4">High</td><td rowspan="4">The river and its major tributaries are deficient in LWD because the removal of mature conifer riparian vegetation has resulted in significant loss of large conifer recruitment from the riparian zone to the river and off-channel rearing habitats. Insufficient LWD is also exacerbated by decreased channel stability and higher peak flows. The result is a lack of cover for salmonids and velocity shadows in the winter for overwintering juvenile Coho and stream-type summer run Chinook Salmon.</td><td colspan="6">Terminal Migration and Spawning:</td></tr>
<tr><td></td><td>4</td><td></td><td>1
6</td><td>2</td><td>5</td></tr>
<tr><td colspan="6">Freshwater Rearing:</td></tr>
<tr><td></td><td>30</td><td></td><td></td><td>23
25</td><td>29</td></tr>
<tr><td rowspan="4">Estuary Water and Sediment Quality</td><td rowspan="4">Moderate</td><td rowspan="4">Historical and present-day log storage has compacted estuarine substrates and caused persistent sediment anoxia in areas long impacted by log storage. In some areas, sediment remains contaminated by coal produced during historical mining operations. Raw sewage has not been discharged into the estuary since the 1950s but agriculture remains a source of fecal coliform contamination. Bivalve shellfish harvesting has largely been closed since 1949 due to high fecal coliform levels. Increasing area of impermeable surfaces with urban development in the lower river and estuary facilitates estuarine pollution (e.g., by metals) through run-off.</td><td colspan="6">Terminal Migration and Spawning:</td></tr>
<tr><td></td><td>7</td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="6">Estuarine Rearing:</td></tr>
<tr><td></td><td></td><td></td><td></td><td>38</td><td>33</td></tr>
<tr><td rowspan="4">Estuary Habitat Area</td><td rowspan="4">High</td><td rowspan="4">Less than half of the original extent of the Nanaimo River estuary marshes exist today due to diking and infilling the marshlands for agriculture and urban development. The area of eelgrass is less than it was historically due to the presence of log storage leases and contamination from other historical sources. The area of eelgrass has possibly recovered to 1980 levels, though some of this area may be patchier than it was historically. Loss of eelgrass and saltmarsh habitat and the food resources they provide is a limiting factor to salmon population productivity.</td><td colspan="6">Terminal Migration and Spawning:</td></tr>
<tr><td></td><td></td><td></td><td>1</td><td></td><td></td></tr>
<tr><td colspan="6">Estuarine Rearing:</td></tr>
<tr><td></td><td>35</td><td></td><td>34</td><td></td><td>33
37a
37b
37c</td></tr>
</table>

5.1 Data Gaps and Recommended Studies

Action items to address data gaps regarding the habitat state indicators and the limiting factors are listed in Table 8. For each action item, MCW provides a recommended work sequence for studies that may be undertaken to fill in data gaps. Note that while all the action items are considered high priorities and may be addressed in any order, it is highly recommended that the causes of watershed instability be identified and addressed before addressing the other action items. Instream and estuarine restoration works are impacted by upslope geological and hydrological processes; therefore, it is necessary to address root causes of habitat and ecosystem change in the watershed sub-basins to ensure that restoration activities are effective over the long term and do not require repeated maintenance.

Data gaps not included in Table 8 include how climate change and overfishing are altering marine productivity, ecosystem dynamics, and predator prey relationships, which affect marine survival of adult salmon; and the extent of illegal fishing in the Nanaimo River. Overharvesting by commercial and recreational fishers contributed to the decline of Steelhead Salmon and other Pacific salmon in the Nanaimo River and poaching remains a potentially significant problem (Brahniuk et al. 1993, Butler et al. 2014, Pellett K., DFO Stock Assessment Biologist, pers. comm.).

5.2 Restoration Priorities

Restoration action items and a recommended work sequence for each action item are listed in Table 9. As stated in the preceding section, the ultimate causes of watershed degradation must be simultaneously addressed through legislative, policy, or management change if the river and estuary restoration action items in Table 9 are to be effective in the long-term.

Table 8. High priority data gaps identified for the Nanaimo River watershed.

Action Item	Relevant Habitat State Indicators	Relevant Salmon Life Stages	Expected Outcomes	Work Sequence
Assess root causes of watershed instability	• Habitat composition • Channel stability • Key spawning areas (length) • Stream discharge	All	• Will identify sources of slope instability and sediments that are causing aggradation and migration barriers to adults. • Will identify the magnitude and frequency of extreme water inputs to the channel that can scour/disturb redds. • Will identify private forest land compliance and enforcement issues to be corrected • Will assist in developing restoration prescriptions that may increase abundance of invertebrates as food resources for juvenile fish in the watershed. • Will allow for the characterization of past and future sedimentation impacts on estuarine juvenile salmon forging habitats.	1. Purchase LiDAR of the watershed and have the LiDAR data updated on a regular basis. This data would be used to produce hillshade imagery and elevation models, which would then be used to identify areas of channel instability, responses of the stream channel beds and banks in the watershed to logging activities, and to assist in restoration planning. 2. Hire an independent fluvial geomorphologist to (a) identify specific root causes of geotechnical and hydrological instability in the Nanaimo River watershed; (b) identify landslide risks to instream habitats; (c) identify sources of and predict volumes of future sediment transport; and (d) identify the magnitude and frequency of extreme inputs of water to the channel. 3. Identify the potential future impacts of sedimentation and extreme water inputs on the estuary. 4. There is reportedly raw habitat data archived at the Nanaimo River Hatchery, including historical slides and aerial photos that could be scanned and used in mapping to increase understanding of watershed changes over time (Butler et al. 2014).
Summer run Chinook Salmon stock assessment		• Terminal Migration and Spawning	• Will help fill gaps in population status information.	1. Annual abundance of summer run Chinook Salmon that spawn in the upper river is poorly understood due to inconsistencies in geographic coverage and timing of upper river snorkel surveys (Burt 2006). Index snorkel sections would need to be established and consistently snorkeled to establish annual abundance. 2. Biological sampling (scale aging) may be performed on summer run carcasses to establish the proportion of stream-type and ocean-type life-history strategies (Burt 2006).
Identify key spawning areas and assess spawning gravel condition	• Stream discharge • Key spawning areas (length)	• Terminal Migration and Spawning • Incubation	• Will update previous assessments of gravel condition. • Will help identify risks to key spawning areas from ongoing aggradation, and low and high flows.	1. Delineate spawning areas for Coho, Pink, and Sockeye Salmon, and conduct escapement snorkel surveys to georeference and then map the upstream and downstream extent of spawning areas. 2. Design and implement a repeatable substrate monitoring program to assess the existing condition of spawning gravels within known important spawning sites for all salmon species so that changes can be tracked over time. To determine the relationship between change in gravel condition and upslope land cover change, this monitoring program would need to simultaneously monitor logging footprints or other major developments in the watershed. The following steps may also be included in the monitoring program:

				a. Record the presence of suitable spawning gravels. Appendix E of the BC Fish Habitat Assessment Procedures provides questions that may assist in evaluating spawning gravel condition at the reach scale (Johnston and Slaney 1996). b. Collect surface and core gravel samples from each study site and analyse particle-size distribution. Refer to the gravel sampling protocols included in Katzel and McKnight (2001) and in Section 5 of the BC Lake and Stream Bottom Sediment Sampling Manual (Ministry of Environment, Lands and Parks 1997). c. Ideally, while sampling gravels, include stream bottom sediment sampling to determine levels of metals, PCBs, and PAHs. d. Take photographs and notes to document channel conditions. e. If DFO locates the maps produced by Hardie (2002), a comparison between 2002 and present-day summer and fall run Chinook Salmon spawning gravel quality can be made. 3. Candidate sites for Chinook Salmon spawning ground intergravel DO measurements and/or depth and velocity measurements were previously identified (Burt 2002) but have not yet been monitored to MCW's knowledge: • Both the Bridge Pool and the side channel on the left side of the river near the Bridge Pool – The side channel appeared likely to experience periods of no surface flow, and so it would be worth investigating egg survival during these time periods. • First Lake Outlet and Transverse riffle 950 m below First Lake Outlet – Establish a depth/velocity transect to monitor the appropriateness of various flows for Chinook Salmon spawning and take intergravel DO measurements to inform whether Jordan incubation trials might be beneficial. • Flats off Hemer Road – This is a shallow wide riffle/glide section of the river that is believed to restrict ascent of spawners under low flow conditions. Establish several transects across the shallowest points to monitor depths and velocities at various flow conditions. This must be done during upstream migration so that depths can be linked to fish passage (or lack of it).
Monitor stream water quality and discharge	• Water temperature • Water quality	• Terminal Migration and Spawning • Incubation • Rearing	• Will track stream water quality and discharge, which can be used to track management efficacy and climate change.	1. Water temperature and discharge is currently logged at the 08HB034 hydrometric station upstream of the Harmac intake. Continued collection of this data is essential given the degree to which high summer temperature and extremes in flow limit salmon production in the watershed. 2. The minimum flow of 3.9 m^3/s at the WSC Station 08HB034 that Harmac and the City agreed to maintain (RDN Phase 1 Water Budget Project report, in Butler et al. 2014) does not capture the impact to river discharge from Harmac's groundwater extraction. Harmac's extraction wells are downstream of its surface water intake and station 08HB034. The minimum required flow measuring point should be moved to a new WSC station installed downstream of the Harmac groundwater wells to account for this groundwater diversion and its effect on lower river flow and aquatic habitats (Butler et al. 2014). 3. Other water quality properties (DO, turbidity, conductivity, nutrients [e.g., total and dissolved phosphorus, nitrogen], metals) should continue to be sampled every year

