Assessing litter loads and composition from urban stormwater discharges in Northland

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Litter on stormwater drain.

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Executive Summary

Over the past few years, Northland Regional Council (Council) has worked with several stakeholders to better understand litter deposition and dispersal across Northland. Council has initiated several programmes and projects with stakeholders and the public to reduce the existing knowledge gaps on litter and plastic contamination within the region. Recent monitoring of shoreline litter in Northland identified extremely high densities of litter in the Hātea River, Whangārei, with up to 2,394 items per 1,000 m^2 recorded quarterly (Litter Intelligence, 2019).

This project was initiated to provide baseline data on the annual load and composition of litter from urban discharges in Northland, with a particular focus on plastic litter. It was undertaken with the help of several stakeholders, namely NorthTec, Whitebait Connection, Whangārei District Council, Far North District Council, Kaipara District Council, Northland District Health Board, and local businesses.

The study involved the use of 51 LittaTraps™ located in 16 different land use categories throughout the region, which were audited quarterly between December 2020 and December 2021.

The key findings of this research are summarised below:

- A total of 21,006 litter items were captured.
- Litter items were primarily made of plastic (71.1%), which is consistent with local, regional, national, and international studies.
- Plastic was the dominant material type in all land use categories.
- Cigarette butts were the most common litter item captured (32.8% of all items).
- There were large differences between the amount of litter captured by different traps. The 'worst' nine traps (17%) captured 50% of all litter and were considered hotspots. In contrast, the 'best' five traps captured less than 1% of all litter.
- Litter loading rates differed significantly between land use categories.
- 'Retail', 'Fast food', 'Car parks', 'Playgrounds/skateparks', 'Transport/Postal' and 'Hospital' land uses were identified as high-risk land uses, with double the overall median loading rate.
- At sites where more than one trap was present, loading rates were higher near the entrance of buildings, in loading zones, or where foot and vehicle traffic was heavier.
- An estimated median 7.5 million litter items, including 5.0 million plastic items are discharged annually from urban stormwater discharges in Whangārei, which is equivalent to 136 items per person each year. In the whole region, an estimated 13.2 million litter items, including 8.7 million plastic items are discharged from the six main urban areas each year.

This study clearly demonstrated that non-treated urban discharges are an important source of litter and plastic to aquatic environments in Northland. The findings in the study can be used to target education and mitigation measures to reduce the amount of litter reaching the coast. The identification of cigarette butts as a high frequency item and six high-risk land uses can be used to target education and mitigation. An educational campaign targeting littering (particularly cigarette littering) combined with the provision of bins, regular site cleaning, and the installation of LittaTraps™ or similar devices at high-risk land uses could lead to significant reductions in litter loads reaching Northland's coast.

Introduction

Recent monitoring of shoreline litter in Northland identified extremely high density of litter in the Hātea River, Whangārei, with up to 2,394 items per 1,000 m^2 recorded quarterly (Litter Intelligence, 2019). To determine the scale of the issue and to estimate how much litter and plastic is reaching our coast annually, the Northland Regional Council initiated a project with NorthTec, Whitebait Connection, Whangārei District Council, Far North District Council, Kaipara District Council, Northland District Health Board, and local business to install and audit 'LittaTraps™' (traps hereafter) at stormwater grates throughout the region.

The key objectives of this year-long study were to:

1) Provide data on the quantity and composition of litter captured at stormwater drains from different land uses,
2) Examine whether there are any seasonal trends in the litter load and the composition of litter items captured,
3) Identify any 'hotspot' sites that generate particularly high litter loads to stormwater drainage systems,
4) Estimate the annual litter and plastic loads entering the coastal environment from six urban areas in Northland, and
5) Provide recommendations to reduce litter loads entering stormwater drainage systems and the coastal environment.

