Water Quality and Ecological Health Assessment of Mugford Drain

By Ella Peoples

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For the Avon-Heathcote Estuary Ihutai Trust

Avon-Heathcote Estuary Ihutai Trust

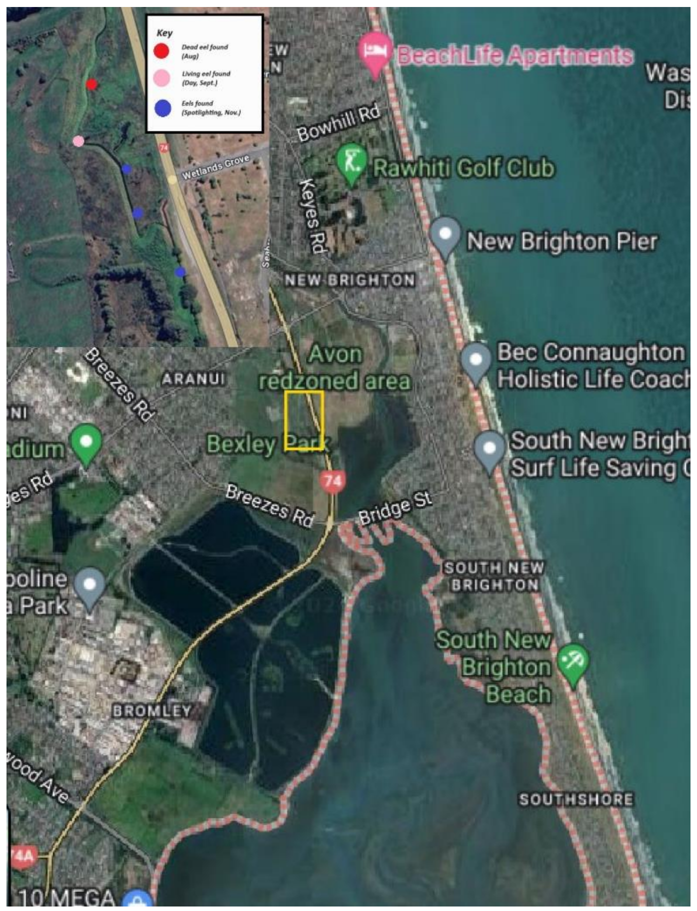
Contents

Abstract

In this investigation (August – November 2023), I undertook a range of different sampling methods to assemble a health assessment of Mugford Drain. These methods were habitat mapping, water quality monitoring, dissolved heavy metals testing, environmental DNA sampling and fish surveillance. These methods were chosen to give broad understanding of the health of the drain, including both the physical properties of the waterway, and the diversity of organisms found within it.

My findings are consistent with Mugford Drain being a waterway which has been subject to large amounts of human disturbance. The water quality of this drain is subpar – low levels of dissolved oxygen present a challenge for the survival and success of stream-dwelling fauna. The pH of the drain is acceptable, and the conductivity falls within reasonable parameters for brackish water. Heavy metal pollution is also an issue further downstream at the Estuary Drain, as is landfill waste, which is washed into this waterway as the drain's banks are eroded. Concentrations of dissolved iron and arsenic were higher than the designated safe limits for aquatic ecosystem health on more than one occasion. However, the Mugford and Estuary Drain system is not beyond redemption – this waterway shows the potential to be restored.

It should be noted that this health assessment only represents a snapshot in time, covering a four-month period between August and November. More thorough monitoring would be needed over a longer period to form a truly comprehensive idea of the health of this drain system, and to account for seasonal and interannual variation in the measured parameters.



Introduction to and history of the site

Mugford Drain (also known as Knight's Drain) is a shallow waterway running through the Bexley area in eastern Christchurch. The drain runs parallel to State Highway 74, from Bexley Reserve to the culvert where it flows into the Estuary Drain, near the gravel driveway often used as a truck stop. Historically, much of the land in Bexley was used as a landfill, including areas which fringe the Mugford and Estuary drains. Accounts from locals living in the area during this period recall entire cars being dumped, along with waste from households, manufacturing and hospitals (Law, 2021). Another area of land around Mugford Drain was previously used as a leather goods factory before conversion to farmland by the Mugford family, for whom the drain is now named. Due to this prior land use, pollution of the waterways is a concern, including heavy metal pollution. The land is now part of Bexley Park which is managed by Christchurch City Council. The Estuary Trust works with Council rangers to organise community volunteers to restore the land and the drain. One of the volunteer groups, Forest & Bird Youth, established some biodiversity monitoring including bird counts, plant surveys and invertebrate surveys. This project aims to take these environmental efforts one step further and look at the overall health of the waterway.

The data used collected from this project can be used as a baseline to track the impacts of future restoration efforts in improving the water quality and ecological health of this drain. The results of the heavy metal testing could be used as evidence of heavy metal pollution from the historic landfills which fringe the Estuary Drain. While the area has faced ecological disturbance from human activities, the reserve is still providing habitat for a range of species. Native birds including pukeko, paradise ducks, gulls and welcome swallows are frequently seen. Migratory wading birds have also been sighted here. Stream macroinvertebrates are not common in Mugford Drain but water boatmen and backswimmers are seen frequently in the central pond of Mugford Reserve (known as Lake Jason). Mugford Drain is also home to New Zealand shortfin eels, a species classed as near threatened (NT) by the IUCN (International Union for the Conservation of Nature). Living and dead eels have been sighted at Mugford Drain by both Estuary Trust and Forest & Bird volunteers. A report on the ecological health of the Estuary Drain was conducted by Pattle Delamore Partners for the Christchurch City Council in 2022. This included information on water and sediment quality, stream macroinvertebrates, fish and aquatic plants.

Habitat Mapping

Methods

I observed the bottom of Mugford Drain on many site walks from the riverbank. For more thorough habitat mapping, I walked the length of the drain from its start to where it flows on and joins with the estuary drain. Every 25 paces, I used a long stick to dig at the bottom of the drain to examine its consistency.