				in the fall/winter after the first heavy rainfall event and in the summer from the stations established by the Community Watershed Monitoring Network: • Nanaimo River (~500 m downstream of Hwy 1 bridge [E287699] and at the Cedar Road bridge [E215789]), • Beck Creek (E290487), • Haslam Creek (E287700) • Holden Creek (E310147), and Lower Holden Creek (E309281). 4. A permanent water temperature logging station (recording hourly) should be established within each of the spawning grounds of summer run Chinook Salmon to identify how water temperature is limiting adult spawning, egg and juvenile survival. A sampling station should be established at each of the temperature logger locations to sample all other important water properties (turbidity, conductivity, nutrients). These water properties should be completed every year in the fall/winter after the first heavy rainfall event and in the summer. 5. Reactivate the WSC stations in Nanaimo River below Fourth Lake (08HB033). A WSC station should be established in Holden Creek to understand and monitor summer base flows. The RDN explored options for installing an RDN-operated hydromet station on Holden Creek, following recommendations in a Phase 2 Water Budget report, but after much site reconnaissance the only suitable location fell through due to landowner access agreement issues (Julie Pisani, RDN, pers. comm. 2021). The Holden Creek area has a high density of groundwater water rights licences and domestic wells. For these reasons, installing this infrastructure remains key to managing impacts of groundwater withdrawal on the stream. 6. The 2013 RDN Phase 1 Water Budget Project report concluded that BC and the RDN need to electronically track groundwater use. 7. The City of Nanaimo and Harmac can make water withdrawal data publicly available online.
Assess estuarine water quality	• Estuary habitat disturbance • Estuary water and sediment quality	• Terminal Migration and Spawning • Rearing in the Estuary	• Will assist in determining whether there are abiotic or factors in the estuary and lower river that may be limiting juvenile or adult survival.	Implement a repeatable monitoring program to assess the condition of intertidal and subtidal water and sediment quality. Samples should be analyzed for the contaminants that are most likely to be derived from boating activities or urban land-based sources: total metals and TBT. Sediment samples should also be analysed for PAHs, PCBs, particle size and total organic carbon.
Map estuary eelgrass area	• Estuary habitat disturbance • Estuarine habitat condition	• Terminal Migration and Spawning • Rearing in the Estuary	• Will ground-truth eelgrass area calculated in this report, which was based on analysis of 2018 orthophotos	1. At a regular frequency, delineate eelgrass by foot, dive, and/or underwater drop camera using a repeatable protocol to distinguish year-to-year variation in growth from long-term trends driven by anthropogenic stressors such as sea level rise, warming temperature, log handling, and land cover alterations. 2. To obtain baseline information about the condition of eelgrass beds for continued monitoring, a transect may be run through eelgrass beds and up to fifteen randomly selected quadrat locations would be subsampled along each transect to identify the eelgrass species, measure eelgrass shoot density, shoot width, and canopy height, and to identify the presence of any reproductive parts (consistent with the SeagrassNet protocol; Short et al. (2006)). Alternatively, one may refer to the Environment Canada (2002) Methods for Mapping and Monitoring Eelgrass Habitat in British Columbia.

				3. Model change in eelgrass bed size and shoot density as a factor of as sea level, water temperature, and land cover alterations

Table 9. Potential restoration projects in the Nanaimo River watershed.

Action Item	Relevant Habitat State Indicators	Relevant Salmon Life Stages	Expected Outcomes	Work Sequence
Stream/river stabilization	• Key spawning areas (length) • Stream discharge	All	• Will decrease slope instability and inputs of sediments that are causing aggradation and migration barriers. • Will decrease the magnitude and frequency of extreme water inputs to the channel that can disturb redds. • Will increase the abundance of invertebrates as food resources for juvenile fish in the watershed. • Will decrease sedimentation impacts on estuarine habitats.	1. Assess root causes of watershed instability, as outlined in Table 8. 2. Resolve problems identified in step 1 before attempting mainstem channel works. For example, a. Implement source control measures for elevated sediment and water inputs from upstream (Slaney and Zaldokas 1997). b. Develop a remediation plan to stabilize areas with high landslide risk. c. Deactivate roads not required for current logging operations. 3. While resolving problems identified in step 1, focus on gravel bar stabilization. a. Identify gravel bars suitable for stabilization (Slaney and Zaldokas 1997). b. Identify site-specific and measurable (ideally, quantitative) goals for stabilization to achieve within a specified time frame. c. Revegetate gravel bars through the planting of species adapted to saturated conditions such as willow. 4. Identify success criteria and monitor the effectiveness of stabilization works.
Instream and off-channel restoration	• Habitat composition • Large woody debris • Channel stability • Stream discharge • Key spawning areas (length)	• Terminal Migration and Spawning • Incubation • Rearing	• Will increase the amount and quality of spawning and rearing habitat.	Instream restoration should focus on restoring key spawning areas or to create new ones via road deactivation, riparian, side-channel and headwater tributary restoration. 1. As discussed in Section 1.2.6.6, many of the restoration opportunities identified first by Gaboury and McCullough (2002) and again by D.R. Clough Consulting (Remillard and Clough 2014, in Butler et al. 2014), have not been undertaken and await funding. 2. Future gravel additions could be used as a maintenance measure to offset the cessation of natural gravel recruitment caused by the South Fork Dam (Smith 2004). Note that this would be a continuing expense as the gravel is displaced at high flows. 3. Lower Nanaimo River water temperatures could possibly be reduced to approximately 17ºC during periods of low flow by excavating holding areas and/or semi-natural groundwater fed side channels with lower than ambient river water temperature (Brahniuk et al. 1993). However, groundwater-fed flow is becoming less reliable with climate change. For example, MCW recently had to re-excavate a side-channel it constructed in the Taylor River watershed only two decades ago. Projects may reasonably only have a lifespan of as little as 10 years due to the combined effects of increasing groundwater extraction in the watershed, aggradation from on-going

				logging, and climate change. Such projects may also contribute to lowering the groundwater table elsewhere in the mainstem. 4. As-built and post-construction monitoring reports should follow any restoration works.
Riparian restoration	• Large woody debris • Channel stability • Stream discharge • Water temperature • Water quality	• Terminal Migration and Spawning • Incubation • Rearing	• Will increase the stability of the stream channel and consequently reduce bank erosion and channel widening, which cause aggradation and migration barriers. • Will decrease the magnitude and frequency of extreme water inputs to the channel that can scour/disturb redds. • Will help mediate stream warming. • Will increase the abundance of invertebrates as food resources for juvenile fish in the watershed.	Most of the Nanaimo River and its tributaries have insufficient riparian buffers to prevent impacts to aquatic habitats, fish, and wildlife. Ultimately, management changes are necessary to restore and preserve the condition and area of riparian habitats in the watershed. However, in the meantime, regulatory agencies could work collaboratively with private landowners and Mosaic Forest Management Corp. to restore reserve zone buffers of mature conifer forest around reaches used for spawning by Chinook Salmon (and other salmon species, if those spawning sites are different). In the Lower Nanaimo River, where summer water temperature consistently reaches levels that cause fish mortality or stress, a community riparian restoration program (either voluntary or with incentives for participation) could be initiated to increase reserve zone riparian vegetation around the Lower Nanaimo River and lower river tributaries, except where the current urban development footprint prevents this. The riparian restoration protocol outlined below is adapted from the BC Riparian Assessment and Prescription Procedures (Koning 1999). Refer to that document for more detailed instructions and information requirements. 1. Conduct a field-based assessment of riparian sites of concern to better evaluate their level of functionality and regeneration: a. Collect data on overstory and understory vegetation, soil characteristics (e.g., drainage, compaction, texture, strength, nutrients and pH), site gradient, stream gradient and width. A site's level of functioning is based on its ability to supply LWD, stream shade, bank and channel stability, and wildlife attributes. b. Select those sites that are not providing sufficient aquatic and terrestrial functions, and have insufficient regeneration, for further assessment (if required) and riparian restoration prescription development. 2. Identify site-specific and measurable (ideally, quantitative) goals for riparian restoration to achieve within a specified time frame. 3. With goals in mind, develop and implement riparian restoration prescriptions. Bancroft and Zielke (2002) and Poulin et al. (2000) provide useful guidelines for restoration prescriptions and silviculture treatments in BC. Prescriptions may involve one or more of the examples below: a. Tree and shrub stocking. Tailor plant species selection to site conditions. b. Juvenile spacing to focus growth on fewer trees and increase stand biodiversity c. Manipulating existing trees to increase wind firmness and reduce potential for future wind-throw problems d. Browse protection of young, palatable tree species with tubing or fenced enclosures