Plastic litter

Plastic pollution is a global and burgeoning environmental issue due to the material's longevity and resistance to decomposition (Andrady, 2015). As a result, plastic items are often the dominant pollutants in various ecosystems (*e.g.,* Bucci *et al.*, 2020; UNEA, 2019), including New Zealand beaches (Ministry for the Environment & Stats NZ, 2019; Martinez & Bamford, 2021). Plastics can directly or indirectly enter aquatic, terrestrial, and atmospheric systems and be transported freely across these systems. Furthermore, plastics can accumulate in the environment, bioaccumulate along the food chain (Carbery *et al.*, 2018), and cause health risks to both wildlife (Puskic *et al.*, 2020; Courtene-Jones *et* al., 2022) and human populations (Rai *et al.*, 2021). Information on the quantity of plastic entering the marine environment from waste generated on land is limited. Jambeck *et al.* (2015) estimated that in 2010, 275 million metric tons (MMT) of plastic waste were generated in 192 coastal countries, with 4.8 to 12.7 MMT reaching the ocean transported by rivers and wind. The authors also predicted that the cumulative quantity of plastic waste that could enter the marine environment from land would increase by an order of magnitude by 2025 without waste management infrastructure and practice improvements. Additionally, Borelle *et al.* (2020) estimated 19 to 23 MMT or 11% of plastic waste generated globally in 2016 entered aquatic ecosystems. Not surprisingly, approximately 80% of marine plastic pollution originates from land-based sources (Ritchie & Roser, 2018), with plastics leaking into the environment as mismanaged waste throughout the production, consumption, and waste management stages of the plastic life cycle (Nielsen *et al.*, 2020).

Marine plastic litter-related issues surpass many other marine problems because plastic is a pervasive and resilient pollutant found in every habitat and ecosystem (*e.g.,* Thompson *et al.*, 2009; Allen *et al.*, 2019; Jamieson *et al.*, 2019). Plastic litter is affecting over 900 marine species and their survival, from plankton to megafauna (Gall & Thompson, 2015; Kuhn *et al.*, 2020). These species can be directly impacted through entanglement and ingestion (*e.g.,* Derraik, 2002; Gregory, 2009; López-Martínez *et* *al.*, 2021; Savoca *et al.*, 2021) and indirectly via exposure to plastic-associated chemicals and microbes (Lavers *et al.*, 2014). There are also concerns that marine litter may serve as a pathway for the introduction of non-native species, which may become invasive (Miralles *et al.*, 2018), and for the transmission of pathogens (Parthasarathy *et al.*, 2019).

The accumulation of plastics in the environment occurs when the rate at which plastics enter an area exceeds the rate of natural removal processes, including clean-up actions. Consequently, plastics can be considered as "poorly reversible pollutants" because a) emissions cannot currently be curtailed (very high rate of production, mismanagement, and 9 – 30% recycling; Geyer *et al*., 2017) and b) they reside in the environment for a long time (Chamas *et al*., 2020). This implies that if plastics accumulate to levels exceeding effect thresholds, negative impacts would not be readily reversed because it will be very difficult to rapidly reduce pollution levels below the threshold (Arp *et al.*, 2021). This is particularly true in areas where weathering processes cause plastics to fragment into micro- and nano-plastic particles that are invisible to the human eye (MacLeod *et al.*, 2021).

To date, our understanding of the distribution of plastics in natural ecosystems other than marine ecosystems is limited. Additionally, the knowledge of the extent and severity of the effects of plastic pollution at population, community, and ecosystem levels is also limited (Windsor *et al.*, 2019).

To guide effective management measures to reduce plastic and litter pollution in aquatic ecosystems, comprehensive research is, therefore, required. More specifically, research needs to expand and focus on identifying and quantifying sources, sinks, fluxes, and fates of plastics and other litter in catchments and transitional waters that are major transport routes to marine ecosystems (*e.g.,* Nelms *et al.*, 2017; Windsor *et al.*, 2019; Weideman *et al.*, 2020).

Litter in New Zealand

Approaches to measuring litter in certain parts of the environment are relatively recent in New Zealand (Prime Minister Chief Science's Advisor, PMCSA, 2019). As a result, evidence-based data to support decisions to drive policies to address the issue of plastic pollution in New Zealand are lacking (PMCSA, 2019). To date, available data on litter have primarily originated from manual litter audit surveys conducted in towns and cities, businesses, schools, households, and shoreline surveys of coastal areas (*e.g.,* Keep New Zealand Beautiful, 2019; Martinez & Bamford, 2021; Litter Intelligence, 2022a). Knowledge gaps still exist regarding how much plastic litter enters the environment and what the main sources are (PMCSA, 2019). Implementing systems that can trap litter would impede one of the major pathways for litter to reach the aquatic environment (Lamont *et al.*, 2019) and help reduce environmental pollution globally (Helinski *et al.*, 2021). In Northland, water collected in the stormwater drainage systems is primarily untreated (*Stormwater drains*, 2022), meaning that there is a potential for considerable input of litter from the stormwater system into local waters and, eventually, the ocean, especially at locations where there is no regular street cleaning.

