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# Microplastic contamination in Te Tai Tokerau-Northland (Aotearoa-New Zealand) beach sediments

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# Report information sheet

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# Executive summary

## The problem

This study aims to identify and quantify microplastics from sand sediments across the Northland region of New Zealand. This region is framed by the Pacific Ocean and the Tasman Sea and known for its famous beaches among surfers and beachgoers. This report characterises the microplastic distribution within this region.

## This project

This study falls under the umbrella of *Aotearoa Impacts and Mitigation of Microplastics* (AIM$^2$) with the purpose of investigating microplastics in the New Zealand environment and the implications for ecosystems. The national research programme is composed of three research objectives: (1) understanding the distribution of microplastics in NZ environments, (2) identifying associated risks and impacts to animals, people, and ecosystems, and (3) identifying solutions ranging microbial mitigation of existing pollution, to prevention of new pollution through outreach and education. This endeavour falls within the first research objective of the program.

## Key results

This project aims to characterise and quantify microplastic distribution in sand sediments from the Northland region across 9 open coastal sites, one dune lake and one estuary site. Microplastic contamination was further investigated under varied beach location (north/south), coast side (east/west), and season (summer/winter). The mean large microplastic particle (LMPP) abundance in Northland sand sediments was 3 MP/kg DW (dry weight) (equivalent to 229 particles/m$^2$ and 4587 particles/m$^3$). Results showed that there was a varying degree of particle abundance in different Northland sites. Microplastic abundance varies among locations within the beach and freshwater sites. Higher microplastic concentrations were seen in beach sites like Mangawhai and Sandy Bay, while lower concentrations were obtained from a lake and an estuary site like Taharoa and Onerahi, respectively. Statistical analysis confirmed significant differences in mean particle abundance based on site using one-way ANOVA. Moreover, in comparison to the microplastic concentration of the Auckland beaches (6 MP/kg DW or 459 particles/m$^2$) investigated by Bridson et al., (2020), the overall mean particle concentration of Northland sites (3 MP/kg DW or 229 particles/m$^2$) was found to be significantly lower compared to that of the Auckland beaches. Three (3) large particle morphologies were distinguished from the samples, with fibres forming the majority of the particles (51%), followed by fragments (36%), and then by films (13%). Characterisation identified the presence of common polymers, polyethylene (PE) polypropylene (PP), and polyethylene terephthalate (PET), in these sand sediments. A significant portion of cellulose and regenerative cellulose (C&RC) was evident as well.

Further analysis showed that the overall abundance of small microplastic particles (SMPP) observed during winter was lower with an average of 405 MP/kg DW, ranging from 0-6044 MP/kg DW compared to the particles seen during summer with an average of 1417 MP/kg DW, ranging from 0-9062 MP/kg DW. However, statistics shows that the difference between the two seasons is not significant ($p=0.065$) based on a 95% confidence level. Analysis of SMMPs also revealed that 82% of particles were ≤25 µm and were predominantly polyethylene and polypropylene.

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# Introduction

Humans have been heavily reliant on plastics since their mass production at the beginning of the 1950s. Hundreds of millions of tonnes of plastics are produced every year and only a small proportion of it is recycled. Most of the plastics are disposed of to landfill, however some end up in the ocean. It has been reported that in 2016, up to 23 million metric tons of plastics are floating in the world's oceans [1,2].

According to the U.S. National Oceanic and Atmospheric Administration (NOAA) and the European Chemicals Agency (ECHA), microplastics are miniscule plastics measuring less than 5 mm in length. They are found in various forms such as nurdles, fibres, fragments, and films. These microparticles are globally recognised as contaminants in marine and terrestrial environments. Microplastic can be classified as either primary, where the particles are industrially designed for commercial use (e.g. plastic nurdles used for plastic manufacturing and glitter), or secondary, where the small pieces of particles were formed through various weathering processes resulting in the fragmentation of larger plastic items or pieces. Microplastics have been identified as derived from plastics of different origins and compositions such as polyethylene (PE), polypropylene (PP), polystyrene (PS), polyester (PET), polyamide (PA), cellulose acetate (CA), and poly(vinyl chloride) (PVC) [3,4]. Microplastics are insoluble in water, nondegradable, and possess various physicochemical properties (size, shape, buoyancy, chemical composition) that determine their bioavailability and ecotoxicity to organisms [5-7]. The following sources have been identified as dominant in releasing microplastics into the environment: abrasion of car tyres, synthetic textiles, litter, marine coatings, road markings, personal care products and plastic pellets [1-6].

Plastic marine debris continuously degrades in the environment, subsequently creating smaller fragments due to weathering factors such as UV radiation (sun), physical and biological degradation. An increasing number of studies have reported the ingestion of these microplastics by a variety of marine organisms across all trophic levels such as birds, marine mammals, fish, and invertebrates [3, 7]. When ingested, the microplastics can remain in the digestive tract and form clumps that can hinder the passage of food and block the digestive system. It can also give a false sense of satiation thus leading to starvation. The release of additives (e.g. plasticisers) and ambient pollutants from the plastics can cause harmful effects by affecting the hormonal and reproductive system, damaging the gastrointestinal tract, causing delayed growth, genotoxicity and in some cases death [8-11]. Microplastics can also act as a carrier for dispersal of chemicals and biota such as invasive species and pathogens thereby potentially endangering marine biodiversity [12]. While there have been many studies reported on the effects of microplastics on marine life the impacts and mechanisms involved are still not fully understood [19-23]. Even less is known about the potential human health effects, with this area of research even more in its infancy, although preliminary findings suggest that life wildlife, there are deleterious effects [24].

Microplastics either sink or float in the marine environment depending on their density. Positively buoyant polymers, such as polypropylene and polyethylene, generally float in seawater as their densities are less than that of seawater. However, factors such as biofouling can cause a usually buoyant polymer to become heavy and accumulate in the sediment or sink to the bottom of the ocean [12]. This manifestation is evident in a recent study reporting microplastic presence in sediments from beaches [9, 13] and freshwater sources [27] of New Zealand. Other studies that investigated the microplastic distribution in New Zealand include the discovery of plastics in a third of turtles and birds found washed up on the shore dead [14], and the sighting of a plastic patch larger than Greenland, which was believed to have originated from New Zealand by a group of researchers looking at the microplastic abundance in the South Pacific [15].

The primary sources of microplastics have been linked to marine and domestic land-based activities (e.g. laundry discharges) [32], and industries including production and waste management. It is widely known that the ocean is considered as a sink for microplastics. However, the marine environment is not always the final fate of microplastics since some studies proved that microplastics can become resuspended into the atmosphere from the sea surface. Therefore, resulting in the continuous cycling between terrestrial and aquatic systems [39,40].

This study aims to contribute to the understanding of the microplastic distribution in Aotearoa New Zealand's beach ecosystems. Specifically, this intends to create baseline data for the Te Tai Tokerau - Northland region coastline and freshwater sites.

# Materials and methods

### *Sampling sites*

Sand sediment samples were supplied to Scion by Northland Regional Council (NRC) via courier. Upon arrival at Scion the samples were immediately stored at -20 °C until required for analysis. Details of the sampling coordinates are provided in Appendix A. The 11 locations sampled for microplastics encompassed the east and west coast of the Te Tai Tokerau - Northland region (Fig.1). Information provided by NRC for each location is provided in Appendix B.


**Figure 1**. *Map of the Northland locations sampled for microplastic analysis*.

### *Sample collection*

The samples were collected during the summer period: November 2019- February 2020 and winter period: August-September 2020. All locations were sampled on an out-going tide to ensure that there was plenty of beach area to sample from. Depending on the size of the beach at least three to four transects (spacing between each transect 50 m) were sampled. A 10 m transect was laid along the last high tide mark (Figure 2a). One metre either side of the transect was marked out and the 2 x 10 m area was divided into a grid consisting of eighty (80) half-metre quadrants (0.5 x 0.5 m) (Figure 2b). The number randomisation function in Excel was used to choose five quadrats from each transect for sampling (see Figures 2a and 2b). These quadrants represented replicates for each transect.


**Figure 2a**. *Example of a transect along the beach*

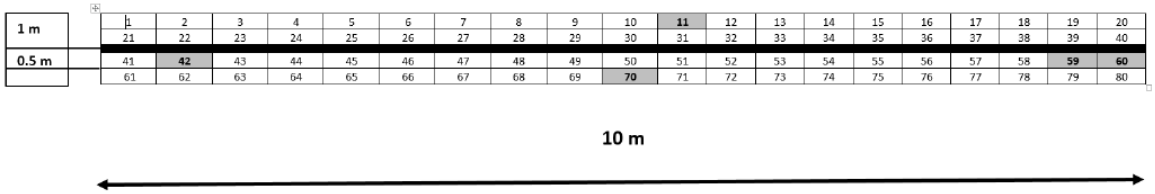


**Figure 2b**. *Transect (centre thick line) and the 80x0.5m$^2$ quadrants.*

Within each of the 5 quadrants, 5 sand cores were taken (from each corner and the centre of the quadrant) with steel corers (5 x 5 cm) to a depth of 5 cm. The 5 cores of sand were combined in a pre-rinsed aluminium tray and sealed with the foil-lined paper lid and wrapped in aluminium foil.

## *Quality Control*

To minimise the risk of any possible contamination during field sampling, the staff wore natural fibres and minimised the use of plastics where possible. Moreover, the staff positioned downwind during sample collection to avoid cross contamination of fibres from clothes shedding. During separation process in the laboratory, all glassware and equipment were rinsed first with tap water then twice with ultra-pure water (distilled water which had passed through a 0.45 µm filter). All washed vessels were covered with aluminium foil when not in use. A cotton laboratory coat was worn during the handling of the sediment and analysis of samples. The use of plastic apparatus was minimised as much as possible. All samples were processed in a controlled room with minimal foot traffic.

