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Impact of rail crossings on passage of Pacific salmon and steelhead in the Fraser River basin

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Summary

We examined the potential impact of railway infrastructure on the ability of Chinook Salmon (*Oncorhychus tschawytscha*), Coho Salmon (*O. kisutch*), Sockeye Salmon (*O. nerka*) and steelhead (*O. mykiss*) within the Fraser River basin to access habitat with the potential to provide important spawning and/or rearing habitat by using intrinsic potential-based modelling. We estimate that up to 1015 km of aquatic habitat with the potential to support spawning and/or rearing may be blocked, representing up to 1.4% of Chinook Salmon, 5.6% of Coho Salmon, 0.5% of Sockeye Salmon, and 6.1% of steelhead total rearing habitat within the project study area and 1.0% of Chinook Salmon, 2.8% of Coho Salmon, 0.9% of Sockeye Salmon, and 0.9% of steelhead spawning habitat in the project study area. In total, an estimated 282 closed-bottom rail crossings are located on streams with the potential to support salmonid spawning and/or rearing habitat.

For every rail crossing there are an estimated 3.5 additional road, trail or dam crossings that may further fragment access to spawning and rearing habitat for our target species. We estimate that rail crossings alone may be blocking up to 101 km of spawning and/or rearing habitat before encountering other stream crossings that may be acting as barriers to fish passage, with 50 km being potentially blocked by just 7 rail crossings and 76 km potentially blocked by 21 rail crossings. When other stream crossings are ignored, approximately 15 railway crossings may block roughly half of the 1,015 km of potential spawning and/or rearing habitat in the study area, and 40 railway crossings may block approximately 75% of the total habitat.

We further estimate that approximately 8% of total potential lateral habitat in the Fraser River basin is blocked by railway infrastructure, at 567 locations covering 13,202 ha. Just under half (48%) of the potentially inaccessible lateral habitat occurs in the Stuart, Morkill, Lower Salmon and Salmon River watersheds.

Several uncertainties are inherent in our model, which may lead to overestimation of the amount of longitudinal habitat blocked by railway infrastructure and either an over- or underestimation of lateral habitat that may be blocked. Field validation will help to refine the level of certainty of model results and may help to form the basis of developing a prioritization strategy for remediating railway barriers blocking the most important habitats.

Introduction

Railways designed for transporting freight have specific requirements for maintaining suitable grades for heavy train cars (McGonigal 2006), generally resulting in railways being located in valley bottoms along wider, flatter terrain and often paralleling major rivers and lakes. These same valley bottoms naturally form productive floodplains that connect valuable habitats for migratory fishes such as Pacific salmon (*Oncorhynchus* spp.) and steelhead (*O. mykiss*), among others, in the form of side channels and sloughs, ponds and oxbows, lakes, and tributary streams emptying into the rivers (Brown 2002). Although relatively short sections of rail line continue to expand in B.C. today, the bulk of B.C.'s railway infrastructure was built in the late 19th century to mid-20th century (Flanigan 1907, Pooley 2013, Regehr 2013, Regehr 2014, ICF 2021, Madison 2021, CSCE 2022, PDMAS 2022, SRY 2022). Consideration for designing stream crossings suitable for maintaining fish passage, on the other hand, is a relatively recent endeavor.

The first studies in the U.S. to examine the problem presented by culverts for fish passage were published in 1956 (McKinley and Webb 1956, Shoemaker 1956, Hoffman et al. 2012), though culvert studies and design guidelines became more prominent in North America in the 1970s (Anderson and Bryant 1980, Copstead et al. 1998, Moore et al. 1999, Hoffman et al 2012). Despite this research, it was not until the mid-1990s and early 2000s that governments in the Pacific Northwest, including British Columbia, began to develop strategies, guidelines and legislation related to fish passage (Hoffman et al. 2012, MFLNRO et al. 2012).

In British Columbia, the *Forests Practices Code of British Columbia Act* was enacted in 1995 and included requirements for proponents of forestry activities to provide fish passage on crossings of fish-bearing streams. This requirement was maintained when the Act was superseded by the *Forest and Range Practices Act* in 2004. Federally, in the absence of authorization, barriers to fish movement contravene section 35 of the *Fisheries Act,* which prohibits the harmful alteration, disruption or destruction of fish habitat. Fisheries and Oceans Canada can also require that an obstruction to fish passage be removed under Section 34.3(2) of the *Fisheries Act* at the Minister's discretion, while section 34.3(4) legally requires that a structure designed to allow fish passage, including a partial obstruction, be properly maintained. Although major rail operators tend to have environmental departments that work on fish passage and other environmental issues, legislation, or guidelines for provision of fish passage specifically along rail lines does not exist in Canada.

Even those crossings that have been designed and installed with fish passage in mind can become degraded over time, leading to perched outlets, culverts collapsing or infilling with debris, and other issues that can impede passage of fish. This is particularly true of closed-bottom crossings, which are commonly used for railway crossings in B.C., due to the challenges with installing and maintaining open-bottom crossings such as arches and bridges (E. Cheung, personal communication November 2020; K. Graf, personal communication May 17, 2021). Replacing crossings under a rail line can be relatively costly compared to replacements of a road crossing, because of the need to maintain the structural integrity of the rail line, and the need to maintain a safe, gentle curvature of the line, which can limit options for constructing detours during construction (McGonigal 2006, E. Cheung, personal communication August 4, 2020). It is therefore important to ensure that limited resources are directed to replacing those crossings that present barriers to the most important habitats when planning and implementing fish passage remediation projects on railway corridors.

There are roughly 10,277 km of railway in British Columbia with an estimated 6,242 stream crossings along the rail length, just over half which occur in the Fraser River basin. Of these crossings, roughly 81% are estimated to be closed-bottom structures such as culverts that could potentially be impeding fish passage (Norris 2022a). Due to railways typically being located in valley bottoms, most of these crossings occur relatively downstream in a watercourse, potentially blocking access to entire streams and their tributaries for migratory fishes. The crossings and rail lines themselves (if located on dykes) may also prevent access to lateral habitats along the floodplain.

Floodplains can provide important rearing and overwintering habitat for juvenile salmonids, and even those habitats that are seasonally flooded can play an important role in the growth and survival of salmonids. Such habitats provide juveniles access to thermal refugia and a higher proportion of terrestrial invertebrates as food sources (Brown 2002). Jeffres et al. (2008) found that juvenile Chinook Salmon (O. tschawytscha) rearing in floodplain habitats had higher growth rates than those rearing in riverine habitats and that ephemeral floodplain habitats provided higher growth rates than perennial floodplain habitats. Floodplain habitats may also be traditionally utilized by spawning salmonids in off-channel ponds with sufficient upwelling, flows and substrates (Hall and Wissmar 2003). For salmonids to use these habitats, adequate hydraulic connection to floodplain habitat is needed to maintain channels and allow new channels to form and provide safe access and egress (Brown 2002).

Intrinsic potential models have been widely applied in North America to examine where aquatic species are most likely to occur, with models commonly being developed for Coho (O. kisutch) and Chinook Salmon and steelhead (Agrawal et al. 2005; Burnett et al. 2007; Busch et al. 2013; Bidlack et al. 2014). Although intrinsic potential modelling generally can not be used as an accurate predictor of a species' distribution, by using geologic features known to limit a species' distribution, such as stream gradient, channel confinement, and stream discharge (among others), the area of focus for a target species can be narrowed by eliminating those areas of a watershed or watercourse that a species is unlikely to use aside from as a movement corridor (Sheer et al. 2009). The use of intrinsic potential models therefore can allow for more accurate estimates of how much habitat may be blocked by railways, by excluding areas that are unlikely to support key life stages for Pacific salmon and steelhead.

