Appendix F Bioresearches environmental monitoring report

Bioresearches
A Babbage Company

New Zealand Steel Limited

Environmental Monitoring of Discharge Receiving Environments 2020-2021

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Environmental Monitoring of Discharge Receiving Environments 2020-2021

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Cover Illustration: South side shoreline looking back to Steel mill (8 August 2019)

CONTENTS

1. INTRODUCTION

1.1 Context

In 2022, New Zealand Steel will seek to replace its stormwater and process water discharge permits which are due to expire (Existing Consents[1]). The replacement consent applications are necessary to authorise its continued operations at the Glenbrook Steel Mill (Steel Mill) located in South Auckland at 131 Mission Bush Road, Glenbrook, Auckland (Site).

This assessment considers the marine receiving environment relevant to New Zealand Steel's five discharge locations related to the operation of the Steel Mill, these are shown in Figure 1.1.

Figure 1.1 Discharge Locations related to New Zealand Steel mill site at Glenbrook

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[1] Permits 41027, 21575, 21576, 21577 (each expiring on 31 December 2021)

At each discharge location, ecological studies were conducted in 2020 at each discharge area with respect to the:

- Concentrations of contaminants in sediments;
- Benthic Community Health, including diversity and abundance of benthic fauna;
- Shellfish quality;
- Distribution and composition of coastal vegetation; and
- Use of intertidal habitats by coastal birds.

In addition, the results of the latest (2021) annual monitoring of shellfish, sediment quality and benthic health at the outfalls are included to form a single report presenting all information to date on the marine receiving environment. The annual monitoring is required under the conditions of Resource Consent 21575, and was undertaken in August 2021, September 2021 (due to Covid19 restrictions) and October 2021. There are three key components to the annual monitoring programme:

- Monitoring of population dynamics and contaminants in Pacific oysters;
- Monitoring of contaminants in sediments; and
- Monitoring of diversity and abundance of benthic fauna. This depends on sediment quality.

1.2 Sampling Programme and Methods

1.2.1 Surficial Sediment Quality

The most significant medium-to-long term implication of water discharges on marine receiving waters is the accumulation of contaminants in the sediment and their impact on benthic organisms, which can reach toxic concentrations over time. For this reason, sediment quality is a primary assessment component of the receiving environment.

The sediment quality parameters of most concern in the Auckland region are:

- Heavy metals: copper (Cu), lead (Pb), zinc (Zn)
- Polycyclic Aromatic Hydrocarbons
- Organochlorines: chlordane, dieldrin, DDT suite, lindane, polychlorinated biphenyls

However, the discharges at the Site are unlikely to contain organic compounds. The metals cadmium (Cd) and chromium (Cr) may be present in discharges, in addition to the metals listed above.

1.2.1.1 Site description

As part of the regular monitoring of the marine receiving environment at the Northside and Southside Outfalls required by the existing consents, surficial sediment monitoring is undertaken biennially in August (having commenced in August 2003). Monitoring has been undertaken at three sites within the consented mixing zone described in the discharge permits for the Northside and Southside Outfalls, Northside Sites A and B, and Southside Site C (Figure 1.2). An additional site in the Taihiki Inlet was added in 2021 as a control site (Site D).

Figure 1.2 *Sediment (☐) and oysters (●* **original** ● current*) monitoring sites*

- Site Northside A (NA) is located 160 m offshore from the Northside Outfall in a settling zone environment, and between 20 m and 70 m north of the low tide Northside discharge channel.
- Site Northside B (NB) is located at mean low water neap tide level, approximately 325 m offshore from the Northside Outfall in an outer zone environment, and between 20 m and 70 m north of the low tide Northside discharge channel.
- Site Southside C (SC) is located adjacent to the low tide Southside Outfall discharge channel, approximately 160 m southwest of the outfall, and is in a settling zone environment.
- Control Site D (CD) was located by Bioresearches to reflect similar site conditions to the mixing zone sites. This site was established in September 2021[2].

Settling zones are areas were most contaminants (~75%) settle out of suspension and become incorporated into benthic sediments. Consequently, settling zones are prone to contaminant accumulation, and some level of degradation is expected. Outer zones are wider estuarine areas downstream of the settling zone or located in higher energy environments where contaminants are less likely to settle permanently. The rate of contaminant accumulation in outer zones is therefore expected to be slower than in settling zones.

In 2020, sediment from three additional marine receiving environments, North Stream, Kahawai Stream and Ruakohua Spillway (Figure 1.1), associated with the New Zealand Steel site were sampled as part of an assessment of effects for consent renewal.

In 2008, sediment from the marine receiving environment was sampled as part of an assessment of effects for the expansion of the Brookside East Landfill. In 2020 sampling occurred at the following three locations along the discharge channel named “North Stream” (Figure 1.3).

- within the mangroves along the channel edges (MZ) at 270 m offshore from the upper extent of the mangroves;
- in a settling zone environment outside the mangroves adjacent to the discharge channel (SZ) located 520 m offshore from the upper extent of the mangroves; and
- in an outer zone location (OZ) at neap tide level approximately 1,080 m offshore from the upper extent of the mangroves.

At the Kahawai Stream outlet, a sample location was established in May 2020, outside the mangroves in a settling zone (KS) 170 m offshore from the higher mark at the base of the stream (Figure 1.4) and sampled in 2020.

At the Ruakohua Spillway marine receiving environment, two sampling locations were established in May 2020, outside the mangroves (Figure 1.5) and sampled in 2020.

- Ruakohua settling zone (RS) 105 m offshore from the higher mark at the base of the Ruakohua Spillway and
- Ruakohua outer zone (RO) 215 m offshore from the higher mark at the base of the Ruakohua Spillway.

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[2] Note sampling at the Control Site was delayed until 27 September 2021, due to covid 19 level 4 lockdown imposed on 18 August 2021.

Figure 1.3 North Stream Sediment and Biota Monitoring Sites, downstream of the landfill

Figure 1.4 Kahawai Stream Sediment and Biota Monitoring Sites

Figure 1.5 Ruakohua Spillway Sediment and Biota Monitoring Sites

Auckland Council Technical Publication 168 "Blueprint for monitoring in urban receiving environments" (2002) (TP168) defines a sample area of 50 m by 30 m parallel to shore. At all sample locations except MZ, a 50 m by 30 m sampling area was defined and sampled following the protocols outlined in TP168. At the MZ sample location, the area of sediment is constrained by the mangroves and stream channel, therefore sediment samples were collected from approximate 50 m transects along either side of the stream channel.

At each site, three replicate samples for metals and one sample for grain size were collected in accordance with TP168. Samples were sent to Hill Laboratories in Hamilton and all three replicate samples were tested for both weak acid metals on the <63 µm sediment fraction and total recoverable metals on the <500 µm sediment fraction (metals = copper, lead, zinc, cadmium, chromium). The grain size samples were sent to Hill Laboratories and wet sieved through a series of six sieves. The sediments retained on the six sieves were dried and weighed, allowing percentage composition of particle sizes to be determined.

In the year 2020, the two Northside locations were sampled on the 13th of March 2020. The remaining seven locations were sampled on the 4th of May 2020. The gap between sampling events was forced due to Covid-19 lockdown restrictions. Ideally all the sampling would have occurred in as short a time frame as possible to provide a snap shot of contaminant concentrations. The delay between sampling at the Northside outfall sites and the remaining sites means comparison should be done with caution, as additional factors may have influenced the sediment contaminant concentrations, such as reduced discharges or changes in discharge quality as a result of the operational changes at the Steel Mill. The two Northside locations were sampled again on the 24th of August 2020 to provide comparison with historical data from the two-yearly consent monitoring studies. The Northside and Southside outfall sites were sampled in August 2021 and the new Control site was sampled in September 2021.

1.2.1.2 Metal trigger values

The discharges at New Zealand Steel contain varying potentially elevated concentrations of the metals cadmium, chromium, copper, lead and zinc. The discharges of contaminated freshwater to the marine receiving waters can result in the dissolution of contaminants and accumulation of contaminants in the receiving environment sediments, which in turn can have impacts on benthic organisms. Sediment quality guidelines are used to assess whether the concentrations of contaminants present in the sediments are likely to result in adverse environmental effects. The Australian and New Zealand Environment and Conservation Council (ANZECC, 2000, 2018) approach provides trigger values with which to compare monitoring data. These are not pass/fail numbers. Rather, exceedance of trigger values spurs further investigation, usually an assessment of benthic invertebrate community health.

The ANZECC (2018) Default Guideline Value (DGV) low and DGV high values have been derived from the effects range low (ERL) and median (ERM) described by the US National Oceanic and Atmospheric Administration (NOAA) (in Morgan and Long, 1991) and updated in 1995 (Long *et al.*, 1995). These DGV's are trigger values which define three ranges in chemical concentrations that are anticipated to be:

1. rarely (less than DGV-Low),
2. occasionally (between DGVs), or
3. frequently (greater than DGV High) associated with biological effects.

The Auckland Council consider some of the trigger values given by ANZECC are inappropriate to the Auckland Region and have modified the DGVs. The reasons for changing ANZECC (2000) Interim Sediment Quality Guideline (ISQG) trigger values are explained fully in "Sediment Quality Guidelines for the Regional Discharges Project" (Williamson & Mills, 2002). This is consistent with the ANZECC (2000, 2018) philosophy of developing trigger values appropriate to local conditions. As the Auckland Region is assessed for effects from discharges, further and better information will accrue, allowing evaluation and improvement of the appropriateness of the trigger values and the assessment procedures. Again, this is consistent with the philosophy endorsed by ANZECC (2000, 2018), which promotes the development of local guidelines which are then used to confirm impacts before proceeding to management actions. Table 1.1 shows the original ANZECC (2000) trigger values and the Auckland Council's suggested amendments.

Table 1.1 ANZECC (2000) Trigger Values for Contaminants and Auckland Council's Suggested Amendments

Chemical / Compound	ISQG Low ANZECC (2000)	ISQG Low ARC	Source of amendment
Metals (mg/kg, ppm, dry weight)			
Cadmium	1.5	1.2	Long *et al.*, 1995
Chromium	80	80	
Copper	65	34	Long *et al.*, 1995
Lead	50	50	
Zinc	200	150	Long *et al.*, 1995

The Auckland Council's 'traffic light' system, as set out below, has been defined to classify a site and provide a management structure.

Concentrations	Management Action
Green	No further action required
Amber	Predict and investigate future trends
Red	Investigate impacts

Table 1.2 Sediment Quality Trigger Values for Red, Amber and Green Conditions (mg/kg dry weight)

Parameter	Red	Source of Red Value	Amber	Green	Source of Amber Green Value
Cadmium	>1.2	Long *et al.*, 1995	0.7 - 1.2	<0.7	ISQG CCME
Chromium	>80	ISQG ANZECC	52 - 80	<52	ISQG CCME
Copper	>34	Long *et al.*, 1995	19 - 34	<19	ISQG CCME
Lead	>50	ISQG ANZECC	30 - 50	<30	ISQG CCME
Zinc	>150	Long *et al.*, 1995	124 - 150	<124	ISQG CCME

TP168 states that the guidelines that are to be used for monitoring the impact of stormwater and wastewater are different in the settling and outer zones, reflecting the different characteristics of these zones (Auckland Regional Council, 2002). In the settling zone, the guidelines refer to the total sediment (<500 µm sediment fraction), excluding shell material and small stones. In the outer zone, the guidelines for heavy metals are applied to the higher of mud fraction (<63 µm sediment fraction), or the total sediment (<500 µm sediment fraction) sample. Thus, all three replicate samples were tested for both weak acid on the <63 µm sediment fraction and total recoverable metals (cadmium, chromium, copper, lead, zinc) on the <500 µm sediment fraction.

1.2.1.3 Grain Size description

Sediment samples were assigned a description based on the main grain size fraction with modifiers based on the next important grain sizes. These descriptions are given as letter codes (gravel=G, sand=S, mud=M, silt=Z). For example, a sample which consisted of mostly sand with a significant proportion of silt and clay would be described as muddy sand and would be denoted **mS**. If the sample had a gravel component it would be described as slightly gravelly muddy sand and would be denoted **(g)mS**. The descriptions of the sediments are based on criteria illustrated in Figure 1.6.

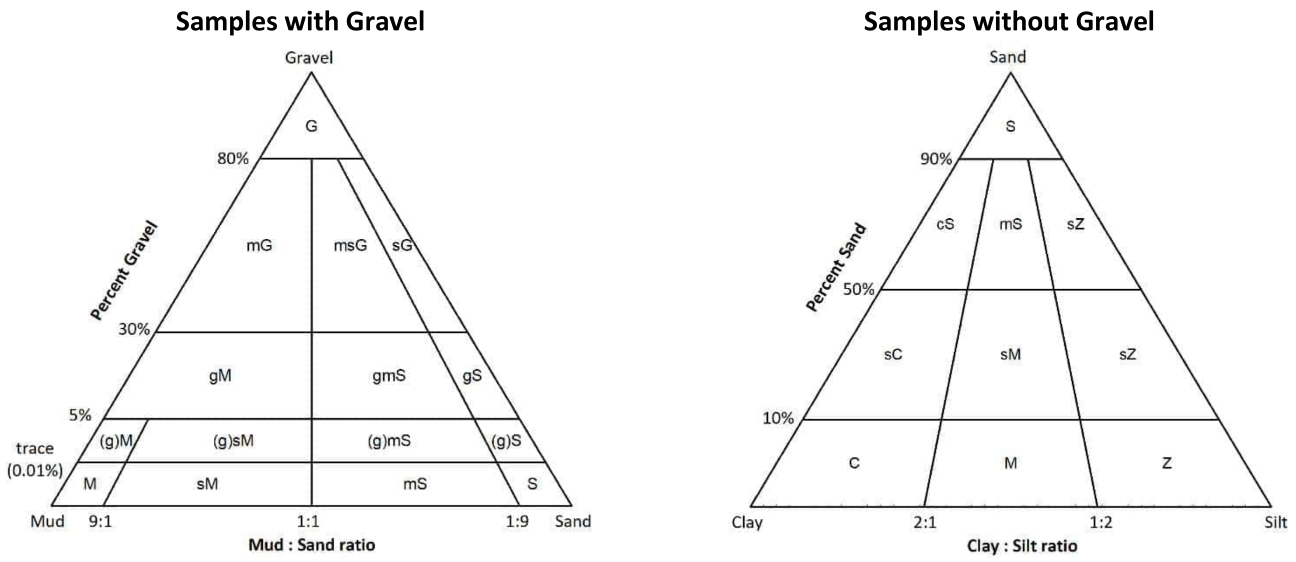

Figure 1.6 Sediment Grain Size Description

1.2.2 Benthic Community Health

A gradient model has been developed on the basis of multivariate analyses of a wide range of biological and environmental variables from settling zone and outer zone receiving environment datasets (Anderson *et al.*, 2006, Kelly, 2008). The model allows individual sites to be classified along a gradient of 'healthy' to 'impacted' communities of benthic organisms. The utility of the multivariate model is to provide a tool for:

a) assessing the current status of sites in the Auckland region on the basis of the benthic communities found there.
b) monitoring the health of benthic communities through time.
c) detecting significant environmental changes in communities.
d) tracking recovery of polluted sites following active management decisions.

The first step in this assessment is an initial screening that takes place based on sediment quality for cadmium, chromium, copper, lead and zinc. The sediment quality is compared with sediment quality guidelines and the site is 'scored' as Green, Amber or Red for sediment quality (Table 1.2). If the site is Green, no further action is required. If the site is Amber or Red, benthic community health is assessed using the soft-sediment sampling methodology defined in Auckland Council Technical Publication 168 "Blueprint for Monitoring in Urban Receiving Environments" (2002) at the sediment sites.

Soft-sediment intertidal sampling methodology consists of 10 cores of 13 cm diameter, 15 cm deep. TP168 states ecological sampling should be undertaken in October to reduce or eliminate the confounding influence of seasonal variability and minimise problems due to recruitment. Due to the need for sediment quality data with which to make assessments sediment sampling was conducted in autumn 2020. Since sampling was required in autumn and outside the timing specified by TP168 sampling of sediment quality and benthic biota was conducted at the same time.

A stratified random approach was used; the sampling area was divided into equal sub-areas (number equivalent to number of samples) and a sample taken from a random position within each sub-area. All samples were sieved on a 0.5 mm mesh sieve and preserved with a 10% glyoxal, 70% ethanol sea water solution. Animals were sorted from sediment before microscopic identification was carried out. Bivalve sizes were recorded for common species.

In March and August 2020, benthic cores were collected at Northside A and Northside B irrespective of the metal concentration assessment, as they were part of the consent renewal studies. In September 2021, benthic cores were collected at the new control site (CD) in Taihiki Inlet. In October 2021, benthic cores were collected at the Northside A site (NA).

1.2.2.1 Benthic Health models – metals and mud

The benthic biota data were added to the dataset of 81 samples used by Anderson *et al.* (2006) for the analysis of benthic ecosystem health. The benthic species found in 2020 and 2021 were matched to the historical dataset in order to perform the Canonical Analysis of Principal coordinates[3] (CAP), which is central to the benthic health assessment. For the 2020 and 2021 data, consistency between the datasets was obtained as outlined in Table 1.3. For the earlier New Zealand Steel data, consistency between the datasets was outlined in each annual report (Bioresearches, 2009, 2011, 2013, 2014, 2015, 2019).

A multivariate CAP was then carried out on the averaged, square root transformed data using Bray-Curtis similarities[4]. The site averaged New Zealand Steel data were added into the analysis as validation sites. The CAP analysis used the original ecological data from Anderson *et al.* (2006) and the associated PC1.500[5] data.

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[3] Canonical Analysis of Principal coordinates (CAP), is a flexible and particularly useful constrained ordination procedure for ecology. It has the advantage of allowing any distance or dissimilarity measure to be used, but also takes into account correlation structure among variables in the response data cloud. It is used to uncover important patterns in the multivariate data by reference to relevant hypotheses.

[4] The Bray-Curtis similarity is the most commonly-used similarity coefficient for biological community analysis, because it obeys many of the 'natural' biological guidelines in a way that most other coefficients do not.

[5] Principal Coordinate based on the total <500 µm sediment fraction quality, or simply a pollution gradient on the basis of log metal concentrations in the total sample.

The PC1.500 was obtained by running a principal components analysis[6] (PCA) analysis on copper, lead and zinc concentrations[7] in sediments from the sites where ecological samples were collected. The PRIMER add-on, PERMANOVA+, was used to carry out the CAP analysis (PRIMER 7.0.13, PRIMER-e).

Table 1.3 Match between the 2020 Benthic Biota Dataset and the Benthic Health Model (CAP)

Taxa in the 2020 dataset	Taxa in the 2021 dataset	Corresponding taxa in the CAP
Cossura consimilis		*Cossura consimilis*
Glyceridae	Glyceridae	Glycera spp.
Magelona dakini	*Magelona dakini*	*Magelona* ident.
	Maldanidae	Maldanidae
Paraonidae	Paraonidae	Paranoid other
	Pectinaria australis	*Pectinaria australis*
Prionospio sp.	Spionidae *Prionospio a.*	Spionid
	Spionidae *Boccardia*	Polydorid complex
Scolecolepides sp.	Spionidae *Scolecolepides b.*	*Scolecolepides benhami*
	Nemertean	Nemertean
	Tritia burchardi	-
Austrovenus stutchburyi	*Austrovenus stutchburyi*	*Austrovenus stutchburyi*
Heteromastus filiformis	*Heteromastus filiformis*	*Heteromastus filiformis*
Nereidae	Nereidae	Nereidae
Theora lubrica	*Theora lubrica*	*Theora lubrica*
	Phoxocephalidae	Phoxocephalids
Unidentified Amphipod species	Unidentified Amphipod species	Amphipod other
Cumacea sp.		Diastylopsis sp.
Alpheus sp.	*Alpheus* sp.	*Alpheus* sp.
Unidentified shrimp		*Alpheus* sp.
Austrohelice crassa	*Austrohelice crassa*	*Helice, Hemigrapsus, Macrophthalmus*
	Hemiplax hirtipes	*Helice, Hemigrapsus, Macrophthalmus*

In 2021 an updated version of the Benthic Health Model (BHM) metals was run over all data accumulated since 2009. In addition, two other models were included in the analyses to be consistent with the modelling routines used by the Auckland Council to assess the health of benthic communities (Hewit and Ellis 2010): the BHM on mud content and the trait-based index (TBI). The BHM on mud content relies on a similar methodology to the BHM on metals with the reference to the multivariate analysis being the percentage mud for each site instead of metal concentrations. The CAP analysis is then based on the mud percentage of the original ecological sites.

The model estimates a CAP value and a predicted PC1.500 or % Mud value for each year of sampling at Northside A and B. The predicted CAP values were matched to the health scores following Table 1.4.

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[6] principal components analysis, is a dimensionality-reduction method that is often used to reduce the dimensionality of large data sets, by transforming a large set of variables into a smaller one that still contains most of the information in the large set.

[7] Obtained using strong acid digestion of the <500 µm sediment fraction.

Table 1.4 Boundaries for Ranking Benthic Health along the PC1.500 Pollution Gradient

	Health group	CAP Metals		CAP Mud	
		min	Max	min	Max
healthy	1 - Extremely good		-0.164		-0.12
	2 - Good	-0.164	-0.067	-0.12	-0.05
↓	3 - Moderate	-0.067	0.023	-0.05	0.02
	4 - Poor	0.023	0.100	0.02	0.10
polluted	5 - Unhealthy	0.100		0.10	

1.2.2.2 Trait-based index (TBI)

The trait-based index combines living characteristics for each benthic species which represents the degree of diversity of benthic communities at a particular site. The index range from 0 (low functional diversity displayed at degraded sites) to 1 (high functional diversity displayed at healthy sites).

Benthic species were categorised according to seven particular traits that influence the benthic ecosystem function. They are the feeding mode (suspension feeder or deposit feeder), mobility, size, living habit (surface sediment or deeper), the degree of sediment activity, the shape (worm shaped or not), and having an erected structure. The Auckland Council has provided a score for each benthic species found during their monitoring programme. Relevant species found during the sampling for New Zealand Steel since 2009 are presented in Table 1.5. The combination of the species-specific TBI scores and the occurrence of species during a sampling event resulted in a TBI score for each sample. The detailed methodology is described in Hewitt *et al.* 2012.

Table 1.5 Species-specific TBI scores for benthic species (alphabetic order) found during benthic sampling since 2009

List of species	Species-specific TBI	List of species	Species-specific TBI
Alpheus	3	*Magelona* ident	3
Amphipod other	3	Maldanidae	5
Aricidea sp.	2	Mysidacea	2
Arthritica bifurcata	3	Nebaliacea	3
Austrovenus stutchburyi	3	Nemertean	3
Capitella	1	Nereidae	3
Oligochaetes	3	*Nucula hartvigiana*	2
Cirratulid	4	Paraonid other	2
Cominella glandiformis	1	*Pectinaria australis*	6
Cossura consimilis	3	Phoxocephalids	3
Diastylopsis sp. (Cumacea)	2	Polydorid complex	6
Glycera spp.	3	Sabellidae	6
Goniadidae	4	*Scolecolepides benhami*	3
Macrophthalmus, Helice	2	*Scolelepis* spp.	2
Heteromastus filiformis	2	Spionid	2
Macomona liliana	2	*Theora lubrica*	4
Mactra ovata	1	*Zeacumantus lutulentus*	3

The BHM CAPs and TBI scores were converted into values ranging from 0 to 1, and then combined to give a combined Health index (Table 1.6). The combination follows these criteria explained in section 5.2. of Hewitt *et al*. 2012:

1. “If the CAPmud score allocated the site to Mud group 1 then Health was calcualted as the average CAPmetals and CAPmud group scores (as we have noted the TBI does not work well when mud content is extremely low).
2. If the CAPmetals score allocated the site to Group 4 or 5, then Health was equal to the TBI group score (reflecting the remaining level of functional redundancy present in these strongly metal-affected communities).
3. Otherwise, health was the average of the CAPmetals, CAPmud and TBI group scores.
4. Recording these scores as:
   a. ≤ 0.2 “extremely good”
   b. 0.2 - 0.4 inclusive “good”
   c. 0.4 - 0.6 exclusive “moderate”
   d. 0.6 – 0.8 exclusive “poor”
   e. ≥ 0.8 “unhealthy with low resilience” “

This overall index ranges from 0 (most healthy site) to 1 (most degraded site) (Table 1.6).

Table 1.6 Conversion of CAP Metals, CAP Mud and TBI scores into values for the Combined Health Score

Health group	CAP Metals		CAP Mud		TBI		Combined Health Score
	Cut-off	Value	Cut-off	Value	Cut-off	Value	
1 - Extremely good	-0.164	0.2	-0.12	0.2	0.4	0.33	≤ 0.2 “extremely good”
2 - Good	-0.067	0.4	-0.05	0.4	0.3	0.67	0.2 - 0.4 inclusive “good”
3 - Moderate	0.023	0.6	0.02	0.6		1.0	0.4 - 0.6 exclusive “moderate”
4 - Poor	0.100	0.8	0.10	0.8			0.6 – 0.8 exclusive “poor”
5 - Unhealthy		1.0		1.0			≥ 0.8 “unhealthy with low resilience”

1.2.3 Shellfish Quality

A summary of the sampling undertaken every year is presented in Table 1.7. The Pacific oysters (*Crassostrea gigas*) were analysed for copper and zinc. Sample site locations are shown in Figure 1.2.

Table 1.7 Summary of planned annual sampling

	NUMBER OF SITES			Number of Individuals Measured at Each Site	Number of Density Quadrats at Each Site	Number of Samples Analysed for Metals at Each Site
	Northside	Southside	Control			
Crassostrea gigas	3	2	1	100	30	12

Sites N6, N5, S3, S5 and TC in the annual monitoring were initially sampled in May 1985 (Bioresearches Ltd, 1985), with sampling at site N10 added in May 1988. Shellfish sites have been permanently marked with pegs. Each sample site consists of an area measuring 50 m long by 2.5 m wide, parallel to the low or high tide mark. In some oyster beds of limited extent, the sample area was reduced to 40 m long.

The Resource Consent now specifies that Pacific oyster monitoring is to be undertaken annually in August.

In 2009 it was noted that at a number of sites (N6, S3 and S5, and TC) the density of oysters was getting very low, and that alternative sites (N6a, S3, S5a, TC) would be required in order to continue sampling. In August 2010 alternative sites were located and sampled as near as possible to the previous sites.

At each site thirty 0.25 m² quadrats were located in the sampling area using random numbers to generate X and Y co-ordinates. Up to one hundred shellfish per site were measured in the field and the individuals returned to the sample quadrat. The 30 density quadrats were also counted in the field with as little disturbance as possible.

Twelve samples of six oysters, of a predetermined size range (between 60-70 mm), were collected per site for metals analysis. Pacific oyster samples collected for metals analyses were sealed in new polyethylene bags in the field. Upon return to the laboratory, the oysters were thoroughly cleaned by scrubbing the shells and removing any major fouling organisms. Any broken or damaged shellfish were discarded and replaced.

The total volume of each replicate sample of oysters was then determined (as part of the measurement of a condition index) and the oysters frozen for processing at a later date. The oysters were thawed and shucked into pre-weighed clean plastic vials. While thawing, the oysters were placed cupped side down to minimise loss of fluid. Each replicate sample of oyster flesh was weighed to obtain a wet weight and the volume of oyster shells was obtained for each replicate sample.

A Condition Index (an indicator of how well an oyster has utilised the internal shell volume available for tissue growth), as set out below, was calculated for the samples analysed for metal concentrations.

$$\text{Condition Index} \quad = \quad \frac{\text{Flesh dry weight} * 100}{\text{Internal shell volume}}$$

Flesh samples were re-frozen as soon as possible after shucking. Frozen flesh samples were delivered to the Watercare Services Limited laboratory at Māngere for metal analysis (copper and zinc).

The copper and zinc dry weight data from each site were statistically tested with Analysis of Variance[8] (ANOVA). If the assumptions of normality and equal variance were not met, then a Kruskal-Wallis[9] one-way ANOVA on ranks was conducted. If the ANOVA rejected a hypothesis of equal means, a multiple comparison of means test (Tukey analysis[10]) was carried out to determine which samples were significantly different.

The conventional criterion for statistical hypotheses testing is p<0.05. When parametric testing has been used, then the summary table uses the following designations for significance:

NSD	=	No significant difference	(p>=0.05)
*	=	Significant difference	(p<0.05)
**	=	Very significant difference	(p<0.01)
***	=	Highly significant difference	(p<0.001)

If the non-parametric testing on ranks has been used, then the summary table uses only NSD or * designations for significance as testing does not provide any greater detail on the level significance of each comparison.