				4. Identify success criteria and monitor the effectiveness of restoration works, measuring parameters such as tree or shrub survival, tree height, stem diameter, canopy cover, evidence of disease, damage or windthrow. 5. Conduct maintenance (brushing, pruning, thinning, watering, repairs) on an annual basis. 6. Write post-construction/restoration and monitoring reports. 7. Acquire necessary covenants to protect restored riparian areas into perpetuity.
Land conservation	- Large woody debris - Channel stability - Stream discharge - Water temperature - Water quality	- Terminal Migration and Spawning - Incubation - Rearing	- Will increase the stability of the stream channel and consequently reduce bank erosion and channel widening, which cause aggradation and migration barriers. - Will decrease the magnitude and frequency of extreme water inputs to the channel that can scour/disturb redds. - Will help mediate stream warming. - Will increase the abundance of invertebrates as food resources for juvenile fish in the watershed.	Restoration efforts can be challenging when land with good rehabilitation potential is not owned by public agencies. Purchasing, protecting, and/or rehabilitating areas of land that contain sensitive woodland, wetland, or riparian features or that support species at risk, particularly areas that are adjacent to existing protected areas is important in combating the forms of habitat degradation identified in this assessment. One parcel of land that was previously identified as of conservation interest is a forest patch in Sensitive Ecosystem Inventory (SEI) Polygon No. NO669A off Timberlands Road, which is Second-growth Forest with an Older Forest component (Butler et al. 2014). Because opportunities to secure old-growth Coastal Douglas-fir forest are limited, acquiring older second-growth fir forest in the lower Nanaimo River Valley is a high priority.
Flow regime restoration	- Habitat composition - Stream discharge - Key spawning areas (length)	- Terminal Migration and Spawning - Incubation - Rearing	- Will increase the amount and quality of spawning and rearing habitat. - Will improve water quality	1. Changing the Fourth Lake water release mechanism so that it releases higher temperature water would provide an additional 15 km of rearing habitat for fish in the Nanaimo River downstream of the lake outlet pipe (Blackman 1981, in Butler et al. 2014). In the 2014 Nanaimo River Baseline Report, it was recommended that Harmac conduct a feasibility assessment to install a multi-port outlet structure with valved inverts at a range of elevations to take advantage of the warmer surface waters in the lake over the withdrawal period (Butler et al. 2014). MCW is unaware whether such a feasibility assessment was completed. 2. Though the City and Harmac release water in the lakes/reservoirs from low-level outlets, where water is cooler than at the surface, the temperature of groundwater extracted from the Nanaimo River base flow by Harmac is lower, generally between 6°C and 10°C. Restoring a more natural proportion of flow supplied by groundwater during the low flow season would help decrease high water temperatures, and stress and incidence of disease in migrating fish (Butler et al. 2014). Linking back to point no. 1, it would also allow for the release of slightly warmer water from Fourth Lake to benefit juvenile fish rearing in the upper river. 3. The number of extreme low flow events has been trending upwards. The number of extreme winter flow events could be reduced by reducing the area of the watershed converted to impermeable surfaces. Landowners and urban developers could be incentivized or required to limit impermeable

				surfaces on their property. These changes would also improve water quality throughout the year. 4. The RDN could initiate a campaign/incentive program that would work with interested agricultural landowners to reverse wetland modifications where possible and to preserve remaining wetlands and their riparian zones (Butler et al. 2014). Wetlands are integral in buffering the watershed against anthropogenic change by storing floodwaters and maintaining surface water flow during dry periods, trapping sediments and stabilizing soils, preserving water quality and groundwater levels, as well as supplying nutrients and insects for fish and wildlife (US EPA 2015).
Estuary restoration	- Estuarine Habitat Area - Estuary habitat disturbance - Estuary water and sediment quality	- Terminal Migration and Spawning - Rearing in the Estuary	- Will increase the area and condition of refuges from predation in the estuary for in-migrating adults. - Will increase the quantity and quality of estuarine habitats for out-migrating juvenile salmon.	1. It has previously been proposed that survival of out-migrating Chinook Salmon juveniles might be improved if a greater portion of the juveniles could be directed to the east side of the estuary (Brahniuk et al. 1993). The river divides into east and west channels through the intertidal flats. In studies conducted by the Pacific Biological Station, it was observed that Chinook Salmon smolts emigrating through the east side of the estuary had three times the survival rate of those migrating out along the west side. It is not fully understood why this would have been the case; however, the east side of the estuary has eelgrass beds that provide refuge and foraging habitat and has a shorter history of log booming and industrial development. 2. Design and implement estuarine restoration prescriptions, and identify site-specific and measurable (ideally, quantitative) goals for the restoration to achieve within a specified time frame. Restoration activities may include: a. Eelgrass transplant – Several methods may be used to transplant eelgrass. Precision Identification (C. Durance (n.d.)) outlines a protocol developed for British Columbia that has generally proven successful with appropriate harvest and planting technique, planting density, and site selection. In this protocol, transplants are considered successful once their density meets or exceeds that of the donor bed, and the target area reaches 100% coverage. There are additional publicly available, useful guidelines for restoration of eelgrass (e.g., Evans and Leschen 2010, Thom et al. 2014). Note that eelgrass transplantation is costly and success is uncertain. Three previous eelgrass transplantation efforts in the estuary, including one by Precision Identification, have failed for reasons not entirely understood. b. Continue to identify opportunities for further conversion of diked lands back to estuarine marsh. The Nature Trust of BC has removed almost all existing berms within their conservancy area in the Nanaimo estuary. Further coordination with other landowners could allow for additional berm removals. The Nature Trust of BC is currently undertaking modelling to determine how sea level rise may impact estuarine vegetation communities. 3. Identify success criteria and monitor the effectiveness of restoration works, ideally measuring not just structural attributes but ecosystem function.

				a. Establish permanent transects to monitor transplanted eelgrass/salt marsh sites and control sites. 10 to 20 years may be needed to judge the success of salt marsh creation (as demonstrated by Dawe et al. 2000 and studies cited therein). 4. Write post-construction/restoration and monitoring reports. 5. Acquire necessary covenants to protect restored areas into perpetuity.

6 CONCLUSIONS

Comprehensive assessments of the Nanaimo River watershed and estuary have been conducted for decades (Brahniuk et al. 1993, Komori Wong Environmental 2002, Burt 2006, Catherine Berris Associates Inc. 2006, Butler et al. 2014). Consequently, much of the information and many of the restoration recommendations in this report have already been presented elsewhere in various forms. With every re-evaluation of the watershed, the message is the same: there are many unaddressed habitat deficiencies in the watershed that limit the productivity of Pacific salmon and other fish populations. The Nanaimo River watershed has a substantial length of stream habitat accessible to salmon populations and has historically been a large producer of Chinook, Coho, Chum, and Pink Salmon. However, degradation of freshwater and estuarine environments has greatly reduced quality and quantity of salmon spawning and nursery areas.

To restore fish habitat condition, the logical course of action is to reduce and remove sources of impacts to fish habitats in the watershed and estuary, which must be led by The City of Nanaimo, RDN, Harmac, Mosaic Forest Management, the Managed Forest Council, Snuneymuxw First Nation, MFLNRORD, DFO, and other key stakeholders. LWD placements, riparian planting, and gravel bar stabilization would be immediately beneficial in more stable sections of the watershed, though other types of instream rehabilitation works should not be attempted if upslope instabilities are not addressed.

Delaying action and rehabilitation increases the financial cost of the work because the legacies of historical riparian logging, upslope instabilities in the watershed, and ongoing forestry and land development continue to degrade the Nanaimo River and its tributaries (Remillard and Clough 2014, in Butler et al. 2014). Additional data collection should only be undertaken when it can cost-effectively improve decisions (Carwardine et al. 2012). Releasing hatchery raised fry and smolts from the Nanaimo River Hatchery might be the quickest means of rebuilding salmon populations in the Nanaimo River (Blackman 1981, in Butler et al. 2014), but recovering self-sustaining wild salmon populations in the Nanaimo River can only be done by restoring the capacity of the watershed and marine environment to support them.

The consequences of inaction are significant, not only for salmon, but for the species that depend on them. The Nanaimo River watershed is notably one of the main producers of the Chinook Salmon that feed the endangered southern resident killer whale (*Orcinus orca*) (Environment and Climate Change Canada 2018). The Nanaimo River's fish have also long been central to the culture and subsistence of the Snuneymuxw First Nation.

7 REFERENCES

Aitkin, J. K. 1998. The Importance of Estuarine Habitats to Anadromous Salmonids of the Pacific Northwest: A Literature Review. U.S. Fish and Wildlife Service, Aquatic Resources Division.

Aro, K. V. 1972. Salmon and Migratory Trout of the Nanaimo River and Adjacent Streams. Fisheries Research Board of Canada Manuscript Report Series No. 1178. Pacific Biological Station, Nanaimo, Bc.

Bancroft, B., and K. Zielke. 2002. Guidelines for Riparian Restoration in British Columbia: Recommended Riparian Zone Silviculture Treatments. Ministry of Forests. https://www.for.gov.bc.ca/hfp/publications/00077/riparian_guidelines.pdf.

Bell, L. M., and R. J. Kallman. 1976. The Nanaimo River Estuary Status of Environmental Knowledge to 1976. Report of the Estuary Working Group, Department of the Environment, Regional Board, Pacific Region. Fisheries and Marine Service, Pacific Environment Institute, West Vancouver, BC. Special Estuary Series No. 5. Page 332.

Bonar, S., and C. Zamora. 2020. Nanaimo River Estuary Eelgrass Study 2015 Updated November 2020. Prepared by Aquaparian Environmental Consulting Ltd. for the Nanaimo Port Authority.

Brahniuk, R., B. Hurst, and B. Tutty. 1993. Nanaimo River Salmon Management Contingency Plan: An Overview. Edited by Dr. B. Riddell, Pacific Biological Station, Nanaimo, BC.

Brayshaw, D. 2018. Artlish and Tahsish River Watershed Assessment. Prepared by Statlu Environmental Consulting for BC Timber Sales Strait of Georgia Business Unit.

Bronstert, A., D. Niehoff, and G. Bürger. 2002. Effects of climate and land-use change on storm runoff generation: present knowledge and modelling capabilities: effects of climate and land-use change on storm runoff generation. Hydrological Processes 16:509–529.

Burt, D. 2002. Reconnaissance of the Nanaimo River. Memo from Dave Burt to Mel Sheng et al.

Burt, D. 2006. Southeast Vancouver Island Summer Chinook Conservation Unit, Nanaimo River Summer Chinook Biological Status Report. Prepared for Fisheries and Oceans Canada.

Butler, G., P. Chapman, R.E. Gullison, M. Kellow, S. Walker, and J. Wolf. 2014. Nanaimo River Baseline Report: Social, Environmental and Economic Values of the Nanaimo River and Watershed. 2nd Edition. Unpublished Report Prepared for the Nanaimo & Area Land Trust. 312 Pp.