Procedural blanks were used throughout the isolation process to assess any potential cross-contamination. An analysis using a procedural blank showed an average of 5 MPs per sample. Analysis showed the presence of microplastics identified as polytetrafluoroethylene (PTFE) and blue polypropylene (PP) fragments. During the investigation, it was found out that the sodium iodide salt from LOBA-ACS reagent, which was used at the end of the peroxidation step was, in fact, contaminated with microplastics identified as PTFE and blue PP. The LOBA chemical was used

only in the summer samples and its use was discontinued thereafter. Due to a substantial amount of procedural blank contamination, the PTFE films and distinct blue PP fragments were excluded from the quantitative analysis of beach sediments. The results expressed in Figure 3 were calculated with the omission of PTFE contaminants and the distinct blue PP in affected samples.

Environmental blanks were collected to monitor for the presence of airborne plastic contamination inside the laboratory. Three (3) blank filter membranes in glass petri dishes were placed on the lab work bench and inside the fume hood. Inspection showed no microplastic in the blanks which indicates a low risk of environment contamination.

## *Separation of microplastics*

The large microplastic particles (LMPP 300 µm - 5 mm) were separated from the sediment following the NOAA protocol [16], using sodium iodide solution as the flotation media. The separation process involved a series of steps which are detailed below.

*Extraction*
Wet sediments in the trays was dried in an oven set at 70 °C. The dried sediment (400 g) was weighed into an 800 mL beaker and 300 mL of sodium iodide solution (5.3 mol/L (797 g NaI per 1 L water); $\rho$ = 1.6 g/mL) was added to it. The mixture was stirred for 10 minutes using a glass rod and allowed to stand for 1 hour after which the floating matter was decanted onto a cascade of 300 µm and 32 µm sieves. The collected matter on the 300 µm sieve was washed into a pre-weighed 600 mL beaker and dried at 70 °C overnight. Any large non-plastic material was thoroughly washed with ultra-pure water before discarding to ensure no microplastic was accidentally lost. The material collected on the 32 µm sieve was washed into a pre-weighed jar and dried at 70 °C overnight. Both fractions were later processed separately and in a slightly different manner. From here on the microplastic collected on the 300 µm sieve are referred to as large microplastic particles (LMPP) and the microplastic collected on the 32 µm sieve are referred to as small microplastic particles (SMPP).

*Wet Peroxidation*

LMPP
The wet peroxidation step was included to digest any remaining organic matter. Iron sulphate (20 mL, 0.05 mol/L, Sigma-Aldrich) and 20 mL of hydrogen peroxide (30%, Merck) solutions were added to the 600 mL beaker containing the dried matter. The mixture was left to stand for 5 minutes during which it bubbled and frothed. The beaker was placed in a water bath at 75 °C and shaken for 30 mins and an additional aliquot of 20 mL hydrogen peroxide added if any organic matter was still visible. This step was repeated until no organic matter was evident. Sodium iodide (Merck, LABO and ECP, ACS reagent) was added to the mixture (15 g NaI per 20 mL of the solution) to increase the density of the solution. The mixtures were heated and shaken in a 75 °C water bath until most of the salt dissolved. The samples were then cooled to room temperature in preparation for the density separation.

SMPP
Ten (10) mL each of iron sulphate solution (0.05 mol/L, Sigma-Aldrich) and hydrogen peroxide solution (30%, Merck) were added to the 600 mL beaker containing the dried matter. The mixture was left to stand for 5 minutes during which time it bubbled and frothed. The beaker was placed in a water bath at 75°C and shaken for 30 mins, and an additional aliquot of 10 mL hydrogen peroxide was added if any organic matter was still visible. The addition of hydrogen peroxide aliquot was repeated until no organic matter was evident. Sodium iodide (ECP, ACS reagent) was added to the mixture (15 g NaI per 20 mL of solution) to increase the density of the solution. The mixture was heated and shaken in the water bath until all the salt had dissolved. The samples were then cooled to room temperature in preparation for density separation.

*Density separation*

LMPP
The room temperature peroxidation was allowed to cool before being transferred to a density separator. To ensure that all microplastics were transferred to the density separator the beaker was

thoroughly rinsed with NaI solution (5 mol/L). The funnels were covered with foil and left to settle overnight at room temperature. The settled matter was discarded, and the remaining solution was filtered through a PCTE filter membrane (Whatman Track-Etched Polycarbonate Membrane, 4.7 cm, 10 µm). The inner wall of the beaker was thoroughly rinsed with Milli-Q-water to ensure complete transfer of microplastics and the surface of the filter membrane was washed thoroughly to ensure complete dissolution of the NaI crystals. The filter membrane were transferred to a labelled glass petri dish and stored in a cool dark place until required for the quantification and analysis step.

SMPP

The same procedure used for LMPP for the transfer of the peroxidised solution and the density separator to rinsing using NaI solution (5 mol/L) was followed for the SMPP mixture. After overnight sedimentation, the settled matter was discarded, and the remaining solution was collected in a pre-washed and pre-weighed capped glass vial (25 mL). Using a dropping pipette, a few drops of the well mixed solution were transferred onto an aluminium oxide filter membrane (Whatman Anodisc, 25 mm, 0.2 µm). The inner wall of the beaker was thoroughly rinsed with ultra-pure water to ensure complete transfer of microplastics and the surface of the filter was washed thoroughly to ensure complete dissolution of the NaI crystals. The weight of the solution transferred onto the membrane was recorded. The filter membrane was transferred to a labelled petri dish and stored in a cool dark place until required for the quantification and analysis steps.

### *Identification, quantification and analysis of microplastics*

LMPP

The collected matter on the filter membranes was examined under a Zeiss Stemi Dv4 stereo microscope with 8-32x magnification to identify potential LMPPs. Plastic particle selection was performed according to previously published guidelines [41], specifically: size <5 mm, absence of cellular or organic structures, fibres of equal thickness throughout entire length, particles of clear and homogenous colour throughout. Fourier Transform Infrared (FTIR) Spectroscopy (Bruker Tensor 27) with attenuated total reflectance (Bruker, single bounce diamond cell) was used for the identification and quantification of the LMPP. All particles were selected for analysis by FTIR spectroscopy. Spectra were processed using the Bruker OPUS software, using the rubberband baseline correction algorithm. The spectra were searched against BioRad KnowItAll library databases for polymers, coatings and fibres using the Euclidean distance algorithm. Using an approach adapted from Kroon et al. (2018), database hits of >70% were positively identified as microplastics, while database hits of <70% were reviewed by an experienced spectroscopist to confirm the identity of the particle. [42]

SMPP

Analysis of SMPPs was performed using a Bruker Hyperion 3000 FTIR-microscope equipped with a 64 x 64 focal plane array (FPA) detector. SMPPs were quantified using the automated approach of Primpke *et al*., (2017). The anodisc membrane was placed between two 25 x 2 mm $CaF_2$ windows and mounted on the microscope stage. A visual image of the samples was collected using the 4x vis objective, followed by FTIR imaging using the 15x cassegrain objective in transmission. Data collection was performed using OPUS version 8.2.28 (Bruker Optics GmbH) software with 4 x 4 binning at a resolution of 8 $cm^{-1}$ with 6 co-added scans. Spectra were manipulated using the OPUS cut, and baseline correction functions prior to data processing.

Data processing was performed using an offline computer running OPUS 7.2. Spectra were compared against a database of common plastic spectra using OPUS search function as previously described (Primpke *et al*., 2018). Image analysis was performed using Python and Simple ITK image processing modules as previously described. [15, 17, 18].

## *Validation*

LMPP

The validity of the method was evaluated using polymer-spiked sediment samples. Coloured polymers were used in the experiment for easy visual sorting during identification. The characteristics and properties of the three (3) polymers used in the spiking experiment are shown in Table 1. In the visual differentiation of microplastics and confirmation of particle count, a low magnification microscope was used. Positive controls were prepared by spiking clean sediments with thirty (30) particles of each polymer type. The negative controls (blank), on the other hand, were devoid of polymers. All experiments were prepared by two analysts and performed in triplicate. Samples were processed following the LMPP quantification described in the methods above; after which the percent recovery of the polymers was determined.

**Table 1**. *Properties of microplastics used in the LMPP validation.*

| Analysis | Polymer type | Size range (µm) | Colour | Morphology | Density ($g/cm^3$) |
|---|---|---|---|---|---|
| LMPP | Polystyrene | 500-1000 | Purple | Fragment | 1.05 |
| | Polyamide | 500-1000 | Green | Fragment | 1.15 |
| | Polypropylene | 500-1000 | Pink | Fragment | 0.92 |
| SMPP | Polyethylene | 38-45 | Orange | Sphere | 0.96 |
| | Polyamide | 30-100 | Green | Fragment | 1.15 |
| | Polystyrene | 100-300 | Purple | Fragment | 1.05 |

SMPP

The validation of instrumental parameters was conducted to determine the rate of detection by the analysis method described above for SMPP. Ten (10) particles of each polymer (refer to Table 1) were applied to a small area of an anodisc filter using a low magnification microscope. This procedure was repeated to make triplicates. The negative controls (blank), on the other hand, were prepared similarly but with no added polymer.

# Results and discussion

### *Validation results*

LMPP

During validation, a chemical change was observed on the polymers, polyamide and polypropylene, after the peroxidation step. FTIR analysis confirmed that the discoloration is a result of oxidation attributed to the presence of an -OH stretch signal evident at the 3400 $cm^{-1}$ band. The number of microplastic particles was recorded through visual inspection, taking note of the altered colours and the identified chemical nature using FTIR-ATR. A high overall recovery (95%) of the spiked polymers was achieved (Table 2).