Physical Description of the Site

Mugford drain is slightly tidal, but most stretches do not exceed a depth of 40 cm even at high tide. Mugford drain has a poorly defined origin adjacent to Bexley Park – the stream gradually becomes covered by a layer of aquatic plants before gradually receding into earth and grass (Fig. 1). A small footbridge crosses the drain at the southern end of Bexley Reserve and around this bridge, small rocks and fallen branches and twigs have accumulated at the bottom of the drain, forming a semi-solid bottom covered by a thin layer of mud and rotting organic matter. From here, the drain flows on into Mugford Reserve. Most of the drain bed consists of a thick layer of tarry mud ranging from dark brown to black in colour (Fig. 2). This mud is covered by a thin layer of rotting organic matter and is stirred up very easily when disturbed.

Figure 1: The source of Mugford Drain is characterized by poorly defined margins and thick aquatic vegetation growing in the waterway.

Figure 2: The colour and consistency of the muddy bottom which covers much of Mugford Drain.

Some stretches of the banks in Mugford Reserve are fringed by carexes, while the banks of the rest of the drain are covered by introduced grasses. A large pond fed by a spring and known affectionately as “Lake Jason” after the local Christchurch City Council ranger, lies at about the mid-point of Mugford Reserve. The bottom of the pond also differs from the main stream, consisting of firm, light brown mud with some algae growing on the bottom of the pond. As the drain flows through the lower half of Mugford Reserve, it becomes slightly narrower and there is a higher occurrence of aquatic plants, which can sometimes block water flow through the drain. From here, the drain exits the reserve and flows parallel to State Highway 74 for several hundred meters before flowing through a small culvert and joining with the Estuary Drain. The Estuary Drain is highly tidal, and hence the water level here varies quite substantially (Fig. 3). The bottom of the Estuary Drain is significantly different from the bottom of Mugford Drain. While the mud here has a very similar consistency to that of Mugford Drain, the colour is much lighter and strongly tinged with red, likely due to high concentrations of iron (visible in Fig. 3). Rocks and concrete debris are scattered along the bed of the Estuary Drain, often visible at low tide. The banks of the drain here are steep, and also fringed by grass. On the west side of the creek, buried rubbish from the landfill has begun to spill out and is visible on the bank at low tide. Below, a map shows the main physical features of the drains (Fig. 4).

Figure 3: Water levels at high (left photo) and low (right photo) tides at the Estuary Drain. Also visible is the red mud, characteristic of the Estuary Drain.

Figure 4: Map of the different bottom types found in Mugford and Estuary drains.

Water Quality

Method

Forming the backbone of my water quality work and the basis of this project was regular monitoring of basic water quality parameters at six sites (Fig. 5) on Mugford Drain through a range of tides and weather conditions (Appendix 1 and 2). I used (Fig. 6) a Hach HQ2200 handheld water meter, with the following probes: pH (Model: PHC101), dissolved oxygen (Model: LDO101), and conductivity (Model: CDC301) all manufactured by Hach. Probes were dipped into the water and left to measure until they had fully calibrated, then results were recorded. If a probe failed to stabilize at a site, no measure was recorded.

Figure 5: Map showing the water testing sites.

Figure 6: A demonstration of typical water sampling methods.

Results

I found notable differences in the measured water quality parameters of dissolved oxygen, conductivity, pH and temperature over time and between sites (Appendix 3). Dissolved oxygen, pH and conductivity are all reduced as temperatures increase, so it is important to note this as a factor when looking at water quality results and what may be causing some anomalies. This should also be something that should be considered when looking to improve water quality.

Dissolved oxygen varied between sites, with sites 2 and 6 having the lowest concentrations, and sites 3 and 4 having the highest concentrations (Fig 7). A notable anomaly in the dissolved oxygen readings occurred in early September at site 4, where the dissolved oxygen readings were beyond the scale of what could be measured by the probe. This was around the time that a large mound of vegetation was blocking the drain's flow downstream of site 4; readings were normal downstream of the blockage. Many factors can affect the concentration of dissolved oxygen in a waterway. As water temperature increases, the amount of dissolved oxygen in the water decreases, therefore temperature can play a major role in determining the concentration of dissolved oxygen. The flow of water can also determine the concentration of dissolved oxygen – faster flowing water has more dissolved oxygen. Biological oxygen demand (BOD) describes how much oxygen is taken up from the water by organisms, and if BOD is high, this can lead to low concentrations of dissolved oxygen. This can particularly be an issue if there are large amounts of bacteria in the water, which consume a lot of oxygen. Algal blooms can also cause elevated concentrations of dissolved oxygen when they photosynthesize during the day but consume oxygen overnight, leading to lower dissolved oxygen concentrations. It is likely that the drain blockage allowed algae to bloom and produce great amounts of dissolved oxygen. The minimum level of dissolved oxygen for fish to survive and spawn is 5.99 mg/L or 6 ppm. Below this level, fish become stressed. At concentrations of 3 mg/L or lower, fish cannot survive (Atlas Scientific 2022). Concerningly, the dissolved oxygen readings at Mugford stream were lower than the threshold for spawning on many occasions, and some readings fell into the lethal range too.

