Salmon Habitat Analysis in the Lower Fraser River & Estuary

Executive Summary

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Disclaimer

This report was produced as part of the UBC Sustainability Scholars Program, a partnership between the University of British Columbia and various local governments and organizations in support of providing graduate students with opportunities to do applied research on projects that advance sustainability and climate action across the region.

This project was conducted under the mentorship of Raincoast Conservation Foundation staff. The opinions and recommendations in this report and any errors are those of the author and do not necessarily reflect the views of Raincoast Conservation Foundation or the University of British Columbia.

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The author would like to thank the following individuals for their contribution, feedback, and support throughout this project:

Dave Scott

Kristen Walters

Overview

The Fraser River is a major watershed for British Columbia and supports every species of salmon found in British Columbia. In the past the Lower Fraser River (LFR) was home to an abundance of different ecosystems, from sloughs to marshes and side channels, that would have supported salmon populations at several different stages of their life. The LFR is especially important for out-migrating salmon. As an estuary it has varying levels of brackish water that allow juvenile out-migrating salmon to adjust to saline water before making their way to the ocean. Previously, the variety of habitats present in the LFR and estuary would've allowed juvenile salmon to spend time in brackish water and adjust to new environments as well as to feed, grow, and seek protection from predators[1]. The modern context of the LFR is much different; colonization led to rapid industrialization

Fig.1: Map of Fraser River Watershed.

[1] Sawyer, Alexandra C., William I. Atlas, Karl M. Seitz, Samantha M. Wilson, and Jonathan W. Moore. 2023. "State-dependent Estuary Stopover Boosts Juvenile Salmon Growth: Implications for Marine Survival." Ecosphere (Washington, D.C)

resulting in the destruction of important habitats and has contributed to a decline in salmon population in the Fraser River.

This project contributes to the larger sustainability issue of the rapid development, urbanization, and ongoing industrialization of the Lower Fraser River and estuary. There are numerous industrial projects currently proposed to be built in or adjacent to the North Arm of the Lower Fraser River, including: a replacement of the George Massey Tunnel, the FortisBC Tilbury Phase 2 LNG Expansion Project, and the Roberts Bank Terminal 2 expansion project, among others. This project aims to understand how, given the ongoing loss and degradation of shoreline and in-river habitat in the Lower Fraser River, we can support out-migrating juvenile salmon by identifying gaps in ecosystem connectivity using maps. These maps will help identify locations for future restoration project aiming to restore a greenway (corridor of high value ecosystems) of habitats for juvenile salmon.

Scope

The scope of this project has two aspects to it: a geographic scope and a topic scope. The scope of the topic for this project includes determining the presence and gaps in salmon rearing habitat in the LFR, which meant limiting the scope of evaluation and in-depth analysis of habitat patches and shoreline habitat. Additionally, as the project intends to support future decision-makers on where ecosystem restoration efforts would be most effective and in what form they take, it is not in this project's scope to propose specific sites, but to provide general areas that need to be examined more closely. The geographic scope of this project was limited to the reach of the Fraser stretching that stretches from the confluence of the Pitt River and the Fraser River down to the Salish Sea. The scope of the project was limited for several reasons including time constraints and computing power. However, the most significant factor that determined the project's geographic scope was the extent of development and alteration that the Lower Fraser River and Estuary has undergone since colonization. To include upstream

Fig.2: Map of study area and it's surrounding context.

reaches could skew the actual interpretation and state of the LFR, as upper reaches are in a more natural state.

Context & State of the LFR

Currently the LFR is a largely industrial area, and much of the shoreline which was once part of the floodplain is now developed and is privately owned. It is home to many large ports, wood product plants, heavy industry manufacturing, wastewater treatment, shipping, pipelines,

and refineries, and more that produce chemicals that can be found leeching and contaminating

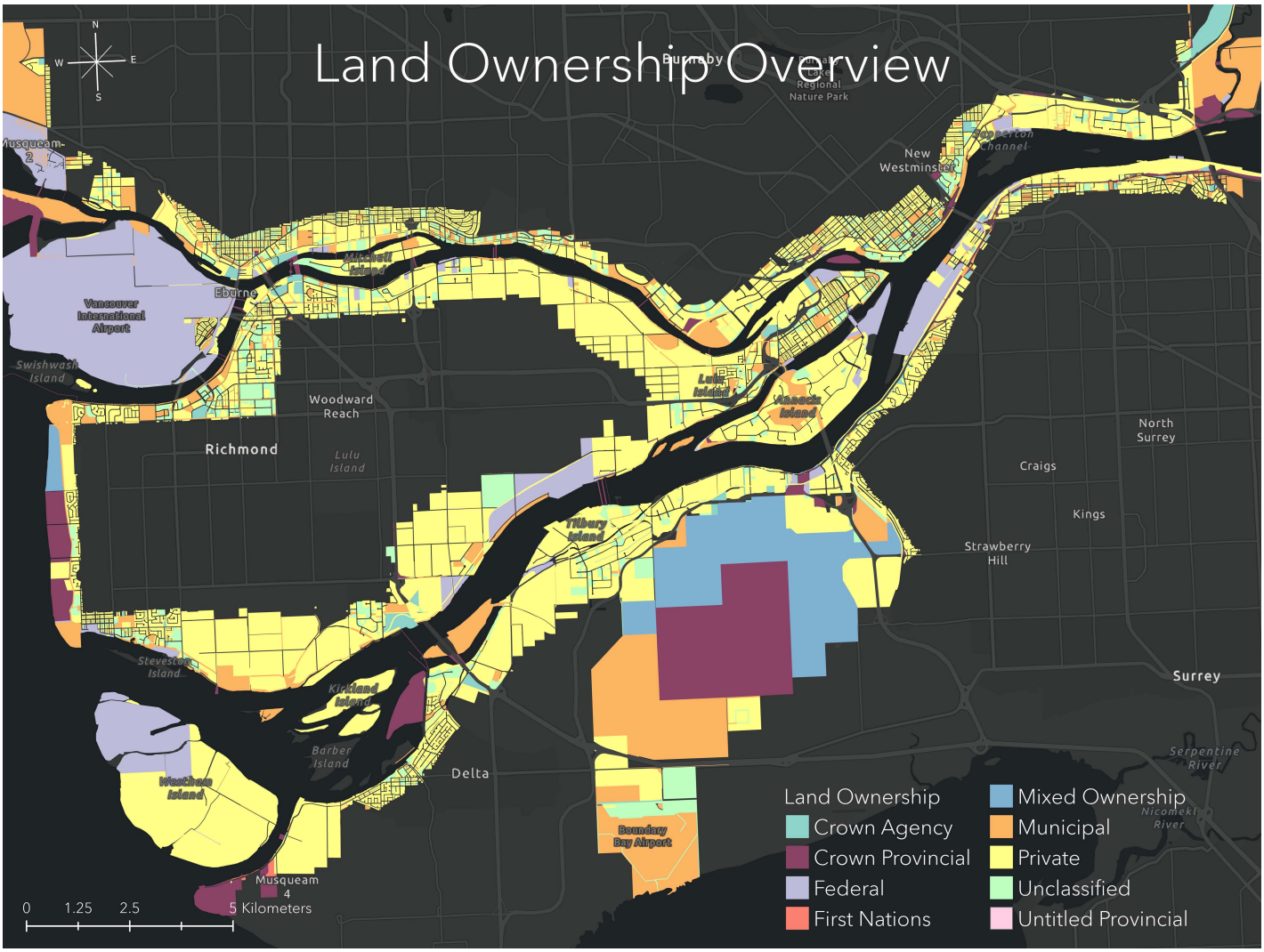

Fig.3: Parcel map of study area noting the level of private ownership.

the LFR. Additionally, much of the shoreline has been hardened to prevent erosion and support industrial activity. Undoubtedly this has impacted the amount and type of ecosystems present along the Lower Fraser River which now mainly consists of low to medium value shoreline [2]. Additionally, habitat patches have been reduced in size and connectivity which affect their value and accessibility by juvenile salmon. Previous restoration efforts have had varying success in recovering habitat function and productivity. Off channel habitat has

[2] Burrard Inlet Environmental Action Program - Fraser River Estuary management Program. 2017. "Habitat Atlas" The Community Mapping Network (Vancouver, B.C.). https://www.cmnbc.ca/atlasgallery/fremp-bieap-habitat-atlas/

also been affected; in attempt to mitigate erosion many channel outlets have been constricted using culverts that make accessing off channel habitat difficult. Further impacts to the river and its habitat connectivity include flood mitigation structures, such as dikes, that have cut off much