**Table 2.** *Results of Validation Experiment for LMPP.*

| Polymer type | Analyst | Recovered amount per replicate | | | Average (n=3) recovery (%) |
|---|---|---|---|---|---|
| | | 1 | 2 | 3 | |
| Polystyrene | 1 | 28 | 27 | 29 | 95 |
| | 2 | 28 | 28 | 30 | |
| Polyamide | 1 | 27 | 29 | 27 | 92 |
| | 2 | 27 | 28 | 28 | |
| Polypropylene | 1 | 30 | 27 | 29 | 98 |
| | 2 | 30 | 30 | 30 | |
| ***Overall recovery*** | | | | | ***95%*** |

SMPP

Validation shows a high rate of success, at 96%, in the detection of artificially spiked microplastic fragments through FTIR-FPA (Table 3). This translates to high reliability of particle counting and identification of the instrument.

**Table 3.** *Results of instrumental parameter validation for SMPP.*

| Polymer type | replicate no. | No. of fragments spiked | No. of spiked successfully identified | Average (n=3) recovery (%) |
|---|---|---|---|---|
| Polyethylene | 1 | 10 | 30 | 100 |
| | 2 | 10 | | |
| | 3 | 10 | | |
| Polyamide | 1 | 10 | 26 | 87 |
| | 2 | 6 | | |
| | 3 | 10 | | |
| Polystyrene | 1 | 10 | 30 | 100 |
| | 2 | 10 | | |
| | 3 | 10 | | |
| ***Success rate*** | | | | **96%** |

## LARGE MICROPLASTIC PARTICLE ANALYSIS

### *Microplastic abundance*

The abundance of microparticles at different sites of the Northland region is expressed in three (3) different units (MP /kg DW, MP/m2, and MP/m3) to be consistent with the literature (see Appendix C). Table 4 summarizes the abundance in terms of MP/kg DW. Concentrations were computed from the average of 3, 5 or 6 replicates of summer samples and 3 replicates of all winter samples. Percent (%) abundance for each type of polymer at each location is also represented graphically in Figure 3.

**Table 4**. *LMPP abundance expressed as MP / kg DW for Northland summer samples*.

| Site Name | Zone | Abundance (MP/kg DW) | |
|---|---|---|---|
| | | *Summer* | *Winter* |
| Ahipara North | West | 1 ± 1 | 6 ± 6 |
| Ahipara South | West | *nd* | 4 ± 5 |
| Waipapakauri North | West | 3 ± 3 | 3 ± 4 |
| Waipapakauri South | West | 5 ± 4 | 2 ± 0 |
| Glinks Gully North | West | 2 ± 1 | 2 ± 4 |
| Glinks Gully South | West | 5 ± 6 | *nd* |
| Omamari North | West | 3 ± 1 | 3 ± 4 |
| Omamari South | West | 7 ± 11 | 2 ± 0 |
| Paihia North | East | 1 ± 2[a] | 6 ± 1 |
| Paihia South | East | -- | 3 ± 1 |
| Rarawa North | East | 2 ± 2 | 2 ± 2 |
| Rarawa South | East | 2 ± 3 | 2 ± 2 |
| Sandy North | East | 8 ± 10 | 9 ± 6 |
| Sandy South | East | 7 ± 4 | 2 ± 1 |
| Waipu North | East | 1 ± 1 | 12 ± 7 |
| Waipu South | East | *nd* | 3 ± 1 |
| Mangawhai North | East | 7 ± 4 | 7 ± 4 |
| Mangawhai South | East | 3 ± 1 | 10 ± 2 |
| Onerahi (North) | Estuary site | *nd* | 1 ± 1 |
| Onerahi (South) | Estuary site | *nd* | 1 ± 1 |
| Taharoa North | Dune lake | 1 ± 1 | *nd* |
| Taharoa South | Dune lake | 1 ± 1 | 1 ± 1 |

[a]*Average value for North and South*
*n.d- none detected*

Results showed that there was a varying degree of LMPP particle abundance in different Northland sites (Table 4). Microplastic abundances vary between locations within the beach, estuary and freshwater sites. High microplastic concentrations were seen in beach sites like Mangawhai and Sandy Bay, while lower concentrations were obtained from a lake and an estuary site like Taharoa and Onerahi, respectively. Statistical analysis confirmed significant differences in mean particle abundance based on site using one-way ANOVA (see Appendix D-1).

On the basis of season, particle abundance during summer and winter ranged from 0-8 MP/kg DW and 0-12 MP/kg DW, respectively. These quantified to a mean abundance of LMPP of 3 MP/kg DW (188 MP/$m^2$) during summer and 4 MP/kg DW (270 MP/$m^2$) for winter (see Appendix C). No significant difference in particle abundance was seen, however, between summer and winter samples (Appendix D-2A) and on the east and west side of the coast (Appendix D-2B) at a 95% confidence level.

In comparison to the microplastic concentration of Auckland beaches (6 MP/kg DW or 459 particles/m$^2$) investigated by Bridson et al., (2020), the overall mean particle concentration of Northland sites (3 MP/kg DW or 229 MP/m$^2$) was found to be significantly lower compared to that of Auckland beaches (Appendix D-2D). It should be noted, that the flotation media used for the Auckland study was of lower density (ρ = 1.2 g/L) compared to that used in this study (ρ = 1.6 g/L), as such abundance values from the Northland study should if anything be bias towards higher values than reported by Bridson et al., 2020. The lower abundances observed in the Northland region correlate with the lower population density of the region compared to Auckland. In addition, the relative abundance of microplastics between the east and west coasts was different for the Auckland (west coast > east coast) and Northland (east coast > west coast) regions. (see Appendix D - 2E & 2F). This observation suggests that much of the microplastic debris on the Auckland west coast has originated from local sources, rather than from the more populous regions of East Australia and south east Asia carried by the East Australian current, as hypothesised by Bridson et al., 2020 [7].

***Polymer composition***

In the characterisation of the particles, polyethylene (PE) was seen in the majority of the analysed sediment samples in both seasons. Polypropylene particles (PP) followed next as the most dominant polymer type while PET and PS were identified in relatively lower quantities. This order of relative mass compositions (PE>PP>PS) conforms to the characteristics of the plastics generated globally and those that are captured from the water and benthic environments seen previously in similar studies [35]. Negligible levels of PVC were observed, although this study used a high-density floatation solution suitable for the recovery of PVC. While PVC is produced and used widely (4th highest production polymer) [37], its negative buoyance likely limits transport and distribution in aquatic environments, settling and depositing into sediment rapidly, rather than being transported to beach environments.

Although the exact sources of the contamination remain unknown, identified polymers are commonly associated with outdoor, recreational, personal and industrial use. PP and PS, for example, are commonly used in outdoor gear and disposable food containers and utensils. PE is used in a variety of household and industrial applications, while PET is used in common fabrics.

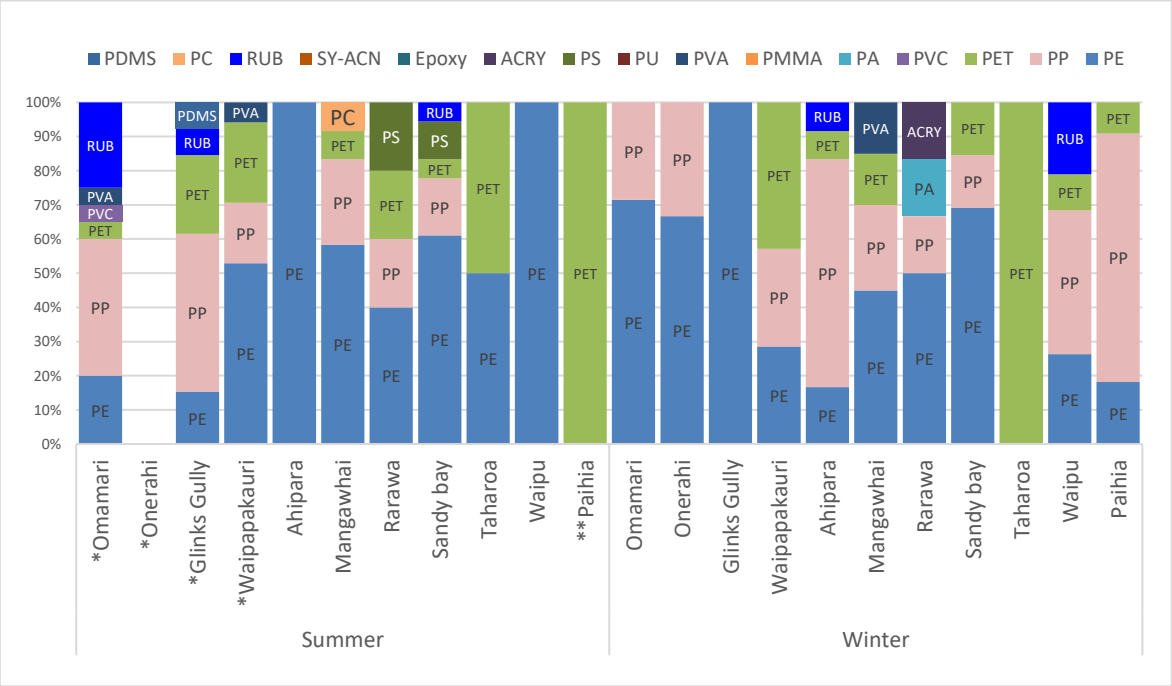


**Figure 3.** Relative abundance (%) of polymer type of *LMPPs identified at the sampling sites in summer and winter. An average of 3 samples were conducted for each site, unless indicated where 5* or 6** were done.*
*Polymer type:* Polymers: RUB = Rubber; PVA = Polyvinyl acetate; PP = Polypropylene; PE = Polyethylene; PET = Polyethylene terephthalate; PVC = Polyvinyl chloride; PA = Polyamide; PC = Polycarbonate; PS = Polystyrene; PDMS = Polydimethylsiloxane; ACRY = Acrylic

Accounting for other particle presence, significant portions of cellulose and regenerative cellulose (C & RC) in the form of fibre, were evident during analysis (see Figure 4). Cellulose fibres are unlikely to be harmful to the environment, but the associated dyes may pose a risk [33]. Based on the result of this study, the fibres identified as cellulose and regenerated cellulose were 93% colourless and the remaining 7% contained black, red, blue and green pigments. Hence, in this study, particles composed of C&RC were not considered as microplastics and were omitted from the overall calculation.