This study focuses on Coho Salmon, Sockeye Salmon (*O. nerka*), Chinook Salmon and steelhead (which are the anadromous form of Rainbow Trout) in the Fraser River basin, with the intention to expand to Pink Salmon (*O. gorbuscha*) and Chum Salmon (*O. keta*) in the future. Coho Salmon, Sockeye Salmon, Chinook Salmon, and steelhead were chosen due to their widespread distribution throughout the Fraser River basin and the relatively well-established habitat parameters in the literature available to guide intrinsic potential modelling for these species. Although we do not currently include all five species of Pacific Salmon in our analysis, we refer to our focal species as "Pacific salmon and steelhead" throughout this report for the sake of simplicity. Our study aims to answer the following questions:

1) What is the extent of (a) longitudinal (i.e., linear stream network) and (b) lateral (i.e., floodplain) habitat that is potentially inaccessible to Pacific salmon and steelhead due to railway crossings in BC's Fraser River basin?

2) To what extent do other barriers (road-stream crossings, trail-stream crossings, dams) potentially exacerbate longitudinal fragmentation in streams where railway barriers may be present?

3) Which rail crossings potentially block the most linear habitat for Pacific salmon and steelhead in the Fraser River basin?

4) In which areas are the highest proportions of lateral habitat potentially blocked by rail lines?

Methods

2.1 Project Scope

We used the GeoBC Railway Track Line, an open-data spatial coverage of the GeoBase National Railway Network dataset for the portion of railway network that occurs in B.C., which is housed by the B.C. Data Warehouse, and overlaid it on the B.C. Freshwater Atlas 1:20,000 streams network and the B.C. Freshwater Atlas 1:20,000 watershed groups. We then removed all watershed groups in the Fraser River basin where the railway track did not intersect, and all watershed groups where Pacific salmon or steelhead (hereafter referred to as "salmon") have not been documented or do not have access, including areas inaccessible due to large dams, natural falls, or subsurface flows where this information was available (Figure 1). Natural falls $\geq$5 m were considered a barrier unless a literature review of the falls site indicated otherwise. To do this, we used a "BC Hydro Dams and Waterfalls" (Mazany-Wright et. al. 2021*a*) layer created by the Canadian Wildlife Federation to identify all mapped major dams and waterfalls $\geq$5 m in height on the landscape. We excluded areas upstream of dams $\geq$5 m because they are less likely to be removed and are complex to remediate; whereas, smaller dams <5 m in height were included in the project scope since they can be more feasibly remediated within a relatively short time frame. We carried out data quality assurance and quality control (QA/QC) on all major dams and falls $\geq$ 5 m in height where Pacific salmon and/or steelhead observations were recorded upstream. Details of data QA/QC for all project components are included in Appendix.

2.2 Habitat Modelling – Longitudinal Assessment

To determine how the rail line is likely to be affecting connectivity on streams within the study area, we *modelled* connectivity and stream habitat using "bcfishpass" (Norris 2022b), an open-source spatial model that builds upon the B.C. Fish Passage Technical Working Group fish passage modelling framework. The model identifies which areas of a stream channel are accessible to anadromous salmonids using gradient thresholds based on known abilities of Pacific Salmon and steelhead to navigate steep sections of river. Chinook Salmon, Sockeye Salmon and Coho Salmon have been documented to pass gradients of 16% (WDFW 2009), while steelhead have been documented accessing gradients of up to 20% (Sheer and Steel 2006, WDFW 2009). The bcfishpass model uses a gradient cutoff of 15% for Pacific Salmon, and a cutoff of 20% for steelhead. Watercourses located downstream of gradient cutoffs are referred to as "potentially accessible" habitat.

We then used intrinsic potential modelling based on stream channel gradient and mean annual discharge to identify stream segments that have the potential to support spawning or rearing (or both) for fish species of interest. Thresholds used for each species were derived from primary literature sources and can be found in Table 1. A multiplier of 1.5 was applied to the lengths of area-based features such as lakes and wetlands where they form a part of a watercourse, to account for the larger area that they typically cover compared to linear stream features. We refer to portions of watercourses with potential spawning or rearing habitat as "potentially usable".

The bcfishpass model also incorporated modelled anthropogenic barriers to fish passage by identifying areas where linear infrastructure (roads, rail lines, major trails) intersects with streams, as mapped in the B.C. Digital Road Atlas and the B.C. Forest Tenure Road Segment Lines layer,

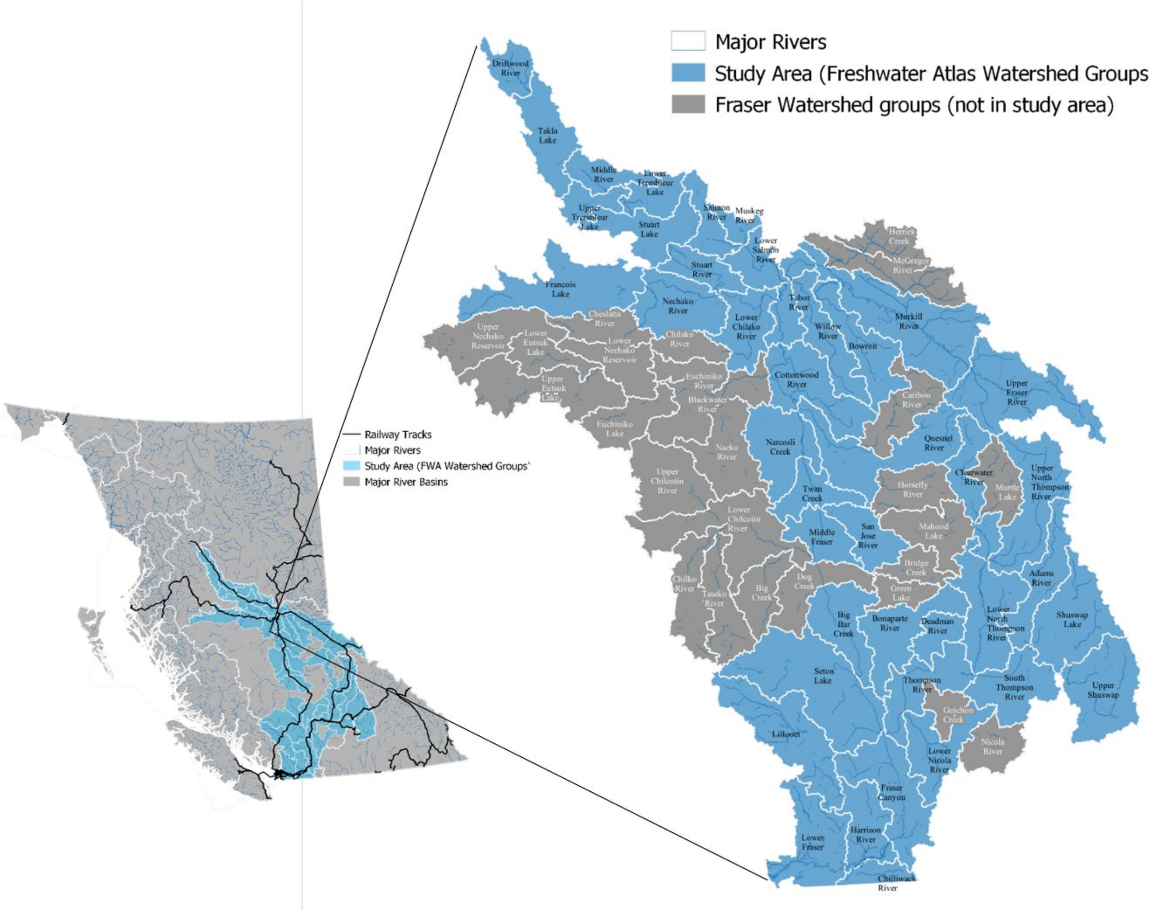

Figure 1. Study area.

both of which are housed in the B.C. Geographic Warehouse. Modelled crossings on "double line" streams, which are mapped as polygons in the B.C. Freshwater Atlas, and crossings on streams that are 6th order or higher, were assumed to be bridges and mapped as passable structures.