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[8] One-Way Analysis of Variance tests if there are any statistical differences between the means of three or more independent groups.

[9] A non-parametric method for testing whether samples originate from the same distribution, based on ranks.

[10] While the ANOVA determines if there are differences in a group of means, the Tukey test is a pairwise analysis that determines which means are statistically significantly different from each other and how significantly different they are.

1.2.4 Coastal Vegetation Survey (2020)

Coastal terrestrial vegetation and intertidal vegetation was surveyed in May 2020. Approximately 9 km of the coastal zone on the eastern side of the Waiuku Estuary, Manukau Harbour was surveyed from 300 m south of the Ruakohua Spillway to the western point of 381 -389 Glenbrook Beach Road, north of the Site.

Both botanical survey and vegetation mapping, using a hand-held GPS unit, was undertaken during the assessments. Species composition and characteristics of the key vegetation types were recorded, including a description of the vegetation, habitat type (marine, estuarine, freshwater, terrestrial), and noting any significant native trees. The ecosystems units were categorised using the Indigenous terrestrial and wetland ecosystems of Auckland grouping (Singers *et al*., 2017), with further subgroups categorised by the dominant species present.

The coastal vegetation communities are divided into two broad groupings, coastal terrestrial vegetation and coastal intertidal vegetation. These groups are further divided into community classes, determined by the dominant vegetation. The general characteristics of the communities are described as:

Terrestrial Vegetation

1. Pines and exotic vegetation [Ex]
2. New Zealand native coastal vegetation [NV]
3. Freshwater transitional vegetation [W1-W7]

Coastal Intertidal Vegetation

4. Mangrove [M]
5. Rush marsh & coastal grass [R]
6. Salt marsh meadow [SM]

1.2.5 Coastal Birds

Coastal bird surveys were conducted in the intertidal habitats of three areas around the perimeter of the Site that were considered to be of interest because of adjacent activities associated with the Steel Mill i.e. Northside/Southside Outfall area, Ruakohua Spillway and the Kahawai to North streams habitats. In addition, counts were undertaken at a notable high tidal roost adjacent to the Kahawai Stream area.

In each discharge area (i.e. Northside/Southside, Ruakohua and Kahawai/North streams; Figure 1.7 and Figure 1.8), six hourly counts were undertaken at each of four seasonal surveys (undertaken in autumn, winter, spring and summer) with 24 sets of data recorded for each area over the twelve month period.

Coastal bird surveys were conducted in May, August and October 2020, and in January 2021 to represent the autumn (March, April, May), winter (June, July, August), spring (September, October, November) and summer (December. January, February) periods respectively.

As shown in Figure 1.9, a significant high tide roost for coastal birds is situated on raised rock platforms on the point to the west of the Kahawai Stream mouth outside, but immediately adjacent to, the Kahawai to North streams area covered in the seasonal surveys. A total of three counts (autumn, spring and summer) were completed at the Kahawai Stream area high tide roost. Winter sampling was delayed by a Covid-19 level 3 lockdown between 12th and 30th August 2020, when access approval was gained no suitable daylight high tides occurred in the limited August (winter) period available, hence no winter high tide roost counts were recorded.

Counts were aided by Nikon Monarch 5 10x42 binoculars and a Kowa TSN-883 Promina tripod-mounted spotting scope with a 25-60 times zoom eyepiece. Before each count, the air temperature was measured using a digi-quartz thermometer; wind speed and barometric pressure were measured with a Silva Alba ADC Summit windwatch and general weather conditions recorded. All data were recorded on pre-prepared, waterproof recording sheets.

Each hour, all birds utilising the habitats in the survey areas were identified and counted. In addition, the habitat use of each species were recorded to provide an overall assessment of the significance of the habitats in terms of feeding, resting or roosting. The codes for the habitat use activities were recorded as follows:

FI : feeding in the intertidal habitat
FW : feeding in or over the water
REI : resting in the intertidal habitat
REW : resting on the water
ROP : resting/roosting on mangroves and riparian trees or structures

Figure 1.7 Bird monitoring areas for Northside / Southside and Ruakohua embayments

Figure 1.8 Bird monitoring area for the Kahawai to North streams embayment, and high tide roosting site location

1.3 Suggested Potential Improvements to the Marine Ecological Monitoring Programme

The marine ecological monitoring programme currently in place provides an extensive and robust data set against which the current application and the ongoing effects of the operation of the Steel Mill can be assessed. In order to strengthen this dataset further and assess the outcomes of any additional mitigation or compensation as a result of consent being granted, the following monitoring recommendations are suggested to be incorporated into the management plans.

- Seasonal coastal bird surveys to support the existing baseline surveys with a particular focus on any proposed compensation actions including constructed or enhanced roosts; (started in late 2021, but not yet reported)
- Vegetation surveys where any vegetation management is proposed or carried out as part of coastal bird management;
- Adding a sediment contaminant and benthic ecology 'control' site against which any changes at the ecology sites adjacent to the Steel Mill discharges can be assessed would strengthen the evaluation of monitoring data. It is recommended that this site be located where sedimentation rates and sediment metal accumulation are predicted to be minimal over the 35 year consent period and close to the oyster monitoring control site in Taihiki Estuary; (Control site established in September 2021 as reported below)
- The interpretation of benthic ecology data against sediment quality could be strengthened by incorporating the Benthic Health Model (BHM) for mud and the Traits Based Index (TBI) into the ecological scoring system, as per that used by Auckland Council. It is expected this will allow the effects from sedimentation and sediment metal accumulation to be better separated out and their effects further understood; (implemented for 2021 monitoring and reported below including an updated assessment of older data)

- Sediment sampling at the Lower North Stream mangrove and outer zone monitoring sites showed possible increases in contaminants over time. It is recommended that further investigation of the NZ Steel discharge to the North Stream is carried out to explore whether any NZ Steel discharges are contributing to this possible increasing trend.
- To provide additional baseline information it is recommended that benthic ecology is sampled at all benthic monitoring sites in the next monitoring round in 2022 or 2023 regardless of contaminant concentration status.

2. SURFICIAL SEDIMENT QUALITY

2.1 Metals in sediments – 2020 and 2021 monitoring

Sediment sampling in 2020 and 2021 is summarised bellow.

Site	March 2020	August 2020	August 2021
Control CD			✓
North stream OZ	✓		
North stream SZ	✓		
North stream MZ	✓		
Kahawai stream KS	✓		
Northside NA	✓	✓	✓
Northside NB	✓	✓	✓
Southside SC	✓		✓
Spillway RS	✓		
Spillway OS	✓		

Metals data for sediments collected in 2020 and 2021 are presented in Table 2.1 to Table 2.7.

Table 2.1 Metals Concentrations, March 2020, August 2020 and August 2021, from Northside A outfall catchment (mg/kg dry weight)

Location	Site	Weak Acid Extraction on Mud Fraction					Total Recoverable Metals on Total Sediments				
		Cadmium	Chromium	Copper	Lead	Zinc	Cadmium	Chromium	Copper	Lead	Zinc
Norths. A **March 20**	A1	< 0.05	15.00	4.70	10.80	73.00	0.171	32.0	8.6	14.1	175.0
	A2	< 0.05	14.60	4.60	10.70	73.00	0.189	33.0	8.5	14.0	185.0
	A3	0.05	14.30	4.70	10.50	71.00	0.171	32.0	8.6	14.2	178.0
	Average	**0.05**	**14.63**	**4.67**	**10.67**	**72.33**	**0.177**	**32.3**	**8.6**	**14.1**	**179.3**
	95% CL	-	0.87	0.14	0.38	2.87	0.026	1.4	0.1	0.2	12.7
Norths. A **August 20**	A1	< 0.05	17.30	4.60	10.80	78.00	0.175	34.00	8.00	16.40	189.00
	A2	< 0.05	16.50	4.50	11.40	78.00	0.164	34.00	8.70	16.00	181.00
	A3	< 0.05	17.00	4.80	11.60	78.00	0.193	36.00	9.00	16.80	200.00
	Average	**< 0.05**	**16.93**	**4.63**	**11.27**	**78.00**	**0.177**	**34.67**	**8.57**	**16.40**	**190.00**
	95% CL	-	1.00	0.38	1.03	-	0.036	2.87	1.27	0.99	23.70
Norths. A **August 21**	A1	< 0.05	14.0	4.4	10.5	73.0	0.160	37.0	9.0	14.3	175
	A2	< 0.05	18.0	4.2	9.7	68.0	0.200	35.0	9.0	14.9	188
	A3	< 0.05	16.0	4.1	9.2	67.0	0.200	35.0	9.0	15.1	210
	Average	**< 0.05**	**16.0**	**4.2**	**9.8**	**69.3**	**0.187**	**35.67**	**9.0**	**14.77**	**191.00**
	95% CL	-	5.0	0.4	1.6	8.0	0.057	2.87	-	1.03	43.95
Red		> 1.2	> 80	> 34	> 50	> 150	> 1.2	> 80	> 34	> 50	> 150
Amber		0.7 - 1.2	52 - 80	19 - 34	30 - 50	124 - 150	0.7 - 1.2	52 - 80	19 - 34	30 - 50	124 - 150
Green		< 0.7	< 52	< 19	< 30	< 124	< 0.7	< 52	< 19	< 30	< 124

Table 2.2 Metals Concentrations, March 2020, August 2020 and August 2021, from Northside B outfall catchment (mg/kg dry weight)

Location	Site	Weak Acid Extraction on Mud Fraction					Total Recoverable Metals on Total Sediments				
		Cadmium	Chromium	Copper	Lead	Zinc	Cadmium	Chromium	Copper	Lead	Zinc
Norths. B **March 20**	B1	< 0.05	14.40	4.40	11.00	61.00	0.062	28.0	7.9	13.0	104.0
	B2	< 0.05	16.00	4.40	11.00	59.00	0.059	28.0	8.1	14.1	103.0
	B3	< 0.05	14.70	3.90	10.00	51.00	0.059	28.0	8.1	13.5	106.0
	Average	**< 0.05**	**15.03**	**4.23**	**10.67**	**57.00**	**0.060**	**28.0**	**8.0**	**13.5**	**104.3**
	95% CL	-	2.11	0.72	1.43	13.14	0.004	-	0.3	1.4	3.8
Norths. B **August 20**	B1	< 0.05	14.50	4.30	10.40	60.00	0.051	29.00	8.00	14.70	101.00
	B2	< 0.06	15.40	4.50	10.20	59.00	0.051	30.00	8.20	14.90	105.00
	B3	< 0.06	14.50	4.20	10.30	58.00	0.046	28.00	7.90	13.90	97.00
	Average	**< 0.06**	**14.80**	**4.33**	**10.30**	**59.00**	**0.049**	**29.00**	**8.03**	**14.50**	**101.00**
	95% CL	0.014	1.29	0.38	0.25	2.48	0.007	2.48	0.38	1.31	9.94
Norths. B **August 21**	B1	< 0.05	16.0	4.3	9.4	54.0	< 0.100	27.0	8.0	13.2	94
	B2	< 0.05	13.0	3.2	6.7	37.0	< 0.100	28.0	8.0	13.0	97
	B3	< 0.05	17.0	4.3	10.0	56.0	< 0.100	26.0	8.0	12.9	105
	Average	**< 0.05**	**15.3**	**3.9**	**8.7**	**49.0**	**< 0.100**	**27.00**	**8.0**	**13.03**	**98.67**
	95% CL	-	5.2	1.6	4.4	25.9	-	2.48	-	0.38	14.13
Red		> 1.2	> 80	> 34	> 50	> 150	> 1.2	> 80	> 34	> 50	> 150
Amber		0.7 - 1.2	52 - 80	19 - 34	30 - 50	124 - 150	0.7 - 1.2	52 - 80	19 - 34	30 - 50	124 - 150
Green		< 0.7	< 52	< 19	< 30	< 124	< 0.7	< 52	< 19	< 30	< 124

Table 2.3 Metals Concentrations, March 2020 and August 2021, from Southside outfall catchment (mg/kg dry weight)

Location	Site	Weak Acid Extraction on Mud Fraction					Total Recoverable Metals on Total Sediments				
		Cadmium	Chromium	Copper	Lead	Zinc	Cadmium	Chromium	Copper	Lead	Zinc
Southside **March 20**	C1	< 0.05	14.40	4.50	10.80	58.00	0.047	23.0	6.4	12.4	87.0
	C2	< 0.05	14.40	4.50	10.70	57.00	0.045	22.0	6.1	12.3	83.0
	C3	< 0.05	14.50	4.20	10.70	55.00	0.050	23.0	6.1	12.1	84.0
	Average	**< 0.05**	**14.43**	**4.40**	**10.73**	**56.67**	**0.047**	**22.7**	**6.2**	**12.3**	**84.7**
	95% CL	-	0.14	0.43	0.14	3.79	0.006	1.4	0.4	0.4	5.2
Southside **August 21**	C1	< 0.05	15.0	4.0	9.9	55.0	< 0.100	25.0	7.0	13.7	93
	C2	< 0.05	16.0	4.4	10.0	58.0	< 0.100	22.0	7.0	12.8	81
	C3	< 0.05	15.0	4.1	10.0	54.0	< 0.100	24.0	7.0	13.6	96
	Average	**< 0.05**	**15.3**	**4.2**	**10.0**	**55.7**	**< 0.100**	**23.67**	**7.0**	**13.37**	**90.00**
	95% CL	-	1.4	0.5	0.1	5.2	-	3.79	0	1.23	19.72
Red		> 1.2	> 80	> 34	> 50	> 150	> 1.2	> 80	> 34	> 50	> 150
Amber		0.7 - 1.2	52 - 80	19 - 34	30 - 50	124 - 150	0.7 - 1.2	52 - 80	19 - 34	30 - 50	124 - 150
Green		< 0.7	< 52	< 19	< 30	< 124	< 0.7	< 52	< 19	< 30	< 124

Table 2.4 Metals Concentrations, August 2021, from the control site D (mg/kg dry weight)

Location	Site	Weak Acid Extraction on Mud Fraction					Total Recoverable Metals on Total Sediments				
		Cadmium	Chromium	Copper	Lead	Zinc	Cadmium	Chromium	Copper	Lead	Zinc
Control **August 21**	D1	< 0.05	12.7	4.0	8.7	46.0	< 0.100	18.0	6.0	9.2	59
	D2	< 0.05	13.1	4.3	9.7	51.0	< 0.100	20.0	6.0	9.4	59
	D3	< 0.05	12.5	4.2	9.5	48.0	0.025	19.9	5.9	8.8	60
	Average	**< 0.05**	**12.8**	**4.2**	**9.3**	**48.3**	**< 0.075**	**19.30**	**5.97**	**9.13**	**59.33**
	95% CL	-	0.8	0.4	1.3	6.3	0.108	2.80	0.14	0.76	1.43
Red		> 1.2	> 80	> 34	> 50	> 150	> 1.2	> 80	> 34	> 50	> 150
Amber		0.7 - 1.2	52 - 80	19 - 34	30 - 50	124 - 150	0.7 - 1.2	52 - 80	19 - 34	30 - 50	124 - 150
Green		< 0.7	< 52	< 19	< 30	< 124	< 0.7	< 52	< 19	< 30	< 124

Table 2.5 Metals Concentrations, May 2020, from North Stream catchment (mg/kg dry weight)

Location	Site	Weak Acid Extraction on Mud Fraction					Total Recoverable Metals on Total Sediments				
		Cadmium	Chromium	Copper	Lead	Zinc	Cadmium	Chromium	Copper	Lead	Zinc
North stream **May 20**	MZ1	< 0.05	16.60	6.20	13.70	65.00	0.038	30.0	10.0	17.7	99.0
	MZ2	< 0.05	16.50	6.60	13.80	67.00	0.037	30.0	10.2	15.6	98.0
	MZ3	< 0.05	16.30	6.70	13.70	63.00	0.039	30.0	11.0	15.8	98.0
	Average	**< 0.05**	**16.47**	**6.50**	**13.73**	**65.00**	**0.038**	**30.0**	**10.4**	**16.4**	**98.3**
	95% CL	-	0.38	0.66	0.14	4.97	0.002	0.0	1.3	2.9	1.4
North stream **May 20**	SZ1	< 0.05	15.10	5.40	11.80	57.00	< 0.010	4.4	0.9	2.1	15.7
	SZ2	< 0.05	15.00	5.40	12.00	58.00	< 0.010	3.8	0.7	2.3	14.7
	SZ3	< 0.05	15.60	5.90	12.10	61.00	< 0.010	4.3	1.0	3.0	15.8
	Average	**< 0.05**	**15.23**	**5.57**	**11.97**	**58.67**	**< 0.010**	**4.2**	**0.9**	**2.5**	**15.4**
	95% CL	-	0.80	0.72	0.38	5.17	-	0.8	0.4	1.2	1.5
North stream **May 20**	OZ1	< 0.05	13.50	3.80	9.40	48.00	0.023	10.5	3.2	5.7	41.0
	OZ2	< 0.05	13.40	3.80	8.90	42.00	0.024	11.4	3.5	6.5	45.0
	OZ3	< 0.05	12.30	4.00	9.50	46.00	0.024	11.8	3.4	5.8	43.0
	Average	**< 0.05**	**13.07**	**3.87**	**9.27**	**45.33**	**0.024**	**11.2**	**3.4**	**6.0**	**43.0**
	95% CL	-	1.65	0.29	0.80	7.59	0.001	1.7	0.4	1.1	5.0
Red		> 1.2	> 80	> 34	> 50	> 150	> 1.2	> 80	> 34	> 50	> 150
Amber		0.7 - 1.2	52 - 80	19 - 34	30 - 50	124 - 150	0.7 - 1.2	52 - 80	19 - 34	30 - 50	124 - 150
Green		< 0.7	< 52	< 19	< 30	< 124	< 0.7	< 52	< 19	< 30	< 124

Table 2.6 Metals Concentrations, May 2020, from Ruakohua Spillway catchment (mg/kg dry weight)

Location	Site	Weak Acid Extraction on Mud Fraction					Total Recoverable Metals on Total Sediments				
		Cadmium	Chromium	Copper	Lead	Zinc	Cadmium	Chromium	Copper	Lead	Zinc
Spillway **May 20**	RS1	< 0.05	13.90	4.20	10.20	53.00	0.061	28.0	7.6	12.8	88.0
	RS2	< 0.05	12.80	4.20	9.80	49.00	0.055	29.0	7.7	11.7	87.0
	RS3	< 0.05	13.20	4.10	9.60	48.00	0.055	29.0	7.3	11.7	86.0
	Average	**< 0.05**	**13.30**	**4.17**	**9.87**	**50.00**	**0.057**	**28.7**	**7.5**	**12.1**	**87.0**
	95% CL	-	1.38	0.14	0.76	6.57	0.009	1.4	0.5	1.6	2.5
Spillway **May 20**	RO1	< 0.05	13.50	4.40	10.60	51.00	0.042	25.0	7.5	12.1	86.0
	RO2	< 0.05	14.10	4.20	10.90	55.00	0.048	26.0	7.7	12.7	87.0
	RO3	< 0.05	14.20	4.40	10.80	54.00	0.045	27.0	7.6	12.6	85.0
	Average	**< 0.05**	**13.93**	**4.33**	**10.77**	**53.33**	**0.045**	**26.0**	**7.6**	**12.5**	**86.0**
	95% CL	-	0.94	0.29	0.38	5.17	0.007	2.5	0.2	0.8	2.5
Red		> 1.2	> 80	> 34	> 50	> 150	> 1.2	> 80	> 34	> 50	> 150
Amber		0.7 - 1.2	52 - 80	19 - 34	30 - 50	124 - 150	0.7 - 1.2	52 - 80	19 - 34	30 - 50	124 - 150
Green		< 0.7	< 52	< 19	< 30	< 124	< 0.7	< 52	< 19	< 30	< 124

Table 2.7 Metals Concentrations, May 2020, from Kahawai Stream catchment (mg/kg dry weight)

Location	Site	Weak Acid Extraction on Mud Fraction					Total Recoverable Metals on Total Sediments				
		Cadmium	Chromium	Copper	Lead	Zinc	Cadmium	Chromium	Copper	Lead	Zinc
Kahawai **May 20**	KS1	< 0.05	10.50	3.40	8.20	41.00	0.038	14.9	4.4	6.4	55.0
	KS2	< 0.05	10.60	3.50	8.40	39.00	0.038	15.6	4.5	6.5	54.0
	KS3	< 0.05	10.70	3.80	8.70	42.00	0.042	14.6	4.4	6.4	54.0
	Average	**< 0.05**	**10.60**	**3.57**	**8.43**	**40.67**	**0.039**	**15.0**	**4.4**	**6.4**	**54.3**
	95% CL	-	0.25	0.52	0.63	3.79	0.006	1.3	0.1	0.1	1.4
Red		> 1.2	> 80	> 34	> 50	> 150	> 1.2	> 80	> 34	> 50	> 150
Amber		0.7 - 1.2	52 - 80	19 - 34	30 - 50	124 - 150	0.7 - 1.2	52 - 80	19 - 34	30 - 50	124 - 150
Green		< 0.7	< 52	< 19	< 30	< 124	< 0.7	< 52	< 19	< 30	< 124

The TP168 states that the total recoverable metals data from settling zone sites should be compared with the guideline trigger values to set the traffic light colour (Auckland Regional Council, 2002). For Outer zones, the traffic light colour is assessed by comparing the guideline trigger values with the higher of the following two sets of analyses:

A. the total recoverable metals in sediment.
B. the weak acid extractable metal from the mud fraction.

Site Northside A is located in a settling zone adjacent to the Northside Outfall (Figure 1.2). The total recoverable and mud fraction concentrations of cadmium, chromium, copper and lead were all classified as ‘Green’ in 2020 and 2021 (Table 2.1). Zinc concentrations in the mud fraction were also in the ‘Green’ category, however the total recoverable zinc concentration was in the ‘Red’ category, and this for the past three sampling events. Therefore, it was recommended that the benthic community was assessed at site Northside A, as these high levels of zinc could pose adverse effects to biological communities.

Sites Northside B, Southside C and Control D are in outer zone areas (Figure 1.2). At sites Northside B and Southside C, the total recoverable and mud fraction weak acid concentrations of cadmium, chromium, copper, lead and zinc concentrations were all classified as ‘Green’ in 2020 and 2021 (Table 2.2, Table 2.3, Table 2.4). Although the contaminant concentrations pose no threat to biological communities at either Northside B, Southside C, or Control D, benthic biota samples were nonetheless collected at Northside B in 2020 and at Control D in 2021, prior to the publication of the contaminant results.

Site MZ is located in the mangroves along the discharge channel, Site SZ is located in a settling zone and the Site OZ is located in an outer zone adjacent to the North Stream outlet. The total recoverable and mud fraction weak acid concentrations of cadmium, chromium, copper, lead and zinc, from all three sites were all classified as ‘Green’ in 2020 (Table 2.5). The benthic community was not required to be assessed at the North Stream sites.

Site RS is located in a settling zone just outside the mangroves and the Site RO is located in an outer zone further away from the Ruakohua Spillway (Figure 1.5). The total recoverable and mud fraction weak acid concentrations of cadmium, chromium, copper, lead and zinc, from both sites were all classified as ‘Green’ in 2020 (Table 2.6). The benthic community was not required to be assessed at the Ruakohua Spillway.

Site KS is located in a settling zone adjacent to the Kahawai Stream outlet (Figure 1.5). The total recoverable and mud fraction weak acid concentrations of cadmium, chromium, copper, lead and zinc, from this site were all classified as ‘Green’ (Table 2.7). The benthic community was not required to be assessed at the Kahawai Stream.

2.2 Comparison of Metal Data in Sediments between sites (2020)

2.2.1 Cadmium in 2020

The majority of total recoverable concentrations of cadmium were similar to that recorded in the mud fraction (Figure 2.1). The major exception was at the Northside Outfall NA site were the total recoverable concentration was significantly higher. Lower total recoverable concentrations were recorded at the North Stream sites SZ and OZ. The mud fraction weak acid concentrations of cadmium were all recorded as not detectable, the method detection limit was 0.05 mg/kg but given the lower total recoverable concentrations recorded it is possible the mud fraction concentrations were lower at the North Stream sites SZ and OZ.

The total recoverable concentrations suggest a minor source of cadmium in the vicinity of the Northside Outfall.

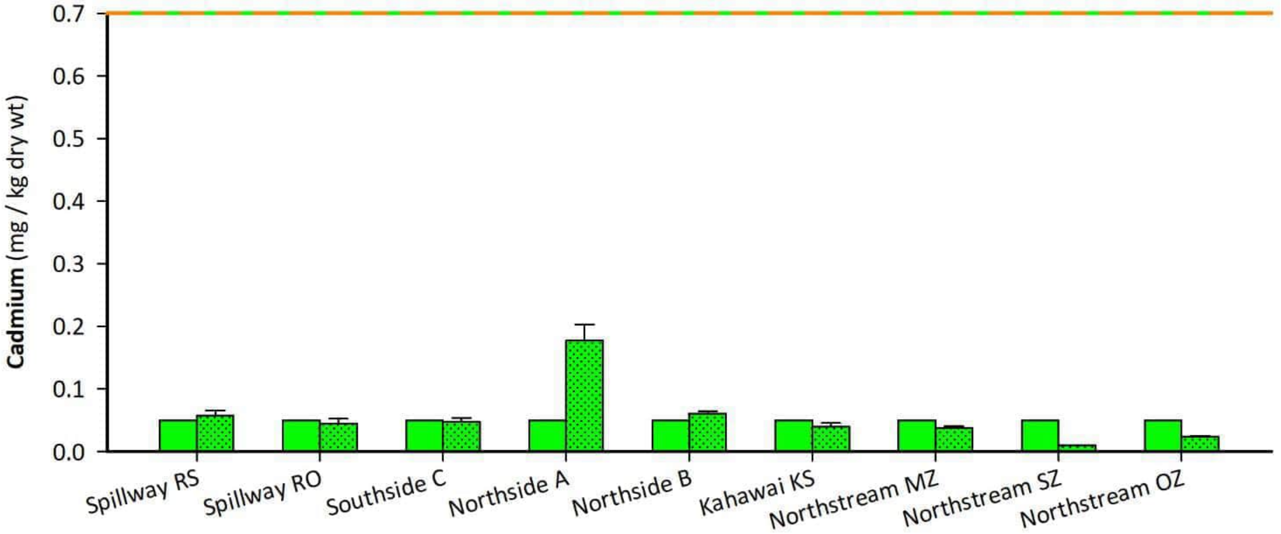

Figure 2.1 ***Dry Weight Concentration of Cadmium in Sediments*** *(🟩 Extractable, ▨ Total Recoverable) (mean ± 95% confidence intervals)*

2.2.2 Chromium in 2020

For most of the sites, the total recoverable concentrations of chromium were higher than that recorded in the mud fraction (Figure 2.2). Exceptions to this occurred at the North Stream where the total recoverable concentrations of chromium were lower than that recorded in the mud fraction at sites SZ and OZ.

The total recoverable concentration of chromium was highest at the Northside Outfall Site NA, and lowest at the North Stream settling zone site SZ. However, the concentrations at the sites RS, RO, NB, and MZ are not that much lower than that recorded at the NA site. The similarity of the total recoverable concentrations suggest that chromium is not related to a discharge but more associated with fine sediment size particles.

When just the mud fraction of sediment was analysed the concentration of chromium was very similar across all sites. The concentration of chromium in the mud fraction at the KS site was lower than all other sites.