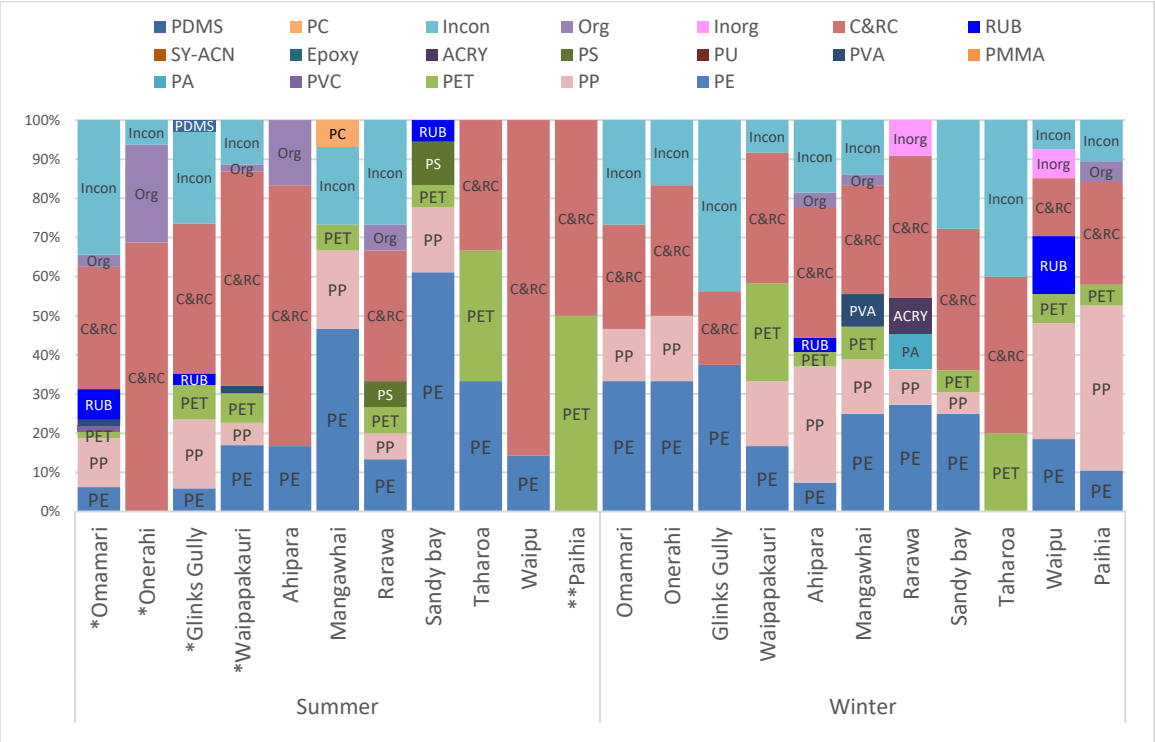


**Figure 4**. *LMPP (%) for various polymer types including non-microplastic particles (C&RC, Organic, Inorganic and Inconclusive) at the various sampling locations.*

### *Morphological features*

In terms of morphology, three (3) microplastic morphologies were distinguished: film, fibre, and fragment. Fibre was the most prevalent morph and a large proportion was attributed to the presence of C & RC particles in both summer and winter. Fragments were identified as PE was predominantly present in summer, while both PP and PE were prevalent in winter. Moreover, PE was also the predominant polymer in the form of film observed in summer and winter. These findings were consistent with previous reports [7].

**Table 5.** *Characteristics of large microplastics across the variables of shape and polymer type for all sites.*
*[1] including rubber*

| Variable | Category | Percentage | |
|---|---|---|---|
| | | *Summer* | *Winter* |
| **Morphology** | Film | 5 | 23 |
| | Fibre | 61 | 39 |
| | Fragment | 34 | 38 |
| **Polymer type** | PE | 16 | 20 |
| | PP | 10 | 18 |
| | PET | 6 | 6 |
| | PS | 1 | - |
| | Other[1] | 5 | 5 |
| | C&RC | 39 | 29 |

## SMALL MICROPLASTIC PARTICLE ANALYSIS

A subset of the locations was analysed for SMPP, based on the highest and lowest number of total particles in the eastern and western beach sites in the region: Omamari, Taharoa, Onehari, and Mangawhai sites.

The mean abundance of SMPP across the four sites (911 MP/kg DW) was significantly higher *(p=0)* than for LMPP (3 MP/kg DW). This highlights the limitations of commonly used visual identification and quantification methods and the importance of identifying smaller (<300 µm) particles for understanding the extent of microplastic pollution in the environment.

Across these four sites, the mean abundance of SMPP was lower in winter (average of 405 MP/kg DW, ranging from 0-6044 MP/kg DW) compared to summer (average of 1417 MP/kg DW, ranging from 0-9062 MP/kg DW). However, statistical analysis demonstrated that the difference between the two seasons is not significant (*p=0.065*) based on a 95% confidence level, as similarly observed for LMPP.

**Table 6**. *SMPP abundance result for selected Northland summer and winter samples expressed as MP/kg DW.*

| *Site* | *Season* | *Polymer excl rubber[1]* | *Total rubber[2]* | *Total all polymers* |
|---|---|---|---|---|
| *Omamari* | Summer | 339 ± 483 | *nd* | 339 ± 483 |
| | Winter | 65 ± 117 | 19 ± 46 | 84 ± 114 |
| *Taharoa* | Summer | 871 ± 1576 | 27 ± 66 | 898 ± 1569 |
| | Winter | 279 ± 430 | 110 ± 147 | 389 ± 524 |
| *Onerahi* | Summer | 1162 ± 1293 | 45 ± 75 | 1207 ± 1366 |
| | Winter | 231 ± 305 | 60 ± 105 | 291 ± 311 |
| *Mangawhai* | Summer | 3297 ± 3695 | 126 ± 308 | 3423 ± 3936 |
| | Winter | 1043 ± 2450 | *nd* | 1043 ± 2450 |

*[1] All identified plastics (excluding rubber)*
*[2] Mostly ethylene–propylene–diene rubber*
*nd - none detected*

Polyethylene was predominant at all sites at both seasons except for Lake Taharoa during winter. The types of polymers found from the analysis of SMPP are consistent with that of the LMPP. Smaller particles were likely derived from the physical and chemical degradation of large microplastic particles in the environment. However, it should be noted that fragmentation of LMPP can occur during sample processing. Meanwhile, some polymer types were exclusively seen in significant proportions based on the result of SMPP analysis. For example, Lake Taharoa (summer), a popular coastal highway for vehicle users was found to have a relatively high fraction of polychloroprene (neoprene), while Mangawhai (summer) and Omamari (summer) were both seen with high proportions of polyamide, none of which were detected in the LMPP analysis.

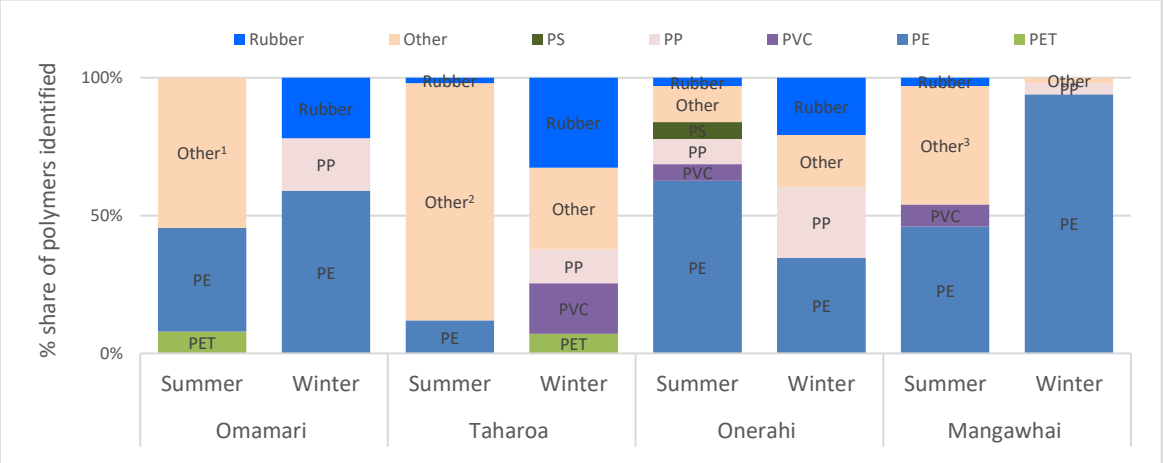


***Figure 5.*** *Proportion (%) of polymer types identified at selected sampling sites from SMPP analysis.*
Polymer type: PP = Polypropylene; PE = Polyethylene; PET = Polyethylene terephthalate; PVC = Polyvinyl chloride; PA = Other1 mostly polyamide, Other2- mostly polychloroprene, Other3- polyamide and Acrylic.

Furthermore, SMPP analysis revealed that particle size of ≤25 µm accounted for 82% of the small microplastics. Figure 6 below shows that all particles from Omamari Winter and Taharoa Summer fell within the size range with 225-300 µm particles only evident in the Taharoa winter samples.