Any field-verified barriers were also mapped and incorporated into the model using the Province of B.C.'s Provincial Stream Crossing Inventory System (PSCIS) database. PSCIS classifies crossings into either open-bottom structures (bridges, open-bottom arch culverts, open-bottom wooden box culverts), fords or closed-bottom structures. Open-bottom structures were considered passable to fish, while closed-bottom structures were considered either passable, potential barriers, or barriers based on a scoring matrix that used a series of measurements to assess the culvert characteristics in relation to the surrounding stream.

We incorporated small dams used for agricultural irrigation and other uses into the model using the "BC Dams" layer, which was compiled previously by the Canadian Wildlife Federation using seven different data sources (Mazany-Wright et. al. 2021*b*).

For rail-stream crossings that appeared to be barriers (i.e., modelled as closed-bottom structures), we measured the length of potentially usable habitat upstream of the crossings for each of the target species to determine the total length of potential spawning and rearing habitat that may be blocked by the rail line. We also calculated the total length of potentially usable habitat for all streams within the study area for each of the target species, to determine what proportion of potentially usable habitat for each species may be blocked by rail lines.

We counted the number of other modelled closed-bottom stream crossings and dams on portions of streams with potentially usable habitat both upstream and downstream of the rail line, to determine the extent of additional fragmentation that may be due to roads, trails, and small dams.

To determine how much potential Pacific salmon and steelhead spawning or rearing habitat may be blocked solely by rail crossings, we examined only those rail crossings with no other potential anthropogenic barriers downstream and measured the amount of potentially usable habitat between the rail crossings and the next modelled barrier upstream.

Table 1. Gradient and discharge thresholds used to model potential spawning and rearing habitat of target species.

	Spawning Habitat		**Rearing Habitat**			
Species	**Channel Gradient (%)**	**Mean annual discharge (m^3/s)**	**Channel Gradient (%)**	**Mean annual discharge (m^3/s)**	**Minimum Lake area (ha)**	**Multiplier (1.5x)**
Chinook Salmon	0-3 (Busch et al. 2011, Cooney and Holzer 2006)	0.46-322.5 (Bjornn and Reiser 1991, Neuman and Newcombe 1977, Woll et al. 2017, Roberge et al. 2002, Raleigh and Miller 1986)	0-5 (Woll et al. 2017, Porter et al. 2008)	0.28-100 (Agrawal et al. 2005)	NA	NA
Coho Salmon	0-5 (Roberge et al. 2002, Sloat et al. 2017)	0.164-59.15 (Bjornn and Reiser 1991, Sloat et al. 2017, Neuman and Newcombe 1977, Woll et al. 2017, McMahon 1983)	0-5 (Porter et al. 2008, Rosenfeld et al. 2000)	0.03-40 (Agrawal et al. 2005, Burnett et al. 2007)	NA	Wetland
Sockeye Salmon	0-2 (Lake 1999, Hoopes 1972)	0.175-65 (Bjornn and Reiser 1991, Woll et al. 2017, Neuman and Newcombe 1977, Roberge et al. 2002)	NA	NA	200 (Woll et al. 2017)	Lake

Finally, we examined all rail crossings while ignoring the presence of other potential barriers both upstream and downstream of the rail crossing, to determine which rail crossings may be blocking the most potential habitat in the absence of other landscape impacts. For this exercise, all rail crossings with another rail crossing downstream were removed from the analysis, to prevent double-counting of the amount of habitat upstream from each rail crossing.

2.3 Habitat Modelling – Lateral Assessment

We identified lateral habitats first by buffering all rail lines located in known Pacific salmon and steelhead-bearing watersheds within the Fraser River basin by 1 km to delineate the lateral habitat study area. Within the lateral habitat study area, we used the B.C. Freshwater Atlas to map all wetlands, lakes, side channels, oxbows, and streams. The B.C. Geographic Warehouse Mapped Floodplains in B.C. layer was also overlaid with the study area and used to identify floodplain areas to include in the analysis. Finally, we overlaid satellite imagery with the study area, and added wet or riparian areas visible on the imagery to the lateral habitat layer that were not already captured in the previous steps. We used a slope cutoff of 4% to delineate the limits of the floodplain habitat, and we removed ridge lines that indicate landforms too steep to be a part of the floodplain by excluding areas with slopes greater than 10%. Urban areas were also excluded using the B.C. Government's Baseline Thematic Mapping Present Land Use Mapping at 1:250,000 and the European Space Agency Land Cover map. Outside of urban areas, the effects of roads and dykes were ignored for the purpose of this analysis.

We considered all lateral habitats located on the river or stream side of the rail line to be potentially accessible habitat for fish, while all polygons on the opposite side of the rail line from the river were considered potentially inaccessible, except in cases where a known open-bottom structure was present (see https://github.com/smnorris/bcfishpass/blob/main/scripts/lateral/README.md- for more details). Although some closed-bottom culverts under the rail line are scored as passable to fish in PSCIS, we expect these closed-bottom structures to hold back sediments and have a major effect on floodplain functionality. We therefore classified lateral habitats connected by closed-bottom structures, including those scored as passable in PSCIS, as inaccessible to fish when on the opposite side of the rail line from the river.

We then measured the area of polygons potentially containing spawning and/or rearing habitat for Pacific salmon and steelhead to determine the amount of lateral habitat that is potentially blocked by the rail line as well as the proportion of all lateral habitat that is potentially blocked by rail. We clustered together polygons within 100 m of one another into a single polygon feature.

We then estimated the total area of potential floodplain habitat in the study area and the total area that is potentially blocked by railway infrastructure. We quantified the number of polygons that may be inaccessible to Pacific salmon and steelhead and summarized the proportion of the total lateral habitat that is potentially blocked for each of the 1:20,000 Freshwater Atlas watershed groups within our overall study area. Finally, we estimated what proportion of the total lateral habitat within each watershed group may be blocked.

Results

3.1 Longitudinal Assessment

There were 3,354 crossings identified along 5,403 km of rail in the study area. Of these, 2,971 (88%) rail crossings were modelled as closed-bottom structures, with just under half (n = 1,396) of these closed-bottom crossings on streams that were potentially accessible to Pacific salmon and steelhead (i.e., not too steep, no known falls or other natural barriers downstream). Of these, 282 rail-stream crossings were on streams with modelled potential to support Pacific salmon and steelhead spawning or rearing.

The amount of potential linear habitat that may be blocked by rail lines was highest for Coho Salmon for both spawning and rearing habitat. For this species, an estimated 261 km of habitat with the potential to support spawning and 924 km of habitat with the potential to support rearing may potentially be blocked (Table 2). When expressed as a per cent of total potential spawning and rearing habitat within the study area, Coho Salmon again have the highest proportion (2.8%) of potential spawning habitat that may be blocked, while steelhead have the highest proportion (6.1%) of potential rearing habitat that may be blocked.