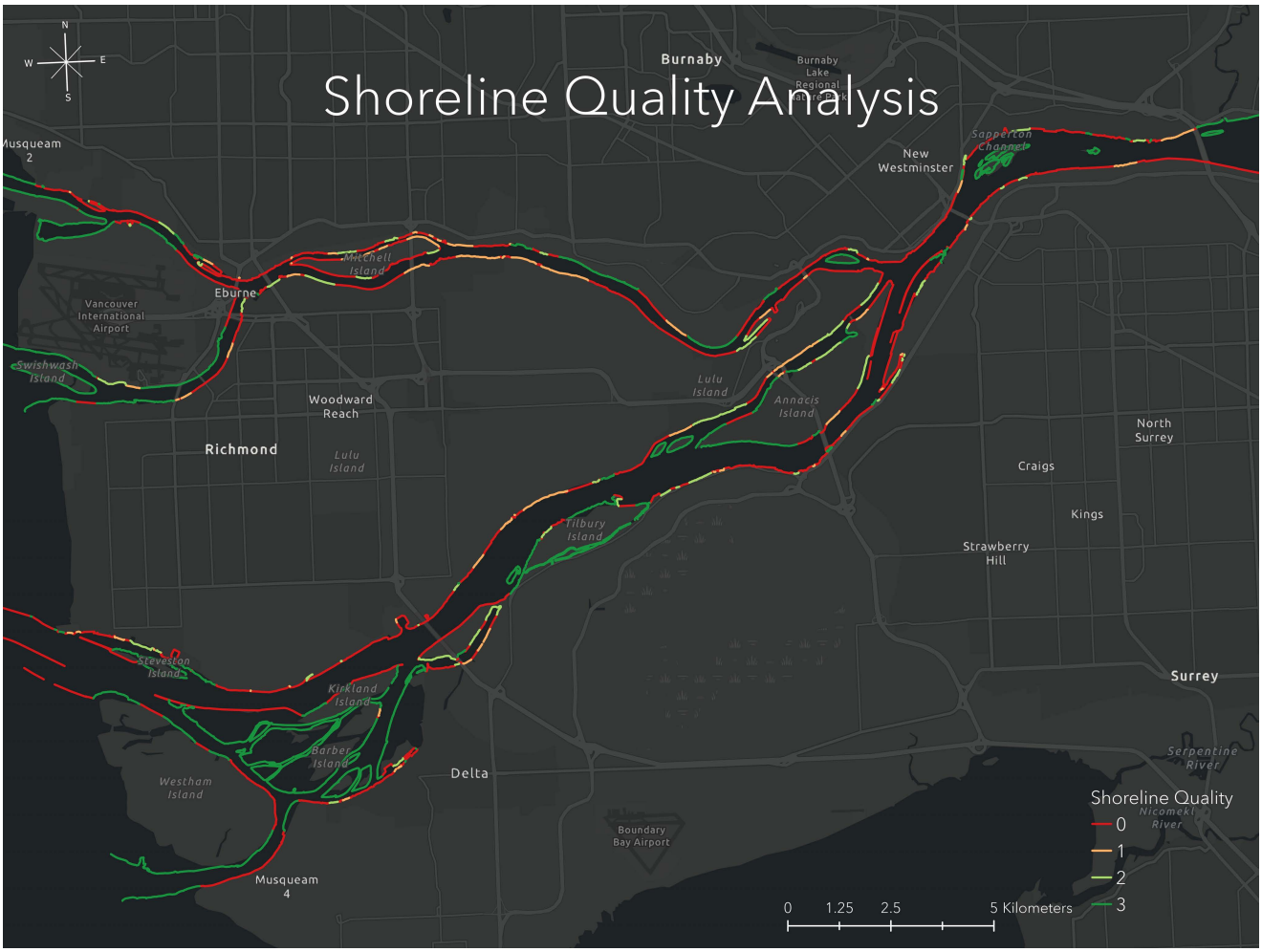

Fig.4: Map of LFR shoreline indicating quality based on state of shoreline (hardened or naturalized) and general ecological value.

of existing crucial habitat. While this infrastructure is important, there may be alternatives that provide a better all round solution. The LFR is clearly in a reduced capacity to support fish production and many of the changes that have been caused by industrialization have compound effects that make this an increasingly inhospitable place for juvenile salmon through loss of habitat and higher flow rates.

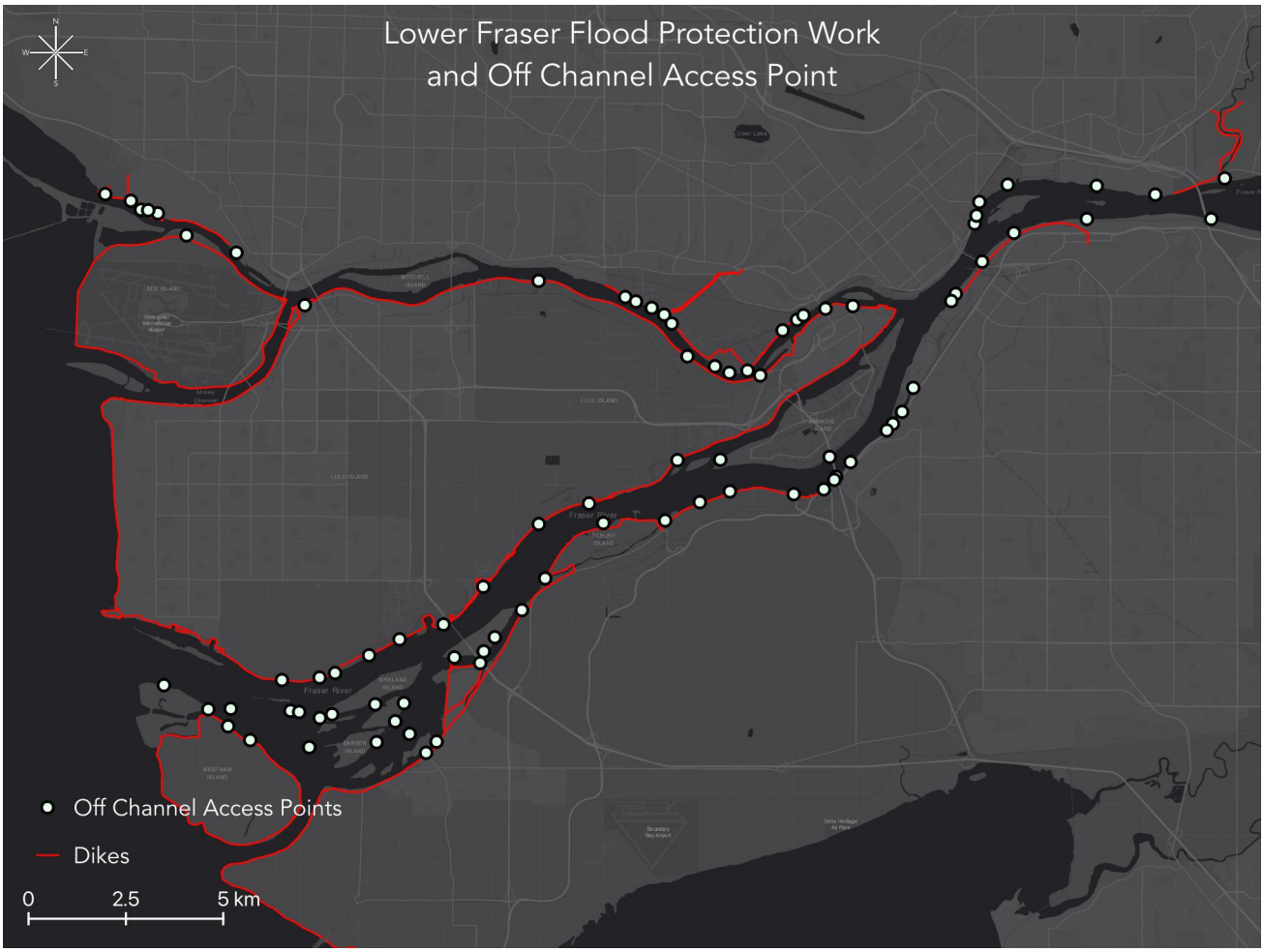

Fig.5: Map of dike system in study area as well as access points to off shore habitat.

Literature Review Takeaways

As part of this study, a comprehensive literature review (See Appendix: A-1) was conducted along with an accompanying annotated bibliography. Key takeaways from previous research conducted mainly on the west coast of the United States provided helpful parameters for the analysis that was conducted in project. The literature review provided parameters surrounding salmon biology and ecology that in turn helped identify areas of valuable habitat along the LFR. Additionally, previous research helped provide examples of what valuable shoreline looked like along rivers in industrialized areas. Lastly, summaries of previous restoration work helped identify key information about the state of the LFR, as well as the state of salmon populations in the LFR, which helped to guide research by providing in depth knowledge of these topics.

Summary of Existing Restoration Projects

Within the last 40 years the Fraser Estuary has seen rapid changes and development due to increasing demands from urban and industrial stressors. As a response to development in the area several entities have put into place and carried out restoration efforts in an attempt to offset or compensate development projects. Initially the Department of Fisheries and Oceans(DFO) Canada carried out restoration[3] work but since the establishment of the Fraser River Estuary Management Program in 1983 over 30 entities[4] from federal to municipal to non-government have cooperated on restoration work in the Fraser Estuary. In an attempt to understand where and how restoration efforts in the future can be most effective summarizing previous work is essential given the broad style and effectiveness of said work.

Restoration work initially started with the DFO's No-Net-Loss Policy which was established in the early 1980's to conserve the estuaries capacities to support fish species which depend on the Fraser. Restoration efforts mainly consisted of what was coined as "Compensation Sites" that dictated that habitat be created whenever development took away existing habitat[5]. These principles were followed into the late 1990's until research conducted[6] which evaluated compensation sites revealed that there was a staggeringly low success rate due to a variety of reasons such as plant selection and construction of sites which often restricted wildlife access to many of the sites.

Following this research restoration efforts began to take more adopt more modern restoration approaches by attempting to mimic ecosystems and increase access to ecosystems year round. More recent research does show increased success rates but still face damage due

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[3] Ron Kistritz. 1996. "Habitat Compensation, Restoration, and Creation in the Fraser River Estuary: Are We Achieving 'No Net Loss' of Fish Habitat". Fisheries and Oceans Canada (Vancouver, B.C.)

[4] Megan Lievesley, Daniel Stewart, Rob Knight, and Brad Mason. 2017. "Marsh and Riparian Habitat Compensation in the Fraser River Estaury: A Guide for Practitioners." The Community Mapping Network (Vancouver, B.C.).

