Fish Passage Barrier Assessment in Wellington City

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Introduction

Freshwater quality has been severely degraded worldwide. Pollution is a widely cited cause of this degradation. Agricultural runoff, industrial discharge, and dumping are key contributors to pollution (Cook *et al*, 2017). This decline in water quality is having drastic effects on freshwater biodiversity. Invasive species are also a common issue affecting biodiversity worldwide (Souty-Grosset *et al*, 2018). In New Zealand, trout are a key freshwater invader. Once trout occupy a stream, it is common for native fish to disappear (Bowie, Jack, and Nelson, 2018). Pollution and invasive species are the most discussed issues for freshwater quality, however, barriers to passage are becoming a pertinent issue as development increases exponentially (Bowie, Jack, and Nelson, 2018; Baumgartner and Silver, 2019).

Physical structures, such as culverts, can create barriers to migrating fish. Freshwater fish need to migrate between habitats to complete their lifecycles (Harris *et al*, 2017). This migration can be between different parts of the freshwater system, or between the sea and freshwater (Chen *et al*, 2019). As human population increases, the demand for water, food, and energy is also increasing. Rapid urbanisation has led to increased development and land use change. Over the last 50 years, irrigation has doubled, and hydropower is expected to double by 2050 (Wilkes, McKenzie and Webb, 2018). Both practices divert and store water, consequently they impede fish passage. Human population is projected to continue growing and urbanising, thus the demand for freshwater services will also keep increasing. Physical barriers have now been recognised as one of the biggest threats to freshwater species globally (Wilkes, McKenzie and Webb, 2018). Therefore, it is important that there is adequate planning and management strategies before such development takes place.

Urban settings are quicky becoming densely populated. Rivers and streams are becoming victim to diversion as roads, houses, and business centres take precedence (Wilkes, McKenzie and Webb, 2018). The most common diversion tactic is via culverts. Streams are diverted into pipes that run underground. These pipes can be as short as 2 metres under a driveway, or up to hundreds of metres long, from the headwaters to the marine outlet. Urban freshwater environments are infrequently recognised as having high ecological value. But as scientists attempt to grapple with degrading ecosystems, urban ecology is becoming increasingly important (Chakravarthy, Charters and Cochrane, 2019).

New Zealand's Freshwater

In New Zealand, there are over 70 major river systems, with thousands of small tributaries webbing across the networks. In total, there are 425,000 kilometres of rivers and streams weaving across the country and 49% of this moves through land that has been modified by agriculture, forestry, or urban settlement (DOC, 2015). Urban streams make up just 1% of New Zealand's total river length but they are the most visible and accessible to New Zealanders. This visibility and accessibility stems from the fact 86% of New Zealand's population live in urban areas (Chakravarthy, Charters and Cochrane, 2019). Unfortunately, urban freshwater ecosystems are seriously threatened by land use change (Freeman and Cheyne, 2008). Therefore, urban streams are largely seeing declines in native species (Larned *et al*, 2016; Franklin and Gee, 2019)

New Zealand is home to hundreds of native freshwater invertebrates and 51 native fish species, 35 of these are endemic (DOC, 2017). Different lifestyles have been adopted by different species. But all must move between habitats at some stage (Jowett and Richardson, 2002). The scale of this movement differs greatly. Some will live their life in the same stream, just moving up or down in search of food. Others, however, must migrate from freshwater to marine habitats to complete their lifecycle. Regardless of the scale of movement, physical barriers can prevent species from accessing habitat vital for their survival. Physical barrier cans see some species eliminated from streams entirely (Franklin *et al*, 2018). Fish that have a marine stage are most affected (Franklin *et al,* 2018; Smith, 2014). Diadromous fish can be broken down into three distinct groups. Catadromous species, such as eels and inanga, live in freshwater but migrate to the sea to spawn. Their juveniles can live in marine habitats for up to 6 months before navigating their way back to freshwater. Anadromous fish, such as lamprey, live at sea and only move to freshwater to reach sexual maturity and breed. Amphidromous species like bullies migrate between marine and freshwater habitats for reasons other than to breed (Smith, 2014). New Zealand has a high proportion of diadromous fish – approximately 16 or the 35 endemic species must migrate to the ocean at some stage, therefore barriers to fish passage has a very large effect on New Zealand's freshwater biodiversity (Jowett and Richardson, 2002).

Barriers affect different species more than others. Some fish, such as eels, koaro, and banded kokopu are adept climbers. These species have no trouble scaling vertical waterfalls and weirs and can swim against the increase water velocity in pipes. Others, however, such as giant kokopu and inanga, are poor climbers (Smith, 2014). These species can be locked out of streams by just one barrier. In urban environments, such as Wellington City some streams are piped from the headwaters right down to the sea. This creates a barrier right from the start, and if there is a large drop between the culvert outlet and the sea, it can be completely inaccessible.

Barriers

There are various structures that can create barrier to fish passage. Some are natural, such as slips and waterfalls, but most are instream structures. The NIWA fish passage assessment tool identifies 10 barriers, of which dams, weirs, culverts, and forwards pose the greatest risk (NIWA, 2020). Individual barriers can vary in characteristics, creating either a higher or lower risk. For example, culverts can have large drop heights with large undercuts, leaving nowhere for even a climbing fish to navigate. Whereas others are level with streams, meaning no climbing is necessary. However, culverts are often much narrower than the natural stream, meaning water velocity increases markedly. Those that cannot grip to the culvert substrate will struggle to swim against the increased flow and become too exhausted to venture further upstream. Other barriers, such as weirs and dams, confront freshwater species with vertical drops that can range from less than a metre high, to hundreds of metres high. Climbing fish can scale some vertical drops, but even they struggle with the larger structures (Franklin *et al*, 2018).

In 2018 NIWA released fish passage guidelines for New Zealand. This document details the recommended practice for instream structures. It also sets out how existing barriers can be modified to improve fish passage. The intention is to improve management of fish passage through out New Zealand. Modifications include adding mussel spat rope, baffles, or rock ramps to a structure. The goal is to provide fish with grip or resting stations, or to alter water flow to allow weaker swimmers to pass (Franklin *et al*, 2018). Figures 1 and 2 show different modification techniques that could be used to improve fish passage.

Figure 1: Spoiler baffles in a culvert slow water velocity (Franklin, 2018).

Figure 2: Spat rope in a culvert. Fish have something to grip as they move upstream (Franklin *et al*, 2018).

In Wellington City, the most common barriers are culverts and weirs. Over the 2019/2020 summer season 213 barriers were mapped, of these, 154 were culverts (NIWA, 2020). This reflects the high prevalence of small streams in the main urban and suburban areas. As Wellington has grown, there has been an increase in the diversion of streams to facilitate development. This was once done with very little consideration for fish passage, but there is now a growing awareness of the issue. Greater Wellington Regional Council (GWRC) began a wide scale project to assess urban stream health in 2016. This project ultimately aims to restore freshwater habitats and increase native fish biodiversity in the Wellington Region (GWRC, 2019).

This study will bring two data sets together. The first, is barrier data collected during the 2019/2020 summer season. This was collected by students from Victoria University of Wellington as part of a project for Greater Wellington Regional Council. The purpose of this study was to establish the situation in Wellington City in terms of fish barriers. Accessible barriers between Miramar, Karori, and Tawa were assessed and uploaded to the NIWA Fish Passage Assessment Tool. These barriers were given risk scores based on their characteristics. Figure 3 demonstrates where barriers were concentrated around Wellington City. The coloured squares represent the barriers marked for GWRC. It is this data that will be used. The grey squares represent presumed barriers based on historical data. This data will not be used as it is not accurate, with some barriers marked in areas where a stream no longer exists. It will be suggested, however, that these barriers ought to be visited and have an assessment conducted.