Methods

Study sites

A total of 41 litter traps were installed in 2020 and 2021 in Northland (Figure 1). An additional 10 traps, previously installed by Whitebait Connection (Mountains to Sea Conservation Trust) and Council, were also used in this study, summing the total number of traps to 51.

Sites selection

Sites were selected to cover a range of different land use types that are broadly representative of the urban areas of the region, while considering factors such as site feasibility (type and dimension of a drain), accessibility (especially on private property), and safety (ability to work safely in the roading corridor). The land use for each trap catchment was classified into one of 16 categories (Table 1; Figure 1), adapted from the 2006 Australian and NZ Standard Industrial Classification (ANZSIC). During this study, one trap became unavailable due to work undertaken on site and a further two traps could not be audited in spring because they were inaccessible during the field collection period.

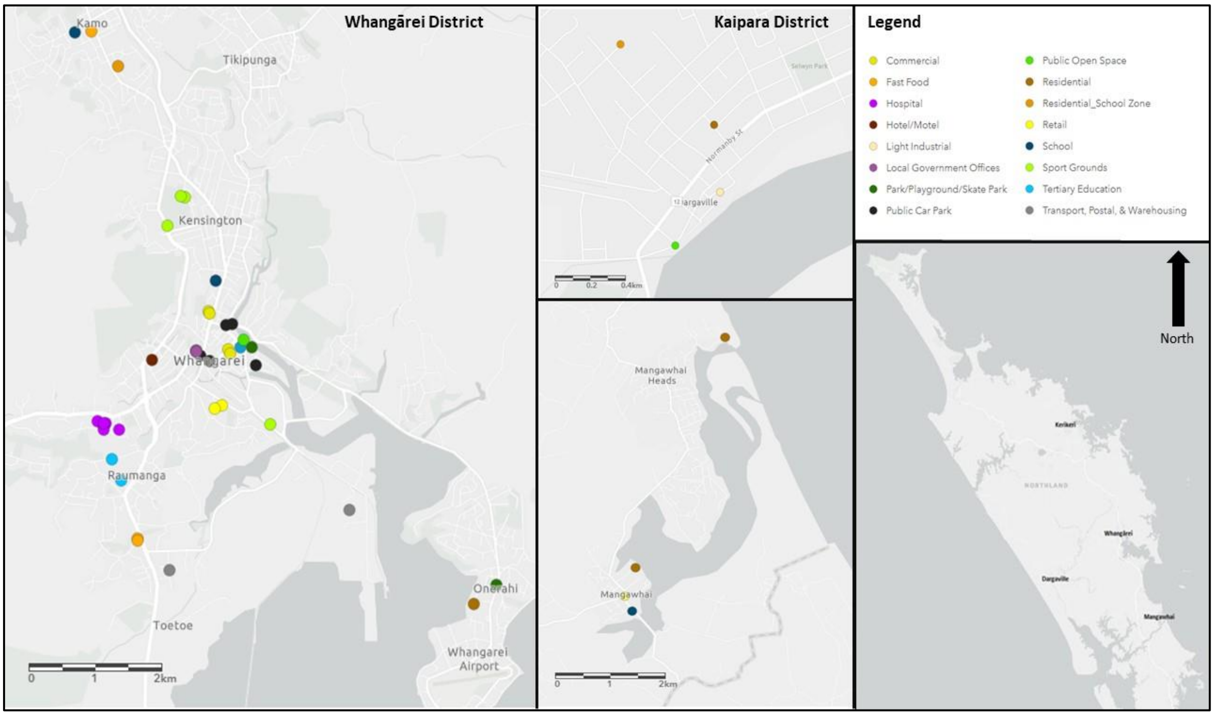

Figure 1: Locations of LittaTraps™ installed in the Kaipara District (Dargaville, Mangawhai) and Whangārei District, in Northland. LittaTraps™ installed in the Far North (n = 3) are not shown.

At some sites, more than one trap was installed to investigate intra-site differences in the litter load and composition. For example, at one 'retail' site, a trap was installed at a stormwater drain in the customer car park and another in the loading bay area. The catchment area for each stormwater catchpit site was delineated in the field by walking the perimeter of the catchment and recording the area using ArcGIS Field Maps (ESRI) on a Samsung Galaxy A21s.