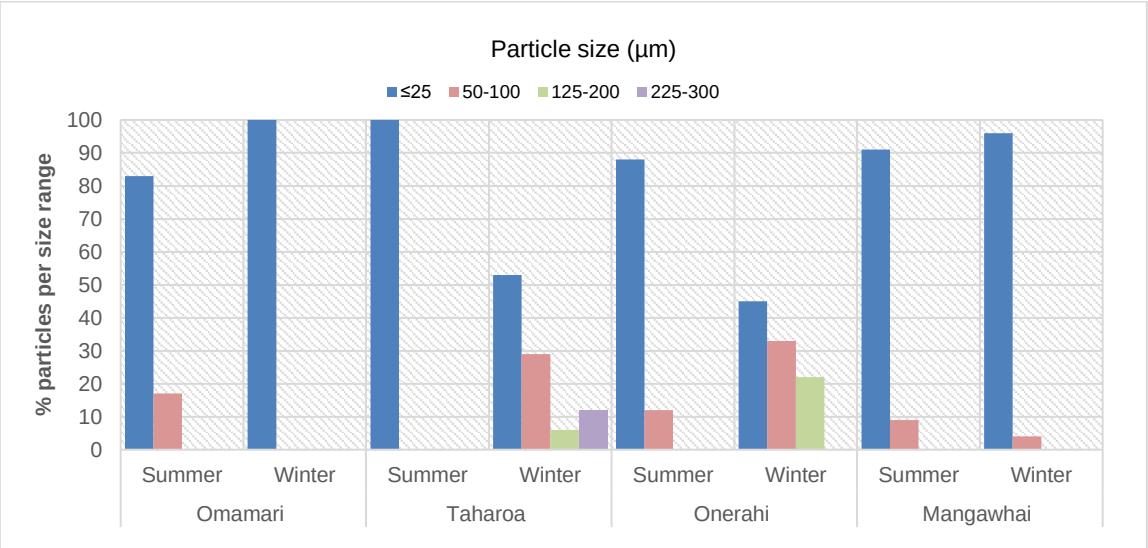


**Figure 6.** *Size distribution of SMPPs identified in sand samples from four sites in summer and winter.*

**MICROPLASTICS TRANSPORT MECHANISM**

Data suggests that contamination of large microplastics (LMPP) in all Northland sites were evident except for the samples from Onerahi, an estuary site known as downstream of the stormwater and wastewater treatment plant (WWTP) in Whangarei. This was surprising given the abundance of microplastic debris observed at this site during sampling. However, sand samples from this site were high in organic debris which made it difficult to digest via peroxidation. It was acknowledged that the abundance of microplastics in Onerahi was likely underestimated due to the obstructing organic matter during scanning. This inference is supported by the small particle analysis confirming the presence of microplastics with an overall mean abundance of 1293 MP/kg DW during summer and 231 MP/kg DW during winter. Comparing the SMPP result of Onerahi to the rest of the selected sites during summer, its abundance was relatively high with a variety of polymers identified. Potential sources of the contamination were possibly from runoff and/or from the WWTP effluent.

Also noteworthy is the higher number of microplastics in the samples from Ahipara beach from summer (1 MP/kg DW) to winter (6 MP/kg DW) which can be explained by the heavy rain event before the sampling during winter. It is likely that microplastics were deposited from the nearby creek during the heavy rain.

Lake Taharoa has a relatively low number of large microplastics in both summer and winter. The microplastics found on the lake's shore are composed of 90% fibres attributed to cellulose/regenerated cellulose, polyester, and polyethylene. The remaining 10% were disregarded due to uncertain characteristics. Lake Taharoa has no known natural inlets or outlets and it is believed that 70% of its water is sourced from rainfall [34]. The sources of microplastics in the freshwater lake remain unknown but it is likely that the recreational activities on the lake contributed to the deposition rate.

Moreover, overall data revealed the presence of large particle fibres in 91% of the samples (in both seasons), with an overwhelming fraction (69%) found during summer. Fibres are of concern due to their ability to cycle between the marine environment and atmosphere. Significant portions of cellulose and regenerated cellulose and polyester were commonly seen. The composition is consistent with the quantities used in textiles and common fabrics for clothing. Clothes are known to shed significant amounts of microfibers during normal wear and are directly released into the atmosphere [32], hence this explains that potential emissions from tourists and beachgoers especially during summer possibly contributed to the contamination.

# Conclusion

This study revealed that large and small microplastic particles were ubiquitous in the coastal and freshwater sites of the Te Tai Tokerau-Northland region of New Zealand. Microplastics were found to have consistent polymer characteristics, and were predominantly PP, PE, and PS, which are commonly associated with outdoor, recreational, personal and industrial use. Fibres were the predominant particle morphology observed in sample taken during the summer, however the proportion of fibres was similar to fragments in winter samples. In addition, SMPP were significantly *(p=0)* higher than LMPP, which are likely generated from the physical and chemical fragmentation of larger microplastics in the coastal environment.

Microplastic abundance did not significantly differ between seasons. Seasonal variations also had no significant effect on the type of polymers identified. Meanwhile, microplastic levels were seen to significantly vary across all sites. The east coast also generally had a higher LMPP count compared to the west. Potential contributors of the plastic contamination include marine and domestic land-based activities, water runoffs, airborne transport and atmospheric fallouts.

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Oliver Bone - Experiencing Marine Reserves

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# Appendix A

Sampling location coordinates

| | LATITUDE | LONGITUDE |
|---|---|---|
| OMAMARI NORTH | -35.8673477 | 173.662825 |
| OMAMARI SOUTH | -35.8723164 | 173.66753 |
| ONERAHI NORTH | -35.7666025 | 174.357334 |
| ONERAHI SOUTH | -35.7670962 | 174.35752 |
| PAIHIA NORTH | -35.2854109 | 174.094349 |
| PAIHIA SOUTH | -35.286821 | 174.096942 |
| RARAWA NORTH | -34.7175429 | 173.075975 |
| RARAWA SOUTH | -34.7200117 | 173.079188 |
| SANDY NORTH | -35.5572355 | 174.473246 |
| SANDY SOUTH | -35.5595612 | 174.47769 |
| TAHAROA NORTH | -35.8097499 | 173.661959 |
| TAHAROA SOUTH | -35.8113558 | 173.661773 |
| WAIPU NORTH | -36.0288554 | 174.505372 |
| WAIPU SOUTH | -36.0317037 | 174.508267 |
| WAIPAPAKAURI N | -35.0399015 | 173.16749 |
| WAIPAPAKAURI S | -35.0432365 | 173.168516 |
| GLINKS GULLY NORTH | -36.0820297 | 173.854919 |
| GLINKS GULLY SOUTH | -36.0905891 | 173.861943 |
| AHIPARA NORTH | -35.1570216 | 173.15765 |
| AHIPARA SOUTH | -35.1611912 | 173.15477 |
| MANGAWHAI NORTH | -36.0801013 | 174.596865 |
| MANGAWHAI SOUTH | -36.0828291 | 174.598486 |

# Appendix B

### Summary of locations provided by Northland regional Council

| Site name | Popular activities |
|---|---|
| **Ahipara WC** | High Seasonal recreational use (beach access for driving and surfing all year) (WAUC/DC) prevailing wind SW, W |
| **Waipapakauri WC** | High Seasonal recreational use (beach access for driving and shellfish collection all year) West Auckland Current/D'Urville Current (WAUC/DC) prevailing wind SW, W |
| **Glinks Gully WC** | High Seasonal recreational use (beach access for driving, fishing and shellfish collection) (WAUC/DC) prevailing wind SW, W |
| **Omamari WC** | High Seasonal recreational use (beach access for driving and fishing) (WAUC/DC) prevailing wind SW, W |
| **Lake Taharoa** | Dune Lake-very popular during summer, High recreational use-Lake, site on west facing shore adjacent to camping and lake access, prevailing wind SW, W |
| **Paihia EC** | Semi-suburban, High Rec Use year-round, busy tourist location (EAUC) prevailing wind E, NE |
| **Rarawa EC** | High Seasonal Recreational Use, East Auckland Current (EAUC), prevailing wind E, NE |
| **Sandy Bay EC** | High Recreational Use (year-round) popular and significant surf break (EAUC) prevailing wind E, NE |
| **Onerahi Upper Whangarei Harbour** | Suburban, adjacent to large vessel maintenance facilities and multiple Stormwater outlets, prevailing wind SW, W, E, NE |
| **Waipu Cove Bay EC** | High Rec Use (year-round) popular surf break (EAUC) busy Campground adjacent to sites, prevailing wind E, NE, SW |
| **Mangawhai EC** | High Rec Seasonal Use, popular surf break (EAUC) busy swimming/surfing beach, prevailing wind E, NE, SW |