In total, the 282 rail stream crossings may be blocking up to 1,015 km of habitat with the potential to support Pacific salmon and steelhead spawning or rearing. The amount of habitat potentially blocked by each rail crossing varies widely, ranging from as little as 0.02 km of habitat to as much as 72 km of potentially useable habitat (Table 3).

When excluding other rail crossings, the median number of modelled potential barriers (road, trail, dam) on potential spawning or rearing habitat upstream and downstream of rail crossings is 0 downstream and 1 upstream. The number of modelled potential barriers (excluding rail) ranges from 0 to 9 downstream of the rail crossings and from 0 to as high as 50 upstream of the rail crossings (Table 3). Put another way, for every 1 of the 282 rail crossings, there are 3.5 times as many additional crossings potentially blocking access to the 1,015 km of modelled potential spawning and/or rearing habitat in the Fraser River basin.

There are 128 rail stream crossings with no modelled barriers downstream, including 49 crossings with no modelled barriers upstream on portions of the stream containing modelled usable habitat with 16 of the 49 crossings containing 1 km or greater (maximum 16 km) of potentially usable habitat upstream. The 128 crossings with no modelled barriers downstream potentially block a combined total of 482 km of potentially usable habitat upstream. Of this, 101 km (21%) of modelled potentially usable habitat is located between the rail line and the next modelled barrier upstream (Table 3). For five

Table 2. Amount and proportion of potential linear spawning and rearing habitat that may blocked by rail lines within the Fraser River basin.

Species	Potential Habitat Potentially Blocked by Rail Crossings (km)	Proportion of Total Potential Habitat in Study Area (%)
Spawning		
Coho Salmon	261.2	2.8
Chinook Salmon	69.6	1.0
steelhead	17.8	0.9
Sockeye Salmon	5.8	0.9
Rearing		
Coho Salmon	924.3	5.6
Chinook Salmon	227.2	6.1
steelhead	112.6	1.4
Sockeye Salmon	40.2	0.5

rail crossings, the next crossing upstream is another rail stream crossing. If these additional five crossings are added to the list, the total amount of potentially usable habitat that the rail crossings may be blocking before encountering a dam, road, or trail crossing potentially acting as a barrier is increased by 2 km to 103 km. Two of the five additional rail crossings have no other modelled stream crossings upstream.

Table 3. Number of modelled stream crossings upstream and downstream of rail stream crossings on potentially usable (modelled potential spawning or rearing habitat) habitat for Pacific salmon and steelhead, and amount of potentially usable habitat potentially blocked by rail lines, total and downstream of the next potential barrier upstream.

Summary Statistic	**Number of Potential Downstream Barriers**	**Number of Potential Upstream Barriers on Portions of Stream with Potential Spawning and/or Rearing Habitat**	**Modelled Spawning and/or Rearing Habitat Upstream of All Rail Stream Crossings (km)**	**Modelled Spawning and/or Rearing Habitat Upstream of Rail Stream Crossings with No Other Modelled Barriers Downstream (km)**	**Total Modelled Potential Spawning and/or Rearing Habitat Between Rail Line and Next Crossing Upstream (km)**
Average	1	3	4	4	1
Max	9	50	72	72	19
Min	0	0	0.02	0.02	0
Median	0	1	1	1	0.2
Total (all crossings)	**219**	**771**	**1015**	**482**	**101**

Of the approximately 101 km of habitat that is potentially blocked by rail lines before encountering other potential barriers, approximately half of this length (50.2 km) is associated with just 7 crossings, and approximately 75% (76.2 km) is associated with 21 crossings. The remaining 25 km length is distributed among 100 crossings, 43 of which have ≤ 100 m of modelled potential habitat upstream before encountering additional crossings. Seven crossings have no modelled potentially usable habitat upstream before encountering the next potential barrier on the stream (Table 4).

When considering all 282 rail crossings that may be blocking access to Pacific salmon and steelhead spawning or rearing habitat, if we ignore potential barriers both upstream and downstream of each rail crossing, approximately 15 rail crossings are potentially blocking access to approximately half of the total potential spawning and rearing habitat for Pacific salmon and steelhead in the study area that may be blocked, and 40 rail crossings are potentially blocking 75% of the total potential habitat that may be blocked (Table 5). However, on these 40 streams, an additional 40 potential barriers are present downstream and 480 potential barriers upstream (14 rail and 466 road/trail/dam crossings), indicating a high level of fragmentation exacerbated by additional crossings. The next 75 crossings following the top 40 all have more than 1 km of modelled potential habitat upstream (range 1.0 km to 6.5 km).

3.2 Lateral Assessment

We estimated total floodplain habitat in the project study area to be 173,022.8 ha, with 13,202.2 ha (7.6%) potentially blocked by railway infrastructure. In total, we counted 567 polygons with potential lateral habitat for Pacific salmon and steelhead that may be blocked by the rail line, with an average polygon size of 23 ha.

Thirty of 40 B.C. Freshwater Atlas 1:20,000 watershed groups within the study area have lateral habitat that is potentially blocked by rail lines. Just under half (47.7%) of the area of potentially blocked lateral habitat is within four watershed groups: the Stuart Lake (19.4%), Morkill River (13.6%), Lower Salmon River (8.8%), and Salmon River (5.9%) watersheds. When expressed as a proportion of total lateral habitat within each watershed, the highest proportion of potentially blocked lateral habitat is relatively similar, with the Stuart Lake, Quesnel River, Lower Salmon River and Salmon River having the highest proportions of lateral habitat potentially blocked (Table 6). Spatial representation of select polygons where lateral habitat may be blocked by rail lines is shown in Figure 2.

Table 4. Amount of modelled potential Pacific salmon and steelhead spawning or rearing habitat potentially blocked by individual rail stream crossings with no modelled potential barriers downstream. The amount of habitat to the next upstream potential barrier (if any) was estimated.

Crossing ID	1:20,000 Freshwater Atlas Watershed Group	Stream Name	Number of Potential Barriers Upstream on Portions of Stream with Potential Habitat	Length of Modelled Potential Habitat Upstream (km)	Length of Modelled Habitat Between Rail Line and Next Potential Barrier Upstream (km)	Cumulative Total Habitat Potentially Blocked (km)	Cumulative Total Habitat Potentially Blocked (%)
197621	Takla Lake	Sitlika Creek	0	19.2	19.2	19.2	18.9
1009904765	Lower Chilako R.	Hutchison Cr.	2	8.3	8.1	27.3	26.9
1013905418	Morkill River	Crooked Creek	0	6.9	6.9	34.1	33.6
1003506134	Cottonwood R.	Meadow-bank Cr	0	5.4	5.4	39.5	38.9
1023204207	Upper North Thompson River	Lyon Creek	3	8.5	4.2	43.7	43.1
1024742020	Lower Fraser R.	Hyland Creek	17	7.0	3.3	46.9	46.3
1024723695	Tabor River	Red Rock Creek	51	57.1	3.2	50.2	49.5
1010305007	Lower Fraser R.	Cougar Canyon Cr.	3	6.5	2.9	53.1	52.4
1024725830	Upper Fraser R.	Titan Creek	1	3.8	2.9	56.0	55.2
1009904822	Lower Chilako R.	Unnamed	0	2.8	2.8	58.8	58.0
1020001252	Takla Lake	Unnamed	11	23.9	2.7	61.6	60.7
1019703303	Tabor River	Bertschi Creek	2	4.4	2.6	64.2	63.3
1024708246	Harrison River	Wades Creek	0	1.7	1.7	65.9	65.0
1020001250	Takla Lake	Unnamed	0	1.7	1.7	67.6	66.6
1010305083	Lower Fraser R.	Unnamed	10	10.3	1.5	69.1	68.1
1002801601	Chilliwack R.	Dunville Creek	9	8.0	1.4	70.5	69.5
1023204151	Upper North Thompson River	Unnamed	0	1.2	1.2	71.7	70.7
1018303506	Shuswap Lake	Victor Creek	1	1.9	1.2	72.9	71.8
51686	Harrison River	Anderson Creek	11	7.3	1.2	74.0	73.0
1010304980	Lower Fraser R.	Unnamed	7	2.7	1.1	75.1	74.1
1023204144	Upper North Thompson River	Unnamed	1	1.7	1.1	76.2	75.2