[5] Ibid

[6] Ibid

to invasive plant species out competing native plantings as well as invasive Canadian Geese which over graze and erode[7]. There are limits to construction efforts as well such as trying to mitigate wave erosion caused by boat wakes. Recently restoration efforts have been conducted by a larger variety of entities in attempts to consolidate restoration knowledge, divide efforts and increase funding.

Restoration efforts today are still on going and focus less on only compensating industrial development but creating ecosystems and ecological connectivity throughout the estuary. Todays efforts have come a long way from the early concept of No-Net-Loss and effectiveness of restoration continue to be the focus of researchers. As such there are many resources that provide site specific information for those who are interested.[8],[9] In essence however trends in restoration work in the Fraser Estuary can be summarized in phases based on the style of the projects. Early project that were largely based on the NNL concept were focused on offsetting habitat destroyed through development. At the time however restoration efforts were more often than not largely inadequate and the nature of compensation often didn't really mean the creation of new habitat but the protection of existing habitat sometimes through the use of rip-rap that can actually be detrimental to accessing off channel habitats. Restoration efforts did improve as time went on such as the creation of tidal marshes beginning in the early 2000's. The issue that many of these newer compensation sites faced however was that the designs used a riprap-bench-riprap technique. This technique can be effective but is largely dependent on the elevation it is built as access is dictated by water levels. As the Fraser estuary is largely influenced by tides access to these site is only feasible for an hour or two per day when water levels are high and thus will not provide much habitat value. More recent restoration efforts have taken more sophisticated technique and have tried to create ecosystem that are not 100% bound by rip-rap therefor having gradual access to the river based on water

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[7] Megan Lievesley, Daniel Stewart, Rob Knight, and Brad Mason. 2017. "Marsh and Riparian Habitat Compensation in the Fraser River Estaury: A Guide for Practitioners." The Community Mapping Network (Vancouver, B.C.).

[8] R. Ingham, D. Hennigar, D. Stewart. 2021. "2021 Site Descriptions of Created Tidal Marshes in the Lower Fraser, Serpentine, and Nicomekl Rivers." British Columbia Wildlife Federation Wetlands Workforce

[9]Ibid

level all the while creating access to marsh habitat. Many sites have created breaks in pre-existing rip-rap as well as the dismantling of culverts to allow access to off channel habitat in the form of streams, rivers, lakes and marsh ecosystems. Additionally, since the majority of the LFR is privately owned and vastly developed, there is very little space to place these restoration sites and therefore sites are quite small. In summary, although there are numerous offsetting sites in the LFR, the value of the majority of these sites is likely quite low.

Methodology

GIS Analysis

We conducted a quantitative analysis to determine where the gaps in ecosystem connectively are in the LFR. We used a multistep analysis, which included the verification of pre-existing data sets, creation of a novel data set, and GIS Analysis.

Before conducting the analysis, parameters had to be established ahead of time. Parameters and baselines from existing work found in the literature review were used to set the study parameters. The study established various parameters surrounding habitat patch value and baseline distance for juvenile salmon habitat[10]. It was established that only patches above 2Ha provided valuable refuge habitat for out-migrating juvenile salmon. Additionally, it is noted in the literature that habitat patches above 12ha provide the highest habitat value[11]. Using these parameters, the study identified and manually mapped habitat patches and restoration sites along the Lower Fraser River within our study area. Using satellite imagery, pre-existing restoration sites, and cross referencing the Metro Vancouver Sensitive Ecosystem Inventory, conducted in 2022, we identified 2200 Ha. Additionally, the study area's coastline was mapped

[10] Hood, W. Gregory, Katie Blauvelt, Daniel L. Bottom, Janine M. Castro, Gary E. Johnson, Kim K. Jones, Kirk L. Krueger, Ronald M. Thom, and Andy Wilson. 2022. "Using Landscape Ecology Principles to Prioritize Habitat Restoration Projects across the Columbia River Estuary." Restoration Ecology

[11] Ibid

using satellite imagery, CMNBC's video imagery[12], and most recent Google Street View. In short, the parameters established along with the verification of previous work allowed for the creation of a novel dataset that would be the basis for the analysis.

The main goal of the analysis was to take an input, being the habitat patch data set, and find the distance between those patches while accounting for the complex shoreline. To find distances between habitat patches along the Lower Fraser River, a raster of the Fraser was created where a value of 1 was assigned to the Fraser's water, and a value of 0 was assigned to land masses. This was done by taking the DataBC's Fraser River polygon[13] and subtracting it from a polygon representing land. From there the polygons were merged and converted into a raster.

Once the raster was created, the Path Distance Tool was run. This tool calculates distances between polygons or points, in this case habitat patch polygons, but limits distance calculations to specific raster values. In this case raster calculations were limited to Value 1 representing water values. This is an important distinction from using straight line distance, which would not take into account the complex shoreline of the Fraser River. Using this tool, distances were accurate and could accommodate zones where salmon, for example, have to double back. This analysis gives a more accurate representation of reality and therefore provides more useful information to readers and users. At first, distances were determined using previous research that determined salmon need habitat patches within at least 5km. After consulting with the project supervisor, it was established that a combined approach should be taken, where we consider the size of the polygons and the distance between them. Using the path distance tool, we calculate 2.5km distances between12Ha patches; this includes 1km distance between patches above 2Ha and 500m distances between all habitat patches regardless of size. All analyses were conducted using ArcGIS pro.

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[12] Burrard Inlet Environmental Action Program - Fraser River Estuary management Program. 2017. "Habitat Atlas" The Community Mapping Network (Vancouver, B.C.). https://www.cmnbc.ca/atlasgallery/fremp-bieap-habitat-atlas/

[13] GeoBC. 2006. "Freshwater Atlas Rivers". Distributed by BC Data Catalogue. https://catalogue.data.gov.bc.ca/dataset/freshwater-atlas-rivers

Summary of Work & Results

The result of our analysis highlights the challenges that out-migrating juvenile salmon, among other life stages and species, face in the LFR. Habitat patches are greatly fragmented. This fragmentation is largely due to the industrial, agricultural, and residential development along the banks of the Fraser. Included for context in mapping is the PMNBC parcel layer[14]. One can see the level of private ownership along the Fraser that not only allowed for the development of the Fraser, but also makes conservation and restoration difficult as the Fraser is a major industrial hub.

[14] DataBC. 2016. "ParcelMap BC Parcel Polygons". Distributed by BC Data Catalogue. https://catalogue.data.gov.bc.ca/dataset/parcelmap-bc-parcel-polygons-ogl

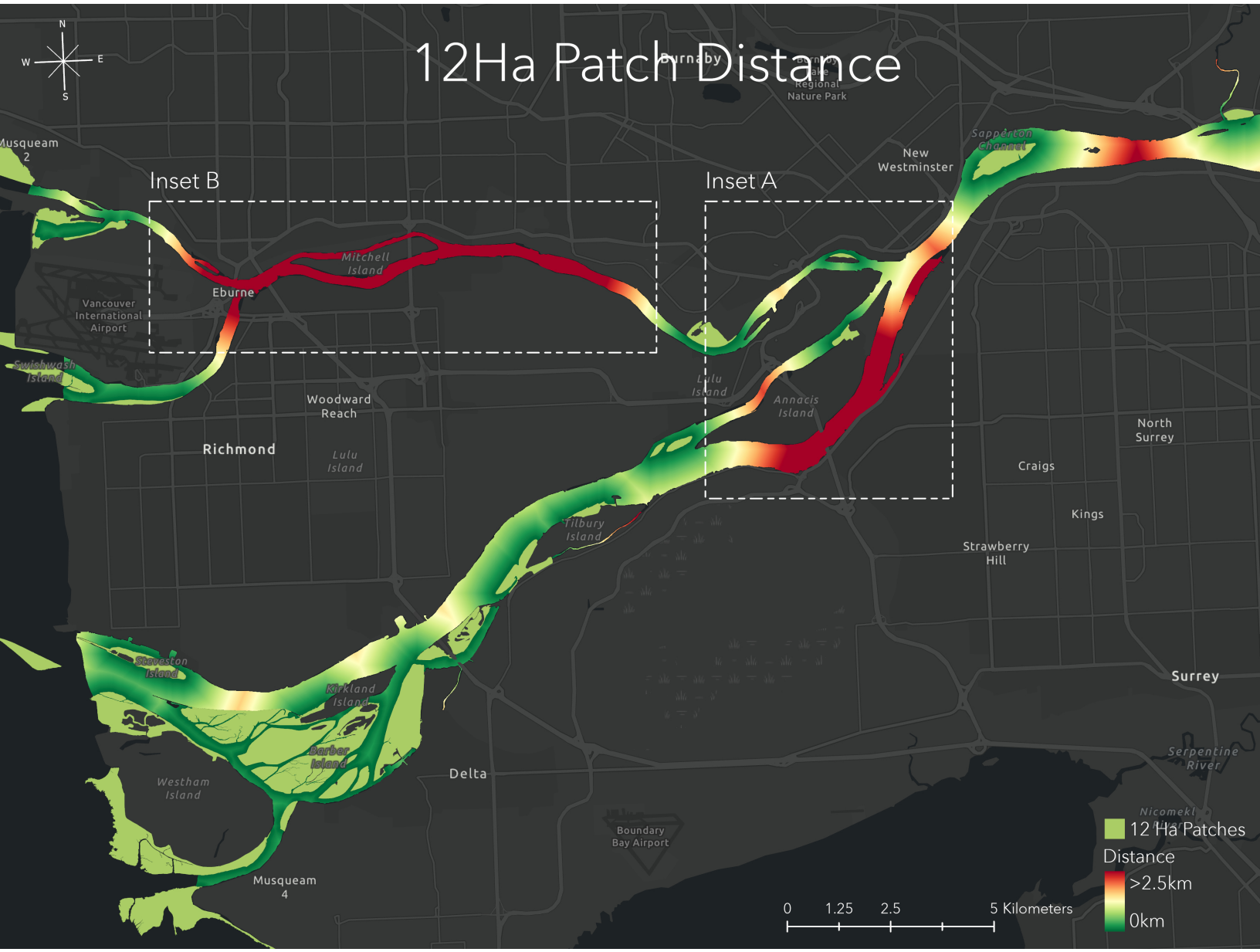

Fig.5: Map of 12Ha habitat patches with a maximum threshold of 2.5km indication regions gaps of large habitat patches

Figure 5 shows habitat patch distance between 12Ha patches with a threshold for 2.5km. 12ha habitat patches are key ecosystems for salmon and are home to complex channel structures that provide ideal habitat conditions. While there are good habitat patches on the upper reaches of the study area and at the lower reaches near the ocean, there are crucial gaps both in the South Arm and North Arm of the Fraser.