Carl, L. M., and M. C. Healey. 1984. Differences in enzyme frequency and body morphology among three juvenile life history types of chinook salmon (*Oncorhynchus tshawytscha*) in the Nanaimo River, British Columbia. Canadian Journal of Fisheries and Aquatic Sciences 41:1070–1077.

Carter, E. W., and D. A. Nagtegaal. 1997. A Preliminary Report on the Adult Chinook Productivity Study Conducted on the Nanaimo River During 1995. Canadian Manuscript Report of Fisheries and Aquatic Sciences 2414. Page 37.

Carter, E. W., and D. A. Nagtegaal. 1998. A Preliminary Report on the Adult Chinook Salmon Escapement Study Conducted on the Nanaimo River During 1996. Canadian Manuscript Report of Fisheries and Aquatic Sciences 2450. Page 35.

Carter, E. W., and D. A. Nagtegaal. 1999. Adult Chinook Escapement Estimate Conducted on the Nanaimo River During 1997. Canadian Manuscript Report of Fisheries and Aquatic Sciences 2482. Page 34.

Carter, E. W., and D. A. Nagtegaal. 2000. Adult Chinook Escapement Assessment Conducted on the Nanaimo River During 1998. Canadian Manuscript Report of Fisheries and Aquatic Sciences 2527. Page 38.

Carter, E. W., D. A. Nagtegaal, and N. K. Hop Wo. 2004. Adult Chinook Escapement Assessment Conducted on the Nanaimo River During 2002. Canadian Manuscript Report of Fisheries and Aquatic Sciences 2691. Page 49.

Carter, E. W., D. A. Nagtegaal, N. K. Hop Wo, and K. E. Jones. 2003. Adult Chinook Escapement Assessment Conducted on the Nanaimo River During 1999 and 2000. Canadian Manuscript Report of Fisheries and Aquatic Sciences 2653.

Carwardine, J., T. O'Connor, S. Legge, B. Mackey, H. P. Possingham, and T. G. Martin. 2012. Prioritizing threat management for biodiversity conservation: Biodiversity threat management prioritization. Conservation Letters 5:196–204.

Catherine Berris Associates Inc. 2006. Nanaimo Estuary Management Plan. Page 133.

City of Nanaimo. 2017, September 29. Nanaimo River Pulse Release to Encourage Chinook Migration. http://www.nanaimo.ca/NewsReleases/NR170929NanaimoRiverPulseReleaseToEncourageChinookMigration.html.

Coble, A. A., H. Barnard, E. Du, S. Johnson, J. Jones, E. Keppeler, H. Kwon, T. E. Link, B. E. Penaluna, M. Reiter, M. River, K. Puettmann, and J. Wagenbrenner. 2020. Long-term hydrological response to forest harvest during seasonal low flow: Potential implications for current forest practices. Science of The Total Environment 730:138926.

Committee on the Status of Endangered Wildlife in Canada. 2018. COSEWIC Wildlife Species Assessments (detailed version), November 2018. http://cosewic.ca/images/cosewic/pdf/2018-wildlife-species-assessments-detailed-november-en.pdf.

Dawe, N., G. Bradfield, W. S. Boyd, D. E. C. Trethewey, and A. N. Zolbrod. 2000. Marsh Creation in a Northern Pacific Estuary: Is Thirteen Years of Monitoring Vegetation Dynamics Enough? Conservation Ecology 4. http://www.consecol.org/vol4/iss2/art12/.

Diewert, R. 2007a. Habitat Requirements for Ocean Type Chinook Salmon. Unpublished report by Fisheries and Oceans Canada.

Diewert, R. 2007b. Habitat Requirements for Coastal Coho Salmon. Unpublished report by Fisheries and Oceans Canada.

Diewert, R. 2007c. Habitat Requirements for Northern Chum Salmon. Unpublished report by Fisheries and Oceans Canada.

Diewert, R. 2007d. Habitat Requirements for Stream Rearing Sockeye Salmon. Unpublished report by Fisheries and Oceans Canada.

Durance, C. (n.d.). Eelgrass Restoration and Compensation in British Columbia. http://depts.washington.edu/uwconf/2007psgb/2007proceedings/papers/7c_duran.pdf.

Earle, S., S. Butler, B. Clayton, M. Erlic, M. Paulsen-Strugstad, R. Stirling, R. Tomkinson, and L. Trigona-Haranay. 2009. Report on the Nature of the Nanaimo River Delta Sediments Adjacent to the Snuneymuxw Reserve in Nanaimo. Prepared by Vancouver Island University. Page 19.

Environment and Climate Change Canada. 2018, September 4. Northern and Southern Resident Killer Whales (Orcinus orca): recovery strategy 2018. https://www.canada.ca/en/environment-climate-change/services/species-risk-public-registry/recovery-strategies/northern-southern-killer-whales-2018.html.

Environment Canada Environmental Protection Program. 1997. Shellfish Growing Area Survey and Classification Program File Report No. 4796-RP-15-01. Shellfish Water Quality Protection Program.

Evans, N. T., and A. S. Leschen. 2010. Technical Guidelines for the Delineation, Restoration, and Monitoring of Eelgrass (*Zostera marina*) in Massachusetts Coastal Waters. Massachusetts Division of Marine Fisheries Technical Report TR-43. http://www.mass.gov/eea/docs/dfg/dmf/publications/tr-43.pdf.

Fisheries and Oceans Canada. 2019a. Vancouver Island Region 1 Salmon Limits, Openings and Closures. https://www.pac.dfo-mpo.gc.ca/fm-gp/rec/fresh-douce/region1-eng.html.

Fisheries and Oceans Canada. 2019b. Area 17 (Nanaimo) - BC Tidal Waters Sport Fishing Guide. https://www.pac.dfo-mpo.gc.ca/fm-gp/rec/tidal-maree/a-s17-eng.html#s-regs.

Fisheries and Oceans Canada. 2019c. NuSEDS-New Salmon Escapement Database System - Open Government Portal. https://open.canada.ca/data/en/dataset/c48669a3-045b-400d-b730-48aafe8c5ee6.

G3 Consulting Ltd. 2005. Nanaimo River Estuary Habitat Assessment Baseline Study Final Report. Prepared for Borden Ladner Gervais.

Gaboury, M., and M. McCullough. 2002. Fish Habitat Restoration Designs for Five East Vancouver Island Watersheds. Prepared for the Ministry of Water, Land and Air Protection Nanaimo, BC. Page 182.

Griffith, R. P. 1992. Feasibility of fisheries enhancement undertakings in selected Vancouver Island streams. Prepared for: Outdoor Recreation Foundation of BC, and Ministry of Environment, Lands and Parks, Nanaimo.

Groom, J. D., L. J. Madsen, J. E. Jones, and J. N. Giovanini. 2018. Informing changes to riparian forestry rules with a Bayesian hierarchical model. Forest Ecology and Management 419–420:17–30.

Groot, C., and L. Margolis. 1991. Pacific Salmon Life Histories. UBC Press, Vancouver, BC.

Hardie, D. C. 2002. Chinook Salmon Spawning Habitat Survey for the Nanaimo River, 2001. Prepared by DL Environmental Services for Fisheries and Oceans Canada, Science Branch, Pacific Region, Pacific Biological Station, Nanaimo, British Columbia.

Harris, P. M., A. D. Neff, and S. W. Johnson. 2012. Changes in Eelgrass Habitat and Faunal Assemblages Associated with Coastal Development in Juneau, Alaska. NOAA Technical Memorandum NMFS-AFSC-240. https://www.afsc.noaa.gov/Publications/AFSC-TM/NOAA-TM-AFSC-240.pdf:59.

Healey, M. C. 1980. Utilization of the Nanaimo River Estuary by Juvenile Chinook Salmon, *Oncorhynchus tshawytscha*. Fishery Bulletin 77:16.

Healey, M. C., and F. P. Jordan. 1982. Observations on Juvenile Chum and Chinook and Spawning Chinook in the Nanaimo River, British Columbia, During 1975-1981. Canadian Manuscript Report of Fisheries and Aquatic Sciences No. 1659.

Hocking, M. D., S. M. O'Regan, R. P. White Collings, J. P. Benner, H. Munro, K. Squires, N. Swain, and K. Lertzman. 2013. Ecosystem-Based Management in the Great Bear Rainforest: A Knowledge Summary for Priority Ecological Questions and Experimental Watersheds Design. Prepared for the Coast Forest Region, BC Ministry of Forests, Lands and Natural Resource Operations.

Hogan, D. L., and B. R. Ward. 1997. Watershed Geomorphology and Fish Habitat. Chapter 2 in Fish Habitat Rehabilitation Procedures. Watershed Restorarion Circular 9. P.A. Slaney and D. Zaldokas, Editors.

Holtby, L., and A. Ciruna. 2007. Conservation Units for Pacific Salmon Under the Wild Salmon Policy. Canadian Science Advisory Secretariat, Sidney, BC.

Hop Wo, N. K., E. W. Carter, and I. Matthews. 2006. Adult chinook escapement assessment conducted on the Nanaimo River during 2004. Canadian Manuscript Report of Fisheries and Aquatic Sciences 2766.

Hop Wo, N. K., D. A. Nagtegaal, and E. W. Carter. 2005. The Effects of Water Release Strategies on Chinook Returning to the Cowichan River and the Nanaimo River. Canadian Manuscript Report of Fisheries and Aquatic Sciences 2715.

Johnston, N. T., and P. A. Slaney. 1996. Fish Habitat Assessment Procedures. Watershed Restoration Technical Circular No. 8. Ministry of Environment, Lands and Parks.
https://www.for.gov.bc.ca/hfd/library/ffip/Johnston_NT1996.pdf.