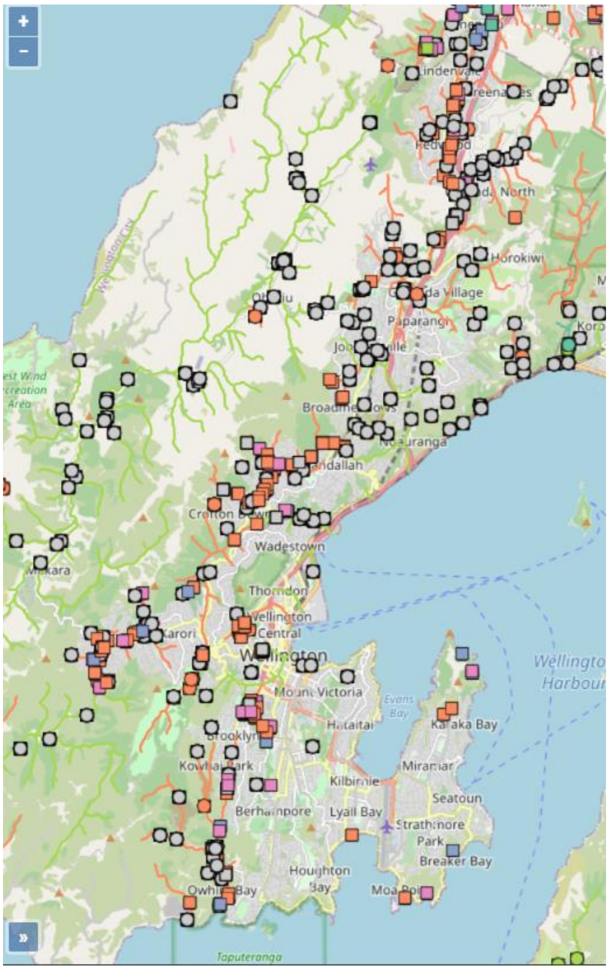

Figure 3: Map showing fish barriers around Wellington City.

The second set of data was collected over previous years by members of GWRC's marine and freshwater science team. It details native fish distribution across Wellington City. This data shows different fish species and the streams, and the sections of each stream where they were found. By comparing both sets of data this study aims to identify which structures are restricting which native fish from different streams and their sections. Comparison will also allow the amount of inaccessible upstream habitat to be quantified.

By identifying these barriers, this study will produce a prioritisation list suggesting which structures should be modified first. Barriers will be prioritised based on the ecological success modification will bring. The results and recommendations that this study produces will contribute to GWRC's wider urban freshwater project that aims to restore native species diversity in Wellington's urban streams.

Methods

Data sets had been collected prior to this project commencing. Two sets were used in this project. The first was fish barrier data collected by students working in collaboration with Greater Wellington Regional Council to map barriers to fish passage around Wellington City. It was sourced from the NIWA Fish Passage Assessment Tool and provided by GWRC. Barriers to fish passage have been mapped across New Zealand. These data are publicly available and can be downloaded as an Excel spreadsheet directly from the NIWA Fish Passage Assessment Tool website (2020). The second was native fish distribution data collected and provided by the Marine and Freshwater Science team at GWRC. Both sets were converted to shape files to be uploaded to GIS software.

ArcGIS was used to compare data sets. When uploaded, the map displayed where fish monitoring data had been collected along each stream, as well as all the barriers that have been mapped. Barriers are represented as black diamonds and fish monitoring sites as red triangles. Figure 1 exemplifies the layout of the data sets. Each fish site had details on what fish and how many individuals were observed. This allowed observations to be made about what fish had access to which streams, and what sections of each stream.

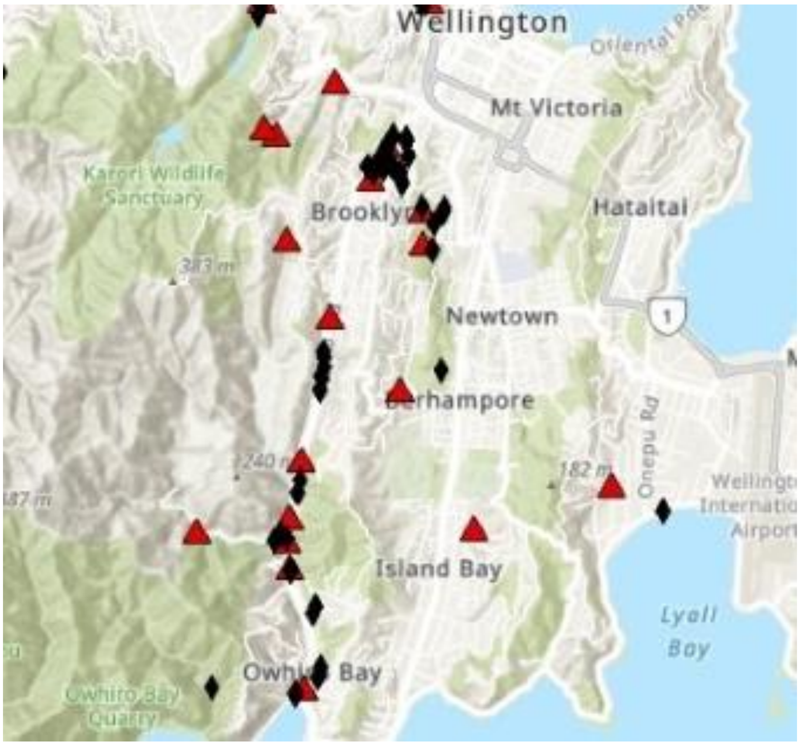

Figure 1: Visualization of the data sets. Red triangles are fish sites and black diamonds are barriers to passage.

For ease of identification, I have numbered each of the fish monitoring sites in each stream. Fish site 1 is the monitoring site at the lowest point of the stream. They are then numbered consecutively going upstream. This is to provide a point of reference when looking at the Figures and Data tables. Figure 2 exemplifies how fish sites were named. Fish site 1 is the closest monitoring site to the outlet, while Fish Site 6 (in this case) is the furthest monitoring site upstream. Fish monitoring sites were named only if they were on a stream or tributary with adequate data to assess.