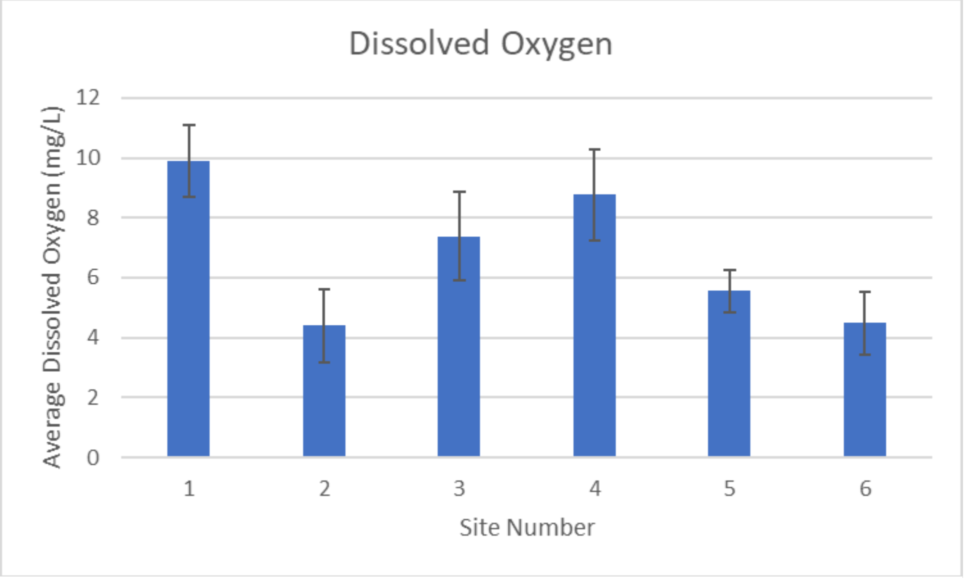


Figure 7: Average dissolved oxygen across sites at Mugford and Estuary Drains. Dissolved oxygen is highest at sites 3 and 4. Error bars show standard error.

Conductivity measures how well a substance can carry an electrical current. The salinity of water strongly influences its conductivity, as salts allow electrical current to flow easily through water. Therefore, the conductivity of water in the drains varies depending on the tide, particularly in the Estuary Drain, which is more affected by the tide due to its proximity to the estuary. Site 6 has the lowest conductivity as this is where fresh water wells up from the spring into Lake Jason, while sites 4 and 5 have the highest conductivity (Fig 9). Conductivity is affected by the amount of dissolved ions in the water. High conductivity in freshwater can also be an indicator of pollution, most likely from sewage or agricultural runoff (Atlas Scientific 2022). Sea water conducts electricity well due to the dissolved salts in it, and backwash from the estuary at high tide can alter the conductivity of the drains. Runoff from the highway may be an additional pollution source in the drains.

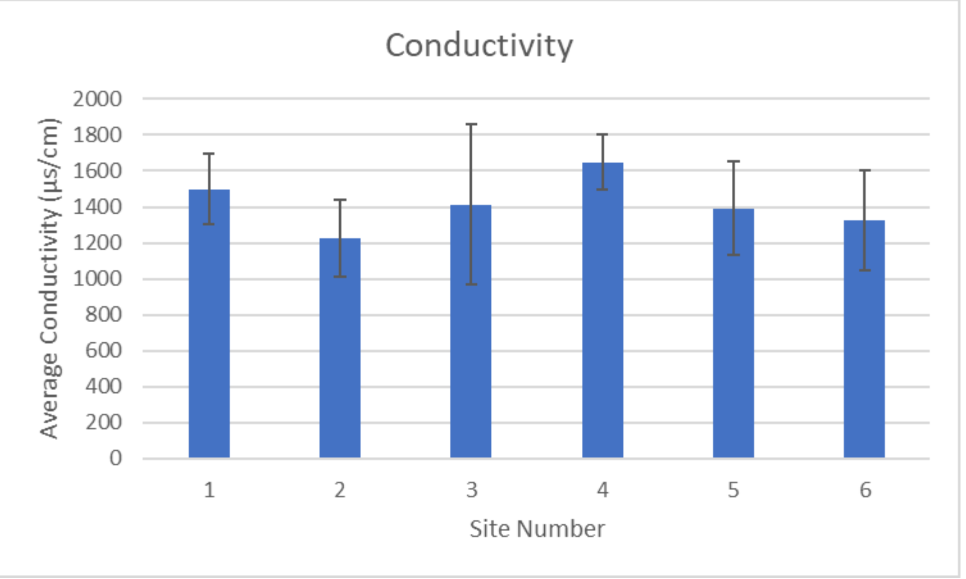


Figure 8: Average conductivity across sites at Mugford and Estuary Drains. Conductivity is much lower at site 6 than the other sites, which is expected as this is a spring-fed pond.

The pH readings taken at the Estuary Drain are consistently lower than readings taken at Mugford or from the spring-fed pond (AKA Lake Jason). pH varies between sites, with the Estuary Drain having a lower pH than other sites, while sites 3 and 4 had the highest pH (Fig 8). pH can be affected by several factors including water temperature, the composition of bedrock and soil under and around the waterway, and anthropogenic inputs into the waterway (United States Environmental Protection Agency 2023b). Readings were all within the safe limits for aquatic organisms and were typical of a semi-tidal stream. Sea water tends to have a pH of around 8.2, while the pH of freshwater ranges between 6.5 and 8.0 (United States Environmental Protection Agency 2023c). The pH of the drain does not seem to increase with proximity to the estuary, but the tidal cycles may have a more complex effect on pH variation in the Mugford and Estuary drains.

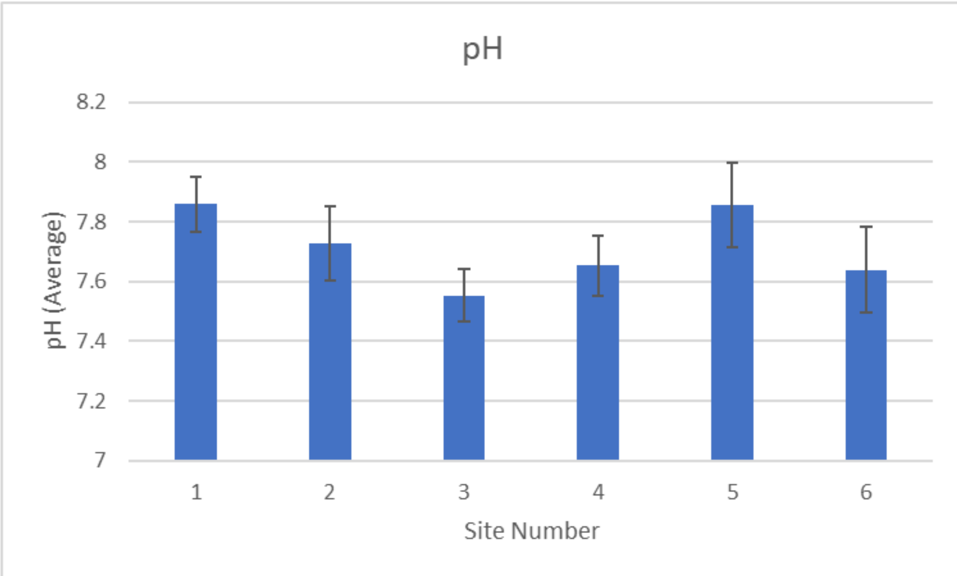


Figure 9: Average pH across sites at Mugford and Estuary Drains. pH is considerably lower at the Estuary Drain compared to the Mugford Drain sampling sites. Error bars represent standard error.