Katzel, M. R., and O. McKnight. 2001. Spawning Gravel Suitability Assessment Sonoma Creek Watershed. Sonoma Ecology Center Technical Advisory Committee. http://spfgtsn.krisweb.com/biblio/nsfb_sec_katzeletal_2001_sonspwngrvl.pdf.

Klein, R. D., J. Lewis, and M. S. Buffleben. 2012. Logging and turbidity in the coastal watersheds of Northern California. Geomorphology 139–140:136–144.

Komori Wong Environmental. 2002. Draft Limiting Factors Analysis of Nanaimo River Chinook Salmon Phase 1 – Information Review. Prepared for Fisheries and Oceans Canada.

Koning, C. W. 1999. Riparian Assessment and Prescription Procedures. Watershed Restoration Technical Circular No. 6. Ministry of Environment, Lands and Parks. http://www.env.gov.bc.ca/wld/documents/wrp/wrt6/index.html.

Kroon, F. J., P. Thorburn, B. Schaffelke, and S. Whitten. 2016. Towards protecting the Great Barrier Reef from land-based pollution. Global Change Biology 22:1985–2002.

Kuglerová, L., J. Jyväsjärvi, C. Ruffing, T. Muotka, A. Jonsson, E. Andersson, and J. S. Richardson. 2020. Cutting Edge: A Comparison of Contemporary Practices of Riparian Buffer Retention Around Small Streams in Canada, Finland, and Sweden. Water Resources Research 56:e2019WR026381.

Lam, C. P., and E. W. Carter. 2010. Adult Chinook Escapement Assessment Conducted on the Nanaimo River During 2009. Canadian Manuscript Report of Fisheries and Aquatic Sciences 2940. Page 47.

Lill, A. F. 2002. Greater Georgia Basin Steelhead Recovery Action Plan. Prepared for the Pacific Salmon Foundation and the Province of BC.

Log Storage Working Group. 2002. Final Report of the Log Storage Working Group. Prepared for the Nanaimo Estuary Management Plan Steering Committee. Page 27.

Luedke, W. 2021. Request Form for Proposed Changes to Conservation Units and/or Census Sites Re: Nanaimo River Spring Chinook.

MacNutt, M. J., S. G. Hinch, C. G. Lee, J. R. Phibbs, A. G. Lotto, M. C. Healey, and A. P. Farrell. 2006. Temperature effects on swimming performance, energetics, and aerobic capacities of mature adult pink salmon (*Oncorhynchus gorbuscha*) compared with those of sockeye salmon (*Oncorhynchus nerka*). Canadian Journal of Zoology 84:88–97.

Mäenpää, H., M. Peura, P. Halme, J. Siitonen, M. Mönkkönen, and A. Oldén. 2020. Windthrow in streamside key habitats: Effects of buffer strip width and selective logging. Forest Ecology and Management 475:118405.

Ministry of Environment and Climate Change Strategy. 2019a. BC Fisheries Information Summary System Pre-2001 Historical Fish Distribution - Zones (50,000) - Data Catalogue. https://catalogue.data.gov.bc.ca/dataset/bc-historical-fish-distribution-zones-50-000.

Ministry of Environment and Climate Change Strategy. 2019b. British Columbia Approved Water Quality Guidelines: Aquatic Life, Wildlife & Agriculture Summary Report.

Ministry of Environment, Lands and Parks. 1993. The Nanaimo River Water Management Plan.

Ministry of Environment, Lands and Parks. 1997. Lake and Stream Bottom Sediment Sampling Manual. https://www.for.gov.bc.ca/hts/risc/pubs/aquatic/lake-stream/index.htm#TOC.

Ministry of Forests, Lands and Natural Resource Operations. 2016. Biogeoclimatic Ecosystem Classification Subzone/Variant Map for the South Island Resource District South Coast Region. ftp://ftp.for.gov.bc.ca/HRE/external/!publish/becmaps/PaperMaps/field/DSI_SouthIslandResourceDistrict_SouthCoastRegion__field.pdf.

Ministry of Forests, Lands, and Natural Resource Operations. 2016. Provincial Framework for Steelhead Management in British Columbia.

Ministry of Sustainable Resource Management. 2002. Ministry of Sustainable Resource Management News Release: Estuary Log Storage Agreement Reached. https://archive.news.gov.bc.ca/releases/archive/2001-2005/2002srm0020-000082.htm.

Ministry of Water, Land and Air Protection, and BC Conservation Foundation. 2004. Vancouver Island Steelhead Recovery Plan (Progress in 2003/2004). Prepared for Habitat Conservation Trust Fund.

Moore, R. D. (Dan), S. Gronsdahl, and R. McCleary. 2020. Effects of Forest Harvesting on Warm-Season Low Flows in the Pacific Northwest: A Review. Confluence: Journal of Watershed Science and Management 4:29.

Nagtegaal, D. A., and E. W. Carter. 1997. Results of Rotary Auger Trap Sampling in the Nanaimo River, 1996. Fisheries and Oceans Canada Canadian Manuscript Report of Fisheries and Aquatic Sciences 2391.

Nagtegaal, D. A., and E. W. Carter. 1998. Results of Rotary Auger Trap Sampling in the Nanaimo River, 1998. Fisheries and Oceans Canada Canadian Manuscript Report of Fisheries and Aquatic Sciences 2468:31.

Nagtegaal, D. A., and E. W. Carter. 2000. Results of Rotary Auger Trap Sampling in the Nanaimo River, 1999. Fisheries and Oceans Canada Canadian Manuscript Report of Fisheries and Aquatic Sciences 2502:34.

Naiman, R. J., and J. R. Sibert. 1978. Transport of nutrients and carbon from the Nanaimo River to its estuary 1: River inputs to an estuary. Limnology and Oceanography 23:1183–1193.

Nanaimo Estuary Fish Habitat and Log Management Task Force. 1980a. Report of the Fish Habitat Sub-Committee to the Steering Committee.

Nanaimo Estuary Fish Habitat and Log Management Task Force. 1980b. Summary Report.

Narver, D. W. 1972. A Survey of some Possible Effects of Logging on Two Eastern Vancouver Island Streams. Fisheries Reserach Board of Canada Technical Report No. 323. Pacific Biological Station, Nanaimo, B.C. Page 59.

Nautilus Environmental. 2008. Environmental Monitoring Program for the Nanaimo River Estuary. Prepared for the City of Nanaimo and Nanaimo Estuary Management Committee.

Oldén, A., M. Peura, S. Saine, J. S. Kotiaho, and P. Halme. 2019. The effect of buffer strip width and selective logging on riparian forest microclimate. Forest Ecology and Management 453:117623.

Picard, C., B. Bornhold, and J. Harper. 2003. Impacts of wood debris accumulation on seabed ecology in British Columbia estuaries. 2nd International Symposium on Contaminated Sediments. Québec City, Canada.

Plewes, R., H. Larratt, and J. Schleppe. 2018. Surface Water Quality Trend Analysis for Regional District of Nanaimo Community Watershed Monitorin Network Data 2011-2017. Prepared by Ecoscape Environmental Consultants Ltd. for the Regional District of Nanaimo.

Poff, N. L., B. P. Bledsoe, and C. O. Cuhaciyan. 2006. Hydrologic variation with land use across the contiguous United States: Geomorphic and ecological consequences for stream ecosystems. Geomorphology 79:264–285.

Porter, M., S. Casley, D. Pickard, M. Nelitz, and N. Ochoski. 2013. Southern Chinook Conservation Units: Habitat Indicators Report Cards. Prepared by ESSA Technologies Ltd., Vancouver, BC.

Poulin, V. A., C. Harris, and B. Simmons. 2000. Riparian Restoration in British Columbia: What's Happening Now, What's Needed for the Future. https://www.for.gov.bc.ca/hfd/library/ffip/Poulin_VA2000.pdf.

Resources Inventory Committee (Canada), and Resources Inventory Committee (Canada). 1998. Standard for Terrestrial Ecosystem Mapping in British Columbia. Resources Inventory Committee.

R.G. Fuller & Associates Ltd. 2000. Nanaimo River Estuary Log Storage Study. Prepared for BC Assets and Land Corporation.

Richardson, J. S., and S. Béraud. 2014. Effects of riparian forest harvest on streams: a meta-analysis. Journal of Applied Ecology 51:1712–1721.

Ross, J. A., D. M. Infante, D. J. Martin, and M. Rey. 2019. Effects of Riparian Timber Harvest on Southeast Alaska Stream Habitat after 30–40 Years: Insights for Management. North American Journal of Fisheries Management 39:328–342.

Sanger, D. M., A. F. Holland, and D. L. Hernandez. 2004. Evaluation of the impacts of dock structures and land use on tidal creek ecosystems in South Carolina estuarine environments. Environmental Management 33:385–400.

Sauter, S. T., J. McMillan, and J. Dunham. 2001. Salmonid Behavior and Water Temperature. Issue Paper 1. Prepared by the United States Environmental Protection Agency as Part of EPA Region 10 Temperature Water Quality Criteria Guidance Development Project.

Semlitsch, R. D., and J. R. Bodie. 2003. Biological Criteria for Buffer Zones around Wetlands and Riparian Habitats for Amphibians and Reptiles. Conservation Biology 17:1219–1228.

Shi, P.-J., Y. Yuan, J. Zheng, J.-A. Wang, Y. Ge, and G.-Y. Qiu. 2007. The effect of land use/cover change on surface runoff in Shenzhen region, China. CATENA 69:31–35.