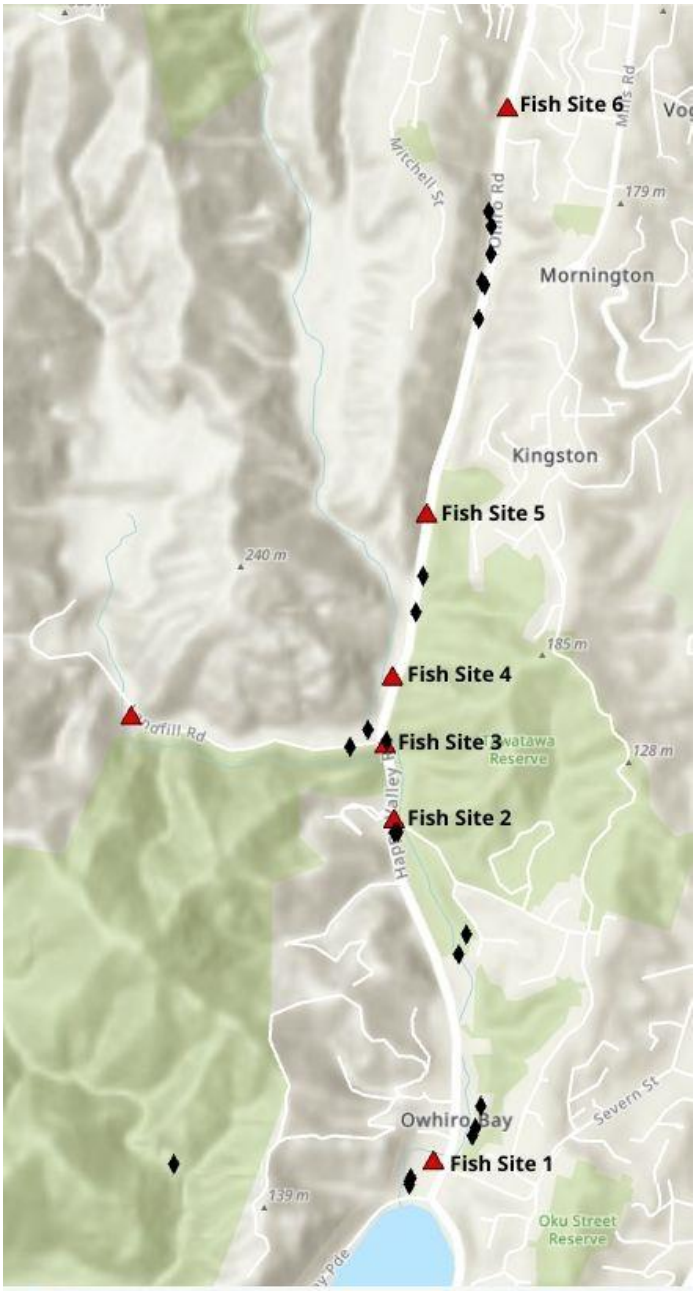

Figure 2: Visualization of how fish monitoring sites were names. Fish site 1 is located closest to the outlet. Subsequent sites are named and numbered consecutively.

Fish species were given abbreviations for identification. A key to interpreting this is found below.

Table 1: Fish Species Identification Key

Scientific Name	Common Name	Study Code
Anguilla dieffenbachii	Longfin eel	LF
Anguilla australis	Shortfin eel	SF
Galaxias fasciatus	Banded kokopu	BK
Galaxias argenteus	Giant kokopu	GK
Galaxias brevipinnis	Koaro	K
Galaxias maculatus	Inanga	I
Gobiomorphus huttoni	Red fin bully	RFB
Gobiomorphus gobioides	Giant bully	GB
Gobiomorphus breviceps	Upland bully	UB
Unidentified	Unidentified	U

When comparing the locations of barrier data and fish data it was discovered Karori Stream, Kaiwharawhara Stream, and Owhiro Stream had the most overlap in the two data sets. The overlap of data provided a clearer understanding of the relationship between barriers and distribution in these streams. Therefore, they became the primary focus of this study. Figures 3 and 4 show the locations of the Wellington City Catchments. Kaiwharawhara, Karori, and Owhiro Catchment. They are all either west or south west of the central city. The location of these catchments has led to less redirection into pipes underground as there is less development. Therefore these streams have the most potential for restoration as they have the most above ground habitat available (Zealandia, 2018; (Chakravarthy, Charters and Cochrane, 2019).

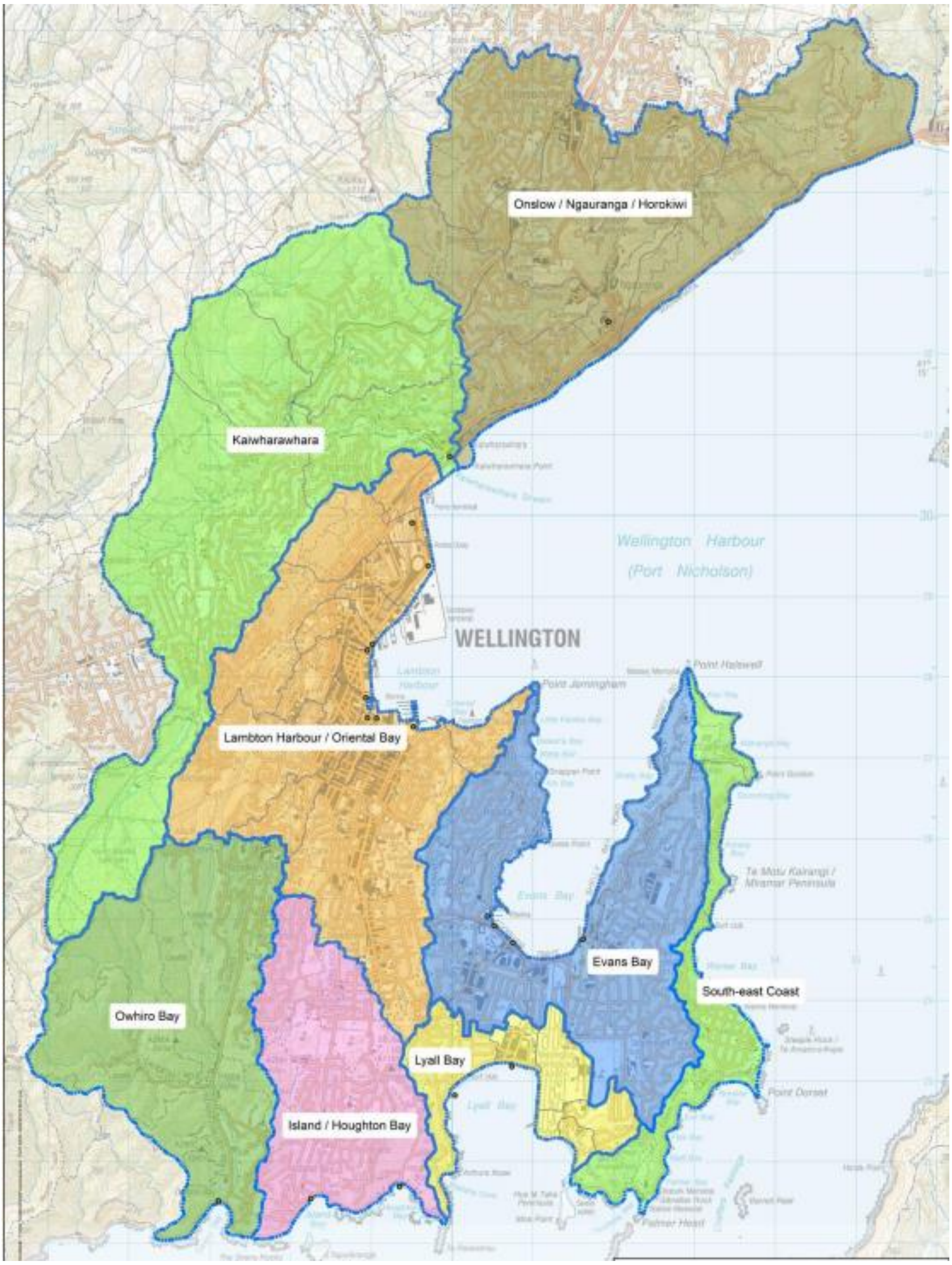

Figure 3: Map showing Wellington City storm water catchments. Kaiwharawhara and Owhiro both border the central city. Kaiwharawhara is the largest catchment and Owhiro has a low level or urban development (Jayaratne, 2014).

Figure 4: Map showing Karori Catchment. It borders Kaiwharawhara and Owhiro catchments to the west. According to these maps the Karori Catchment has the least amount of urban development (Tonkin and Taylor, 2020).

Fish data were limited, for example, at 10 sites just one individual of a species was recorded. Therefore, for the purpose of this study, the abundance of a species at each monitoring site was not taken into consideration. The presence of one individual signifies the species is capable of reaching that section of the stream. This method leaves no room for human error in identification. Therefore, research into the climbing capabilities of each fish was conducted in order to identify any surprising results in where fish were accessing. Table 2 shows the climbing abilities of the species observed in this study. This information led to questioning the Kaiwharawhara Stream dataset. Giant kokopu (poor climbers) were observed further upstream than koaro and red fin bully, both of which have great to excellent climbing abilities (GWRC, 2020; Tasman District Council, 2009; MPI, 2015; NIWA 2016; NIWA, 2018). This subsequently led to recommendations on further data gathering to clarify the data.

Table 2: Climbing abilities of fish species observed in this study. This leads to the expectation that LF, SF, K, and BK will be found further upstream than others if there are barriers to fish passage.