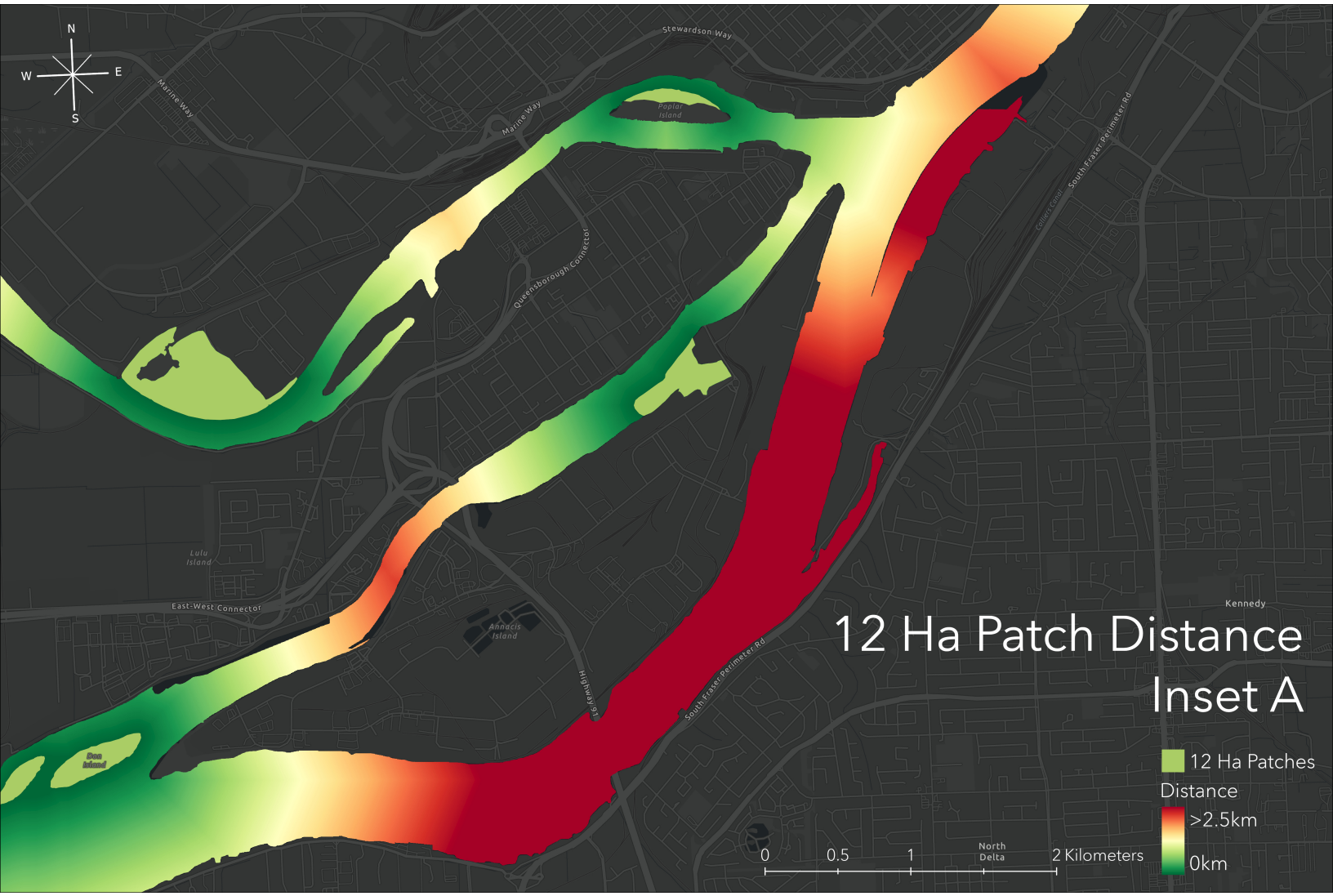

Fig.6: Inset A of 12 Ha habitat patch analysis focusing on Annacis Island's major habitat gap

The Lower Fraser's major gaps fall along Annacis Island 's SE shoreline. This area is highly privatized and industrialized. Home to many large import vehicles holding areas and heavy industrial activity. On the southern shore a steep embankment and soil stability structure have hardened the shoreline and reduced access to streams in the area.

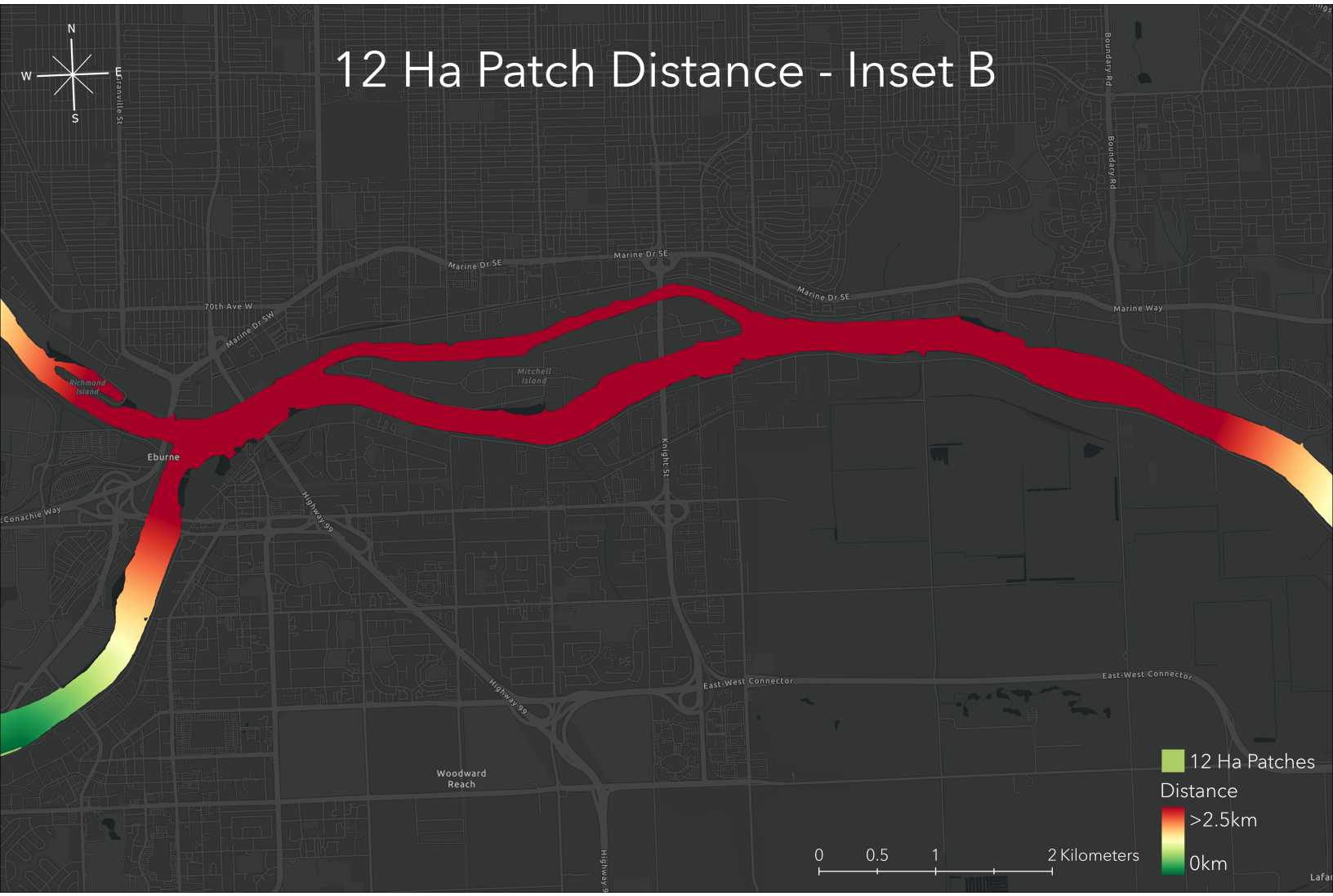

Fig.7: Inset B of 12 Ha habitat patch analysis focusing on the Fraser's North Arm highlighting reaches major habitat gap

The North Arm of the LFR sees a large stretch without any habitat patches above 12Ha. This stretch reaches from YVR to just passed Boundary Rd. This area is one of the older industrial areas in Metro Vancouver and has not only seen industrial development, but has also been subject to residential, commercial, and public infrastructure development. As a result, land values in the area are very expensive and space for restoration is very limited, especially at larger scales.