Typically, the dissolved oxygen concentration in a waterway decreases as temperature increases. In Fig. 10 below, the dissolved oxygen concentration has been graphed against the water temperature. While some trends are visible between the average dissolved oxygen concentration and the average water temperature across all sites, there are most likely other factors which are affecting the concentration of dissolved oxygen in this waterway. These could include rainfall events, input of pollutants and stream blockages (Atlas Scientific).

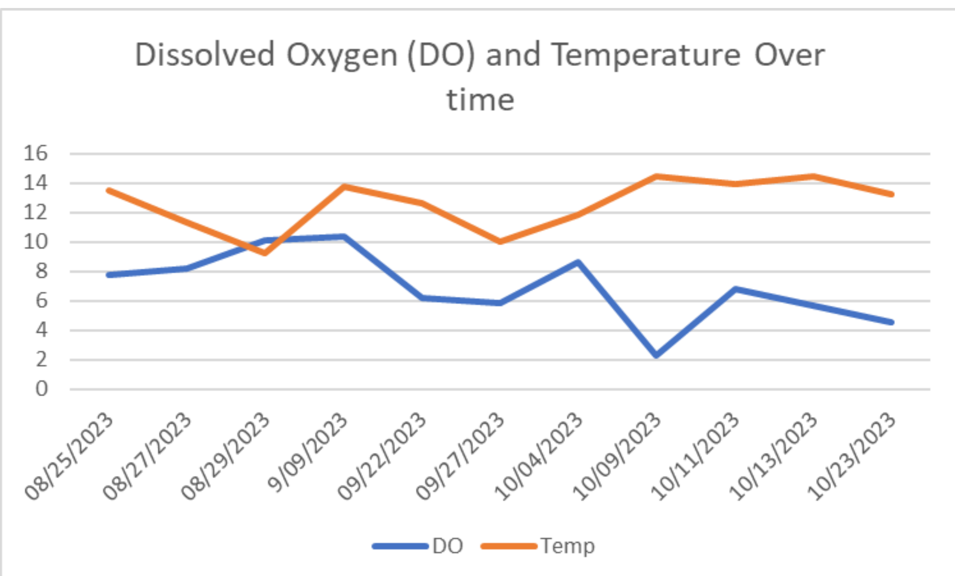


Figure 10: The relationship between average dissolved oxygen and average temperature across all sites over time. As temperature increases, dissolved oxygen levels should decrease. This chart does not show this exact effect, as other factors impact dissolved oxygen levels.

Heavy Metals

A key part of this project involved testing the water in both Mugford Drain and nearby Estuary Drain for heavy metals. Samples were taken at sites 1 and 4 shown on the map above. This was deemed important due to the previous land use of Mugford Reserve and the surrounding area. The manufacture of leather goods has been associated with heavy metal pollution, including arsenic and chromium (Junaid et al. 2017, Sivaram and Barik 2019) and leachate from landfills often contains significant amounts of heavy metals, many of which are harmful to aquatic life (Essien et al. 2022, Donnachie et al. 2014). The abiotic conditions of a stream, such as pH and dissolved organic carbon (DOC) can also affect the severity of heavy metal pollution on aquatic ecosystems (Cardwell et al. 2023, Sciera et al. 2004). For this reason, it is difficult to develop a single fixed measure of what a safe concentration is for each heavy metal contaminant. Using the Australia and New Zealand guidelines (ANZG), I chose to use the threshold deemed to provide protection to 95% of species found in waterways, as this is what is recommended for sampling in mildly-to-moderately degraded habitats.

Method

Using a sampling kit provided by Christchurch City Council's water quality laboratory, water was syringed from the stream and passed through a filter, which is fine enough to retain these contaminants. Samples were taken during wet and dry conditions and processed by the Christchurch City Council's Three Waters Laboratory. The metals which were tested for during the dry sampling round were arsenic, cadmium, chromium, copper, iron, lead, manganese, mercury, nickel and zinc. The metals tested for in the wet sampling round were arsenic, copper, iron, nickel and lead.

Results

Elevated levels of some of the heavy metals were found in Mugford and Estuary drain water (Appendix 4). Iron, arsenic and copper were all present in concentrations which were higher than the recommended ANZG toxicant guidelines. This is unsurprising, given the previous use of the land and is consistent with prior reports on the water quality of the site.

There is no current official guideline concentration for iron in aquatic ecosystems in NZ and Australia, so the Canadian guideline of 300 µg/L was used as a set safe level for the recorded values to be assessed against. The water in Mugford Drain exceeded the safe level during dry weather sampling in October but was well below the safe level during wet weather sampling in November. The water in Estuary Drain exceeded the safe level by more than ten times in October and more than three times in November (Fig. 11). This is consistent with the 2022 Pattle Delamore report. While iron is an essential nutrient in the natural environment, iron toxicity can also have adverse effects on aquatic life in high concentrations. Fish experiencing chronic exposure to iron toxicity tend to experience symptoms including lethargy, inactivity, gill discolouration, disorientation and swimming abnormalities (Roberts, 2023).