Species	Climbing Ability
Longfin eel	Excellent
Shortfin eel	Excellent
Koaro	Excellent
Banded kokopu	Great
Red fin bully	Good
Inanga	Poor
Giant kokopu	Poor
Giant bully	Poor
Upland bully	Poor

I used observational date to complement the fish barrier data. Not all barriers that were located during the 2019/2020 summer season were mapped due to inaccessibility. Therefore, they are not present in the fish barrier data used for this project but still pose risk to fish passage. When it was suspected a fish barrier could be present that was not represented in the data set, Google Earth was consulted. Google Earth was also used as a measuring tool and to provide visual aids.

Recommendations for barrier modification were based of the location of the barrier in the stream and its relation to other barriers. The fish diversity either side of the barrier was used to inform whether modification would provide ecological benefits. If data were insufficient then it was recommended further monitoring take place before barrier modification. This is to ensure the greatest ecological success from barrier modification.

Results

Comparing fish barrier location and fish distribution revealed which barriers are the most problematic in Kaiwharawhara, Owhiro, and Karori streams. These streams are the focus streams for restoration potential. It also revealed that there is currently a disconnect in the available data, with a lot of barrier data having been collected in areas that fish distribution has not been monitored and vice versa. The most common barriers across these streams were culverts followed by weirs. Karori Stream had the most total barriers followed by Owhiro then Kaiwharawhara. However, Owhiro Stream had the most barriers per 100 metres followed by Karori and Kaiwharawhara Streams. Owhiro Stream also had the most fish monitoring sites per 100 metres, followed by Kaiwharawhara Stream then Karori Stream. Figure 5 visualizes the types and frequencies of barriers across the three focus streams. Table 3 shows the number of barriers and fish monitoring sites per 100 metres in each stream. Figure 6 then shows the locations of all barriers throughout Wellington City and their relation to the fish monitoring sites.

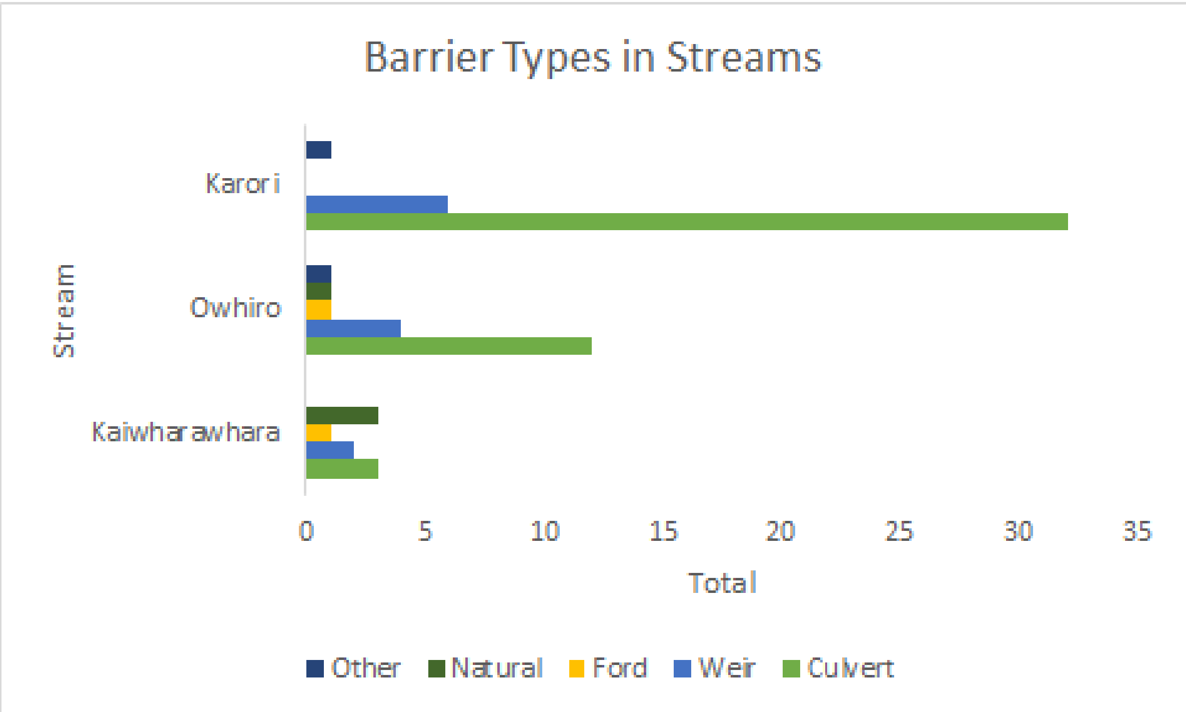

Figure 5: Graph showing the frequency and variety of barriers across the three focus streams.

Table 3: Frequency of barriers and monitoring sites across focus streams. Calculated from approximate length (Google Earth) and the number of mapped barriers and fish sites. Does not include known barriers that are not mapped, just those represented in the barrier data set.

	Owhiro Stream	Karori Stream	Kaiwharawhara Stream
Stream Length	3800m	11600m	6400m
Total Barriers	19	39	9
Barrier/100m	1/200m	1/297m	1/711m
Total Fish Sites	6	8	6
Site/100m	1/633m	1/1450m	1/1066m