*EC- East coast*
*WC- West coast*

# Appendix C

**Large microplastic particles: Mean Concentrations per Site (MP/kg DW, MP/$m^2$, MP/$m^3$)**

| Site Name | Zone | *Summer* | | | *Winter* | | |
|---|---|---|---|---|---|---|---|
| | | MP / kg DW | MP / $m^2$ | MP / $m^3$ | MP / kg DW | MP / $m^2$ | MP / $m^3$ |
| Ahipara North | West | 1 ± 1 | 56 ± 98 | 1127 ± 1951 | 6 ± 6 | 369 ± 385 | 7386 ± 7708 |
| Ahipara South | West | *nd* | *nd* | *nd* | 4 ± 5 | 295 ± 363 | 5904 ± 7254 |
| Waipapakauri North | West | 3 ± 3 | 256 ± 205 | 5119 ± 4095 | 3 ± 4 | 225 ± 255 | 4493 ± 5103 |
| Waipapakauri South | West | 5 ± 4 | 356 ± 251 | 7118 ± 5029 | 2 ± 0 | 171 ± 2 | 3418 ± 43 |
| Glinks Gully North | West | 2 ± 1 | 107 ± 98 | 2142 ± 1956 | 2 ± 4 | 182 ± 315 | 3641 ± 6307 |
| Glinks Gully South | West | 5 ± 6 | 203 ± 237 | 4057 ± 4730 | *nd* | *nd* | *nd* |
| Omamari North | West | 3 ± 1 | 217 ± 82 | 4344 ± 1642 | 3 ± 4 | 242 ± 276 | 4834 ± 5522 |
| Omamari South | West | 7 ± 11 | 501 ± 787 | 10029 ± 15744 | 2 ± 0 | 183 ± 6 | 3659 ± 126 |
| Paihia North/ South | East | 1 ± 2 | 88 ± 150 | 1770 ± 3003 | 6 ± 1 | 371 ± 107 | 7416 ± 2138 |
| Paihia North/ South | East | *nd* | *nd* | *nd* | 3 ± 1 | 217 ± 95 | 4332 ± 1896 |
| Rarawa North | East | 2 ± 2 | 182 ± 178 | 3644 ± 3557 | 2 ± 2 | 159 ± 152 | 3179 ± 3034 |
| Rarawa South | East | 2 ± 3 | 122 ± 211 | 2434 ± 4216 | 2 ± 2 | 174 ± 177 | 3485 ± 3534 |
| Sandy North | East | 8 ± 10 | 629 ± 762 | 12578 ± 15249 | 9 ± 6 | 697 ± 469 | 13939 ± 9379 |
| Sandy South | East | 7 ± 4 | 516 ± 312 | 10315 ± 6230 | 2 ± 1 | 235 ± 203 | 4692 ± 4063 |
| Waipu North | East | 1 ± 1 | 56 ± 98 | 1129 ± 1956 | 12 ± 7 | 814 ± 432 | 16285 ± 8646 |
| Waipu South | East | *nd* | nd | *nd* | 3 ± 1 | 213 ± 90 | 4251 ± 1798 |
| Mangawhai North | East | 7 ± 4 | 486 ± 275 | 9712 ± 5496 | 7 ± 4 | 530 ± 298 | 10605 ± 5952 |
| Mangawhai South | East | 3 ± 1 | 237 ± 102 | 4746 ± 2048 | 10 ± 2 | 686 ± 156 | 13715 ± 3112 |
| Onerahi (North) | East | *nd* | *nd* | *nd* | 1 ± 1 | 57 ± 100 | 1149 ± 1991 |
| Onerahi (South) | East | *nd* | *nd* | *nd* | 1 ± 1 | 60 ± 104 | 1197 ± 2073 |
| Taharoa North | West | 1 ± 1 | 68 ± 118 | 1365 ± 2364 | *nd* | *nd* | *nd* |
| Taharoa South | West | 1 ± 1 | 65 ± 112 | 1297 ± 2246 | 1 ± 1 | 66 ± 114 | 1319 ± 2285 |

*ND- none detected*

# Appendix D

## A. Statistical Results (LMPP)

### 1. ONE WAY ANOVA – NORTHLAND SITES

NORTH VS SOUTH

**One-way ANOVA: MP/kg DW versus Location**

#### Method

| | |
|---|---|
| Null hypothesis | All means are equal |
| Alternative hypothesis | Not all means are equal |
| Significance level | α = 0.05 |

*Equal variances were assumed for the analysis.*

#### Factor Information

| Factor | Levels | Values |
|---|---|---|
| Location | 11 | Ahipapara, Glinks, mangawhai, Omamari, Onerahi, Paihia, Rarawa, Sandy, Taharoa, Waipapakauri, Waipu |

#### Analysis of Variance

| Source | DF | Adj SS | Adj MS | F-Value | P-Value |
|---|---|---|---|---|---|
| Location | 10 | 538.8 | 53.88 | 3.29 | 0.001 |
| Error | 137 | 2240.7 | 16.36 | | |
| Total | 147 | 2779.4 | | | |

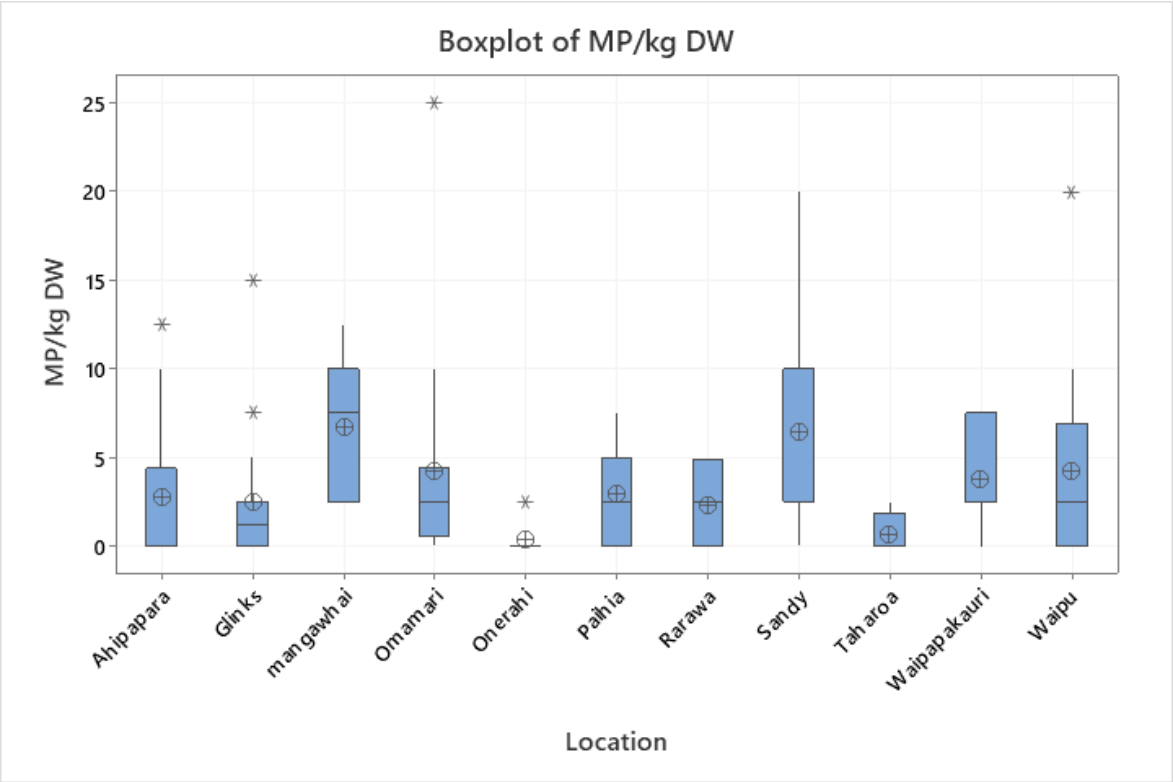
#### Model Summary

| S | R-sq | R-sq(adj) | R-sq(pred) |
|---|---|---|---|
| 4.04417 | 19.38% | 13.50% | 5.84% |

#### Means

| Location | N | Mean | StDev | 95% CI |
|---|---|---|---|---|
| Ahipapara | 12 | 2.71 | 4.32 | (0.40, 5.02) |
| Glinks | 16 | 2.499 | 3.975 | (0.500, 4.499) |
| mangawhai | 12 | 6.66 | 3.59 | (4.36, 8.97) |
| Omamari | 16 | 4.21 | 6.17 | (2.21, 6.21) |
| Onerahi | 16 | 0.312 | 0.854 | (-1.687, 2.312) |
| Paihia | 12 | 2.915 | 2.574 | (0.607, 5.224) |
| Rarawa | 12 | 2.253 | 2.204 | (-0.056, 4.561) |
| Sandy | 12 | 6.46 | 6.16 | (4.15, 8.77) |
| Taharoa | 12 | 0.625 | 1.130 | (-1.684, 2.933) |
| Waipapakauri | 16 | 3.749 | 2.886 | (1.750, 5.748) |
| Waipu | 12 | 4.17 | 5.96 | (1.86, 6.47) |

*Pooled StDev = 4.04417*


Boxplot of MP/kg DW
MP/kg DW
25
20
15
10
5
0
Ahipapara
Glinks
mangawhai
Omamari
Onerahi
Paihia
Rarawa
Sandy
Taharoa
Waipapakauri
Waipu
Location

## T-TEST COMPARISONS

### 2A. Summer vs Winter

#### Method

| | |
|---|---|
| Null hypothesis | All means are equal |
| Alternative hypothesis | Not all means are equal |
| Significance level | α = 0.05 |

*Equal variances were assumed for the analysis.*

#### Factor Information

| Factor | Levels | Values |
|---|---|---|
| Season | 2 | Summer, Winter |

#### Analysis of Variance

| Source | DF | Adj SS | Adj MS | F-Value | P-Value |
|---|---|---|---|---|---|
| Season | 1 | 37.61 | 37.61 | 2.00 | 0.159 |
| Error | 146 | 2741.83 | 18.78 | | |
| Total | 147 | 2779.43 | | | |