Discussion

This analysis provides preliminary insight into the potential effects of railway infrastructure on the ability of Pacific salmon and steelhead to access important spawning and rearing habitats. The proportion of habitat that may be blocked for each species ranged from 0.5 to 6% of modelled linear spawning and rearing habitat, though this represented as much as 924 km of rearing habitat for Coho Salmon. As much as 8% of lateral habitat could also be disconnected; however, these estimates should be viewed as preliminary, and the actual amount of habitat blocked is likely lower due to a number of known inherent errors:

1) Not all modelled closed-bottom crossings actually contain closed-bottom structures. We modelled 88% of rail stream crossings as closed-bottom structures. By comparison, the B.C. Forest Practices Board audited 1,110 road stream crossings in 19 watersheds in 2009 and found that closed-bottom structures were used in 66% of crossings, though this increased to 91% on streams considered to have marginal habitat for fish (Forest Practices Board 2009). Assessments of 18,000 road-stream crossings from 2008 to 2017

Table 5. Top 40 rail crossings potentially blocking the most potential spawning and rearing habitat for Pacific Salmon and steelhead in the Fraser River basin, when ignoring the effects of other crossings upstream and downstream of the rail crossings.

Crossing ID	1:20,000 Freshwater Atlas Watershed Group	Stream Name	Number of Potential Barriers Down-stream	Number of Potential Barriers Upstream on Portions of Stream with Potential Spawning and/or Rearing Habitat	Length of Modelled Potentially Usable Habitat Upstream (km)	Cumulative Potentially Usable Habitat Potentially Blocked by Rail (km)	Cumulative Potentially Usable Habitat Potentially Blocked by Rail (%)
1024723694	Tabor River	Cale Creek	0	37	71.7	71.7	7.1
1019703257	Tabor River	Tabor Creek	1	17	57.9	129.5	12.8
1024723695	Tabor River	Red Rock Cr.	0	51	57.1	186.6	18.4
1010305109	Lower Fraser R.	Salmon River	3	37	49.4	236.1	23.3
1014904165	Narcosli River	Australian Cr.	1	22	45.8	281.9	27.8
1014904171	Narcosli River	Cuisson Creek	2	15	35.2	317.1	31.3
1017104195	Quesnel River	Barlow Creek	3	34	31.9	349.1	34.4
1020001252	Takla Lake	Unnamed	0	11	23.9	373.0	36.8
1024403842	Willow River	Hay Creek	1	34	23.5	396.5	39.1
62711	Stuart Lake	Prairie Meadow Cr.	2	17	19.5	416.0	41.0
197621	Takla Lake	Sitlika Creek	0	0	19.2	435.2	42.9
1024712996	Lower Fraser R.	Benson Canal	1	14	18.9	454.2	44.8
1015605314	Nechako River	Hulatt Creek	0	16	18.5	472.7	46.6
1011508272	Lower North Thompson R.	Paul Creek	0	8	16.9	489.6	48.2
1013905446	Morkill River	Unnamed	1	8	15.9	505.5	49.8
1024704084	Lower Fraser R.	Nathan Creek	3	11	15.1	520.6	51.3
1004300501	Driftwood R.	Unnamed	0	1	14.5	535.1	52.7
1019302266	Stuart Lake	Unnamed	2	1	14.3	549.3	54.1
1019302252	Stuart Lake	Unnamed	3	3	14.3	563.6	55.5
1019703286	Tabor River	Bittner Creek	1	15	14.2	577.8	56.9
1010305055	Lower Fraser R.	Whonnock Creek	0	11	13.7	591.6	58.3
1024714088	Lower North Thompson R.	Heffley Creek	0	5	13.4	604.9	59.6
1017502222	San Jose River	Dingwall Creek	2	4	11.2	616.1	60.7
1019106896	S. Thompson R.	Pringle Creek	0	8	10.9	627.1	61.8
1019703310	Tabor River	Haggith Creek	1	7	10.5	637.6	62.8
1010305083	Lower Fraser R.	Unnamed	0	10	10.3	647.9	63.8
1005406273	Francois Lake	Tatin Creek	0	2	9.8	657.7	64.8
1018303492	Shuswap Lake	Broderick Creek	9	3	9.7	667.5	65.8
1009904800	Lower Chilako R	Zelkwas Creek	0	4	9.1	676.6	66.7
1023204207	Upper North Thompson R.	Lyon Creek	0	3	8.5	685.1	67.5
1015605359	Nechako River	Unnamed	0	2	8.5	693.6	68.4
1010305119	Lower Fraser R.	Yorkson Creek	0	15	8.4	702.0	69.2
1009904765	Lower Chilako R	Hutchison Creek	0	2	8.3	710.4	70.0
1010304991	Lower Fraser R.	Cranberry Slough	0	5	8.1	718.5	70.8
1002801601	Chilliwack R.	Dunville Creek	0	9	8.0	726.5	71.6
51686	Harrison River	Anderson Creek	0	11	7.3	733.8	72.3
1014904188	Narcosli River	Kersley Creek	3	8	7.2	741.0	73.0
1024742020	Lower Fraser R.	Hyland Creek	0	17	7.0	748.0	73.7
1013905418	Morkill River	Crooked Creek	0	0	6.9	754.8	74.4
1010702834	Lillooet River	Unnamed	1	2	6.5	761.3	75.0

Table 6. Lateral habitat potentially blocked by railway infrastructure in the Fraser River basin, by Freshwater Atlas 1:20,000 watershed group.

1:20,000 Watershed Group	Total Lateral Habitat Area (ha)	Total Potentially Isolated Lateral Habitat Area (ha)	Proportion of Lateral Habitat in Watershed Group Potentially Isolated (%)	Proportion of all Lateral Habitat in Study Area Potentially Isolated (%)
Stuart Lake	5518.0	2557.1	46.3	19.4
Quesnel River	283.3	84.3	29.8	0.6
Lower Salmon River	4433.7	1166.5	26.3	8.8
Salmon River	3416.9	776.1	22.7	5.9
Upper Shuswap River	819.7	129.4	15.8	1.0
Cottonwood River	2972.1	444.3	14.9	3.4
Fraser Canyon	4397.9	629.0	14.3	4.8
Muskeg River	144.4	20.6	14.3	0.2
Willow River	3402.4	377.0	11.1	2.9
Upper Fraser River	7088.7	726.6	10.3	5.5
Narcosli River	2097.4	213.2	10.2	1.6
Nechako River	7246.7	695.1	9.6	5.3
Morkill River	18904.9	1793.3	9.5	13.6
Tabor River	6060.7	549.2	9.1	4.2
Upper North Thompson R.	6850.0	408.4	6.0	3.1
Driftwood River	3599.2	203.7	5.7	1.5
Francois Lake	10242.8	529.0	5.2	4.0
Lower North Thompson R.	11788.9	566.2	4.8	4.3
Takla Lake	12685.5	388.1	3.1	2.9
Lillooet River	2625.5	74.6	2.8	0.6
Shuswap Lake	11362.5	309.4	2.7	2.3
Harrison River	5965.2	145.9	2.4	1.1
San Jose River	4044.2	97.4	2.4	0.7
Lower Trembleur Lake	635.8	14.9	2.3	0.1
South Thompson River	7077.7	144.0	2.0	1.1
Thompson River	9783.3	107.9	1.1	0.8
Middle River	4644.5	48.7	1.0	0.4
Lower Chilako River	2259.3	1.3	0.1	0.0
Upper Trembleur Lake	3264.6	0.9	0.0	0.0
Seton River	6282.7	0.4	0.0	0.0
Adams River	127.3	0.0	0.0	0.0
Big Bar Creek	557.6	0.0	0.0	0.0
Bonaparte River	3.5	0.0	0.0	0.0
Bowron River	40.9	0.0	0.0	0.0
Clearwater River	48.6	0.0	0.0	0.0
Deadman River	8.1	0.0	0.0	0.0
Lower Nicola River	35.8	0.0	0.0	0.0
Middle Fraser River	14.5	0.0	0.0	0.0
Stuart River	66.5	0.0	0.0	0.0
Twan Creek	2221.8	0.0	0.0	0.0
Total	**173022.8**	**13202.2**		