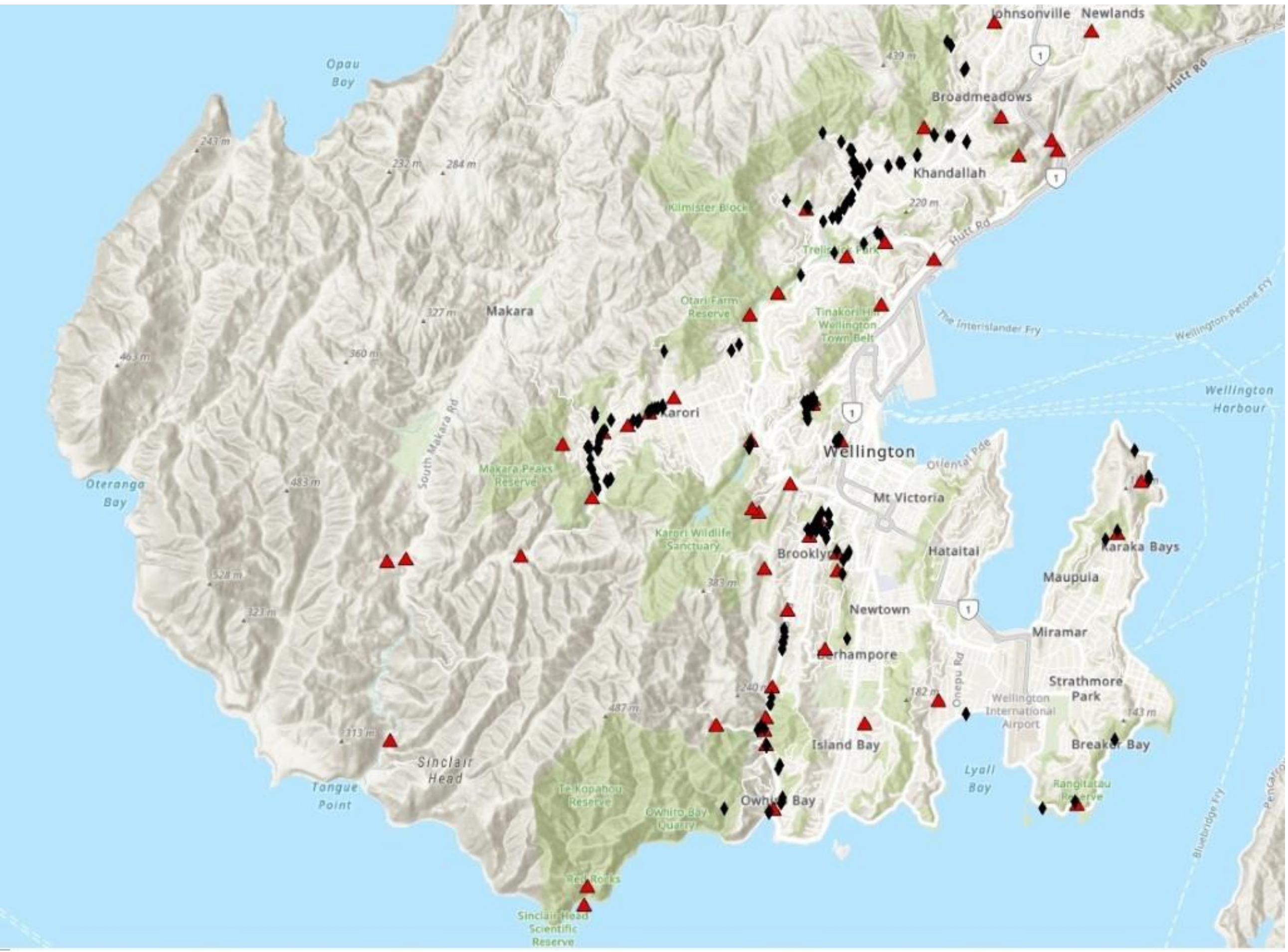

Figure 6: Distribution map of barriers and fish monitoring sites across Wellington City. Red triangles represent fish monitoring sites while black diamonds are barriers to fish passage.

Kaiwharawhara Stream

Kaiwharawhara Stream is the only urban stream with a natural estuary mouth entering the harbour. It had the least barriers (9) to fish passage mapped. Closer observation of the barrier data on the NIWA website revealed that many of the barriers in the lower section were not on the main stream, but small tributaries. While this makes the tributaries hard to access, the main stream remains unobstructed. There were six monitoring sites throughout the Kaiwharawhara Stream. Figure 7 shows the locations of barriers and fish sites in the stream. Kaiwharawhara had the highest fish diversity of all the streams surveyed. Eight native freshwater fish species have been observed. Table 4 summarises the fish species found in the stream and where they were observed.

Figure 7: Locations of barriers to fish passage (black diamonds), fish monitoring sites (red triangles) in the Kaiwharawhara Stream and an unmapped barrier in the lower section.

Table 4: Kaiwharawhara Fish Summary Data. Species diversity and number of individuals found at each fish monitoring site in the Kaiwharawhara Stream.

	Fish Site 1	Fish Site 2	Fish Site 3	Fish Site 4	Fish Site 5	Fish Site 6
LF	1	2	6	4	3	2
SF	1	1	0	0	0	1
BK	1	1	0	16	9	8
GK	1	0	0	1	0	0
K	1	0	0	0	0	0
I	1	0	0	0	0	0
GB	1	0	0	0	0	0
RFB	1	6	0	0	0	0
U	0	3	5	0	5	0

There was a significant drop in species diversity after fish site one. However, Figure 7 does not show a barrier present between fish site one and two. Google Earth, however, shows that the stream disappears for approximately 115 metres. It is likely there is a pipe in this section. Koaro, inanga, and giant bully do not have access to the upstream habitat, suggesting they cannot pass through the pipe. Red fin bully do not appear after fish site two. There are three barriers between fish site two and three. Two of these barriers are on tributaries, while one is on the main stream. Thus, this barrier is likely obstructing fish passage. Only Longfin and short fin eels, and banded kokopu have access to the higher reach of the Kaiwharawhara Stream.

One giant kokopu was recorded at fish site 4. Koaro were not observed past fish site one. This is interesting as giant kokopu are not climbing fish, thus struggle to pass through culverts and climb weirs, whereas koaro are very adept climbers (DOC, 2017; Franklin and Gee, 2017). This suggests a potential miss identification in the original data set. However, giant kokopu have been documented establishing landlocked populations. Normally, they breed in freshwater and the juveniles drift out to sea before returning to mature. Studies by David *et al* (2004) and Bonnet *et al* (2002) showed giant kokopu have flexible recruitment strategies. There is not enough data to determine what is occurring in this instance therefore it is a key focus for future studies.

Owhiro Stream

Owhiro Stream had 19 barriers mapped. Four fish species were observed across five fish sites. Like the Kaiwharawhara Stream Owhiro Stream has a natural estuary mouth, however it enters the ocean on the south coast rather than the harbour. There is significantly less fish diversity in this stream, with just four species being observed. Table 5 summarises the fish distribution. The fish sites referred to in this table are visible on Figure 8. Figure 8 visualises the locations of barriers and fish sites.

Table 5: Owhiro Stream Fish Summary Data. Species diversity and number of individuals found at each fish monitoring site in the Owhiro Stream.

	Fish Site 1	Fish Site 2	Fish Site 3	Fish Site 4	Fish Site 5
LF	1	4	1	8	5
SF	4	4	0	3	1
BK	0	1	0	2	5
RFB	10	3	0	0	0

Red fin bully are only present at fish sites one and two. There are no barriers between fish site two and three, however fish site three is just downstream of a culvert and a weir. Long fin and short fin eels, and banded kokopu are present throughout the stream. These three species have good climbing abilities (GWRC, 2020; Tasman District Council, 2009) thus can navigate the numerous culverts and weirs throughout the stream. There are three barriers (a ford and two weirs) very close to the mouth of Owhiro Stream that could be preventing other fish, such as inanga and giant kokopu from accessing the upstream habitat.

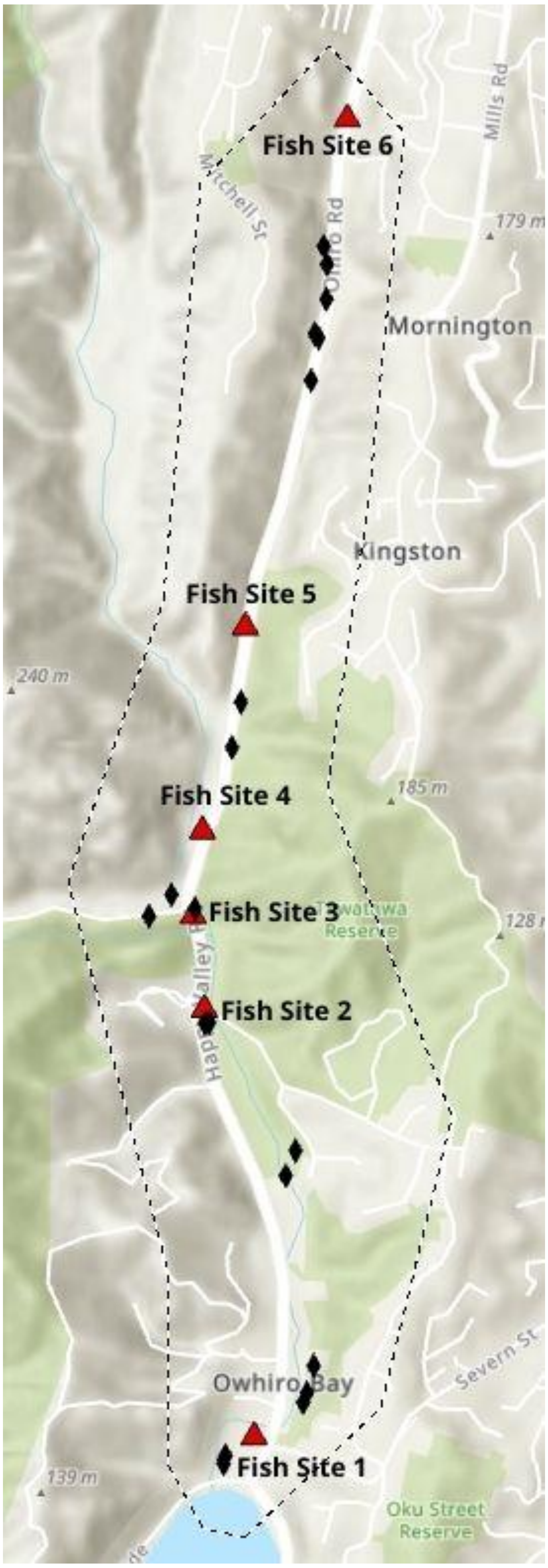

Figure 8: Locations of barriers to fish passage (black diamonds) and fish monitoring sites (red triangles) in the Owhiro Stream.