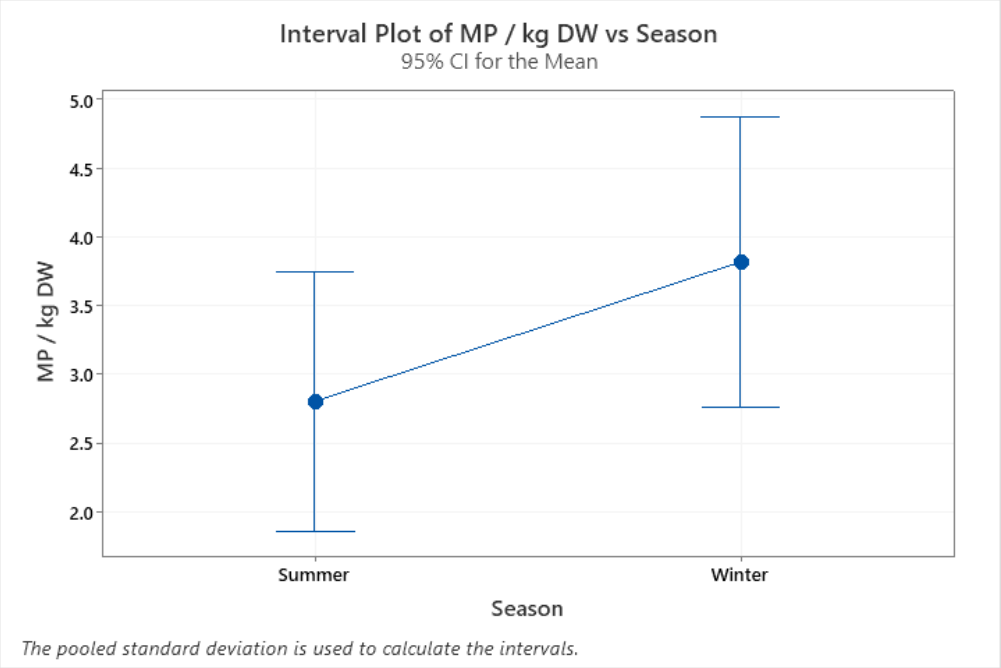
#### Model Summary

| S | R-sq | R-sq(adj) | R-sq(pred) |
|---|---|---|---|
| 4.33355 | 1.35% | 0.68% | 0.00% |

#### Means

| Season | N | Mean | StDev | 95% CI |
|---|---|---|---|---|
| Summer | 82 | 2.803 | 4.397 | (1.858, 3.749) |
| Winter | 66 | 3.817 | 4.253 | (2.763, 4.872) |

*Pooled StDev = 4.33355*




*The pooled standard deviation is used to calculate the intervals.*

## 2B. East vs West (excluding Taharoa and Onerahi)

### Method

| | |
|---|---|
| Null hypothesis | All means are equal |
| Alternative hypothesis | Not all means are equal |
| Significance level | α = 0.05 |

*Equal variances were assumed for the analysis.*

### Factor Information

| Factor | Levels | Values |
|---|---|---|
| Coast | 2 | East, West |

### Analysis of Variance

| Source | DF | Adj SS | Adj MS | F-Value | P-Value |
|---|---|---|---|---|---|
| Coast | 1 | 40.34 | 40.34 | 1.95 | 0.165 |
| Error | 118 | 2440.90 | 20.69 | | |
| Total | 119 | 2481.24 | | | |

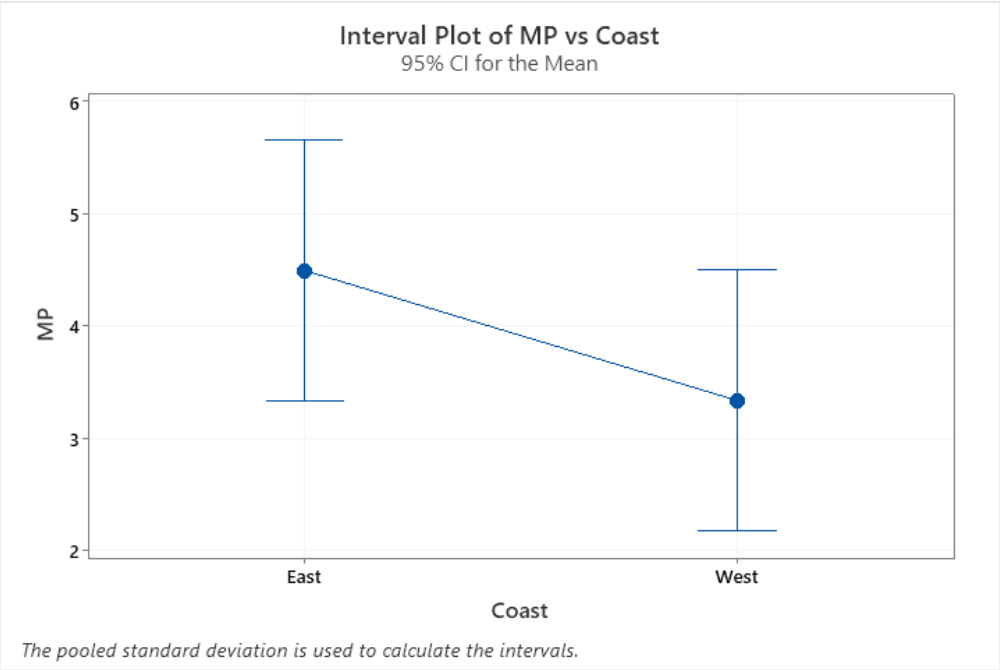
### Model Summary

| S | R-sq | R-sq(adj) | R-sq(pred) |
|---|---|---|---|
| 4.54814 | 1.63% | 0.79% | 0.00% |

### Means

| Coast | N | Mean | StDev | 95% CI |
|---|---|---|---|---|
| East | 60 | 4.491 | 4.642 | (3.328, 5.654) |
| West | 60 | 3.331 | 4.452 | (2.169, 4.494) |

*Pooled StDev = 4.54814*




## 2C. North vs South

## One-way ANOVA: MP/kg DW versus Site

### Method

| | |
|---|---|
| Null hypothesis | All means are equal |
| Alternative hypothesis | Not all means are equal |
| Significance level | α = 0.05 |
| Rows unused | 6 |

*Equal variances were assumed for the analysis.*

### Factor Information

| Factor | Levels | Values |
|---|---|---|
| Site | 2 | North, South |

### Analysis of Variance

| Source | DF | Adj SS | Adj MS | F-Value | P-Value |
|---|---|---|---|---|---|
| Site | 1 | 10.99 | 10.99 | 0.57 | 0.453 |
| Error | 140 | 2721.42 | 19.44 | | |
| Total | 141 | 2732.41 | | | |

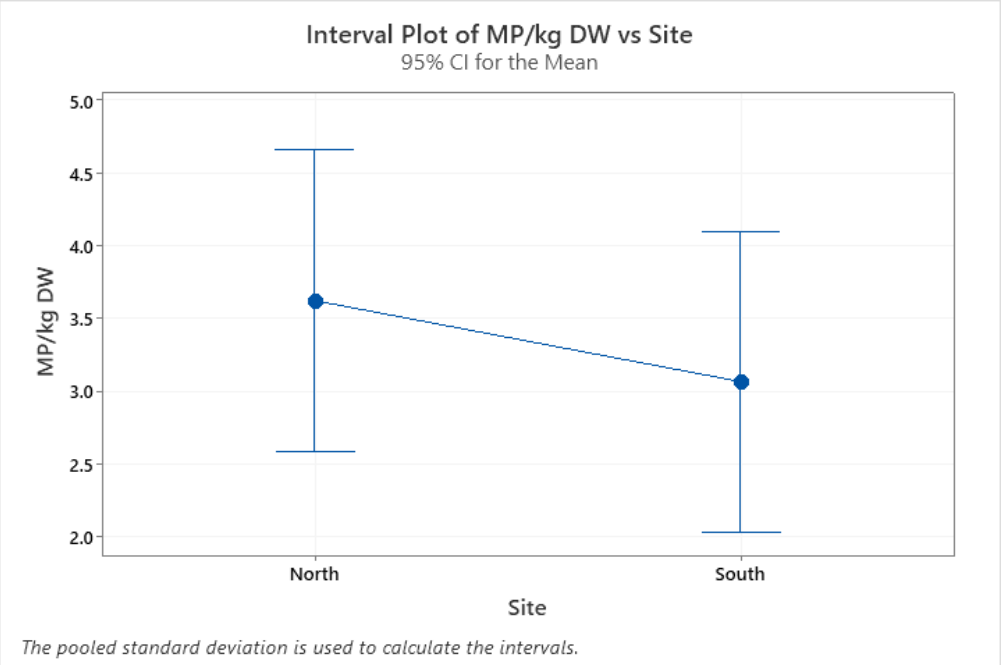
### Model Summary

| S | R-sq | R-sq(adj) | R-sq(pred) |
|---|---|---|---|
| 4.40893 | 0.40% | 0.00% | 0.00% |

### Means

| Site | N | Mean | StDev | 95% CI |
|---|---|---|---|---|
| North | 71 | 3.619 | 4.485 | (2.584, 4.653) |
| South | 71 | 3.062 | 4.332 | (2.028, 4.097) |

*Pooled StDev = 4.40893*




*The pooled standard deviation is used to calculate the intervals.*

## 2C. Auckland vs. Northland

### Two-Sample T-Test and CI: MP/kg DW, Region

#### Method

$\mu_1$: population mean of MP/kg DW when Region = Auckland
$\mu_2$: population mean of MP/kg DW when Region = Northland
Difference: $\mu_1 - \mu_2$

*Equal variances are not assumed for this analysis.*

#### Descriptive Statistics: MP/kg DW

| Region | N | Mean | StDev | SE Mean |
|---|---|---|---|---|
| Auckland | 55 | 6.03 | 7.20 | 0.97 |
| Northland | 148 | 3.26 | 4.35 | 0.36 |