yielded relatively similar results, with 66% of crossings having closed-bottom structures (Mount 2017), though it is not clear whether crossings modelled as bridges were among those assessed. On the other hand, the type of crossing structures used in railway construction tend to differ from those used on resource roads, due to the load-bearing requirements of the tracks (AREMA 2003). It is also possible that some open-bottom structures act as barriers to fish, if they contain pilings or in-stream concrete footings that constrict the stream channel. Field verification is required to determine how accurate our estimates of structure type were.

2) Not all closed-bottom crossings are necessarily barriers to fish passage. The size of the crossing relative to the natural stream width, the crossing length, the slope of the crossing, whether the crossing is perched above the streambed, whether the crossing is embedded in the streambed, and whether the crossing is backwatered are some of many factors that may influence the velocity of water moving through a culvert, thereby affecting a crossing's ability to pass fish at some or all flows (Belford and Gould 1989, Mueller et al. 2008, B.C. Ministry of Environment 2011, Johnson et al. 2012). While the likelihood of a closed-bottom crossing presenting a barrier is relatively high (Forest Practices Board 2009, Mount 2017), our model assumes 100% of closed-bottom structures are barriers to fish passage, which is unlikely to be the case. For example, Mount (2017) found that 81% of closed-bottom structures were barriers to fish passage, and an additional 11% were potential or partial barriers when assessing 18,000 road stream crossings on resource roads in B.C. Considering that rail crossings tend to be located in valley bottoms with lower gradients, the number of closed-bottom crossings that act as barriers may actually be lower than those found on resource roads with more varied slopes and terrain.

3) Not all modelled habitat is actually suitable for spawning or rearing. Intrinsic potential habitat analyses can help identify reaches that are likely to contain habitat that is suitable for a particular species of fish to spawn or rear in (Sheer et al. 2009); however, field verification is required to confirm whether reaches identified by the model actually possess the characteristics required for carrying out these important life history stages. In some cases, the

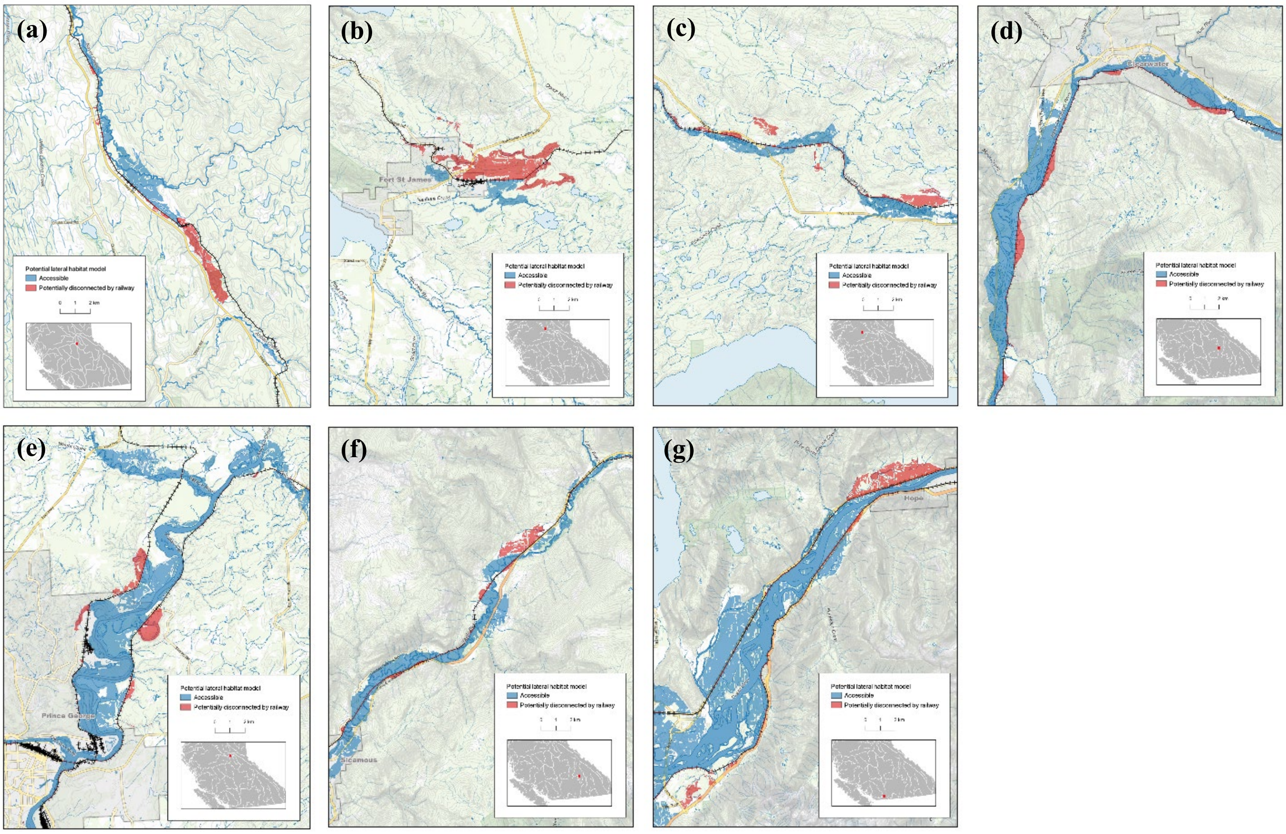

Figure 2. Lateral habitat potentially blocked by rail infrastructure in select regions of the (a) Cottonwood River/Tabor Creek, (b) Clearwater River/Lower North Thompson/Upper North Thompson, (c) Francois Lake, (d) Stuart Lake, (e) Upper Fraser River, (f) Shuswap Lake, and (g) Fraser Canyon B.C. Freshwater Atlas 1:20,000 watershed groups.

modelled potential habitat may occur on a watercourse that is dry during the times of the year when spawning or rearing may occur. In other cases, there may not be suitable substrates present for spawning, or there may be insufficient habitat complexity such as deep pools, overhead and instream cover, or suitable temperatures to support rearing. Comparison with existing datasets such as the Pacific Salmon Explorer (Pacific Salmon Foundation 2020) demonstrated that these intrinsic potential models successfully identified almost all known spawning and rearing habitat; however, field validation frequently found that other habitat modelled as suitable was not. This indicates that intrinsic potential models are generous, and that less actual suitable habitat is likely found upstream of rail crossings than identified here.