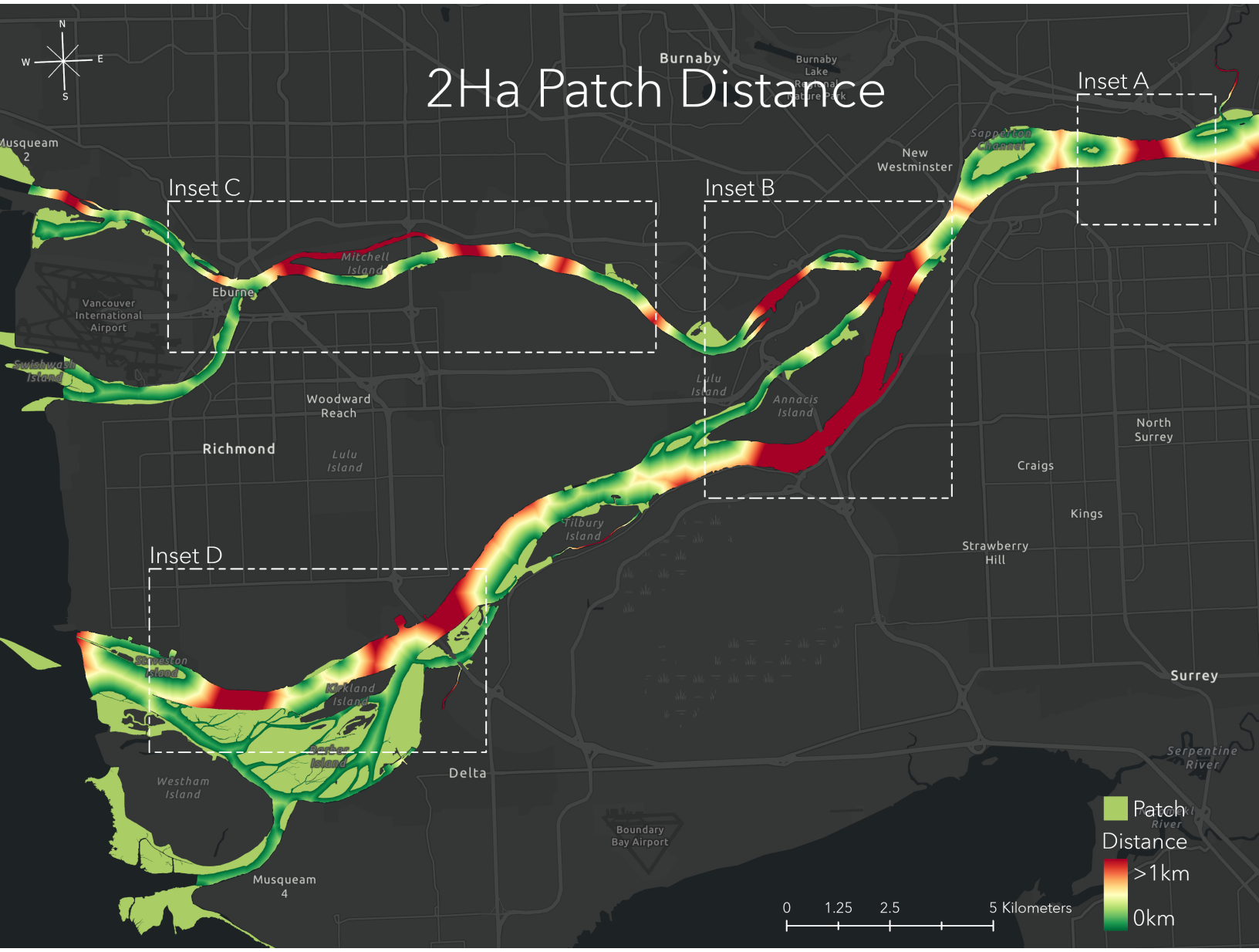

Fig.8: Map of 2Ha habitat patches with a maximum threshold of 1km indication regions gaps of high value habitat patches

The 2ha analysis uses a larger pool of habitat patches but also reduces the threshold distance to 1km. 2Ha patches are the smallest habitat patch size that still support complex off channel stream networks. Many of the gaps present in the 12 Ha analysis are still present but other sections of gaps can also be seen, namely in New Westminster and in the South Arm between Richmond and Delta.

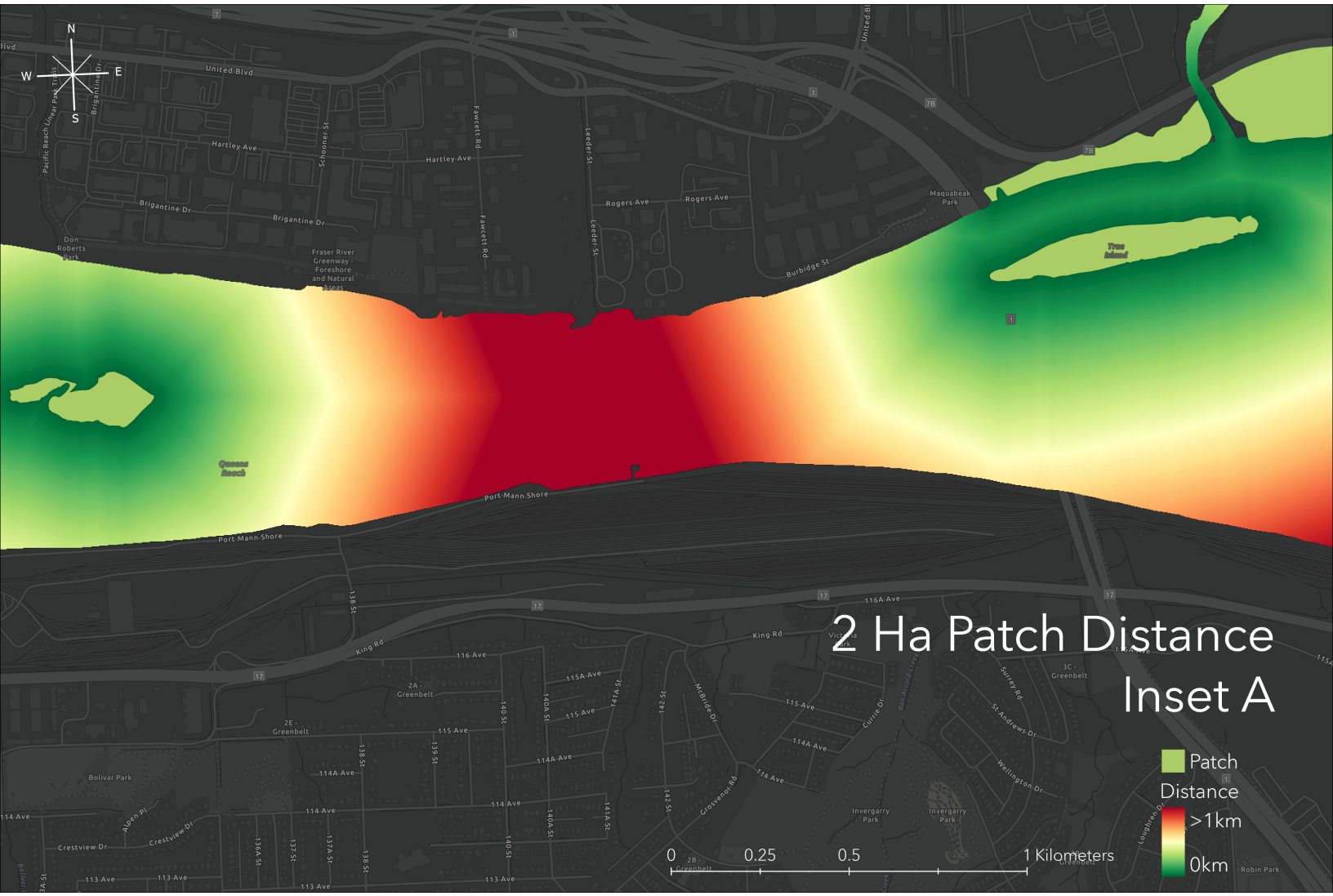

Fig.9: Inset a of 2 Ha habitat patch analysis focusing on New Westminster which is home to a habitat patch gap.

New Westminster does generally have larger and valuable habitat patches, but there is a heavy amount of shoreline hardening near the downtown core due to residential and office buildings on the water. On the south shore a large rail yard has a very long rip rap shoreline with no habitat patches that creates a crucial gap in habitat.