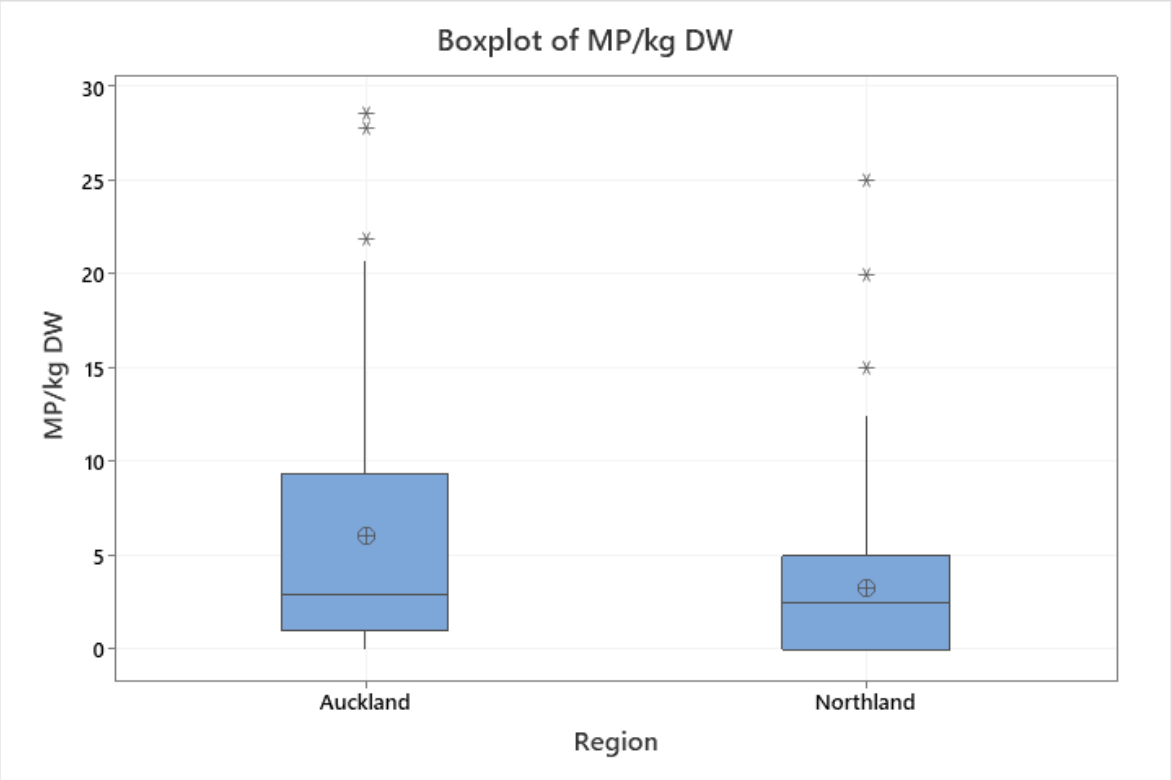
#### Estimation for Difference

| Difference | 95% CI for Difference |
|---|---|
| 2.77 | (0.71, 4.83) |

#### Test

Null hypothesis $H_0$: $\mu_1 - \mu_2 = 0$
Alternative hypothesis $H_1$: $\mu_1 - \mu_2 \neq 0$

| T-Value | DF | P-Value |
|---|---|---|
| 2.68 | 69 | 0.009 |



## B. Statistical Results (SMPP)

### One-way ANOVA: Concentration versus Site

#### Method

| | |
|---|---|
| Null hypothesis | All means are equal |
| Alternative hypothesis | Not all means are equal |
| Significance level | α = 0.05 |

*Equal variances were assumed for the analysis.*

#### Factor Information

| Factor | Levels | Values |
|---|---|---|
| Site | 4 | Mangawhai, Omamari, Onerahi, Taharoa |

#### Analysis of Variance

| Source | DF | Adj SS | Adj MS | F-Value | P-Value |
|---|---|---|---|---|---|
| Site | 3 | 26961067 | 8987022 | 2.81 | 0.050 |
| Error | 44 | 140806981 | 3200159 | | |
| Total | 47 | 167768048 | | | |

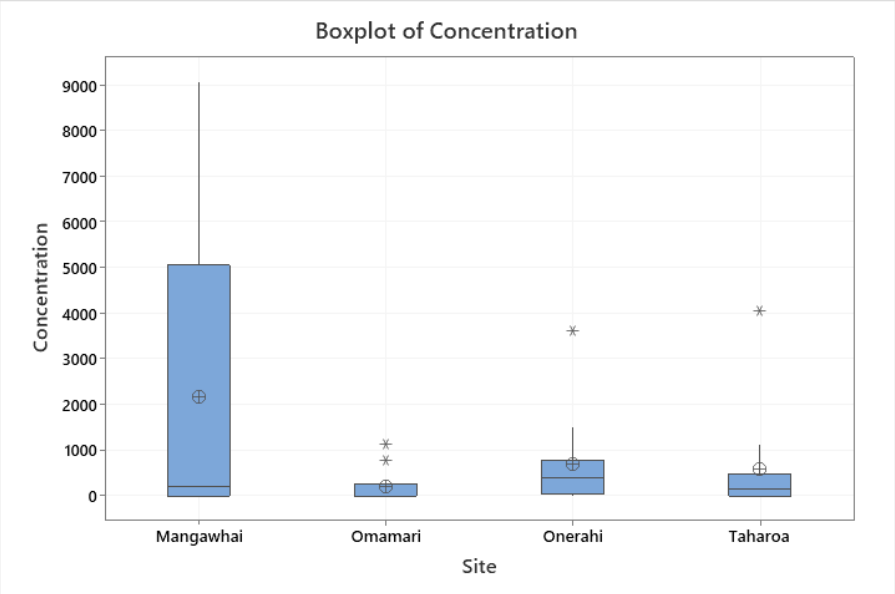
#### Model Summary

| S | R-sq | R-sq(adj) | R-sq(pred) |
|---|---|---|---|
| 1788.90 | 16.07% | 10.35% | 0.12% |

#### Means

| Site | N | Mean | StDev | 95% CI |
|---|---|---|---|---|
| Mangawhai | 12 | 2170 | 3213 | (1129, 3211) |
| Omamari | 12 | 202 | 364 | (-839, 1243) |
| Onerahi | 12 | 697 | 1019 | (-344, 1737) |
| Taharoa | 12 | 575 | 1144 | (-466, 1616) |

*Pooled StDev = 1788.90*



**T- test comparison: Concentration vs. Season**

## Method

$\mu_1$: population mean of Concentration when Season = Summer
$\mu_2$: population mean of Concentration when Season = Winter
Difference: $\mu_1 - \mu_2$

*Equal variances are not assumed for this analysis.*

## Descriptive Statistics: Concentration

| Season | N | Mean | StDev | SE Mean |
|---|---|---|---|---|
| Summer | 24 | 1417 | 2290 | 467 |
| Winter | 24 | 405 | 1232 | 251 |

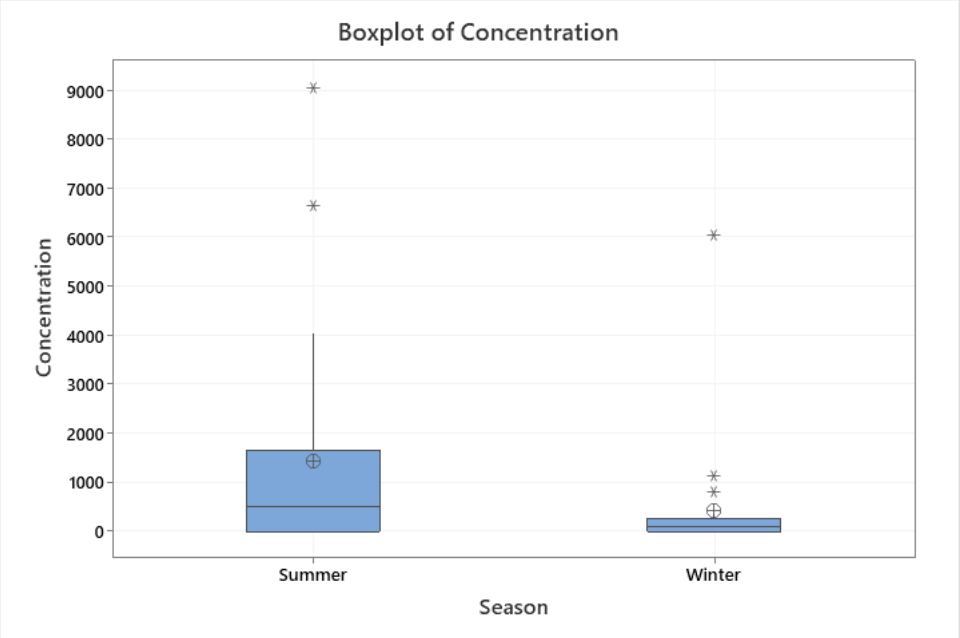
## Estimation for Difference

| Difference | 95% CI for Difference |
|---|---|
| 1013 | (-65, 2090) |

## Test

| | |
|---|---|
| Null hypothesis | $H_0$: $\mu_1 - \mu_2 = 0$ |
| Alternative hypothesis | $H_1$: $\mu_1 - \mu_2 \neq 0$ |

| T-Value | DF | P-Value |
|---|---|---|
| 1.91 | 35 | 0.065 |



**Two-Sample T-Test and CI: Concentration vs. sampling location**

**One-way ANOVA: MP/kg DW versus Site**

## Method

| | |
|---|---|
| Null hypothesis | All means are equal |
| Alternative hypothesis | Not all means are equal |
| Significance level | α = 0.05 |

*Equal variances were assumed for the analysis.*

## Factor Information

| Factor | Levels | Values |
|---|---|---|
| Site | 2 | North, South |

## Analysis of Variance

| Source | DF | Adj SS | Adj MS | F-Value | P-Value |
|---|---|---|---|---|---|
| Site | 1 | 10.99 | 10.99 | 0.57 | 0.453 |
| Error | 140 | 2721.42 | 19.44 | | |
| Total | 141 | 2732.41 | | | |

## Model Summary

| S | R-sq | R-sq(adj) | R-sq(pred) |
|---|---|---|---|
| 4.40893 | 0.40% | 0.00% | 0.00% |

## Means

| Site | N | Mean | StDev | 95% CI |
|---|---|---|---|---|
| North | 71 | 3.619 | 4.485 | (2.584, 4.653) |
| South | 71 | 3.062 | 4.332 | (2.028, 4.097) |

*Pooled StDev = 4.40893*