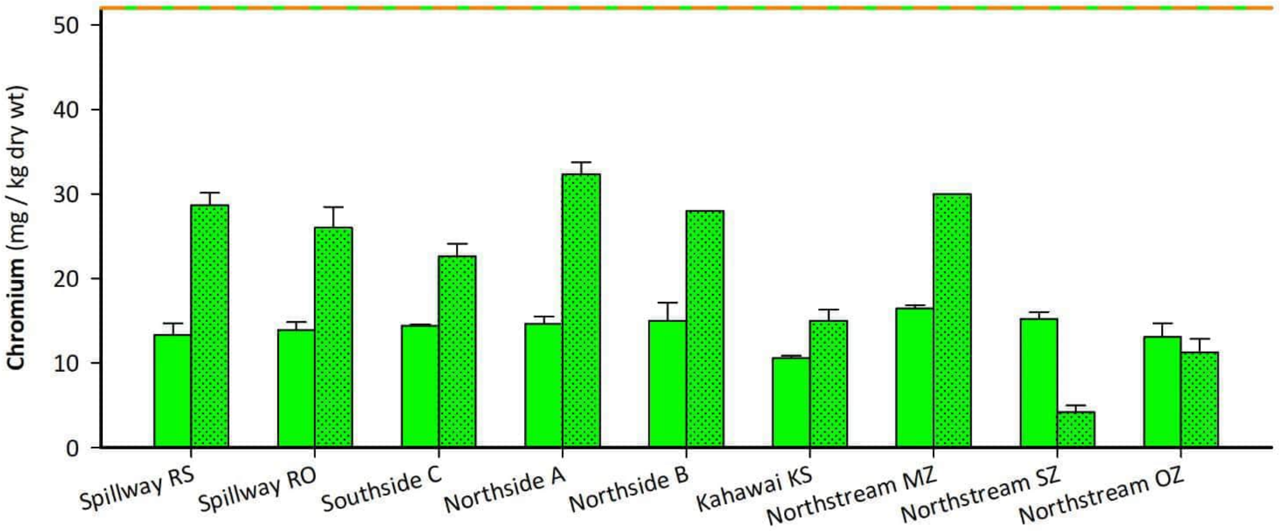

Figure 2.2 ***Dry Weight Concentration of Chromium in Sediments*** *(🟩 Extractable, ▨ Total Recoverable) (mean ± 95% confidence intervals)*

2.2.3 Copper in 2020

At the majority of sites, the total recoverable concentrations of copper were higher than that recorded in the mud fraction (Figure 2.3). Exceptions to this occurred at the North Stream were the total recoverable concentrations of copper were lower than that recorded in the mud fraction at sites SZ and OZ.

The total recoverable concentration of copper was highest at the North Stream mangrove site MZ, and lowest at the North Stream settling zone site SZ. However, the concentrations at the sites RS, RO, NA, and NB are not that much lower than that recorded at the MZ site. The similarity of the total recoverable concentrations suggest that copper is not related to a discharge but more associated with fine sediment size particles.

When just the mud fraction of sediment was analysed the concentration of copper showed a decreasing concentration from the North Stream discharge. The concentration of copper at the KS site was lower than all other sites.

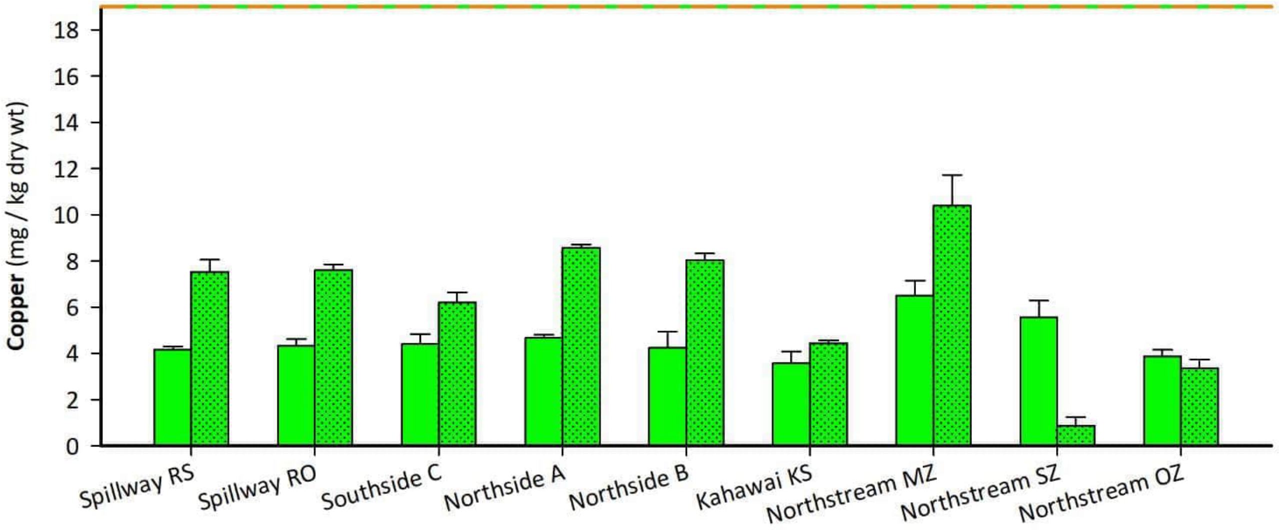

Figure 2.3 Dry Weight Concentration of Copper in Sediments (🟩 Extractable, ░ Total Recoverable) (mean ± 95% confidence intervals)

2.2.4 Lead in 2020

For most of the sites, the total recoverable concentrations of lead were slightly higher than that recorded in the mud fraction (Figure 2.4). Exceptions to this occurred at the Kahawai Stream and North Stream where the total recoverable concentrations of lead were lower than that recorded in the mud fraction at sites KS, SZ and OZ.

The total recoverable concentration of lead was highest at the North Stream mangrove site MZ, and lowest at the North Stream settling zone site SZ. However, the concentrations at the sites RS, RO, NA, NB and SC were not that much lower than that recorded at the MZ site. The similarity of the total recoverable concentrations suggest that lead is not related to a discharge but more associated with fine sediment size particles.

When just the mud fraction of sediment was analysed the concentration of lead showed a decreasing concentration

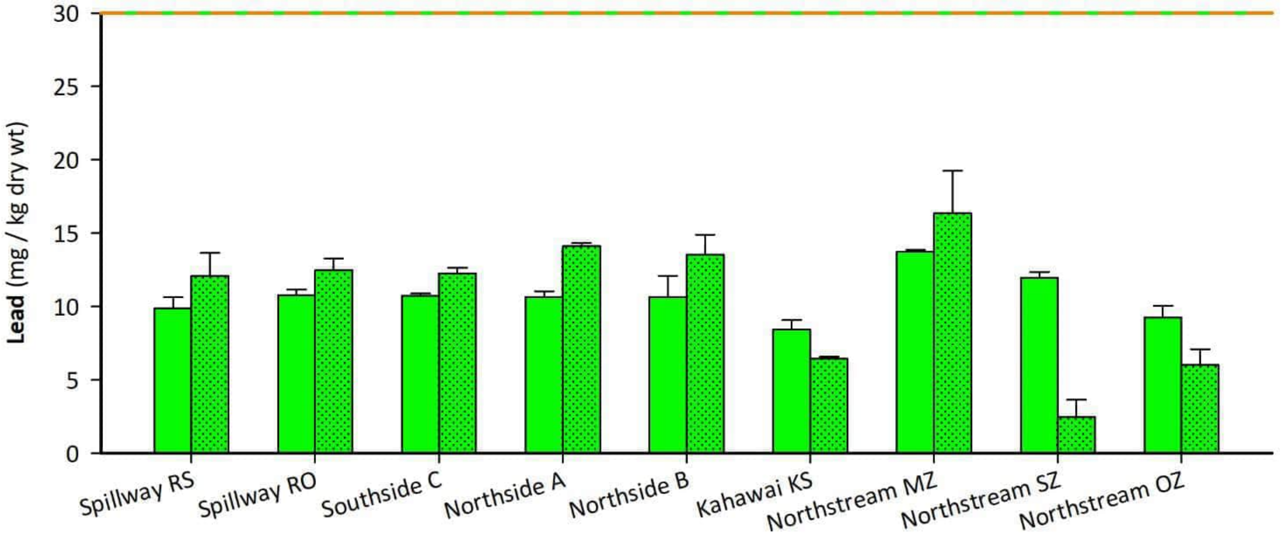

Figure 2.4 ***Dry Weight Concentration of Lead in Sediments*** *(🟩 Extractable, ░ Total Recoverable) (mean ± 95% confidence intervals)*

2.2.5 Zinc in 2020

For most of the sites, the total recoverable concentrations of zinc were higher than that recorded in the mud fraction (Figure 2.5). Exceptions to this occurred at the North Stream where the total recoverable concentrations of zinc were lower than that recorded in the mud fraction at sites SZ and OZ.

The total recoverable concentration of zinc was highest at the Northside Outfall site NA, and lowest at the North Stream settling zone site SZ. The concentration of zinc in the total sediment fraction was high enough to place it in the red category suggesting potential adverse effects to biota were possible. The concentrations at the sites NB and MZ were also elevated, but the sediments at those sites were categorised as green, indicating adverse effects to biota were not likely. When just the mud fraction of sediment was analysed the concentration of zinc showed a decreasing concentration from both the Northside outfall and the North Stream discharges. The concentration of zinc at the KS site was lower than all other sites. The total recoverable concentrations suggest a source of zinc in the vicinity of the Northside outfall, and the mud fraction concentrations, an association with finer sediment particles and a source at the North Stream.

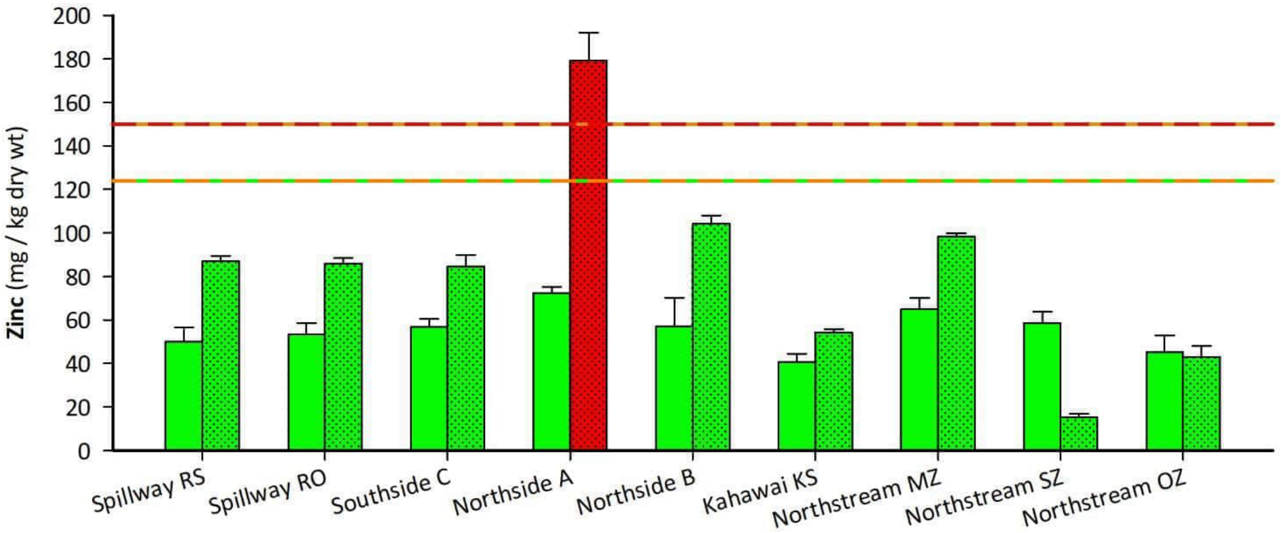

Figure 2.5 ***Dry Weight Concentration of Zinc in Sediments*** *(🟩 Extractable, ░ Total Recoverable) (mean ± 95% confidence intervals)*

2.3 Comparison of Metal Data in Sediments 2003-2021

At sites NA, NB and SC sediment quality data has been collected as part of the annual monitoring requirements (Bioresearches reports 2003 to 2021). Data on dry weight metal concentrations in sediments from the previous annual surveys are presented in Table A1.1, in Appendix 1 and shown graphically in Figure 2.6 to Figure 2.10. The symbol colours green, amber and red indicate Auckland Council's 'traffic light' sediment quality classification, and the coloured reference lines indicated the boundary between the sediment quality classifications. Additional older data points are also available for the North Stream sites MZ, SZ and OZ (Bioresearches 1998a, 2008) and are presented in Table A1.2, in Appendix 1.

Between 2003 to 2021, the total recoverable concentrations of cadmium decreased at sites Northside A, and increased at Northside B and Southside C (Figure 2.6). However, while the concentrations at site Northside B and Southside C remained relatively similar, the higher concentrations at Northside A showed larger fluctuations. From 2017 the concentration at Northside A has shown increases returning the concentration to that similar to those recorded prior to 2005. The extractable concentrations of cadmium were at or near the method detection limit, at all three sites.

Between 2003 to 2021, the total recoverable concentrations of chromium have decreased slightly at sites Northside A, B and Southside C, while the extractable concentrations of chromium have decreased at Northside B and Southside C but increased slightly at Northside A (Figure 2.7). At the Northside sites A and B, the recent trend to 2020 was for slight increases in the total recoverable and extractable concentrations, this has abated in 2021. Whereas at the Southside site both total recoverable and extractable concentrations have not shown any trends other than minor fluctuations.

Between 2003 to 2021, the total recoverable and extractable concentrations of copper have remained relatively similar with slight decreases at all three sites (Figure 2.8).

Between 2003 to 2021, the total recoverable and extractable concentrations of lead have shown fluctuations but have ultimately decreased at all three sites over time (Figure 2.9).

Between 2003 to 2021, the extractable concentrations of zinc have remained relatively similar with slight decreases at all three sites. However, the total recoverable concentrations have varied between sites, with the Southside site remaining relatively similar over time with a slight increase, the Northside B outer zone site showing significant fluctuations but overall showing a slight decrease over time, the Northside A settling zone site showed a decrease over time but with several significant fluctuations (Figure 2.10). At Site Northside A, has shown a consistent rate of increase in total recoverable concentrations since 2017. This followed a period of consistent decreases between 2009 and 2017. On all but one monitoring occurrence the total recoverable concentration of zinc has exceeded the amber threshold levels requiring benthic community monitoring.

Overall, between 2003 and 2021, the total recoverable detected concentrations of chromium, copper and lead have remained similar or slightly decreased over time at the majority of outfall sites, the total recoverable concentrations of chromium have remained similar or slightly increased over time at the majority of outfall sites, while the total recoverable concentrations of zinc have remained similar with slight increases at Southside C, slight decreases at Northside B, but had significant variations at Northside A with an overall decrease, but with a recent consistent increasing trend.

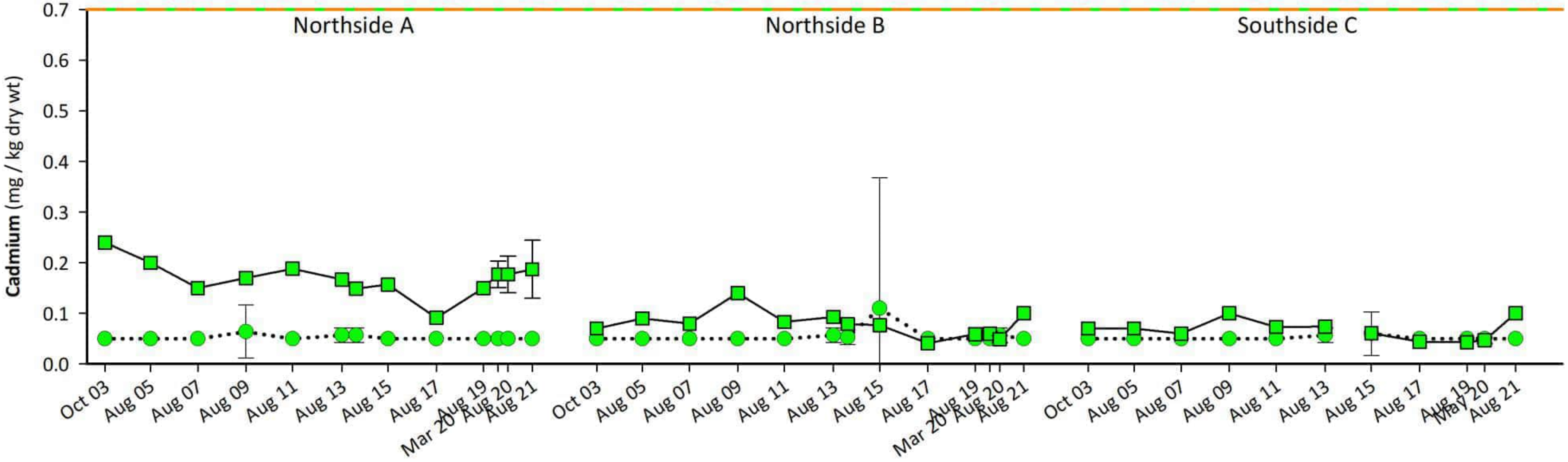

Figure 2.6 Concentration of Cadmium in Sediments – Dry Weight *(○ Extractable, □ Total Recoverable) (mean ± 95% confidence intervals (⌶))*

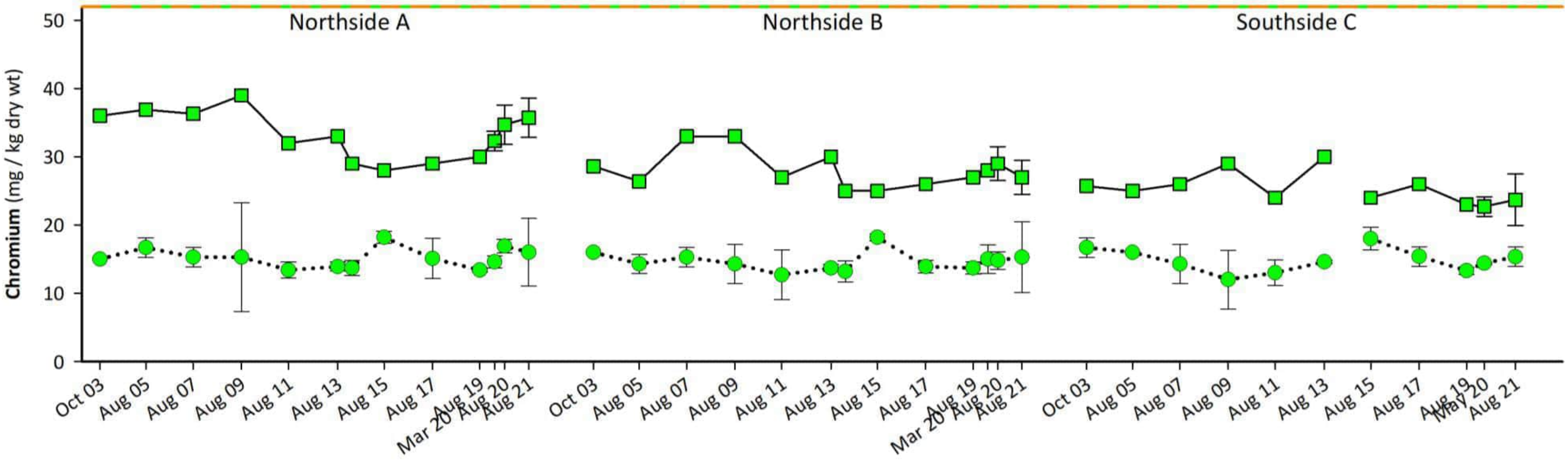

Figure 2.7 Concentration of Chromium in Sediments – Dry Weight *(○ Extractable, □ Total Recoverable) (mean ± 95% confidence intervals (⌶))*

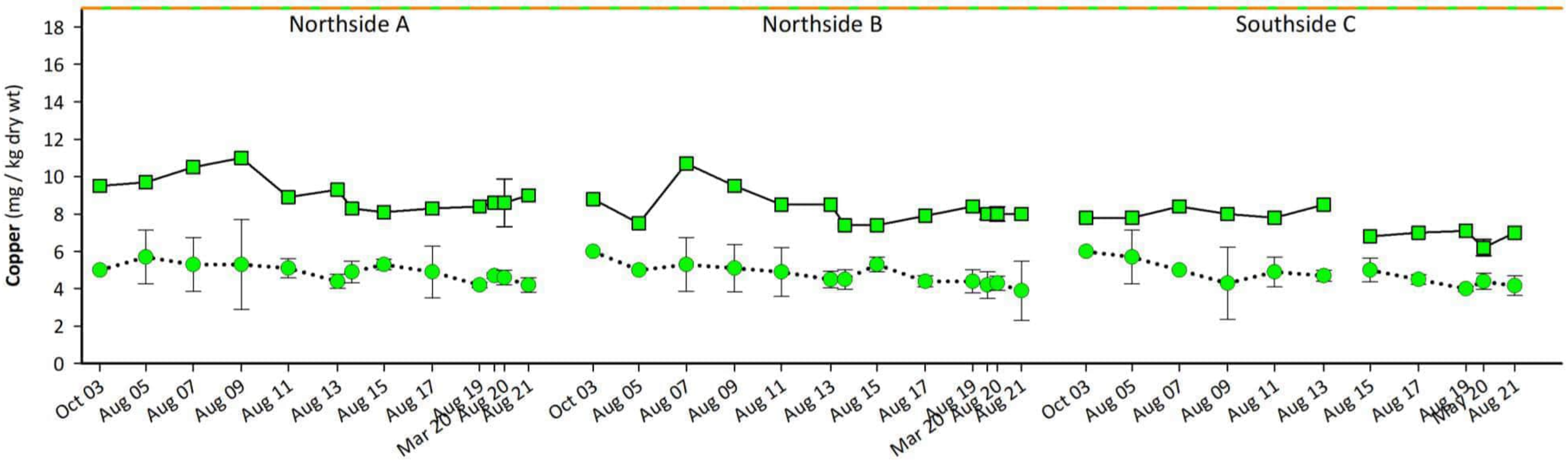

Figure 2.8 ***Concentration of Copper in Sediments – Dry Weight*** *(○ Extractable, □ Total Recoverable) (mean ± 95% confidence intervals (⌶))*

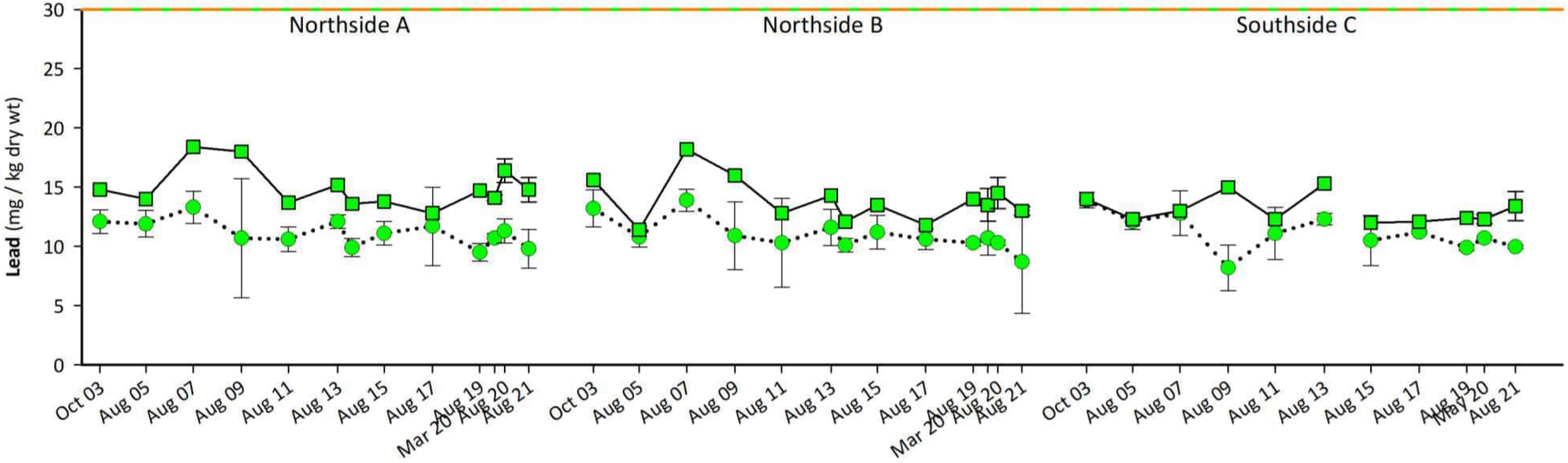

Figure 2.9 ***Concentration of Lead in Sediments – Dry Weight*** *(○ Extractable, □ Total Recoverable) (mean ± 95% confidence intervals (⌶))*

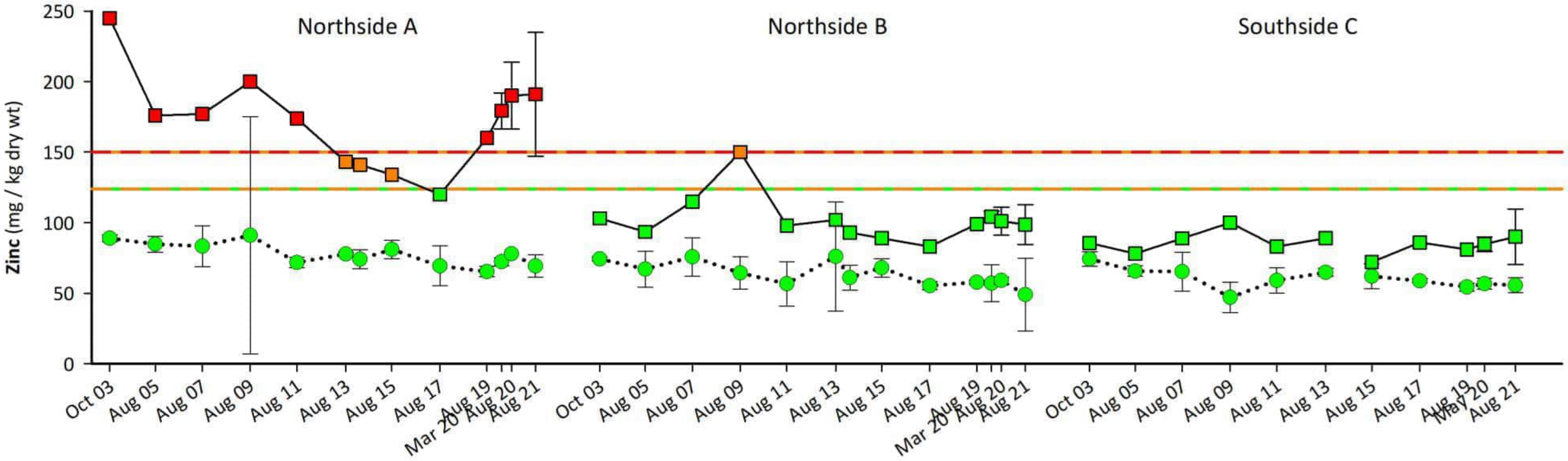

Figure 2.10 ***Concentration of Zinc in Sediments – Dry Weight*** *(○ Extractable, □ Total Recoverable) (mean ± 95% confidence intervals (⌶))*

At the North Stream sites the total recoverable concentrations of chromium, copper, lead and zinc have increased between 1998 and 2020 at the mangrove zone site (MZ), but decreased at the settling zone site (SZ) (Table A1.2). The method detection limit in 1998 for cadmium was significantly higher than in later surveys making comparison meaningless. The sediment quality was not assessed at the outer zone site (OZ) in 1998 but an increase has been recorded between 2008 and 2020 for copper, lead and zinc.

Weak acid extraction concentrations of the mud fraction were only conducted in 2008 and 2020 for copper, lead and zinc (Table A1.2). At the mangrove (MZ) and outer zone (OZ) sites small decreases were recorded, but small increases were recorded for lead and zinc at the settling zone site (SZ). While the concentrations were classified as 'Green', the increases in total recoverable concentration of chromium, copper and zinc at the mangrove and outer zone sites suggest potential accumulative effects and an investigation of the source should be considered along with future monitoring.

2.4 Sediment Grain Size – 2020 and 2021 comparison between sites

The grain size analysis for sediment is presented in Table 2.8, Table 2.9, Table 2.10 and Figure 2.11.

At the North Stream sites the mangrove zone (MZ) sediment was dominated by silt and clay sized particles at 94% in 2020 (Table 2.8). Outside the mangroves at the settling zone (SZ) site the sediment was dominated by find sand (77%) and consequently the proportion of silt and clay was greatly reduced at 9%. Further offshore at the outer zone (OZ) site the sediment was again largely sandy with fine and very fine sand combined making up 58% of the particles but the proportion of silt and clay had increased from the settling zone site to 35%. The MZ site was classified as slightly gravelly Mud, (g)M, the SZ site slightly gravelly Sand, (g)S, and the OZ site as slightly gravelly muddy Sand, (g)mS.

Sediment at the Kahawai Stream settling zone site contained in 2020 a low to moderate proportion of silt and clay (45%) with a similar proportion of fine and very fine sand combined (44%) (Table 2.8). The sediment was classified as gravelly muddy Sand, gmS.

The sediments at the three outfall sites (NA, NB, SC) had lower proportions of silt and clay sized particles than the spillway sites in 2020 (Table 2.9, Figure 2.11). While all three were classified as slightly gravelly sandy Mud, (g)sM, the silt and clay proportion varied from 55% at the Southside settling zone site (SC) to 82% at the Northside outer zone site (NB), and the proportion of fine sand varied between 24% at SC to 7% at NB.