Karori Stream

Karori Stream also has a natural estuary mouth, entering the ocean on the south coast of Wellington, west of the Owhiro Stream. It had the highest number of barriers at 39 with the large majority being culverts. However, many did not disrupt the main stream. Instead tributaries that are mostly piped beneath residential areas until they meet the main stream make up most of the mapped barriers. Like Kaiwharawhara, this obstructs access to these tributaries, but leaves the main stream accessible. Karori Stream had the highest number of unidentified fish observed at 22, with 20 unidentified at just one fish site. Table 6 shows the species diversity and distribution, and Figure 9 shows the locations of barriers and fish sites throughout the Karori Stream.

Table 6: Karori Stream Fish Summary Data. Species diversity and number of individuals found at each fish monitoring site in the Owhiro Stream.

	Fish Site 1	Fish Site 2	Fish Site 3	Fish Site 4	Fish Site 5	Fish Site 6	Fish Site 7	Fish Site 8
LF	23	5	5	0	13	1	2	0
SF	0	0	0	0	0	1	0	1
BK	0	0	0	7	0	0	0	0
K	0	5	0	3	0	0	0	0
UB	22	4	2	0	3	0	0	0
U	0	0	0	0	20	2	0	0

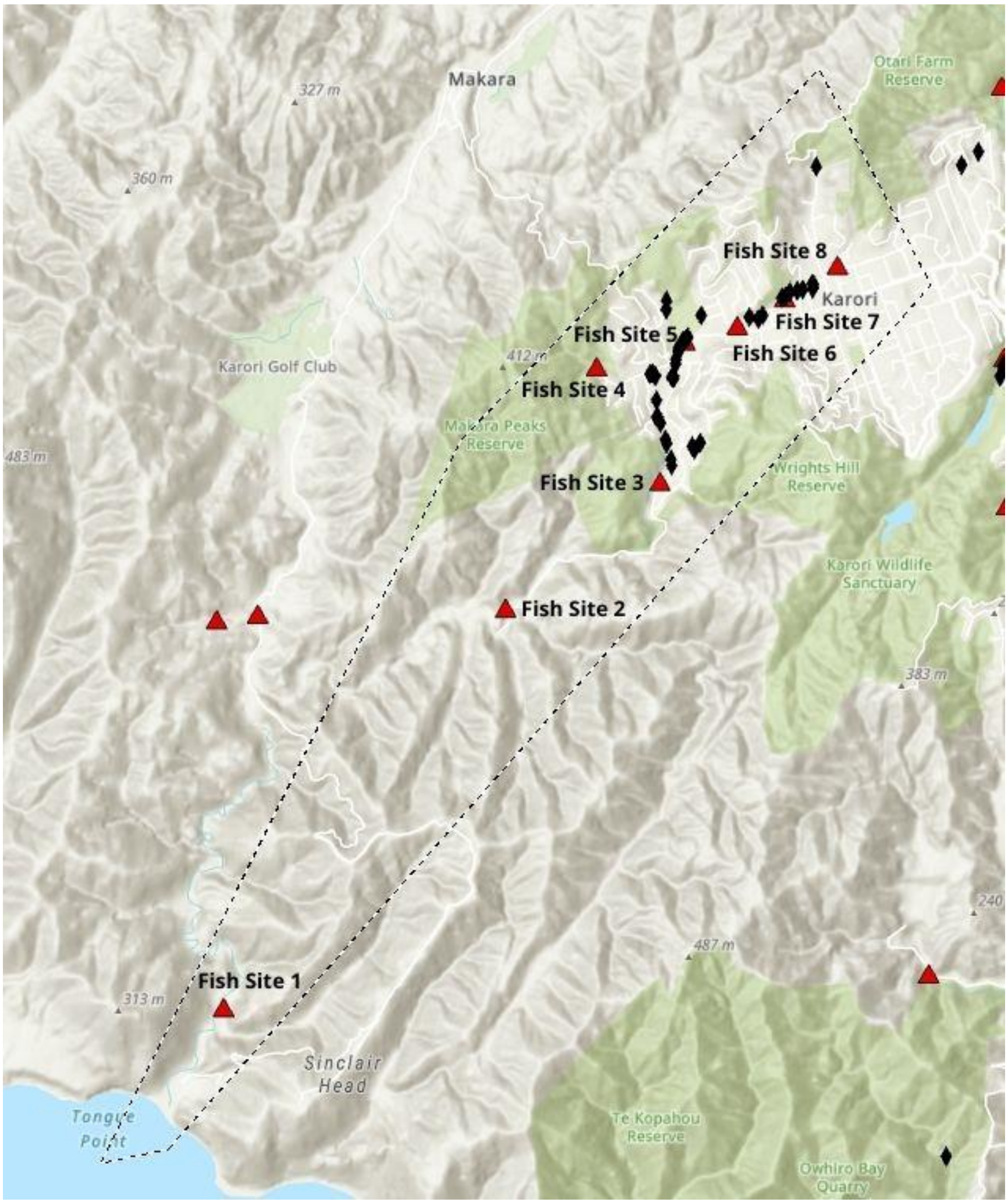

Figure 9: Locations of barriers to fish passage (black diamonds) and fish monitoring sites (red triangles) in the Karori Stream.

Five different species have been observed in the Karori Stream. Only the eel species' have been observed in the highest reaches of the stream. Banded kokopu and koaro, both adept climbers are not observed beyond fish site four. There are however, 20 unidentified species at fish site five and two at fish site six. Therefore, it cannot be ruled out that these species are not making it further upstream.

Most of the barriers between fish site four and six are culverts, with most connecting underground tributaries to the mainstream rather than obstructing the mainstream itself. There are two weirs on the mainstream. One is very degraded and broken down, creating undercuts and steep drops (NIWA, 2020), which could be preventing koaro and banded kokopu reaching the upstream habitat.

Upland bully are common in the lower section of the stream but decline steadily and are not observed past fish site five. Fish site five is in a section of stream that has a cluster of barriers. The broken weirs are in this section along with four culverts. According to this data, this section of stream is very problematic for fish passage.

Other Streams

The three focus streams above have a natural estuary mouth and the most above ground habitat available in Wellington City. All other streams are piped for most of their reach, only being above ground for small sections. For example, the Kumutoto Stream is above ground for just 90 metres between its headwaters in Kelburn and its outlet in the Wellington Harbour. A natural estuary mouth is key in supporting a diverse population due to the marine stage in many species' lifecycles. Those, such as inanga and giant kokopu, that cannot climb are barred from accessing the stream from the very start of their lives.

Kumutoto, along with streams in Central Park, Prince of Wales Park, the Botanical Gardens, and Miramar have very little fish diversity. Just banded kokopu, eels, and koaro have been observed in these streams. This is to be expected given these streams are largely part of the underground storm water network.

The Korimako Stream, the main tributary to the Kaiwharawhara Stream, has just two fish sites. The lower section of this stream is relatively unobstructed as it flows into the Kaiwharawhara, but the upper section is littered with barriers, primarily culverts. Like in other heavily piped streams around Wellington City, just banded kokopu and eels have been observed at the fish sites. The lower section has some potential for higher diversity, however there is no data to support this claim. Furthermore, the unmapped pipe in the lower Kaiwharawhara will severely limit this potential. Figure 10 demonstrates the high volume of fish barriers in the upper Kumutoto Stream.