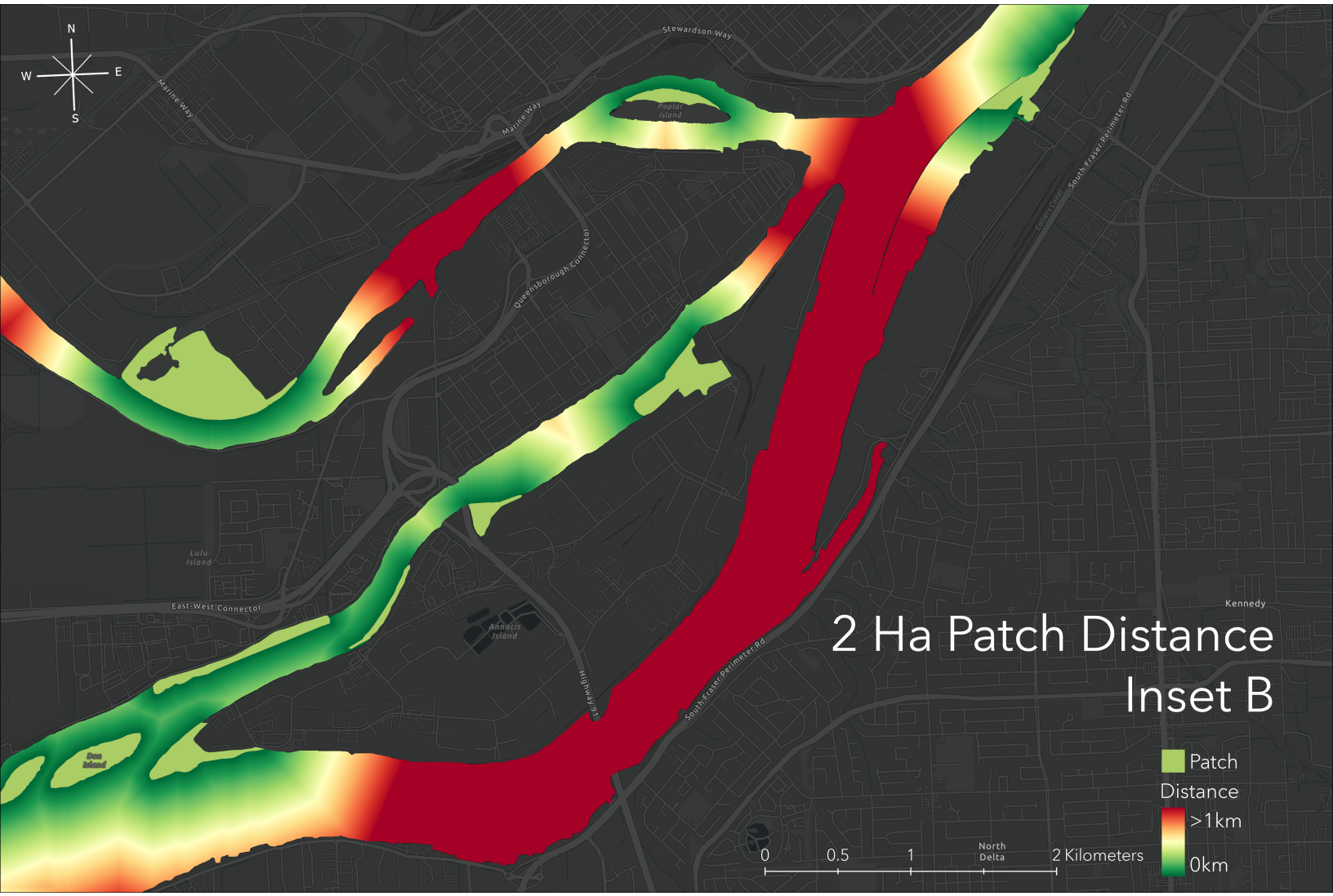

Fig.10: Inset B of 2 Ha habitat patch analysis focusing on the Annacis Island complex habitat patch gap.

Annacis Island once again sees large gaps in habitat patches due to industrial development and a high level of privately owned land. This resulted in depleted 2Ha habitat patches in addition to 12Ha habitat patches.

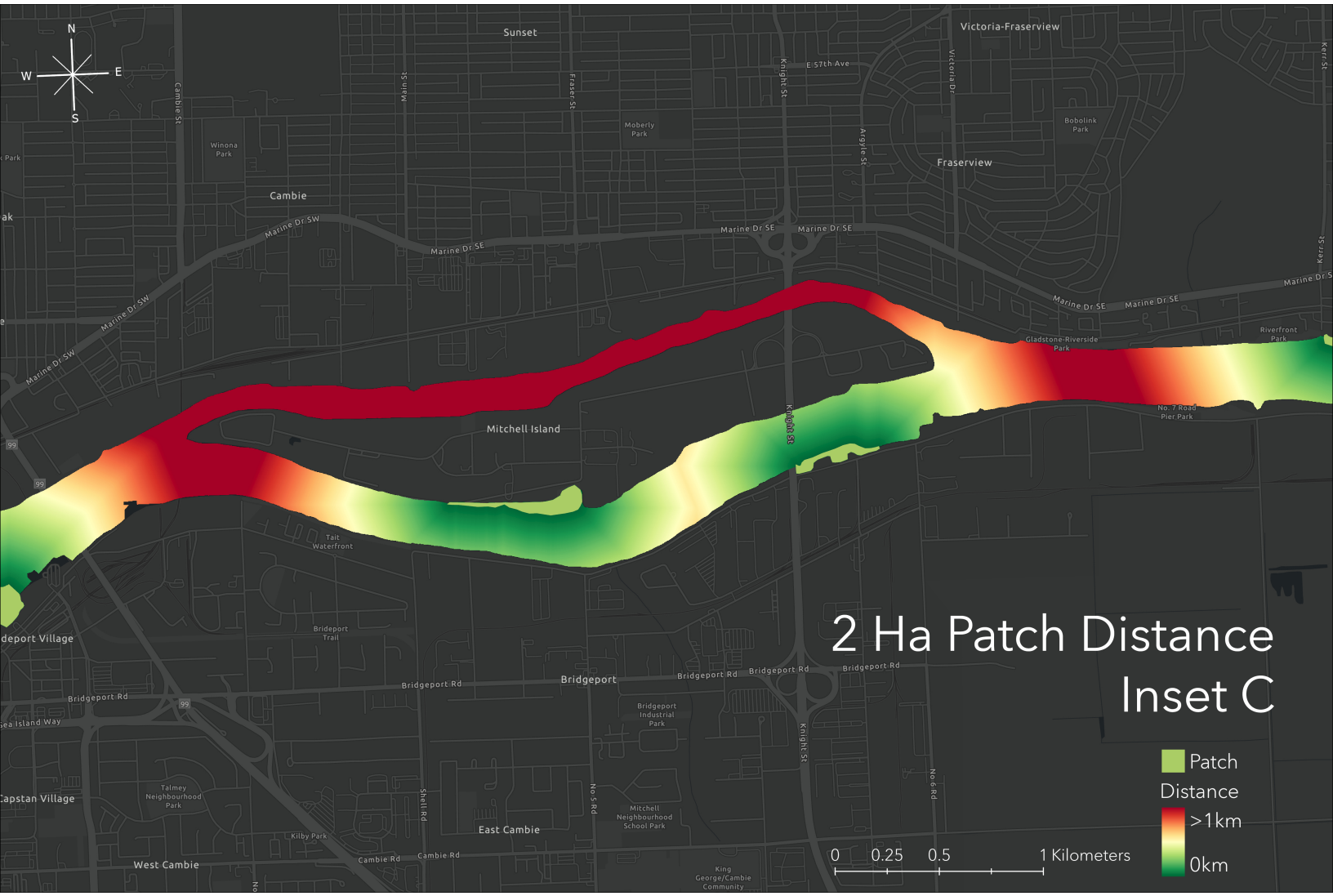

Fig.11: Inset C of 2 Ha habitat patch analysis focusing on the Fraser's North Arm identifying gaps in habitat especially in Mitchell Island's north shore.

The North Arm stretch between Boundary and YVR sees more 2Ha habitats especially along the south shore but still sees large gaps along the north shore citing many of the same issues as the 12Ha patch size.

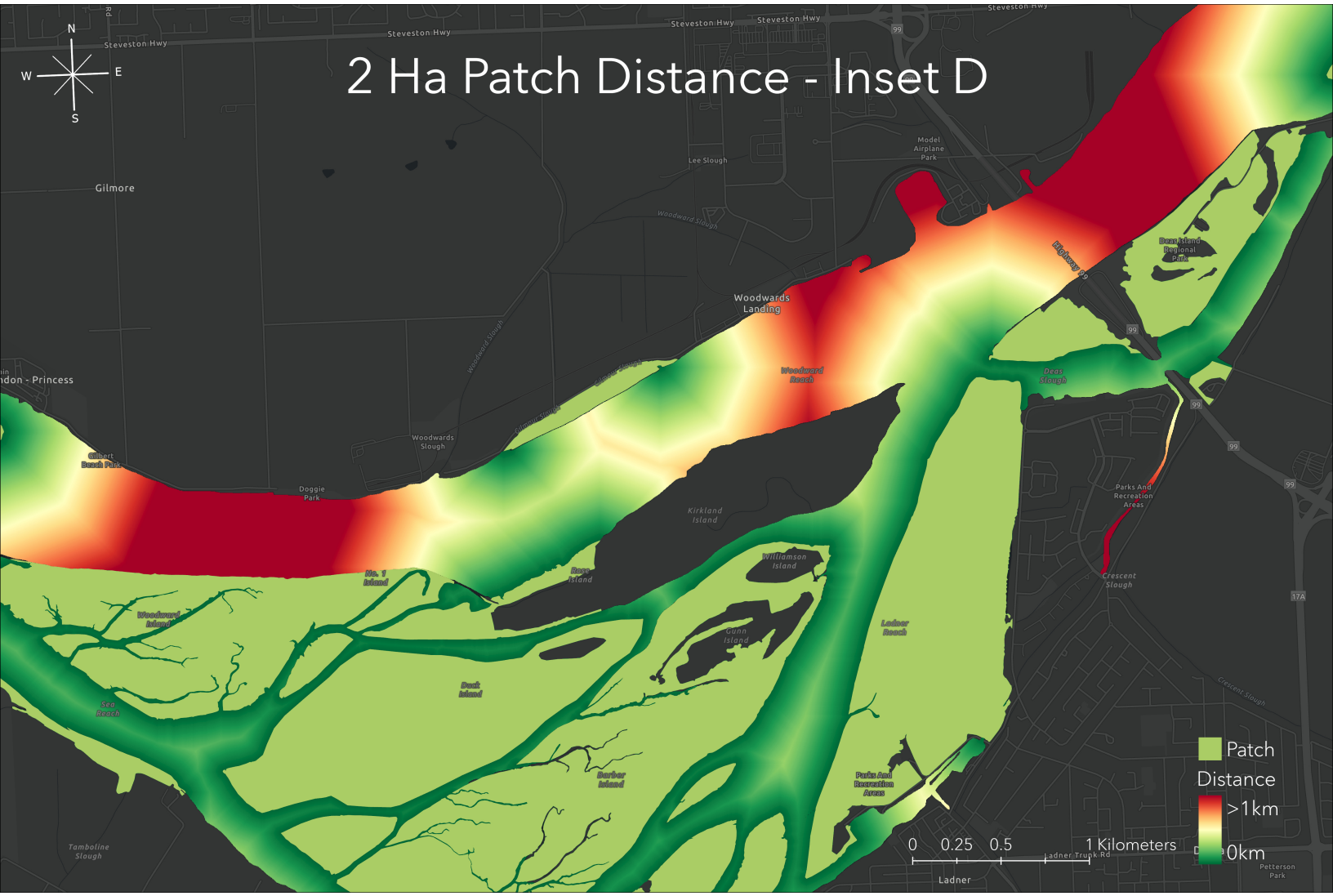

Fig.12: Inset D of 2 Ha habitat patch analysis focusing on Fraser's Lower Arm that is home to plenty of habitat and and unfortunate diking system closing off access