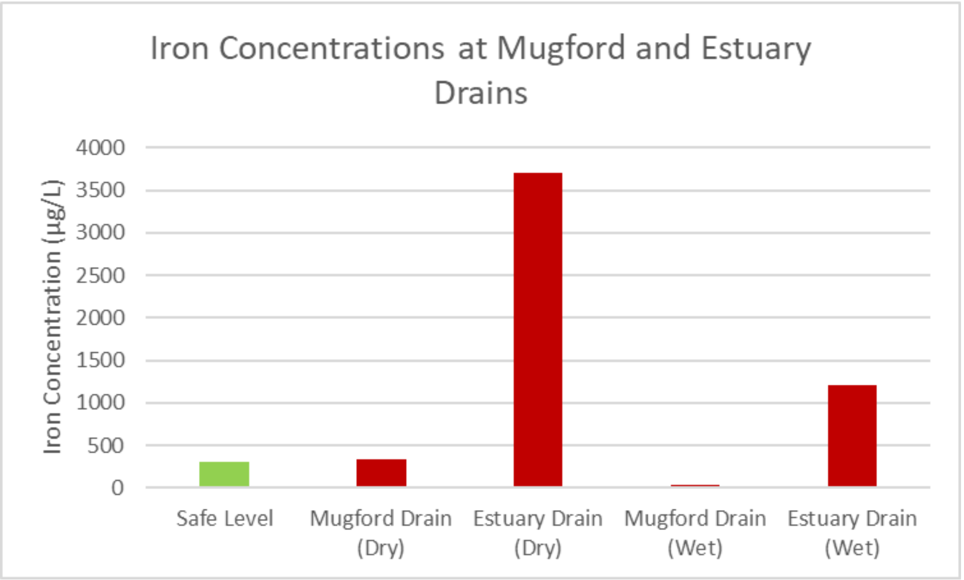


Figure 11: Concentration of dissolved iron at Mugford and Estuary Drains (red) compared to the safe standard (green). Levels are very elevated at the Estuary Drain site.

Arsenic concentrations were almost double the ANZG toxicant guideline value in the water at the Estuary Drain during wet sampling conditions. Other readings were all below the safe level (Fig. 12). Arsenic is a toxic and carcinogenic chemical which is found in lead acid batteries and in waste from industrial processes such as mining and manufacturing (Patel et al. 2023). Arsenic is also known for bioaccumulating in tissue and can cause physiological disorders in aquatic organisms (Zhang et al. 2022, Byeon et al. 2021). These recent results differ from the 2022 Pattle Delamore report, which showed no Arsenic concentrations above the ANZG toxicant guideline value.

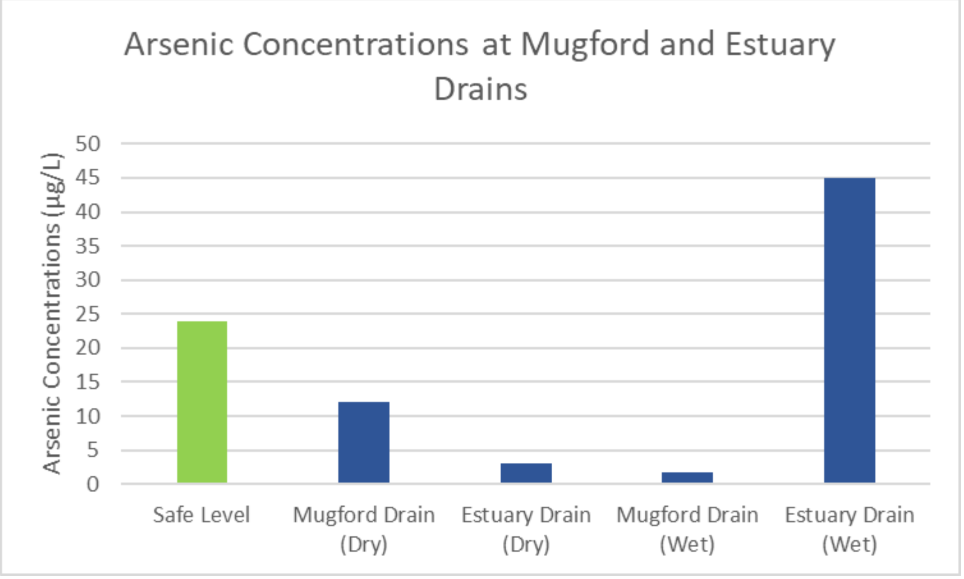


Figure 12: Dissolved arsenic concentrations at Mugford and Estuary Drains. The level is elevated at the Estuary drain during wet conditions.

Copper concentrations in Mugford drain water either approached or equaled the ANZG toxicant guideline value, while concentrations in Estuary drain water slightly exceeded the guideline value (Fig. 13). This is consistent with the 2022 Pattle Delamore report, which found elevated concentrations of dissolved copper in Estuary Drain water. Copper is another essential nutrient but can be toxic to aquatic life at high concentrations and is classed as the highest risk heavy metal contaminant in the United Kingdom (Donnachie et al. 2014). Acute exposure to high concentrations of copper can be fatal, while chronic exposure may lead to lower rates of survival, growth and reproduction in many aquatic species. Copper toxicity is also associated with altered brain function and metabolism and is known to bioaccumulate in both humans and in aquatic organisms (United States Environmental Protection Agency 2023a, Bao et al. 2020).