Table 1: Land use catchment classification used in this study.

Main catchment types	
- Commercial	- Public open space
- Fast food	- Residential
- Hospital	- Residential-School zone
- Hotel/Motel	- Retail
- Light industrial	- School
- Local government offices	- Sports ground
- Park/Playground/Skate Park	- Tertiary education
- Public car park	- Transport, Postal & Warehousing

Materials

LittaTrap™, a Catch Basin Insert

In this study, we used the versatile and patented EnviroPod® gross pollutant trap, called LittaTrap™. The net can easily be removed at any given time, allowing low cost and frequent maintenance (Stormwater360, 2022). In most cases, the retained gross pollutants inside a trap basket are kept dry as excess water is allowed to drain from it (Hannah, 2013; Stormwater360, 2022; Figure 2).

In the trap model used, the net captured macro-plastics (plastic debris greater than or equal to 5 mm in length; Helsinki *et al.*, 2021) and gross pollutants larger than the 5 mm. Smaller litter items (*e.g.,* 2 – 4 mm plastic pellets) can also be trapped by organic matter in the traps but these were not considered in this study.

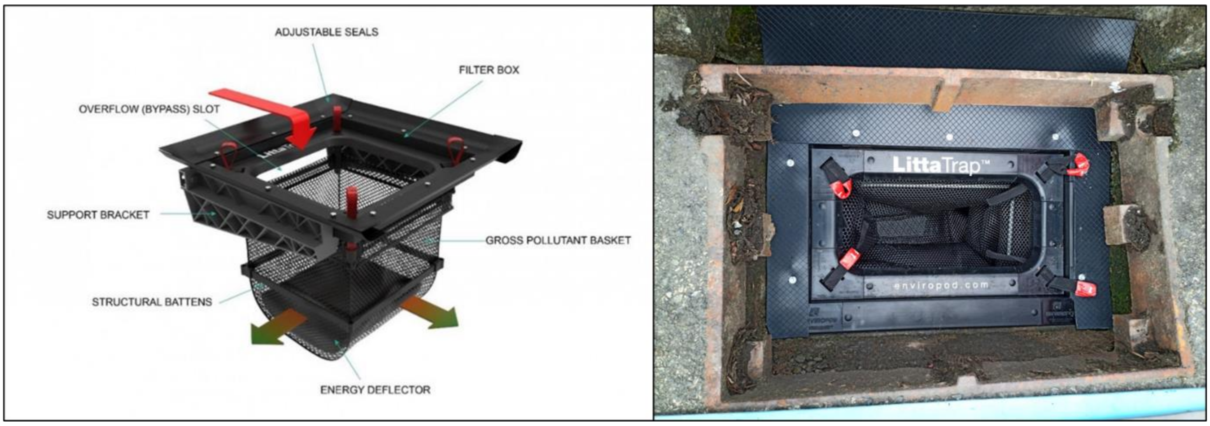

Figure 2: Left: LittaTrap™ prototype (Source: Stormwater360); Right: Example of a new Littatrap installed in a stormwater catchpit in Whangārei (Photo: E. Martinez).

Field and sampling methodology

All traps were emptied at the start of the project in December 2020. The contents of all the traps were then emptied and audited quarterly over a year, typically at the end of an austral season (*i.e.,* summer: Dec-Feb; autumn: Mar-May; winter: Jun-Aug; and spring: Sep-Nov; Appendix 1). Effort was taken to empty all traps within the shortest timeframe possible, depending on staff availability, weather conditions, and accessibility of the traps (*e.g.,* vehicle parked on top of a grate).

The content of each trap was emptied on site and stored in a labelled container. Each net was inspected and cleaned before being placed back into each catchpit to ensure that there was no litter remaining from the previous audit (Figure 3). All samples were then returned to NorthTec campus to be audited.

The contents of each trap were first dried and then the total volume and gross dry weight (kg/g) recorded. The gross pollutant contents were then manually separated into two main categories: 'organic matter and minerals' (OMM) and 'litter'. The volume in litres (L) and weight in grams (g) of each category were recorded for the corresponding trap.

Figure 3: Example of manual maintenance of an Enviropod® LittaTrap^{TM} in three steps (LittaTrapTM, n.d.).