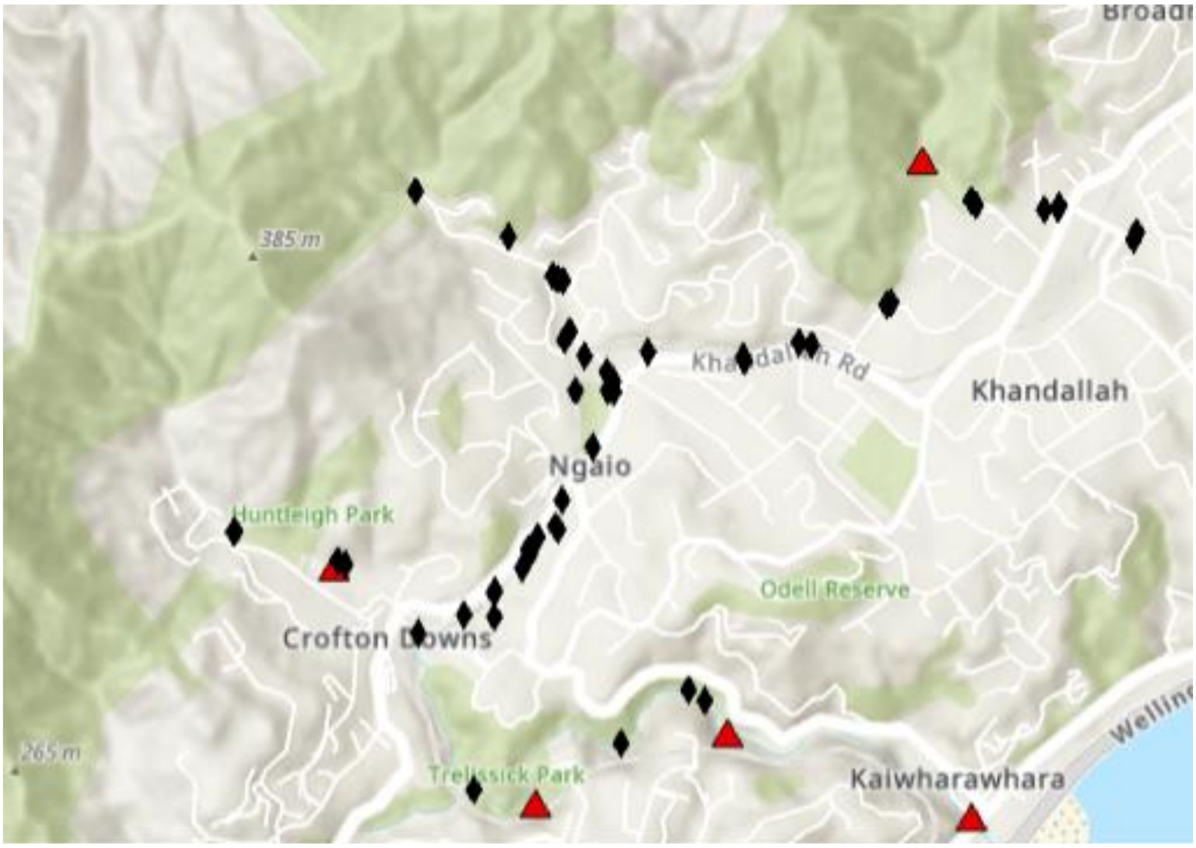

Figure 10: Locations of barriers to fish passage (black diamonds) and fish monitoring sites (red triangles) in the Kumutoto Stream.

Discussion

By comparing the fish distribution data with the fish barrier data in Wellington City streams, some barriers have been identified as key threats to fish diversity. Therefore, these barriers should be prioritised for modification to enhance the freshwater biodiversity. The highly modified nature of Wellington's stream network has resulted in very few streams with natural estuary mouths. However, three key streams remain unmodified at the mouth and are the primary focus of recommendations. More data does need to be gathered, however. This is needed as there are some unexpected observations in the current data set that need to be reevaluated. Fish distribution data is also sporadic relative to fish barrier data, so it is hard to pinpoint exactly which barrier is the cause of diversity decline.

Kaiwharawhara

The unmapped pipe in the lower section of the Kaiwharawhara Stream is likely preventing nonclimbing fish such as inanga from accessing the upstream habitat. The stretch of stream between this pipe and the next one is suitable for supporting increased fish populations. It runs through Trelissick Park, a restoration site that has been replanted with native vegetation that provide native fish with shelter and food. Modifying this culvert will create a large habitat space between the mouth of the stream and the culverts higher up in the catchment on both the Kaiwharawhara and Korimako Streams. Figure 11 shows the location of the unmapped culvert, while Figure 12 shows it in relation to the stream mouth and the next two culverts upstream in the Kaiwharawhara and Korimako Streams.

This pipe needs to be modified first as it causes the greatest biodiversity decline between fish sites. This is not only in the Kaiwharawhara Stream, but across all the streams that were assessed in this study. The lower section of the Kaiwharawhara Stream has the greatest biodiversity of all monitored streams, thus the greatest ecological potential comes from modifying this pipe. However, before it can be modified, it needs to be assessed. It is recommended that is assessed in the same manner as other mapped pipes in the catchment, with the NIWA Fish Passage Assessment Tool. This is to ensure the assumptions about length and exact location that have been made in this study can be confirmed. It will also allow for a best assessment of how the pipe should be modified.

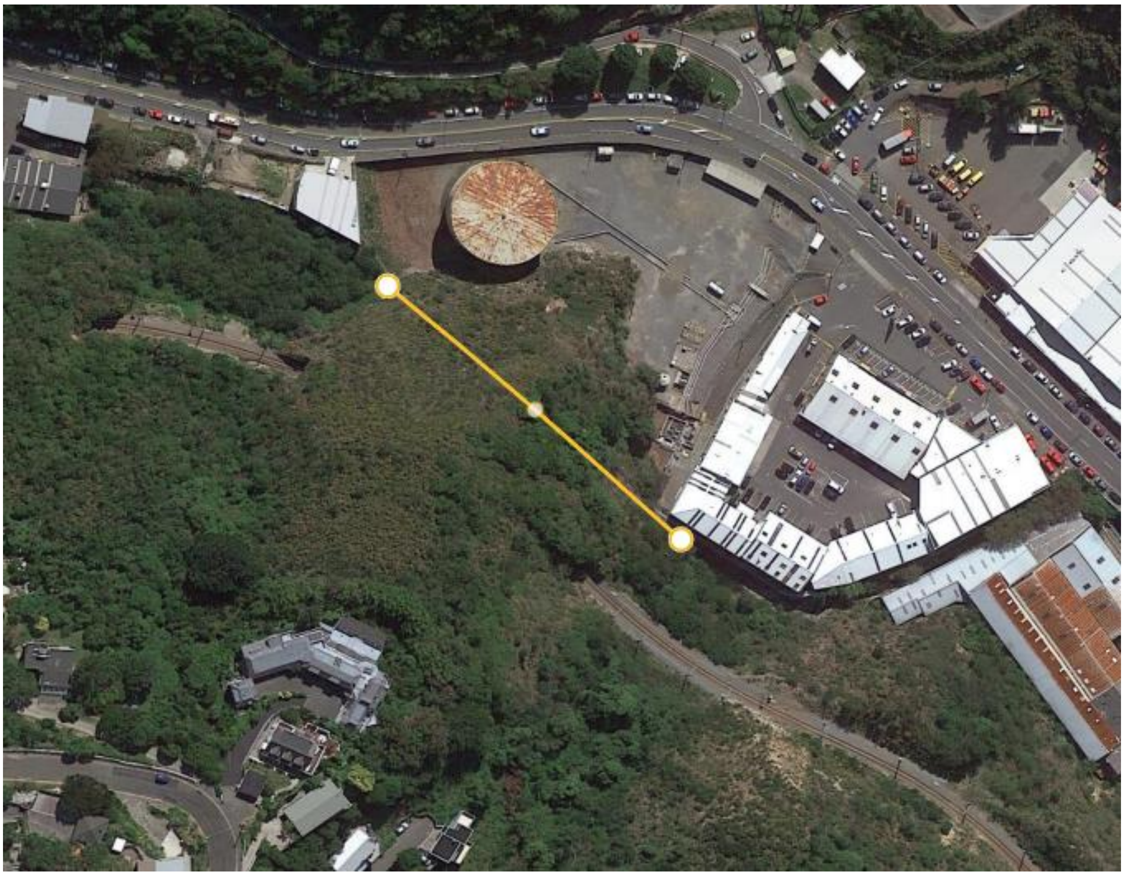

Figure 11: Unmapped pipe in the lower Kaiwharawhara Stream.