The sediments from both sites below the Ruakohua Spillway contained high proportions (>80%) of silt and clay sized particles in 2020 (Table 2.8). The settling zone site (RS) was described as slightly gravelly sandy Mud, (g)sM, while the outer zone site (RO) with marginally lower fine sand content was described as slightly gravelly Mud, (g)M.

Table 2.8 Sediment Grain Size, May 2020

Grain Size		Percentage Dry Weight								
		Ruakohua Spillway		Southside	Northside[11]		Kahawai Stream	North Stream		
(mm)	Class	RS	RO	C	A	B	KS	MZ	SZ	OZ
> 3.35	Gravel									
3.35 - 2.00	Granules	< 0.1	< 0.1	0.9	0.4	< 0.1	5.1	1.1	1.7	1.7
2.00 - 1.00	Very Coarse Sand	< 0.1	< 0.1	2.9	0.6	< 0.1	0.4	0.4	< 0.1	0.8
1.00 - 0.500	Coarse Sand	< 0.1	< 0.1	3.8	0.9	0.2	1.0	0.5	0.2	1.4
0.500 - 0.250	Medium Sand	1.1	0.8	8.1	4.6	0.9	3.9	0.5	2.1	2.9
0.250 - 0.125	Fine Sand	5.1	3.6	23.6	15.5	7.0	28.1	1.9	77.3	44.0
0.125 - 0.063	Very Fine Sand	5.3	4.7	6.1	8.7	10.1	16.2	1.6	9.9	14.0
< 0.063	Silt & Clay	88.4	90.8	54.7	69.3	81.9	45.3	94.0	8.7	35.3
Classification		**(g)sM**	**(g)M**	**(g)sM**	**(g)sM**	**(g)sM**	**gmS**	**(g)M**	**(g)S**	**(g)mS**

Table 2.9 Sediment Grain Size, August 2020

Grain Size		Percentage Dry Weight	
		Northside	
(mm)	Class	A	B
> 3.35	Gravel		
3.35 - 2.00	Granules	0.3	< 0.1
2.00 - 1.00	Very Coarse Sand	0.3	< 0.1
1.00 - 0.500	Coarse Sand	0.7	0.1
0.500 - 0.250	Medium Sand	5.3	0.3
0.250 - 0.125	Fine Sand	19.9	1.8
0.125 - 0.063	Very Fine Sand	9.5	5.3
< 0.063	Silt & Clay	64.0	92.4
Classification		**(g)sM**	**(g)M**

Table 2.10 Sediment Grain Size, August 2021

Grain Size		Percentage Dry Weight			
(mm)	Class	Northside A	Northside B	Southside C	Control[12] D
> 3.35	Gravel	2.6	< 0.1	2.1	< 0.1
3.35 - 2.00	Granules				
2.00 - 1.18	Very Coarse Sand	1.0	< 0.1	3.1	< 0.1
1.18 - 0.600	Coarse Sand	1.1	0.2	4.2	< 0.1
0.600 - 0.300	Medium Sand	4.2	0.9	5.1	0.6
0.300 - 0.150	Fine Sand	15.1	10.6	10.8	4.4
0.150 - 0.063	Very Fine Sand	10.7	9.2	6.7	21.3
< 0.063	Silt & Clay	65.3	79.1	68.1	73.6
Description		(g)sM	(g)sM	(g)sM	(g)sM

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[11] Note samples were collected March 2020 just prior to Covid lockdown which delayed the additional sites until May 2020

[12] Note sampling at the Control Site was delayed until 27 September 2021, due to covid 19 level 4 lockdown imposed on 18 August 2021.

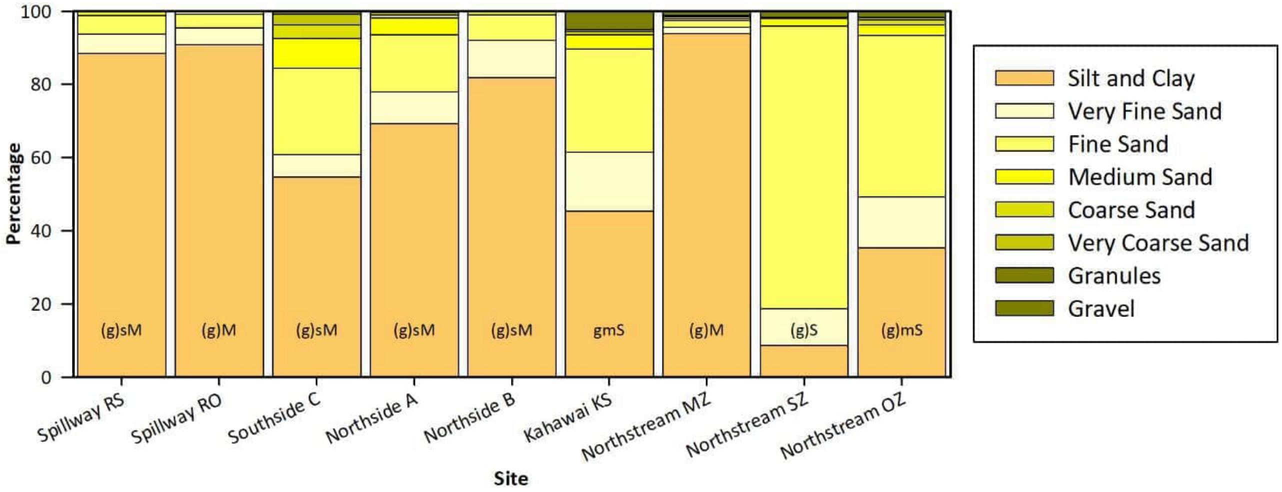

Figure 2.11 Sediment Grain Size, Percentage Weight, May 2020

In 2021, all four sites (including Control) had significant proportions of sediment in the mud fraction (<0.63 mm), over 50% at Northside A, Southside C and Control D, with over 75% at Northside B (Table 2.9). The bulk of the remaining sediment was classed as fine sand with between 17 to 26%. Sites Northside A and Southside C had small (2 – 5%) proportions of gravel sized material mostly shell, with the other two sites recording trace (<0.5%) amounts of gravel. The sediment particle size distribution at all four sites was described as slightly gravely sandy Mud ((g)sM). All were very poorly to poorly sorted, indicating a wide range of grain sizes.

2.5 Sediment Grain Size – comparison 2003 - 2021

At sites NA, NB and SC sediment grain size data has been collected as part of the annual monitoring requirements (Bioresearches 2003, 2005, 2007, 2009, 2011, 2013, 2014, 2015, 2017, 2019, 2020 and 2021). Data on percentage composition of particle sizes in sediments from all previous annual surveys are presented in Table A1.3, in Appendix 1 and shown graphically in Figure 2.12 to Figure 2.14.

At the Northside settling zone site (NA) the proportion of silt and clay has varied between 46 and 80%, averaging 61%. Between 2003 and 2021 the proportion of silt and clay increased while the proportion of most other grain sizes decreased. Data from October 2003, August 2005 and 2015 appear to be anomalous with greater proportions of gravel and coarse sand (Figure 2.12), this is likely due to a greater amount of shell material being present in the sediments.

At the Northside outer zone site (NB) the proportion of silt and clay has varied between 50 and 92% averaging 72%. Between 2003 and 2021, the proportion of silt and clay has decreased, the proportion of very fine sand increased, and the proportion of all other grain sizes decreased. Data from August 2015 appears to be anomalous with greater proportions of gravel and coarse sand (Figure 2.13), this is likely due to a greater amount of shell material being present in the sediments.

At the Southside settling zone site (SC) the proportion of silt and clay has varied between 39 and 73% averaging 62%. Between 2003 and 2021 the proportion of silt and clay has decreased while the proportion of medium and coarse sand has increased. Data from August 2005 and 2015 appear to be anomalous with greater proportions of gravel and coarse sand (Figure 2.14), this is likely due to a greater amount of shell material being present in the sediments.

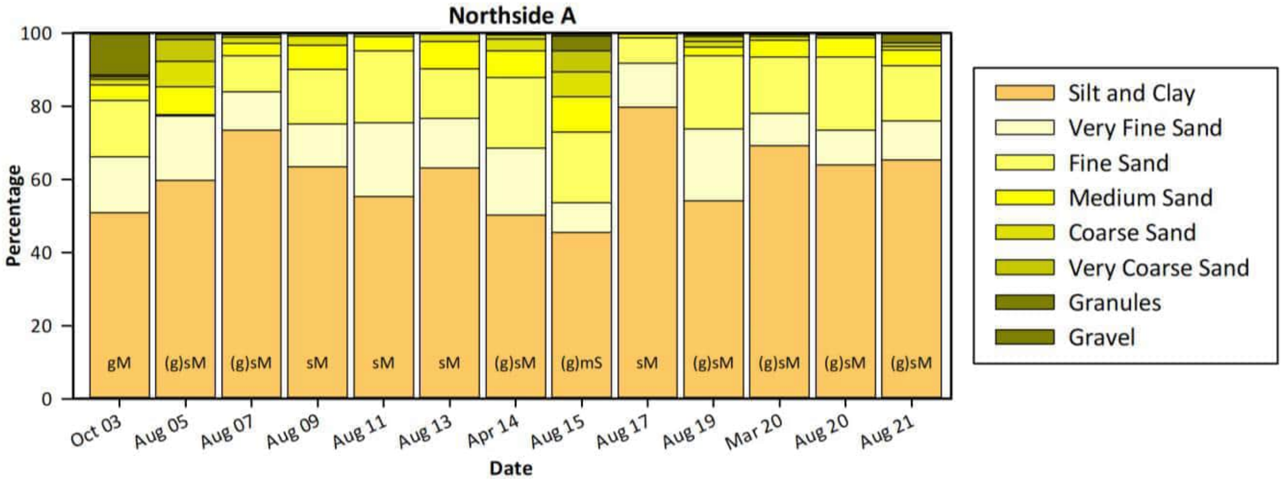

Figure 2.12 Changes in Sediment Grain Size at Northside A 2003 to 2021

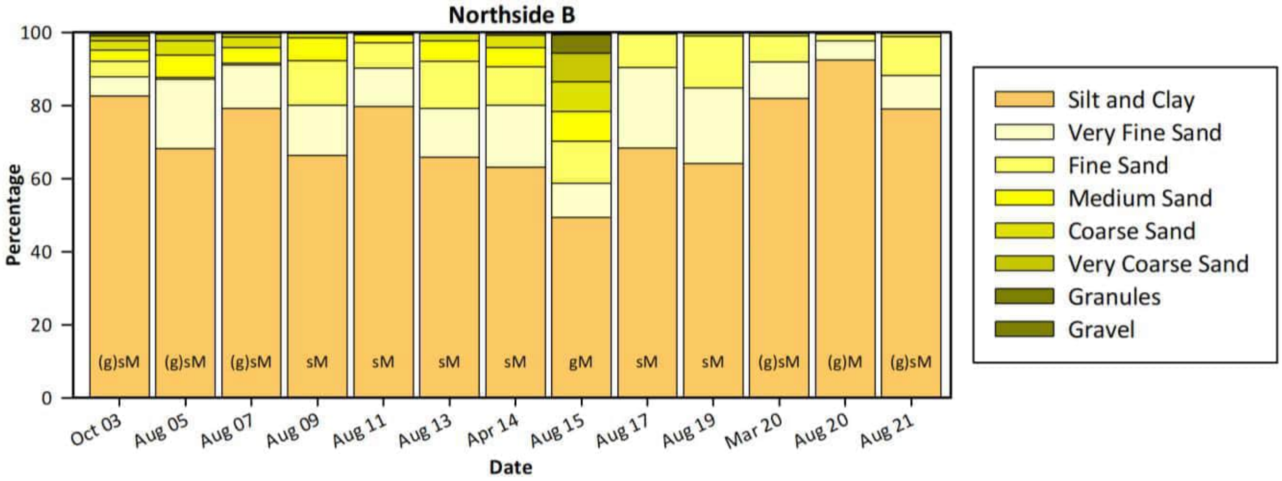

Figure 2.13 Changes in Sediment Grain Size at Northside B 2003 to 2021

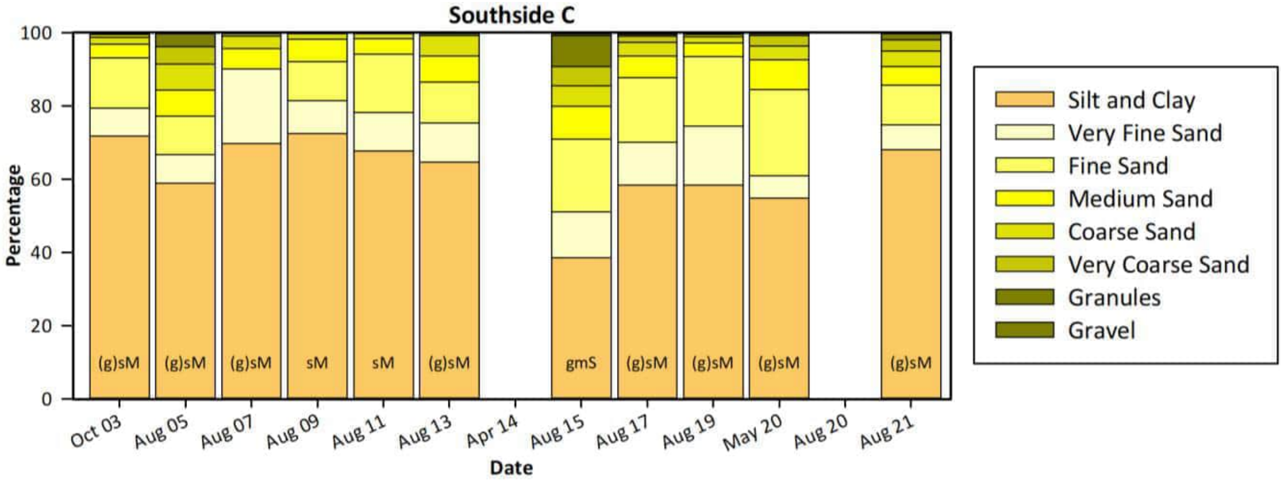

Figure 2.14 Changes in Sediment Grain Size at Southside C 2003 to 2021

3. BENTHIC COMMUNITY HEALTH

The initial screening of surficial sediment quality for total recoverable zinc exceeded sediment quality guidelines in the Northside A site in March 2020 (179 mg/kg dry weight), in August 2020 (190 mg/kg dry weight), and in August 2021 (191 mg/kg dry weight), triggering the requirement for a benthic community health assessment at Site Northside A. Benthic biota was also sampled from Site Northside B in 2020 before sediment quality results were published. Since the Northside A site exceeded the zinc sediment quality trigger value, benthic biota was also collected at the newly established Control site in September 2021.

3.1 Benthic communities

Benthic biota was collected from 10 sediment cores at each of the sites Northside A and Northside B on the 13th of March 2020 and the 24th of August 2020. Ten sediment cores were collected at sites Northside A and Taihiki Control in October 2021. Results are presented in Table 3.1, Table 3.2, and Table 3.3.

Table 3.1 Northside A Benthic Biota Data 2020 (no. per core)

TAXA Site	Northside A – March 2020										Ave. A	Northside A – August 2020										Ave. A
Replicate	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	March	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	August
PHYLUM ANNELIDA																						
CLASS POLYCHAETA																						
Heteromastus filiformis	18	7	16	19	8	17	11	4	10	7	11.7	61	14	62	27	30	17	16	27	27	33	31.4
Cossura consimilis												1										0.1
Nereidae	11	4	1	4	5	8	10	16	8	8	7.5	5	7	12	7	7	8	2	6	9	1	6.4
Paraonidae	2	4	1	1	4	2	1	3		1	1.9	2	2	2	1	2		3	1	1	1	1.5
Pectinaria australis													1								1	0.2
Glycera spp.															1							0.1
Spionidae					1						0.1	2		2								0.4
PHYLUM MOLLUSCA																						
CLASS BIVALVIA																						
Austrovenus stutchburyi														1								0.1
Theora lubrica																			1			0.1
PHYLUM ARTHROPODA																						
CLASS CRUSTACEA																						
ORDER AMPHIPODA																						
Unid. Amphipod	4		2	1	1	2	2	1	2		1.5	5	5	6	4	3	2	2	1	4	3	3.5
ORDER DECAPODA																						
Austrohelice crassa		2	2	1	3	1	1	2	1		1.3	1	1	2								0.4
Juvenile crab					1			1			0.2	1			1							0.2
Alphaeus sp.									1		0.1											
Unid. Shrimp								1			0.1											
PHYLUM CHORDATA																						
CLASS VERTEBRATA																						
Unid. teleost (fish)		2				1					0.3											
Total Number of Species/Taxa	**4**	**5**	**5**	**5**	**7**	**6**	**5**	**7**	**5**	**3**	**10**	**8**	**6**	**7**	**6**	**4**	**3**	**4**	**5**	**4**	**5**	**5**
Total Number of Individuals	**35**	**19**	**22**	**26**	**23**	**31**	**25**	**28**	**22**	**16**	**25**	**78**	**30**	**87**	**41**	**42**	**27**	**23**	**36**	**41**	**39**	**44**

Table 3.2 Northside B Benthic Biota Data 2020 (no. per core)

TAXA / Site	Northside B – March 2020										Ave. B	Northside B – August 2020										Ave. B
Replicate	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	March	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	August
PHYLUM ANNELIDA																						
CLASS POLYCHAETA																						
Cossura consimilis	13	22	14	16	3	13	11	16	17	6	13.1											
Heteromastus filiformis	41	57	58	46	27	37	43	63	42	39	45.3	30	17	24	42	33	19	36	37	46	68	35.2
Magelona dakini						1		2			0.3											
Nereidae	3			1	5	2	6	4	2	7	3	2	4	1	3	2	2	3	4	2	1	2.4
Paraonidae	8	15	7	38	9	17	8	8	8	27	14.5	12	5	27	12	5	1	10	5	27	20	12.4
Spionidae																	1					0.1
PHYLUM MOLLUSCA																						
CLASS GASTROPODA																						
Cominella glandiformis																		1				0.1
CLASS BIVALVIA																						
Austrovenus stutchburyi										1	0.1											
Theora lubrica	1			1	1				1	1	0.5	5	2	2	1		2	1	5	1	4	2.3
PHYLUM ARTHROPODA																						
CLASS CRUSTACEA																						
ORDER AMPHIPODA																						
Unid. Amphipod	4	1	5	4	1	1	1	1	1	3	2.2	4	6	10	3	4	10	10	5	9	13	7.4
ORDER CUMACEA																						
Unid. Cumacea																		1				0.1
ORDER DECAPODA																						
Hemiplax hirtipes	1			1	3		1	1		1	0.8			1		1		1		2		0.5
Juvenile crab												1										0.1
Total Number of Species/Taxa	**7**	**4**	**4**	**7**	**7**	**6**	**6**	**7**	**6**	**8**	**9**	**6**	**5**	**6**	**5**	**5**	**6**	**8**	**5**	**6**	**5**	**6**
Total Number of Individuals	**71**	**95**	**84**	**107**	**49**	**71**	**70**	**95**	**71**	**85**	**80**	**72**	**47**	**72**	**71**	**48**	**46**	**78**	**65**	**100**	**109**	**71**

Table 3.3 Northside A and Control, Benthic Biota Data 2021 (no. per core)

TAXA / Site	Northside A – October 2021										Ave. A	Control – September 2021										Ave. D
Replicate	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	2021	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	2021
PHYLUM ANNELIDA																						
CLASS OLIGOCHAETA												1		2					1	1		0.5
CLASS POLYCHAETA																						
Glyceridae										1	0.1		1						1			0.2
Heteromastus filiformis	53	59	63	78	37	65	49	53	71	35	56.3		47	30	23	3	22	22	33	23	28	23.1
Magelona dakini													1	2						1	3	0.7
Maldanidae																		1				0.1
Nereidae	1	1	1	1	1			1	1	1	0.8	1	2		1		1	1			1	0.7
Paraonidae		1	1			4					0.6	1	3	2			1	4		2		1.3
Pectinaria australis												29							1			3
Spionidae *Boccardia*																				1	1	0.2
Spionidae *Prionospio a.*													4	1				1		5	1	1.2
Spionidae *Scolecolepides b.*														1				1				0.2
PHYLUM NEMERTEA												1	3	3	1				2	1		1.1
PHYLUM MOLLUSCA																						
CLASS GASTROPODA																						
Tritia burchardi	1					1			1		0.3											
CLASS BIVALVIA																						
Austrovenus stutchburyi					1			1			0.2											
Theora lubrica				1							0.1											
PHYLUM ARTHROPODA																						
CLASS CRUSTACEA																						
ORDER AMPHIPODA																						
Phoxocephalidae	1	4	1	3	1	1		2	4	1	1.8	2	2		1	1				3	10	1.9
Unid. Amphipod					1	2			1		0.4	1										0.1
ORDER DECAPODA																						
Alpheus sp.																	1					0.1
Austrohelice crassa		1				1					0.2	4	2			2	2	1	1	2		1.4
Hemiplax hirtipes					2		2	2		2	0.8		1			1		1	3		3	0.9
Total Number of Species/Taxa	**4**	**5**	**4**	**4**	**6**	**6**	**2**	**5**	**5**	**5**	**4.6**	**8**	**10**	**7**	**4**	**4**	**5**	**8**	**7**	**9**	**7**	**6.9**
Total Number of Individuals	**56**	**66**	**66**	**83**	**43**	**74**	**51**	**59**	**78**	**40**	**61.6**	**40**	**66**	**41**	**26**	**7**	**27**	**32**	**42**	**39**	**47**	**36.7**

The most important taxa for both sampling periods in 2020 and in 2021 were polychaetes *Heteromastus filiformis* and Nereidae at sites A and B, and Paraonidae at site B, as shown in Table 3.1 to Table 3.3. When compared with previous years, *Heteromastus filiformis* was always dominating the biota since 2015, and Paraonidae reduced in abundance over time (Table 3.4). The Control Site showed the same profile in September 2021.

Table 3.4 Main Benthic Taxa Compared over the Years of Sampling at Northside A and B

Main taxa	**2009 October**		**2011 October**	**2013 October**	**2014 April**		**2015 October**	**2019 October**	**2020 March**		**2020 August**		**2021 October**	
	A	**B**	**A**	**A**	**B**	**A**	**A**	**A**	**A**	**B**	**A**	**B**	**A**	**Control**
Cossura consimilis	0.5	63	0.1	0.1	17.7	8.8	0.3			13.1	0.1	10.2		
Heteromastus filiformis	27.6	12.9	13.6	40.7	2.8	3.6	13.9	19.8	11.7	45.3	31.4	35.2	56.3	23.1
Nereidae	6.6	2.7	3.1	1.3	0.9	0.8	2.3	2.6	7.5	3.0	6.4	2.4	0.8	0.7
Paraonidae	34.4	69.1		2.9	18.7	10.7	5.1		1.9	14.5	1.5	12.4	0.6	1.3
Spionidae	0.7	3.1		0.1				3.9	0.1		0.2	0.1		1.6
Austrovenus stutchburyi	0.8		0.1	0.2			0.2			0.1	0.1		0.2	
Theora lubrica		0.4		0.2	0.3	0.1	0.1			0.5	0.1	2.3	0.1	
Amphipods	0.1		0.3				1.0	8.9	1.5	2.2	3.5	7.4	2.2	2.0

3.2 Benthic health models – metals and mud

The results for each BHM and health scores from 2009 to 2021 at sites Northside A, Northside B and the Control are presented in Table 3.5.

Table 3.5 Benthic Health models – CAP Metals and CAP Mud results with associated Health scores and environmental variables for Northside A, Northside B and Control

Site	**Date**	**BHM Metals**		**BHM Mud**		**Environmental variables**			
		CAP$_{\text{Met}}$	**Health$_{\text{Met}}$**	**CAP$_{\text{Mud}}$**	**Health$_{\text{Mud}}$**	**Cu**	**Pb**	**Zn**	**% mud**
NORTHSIDE A	Aug 2009	0.0557	4	0.0672	4	11.00	18.00	200	63.5
	Aug 2011	0.0903	4	0.0744	4	8.90	13.70	174	55.4
	Aug 2013	0.0519	4	0.0634	4	9.30	15.20	143	63.2
	Apr 2014	0.0064	3	0.0289	4	8.30	13.60	141	50.3
	Aug 2015	0.0802	4	0.0633	4	8.10	13.80	134	45.5
	Aug 2019	0.0556	4	0.0784	4	8.4	14.7	160	54.2
	Mar 2020	0.0809	4	0.0744	4	8.57	14.1	179.3	69.3
	Aug 2020	0.0788	4	0.0822	4	8.6	16.4	190	64.0
	Aug 2021	0.0514	4	0.0806	4	9	14.77	191	65.3
NORTHSIDE B	Aug 2009	0.0577	4	0.0723	4	9.50	16.00	150	66.4
	Apr 2014	-0.0087	3	0.0281	4	7.40	12.10	93	63.2
	Mar 2020	0.0492	4	0.0942	4	8.03	13.53	104.3	81.9
	Aug 2020	0.0589	4	0.0900	4	8.03	14.50	101	92.4
CONTROL	Sep 2021	-0.0122	3	0.0468	4	5.97	9.13	59.3	73.6

In 2021 the Northside A site obtained a CAP Metals score of 0.0514 and a CAP Mud score of 0.0806 (Table 3.5). Benthic health was therefore ranked as 4 for both models, which is indicative of poor ecological condition.

The Control Site showed lower values for both models than the Northside sites. The CAP Metals score of -0.0122 was indicative of a moderate health by the model, while the CAP Mud score of 0.0468 matched a poor health condition of the benthic communities.

The CAP scores estimated in 2020 and 2021 were similar to scores estimated during the previous years, except for the year 2014 which showed values similar to the Control site in 2021 (Figure 3.1), or lower than the Control site in 2021 (Figure 3.2).

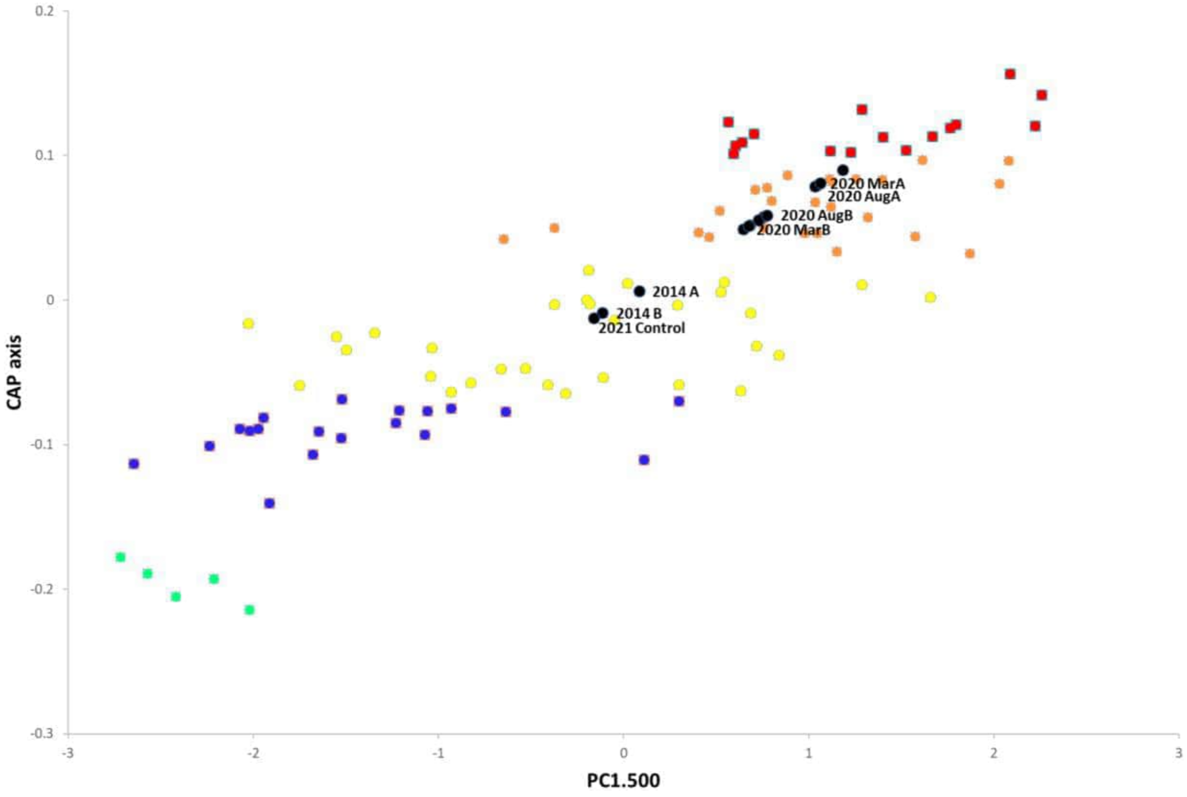

Figure 3.1 CAP scores of NZ Steel sites compared to the sites of the BHM Metals

Figure 3.2 CAP scores of NZ Steel sites compared to the sites of the BHM Mud

3.3 Trait based index and combined scores

The TBI scores for 2021 were 0.12 at Northside A and 0.24 at the control Site (Table 3.6). Historically, TBI scores ranged between 0.1 and 0.2 at both Northside sites, the exception being during the year 2009 at Northside A with a TBI score of 0.24, similar to that of the Control Site monitored in 2021. The combined health scores were all around 0.8 which matches a “marginal” health.