Sibert, J. 1974. Residence of Juvenile Salmonids in the Nanaimo River Estuary. Fisheries and Marine Service Technical Report No. 537. Page 26.

Sibert, J. 1979. Review of Salinity, Biological Productivity, and Other Aspects of Habitat on the Nanaimo River Delta in Relation to Intertidal Log Storage. Fisheries and Oceans Canada.

Slaney, P. A., and D. Zaldokas. 1997. Fish Habitat Rehabilitation Procedures. Watershed Restoration Technical Circular No. 9. Ministry of Environment, Lands and Parks. http://www.env.gov.bc.ca/wld/documents/wrp/wrtc_9.pdf.

Smith, A., and J. Meggs. 2009. Nanaimo Estuary Terrestrial Monitoring Program. Prepared by Streamline Environmental Consulting Ltd.

Smith, B. 2004. Spawning Gravel Placements in Ash and Nanaimo River Watersheds, Vancouver Island (2003). Prepared by the BC Conservation Foundation for the Habitat Conservation Trust Fund and Ministry of Water, Land and Air Protection Fisheries Section. Page 45.

Stalberg, H. C., R. B. Lauzier, E. A. MacIsaac, M. Porter, and C. Murray. 2009. Canada's Policy for Conservation of Wild Pacific Salmon: Stream, Lake, and Estuarine Habitat Indicators. Kamloops: Fisheries and Oceans Canada; Oceans, Habitat and Enhancement Branch.:151.

Sweeney, B. W., and J. D. Newbold. 2014. Streamside Forest Buffer Width Needed to Protect Stream Water Quality, Habitat, and Organisms: A Literature Review. JAWRA Journal of the American Water Resources Association 50:560–584.

Thom, R. M., J. L. Gaeckle, K. E. Buenau, A. B. Borde, J. Vavrinec, L. Aston, and D. Woodruff. 2014. Eelgrass (Zostera marina L.) Restoration in Puget Sound: Development and Testing of Tools for Optimizing Site Selection. http://protectzanglecove.org/assets/20140901_Eelgrass_Restoration_In_Puget_Sound.pdf.

Timberline Natural Resource Group. 2010. Tree Farm Licence 46 Timber Supply Analysis Report Management Plan 5. Prepared for The Teal-Jones Group.

Tredger, D. 1986. NEMC Fisheries Improvement Unit Reconnaissance Report.

Tripp, D., L. Nordin, J. Rex, P. Tschaplinski, and J. Richardson. 2017. The Importance of Small Streams in British Columbia. Forest and Range Evaluation Program (FREP) Extension Note 38.

Tschaplinski, P., and R. G. Pike. 2010. Riparian Management and Effects on Function (Chapter 15). In Pike, R.G., T.E. Redding, R.D. Moore, R.D. Winkler, and K.D. Bladon (editors). Compendium of Forest Hydrology and Geomorphology in British Columbia. B.C. Ministry of Forest and Range, Forest Science Program, Victoria, B.C. and FORREX Forum for Research and Extension in Natural Resources, Kamloops, B.C. Land Management Handbook 66.

US EPA. 2015, April 9. Why are Wetlands Important? Overviews and Factsheets. https://www.epa.gov/wetlands/why-are-wetlands-important.

Watson, N. M., Canada, and Department of Fisheries and Oceans. 2015. Spring run chinook escapement study on the upper Nanaimo River in 2012 and historical data review. Canadian Manuscript Report of Fisheries and Aquatic Sciences 3080. Fisheries and Oceans Canada, Nanaimo, BC. Fisheries and Oceans Canada, Nanaimo, B.C.

Windom, H. L. 1992. Contamination of the marine environment from land-based sources. Marine Pollution Bulletin 25:32–36.

Winkler, R. D., R. D. Moore, T. E. Redding, D. L. Spittlehouse, B. D. Smerdon, and D. E. Carlyle-Moses. 2010. The Effects of Forest Disturbance on Hydrologic Processes and Watershed Response (Chapter 7). In Pike, R.G., T.E. Redding, R.D. Moore, R.D. Winkler, and K.D. Bladon (editors). Compendium of forest hydrology and geomorphology in British Columbia. B.C. Ministry of Forest and Range, Forest Science Program, Victoria, B.C. and FORREX Forum for Research and Extension in Natural Resources, Kamloops, B.C. Land Management Handbook 66.

APPENDIX 1: FRESHWATER RISK ASSESSMENT METHOD FOR SALMON WORKSHOP RESULTS – NANAIMO RIVER CHINOOK SALMON

Terminal Migration and Spawning

LF1: Predation of adults in the estuary and lower river by pinnipeds

Present	Future
Moderate	High

Rationale: Data from other East Coast of Vancouver Island watersheds suggests that mortality due to predation may be relatively high. Surveys in the Puntledge River estuary (M. Sheng, DFO) found a resident population of 40–60 seals, which contributed to an estimated ~30% mortality of terminal adult Chinook Salmon. In November to December, the pinniped population in the Nanaimo River estuary is on average 20 seals and 1–2 sea lions. It is not known what the abundance of pinnipeds is in the summer when the summer run Chinook Salmon is migrating. Seals will predate upon summer and fall run Chinook Salmon upriver to as high as the highway bridge and they may target on females. Chinook Salmon are particularly vulnerable during low flows at White Rapid Falls—an issue that will worsen in the future as climate change exacerbates low flows.

Light pollution and the log booms may exacerbate predation by pinnipeds. In the Cowichan River estuary, there is anecdotal evidence that there was higher mortality in a year with log booms rather than a year without log booms. Sea lions use the log booms as a haulout and light pollution increases fishes' visibility to predators. For instance, seals have been observed using the lights at road crossings to target fish.

LF2: Limited or delayed spawner access

Present	Future
High	Very High

Rationale: Delayed or limited summer run and fall run Chinook Salmon spawner access due to low flows is a major issue. Minimum flow rates in the lower river established to protect fish passage are regularly not being met between May and September (minimum required rate of 3.9 m^3/s). Low flow events below 5 and 3 m^3/s have been occurring with increasing frequency. The end of the summer run frequently becomes stuck at the Bore Hole due to impassible flows. In 2019, 100–200 out of 500 fish were unable to pass the Bore Hole.

As the spring flow window shrinks due to less snowpack and spring precipitation with climate change, extreme low flows have been beginning earlier, even by late April. Consequently, fish have less time to migrate into the lakes upstream. Low flows coupled with high temperatures can lead to fish kills. Population growth in the lower watershed is increasing groundwater withdrawal from the Cassidy Aquifer (Aquifer 161), which may supply a significant component of the base flow in the lower reaches of the Nanaimo River during low flows in late summer and early fall. Already, areas like Haslam Creek have dried up completely in the summer due to well pumping. Total watershed low flow period (June–September) yield is expected to decline by up to 60% in the next 50 years, based on the literature review completed for the habitat status report.

LF3: Potential delays in upstream migration due to physical barriers (natural or anthropogenic)

Present	Future
Very High	Very High

Rationale: The most biologically productive side of the estuary is the east side; the west side is impacted by present and historical industrial activities. However, fish currently migrate primarily through the west side because the west channel into the lower Nanaimo River is the only channel accessible to adults at low tide (at high tide, all channels into the lower Nanaimo River may be used). The Bore Hole and White Rapids Falls also act as low flows barriers during upstream migration, increasing fish mortality and stress.

LF4: Aggradation creates a migration barrier in the lower river

Present	Future
Very Low	Low

Rationale: There is high water in the lower river until about June therefore adult summer run Chinook Salmon that enter before this time are not affected by aggradation. Additionally, Chinook Salmon can migrate through shallow water (a couple of inches deep). However, aggradation may be an issue during summer drought conditions as adults migrate from holding in lakes to river spawning grounds. Aggradation is an issue at Kelly's Flats (just up from Firehouse Pool), and the size of the lower river gravel bars at the entrance to the east channel of the estuary is increasing, which diverts more water down the western estuary channel.

LF5: Loss of safe migration route through the lower river due to channelization, loss of habitat complexity and instream cover features

Present	Future
Very High	Very High

Rationale: Lack of habitat complexity is a key issue. There has been a marked increase in sedimentation, reduction in riparian forest cover, and loss of large woody debris with logging. Riparian forest cover and large woody debris play a fundamental role in providing refuge to migrating adults. Adults also rely on pools and there are few deep pools for fish to hold in, particularly in the summer. The lower river is getting wider and shallower (supported by spatial and on-the-ground evidence), exposing fish to stressors such as high temperatures, predation, and poaching. Summer run Chinook Salmon that can get up into the lakes before the decreased flows are safe; those that migrate during the end of the run may become stranded if water levels drop.

LF6: High water temperatures in the lower river and estuary during the late summer/early fall can increase mortality and sublethal stress

Present	Future
Moderate	Very High

Rationale: Water temperatures regularly exceed 20°C in the lower river in the summer, which may be an issue for summer run Chinook Salmon entering early in the season but is more likely to impact fall run Chinook Salmon. High temperatures can cause stress and mortality and impact gametic fitness. Fish kills due to high water temperatures have been known to occur in the lower river.

LF7: Poor water quality conditions during migration period (low DO, coliform levels, deleterious substances)

Present	Future
Very Low	Moderate

Rationale: Low dissolved oxygen and high coliform levels frequently occur in the lower river in the summer due to a combination of high temperatures, agricultural and septic runoff. Summer run Chinook Salmon are thought to move quickly through the lower river to access holding habitat in the lakes above so poor water quality should be of lesser concern to this population. Historical coal mining and raw sewage discharge into estuary have had legacy impacts on sediment quality. Coastland leachate has been a problem in the recent past. The Duke Point sewage pipe broke last year and sewage entered Holden Creek for months.