Despite the intrinsic potential models being inherently generous, the mean annual discharge thresholds used for spawning and rearing may be more conservative than those actually used by fish. For example, there are known spawning and rearing areas for Chinook Salmon in the mainstem North Thompson River (DFO 1999), where mean annual discharge is estimated to be 425.9 m^3/s (Perkins 2015).

4) There are inherent errors in the gradient and barrier thresholds that we use in our intrinsic potential modelling. For example, some fish are capable of navigating past significant gradients that would otherwise normally be inaccessible to fish, possibly due to the arrangement of step-pools or other habitat features, particular flow conditions, or the relative size and strength of the individual fish. In other cases, we may not capture a set of falls in our model and erroneously model that portion of stream upstream as accessible to Pacific salmon or steelhead.

5) This analysis provides a snapshot in time based on the most current layers available in the B.C. Freshwater Atlas, PSCIS, the GeoBC Railway track line, and other outside data sources. These data sources may not accurately reflect what is present on the ground today. For example, the GeoBC Railways Track Line was updated during the course of our analysis, with some tracks being removed from the dataset because they had been transformed into trails or otherwise abandoned. In other cases, streams may have changed course, dried up, or otherwise changed from what is reflected in the B.C. Freshwater Atlas, and roads and other land uses may not be up to date in our mapping sources.

The bcfishpass model uses a combination of modelled stream crossings, which were generated where mapped infrastructure crosses mapped streams, and field assessment data stored in the PSCIS database. Sometimes modelled crossings were far enough from the PSCIS crossing location that it was not clear whether the stream was mapped incorrectly or if the PSCIS crossing was on an unmapped tributary. If the modelled and PSCIS crossings were combined but are actually separate, the number of crossings will have been under-estimated; whereas, if the crossings were kept separate but are actually the same, the crossing may essentially have been double counted. In the case of the latter, the amount of habitat upstream may not be accurately represented if the stream channel is not mapped accurately.

There may also be instances where crossings have been upgraded or replaced that are not captured in PSCIS. For example, among all of the crossings with no known additional crossings downstream, the crossing with the largest amount of potential habitat upstream before encountering additional barriers is Sitlika Creek (crossing ID 197621). The Canadian Wildlife Federation partnered with the Canadian National Railway Company and Takla First Nation in 2021 to remove this crossing from an inactive rail line and is therefore now passable to fish (Canadian Wildlife Federation 2022). There may be other examples of this type of work that has been completed but is not captured in the model.

6) The approaches used here to identify lateral habitats and their connectivity status were preliminary and have not been validated by field assessments. Salmonids may use lateral habitats that are only wetted for six to eight weeks of the year, particularly in interior portions of the Fraser Basin, where hydrographs are dominated by snow (R. Bailey, personal communication March 2, 2022). Depending on the time of year that the area was surveyed, these lateral habitats may not have been identified in mapping and satellite imagery and may therefore present a potential under-estimate of the total lateral habitat in the study area and the amount of lateral habitat that may be blocked by rail lines.

We excluded all urban areas from our lateral habitat analysis due to the challenge presented in distinguishing rail impacts from other land-use impacts in these areas. The alteration or removal of lateral habitats through draining, channelization, and diking for agricultural, urban and industrial uses has rendered much of the lateral habitat unusable even in the absence of rail lines, particularly in the lowest reaches of the Fraser River through the Lower Mainland, where only 15% of historic lateral habitat is estimated to remain accessible to salmonids (Finn 2021).

Due to the dynamic nature of rivers and channel formation, not all floodplain habitat is usable all of the time, due to changes in channel morphology as the active channel(s) shifts through the floodplain over time. For example, oxbows may become cut off from flows as the river channel shifts, and then remain disconnected for several years, preventing access for use by fish. In addition, some lateral habitats may be accessible on an annual basis, while others may only be accessed during a 1 in 10-year flood return period, or greater. Usable habitat is therefore likely only a fraction of the potential floodplain habitat estimated here at any given time. However, we do not consider this a potential source of error in our floodplain habitat estimates, since functioning hydraulic and channel formation processes are important for forming and maintaining these habitats over time.

The floodplain mapping model used in this analysis is relatively simple and could be refined to more accurately reflect floodplain habitats using one of several models, including: a valley/channel confinement algorithm developed by Nagel et al. (2013), which identifies valley widths using modelled channel depth and a multiplier (the default is three times channel depth) combined with elevation to define the floodplain; Active River Area PATHDISTANCE modelling, which uses a combination of elevation and distance from the stream channel to determine the “cost” of water traveling upslope (Smith et al. 2008); and the Topographic Position Index, which can be used in combination with our existing modelling to refine landform feature identification and better distinguish between, for example flat floodplain areas and plateaus (Jenness 2006, Lindsay 2014). Though there are more complex hydrologic models that can be used to predict present and future flood scenarios (e.g., Yamazaki et al. 2011, Gaur et al. 2018, Craig et al. 2020), these are likely too detailed for the purposes of this exercise.

We estimated the impact of fragmentation from other infrastructure to be roughly 3.5 times that which is potentially caused by railway infrastructure in the Fraser River basin for longitudinal habitat on which rail crossings occur Railways and highway infrastructure often run in parallel along valley bottoms, and urban and rural resource roads are abundant on the B.C. landscape. Despite this, our study indicates that roughly one-fourth of the potential spawning and/or rearing habitat that may be blocked by rail lines could potentially be regained by remediating railway barriers alone.

Given the potential errors described, this exercise is not meant to prioritize barrier remediation, but instead provide an initial estimate of the scope of the effects of rail lines on Pacific salmon habitat connectivity. Field assessments are required to confirm whether rail-stream crossings are barriers, and whether modelled spawning and rearing habitat is actually suitable at individual locations. Knowing where the highest potential habitat gains may be can help to guide field investigations which, in combination with stakeholder inputs, can help to guide where remediation efforts should be focused to realize the best gains in terms of both habitat quantity as well as quality. Future efforts may also include examining sets of rail and non-rail barriers combined to determine where potential habitat gains may be the most optimal. For example, there may be instances where remediating a rail barrier could result in 100 m of habitat gain on its own but could result in several kilometers of habitat gain if one or more additional barriers upstream are also remediated.

We did not attempt to quantify the degree to which other land uses may be exacerbating loss of habitats or loss of access to lateral habitats from rail lines. We recognize that these land uses will affect the ability to recover some of these habitats and their functions, and further investigation is required both in the field and through refinement of the lateral habitat model to help identify where priority areas for remediation may be.

There may be auxiliary impacts to fish passage and connectivity that are not fully captured in our model. For example, a portion of the mainstem Eagle River in the Shuswap Lake watershed group was redirected near Mile 15.5 when the railway was built, which has resulted in mortalities of out-migrating juvenile salmonids that become entrained against the rail ballast when traveling through the diverted channel (R. Bailey, personal communication May 17, 2022; D. Pehl, personal communication May 19, 2022). While loss of access to floodplain habitat in the Eagle River is accounted for in our lateral habitat analysis, quantifying impacts to safe access and egress of fish is outside the scope of our analysis. Local knowledge is required to identify and address such additional connectivity issues.

Our model outputs currently lack error estimates, which we hope to generate in future iterations of this analysis. An error estimate for the proportion of crossings that are open-bottom structures could be generated by field-verifying a random subset of crossings along the rail line. We could also correct for the percent of closed-bottom crossings that we expect to be passable to Pacific Salmon and steelhead by:

- incorporating work completed by Finn (2021), who modelled probabilities of a stream crossing being a barrier on watercourses in the lower Fraser River to be between 17% and 81%, with a mean probability of 56%;
- applying a passability probability using the number of passable versus potential/partial versus impassable crossings estimated by Mount (2017);
- examining a subset of PSCIS crossings on and in close proximity to rail lines in the Fraser River basin; or

- field verification of a random subset of rail crossings.