The TBI scores, since 2009 have all been below 0.3, which indicates low levels of functional redundancy at highly degraded sites (Drylie 2021). The low functional redundancy found in the Waiuku estuary is consistent with low scores found by the Auckland Council monitoring programme in the Manukau at sheltered creeks. These sites generally consist of a low diversity of species living at the surface of the sediment dominated by polychaetes with no sand-case structure, low mobility, and being deposit feeders. These characteristics give the lowest scores in terms of ecosystem function. The combined Health scores over the years ranged from 0.7 (‘poor health’) to 1 (‘unhealthy with low resilience’).

Table 3.6 Trait Based Index scores with associated Health for Northside A, Northside B and Control

Site	Date	TBI		Combined health score
		TBI scores	TBI Health	
NORTHSIDE A	Aug 2009	0.24	low	1
	Aug 2011	0.16	low	1
	Aug 2013	0.15	low	1
	Apr 2014	0.18	low	0.8
	Aug 2015	0.13	low	1
	Aug 2019	0.10	low	1
	Mar 2020	0.08	low	1
	Aug 2020	0.17	low	1
	Aug 2021	0.12	low	1
NORTHSIDE B	Aug 2009	0.20	low	1
	Apr 2014	0.15	low	0.7
	Mar 2020	0.12	low	1
	Aug 2020	0.11	low	1
CONTROL	Sep 2021	0.24	low	0.8

3.4 Limitations of Health Scores

BHMs may have limitations to the use in the Waiuku estuary. Benthic composition found at Northside A and B, as well as at the Control Site do not match well with the benthic communities used to create the BHM at the 95 sites monitored by council (Figure 3.3).

Key benthic species to match good scores in the BHM are bivalves like *Nucula* and cockles. Northside A shows evidence it was a historic cockle bed, however reductions of contaminant levels and or mud content may not be enough to trigger a return of live cockles to the site. Cockles prefer sandy habitats (Drylie 2021). Sites with mud content more than 50% tend to have poor benthic health scores, like many tidal creeks in the Manukau Harbour, including the inner reaches of the Waiuku estuary.

Heteromastus filiformis is a common polychaete in muddy sites and is by far the most dominant species in the samples collected for New Zealand Steel. Numbers were at least 3 times higher than in any site from the models, therefore driving the NZST sample points (+) away from the other sites (●) in Figure 3.3. *Heteromastus* polychaetes were more abundant in degraded sites in the Manukau Harbour, and their high numbers in the New Zealand Steel samples contributed largely to the poor health scores.

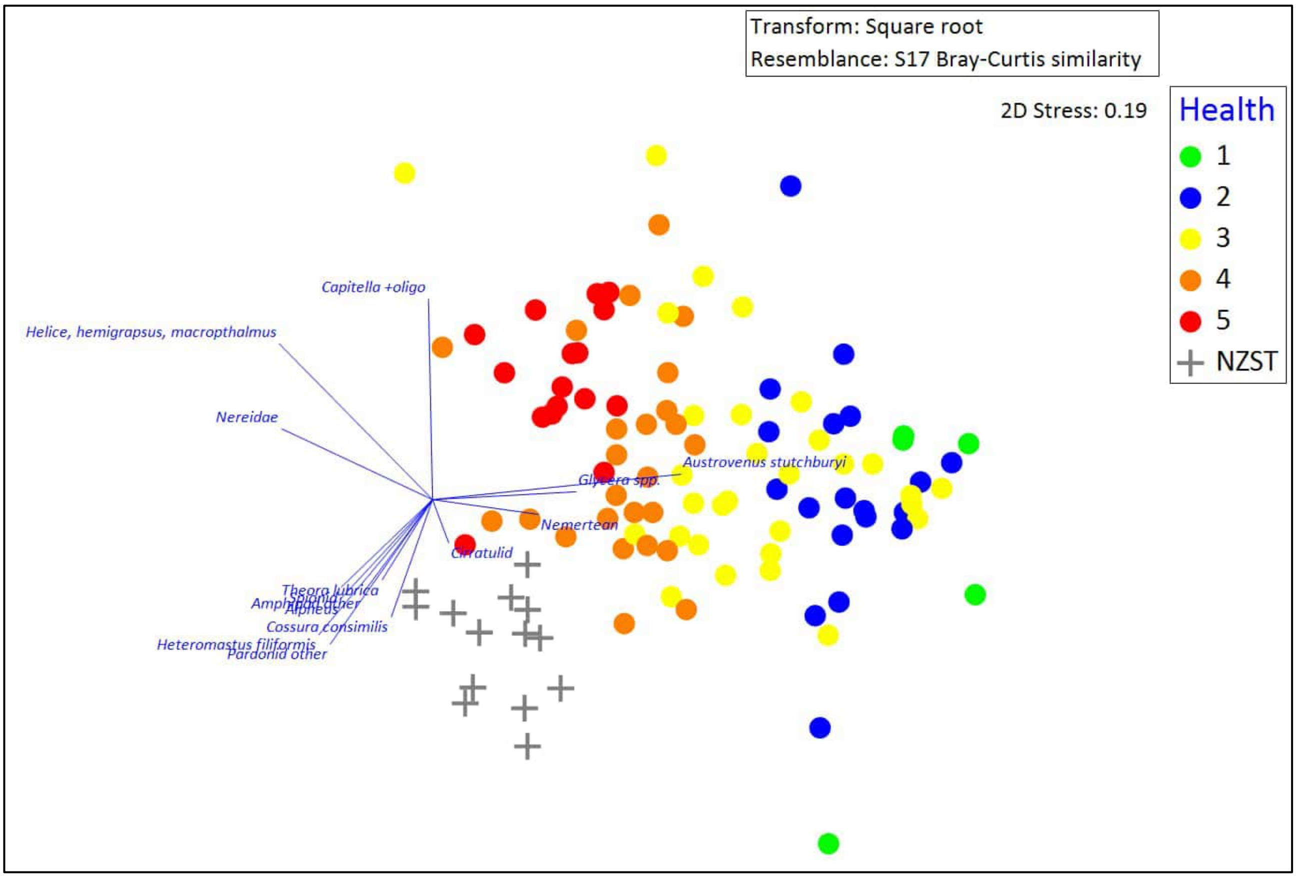

Figure 3.3 *Non-Metric Dimensional Scaling based on the 95 intertidal sites of the Benthic Health models with their corresponding health from the Metals model. New Zealand Steel (NZS) sites were added as well as key species variables.*

The Health predicted by the BHM Metals is not a good indicator of the level of contaminant exposure in the mudflats adjacent to the New Zealand Steel outfalls, as the lower concentrations of metals at Northside B Site do not translate to a better health in the model compared to the Northside A Site. Mud% seems however to have a stronger influence in the benthic communities in the Waiuku area.

4. SHELLFISH QUALITY

4.1 Pacific Oyster Abundance and Size

Biological data for the oyster samples from August 2020 and August 2021 are summarised in Table 4.1 and Table 4.2. Historical annual biological data are presented in Table A2.1 in Appendix 2.

Table 4.1 Biological Data for natural oyster populations in 2020

Site		n	mean	S.D.	±95%CI	Site		n	mean	S.D.	±95%CI
Northside 5 (N5)	(13 August 2020)					Southside 3a (S3a)	(26 August 2020)				
	Natural population:						Natural population:				
	Density (No./0.25 m^2)	30	0.93	2.10	0.78		Density (No./0.25 m^2)	30	17.93	23.04	8.60
	Length (mm)	28	51.00	13.67	5.30		Length (mm)	100	51.03	49.07	9.74
	Condition Index	12	6.86	1.42	0.90		Condition Index	12	6.00	0.77	0.49
	Samples analysed for metals:						Samples analysed for metals:				
	Length (mm)	12	60-70	-	-		Length (mm)	12	60-70	-	-
Northside 6a (N6a)	(13 August 2020)					Southside 5a (S5a)	(26 August 2020)				
	Natural population:						Natural population:				
	Density (No./0.25 m^2)	30	23.17	32.37	12.09		Density (No./0.25 m^2)	30	2.00	6.26	2.34
	Length (mm)	100	43.01	10.88	2.16		Length (mm)	63	46.13	12.92	3.25
	Condition Index	12	5.63	1.02	0.65		Condition Index	12	7.13	1.72	1.09
	Samples analysed for metals:						Samples analysed for metals:				
	Length (mm)	12	60-70	-	-		Length (mm)	12	60-70	-	-
Northside 10 (N10)	(13 August 2020)					Taihiki Control (TC)	(14 August 2020)				
	Natural population:						Natural population:				
	Density (No./0.25 m^2)	30	29.30	30.26	11.30		Density (No./0.25 m^2)	30	1.90	6.98	2.61
	Length (mm)	100	47.70	13.35	2.65		Length (mm)	57	46.70	12.89	3.42
	Condition Index	12	7.06	1.50	0.95		Condition Index	12	4.51	1.04	0.66
	Samples analysed for metals:						Samples analysed for metals:				
	Length (mm)	12	60-70	-	-		Length (mm)	12	60-70	-	-

Table 4.2 Biological Data of the natural oyster populations in 2021

Site		n	mean	S.D.	±95%CI	Site		n	mean	S.D.	±95%CI
Northside 5 (N5)	(16 August 2021)					Southside 3a (S3a)	(17 August 2021)				
	Natural population:						Natural population:				
	Density (No./0.25 m^2)	30	0.70	2.42	0.90		Density (No./0.25 m^2)	30	17.20	16.99	6.34
	Length (mm)	21	53.00	13.81	6.29		Length (mm)	100	46.27	15.43	3.06
	Condition Index	12	5.62	0.74	0.47		Condition Index	12	5.93	0.92	0.59
	Samples analysed for metals:						Samples analysed for metals:				
	Length (mm)	12	60-70	-	-		Length (mm)	12	60-70	-	-
Northside 6a (N6a)	(16 August 2021)					Southside 5a (S5a)	(17 August 2021)				
	Natural population:						Natural population:				
	Density (No./0.25 m^2)	30	37.07	49.17	18.36		Density (No./0.25 m^2)	30	0.07	0.25	0.09
	Length (mm)	100	47.83	11.97	2.38		Length (mm)	2	43.50	14.85	133.42
	Condition Index	12	5.07	0.80	0.51		Condition Index	12	9.12	2.29	1.45
	Samples analysed for metals:						Samples analysed for metals:				
	Length (mm)	12	60-70	-	-		Length (mm)	12	60-70	-	-
Northside 10 (N10)	(16 August 2021)					Taihiki Control (TC)	(27 September 2021)				
	Natural population:						Natural population:				
	Density (No./0.25 m^2)	30	21.00	25.79	9.63		Density (No./0.25 m^2)	30	4.70	10.40	3.88
	Length (mm)	100	43.57	11.37	2.26		Length (mm)	100	47.90	20.20	4.01
	Condition Index	12	6.76	0.80	0.51		Condition Index	12	4.79	0.78	0.50
	Samples analysed for metals:						Samples analysed for metals:				
	Length (mm)	12	60-70	-	-		Length (mm)	12	60-70	-	-

KEY

N = number of shellfish samples
S.D. = standard deviation
CI = confidence intervals for t distribution (mean ± 95% CI)

4.1.1 Density of Pacific Oysters

The density of the oyster populations at all sites showed similar values between the previous survey (2020) and this survey (2021), as shown in Figure 4.1. Sites Northside 5 and 10 and Southside S3a recorded small decreases while the Taihiki Control and Northside 6a Sites recorded small to moderate increases. The mean density at Southside 5a showed a significant decrease between 2019 and 2020 and this decrease has continued in 2021. Mean density was low at Northside 5, Southside 5a and at Taihiki Control (< 10 oysters /0.25 m^2). The highest mean density recorded in August 2021 was at Northside 6a (37 ± 18 oysters /0.25 m^2). The ranges in density of oysters at the six sites between 1985 and 2021 are:

Northside 5	0.63	-	78.57	
Northside 6	3.60	-	40.40	
Northside 6a	9.50	-	37.07	(2010 -)
Northside 10	8.57	-	75.50	(1988 -)
Taihiki Control	1.03	-	94.50	
Taihiki Control	1.90	-	33.20	(2010 -)
Southside 3	12.37	-	36.73	
Southside 3a	10.80	-	21.23	(2010 -)
Southside 5	2.30	-	57.67	
Southside 5a	0.07	-	7.57	(2010 -)

When the densities of the oysters for all annual monitoring programmes were compared (Figure 4.1), a few major changes were evident. The density of oysters at Southside 5 has declined steadily since 1987, most likely as a result of habitat change caused by colonization and proliferation of mangroves seawards of the site. This needed a change of sample site location in August 2010. Since the initial high in August 2010, density decreased to a low in August 2016, followed by a significant increase in density in August 2017, but has since decreased to a low in August 2021. Densities at Site Southside 3 have remained relatively similar over the 36 year period, however, the density record in 2011 was the lowest recorded. Site Southside 3 has suffered similar mangrove proliferation to Site Southside 5, but only over half of the site, therefore the sample site was repositioned in August 2010. Since August 2010, densities have increased at Site Southside 3a. At Northside 5, the density of oysters peaked in May 1990 and decreased to a low in May 1995, recovered slightly in the following years but decreased to a low in August 2014. Density increased slightly following 2014, but has decreased gradually to a low in August 2019, with similarly low densities recorded in August 2020 and 2021. The density of oysters at Northside 6 declined steadily since 1988 to a low in May 2009, after which it was necessary to move the site location to an adjacent area with higher densities. The density at Site Northside 6a decreased initially to a low in August 2015, but has since recovered (37 ± 18 oysters /0.25 m^2 in 2021). The density of oysters at Northside 10 declined between 1992 and 1995 and had recovered to densities similar to pre 1993 by 1997. Since 1997, the density of oysters at this site has gradually declined a small amount, with fluctuations. The density decreased markedly between 2010 and 2011.

The density of oysters at the Taihiki Control Site has been variable, with a maximum in 1987 of 95 oysters /0.25 m^2 followed by a steady decrease in density to the 1993 minimum of 6 oysters /0.25 m^2. Density remained low with a maximum of 18 oysters /0.25 m^2 between 1993 and 1999. The density had increased to 33 /0.25 m^2 in 2000, the highest recorded since 1991. Between 2005 and 2008, the density decreased to almost none. Mud deposition, much of it from the adjacent farmland, appears to have been a major contributing factor to the decrease in density. Although the density of the oysters has decreased to low levels on the transect (originally set up in 1985), there was still an adequate population of oysters adjacent to the site to sustain the annual sampling for metals. The density of oysters was not measured by the Auckland Council in late 2003 and 2004. The density at the Taihiki Control Site decreased to a new low of 1 oyster /0.25 m^2 in 2008. The density at the Taihiki Control Site was not recorded in 2009, and in 2010 the location of the sampling area was moved as no oysters were present in the original sample area. The density decreased markedly at the relocated control site, between 2010 and 2011. Oyster populations in the Manukau Harbour and other areas of northern New Zealand suffered from the effects of a naturally introduced oyster virus between 2010 and 2011. This has resulted in significant mortality with ongoing reduced settlement of juveniles, thus a reduction in the density of oyster populations. Between 2011 and

2020 the density was still low at the Taihiki Control Site decreasing to a new low of 1.9 /0.25 m^2 in 2020. The density at the Taihiki Control Site has increased since 2020, coinciding with the erosion of soft sediment covering the rock shelf the site is located on.

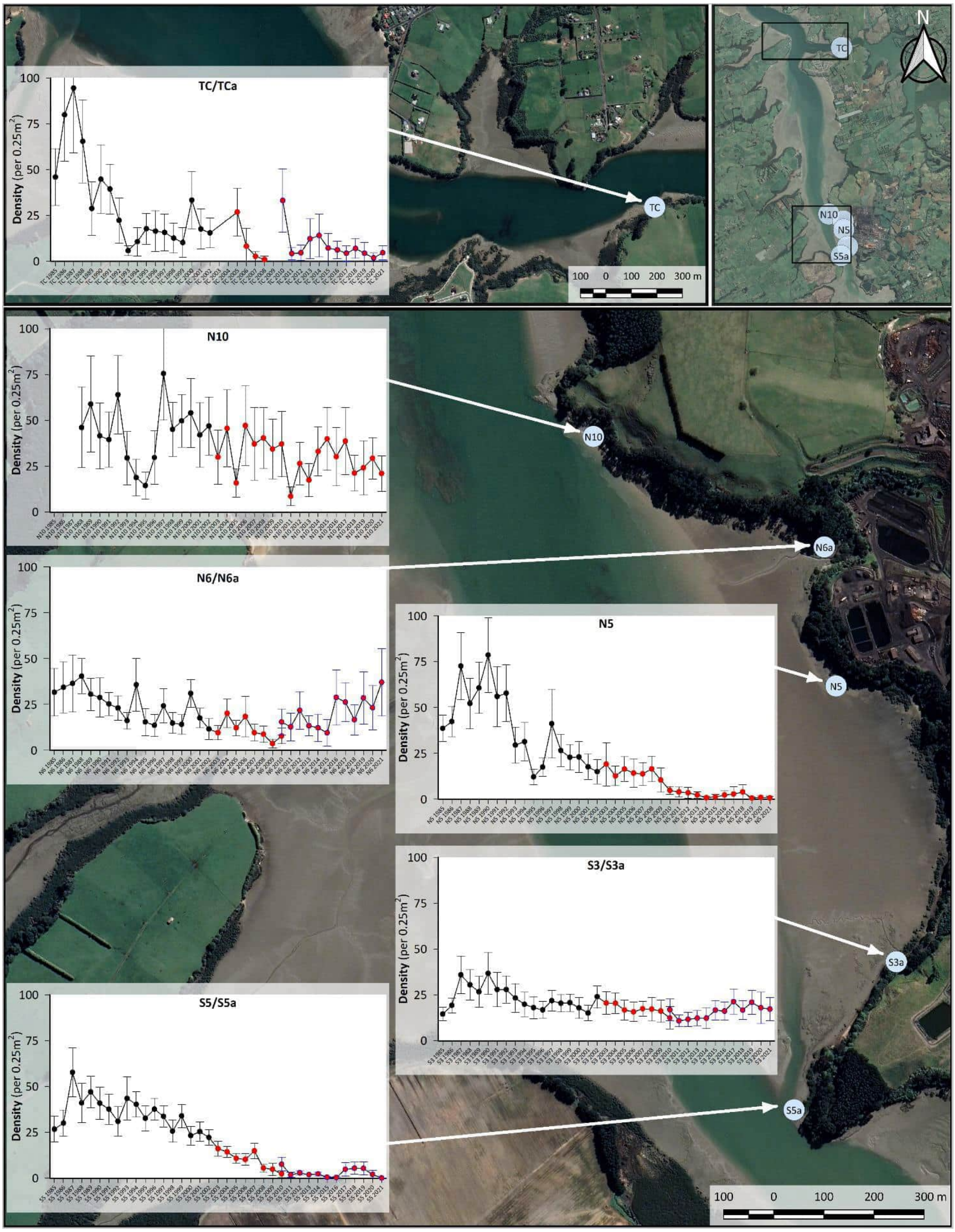

Figure 4.1 Oyster Density - Annual Results 1985 - 2021. Northside Sites, Taihiki Control and Southside Sites. *(Mean ± 95% confidence intervals) (● = May samples, ● = August samples, ○ = Site relocated)*

4.1.2 Length Data for Pacific Oysters

A comparison between the 2020 and 2021 surveys of the mean length data of oysters measured showed contrasting trends between sites. Mean oyster lengths decreased between 2020 and 2021 at sites south of the discharges and at Northside 10, while the sites Northside 5, Northside 6a and Control showed increases in mean length, as shown in Figure 4.2.

At sites Southside 3a, 5a and Northside 10, both the density and mean length decreased between 2020 and 2021 suggesting loss of adult population without recruitment. The increases in length at Site Northside 5 did not parallel an increase in densities, indicating poor recruitment of juveniles and ageing of the population present. At Site Northside 6a and the Taihiki Control, both the density and mean length increased between 2020 and 2021 suggesting the population is recovering with healthy recruitment and growth.

Between the first survey (1985) and the most recent survey (2021), sites Southside 3/3a and 5/5a and Northside 5, have shown no obvious annual trend in mean lengths of the oyster populations, with between 3 and 7 mm of difference in mean length between 1985 and 2021. However, over this period these sites have recorded variations in the mean length with the range of length from maximum to minimum, of 21.9, 17.9 and 15.5 mm respectively.

At the Northside Sites 6/6a and 10 the variation in mean lengths was in the order of 56 - 58 mm over the full length of the monitoring, with a decreasing trend over time. At Northside 6/6a the mean length has decreased by 17 mm since the first survey in 1985, but the range between the highest and lowest mean lengths is 56 mm indicating considerable variation over time. When the mean length data from just the relocated Northside Site 6a is assessed, the variation is smaller with a difference of only 19 mm, with a small increasing trend over time. At Northside 10 the mean length has decreased by 19 mm since 1988 and mean lengths have ranged from 30 to 88 mm over the course of the study.

At the Taihiki Control Site the variation in mean lengths was in the order of 48 mm over the full length of the monitoring, with a 11 mm increasing trend over time. This high length range is due to a major drop in length in 2016 at 14 mm while the mean length recorded over the monitoring of the relocated Taihiki Control Site is 38 mm.

The ranges in mean length (mm) of oysters at the six sites between 1985 and 2021 are:

Northside 5	39.0 - 54.5		Southside 3	35.1 - 57.0	
Northside 6	40.0 - 86.8		Southside 3a	35.6 - 51.0	(2010 -)
Northside 6a	30.9 - 49.4	(2010 -)	Southside 5	39.0 - 51.0	
Northside 10	29.6 - 88.0	(1988 -)	Southside 5a	33.1 - 46.1	(2010 -)
Taihiki Control	36.7 - 61.9				
Taihiki Control	14.3 - 50.9	(2010 -)			

Based on Figure 4.2, there has been no common or long-term trend of increase or decrease in length at the sites sampled. However, all sites except Northside 5 and the Taihiki Control, have shown decreases in length between the first and latest data. The recorded changes are considered to be the result of normal ageing and recruitment of oyster populations, with some effects from habitat changes due to sedimentation or proliferation of mangroves.

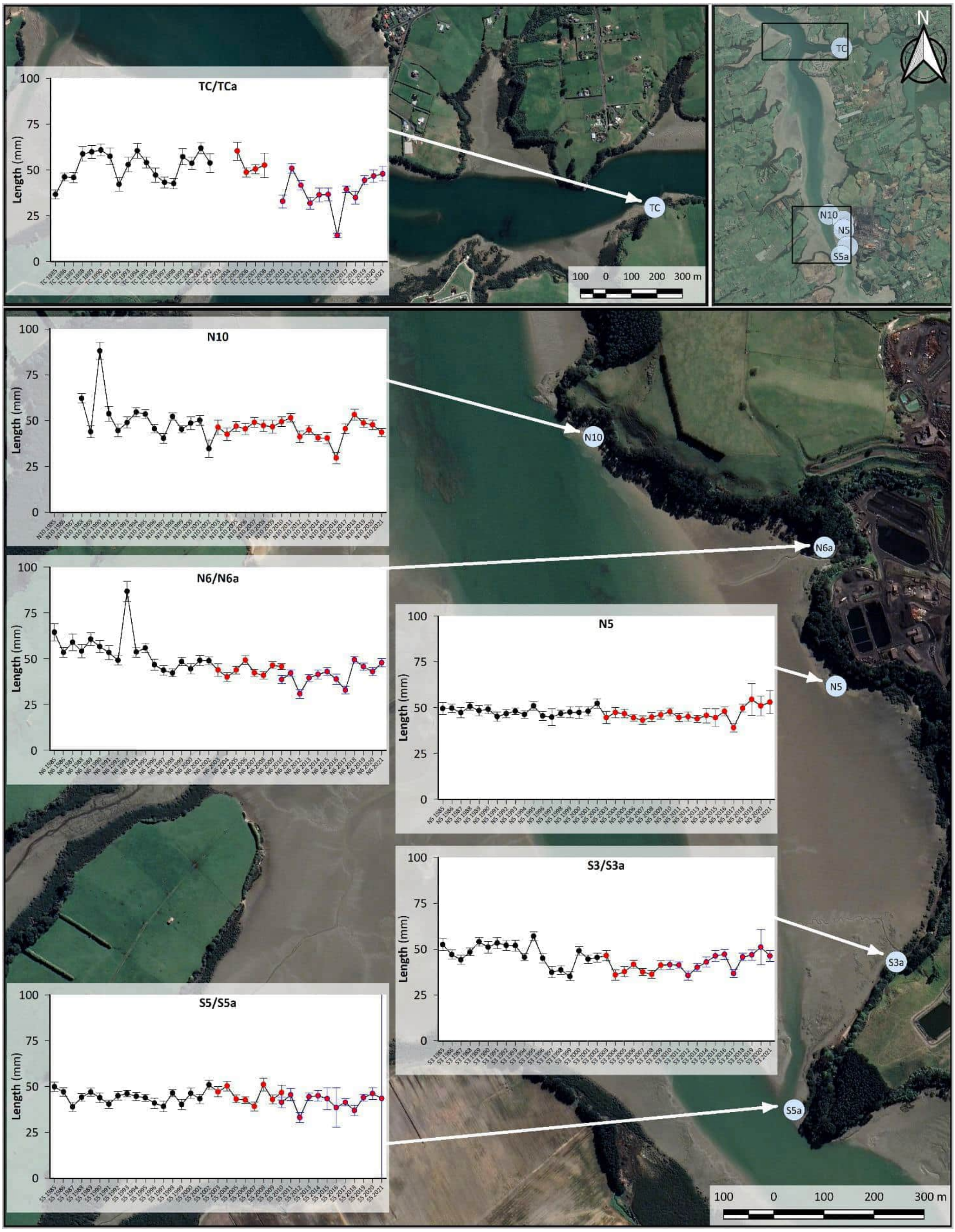

Figure 4.2 Oyster Length - Annual Results 1985 - 2021. Northside Sites, Taihiki Control and Southside Sites. (mean ± 95% confidence intervals)

(● = May samples, ● = August samples, ○ = Site relocated)

4.1.3 Condition Indices for Pacific Oysters

The Condition Index is an indicator of how well an oyster has utilised the internal shell volume available for tissue growth. The 2020 and 2021 mean condition index metrics for each site based on flesh dry weight per shell volume data are presented summarised in Table 4.1 and Table 4.2 and compared between sites for 2021 in Figure 4.3. The lowest mean condition index recorded in 2021 was from the Control Site (4.79 ± 0.78) and the highest mean condition index from Southside 5a (9.12 ± 2.29). The condition index at Southside 5a was statistically significantly higher than the other mixing zone sites and the Control Site. The condition index at Northside 10 was statistically significantly higher than at Northside 6a and the Control Site. With the exceptions of Southside 5a and Northside 10 the condition indices at the mixing zone sites were not statistically different from the Taihiki Control Site.

Between the 2020 and 2021 surveys, there was no significant change in the mean condition indices within each site (refer Figure 4.4).

Between the first surveys, and the most recent survey in 2021, the condition index has shown decreases at all sites except Southside 5 Site. The decreases at sites Southside 3 and at the Taihiki Control Site were statistically significant, as was the increase at the Southside 5 Site (refer Figure 4.4). Figure 4.4 shows that at most sites the condition index declined between the first surveys in 1985 and 2008. With the lowest values recorded (< 4) at mixing zone sites in 2008, however the Taihiki Control Site was considerably higher (8). From 2008 to 2014, the condition indices increased to values similar or higher than that of the late 1990s at all sites. The year 2014 marked the highest values for the sites Southside 3 and 5 and Northside 5 over the 36 year study period.