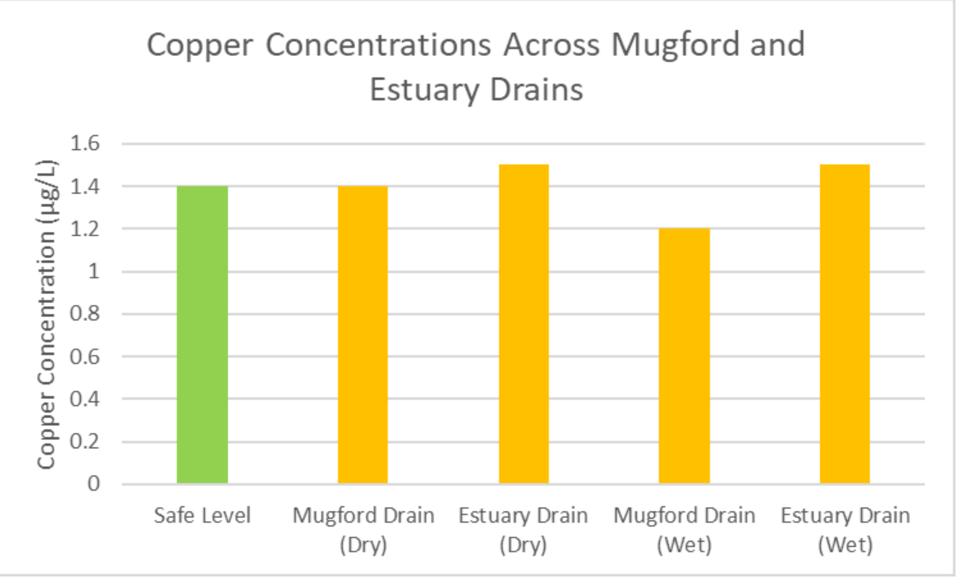


Figure 13: Dissolved copper concentrations at Mugford and Estuary Drain sites. Levels were approaching or exceeding safe limits at all sites under all conditions.

All measured cadmium, chromium, lead, manganese, mercury, nickel and zinc concentrations were below the ANZG guideline value providing protection for 95% of species.

Environmental DNA (eDNA)

Environmental DNA (eDNA) is a relatively new method of surveying biodiversity in an area. Organisms leave small traces of their genetic material when they pass through the environment, which can then be washed into waterways. A sample of water can then be taken from the body of water to determine which organisms are living in and around it through environmental DNA metabarcoding analyses. Short sequences of DNA known as barcodes act as a unique identifier for species or for broader taxonomic groups. Primers are used to amplify DNA, which is then sequenced. Metabarcoding allows the DNA sequences of many organisms to be identified from a single sample. This method is more efficient than undertaking many surveys for many different taxonomic groups (WilderLab).

Method

An eDNA kit and analysis package was purchased from WilderLab and sampling was undertaken at Mugford Drain. Water was syringed from the stream and passed through a 5.0 µm filter (Fig. 14) to retain environmental DNA from the site. Unfortunately, the filter clogged before the maximum amount of water could be filtered, but enough was filtered through for analysis (300 mL). Samples were then couriered to WilderLab in Wellington to be analysed.

Figure 14: The apparatus used for eDNA sampling.

Results

Most notable, was the recorded presence of New Zealand shortfin eels (*Anguilla australis*) (Fig 15). This species has been sighted previously by both Estuary Trust and Forest & Bird volunteers, but these results provide robust confirmation that this species is present in the waterway.

There was a notable lack of EPT macroinvertebrate species. EPT species include Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies); mayflies and stoneflies are pollution

sensitive taxa which are indicators of water quality, while a lack of caddisflies indicates that there was little rocky habitat in the waterway (Hamid and Rawi 2017, Smith 2016). The lack of these taxa suggests poor water quality at the Mugford site, which would be consistent with our water quality monitoring and heavy metal testing results.

The taxonomy-independent community index (TICI) score is an experimental tool which can be used as another measure of the ecological health of a waterway and is generated by WilderLab in their reports. The Mugford site TICI score was 73.61, which is classed as very poor, indicating that the ecological community of this stream is dominated by tolerant species such as oligochaetes and other aquatic worms rather than sensitive species such as EPT taxa. Together with our water quality data, this indicates that Mugford stream's ecological health has been compromised by anthropogenic disturbance. Remediation and restoration efforts will be needed to bring more sensitive taxa back to this waterway.

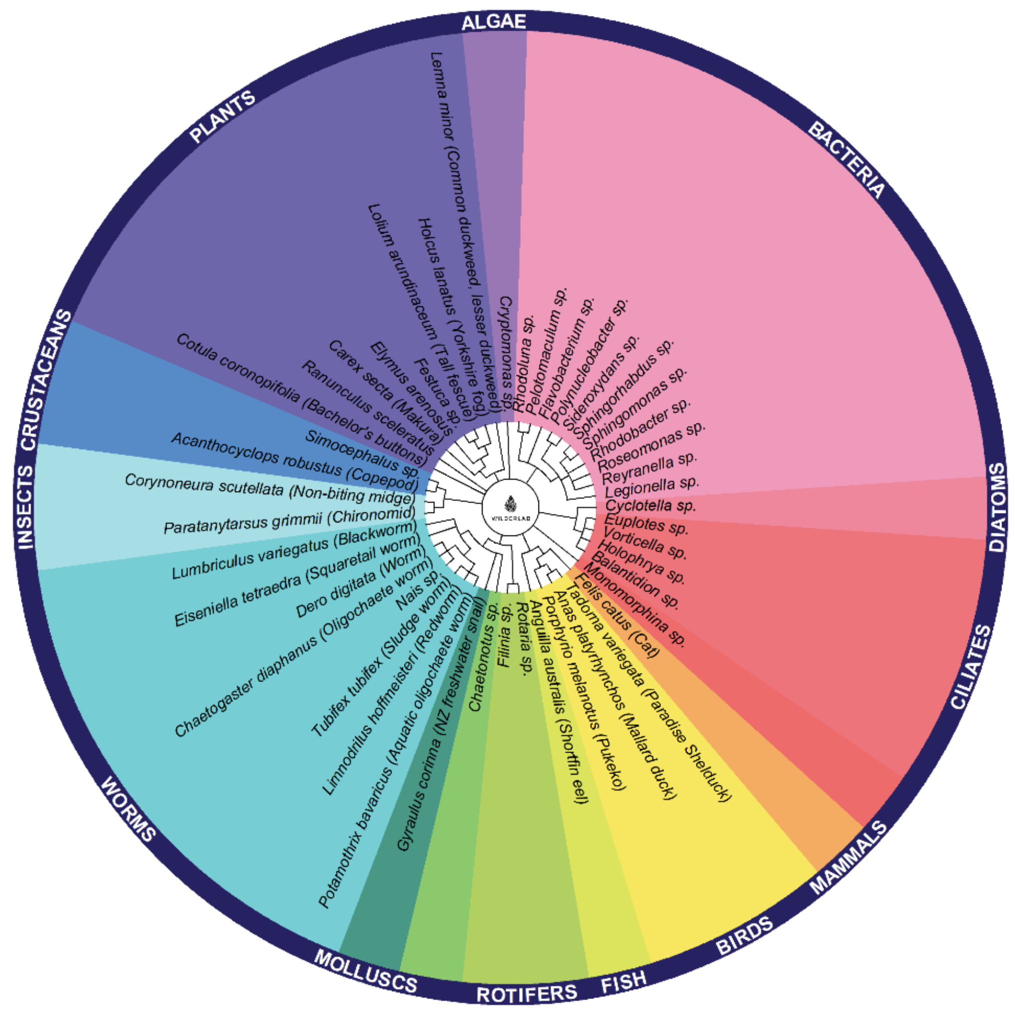


Figure 15: Chart showing the richness of various taxa found in the eDNA results. Provided by Wilder Lab.