Next Steps

This report summarizes the first phase of an effort to quantify the extent to which rail lines may be blocking passage for Pacific salmon and steelhead in the Fraser River basin. The next steps that will be included in the second phase of this project include:

- Expanding the analysis to the entire active rail network in B.C., which will include the Skeena watershed, Vancouver Island streams, and the Squamish watershed. Railways that have been converted to trails but may still maintain the original drainage structures may also be added to the study.

- Developing intrinsic potential models for Pink Salmon and Chum Salmon and including them in future iterations of the model.

- Refining existing intrinsic potential models by adding a channel confinement layer and more accurate discharge data, including monthly discharge estimates in relation to the time of year that each life stage of each species uses spawning and rearing habitat.

- Refining the lateral assessment layer using one of the several options discussed in the previous section.

- Adding error estimates to the results where feasible, such as adjusting the overall amount and percent of habitat that may be blocked by the proportion of modelled closed-bottom structures found to be passable through previous field assessments.

- Examining sets or rail barriers combined with road, trail, and dam crossings to determine where barrier removal may be the most optimal when considering other crossings on the landscape.

- Performing field validation and creating a preliminary list of priority barriers for remediation with input from local stakeholders.

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Appendix

Methods

Dams and Falls

We used the "BC Hydro Dams and Waterfalls" and "BC Dams" layers created from seven separate data sources by the Canadian Wildlife Federation for their watershed connectivity planning and prioritization projects to determine definitive barriers to fish passage (BC Hydro Dams and Waterfalls layer) and potential barriers to fish passage (BC Dams layer) in our model. QA/QC was performed on these layers to ensure accurate georeferencing, remove duplicates, and identify dams equipped with fish passage facilities. For details on QA/QC measures undertaken, refer to Mazany-Wright et. al. 2021*a*,*b*.

In addition to QA/QC of the BC Hydro Dams and Waterfalls layer, we undertook a manual review of all falls 5 m in height or greater, all major dams where Pacific Salmon or steelhead observation records were present upstream, and all streams where flows were modelled to be subsurface. Fish observations were collected from the B.C. Geographic Warehouse "Known BC Fish Observations and BC Fish Distributions" layer, which houses fish observations in official B.C. governmental databases, including the B.C. Fisheries Inventory Summary System. We reviewed the source literature of each observation/falls point in the database, where available, to ensure that the observations were valid. Where observation record source reports were not available or a conclusive confirmation of the fish or falls observation could not be verified based on the parent literature review, additional white and grey literature sources for the stream in question were reviewed to verify the upstream extent of Pacific Salmon and/or steelhead distributions in the stream and/or the presence/absence of a falls barrier.

Stream Crossings

For modelled crossings where field verifications were not available, we undertook a desktop-based QA/QC exercise using satellite imagery to ensure that modelled crossings were being accurately represented as either open-bottom or closed-bottom crossings. This was completed on all modelled crossings within the study area and included not only the rail line but also all road, dam, and trail crossings upstream and downstream of the rail line. Any modelled crossings where either a road or a watercourse/waterbody did not actually exist based on the satellite imagery were removed from the model during this step. For the purposes of this exercise, any modelled closed-bottom crossing was assumed to be a barrier to fish passage, unless otherwise verified to be passable in PSCIS.

Rail-stream crossings that have PSCIS assessments completed on them were matched to modelled rail-stream crossings using an automated script and assigned as either a barrier or passable based on the PSCIS category. PSCIS-assessed crossings were then manually reviewed to ensure that the correct PSCIS assessment was matched to the modelled rail crossing and not an assessment from a nearby road or trail.

Results

Dams and Falls

For results of the BC Hydro Dams and Waterfalls layer and BC Dams layer QA/QC, please refer to Mazany-Wright et al. 2021*a* and Mazany-Wright et al. 2021*b* respectively.

We manually reviewed 51 falls, major dams, and areas with suspected subsurface flow where anadromous fish observations were recorded upstream (Table A1). Of these, roughly half were found to be passable, due either to no falls being present, falls being passable, or verified fish observations in areas suspected to have subsurface flows.

Stream Crossings

We reviewed 25,560 modelled stream crossings (road, trail, rail, dam/weir crossings) within the project study area (Table A2), including 4,873 rail crossings, 2,274 crossings downstream of rail lines, 13,211 crossings upstream of rail lines, and 5,202 crossings on streams not associated with railway infrastructure. Of these, 86% were found to be correctly classified.

Only six crossing that were modelled as a bridge were found to be a closed-bottom structure, while 1,012 crossings modelled as closed-bottom structures were found to be bridges (Table A3). Either no road or no stream was present for 2,227 modelled crossing points.

We reviewed all rail stream crossings that were matched to PSCIS assessments to ensure that they were appropriately matched. Only 20 modelled rail stream crossings were matched to a PSCIS assessment. Four PSCIS crossings were found to be road stream crossings that were erroneously classified as rail stream crossings because of spatial proximity. Three of the crossings were on streams with no modelled Pacific salmon and steelhead spawning or rearing habitat upstream and were therefore removed from the dataset. One of the crossings was erroneously matched to a PSCIS assessment of a highway crossing and had modelled habitat upstream; however, this location also had a correct PSCIS assessment for the rail stream crossing, which was assessed as passable (Table A4).

Table A1. Summary of QA/QC for falls, major dams and subsurface flows with anadromous fish observations upstream.

Barrier Type	Total	Number Reviewed	Barrier Confirmed	Passable/ no falls/ erroneously classified barrier	Unknown
Falls	19	17	9	7	2
Major Dam	2	2	2	0	0
Subsurface Flow	33	32	7	18	7
Total	**54**	**51**	**18**	**25**	**9**

Table A2. Modelled stream crossing QA/QC within the project study area.

Reviewed by Type	Number Reviewed
Dam	415
Rail	4,873
Road, Demographic	4,675
Road, Resource/Other	15,523
Trail	73
Weir	1

Table A3. Modelled stream crossing QA/QC review results.

Review Results	Count
Modelled as bridge, structure appears to be a closed-bottom structure	6
Flagged for further review, imagery inconclusive but suggests coding is incorrect	198
Modelled as culvert, ford present	125
No road or stream present	2,227
Modelled as culvert, bridge/open-bottom structure is present in imagery	1,012
No fix/imagery inconclusive	21,992

Table A4. QA/QC results for PSCIS assessments matched to rail stream crossings.

PSCIS ID	Assessment	QA/QC Result
51686	Barrier	Rail stream crossing - retained
62711	Barrier	Rail stream crossing - retained
124639	Barrier	Rail stream crossing - retained
125845	Barrier	Rail stream crossing - retained
125847	Barrier	Road stream crossing - removed
125848	Barrier	Rail stream crossing - retained
126057	Barrier	Rail stream crossing - retained
126060	Barrier	Rail stream crossing - retained
126065	Barrier	Rail stream crossing - retained
126066	Potential	Road stream crossing – removed
126067	Potential	Road stream crossing – removed
196303	Barrier	Rail stream crossing - retained
197600	Barrier	Road stream crossing – removed
197621	Barrier	Rail stream crossing - retained
197622	Barrier	Rail stream crossing - retained
197623	Barrier	Rail stream crossing - retained
197624	Barrier	Rail stream crossing - retained
197627	Barrier	Rail stream crossing - retained
197630	Barrier	Rail stream crossing - retained
197631	Barrier	Rail stream crossing - retained