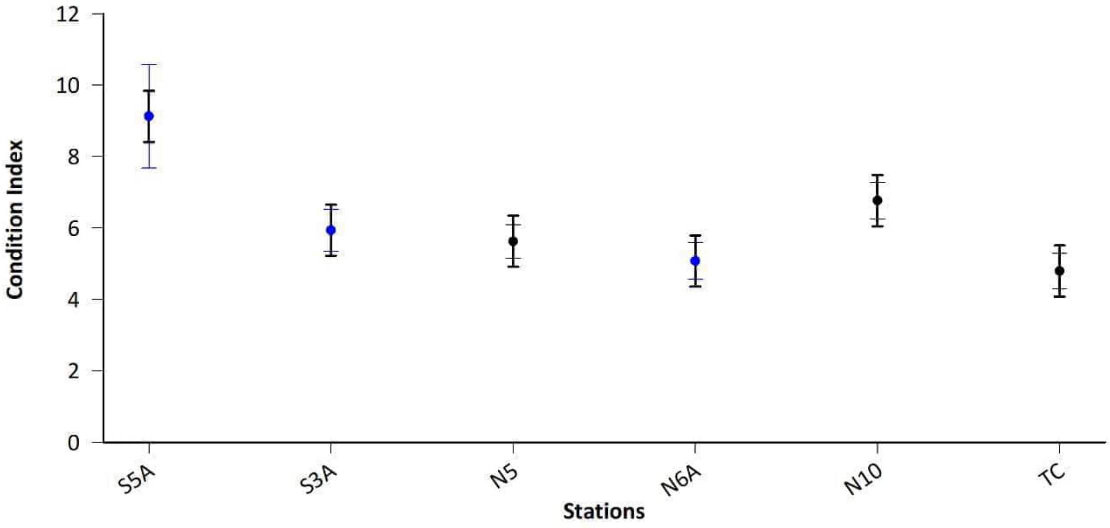

Figure 4.3 Oyster Condition Indices for August 2021
*(mean ± 95% confidence intervals (thin bar) and HSI (α=0.05) (**bold bar**))* (○ = Relocated Sites)

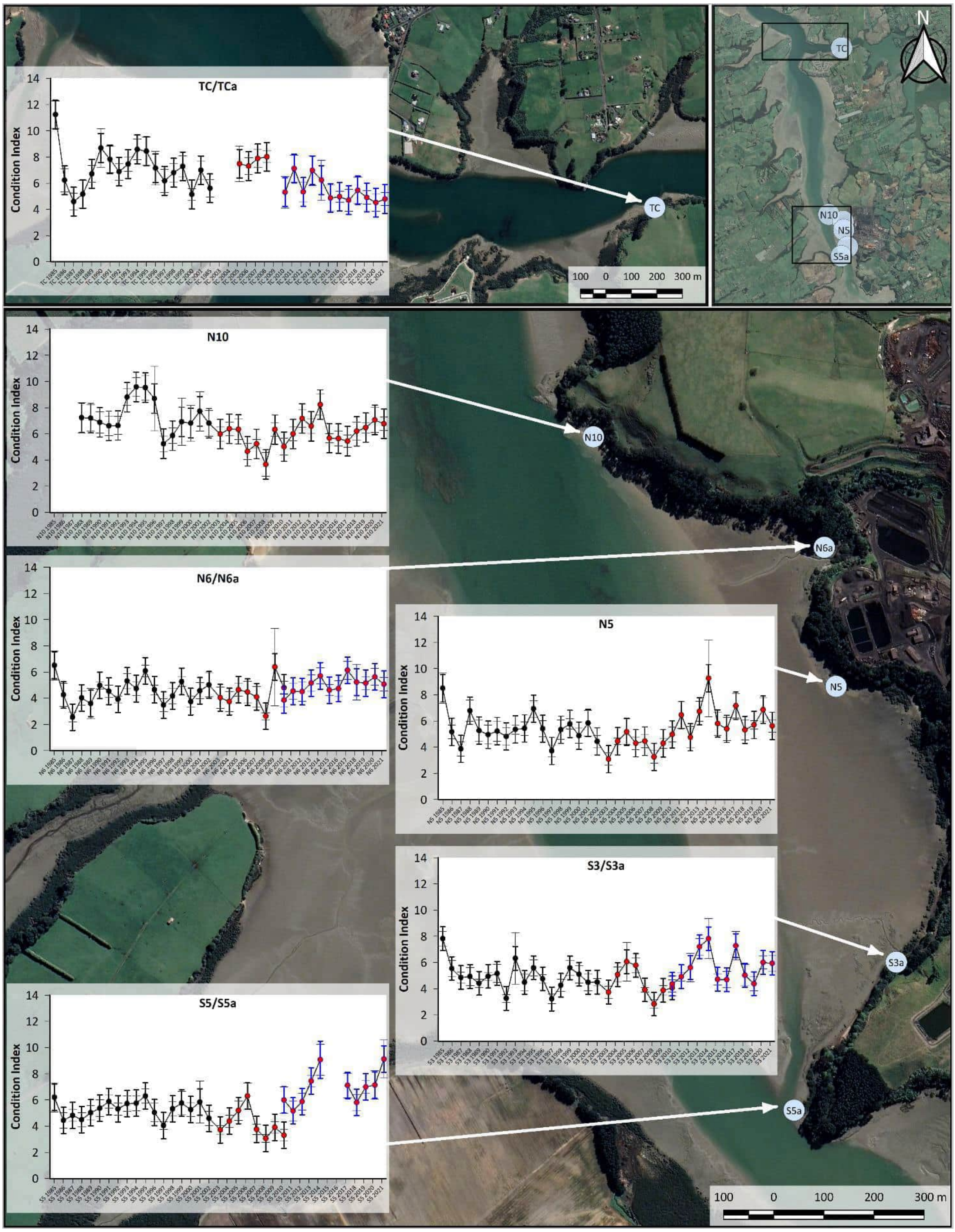

Figure 4.4 Oyster Condition Indices - Annual Results 1985 - 2021*. (mean ± 95% confidence intervals (thin bar) and HSI (α=0.05) (bold bar))* (● = May samples, ● = August samples, ○ = Site relocated)

4.2 Metals in Pacific Oysters

4.2.1 Data Presentation and Analysis

The current 2021 raw metals data for oysters are presented as Table A2.2 in Appendix 2 and summarised in Table 4.3 and Table 4.4 and shown graphically in Figure 4.5 to Figure 4.8. Long term trends are discussed for dry weight data as these are the data provided directly by the laboratory tests. The wet weight data are calculated from the dry weight results and percentage moisture data.

Table 4.3 Analysis of Metals in Oysters – August 2021 *(Concentration mg/kg dry weight)*

Metals Analysed	**NORTHSIDE SITES**						**TAIHIKI CONTROL**	
	N5		**N6a**		**N10**			
	mean	**95%CI**	**mean**	**95%CI**	**mean**	**95%CI**	**mean**	**95%CI**
Copper	316.7	29.7	339.2	49.2	261.7	32.2	260.8	38.1
Zinc	3092	301	7033	586	2292	263	2017	316
Metals Analysed	**SOUTHSIDE SITES**							
	S3a		**S5a**					
	mean	**95%CI**	**mean**	**95%CI**				
Copper	334.2	34.7	264.2	36.3				
Zinc	2608	316	2283	301				

Table 4.4 Analysis of Metals in Oysters – August 2021 *(Concentration mg/kg wet weight)*

Metals Analysed	**NORTHSIDE SITES**						**TAIHIKI CONTROL**	
	N5		**N6a**		**N10**			
	mean	**95%CI**	**mean**	**95%CI**	**mean**	**95%CI**	**mean**	**95%CI**
Copper	27.28	3.16	27.67	3.39	28.42	3.69	27.09	3.42
Zinc	264.6	24.1	581.5	62.1	248.6	29.1	209.7	29.5
Metals Analysed	**SOUTHSIDE SITES**							
	S3a		**S5a**					
	Mean	**95%CI**	**mean**	**95%CI**				
Copper	31.00	2.53	30.25	3.26				
Zinc	242.4	26.2	261.9	28.4				

KEY

mean = Arithmetic mean (n = 12)

CI = confidence intervals for t distribution (mean ± 95% CI)

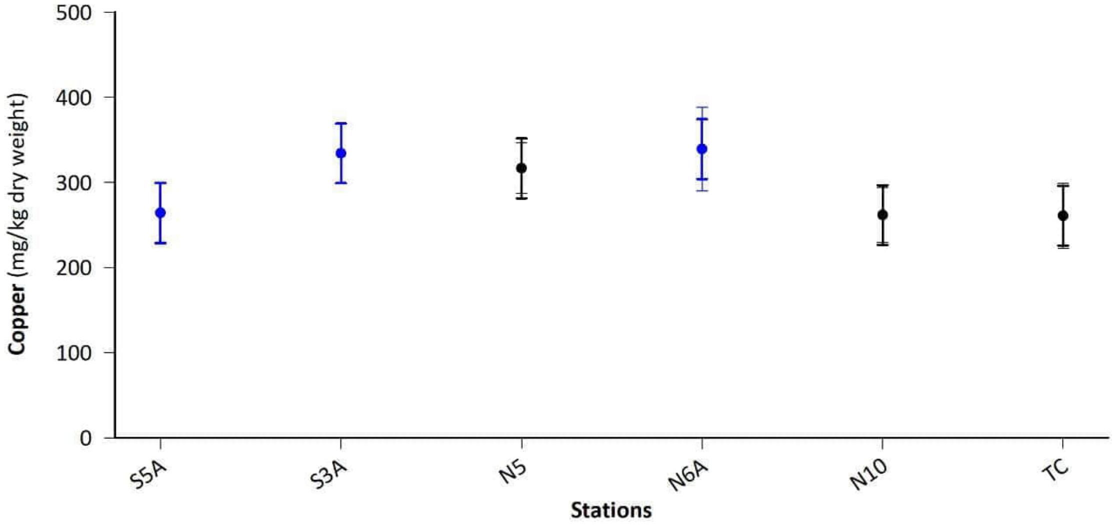

Figure 4.5 Concentration of Copper in Oysters 2021 – Dry Weight
*(mean ± 95% confidence intervals (thin bar) and HSI (α=0.05) (**bold bar**))* (○ = Relocated Sites)

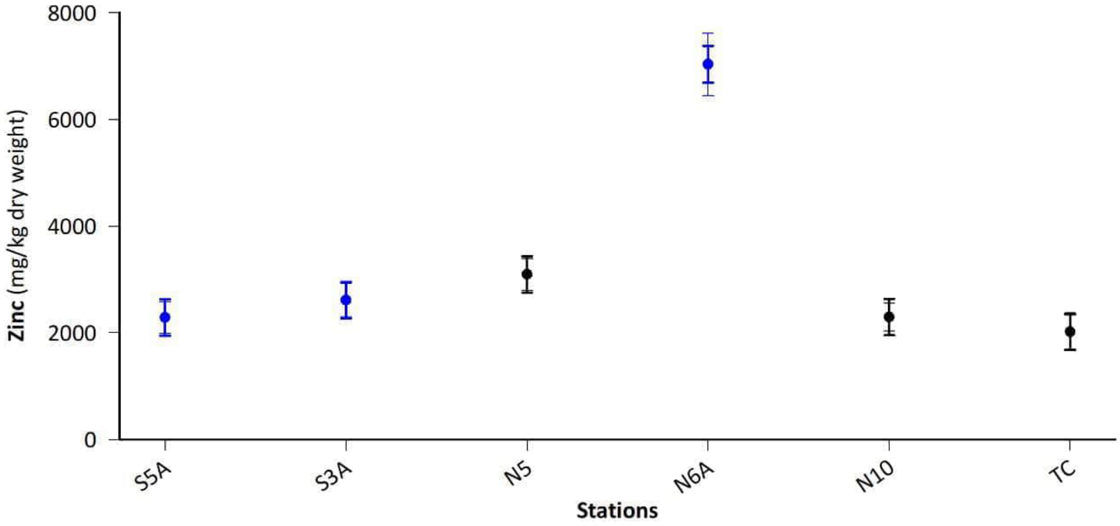

Figure 4.6 Concentration of Zinc in Oysters 2021 – Dry Weight
*(mean ± 95% confidence intervals (thin bar) and HSI (α=0.05) (**bold bar**))* (○ = Relocated Sites)

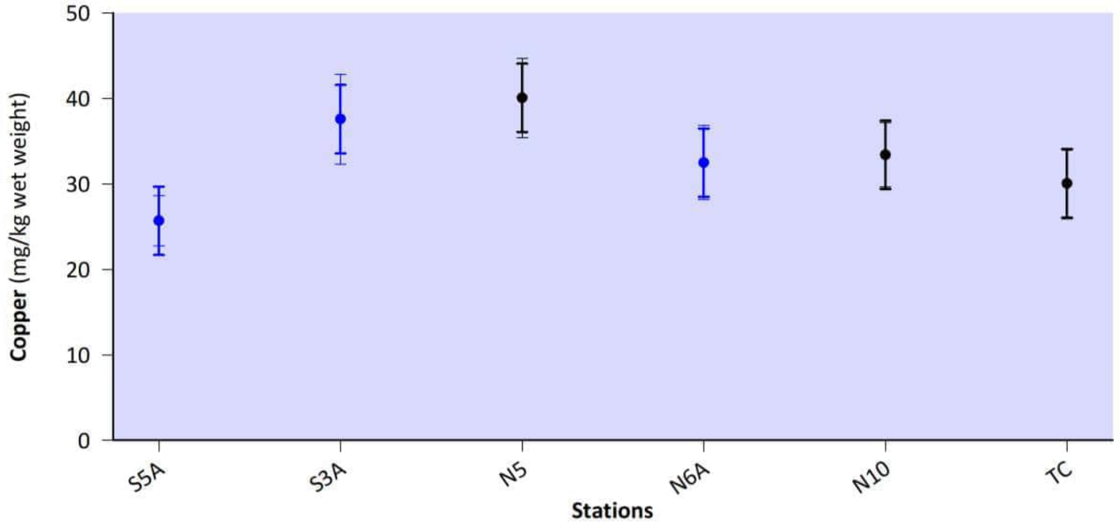

Figure 4.7 Concentration of Copper in Oysters 2021 – Wet Weight
*(mean ± 95% confidence intervals (thin bar) and HSI (α=0.05) (**bold bar**))* (○ = Relocated Sites)

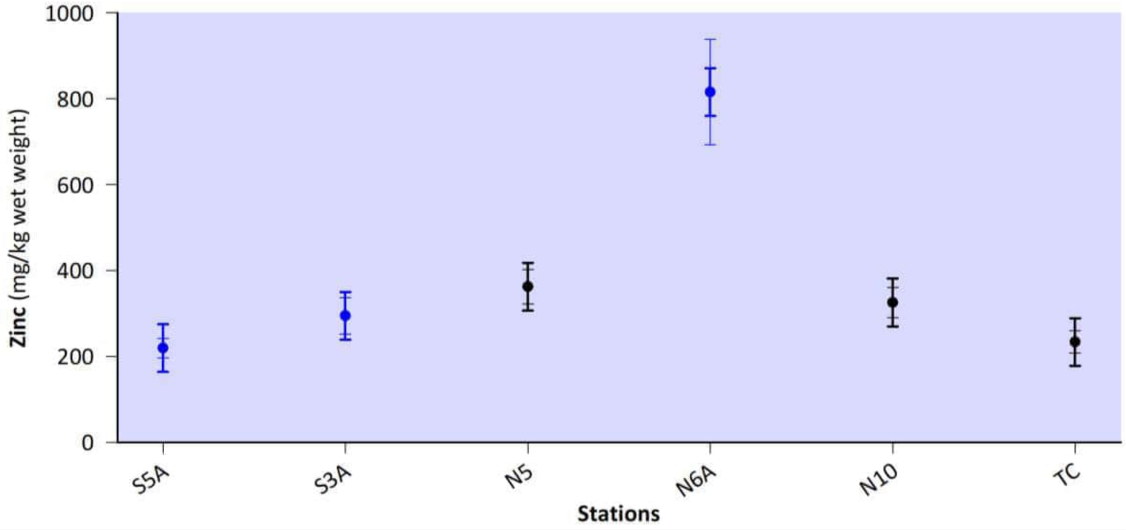

Figure 4.8 Concentration of Zinc in Oysters 2021 – Wet Weight
*(mean ± 95% confidence intervals (thin bar) and HSI (α=0.05) (**bold bar**))* (○ = Relocated Sites)

Results of the ANOVAs and Tukey analyses for copper and zinc dry weight data are presented in Table A2.4 and Table A2.6.

In the following discussion, statistical significance was determined by two methods:

- Honest Significant Intervals (HSI) (Andrews *et. al.,* 1980) with a 95% level of significance;
- Tukey analysis between sample means for which $p<0.05$ is the criterion for a statistically significant difference between sample means.

Where ANOVA and Tukey analysis have been performed and presented, those results have been used to determine statistically significant differences between multiple sites. When comparing the difference between two samples at a site over time (Figure 4.9 and Figure 4.10) the HSI has been used to determine statistical significance.

4.2.2 Comparison of 2021 Dry Weight Data between sites

4.2.2.1 Copper

The current copper in oysters data are summarised in Table 4.3, and shown graphically in Figure 4.5. The Northside 6a Site had the highest mean concentration of 339 mg/kg dry weight, while the Taihiki Control Site had the lowest recorded value of 260 mg/kg dry weight. The concentration at the sites Southside 3a and Northside 6a were statistically higher than at the Taihiki Control Site and Northside 10, the remaining mixing zone sites were statistically from the Control Site.

The highest concentration of copper was recorded at Northside 6a which is the site nearest the Northside outfall, however the concentration at sites Northside 5 and Southside 3a were also elevated, suggesting the Northside outfall was not the sole cause of the elevated concentrations.

4.2.2.2 Zinc

The current zinc in oysters data are summarised in Table 4.2, and shown graphically in Figure 4.6. The Northside outfall Site (Northside 6a) had the highest mean concentration at 7,033 mg/kg dry weight, which was statistically significantly higher than at all other sites. The concentration at the Northside 5 site was statistically higher than at the Taihiki Control Site and the two boundary mixing zone sites Northside 10 and Southside 5a. These results show an outfall effect of increased zinc in oysters in the vicinity of the Northside outfall within the mixing zone. Dry weight zinc concentrations in oysters at all mixing zone sites other than Northside 5 and 6a were not statistically significantly different from the Taihiki Control Site. Given the statistically significantly decrease between Northside 6 and the other Northside sites 5 and 10, the effects of the Northside outfall were confined to relatively close to the discharge point of the Northside Outfall.

4.2.3 Comparison of Annual Dry Weight Metal Data for Pacific Oysters 1985-2021

Data on dry weight metals concentrations in Pacific oysters from this survey (August 2021) and the 36 previous annual surveys (Bioresearches Ltd 1985 to 1989; Bioresearches 1991a, 1991b, 1992, 1994a, 1994b, 1995 to 2020) are presented in Table A2.3 and Table A2.5, and compared in Figure 4.9 and Figure 4.10. Statistical significance between two means is determined graphically by HSI with a 95% level of significance.

4.2.3.1 Copper

Mean copper concentrations in oysters decreased at sites Northside 5 and 10 and the Taihiki Control and increased at sites Southside 3a, 5a and Northside 6a, between 2020 and 2021 (Table A2.3). None of the changes were statistically significant (Figure 4.9).

Over the course of the monitoring the mean copper concentrations in oysters have increased between May 1985 and August 2021 at the Taihiki Control Site and all mixing zone sites, except Northside 5. None of the changes were statistically significant.

Mean copper concentrations in oysters at the Northside and Southside sites showed similar trends in 36 years of survey. All showed increases in the concentration of copper in the initial surveys with all mixing zone sites showing peaks in concentrations between 1992 to 1998. An additional peak concentration was recorded in 2003 at all mixing zone sites and in 2008 at Northside 10. This was followed by a period of decreases in the concentration of copper, with lows recorded in the last few years similar to or lower than those initially recorded in the late 1980's (Table A2.3). The decreasing trends in the concentration of copper reversed in 2018, with minor increases observed at all sites, except Northside 5, since 2018 (Figure 4.9).

The Taihiki Control Site has shown a slightly different trend to the mixing zone sites during the past 36 years, with first increases until 1993, with a statistically significant decrease in 1994, followed by a period of relatively stable concentrations between 1994 and 2012. In 2013 the concentration increased significantly and remained so for a few years. Since 2016 the concentration has been similar to the stable concentrations recorded between 1994 and 2012 (Figure 4.9). These changes were likely reflective of changes or events in the nearby land use.

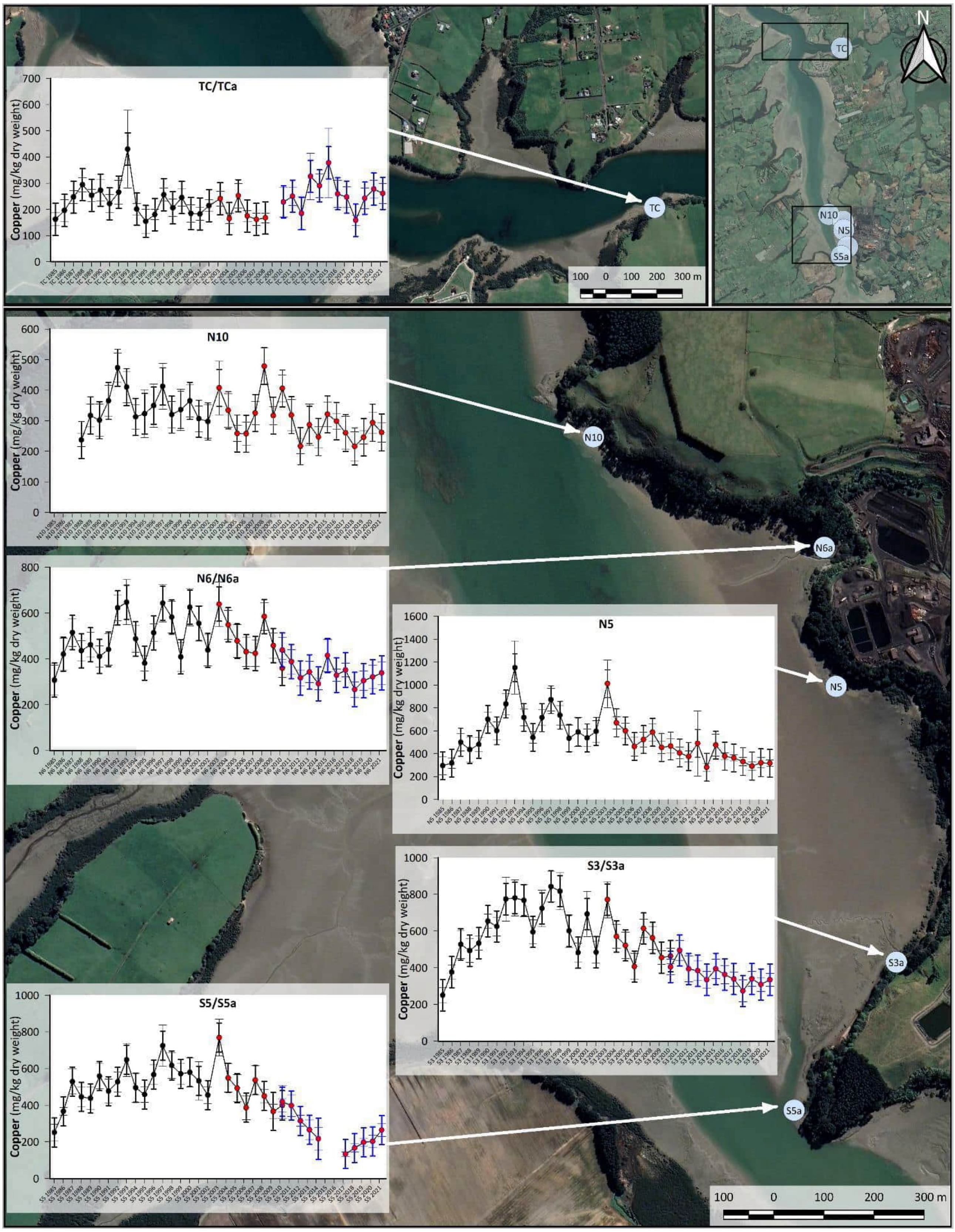

Figure 4.9 Copper Concentrations in Oysters** (dry weight) **- Annual Results 1985 - 2021.
*(mean ± 95% confidence intervals (thin bar) and HSI (α=0.05) (**bold bar**))*
(● = May samples, ● = August samples from 2003, ● = August samples from relocated Site)

4.2.3.2 Zinc

The results from the 2021 survey showed that the mean zinc concentration in oysters had increased at sites Northside 5 and Southside 3a and 5a, but decreased at sites Northside 6a and 10 and the Control, when compared with the results from the 2020 survey (Table A2.5). The changes at all sites were not statistically significant in 2021 (Figure 4.10).

The mean concentration of zinc in oysters has decreased over time between 1985 and 2021 within the mixing zone at sites Northside 5 and 10 and Southside 3a and 5. The mean concentration of zinc in oysters has increased over time between 1985 and 2021 at Northside 6a and the Taihiki Control Site. None of the changes over time were not statistically significant. Like with copper, the mean concentrations of zinc in oysters from mixing zone sites increased from initial concentrations in 1985 to highs between 1992 and 1998, with secondary peaks in 2003 at all sites and 2008 at Northside 6 and 10. The 2003 peak was followed by a period of decrease in the concentration of zinc, with lows recorded in the last few years lower than those initially recorded in the late 1980's (Figure 4.10). The Site Northside 6 has always had higher concentrations of zinc than all other sites. The concentration of zinc in oysters at the Taihiki Control Site showed comparatively stable concentrations over the 36 years.

4.2.4 Wet Weight Data for Zinc

A review of standards for the zinc concentration in Pacific oysters that could be used as an environmental effect criteria in an Environmental Monitoring Program was undertaken by Stanley and Associates in 1988. As a result of the review, agreement was reached with the (then) Auckland Regional Water Board on two criteria for defining unacceptable levels for the zinc concentrations in Pacific oysters. Later reviews, as a result of consent renewal, have supported the continuation of the use of these criteria. The existing Resource Consent 21575 specifies the following criteria in condition 4.6:

1. **Within the mixing zone**, the maximum concentration of zinc in Pacific oysters should not exceed the Alert Level (1,000 mg/kg zinc, wet weight).
2. **Outside the mixing zone**, the maximum concentration of zinc in Pacific oysters should not exceed the Response Level (500 mg/kg zinc, wet weight).

Average concentration of zinc for each annual survey since 2000 show that none of the sites within or outside the mixing zone have reached the 'alert' concentration of 1,000 mg/kg zinc wet weight (as indicated by solid red reference line), during the period of the existing Resource Consent 21575 (Figure 4.11).

Sites Southside 5 and Northside 10 are located either on the mixing zone boundary or just inside and the Taihiki Control site is located outside the mixing zone, none of the wet weight zinc concentration at these sites have reached the Response concentration of 500 mg/kg zinc wet weight, during the period of the existing Resource Consent 21575 (as indicated by dashed orange reference lines in Figure 4.11).

Since the late 2000, all mixing zone sites with the exception of Northside 6 have shown stable or declining trends with zinc wet weight concentrations becoming more similar to the concentrations recorded at the Taihiki Control site (Figure 4.11). This is more clearly evident when four value moving average data is compared graphically in Figure 4.12.