An area that is home to many habitat patches, especially larger ones but faces 1km connectivity issues, is the South Arm marshes near the mouth of the Fraser. Gaps in this area are mainly due to extensive diking that has cut off access to larger habitat patches on the southern shore. As a result, salmon have to swim around these dikes to reach the habitat patches.

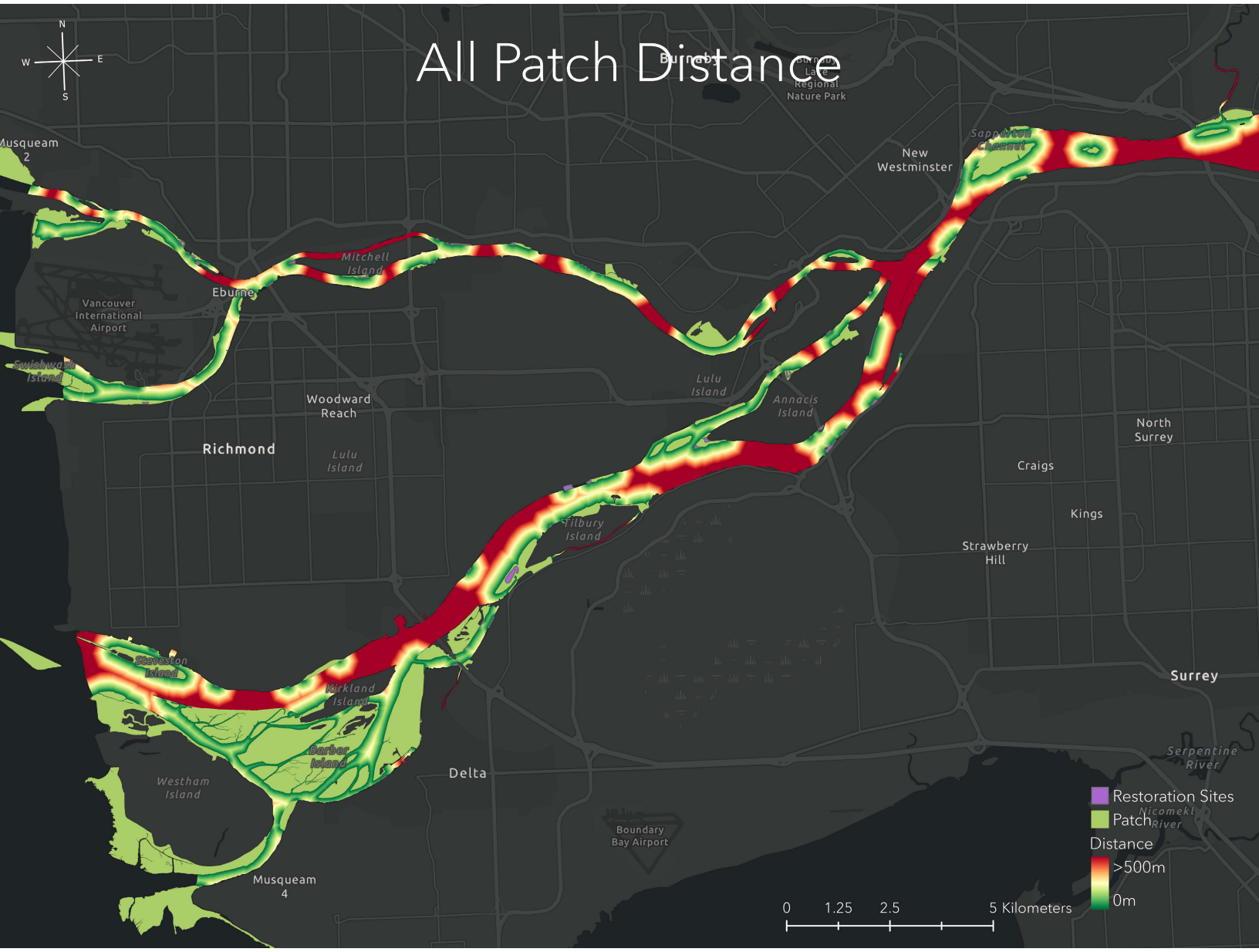

Fig.13: Map of all habitat patch and restoration sites along with a 500m threshold demonstrating fractured ecological connectivity

The 500m analysis considers all habitat patches regardless of size, including small restoration sites. This map shows the extent of habitat gaps on the Fraser even when all habitat patches are included. No reach of the Fraser in the study area, with the exception of the Delta marshes, is exempt from gaps. A 500m analysis was conducted, because regardless that many of these small patches don't support salmon for extensive periods of time, they can provide temporary protection and respite. The caveat is that since these areas don't provide long-term

protection and respite, the distance between these patches should be shorter in order to be of value to out-migrating salmon. This map clearly highlights how extensively developed and, in some cases, hardened the shoreline along the LFR is. The results is that many areas juvenile salmon may have to migrate downstream for multiple tidal cycles before encountering suitable rearing habitats.

Recommendations

While proposing specific sites for restoration is out of the scope of this project, it is clear that certain areas require intervention to support salmon populations. While each of the patch analyses tells an important story, the 2Ha patch analysis tells a good overarching story of the problem and where there are major gaps. Additionally, habitat restoration and conservation should be focused on creating the largest possible habitats or increasing the density of habitats. 2Ha habitat being the smallest that can support complex structures are therefore crucial baseline for habitat restoration. Recommendation would be to implement larger restoration sites in areas that don't have habitat patches. While there are many limiting factors that come into play when trying to implement a restoration project, such as funding and landownership, these are areas that are limited in habitat for out migrating juvenile salmon and in order to protect salmon populations in the LFR, it is essential to provide adequate habitat. These recommendations hopefully provide a clear narrative of the dire state of habitat in the Fraser and will help not only decision makers in locating potential salmon habitat restoration projects, but also in helping educate the public on the state of the Fraser and salmon and increase the awareness of changes that need to be made. It is important to note that while this project provides insightful information on the state of the Fraser shoreline, and the habitat available for out migrating salmon, this project is in no way an exhaustive and all-encompassing study. There are many aspects that affect out-migrating salmon that are beyond the scope of this project such as water quality, the effects of log booms, and vessel traffic, just to name a few. Nonetheless the information presented in this project hopefully helps fill in at least one gap in the story of salmon and the Lower Fraser River and Estuary.

Cited Resources

1. Burrard Inlet Environmental Action Program - Fraser River Estuary management Program. 2017. "Habitat Atlas" The Community Mapping Network (Vancouver, B.C.). https://www.cmnbc.ca/atlasgallery/fremp-bieap-habitat-atlas/

2. Sawyer, Alexandra C., William I. Atlas, Karl M. Seitz, Samantha M. Wilson, and Jonathan W. Moore. 2023. "State-dependent Estuary Stopover Boosts Juvenile Salmon Growth: Implications for Marine Survival." Ecosphere (Washington, D.C)

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6. Hood, W. Gregory, Katie Blauvelt, Daniel L. Bottom, Janine M. Castro, Gary E. Johnson, Kim K. Jones, Kirk L. Krueger, Ronald M. Thom, and Andy Wilson. 2022. "Using Landscape Ecology Principles to Prioritize Habitat Restoration Projects across the Columbia River Estuary." Restoration Ecology.

Data Sources

1. GeoBC. 2006. "Freshwater Atlas Rivers". Distributed by BC Data Catalogue. https://catalogue.data.gov.bc.ca/dataset/freshwater-atlas-rivers

2. DataBC. 2016. "ParcelMap BC Parcel Polygons". Distributed by BC Data Catalogue. https://catalogue.data.gov.bc.ca/dataset/parcelmap-bc-parcel-polygons-ogl

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Appendix

A-1: Annotated Bibliography

Using Landscape Ecology Principles to Prioritize Habitat Restoration Projects across the Columbia River Estuary.

Hood, W. Gregory, Katie Blauvelt, Daniel L. Bottom, Janine M. Castro, Gary E. Johnson, Kim K. Jones, Kirk L. Krueger, Ronald M. Thom, and Andy Wilson. 2022. "Using Landscape Ecology Principles to Prioritize Habitat Restoration Projects across the Columbia River Estuary." Restoration Ecology 30 (3): e13519. https://doi.org/10.1111/rec.13519.