Eel Surveillance

Anecdotal evidence

Eels have been spotted in Mugford Drain on at least two occasions. Volunteers at a Forest & Bird Youth tree planting found a dead eel on the stream bank (species indeterminable) in August 2023 (Fig 16). Estuary Trust volunteers also sighted eels in the stream while wading through the water to remove vegetation that was blocking the waterway. From description, these were most likely shortfin eels. Smaller eels ranged in size from 20 – 40 cm, while larger eels were also sighted. Size is strongly correlated with age in many eel species, meaning that a range of different age classes are likely present in the drain (Simon 2007).

Spotlighting for eels

A night walk of Mugford Drain was used to provide an indication of eel abundance. Seven eels of varying sizes were sighted in the drain. Several of these were positively identified as shortfin eels, which is consistent with environmental DNA results from the site. Photos were taken but on later inspection eels were either not visible in these or were extremely blurred and therefore the images have not been included in this report. Video evidence of the eels was obtained and a screenshot from this video has been added below (Fig. 17). While not regularly visible during the day, eels were abundant in Mugford Drain at night. The eels observed were very active and appeared to be in good health, displaying normal swimming behaviour.

Figure 16: A dead eel of uncertain species (either A. australis or A. dieffenbachii). Found by volunteers in August 2023.

Figure 17: A New Zealand shortfin eel/tuna sighted while spotlighting at Mugford Reserve at night. Sighted in November 2023.

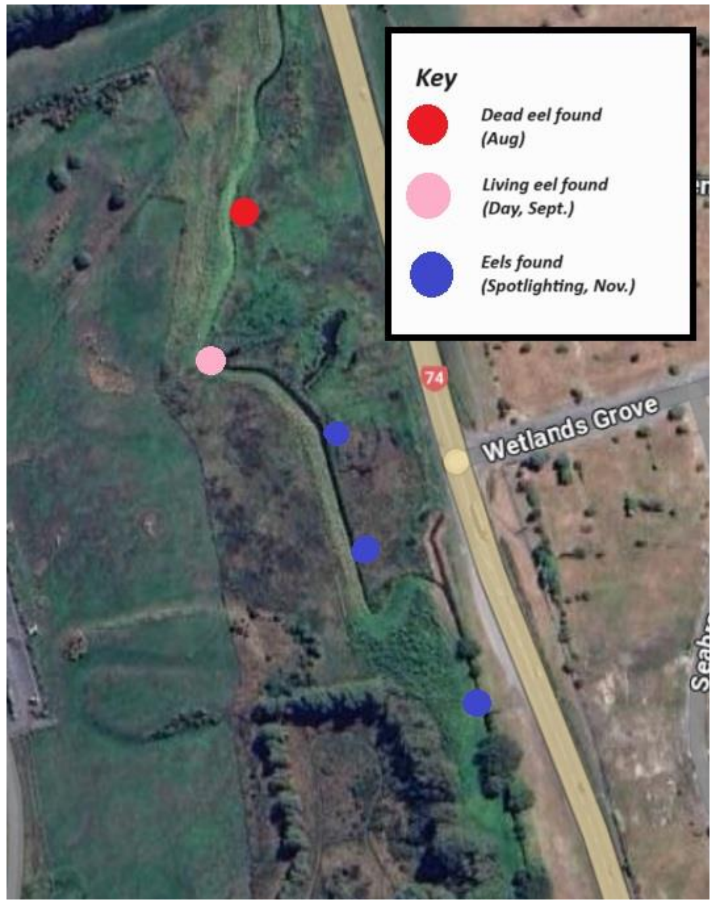


Figure 18: Map of sightings of eels at Mugford Drain.

The findings on the eel population of Mugford Drain contrast to the 2022 report by Pattle Delamore which reported a single eel "in poor condition, with lethargic movements, abnormal colouring and some irritation of the fins" found in the Estuary Drain. While the fish community in the Estuary Drain is perhaps best described as depauperate, the eel population in Mugford Drain appears to be thriving. To reach Mugford Drain, eels would need to swim through the culvert which joins the Estuary Drain to the estuary and then through the culvert which joins Mugford and Estuary drains. It's unlikely that the eels would suffer much from ill effects of the Estuary Drain's pollution during this short transit. Eels spending longer periods of time in the Estuary Drain would be more likely to suffer severe effects from chronic exposure to heavy metal pollution. The recommendation from Pattle Delamore was to translocate fish from Estuary Drain to another location, and then block fish from migrating further up the Estuary Drain using a barrier. Depending on where the barrier is placed, this could have detrimental effects on the eel population of Mugford Drain, as they would no longer be able to move between the drain and the estuary and ocean. The health of the Mugford Drain eel population should be considered before any action is taken to remediate the Estuary Drain.