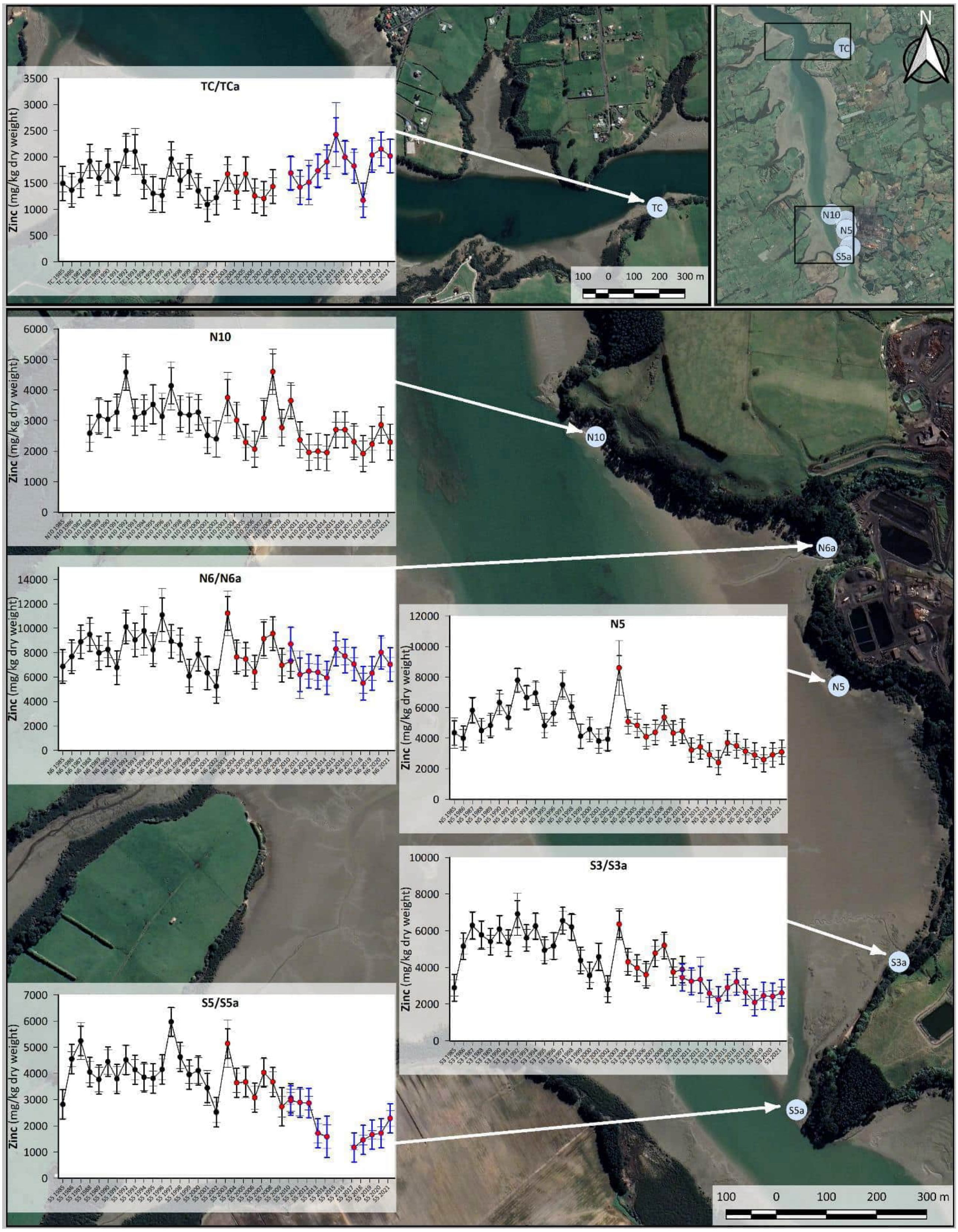

Figure 4.10 Zinc Concentrations in Oysters** (dry weight) **- Annual Results 1985 - 2021.
*(mean ± 95% confidence intervals (thin bar) and HSI (α=0.05) (**bold bar**))*
(● = May samples, ● = August samples from 2003, ● = August samples from relocated Site)

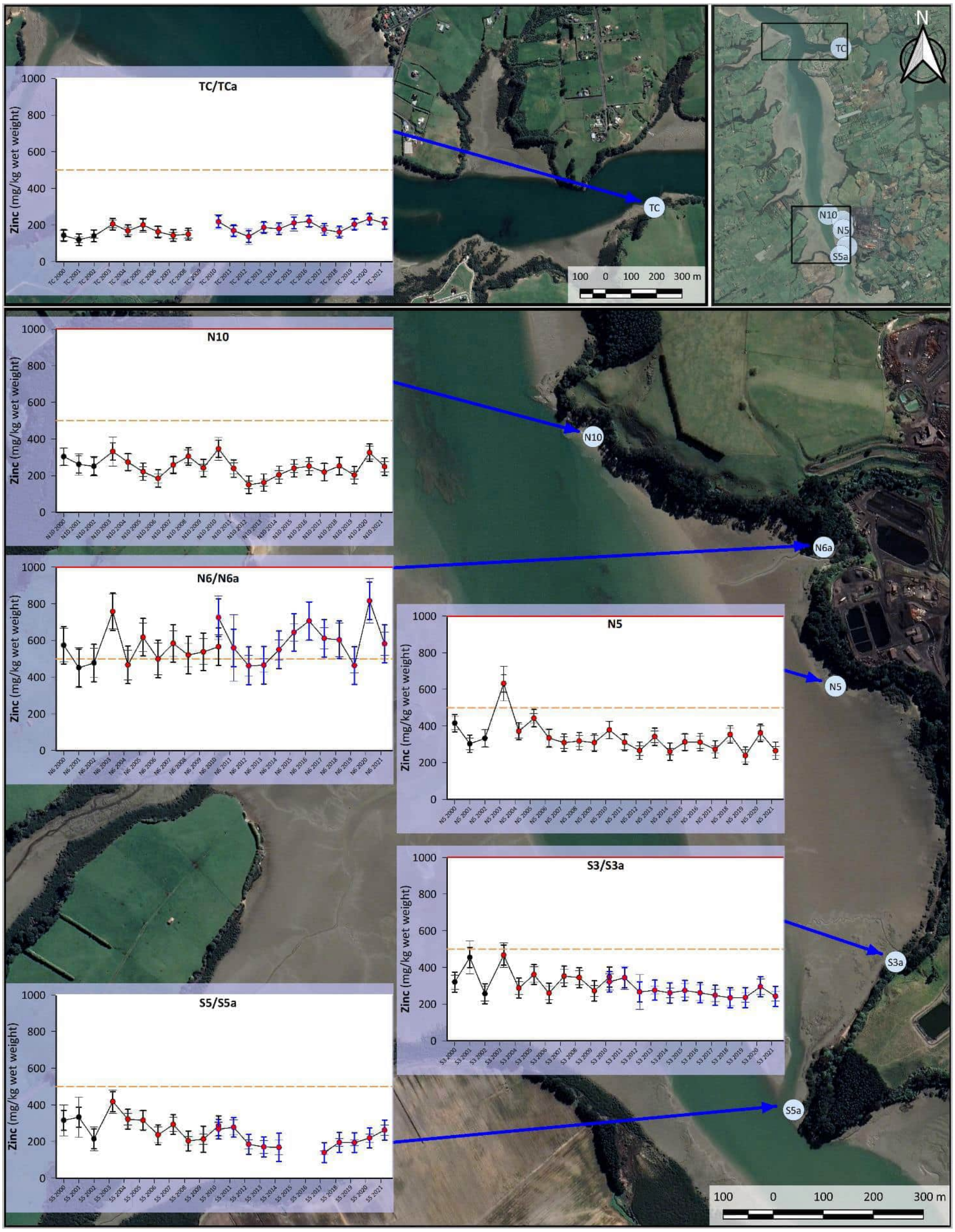

Figure 4.11 ***Zinc Concentrations in Oysters*** *(wet weight)* ***- Annual Results 2000 - 2021.***

*(mean ± 95% confidence intervals (thin bar) and HSI (α=0.05) (**bold bar**))*

(● = May samples, ● = August samples from 2003, ● = August samples from relocated Site)

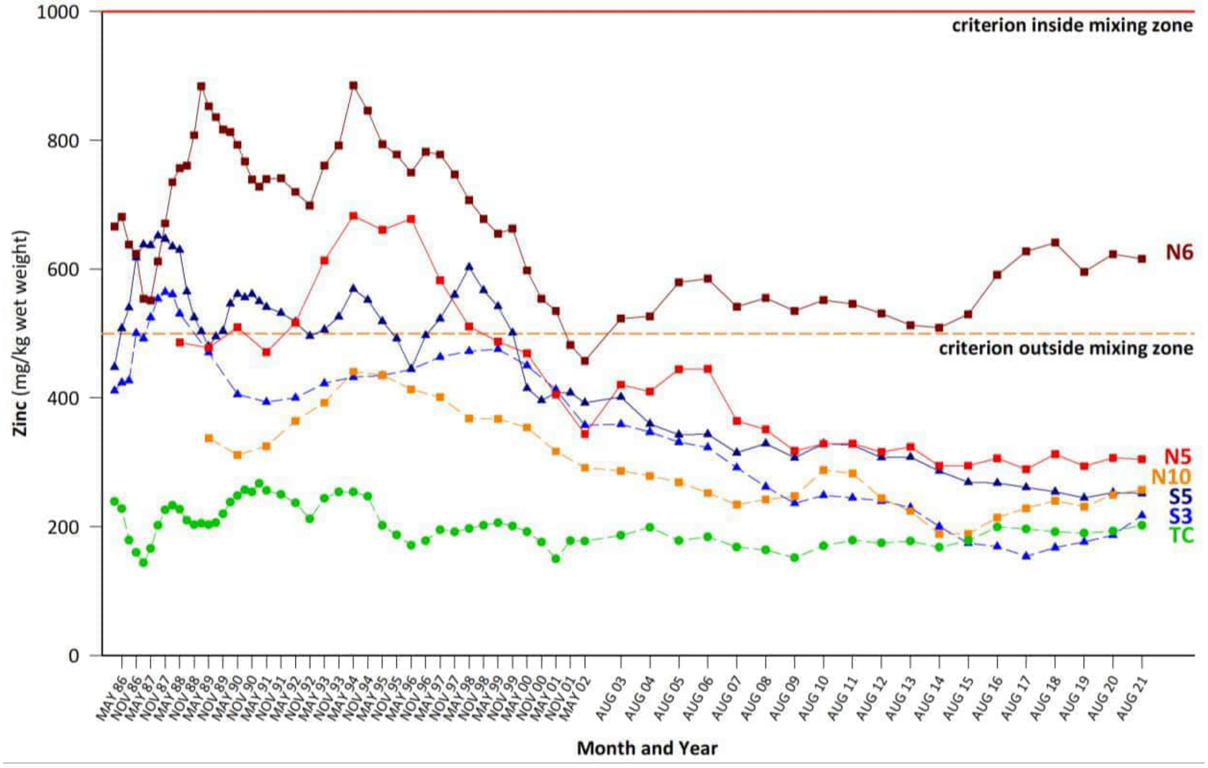

Figure 4.12 Moving average of wet weight Zinc concentrations in Oysters *(mg/kg wet weight)*

5. COASTAL VEGETATION

The Waiuku Estuary is one of the four main branches of the Manukau Harbour, running about 11 km from its mouth at Clarks Beach upstream to Waiuku township. The estuary is considered to be an ancient discharge point for the Waikato River. Much of the estuary is soft mud, with areas of sandstone and occasional deposits of hard substrate (mostly discarded ballast from historic shipping). The majority of the landward landscape is pasture, with some industrial land (New Zealand Steel-owned) and to the north and south, a residential village (north) and township (south).

Within the project area, the upper intertidal and mean high water springs (MHWS) is often a clearly defined boundary at the base of a vertical cliff or mudstone/sandstone shelf, which defines the extent of the Coastal Marine Area (CMA). The intertidal vegetation to MHWS is dominated by mangroves (*Avicennia marina* subsp. *australasica*), with patches of rushes and salt marsh vegetation near the MHWS level, transitioning into pines and pasture or occasionally narrow bands of native coastal vegetation then pasture.

5.1 Terrestrial Vegetation

5.1.1 Pines and Exotic Vegetation

This community dominated the cliff edges of the eastern coast of the Waiuku Estuary. The trees are dominantly pines, either radiata pine (*Pinus radiata*) or macrocarpa (*Cupressus macrocarpa*). The trees are well established and mature, and appeared to have be planted along the cliff edge, likely to mitigate the wind velocity from the west coast. The trees generally formed a band approximately 10m wide, fenced off on top of the cliff face, with occasional areas around New Zealand Steel, where the depth of the pines exceeded 100 m. The other dominant exotic coastal vegetation is pasture grass, which either formed the edge of the terrestrial vegetation or is the dominant ground cover between or under the pines. Exotic weed species, pampas grass (*Cortaderia selloana, C. jubata*), tree privet (*Ligustrum lucidum*), gorse (*Ulex europaeus*), woolly nightshade (*Solanum mauritianum*), coastal wattle (*Acacia sophorae*), boxthorn (*Lycium ferocissimum*) are patchily common, often mixed in with the native vegetation and also providing the early successional growth on slips and fallow pasture areas.

5.1.2 New Zealand Native Coastal Vegetation

The native coastal vegetation is visually dominated by pōhutukawa (*Metrosideros excelsa*). The pōhutukawa formed a patchily linear band on the cliff faces on the eastern side of the estuary, usually surrounded and backed by exotic vegetation, and large mature pōhutukawa trees are present on the majority of the points and promontories. Pōhutukawa have been planted as amenity trees in a single row on grassed coastal zone of the residential areas in the north of the survey site.

In addition to the pōhutukawa, areas of mixed native coastal trees and shrubs are present in the southern part of the survey area, mostly adjacent to the Site, and usually within the embayments.

The areas of mixed native vegetation comprised karaka (*Corynocarpus laevigatus*), a mix of tree ferns, ponga, mamaku, wheki (*Cyathea dealbata, C. medullaris, Dicksonia squarrosa*), and native shrubs, dominated by māpou (*Myrsine australis*), mahoe (*Melicytus ramiflorus*), karamu (*Coprosma robusta*), koromiko (*Veronica (Hebe) stricta*), coastal five-finger (*Pseudopanax lessonii* X *crassifolius*), kawakawa (*Piper excelsum*) and cabbage trees (*Cordyline australis*).

5.1.3 Freshwater Transitional Vegetation

In areas where streams or freshwater flow paths accessed the coast, freshwater wetland habitats are often present. The species within these areas is usually dominated by one or two wetland species forming a monoculture with occasional patches of other wetland plants present as the wetland transitioned to intertidal salt marsh or rush marsh.

The dominant wetland species are raupo (*Typha orientalis*) in the south and reed sweet-grass (*Glyceria maxima*) in the north, with patches of giant umbrella sedge (*Cyperus ustulatus*).

5.2 Coastal Intertidal Vegetation

5.2.1 Mangrove

Mangroves are patchily common throughout the area, usually forming a monospecific community in the upper to mid-tidal area, and common in the sheltered embayments with soft substrate.

5.2.2 Rush Marsh and Coastal Grass

The rush marsh and coastal grass community comprised of jointed wire rush, oioi (*Apodasmia similis*) and sea rush (*Juncus kraussii* subsp. *australiensis*), with areas of bugger grass (*Austrostipa stipoides*). The community is present in small patches (10 m^2 or less) or formed narrow bands, averaging 2 m wide in the upper intertidal area at approximate MHWS, between the upper extent of the mangroves and the land.

Jointed wire rush was dominant species, and when present often formed a monospecific community. On occasion, within some sheltered upper intertidal areas the rush marsh graded into salt marsh meadow and formed a diverse community of mixed species.

5.2.3 Salt Marsh Meadow

The salt marsh meadow habitats are communities dominated by native herbaceous salt marsh plants. The community is comprised of sea primrose (*Samolus repens*), selliera (*Selliera radicans*), glasswort (*Salicornia quinqueflora*), native celery (*Apium prostratum*), slender club rush (*Isolepis cernua var. cernua*), and occasionally the exotic orache (*Atriplex prostrata*).

The community either formed discrete patches in the upper intertidal, generally above the upper extent of the mangroves, or occasionally formed a mosaic associated with the rush marsh. The community is common at the interface with the fresh/brackish influence were the streams entered the coastal environment.

5.3 Coastal Vegetation Zones 1-14

The coastal vegetation communities were divided into 14 zones each approximately 0.5 km in length from south to north on the eastern coast of the Waiuku Estuary. The zones covered 8.5 km, extending from 300 m south of Ruakohua Stream outlet to the rocky point off 381 Glenbrook Beach Road. The coastal vegetation communities within each zone are mapped in Figure 5.1 to Figure 5.14, illustrating the extent of the communities, based on the Google Earth image dated 11 September 2020, and described below. The species lists of the vegetation are presented in Appendix 3.

5.3.1 Zone 1 South of Ruakohua Stream Outlet to The Needles

The terrestrial vegetation immediately south of the Ruakohua Stream outlet is mainly pasture with occasional gorse, woolly nightshade and large mature radiata pines. North of the stream outlet occasional patches of karaka with early successional native shrubs, flax, mahoe, māpou, mingimingi, hangehange, ponga, cabbage tree, were present.

At MHWS, small patches of salt marsh, mainly sea primrose with some selliera and native celery, are occasionally present, with a narrow band of rushes, oioi, on the south face curve of the embayment. The majority of the embayment is clear of mangroves except for a band, averaging 5 m wide, which extended immediately north and south of the stream outlet. The mangroves are mature, up to 4 m tall.

Two freshwater wetland habitats are present, the larger one in the south (W1) is dominated by raupo, with flax, before transitioning to an oioi dominated rush marsh (Photo 1).

Photo 1 ***Wetland 1 area with raupo and flax transitioning to oioi in the upper intertidal. Coastal cliff vegetation pasture with mature pines.***

Photo 2 Native coastal vegetation backed by pines, transitioning to mangroves.

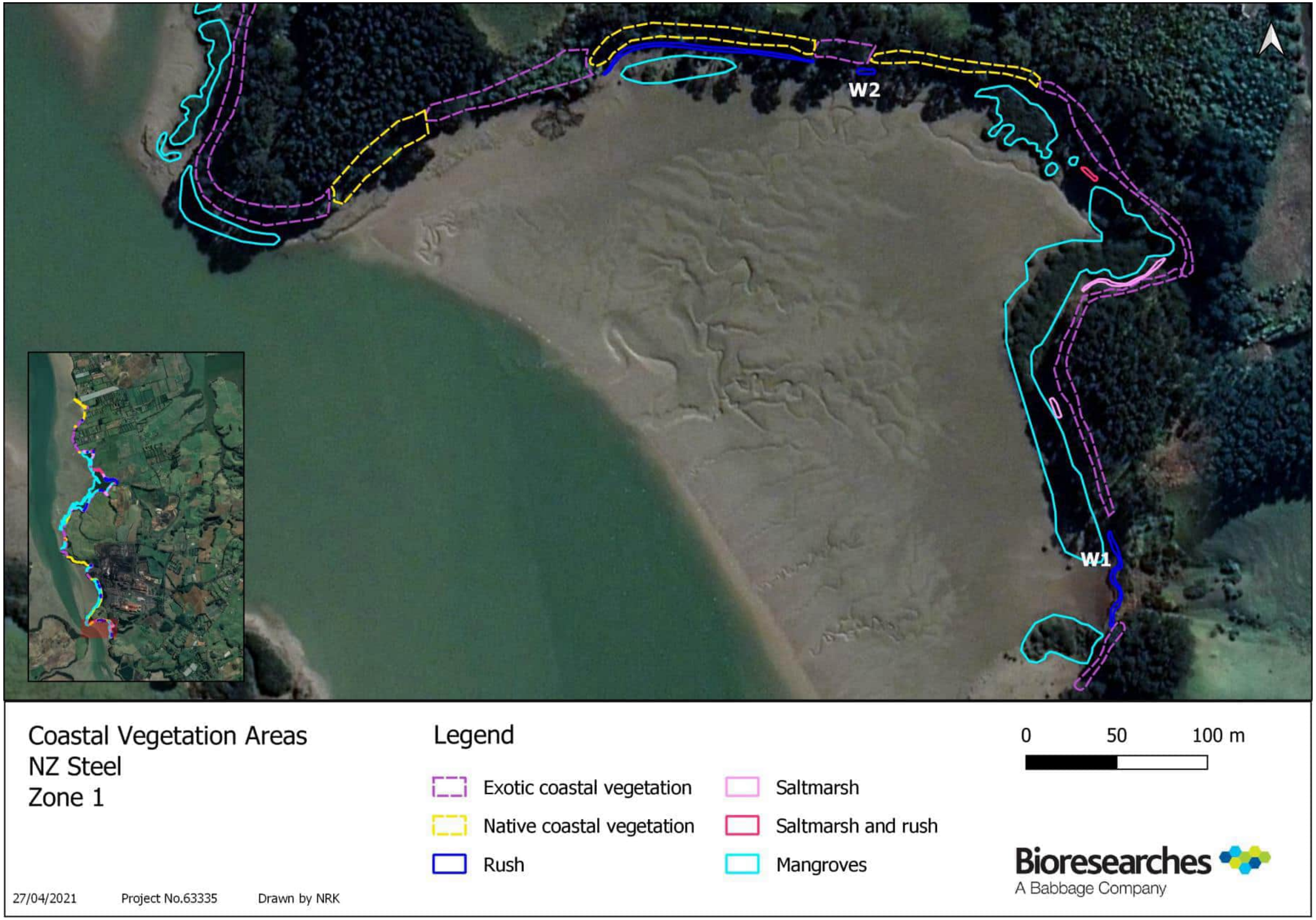

Figure 5.1 Zone 1 South of Ruakohua Stream Outlet to The Needles

5.3.2 Zone 2 The Needles to North of Southside Outfall

The terrestrial coastal vegetation from north of The Needles to north of the Southside Outfall is predominantly pasture with a line of regularly spaced pōhutukawa (Photo 3), with occasional areas of gorse, privet and exotic vegetation. Aside from a few areas of mangroves near The Needles the intertidal coastal vegetation is negligible (Photo 4).

Photo 3 Line of pōhutukawa backed by pasture.

Photo 4 Intertidal north of The Needles.

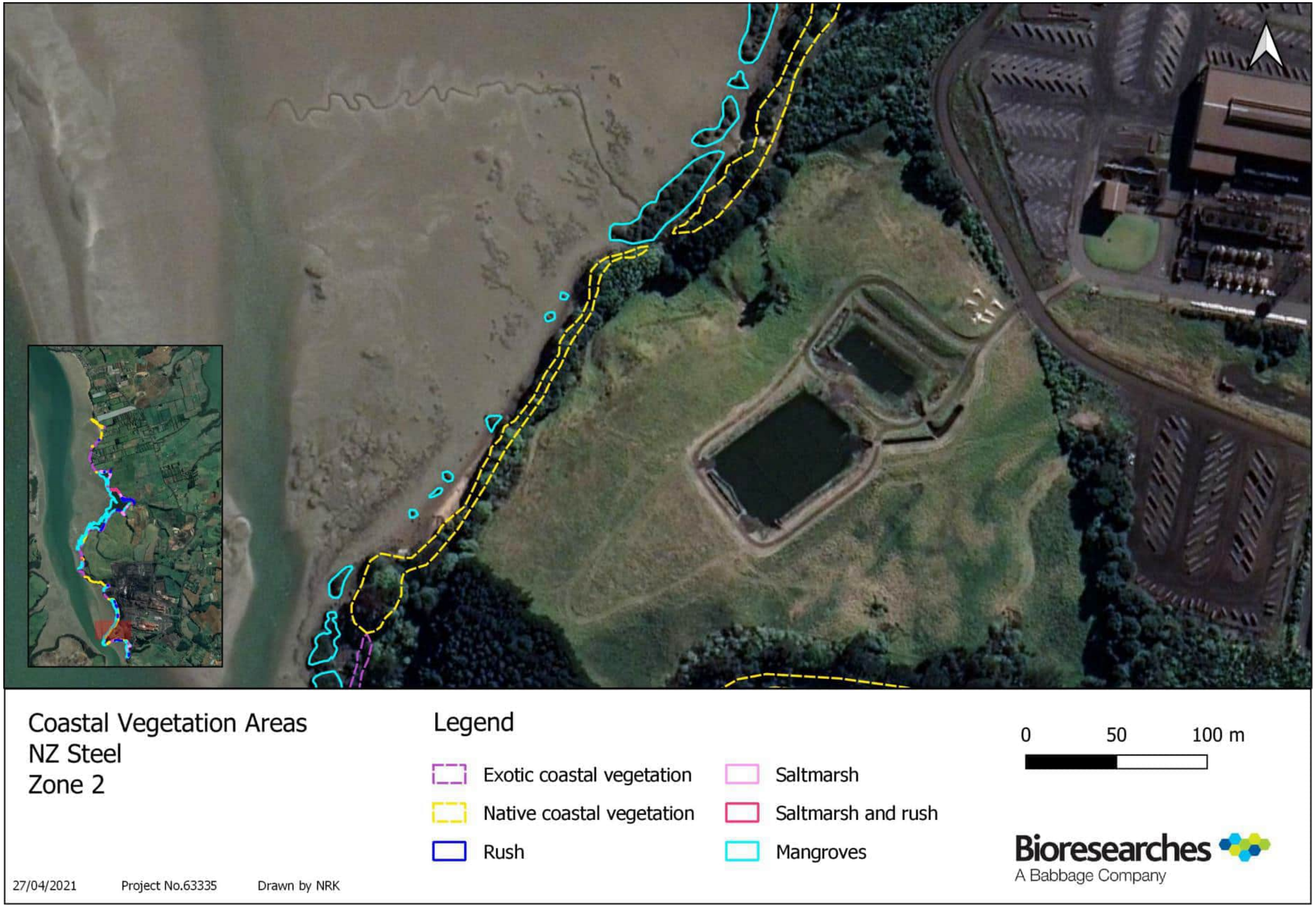

Figure 5.2 Zone 2 The Needles to North of Southside Outfall

5.3.3 Zone 3 Mill Site Between Southside Outfall and Northside Outfall

Between the Southside and Northside Outfalls, a narrow band of native vegetation, associated with exotic weed species, is present on the cliff face, backed by an extensive area of pines. The native vegetation is comprised of pōhutukawa, flax, mahoe, kawakawa and *Coprosma* species, with sections of pine, toetoe, gorse and privet (Photo 5).

Photo 5 Native vegetation backed by pines, grading into a band of oioi in upper intertidal.

The intertidal vegetation is comprised of intermittent bands of oioi at MHWS. A freshwater marsh (W3) is present in the northern part of Zone 3. The marsh transitioned from the pines, through flax to raupo and marsh club-rush to oioi and bare intertidal flats (Photo 6).

Photo 6 Bands of raupo – marsh club rush – oioi at W3.

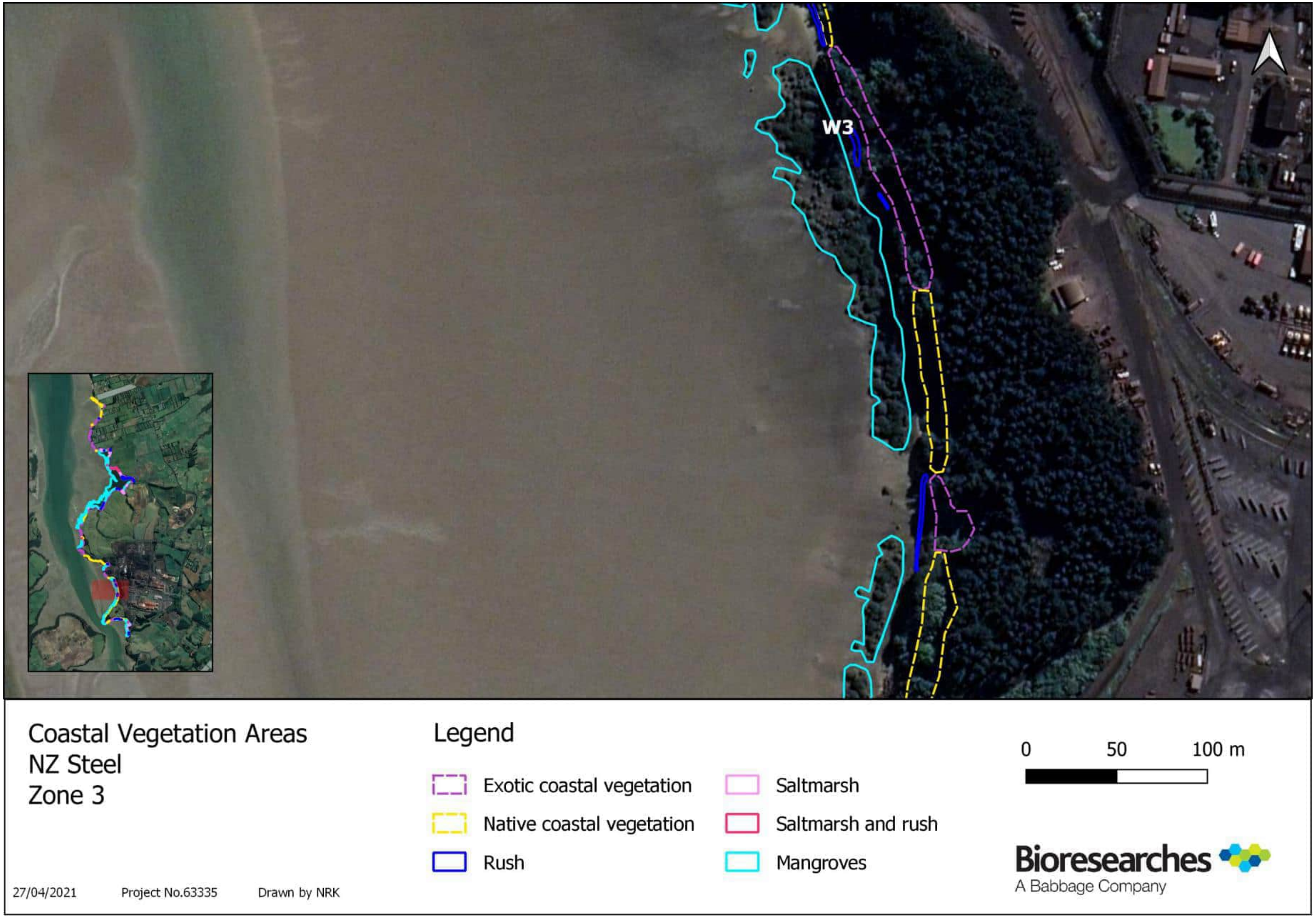

Figure 5.3 Zone 3 Steel Mill Site between Southside Outfall and Northside Outfall

5.3.4 Zone 4 Steel Mill Site Including Northside Outfall

Towards the southern end of the headland (Photo 7) the terrestrial vegetation is comprised of pōhutukawa overhanging the intertidal area. Immediately north of the point to the Northside Outfall the vegetation is comprised of exotic pines, macrocarpa and radiata pine, with areas of pampas where the pines are not present. The intertidal vegetation is depauperate, prior to the area surrounding the outfall (Photo 8).