LF8: Mortality due to unsanctioned fishing

Present	Future
Moderate	Moderate

Rationale: Poaching is an issue for stranded summer run Chinook Salmon at the Bore Hole. The Nanaimo River Hatchery has found evidence of unsanctioned fishing (i.e., many triple hooks) particularly at the Borehole and highway. Several workshop attendees perceived that poaching had decreased in the last few years, but it may increase in the future with population growth in the lower Nanaimo River area. Unsanctioned fishing tends to cease during the summer when recreational swimmers are present.

LF9: Lack of high quality and quantity of spawning habitat

Present	Future
Very High	Very High

Rationale: Habitat surveys over the last two decades have found low availability of spawning habitat. There is documentation that spawning habitat has been damaged due to extensive logging and the spawning habitat above Second Lake is thought to be underutilized due to colder temperatures flowing from the Fourth Lake dam. Quality spawning habitat has been at risk to damage from extreme high flows in the fall and winter and associated increases in sedimentation. For example, in 2019, the spawning gravel at the outlet of First Lake blew out, leaving areas with chest deep water and only basketball size boulders. This was the prime spawning habitat for summer run Chinook Salmon (~20–30% of the run). The First Lake blow out is believed to have originated from high flow in nearby Deadwood Creek (an area with <30 m wide riparian buffers where instability has been observed). The Deadwood Creek channel appears to no longer be able to dissipate energy from high flow events. Spawning habitats are expected to become increasingly at risk of damage as the frequency and magnitude of extreme precipitation events, and therefore peak flows, increases with climate change.

LF10: Disturbance to natural spawning activity due to anthropogenic impacts

Present	Future
Very Low	Moderate

Rationale: Many people swim in the lower river in the summer, which can disturb fish migration. Telemetry work (M. Sheng) has shown that fish disturbed by these activities move back downstream or slow migration, putting them at greater risk from poaching, predation, and high temperature. The impact to fish populations is greater in low flow years and will increase as the population density increases.

LF11: Pre-spawn mortality due to disease

Present	Future
Very Low	Unknown

Rationale: Poor water quality greatly elevates the risk of pre-spawn mortality due to disease, such as ichthyophoniasis caused by the protozoan *Ichthyophonus hoferi*. Pre-spawn mortality due to this protozoan has been observed as high as 30% (Banks B. and B. Herman, Nanaimo River Hatchery, pers. comm. 2019); however, representatives from the Nanaimo River Hatchery at the workshop felt that this had not been an issue in recent years.

LF12: Mortality due to predation at spawning grounds

Present	Future
Very Low	Unknown

Rationale: This is not thought to be an issue. Predation by bears, trout etc. is a natural process.

Incubation

LF13: High suspended sediment loads and low DO that reduce egg to fry survival and emergence of alevins

Present	Future
High	Very High

Rationale: High turbidity in the fall and winter is a problem during incubation. Turbidity data logged in the lower river shows that the frequency of high turbidity events has increased with the increased frequency of extreme precipitation and flow events. Such events can also increase scour. Dissolved oxygen content is not believed to be a problem during incubation; however, it is not known whether spawning gravels are being covered from above with excessive fine sediment due to high turbidity events. There is no information on intergravel flow through gravels in the Nanaimo River. Forest management practices increase the frequency and magnitude of high turbidity events. Deadwood Creek, which drains into the Nanaimo River at outlet of First Lake, has been identified as a major sediment source during high precipitation events.

LF14: Non-optimal water temperatures that reduce fry survival by changing emergence time in relation to food availability

Present	Future
Moderate	High

Rationale: Increasing water temperature causes eggs/alevins to develop faster, causing them to emerge earlier than the stream insect population. Timing with insect production is critical; if they emerge too early, insects may not be available. Early emergence is not an issue above Second Lake, where the water is cold, but it may be an issue below First Lake as eggs and spawning areas are exposed to warm surface water from the lake. Total forest cover loss in the watershed and inadequate riparian forest exacerbate extremes in stream temperature. As temperatures in the river become more extreme, the ideal growth period is being reduced.

LF15: Lower low flows that dewater redds and reduce incubation survival

Present	Future
Very Low	Unknown

Rationale: Fall of 2019 was dry with little to no rain for ~1 month; however, the area where Chinook Salmon are spawning remains wetted. Consequently, low flows dewatering redds is generally not considered an issue.

LF16: More frequent and higher peak flows over winter can scour/disturb redds

Present	Future
Very High	Very High

Rationale: Fall and winter high flow events are becoming more frequent and more extreme, driven by historical and present-day logging practices and, most recently, climate change. These high flows can scour/disturb redds, lowering survival.

LF18: Reduced egg to fry survival due to chum overspawn

Present	Future
Very Low	Unknown

Rationale: Chum do not make it up to the area in which the summer run spawns; therefore, this is not an issue for summer run Chinook Salmon.

LF19: Predation of eggs and alevins by fish (sculpins, trout) and birds (mergansers)

Present	Future
Moderate	Moderate

Rationale: Chinook Salmon eggs and alevins species are naturally preyed upon by other species. However, land cover alterations that have caused a lack of large woody debris in the stream, lack of pools, and riparian cover, have made Chinook Salmon more vulnerable to predation or reduced the abundance of alternative food sources for predators (DFO notes that B. Tutty thought that this should be scored as ‘low’, but others disagreed).

LF20: Egg/alevin mortality due to redd disturbance by invasive or expanding endemic species (e.g., didymo)

Present	Future
Very Low	Unknown

Rationale: Didymo not a factor in this population.

LF21: Egg mortality due to redd disturbance by humans

Present	Future
Very Low	Unknown

Rationale: The areas in which summer run Chinook Salmon spawn are usually left alone in October; therefore, no significant redd disturbances have been noted.

Freshwater Rearing

LF22: Mortality or fitness impacts due to poor water quality (e.g., temperature, TSS, dissolved oxygen levels)

Present	Future
Low	Moderate

Rationale: Higher water temperatures and low dissolved oxygen levels may impact juveniles rearing or outmigrating through the lower river to an unknown degree. Fish stuck below the Bore Hole may be at greater risk. Climate change will exacerbate these impacts.

LF23: Mortality or fitness impacts due to inadequate instream complexity and riparian complexity

Present	Future
High	Very High

Rationale: Riparian quality is related to the ability of the river to provide adequate nutrient inputs, food resources, and refuge to juvenile salmonids, as well as to regulate stream temperature and maintain channel stability. There has been significant loss of mature conifer riparian forest in the watershed, which has reduced the amount of riparian cover and inputs of large woody debris. There are several areas where logging or agricultural development occurred to within 30 m or less of the stream bank. Work in the Cowichan River watershed suggests that salmon population productivity is highly dependent on producing fry in better condition, which in the Nanaimo River will require restoring riparian condition and off channel habitats along the river.

Analysis of 5 cm high resolution drone video footage obtained in the upper river in 2019 found only 2–10 pieces of large woody debris present per kilometre (and 0 pieces in two reaches). It is likely that the lower river is similarly deficient in large woody debris.

LF24: Increased stranding in isolated off-channel habitat and tributaries can occur with rapid decreases in flow

Present	Future

High	High

Rationale: There is little off-channel habitat along the Nanaimo River, which greatly reduces the availability of high-quality rearing habitat that can provide refuge from high winter flows. Tributaries to the upper river have been infilled with significant volumes of sediment, which could lead to stranding. There is slightly more off-channel habitat in the lower river than the upper river; however, many areas of the lower river have been channelized. It was noted during the workshop that one side channel below the highway has now become isolated from the mainstem. River downcutting contributes to isolation of the mainstem from its floodplain. There is the possibility of restoring off-channel habitat in the lower river, perhaps by working with private landowners.

LF25: High flows impacting fry and smolts

Present	Future
High	Very High

Rationale: High flows have been increasing in frequency and magnitude, driven by logging and climate change (climate change is increasing the frequency and magnitude of extreme fall/winter precipitation events). High flows interact with other impacts caused by logging, including decreased channel stability, increased sediment availability, and lack of instream large woody debris, to increase the likelihood of fish mortality. This will have greater impacts on stream-type Chinook Salmon. It is not known how frequently fish might be flushed from the system during high flows. There are data gaps around juvenile residency time and overlap with periods of peak flows. DFO do not know the rearing carrying capacity of the river.

The increasing frequency and magnitude of channel altering high flows will need to be factored into any instream restoration projects. There are estimates that restoration projects that would have previously had a lifespan of 25 years may only function for half that time under the future climate regime.

LF26: Mortality or fitness impacts due to lack of food

Present	Future
High	Very High

Rationale: Riparian forest loss and total forest loss due to logging has resulted in loss of instream habitat complexity, loss of nutrient inputs, and decreased insect production. Higher peak flows in fall and winter may also be washing nutrients and insects out of the system more quickly. If there is insufficient instream food availability, smolts will leave the river earlier, which negatively impacts marine survival. The best strategy to achieve higher marine survival is to improve instream growth.

LF27: Mortality or fitness impacts due to competition with alien invasive species

Present	Future
Low	Moderate

Rationale: Yellow Perch, Pumpkinseed, Smallmouth Bass, Largemouth Bass, and American Bullfrog in the lower river reaches and/or Quennell Lake (Holden Creek area) may compete with juvenile Chinook Salmon. There is low confidence in the scoring as not much is known about this.

LF28: Mortality or fitness impacts due to competition, disease, interaction with other species/hatchery fry

Present	Future
Very Low	Unknown

Rationale: This has been ranked as 'very low' but is somewhat of a data gap. The Nanaimo River Hatchery has stated that hatchery fry move downstream immediately after being released and so are out of the freshwater system fairly quickly. However, it is unknown whether hatchery and wild fish are occupying different spaces both in-river and in the marine environment. In the Cowichan River, hatchery and wild fish appear to use different strategies in terms of how they occupy and move through the river. Hatchery fish move straight out to the estuary (already at size when released), resulting in a low level of overlap and interaction with wild fry. Competition between Chinook Salmon fry and Peamouth Chub may also occur.