Litter items were manually sorted, classified, and counted according to the type of material (Table 2) and further categorised by their function (*e.g.,* plastic: cigarette butts; metal: foil wrapper). Items whose origin and/or use were unidentifiable were classified as 'Other'. Categories were based on the Litter Intelligence Litter Categories (Litter Intelligence, 2022b), and on Te Taitokerau Debris Monitoring Project (TTTDMP) to allow for comparison with data collected elsewhere within the region and New Zealand.

Table 2: Types of material used to classify litter items captured by LittaTraps^{TM} across Northland between December 2000 and December 2021.

Main types of litter material	
- **Plastic**	- **Cloth, Fabric, & Textiles**
- **Foamed Plastic**	- **Paper & Cardboard**
- **Glass & Ceramic**	- **Wood**
- **Metal**	- **Other**
- **Rubber**	

After each count, the weight (g) to the nearest 0.01 g of each litter category was recorded. The litter items were then laid out on a 2 cm x 2 cm grid and photographed, with the date and site number, for future reference (Figure 4).

Analysis

Trap content characteristics & composition of litter captured

The proportions (percentage) of organic material by dry mass and volume were calculated. To compare the proportion and composition of litter captured in traps, seasons, and material type were also added as a variable.

Loading rates

The catchment area (ha), the number of traps per land use categories, and the number of days a trap was capturing gross pollutants varied. To standardise data, the litter loading rate or capture load for each trap was calculated as the number of items (n) or weight (kg) per hectare per day (ha^{-1}. day^{-1}). For organic matter, loading rates were calculated by dry mass (kg. ha^{-1}. day^{-1}).

Figure 4: Examples of litter captured by a LittaTraps™ installed at a sport ground in Whangārei, Northland, in Autumn 2021 (Photo: E. Martinez).

High risk land uses

High risk land uses were identified if the loading rate by count was more than double the median loading rate of items per hectare per day (ha^{-1}. day^{-1}).

Identifying hotspots

The total number of traps that captured 50% or more of the total litter were deemed 'hotspots'. The calculation was based on count data standardised to the total number of items per year to take into account the different number of days a trap was installed.

Comparison of litter collected by LittaTraps™ and at shoreline surveys along the Hātea River in Whangārei

Council has been conducting quarterly shoreline surveys at a site in the Hātea River, Whangārei (-35.729900 S, 174.334905 E) since 2019 (*Litter Intelligence*, 2022a). Data collected in 2021 were used to compare the annual composition of litter (percentage) that accumulated at the Hātea River shoreline site and litter captured by traps in Whangārei city. Litter data collected by TTTDMP between December 2019 and November 2020 at Onerahi (-35.765069 S, 174.357645 E), further downstream along the Hātea River, were also used for comparison.

Estimation of litter released by the stormwater networks in Northland

To estimate the quantity of litter released annually from the stormwater networks, land use maps were developed for the six main urban areas, using ArcGIS Pro (version 3.0.4, ESRI). The urban areas were first delineated, based on the ward boundaries. A pairwise clip with 'urban areas' and the LINZ primary parcel layer was then undertaken. Land use for each property parcel was initially assigned based on the VNZ category. Land uses were then manually checked and updated using data sources including the LINZ New Zealand topographic map layer, businesses registered on google maps and local knowledge (Figure 5). The roading network was assigned a land use based on the land use of the adjacent parcels.

The total catchment areas (ha) were calculated for each of the 16 land use categories using the calculate geometry function in ArcGIS Pro. The residential land use catchment area included residential roads but excluded residential property parcels as most residential properties do not have stormwater drains. Land use areas such as 'pastoral' and 'forestry' were excluded from this analysis as they are unlikely to act as significant sources of litter to the stormwater network (Weideman *et al.*, 2020) and were not sampled in this study. A land use category 'other' included land uses such as churches, airport, utility assets and state highways, was also excluded as these land uses were not sampled in this study.

The total annual estimate of litter load (including 95% confidence intervals) to the stormwater networks was then calculated by multiplying the median loading rate (n. ha^{-1}. yr^{-1}) for each of the main land use activities by their respective total catchment area (ha) within each urban area.