Figure 12: Wide angle view of lower catchment including Kaiwharawhara Stream and Korimako Stream. Stream mouth (lower right corner) and first mapped barriers (lower and upper left) marked by blue point. Unmapped barrier visible in yellow.

The presence of giant kokopu upstream of at least 3 barriers while koaro are confined to the lower section between fish sites one and two ought to be investigated further. Koaro are found in streams that require traveling through numerous culverts to access, such as that in Miramar. Giant kokopu, however, are not good climbers and struggle to access habitat that has been modified. Therefore, it is also recommended that the fish sites in the Kaiwharawhara Stream are revisited. If giant kokopu are still found upstream of three culverts then it is a good sign that the barriers will only need small modifications. It is also possible giant kokopu have established a landlocked population upstream. This would be a significant discovery for a population that is declining nationally (Baker and Smith, 2007). If not, then the presence of giant kokopu in the current data set could be a result of misidentification.

<u>Owhiro Stream</u>

The Owhiro Stream had significantly less biodiversity that the Kaiwharawhara. The first barrier is also a lot close to the stream mouth than in the Kaiwharawhara. There is a cluster of one ford and two weirs in the lower section that should be prioritised for modification. Upstream of these barriers the stream remains unmodified for approximately 1.5 kilometers. The barriers visible on the maps in this stretch of the stream are all on tributaries and do not obstruct the mainstream. Therefore there is a lot of potential habitat upstream of the first barrier cluster. If these barriers can be modified the Owhiro Stream will have nearly two kilometers of accessible habitat before the first barrier.

The natural estuary mouth of the Owhiro Stream presents an opportunity to increase the overall diversity of the Owhiro Stream. Non climbing diadromous fish like giant kokopu and inanga may not be present in the stream due to there being no suitable habitat downstream of the first three barriers. If these are modified there is potential to establish a population in the stream, increasing the overall diversity. Both of these species are categorized as declining nationally by DOC (2017) so facilitating the establishment of a new population in the Owhiro Stream will be a significant achievement for their conservation.

<u>Karori Stream</u>

Modifying barriers in the Karori Stream will allow koaro, upland bully, and banded kokopu to expand their range in the stream. The main stream remains relatively unobstructed until it reaches the Karori Park sports filed. There is a cluster of barriers that could be preventing access that should be prioritised for modification. However, after this cluster the stream becomes highly modified. It starts to flow through the main residential area of Karori.

So modifying these barriers will not create as much extra habitat as modifying the recommended barriers in the Owhiro and Kaiwharawhara Streams.

It is therefore recommended that the lower stream be further investigated. The biodiversity is very low despite the stream flowing through a valley with little residential development. The stream beyond the Karori urban center was not investigated when barriers were being map, therefore there may be unknown barriers further downstream that could be preventing fish passage. If there are barriers in the lower section of the stream then these should be assessed and prioritised for modification first. There are only two fish sites in the lower stream too. The data collected at these sites is the only representation of diversity for the nearly 10 kilometers of stream before the residential area. A thorough investigation of the lower section of this stream will provide a more robust representation of the species currently accessing the Karori Stream. Existing fish sites upstream should also be revisited. This is due to the high number of unidentified fish that were observed. If fish in this section can be identified then it will inform the current distribution with greater clarity.

Other Streams

Streams in highly developed areas of Wellington City that are piped to their outlet are already disadvantaged. It is unlikely the biodiversity of these streams will increase unless there is major modification of the pipe network they have been redirected into. Therefore the focus for these streams should be on enhancing the habitat that is already there to ensure the fish that are present are sustained. Further research into the habitat quality of these sites and the abundance of individual species needs to be completed to get a clear understanding of the current situation. Modifying barriers to these sites should be considered when the focus streams have been improved.

Prioritisation Summary and Recommendations for the 2020/2021 Monitoring Season

The above recommendations are prioritised for the greatest ecological benefits. Before modifications to barriers are made it is first recommended that factors other than physical barriers to passage should be considered. This is due to the big difference in biodiversity in the main streams. Habitat quality is also key in supporting populations. If barriers are modified but the habitat is unsuitable then efforts will be unsuccessful. If it is found that habitat quality needs improving then this should be the first priority for restoration efforts. Once this has been established barriers should be modified in a tier system that will allow for progressed fish passage over time. Note that this system should be established over a number of years to ensure adequate monitoring and adjustments to priorities are made as new information and data is collected.

Tier 1 (Highest Priority)

- Unmapped barrier (presumable culvert): lower Kaiwharawhara Stream
- Clustered barriers: Owhiro Stream

Following the modification of these barriers, monitoring needs to occur to establish whether it has been successful in encouraging fish passage further upstream.

Tier 2

- Railway culvert: Kaiwharawhara Stream
- Culvert under Churchill Drive: Kaiwharawhara Stream
- Culvert under Murchison Street: Owhiro Stream
- Weir and Culvert under Happy Valley Road : Owhiro Stream

These barrier modifications will further extend the potential range of fish in each stream. The NIWA Fish Passage Assessment Tool will show the exact location of each. Monitoring following modification will need to occur again.

Tier 3

- Various culverts (in order of occurrence): Korimako Stream
- Remaining culverts: Kaiwharawhara Stream and Owhiro Stream
- Weir near Karori Park: Karori Stream
- Culverts in order of occurrence: Karori Stream

Tier 4

- Culverts of non-focus streams: various streams

Modification of barriers is a long term vision for the restoration of Wellington’s urban freshwater habitats. Short term recommendations include using the current barrier and fish distribution data to inform where to focus future monitoring efforts. There are some streams, for example the Ngauranga Stream that have been monitored for fish diversity but do not have any barriers mapped. It is unlikely there are no barriers given it is in an urban location. There are also streams, such as the Wellington City extent of the Porirua Stream between

Churton Park and Linden that have barrier data but no fish distribution data. Therefore, it is recommended the current data set be updated and matched to create a clear picture of the situation in all of Wellington city's urban streams. This will result in more barriers being identified as key threats and new modification recommendations can be made.

Another potential future project would be to update stream network maps. Currently many maps do not accurately show when a stream is above or below ground. This makes networks very misleading. This could be combined with an up to date storm water network map to show the connections of streams between pipes. Understanding the storm water system will also provide a better understanding of where fish are travelling underground to access habitat, especially in streams that are primarily underground.

Conclusion

The declining state of freshwater throughout New Zealand's urban centers has created a need for immediate action and restoration. Wellington City has a lot of streams that have all been modified to some extent. The Kaiwharawhara, Owhiro, and Karori Streams hold the most potential for ecological improvements due to the amount of above ground habitat available. Establishing new populations of fish species in these streams will be significant in creating a sustainable future for these fish. It is recommended more information be gathered regarding the habitat quality of these streams. Once it has been established the habitat is of a suitable standard, barriers should be modified. The first barriers to be modified are those in the lowest sections of the streams. By working up the stream the potential range of fish will increase over time. The success of these modifications relies on continued monitoring and updating of information to keep up with new threats and future development as they arise. Urban freshwater ecology presents opportunities for significant contributions to the conservation of endemic freshwater fish species, and Wellington City has the potential to become a leader for New Zealand's urban centers.

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