LF29: Mortality due to high levels of predation

Present	Future
Very High	Very High

Rationale: Mortality due to predation is exacerbated by low flow conditions. Ocean-type smolts outmigrating in the spring may be particularly exposed to predation as water levels drop. In the Cowichan River, for example, mortality due to predation is estimated at 20–30% in high water but 70% in low water. There are limited places for fish to take refuge from predation given that there is limited riparian cover and large woody debris and few pools in the lower river. Climate change will exacerbate low flows.

LF30: Mortality or fitness impacts due to anthropogenic disturbance

Present	Future
Very Low	Low

Rationale: Swimmers and sun tan lotion, beer bottles, garbage etc. may have an impact on fish and aquatic insects.

LF30.5: Aquifer drawdowns, direct mortality through pumping, domestic use

Present	Future
Low	High

Rationale: Groundwater from aquifers in the lower watershed is withdrawn by the Harmer pulp mill and to supply residential wells. The Cassidy Aquifer (Aquifer 161) may supply a significant component of the base flow in the lower reaches of the Nanaimo River during low flows in late summer and early fall, consequently withdrawals from the aquifer throughout spring and summer exacerbate low flow conditions and high water temperatures. Increasing the proportion of river flow that is supplied by the Cassidy Aquifer in the summer would improve lower river rearing conditions.

LF31: Mortality or fitness impacts due to disease

Present	Future
Very Low	Unknown

Rationale: This is largely a data gap as not a lot is known about mortality or fitness impacts due to disease on the summer run Chinook Salmon population in the Nanaimo River.

LF32: Mortality or fitness impacts due to hatchery introgression

Present	Future
Very Low	Unknown

Rationale: The summer run Chinook Salmon population is enhanced by the Nanaimo River Hatchery. DFO estimates that the proportion of natural influence of fish in the population is 0.6, which is below DFO's recommended proportion of natural influence of fish in an enhanced population (0.72). This may be having unknown behavioural impacts on juveniles and adults. There is a growing pool of evidence that hatchery and wild genetic interaction is detrimental to the viability of offspring in natural environments.

Estuarine Rearing

LF33: Low early marine survival of chinook fry and smolts in the estuary/nearshore marine due to the lack of adequate food supply

Present	Future
Very High	Very High

Rationale: It is thought that the east side of the estuary provides most of the food resources because log storage and other industrial activities on the west side of the estuary greatly reduced the area of intertidal eelgrass on that side of the estuary. However, flow from the Nanaimo River principally directs juveniles towards the west side of estuary from April to June. Consequently, the ability of Chinook Salmon fry and smolts to find adequate food resources may be compromised. Additionally, channels potentially used during outmigration can be full of wind debris from log storage, covering intertidal estuarine marsh used for feeding and refuge.

The eelgrass area in the estuary is presently less than what it would have been historically before log storage began in the estuary. The eelgrass area has possibly recovered to 1980 levels, based on 2020 survey results. However, analysis of high-resolution orthophotos suggested that the area of eelgrass was at least 300,000 m^2 smaller in 2018 than 2020. It would be important to ground-truth eelgrass area by dive and/or underwater camera on a regular basis to differentiate year-to-year variation in eelgrass extent, which can be as much as 11–50%, from anthropogenically-driven trends. Further, it is important to differentiate between sparse and patchy eelgrass versus dense continuous beds, as the two do not provide the same value in terms of food resources and refuge.

Sea level rise will impact the availability of food resources in the estuary. Vegetation distribution will change and eelgrass and estuarine marsh may be lost if elevational shifts in vegetation communities cannot keep pace with changes in sea level or if vegetation communities do not have the space to shift if substrate is unsuitable or urban development blocks landward retreat.

LF34: Predation of smolts in the lower river and estuary

Present	Future
Moderate	Moderate

Rationale: Predation is a natural process; however, predation may be greater than was historically experienced because intertidal and subtidal habitat that provides refuge for juvenile salmon has been lost and juvenile salmon may be stressed by disturbance from log handling activities, poor water quality, or reduced food resources. For instance, because of the extent of loss of mature conifer riparian forest, there are fewer inputs of large conifer large woody debris, which fish use as cover from predation.

It is not known whether the log booms are a net positive in terms of providing refuge from predation for juvenile salmon or whether these areas act as a sink by bringing them into increased contact with seals. Light sources around the estuary can increase predation of juvenile salmon by seals at night.

LF35: Mortality of fry and smolts due to predation and competition from invasive species

Present	Future
Very Low	Low

Rationale: There is currently little information about invasive fish species in the estuary. DFO expects that European Green Crab will eventually move into the Nanaimo River estuary, with unknown consequences for juvenile salmon.

LF37a: Loss of good quality marine riparian habitat

Present	Future
Very High	Very High

Rationale: Marine riparian habitat has been lost on all sides of the Nanaimo River estuary due to industrial and residential development and agriculture. There are fewer natural sources of mature conifer large woody debris, which is used by fish as refuge from predation. An exception would be Holden Channel, which has over 4 km of mature forest riparian extending to Jack Point.

LF37b: Loss of good quality intertidal habitat (i.e., estuarine marsh, eelgrass)

Present	Future
Very High	Very High

Rationale: There has been loss and alteration of estuarine marsh habitat due to agricultural diking and introduction of invasive species. There has been a loss of intertidal eelgrass habitat over time due to log storage and other industrial activities. Log storage and other industrial activities have rendered sediments more anoxic and log storage has also compacted sediments; these impacts make it more difficult for sensitive vegetation like eelgrass to recolonize. Climate change will potentially pose a more severe threat to intertidal estuarine habitats as sea level rise may alter or result in the loss of further estuarine marsh and eelgrass. Due to urban development in the lower watershed, there is presently limited space for these intertidal vegetation communities to retreat.

LF37c: Loss of good quality subtidal habitat (e.g., eelgrass, kelp forests)

Present	Future
Very High	Very High

Rationale: There has been a loss of eelgrass habitat over time due to log storage and other industrial activities. Log storage and other industrial activities have rendered sediments more anoxic and log storage has also compacted sediments; these impacts make it more difficult for sensitive subtidal habitats like eelgrass to recolonize. The degree to which benthic mudflats in the Nanaimo River estuary themselves are used as a food source by juvenile fish is unknown. There has also been loss of kelp forests around the Strait of Georgia, which has further reduced habitat complexity and productivity in the nearshore environment.

LF38: Reduced survival due to decreased water quality from ballast dumping, industrial discharge, and sewage effluent in the estuary

Present	Future
High	High

Rationale: Runoff from agriculture in the lower watershed is an important source of nutrient and fecal coliform contamination. There is also the substantial legacy effect of coal tailings and log storage in the estuary on sediment quality. There is presently no direct discharge of pollutants into the estuary and no evidence that federal quality guidelines are regularly exceeded (but note that there were Coastland leachate issues in the past); however, there is abundant literature to show that increasing coastal development and urbanization is negatively correlated with marine habitat quality and quantity and fish abundance. Impervious surfaces in urbanized areas increase runoff of pollutant-laden surface water from roads and vehicles. Most metal contaminants that enter the aquatic environment in water will eventually sorb to sediment in the estuary, thereby becoming less bioavailable unless the sediment is disturbed (e.g., through dredging).

The Nature Trust (Tom Reid) is presently monitoring water quality in the estuary as part of a greater estuary resilience project, using a combination of CTD monitoring, turbidity monitoring at Jack point, water quality profiles, and plant productivity assessments.

LF39: Mortality or reduced fitness due to direct anthropogenic interference, not covered by previous LFs

Present	Future
Low	Low

Rationale: Some workshop attendees commented that this limiting factor had already been covered by limiting factors focused on water quality in the estuary. Urbanization and log storage activities are the main sources of impacts on the west side of the estuary and have been covered elsewhere.

Marine

LF40: Low marine survival due to inadequate food supply (abundance or value)

Present	Future
Very Low	Unknown

Rationale: None provided.

LF41: Low marine survival (<1%) in the Strait of Georgia due to low marine productivity, poor water quality, increase mean water temp

Present	Future
Very Low	Unknown

Rationale: None provided.

LF42: Low marine survival due to competition for food

Present	Future
Very Low	Unknown

Rationale: None provided.

LF43: Low marine survival due to high rate of predation by orcas, pinnipeds

Present	Future
Very Low	Unknown

Rationale: None provided.

LF44: Low marine survival due to high rate of predation in nearshore environments

Present	Future
Very Low	Unknown

Rationale: None provided.

LF45: Mortality or fitness impacts due to competition with aquatic invasive species

Present	Future
Very Low	Unknown

Rationale: None provided.

LF46: Mortality due to impacts related to offshore habitat destruction

Present	Future
Very Low	Unknown

Rationale: None provided.

LF47: Mortality or sub-lethal effects due to pollutants

Present	Future
Very Low	Unknown

Rationale: None provided.

LF48: Mortality or fitness impacts due to disease

Present	Future
Very Low	Unknown

Rationale: None provided.

LF49: Mortality or fitness impacts due to HABS

Present	Future
Very Low	Unknown

Rationale: None provided.

LF50: Mortality due to fishing

Present	Future
High	High

Rationale: Exact mortality is unknown; DFO needs to look at Avid Anglers data. There is also no data on distribution of early summer run Chinook Salmon in the marine environment. However, recent regulations have decreased the spatial scale of fishing. Mortality due to catch and release may be underestimated.