Created a framework to restore habitat and reduce fragmentation through the creation of "stepping stones". This was done through establishing landscape priorities for different salmon species and

development stages. An analysis was conducted using areas of habitat patches, matrices and confluence to establish areas of low habitat connectivity. Optimally, habitat should fall maximum 5km from each other. This article can be used as a model to conduct and analysis of habitat connectivity within the Lower Fraser. Specifically, the methodology and framework established could be useful to conduct our own analysis and establish current habitat patches.

Comparison of Subyearling Fall Chinook Salmon's Use of Riprap Revetments and Unaltered Habitats in Lake Wallula of the Columbia River

Garland, Rodney D., Kenneth F. Tiffan, Dennis W. Rondorf, and Loreley O. Clark. 2002. "Comparison of Subyearling Fall Chinook Salmon's Use of Riprap Revetments and Unaltered Habitats in Lake Wallula of the Columbia River." North American Journal of Fisheries Management 22 (4): 1283–89. https://doi.org/10.1577/1548-8675(2002)022<1283:COSFCS>2.0.CO;2.

Clear analysis on the impact of substrate size and the presence of sub-yearling Chinook Salmon. While this study was conducted in an upland lacustrine and riverine conditions not estuarine the evaluation of shoreline conditions is still relevant and the study found conclusive evidence after conducting a regression analysis that substrate size was a key factor in the presence or absence of salmon indicating that shoreline conditions such as rip-rap are not suitable habitat for sub-yearling salmon and in fact reduce the amount of habitat available for salmon. This study will help to inform what is and is not found as suitable habitat in the Lower Fraser River.

Ecological Effects of Shoreline Armoring on Intertidal Habitats of a Puget Sound Urban Estuary

Morley, Sarah A., Jason D. Toft, and Karrie M. Hanson. 2012. "Ecological Effects of Shoreline Armoring on Intertidal Habitats of a Puget Sound Urban Estuary." Estuaries and Coasts 35 (3): 774–84. https://doi.org/10.1007/s12237-012-9481-3.

This study focused on the Duwamish River's shoreline conditions to evaluate the amount of hardened shoreline and if there were impacts on invertebrates, temperature and salmonid diet to try to understand the impact hardened shoreline have on salmonids. Temperature fluctuation were deleted in hardened shorelines which could impact younger salmon. Invertebrate counts were tenfold greater in unarmoured sites and while diets were not different for chinook there were diet differences for other salmon species. This indicates that hardened shorelines can be hostile places for salmon. More specifically to this project the methodology for mapping the shoreline should be considered especially for areas of low certainty. Additionally, the article established the kinds of hardened shoreline as well and noting absence, presences, and vegetation on shorelines and includes them in the study, a crucial aspect.

Habitat Use by Juvenile Chinook Salmon in the Nearshore Areas of Lake Washington: Effects of Depth, Lakeshore Development, Substrate, and Vegetation.

Tabor, Roger A., Kurt L. Fresh, Richard M. Piaskowski, Howard A. Gearns, and Daniel B. Hayes. 2011. "Habitat Use by Juvenile Chinook Salmon in the Nearshore Areas of Lake Washington: Effects of Depth, Lakeshore Development, Substrate, and Vegetation." North American Journal of Fisheries Management 31 (4): 700–713. https://doi.org/10.1080/02755947.2011.611424.

Supplementary article which highlights juvenile salmon habitat usage. The main take aways which this article provides in context to out study is that once again fewer than expected salmon were found along hardened shorelines. However species did use overhanging structures such as bridges. This was also reflected in the use of overhanging vegetation both day and night depending on sub-species (generally a notable portion of salmon left over head vegetation areas at night however.) Sediment and depth also played a role but may be out of the scope of this project.

Factors Influencing the Resilience of Created Tidal Marshes in the Fraser River Estuary, British Columbia.

Stewart, Daniel, Megan Lievesley, James E. Paterson, Daniel Hennigar, Robyn Ingham, Rob Knight, Brad Mason, and Eric Balke. 2024. "Factors Influencing the Resilience of Created Tidal Marshes in the Fraser River Estuary, British Columbia." Wetlands 44 (5): 53. https://doi.org/10.1007/s13157-024-01802-x.

Insightful article which relays information on the resilience of created tidal marshes as habitat restoration project. Although there is success within these project there are also shortcomings which this article aimed to find to help establish better practices. Most notable were the plant dynamic and site erosion. Invasive species were found especially at up stream sites with increasing dominance. This is likely due to decreased salinity and inundation. Recession caused by erosion is likely caused by wake erosion or Canada Goose grazing among others. This outlines the need for better project design, location and maintenance than creating "resilient marshes over time". While out of the scope of this project looking at monitoring and maintenance plans could vastly increase the potential success of these project. More importantly this article will help in choosing appropriate site to propose habitat restoration work.

Living Shorelines for the Vancouver Region: Ideas for restoring coastal habitats and adapting to sea level rise

Jackson-Drouin, Natasha, Sarah Primeau. 2021. "Living Shorelines for the Vancouver Region: Ideas for restoring coastal habitats and adapting to sea level rise." UBC Sustainability Scholars 2020. https://sustain.ubc.ca/sites/default/files/2020-90_Living Shorelines for the Vancouver Region_JacksonDrouin.pdf

Student body of work that looks at the creation of coastal habitat many examples of which contain examples of salt marshes. While it has been establish that the creation of salt marshes require more than a good initial design but long term management it raises the important point that many of these restoration sites now fall within urban context. As a result, in establishing areas that would be adequate for habitat restoration one has to address the political and social aspect of these project such as: funding, public support, human use, etc. This document highlights project that while may not focus 100% on habitat restoration it does show restoration project which also address human used.

Cohort-Specific Variation in Juvenile Coho Salmon Habitat Use

Bradley, Catherine, Suresh Andrew Sethi, Joshua Ashline, and Jonathon Gerken. 2017. "Cohort-Specific Variation in Juvenile Coho Salmon Habitat Use." Ecology of Freshwater Fish 26 (4): 695–706. https://doi.org/10.1111/eff.12317.

Article that looks at habitat use by different ages Coho Salmon in freshwater rearing habitat to better inform restoration efforts. As such this article is useful in informing where restoration efforts may be best located and the habitat type that will help Coho salmon species specifically. For instance coho under a year prefer shallow, wide stream reaches with in-stream vegetation. More information can be found in the article specifying more variable such as woody debris, specific depth and widths, overhead canopy, etc.

Contrasting Functional Performance of Juvenile Salmon Habitat in Recovering Wetlands of the Salmon River Estuary, Oregon, U.S.A

Gray, Ayesha, Charles A. Simenstad, Daniel L. Bottom, and Trevan J. Cornwell. 2002. "Contrasting Functional Performance of Juvenile Salmon Habitat in Recovering Wetlands of the Salmon River Estuary, Oregon, U.S.A." Restoration Ecology 10 (3): 514–26. https://doi.org/10.1046/j.1526-100X.2002.01039.x.

Evaluates Chinook salmon density in salmon river estuary at different stages of marsh restoration based on dikes being removed at different intervals. This gives a the unique ability to be able to asses at what stage of restoration chinook salmon begin to really rehab locations and at what stage salmon habit the most.

Changes in Habitat Availability for Outmigrating Juvenile Salmon (Oncorhynchus Spp.) Following Estuary Restoration.

Ellings, Christopher S., Melanie J. Davis, Eric E. Grossman, Isa Woo, Sayre Hodgson, Kelley L. Turner, Glynnis Nakai, Jean E. Takekawa, and John Y. Takekawa. 2016. "Changes in Habitat Availability for Outmigrating Juvenile Salmon (Oncorhynchus Spp.) Following Estuary Restoration." Restoration Ecology 24 (3): 415–27. https://doi.org/10.1111/rec.12333.

This article provides useful information regarding the effectiveness of restoration efforts in estuary habitats by monitoring and evaluating pre and post restored habitats using a variety of parameters. Results show that habitat opportunity potential quickly increases following estuarine restoration even if a site has been diked, fragmented from proximal habitat or excluded tidal flows in the past indicating that habitat functionality can increase rapidly following restoration(as quickly as 1 year). It is important to note that this article doesn't look at the long term success of restoration efforts which other articles have mentioned may be a concern. Nonetheless, the paper offers very useful insight into picking suitable estuarine habitats for for future restoration efforts.

A-2: Flood Mitigation Citations

1. Beck, Mike. n.d. "Valuing the Flood Reduction Benefits of Marsh Restoration."

2. Rabinowitz, Tasha, and Jessica Andrews. n.d. "Valuing the Salt Marsh Ecosystem: Developing Ecosystem Accounts," no. 16.

3. Taylor-Burns, Rae, Christopher Lowrie, Babak Tehranirad, Jeremy Lowe, Li Erikson, Patrick L. Barnard, Borja G. Reguero, and Michael W. Beck. 2024. "The Value of Marsh Restoration for Flood Risk Reduction in an Urban Estuary." Scientific Reports 14 (1): 6856. https://doi.org/10.1038/s41598-024-57474-4.

4. Vuik, Vincent, Bas W. Borsje, Pim W. J. M. Willemsen, and Sebastiaan N. Jonkman. 2019. "Salt Marshes for Flood Risk Reduction: Quantifying Long-Term Effectiveness and Life-Cycle Costs." Ocean & Coastal Management 171 (April):96–110. https://doi.org/10.1016/j.ocecoaman.2019.01.010.

5. Wang, Jiang-Jing, Xiu-Zhen Li, Shi-Wei Lin, and Yu-Xi Ma. 2022. "Economic Evaluation and Systematic Review of Salt Marsh Restoration Projects at a Global Scale." Frontiers in Ecology and Evolution 10 (April). https://doi.org/10.3389/fevo.2022.865516.