Recommendations

These are recommendations that I believe would improve the quality of this waterway. Riparian planting has been started around the edges of Mugford Drain and Lake Jason. I would strongly recommend this continues and is extended further downstream. Plantings would also act as a buffer to prevent runoff into the drain including decreasing the flow of heavy metals and other contaminants from the nearby highway. Dissolved oxygen, pH and conductivity all decrease as water temperature increases (Oyem et al. 2014). Planting trees and shrubs along the banks of the drain would cool the water, increasing the dissolved oxygen concentration and helping to stabilize the conductivity and pH. Rocks could be added to the drain to create riffles, which would help to oxygenate the water. Adding rocks would increase the number of microhabitats (Cook and Sullivan 2018) and provide habitats for caddisflies, which are not currently present in the drain (Smith 2016). Removing regular blockages in the drain could improve the water flow, preventing dissolved oxygen anomalies, algal overgrowth and other issues. This would add to the workload of the volunteers but would have positive impacts on drain water quality. Improving the water quality would be the primary step in bringing freshwater invertebrates back to the drain.

I recommend that the sampling undertaken for this project be repeated to track if and by how much water quality and biodiversity are improved by restoration efforts. An annual repeat would be ideal, but if the budget does not allow for this, every 2 years would likely be adequate. I also recommend that if remediation work is considered for the Estuary Drain, including the fish evacuations and barriers proposed by Pattle Delamore partners in 2022, the health of the Mugford Stream eel population should be considered.

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Appendices

Appendix 1: GPS coordinates for each of the sampling sites

Site Number	Latitude	Longitude
1	43°31'18.0"S	172°43'12.1"E
2	43°31'17.0"S	172°43'11.5"E
3	43°31'05.8"S	172°43'08.5"E
4	43°30'59.3"S	172°43'04.1"E
5	43°30'56.1"S	172°43'05.0"E
6	43°31'01.4"S	172°43'06.1"E

Appendix 2: Sampling Session Information

Date	Time	Tide	Weather
25/08/2023	14:15	Outgoing	Sunny
27/08/2023	11:15	High	Sunny
29/08/2023	9:37	Low	Sunny
9/09/2023	10:33	Incoming	Overcast
22/09/2023	9:05	High	Overcast
27/09/2023	10:28	Low	Rainy
4/10/2023	10:37	Outgoing	Sunny
11/10/2023	11:02	Incoming	Sunny
13/10/2023	11:22	Low	Overcast
23/10/2023	9:55	Incoming	Sunny
9/11/2023	9:55	Incoming	Sunny

Note: Tides were considered "high" or "low" if they were within 1.5 hours of the exact low or high tide at Lyttelton. Tides in between this time were classed as incoming or outgoing.

Appendix 3: Water quality monitoring results

Date	Site #	DO	Temp	Cond	pH
25/08/2023	1	4.08	15.8	N/A	7.12
	2	4.04	14.1	N/A	7.5
	3	10.22	14.3	N/A	7.46
	4	14.82	13.4	N/A	7.8
	5	5.6	9.9	N/A	7.38
27/08/2023	1	5.03	13.1	1457	7.27
	2	3.26	10.4	1854	7.52
	3	N/A	12.5	N/A	7.62
	4	13.97	10.9	2184	7.84
	5	10.43	9.9	2137	7.59
29/08/2023	1	4.85	10.6	1348	7.18
	2	4.48	10.8	1271	7.47
	3	15.39	9.1	1254	7.62
	4	19.78	8.1	2158	8.05
	5	6.25	7.7	2150	7.38
10/09/2023	2	7.86	14	1424	7.59
	3	18.48	14.7	1051	7.74
	4	N/A	13.6	1722	8.54
	5	10.92	12.3	2189	8
	6	4.36	14.2	162.6	7.58
22/09/2023	1	10.33	12.9	1864	7.31
	2	3.03	11.9	1936	7.63
	3	5.68	12	540	7.68
	4	7.99	13.5	1702	8.01
	5	8.15	12.3	1783	8.26
	6	2.23	13.4	163.3	7.59
27/09/2023	1	4.87	11.4	1321	7.05
	2	3.45	10.4	2099	7.73
	3	8.04	9.3	887	7.76
	4	7.52	9.3	2199	8.29
	5	7.43	8.2	2175	8.72
	6	3.85	11.3	162.9	7.89
04/10/2023	1	10.7	12.1	6.24	7.6
	2	7.23	11.8	4.17	7.68
	3	8.11	10.9	1190	7.76
	4	11.2	12.5	2.26	7.98
	5	7.1	10.3	2079	7.67
	6	7.37	13.5	159.9	8.03
11/10/2023	1	4.45	15.3	1089	7.09
	2	3.84	13	958	7.66

Date	Site #	DO	Temp	Cond	pH
11/10/2023	3	5.41	13	773	7.68
	4	14.66	N/A	2.34	8.23
	6	5.44	14.5	160.3	8.02
13/10/2023	4	5.68	14.3	1989	8.06
	5	3.9	12.1	2092	7.65
	3	8.57	15.7	840	7.82
	1	4.4	15.6	1402	7.32
23/10/2023	1	4.13	15.2	1281	6.97
	2	1.92	11.5	1364	7.75
	3	1.66	12.3	681	7.69
	4	10.16	14	2165	8.13
	5	4.34	12.4	2.21	7.78
	6	4.77	14	162.2	7.83
09/11/2023	1	3.71	16.6	1247	7.17
	2	1.61	13.3	989	7.72
	4	2.8	14.8	1677	8.08
	5	1.42	13	1975	8.19
	6	1.67	14.6	162.5	7.87

Appendix 4: Heavy metal testing results. Concentrations are measured in milligrams per liter (mg/L).

Heavy Metal	Estuary Drain (Dry)	Estuary Drain (Wet)	Mugford Drain (Dry)	Mugford Drain (Wet)
Arsenic	0.0031	0.045	0.012	0.0017
Cadmium	<0.000050	N/A	<0.000050	N/A
Chromium	0.0012	N/A	0.00066	N/A
Copper	0.0015	0.0012	0.0014	0.031
Iron	3.7	1.2	0.34	0.31
Lead	<0.00010	0.00069	0.00015	0.00010
Manganese	0.46	N/A	0.42	N/A
Mercury	<0.00010	N/A	<0.00010	N/A
Nickel	0.0017	0.00035	0.0011	0.00044
Zinc	0.0076	N/A	0.0013	N/A