In the embayment around the outfall mangroves are present in the mid to upper intertidal, where they formed a band following the line of the intertidal channel before transitioning to rush marsh and herbaceous salt marsh habitat. The vegetation comprising the rush marsh and salt marsh habitat surrounding the outfall and outlet is estuarine in the upper intertidal and does not fall within the definition of a "river or connected area" under the Resource Management (National Environment Standards for Freshwater) Regulations 2020 (NES-F). It showed a high species diversity, with oioi, sea rush, flax, marsh club rush, sea primrose, native celery (Photo 9), remuremu, slender club rush (*Isolepis cernua* var. *cernua*) and glasswort (*Sarcocornia quinqueflora*).

North of the outfall the cliff edge vegetation is comprised of early successional native species, mahoe, flax, rangiora, kawakawa with gorse and pampas. No intertidal vegetation is present.

Photo 7 Point north of Southside outfall.

Photo 8 Exotic pines and lack of intertidal vegetation between outfalls.

Photo 9 Native sea celery and sea primrose herbaceous salt marsh.

Figure 5.4 Zone 4 Steel Mill Site Including Northside Outfall

5.3.5 Zone 5 North of Northside Outfall to Okohaka Point

North of the Northside Outfall the coastal vegetation continued for approximately 500m in a thin band, before changing to exotic pines and pasture approximately 200m from Okohaka Point. Aside from the red algae *Gracilaria*, no intertidal vegetation is present (Photo 10).

Photo 10 **Coastal vegetation in Zone 5, north to Okohaka Point. Native coastal scrub, backed by pines with no salt-marsh or rush-marsh habitat.**

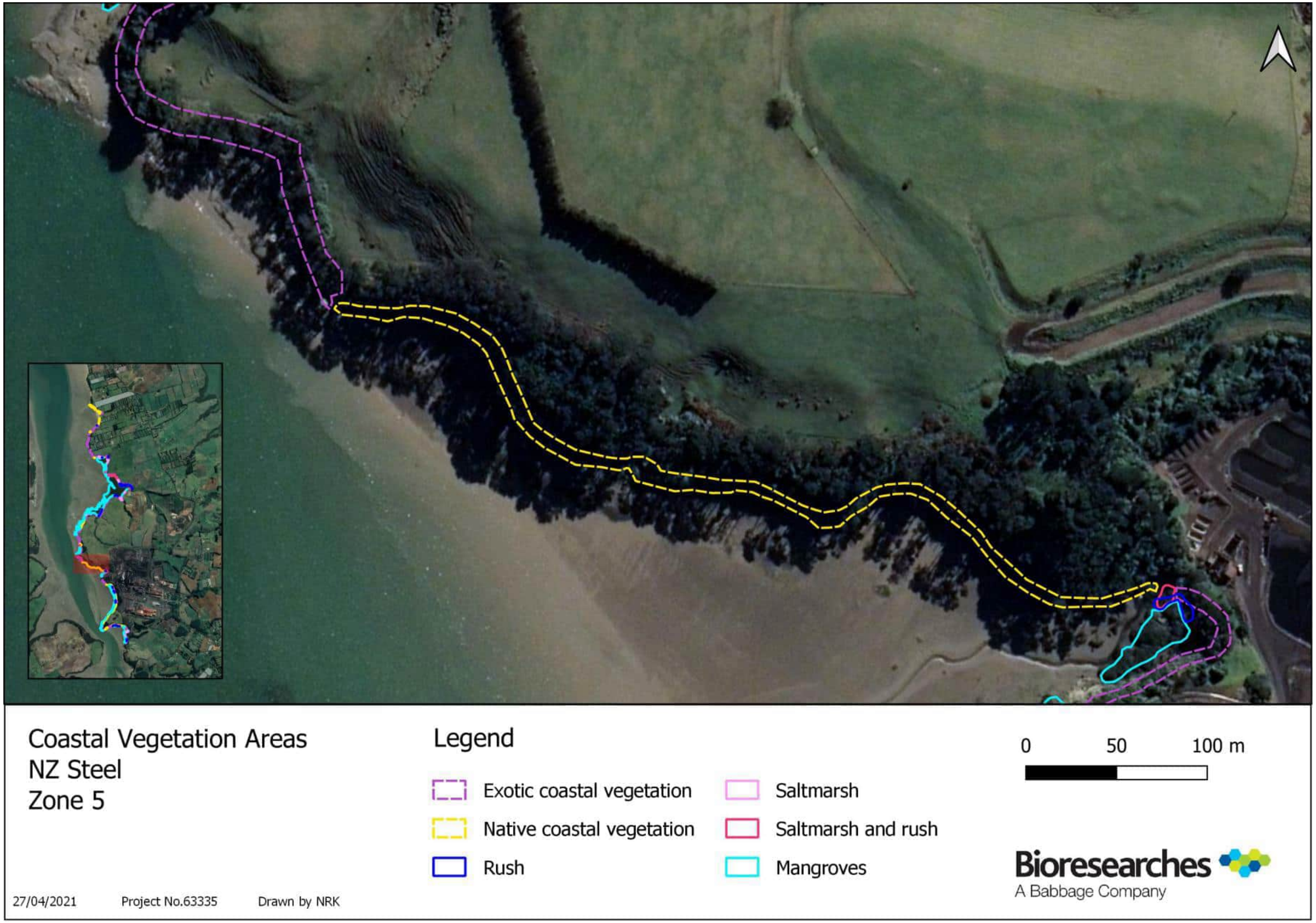

Figure 5.5 Zone 5 North of Northside Outfall to Okohaka Point

5.3.6 Zone 6 Okohaka Point North

North of Okohaka Point the terrestrial coastal vegetation is comprised of pasture with a block of pines and occasional small areas of native coastal vegetation (Photo 11). Two areas of mangroves are present, in one area growing directly against the base of the coastal cliff. With the exception of an elevated ledge with oioi, sea primrose and bastard grass (backed by a patch of native shrubs) (Photo 12) there is no intertidal coastal vegetation.

Photo 11 Coastal vegetation north of Okohaka Point, pines and gorse, no intertidal vegetation.

Photo 12 Elevated ledge with oioi, sea primrose, and bastard grass, backed by native shrubs.

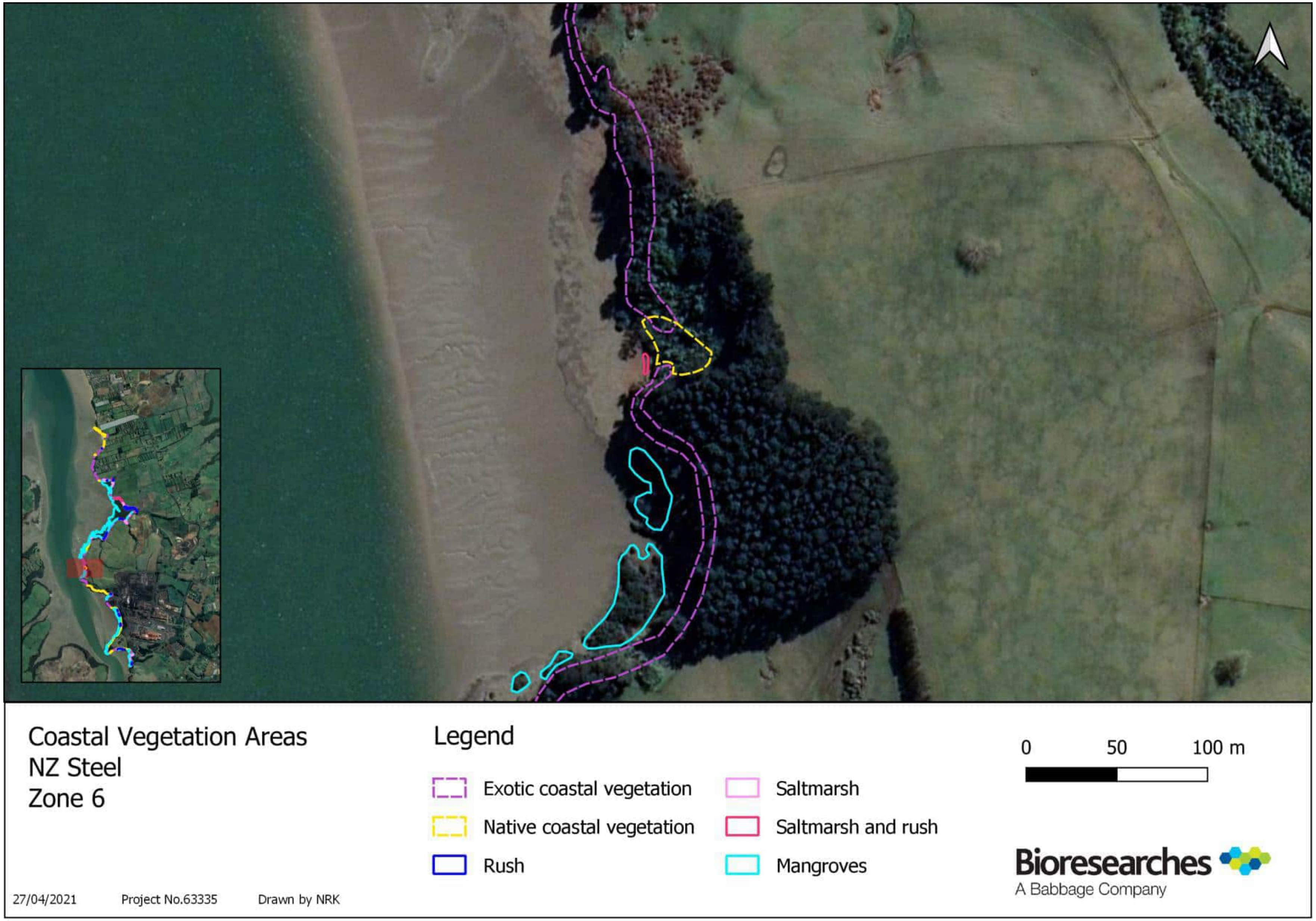

Figure 5.6 Zone 6 Okohaka Point North

5.3.7 Zone 7 Higgins Road South

The flat coastal area west of Higgins Road is pasture, with a thin band of either pines or native shrubs, māpou, flax, kawakawa, directly adjacent to the coast (Photo 13). The intertidal vegetation is sparse with occasional mangroves and occasional small, mostly isolated patches rushes or saltmarsh.

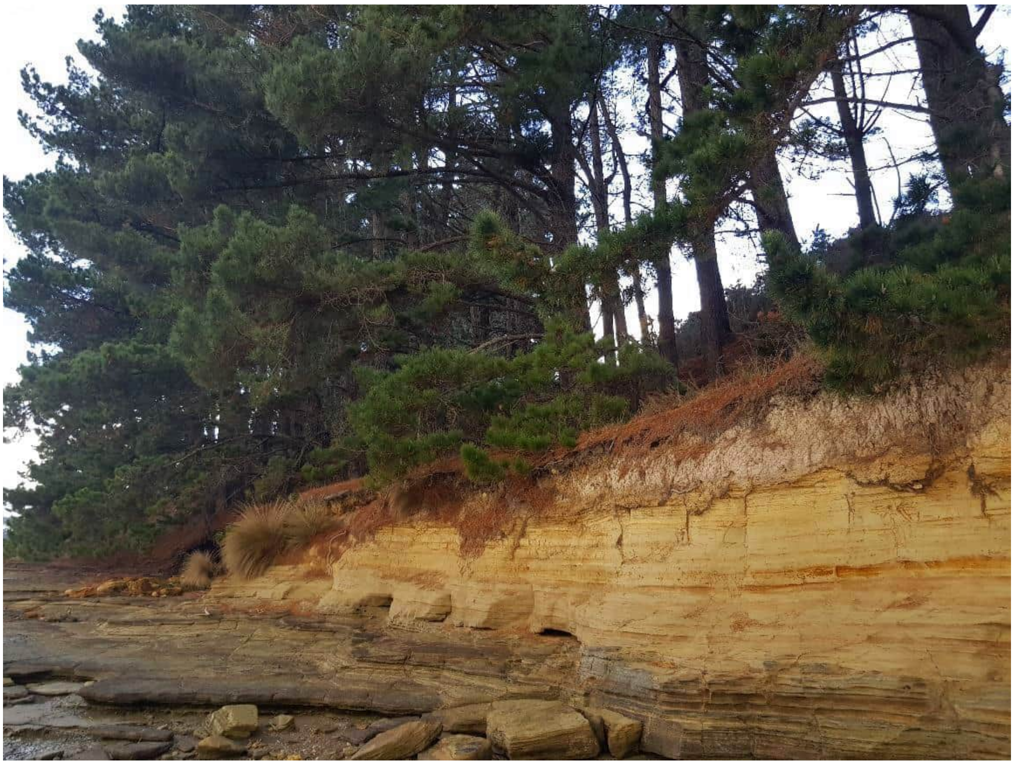

Photo 13 Pines backed by pasture on coastal cliffs, no intertidal vegetation.

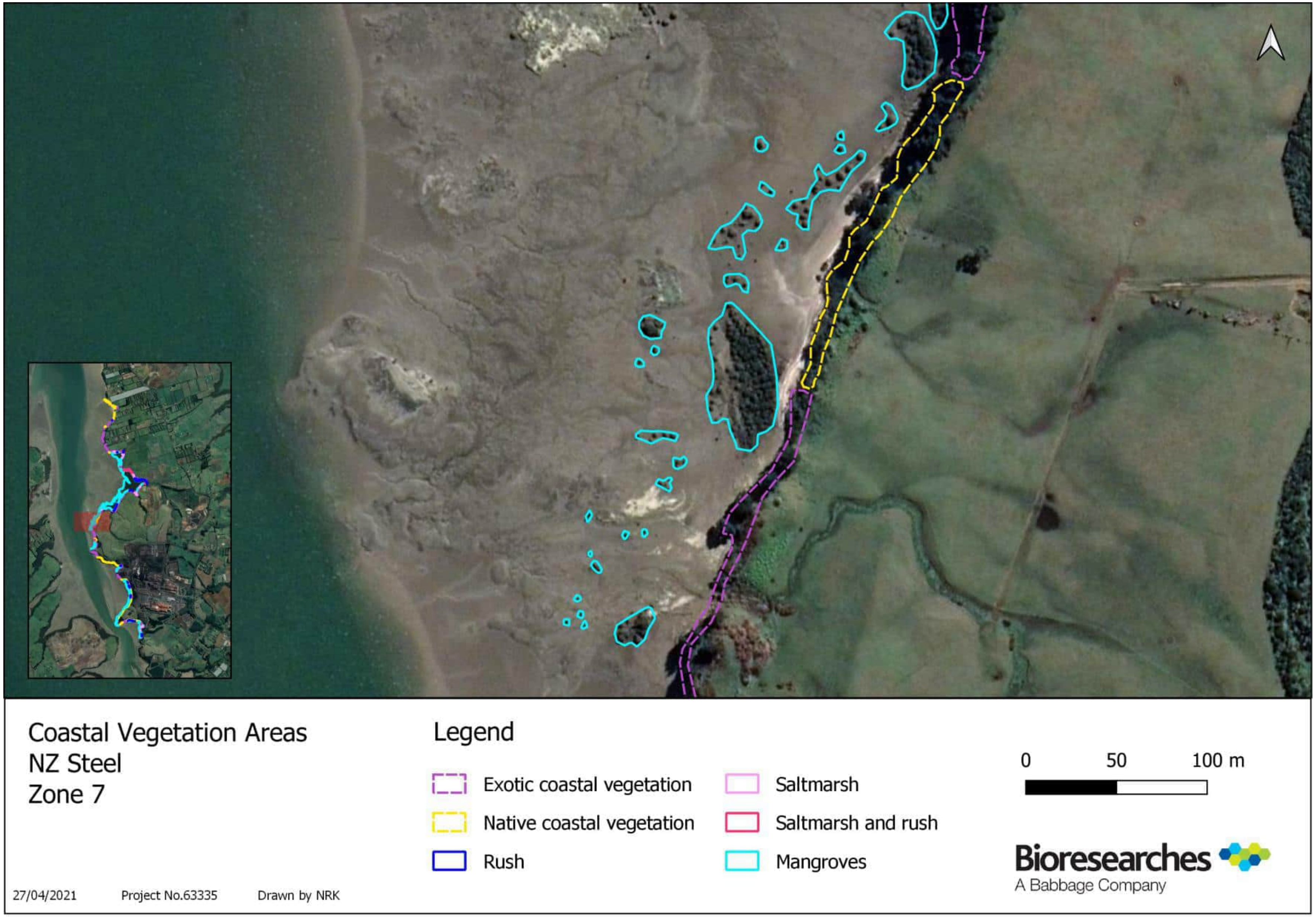

Figure 5.7 Zone 7 Higgins Road South

5.3.8 Zone 8 Higgins Road North

North of Higgins Road the pasture with a thin band of pines comprised the coastal edge vegetation. Mangroves formed a dense patch within an incised embayment and continued in patches northwards (Photo 14). On the western bank of the embayment the mangroves grew hard against the cliff edge, with an unusual tall but slender growth form. The native jointed rush oioi formed an extensive linear band from the base of the embayment northwards for approximately 200 m. At the base of the embayment a small stream discharged to the intertidal forming a brackish wetland (W4). The wetland comprised a mix of coastal vegetation and freshwater with marsh club-rush (Photo 15), mangroves, oioi (Photo 16), sea rush, sea primrose, remuremu, native celery and slender club rush near the outlet. North of where the band of oioi finished, aside from occasional mangroves, the intertidal vegetation is negligible.

Photo 14 Slender growth form of mangroves in the upper intertidal at the base of the cliff.

Photo 15 Marsh club-rush dominated wetland (W4).

Photo 16 Oioi band north of W4 embayment.

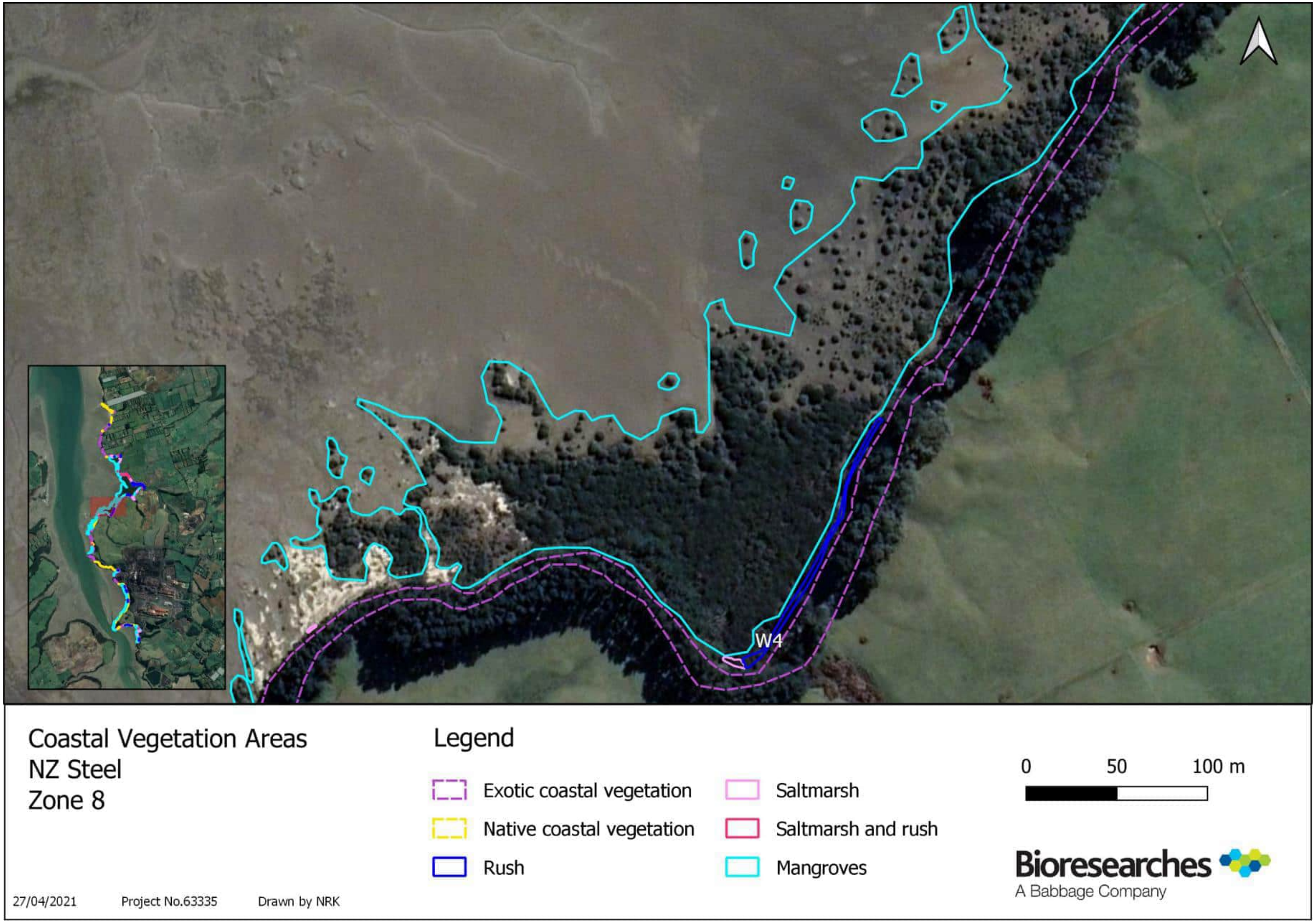

Figure 5.8 Zone 8 Higgins Road North

5.3.9 Zone 9 Brookside Road – Glenbrook Road Catchment Estuary

The catchment north of Brookside Road and west of Glenbrook Road drained via two watercourses into a large embayment. The northern and lager watercourse is North Stream while the southern water course is small and unnamed between Kahawai and North Streams. The embayment formed a monoculture of mangroves, covering an area of approximately 11 hectares. The coastal edge vegetation is pasture (or agriculture) with pines.

At and below the MHWS level, both the south face and north face of the embayment supported an extensive band of oioi dominated sea rush habitat with large areas of salt marsh habitat dominated by glasswort in the south and sea primrose in the north. The northern band of sea rushes was over 20 m wide in places and transitioned to the land from oioi dominated habitat, through areas of salt-marsh ribbon-wood to occasional patches of pampas, flax and gorse (Photo 17).

The southern stream transition formed a diverse habitat with freshwater habitat, mangroves, rush marsh and extensive herbaceous salt marsh meadows separated by drainage channels. In the upper freshwater to saltwater transition area the estuarine slender club rush dominated the meadows, whereas further seaward sea primrose dominated.

The northern freshwater – saltwater interface is a clear 60 m long demarcation line between a monoculture of the exotic pest plant reed sweet-grass and the mangrove habitat (Photo 18, Photo 19), which then transitioned to the extensive rush marsh habitat in the northern embayment (Photo 20).

Photo 17 Salt marsh meadow with sea primrose, native sea celery, remuremu, slender club rush.

Photo 18 Reed sweet-grass monoculture.

Photo 19 Reed sweet-grass and mangrove interface.

Photo 20 Start of northern rush marsh band.

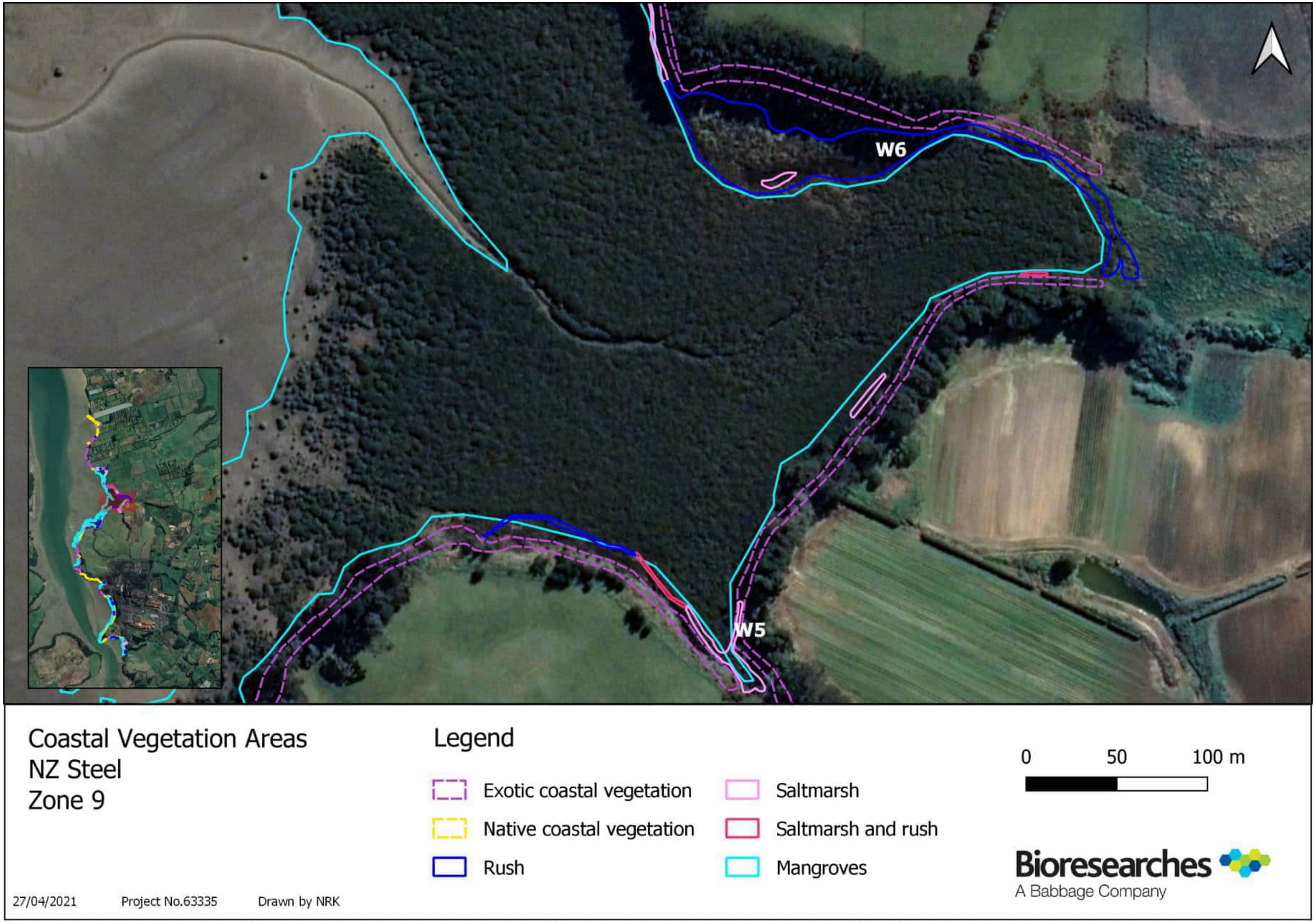

Figure 5.9 Zone 9 Brookside Road – Glenbrook Beach Road Catchment Estuary