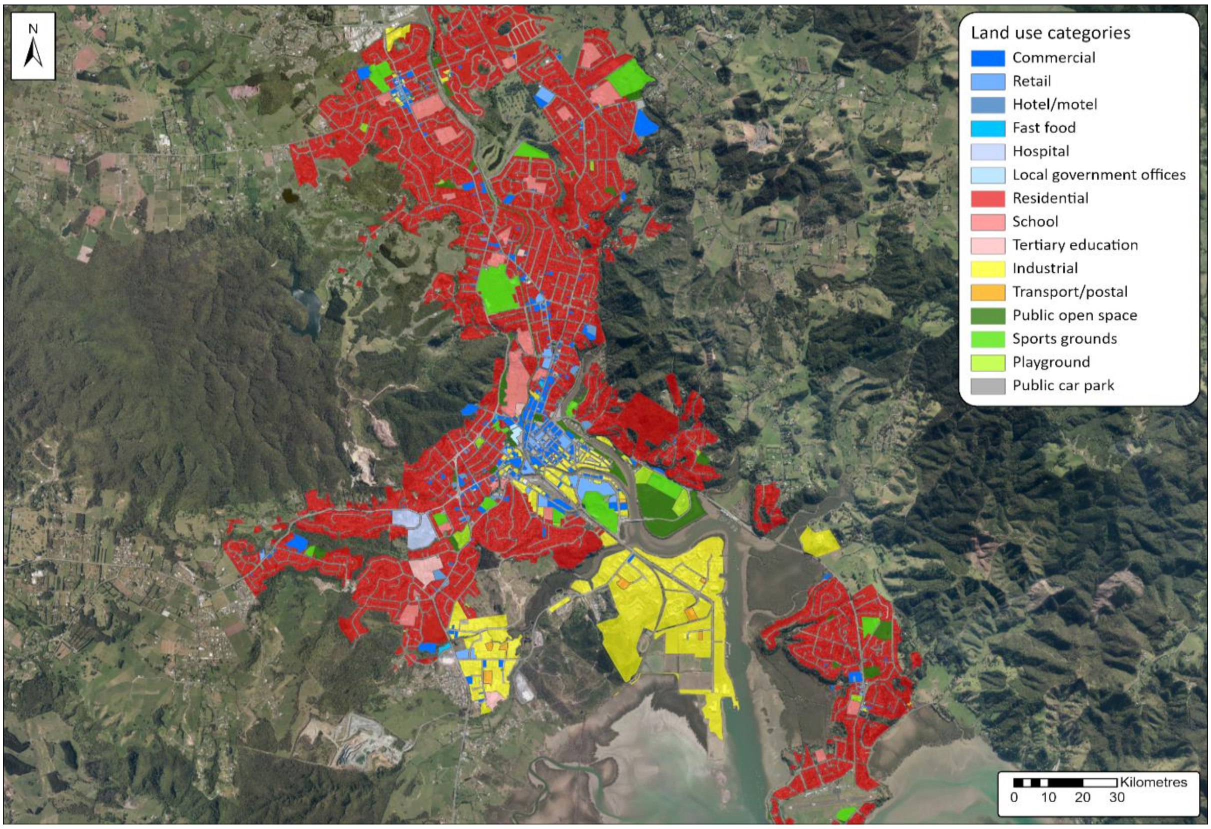

Figure 5: Example of the land use layer created for six urban areas of Northland.

Data analysis

Prior to statistical analysis, data were standardised per hectare per day. This was deemed necessary to account for variations in (i) catchment areas (ha) and (ii) the number of days between audits for each trap. Data failed the Kolmogorov-Smirnov normality test. Non-parametric tests (Mann-Whitney U, Kruskal-Wallis, and Pearson's chi-square test) were used to test for differences between different variables (*e.g*., land use). A multiple comparison Dunn-Bonferroni *post hoc* test was also performed to detect which groups in pairs were significantly different. For all statistical tests conducted, significance was assessed at $p < 0.05$ and trends at $p < 0.1$. Finally, when examining potential relationship between a variable and land use categories, sample size was small for many of these categories. Results presented here should, therefore, be interpreted with caution.

Results

Litter quantity and composition

A total of 21,006 litter items were captured between December 2020 and December 2021 by the 51 traps. Plastic was the most common type of material by item, accounting for 71.1% (n = 14,930) of all items (Figure 6) and 49.4 % (n = 3.873 kg) of the total dry mass of all items captured (Figure 7). The second most common material type was ‘glass & ceramics’ by item (6.4%, n = 1,339, Figure 6) and weight (15.5%, n = 1.219 kg; Figure 7).

Figure 6: Composition (by item) of litter items captured by LittaTraps™ across Northland in 2021. The total count of litter items determines the cell size of each material category.

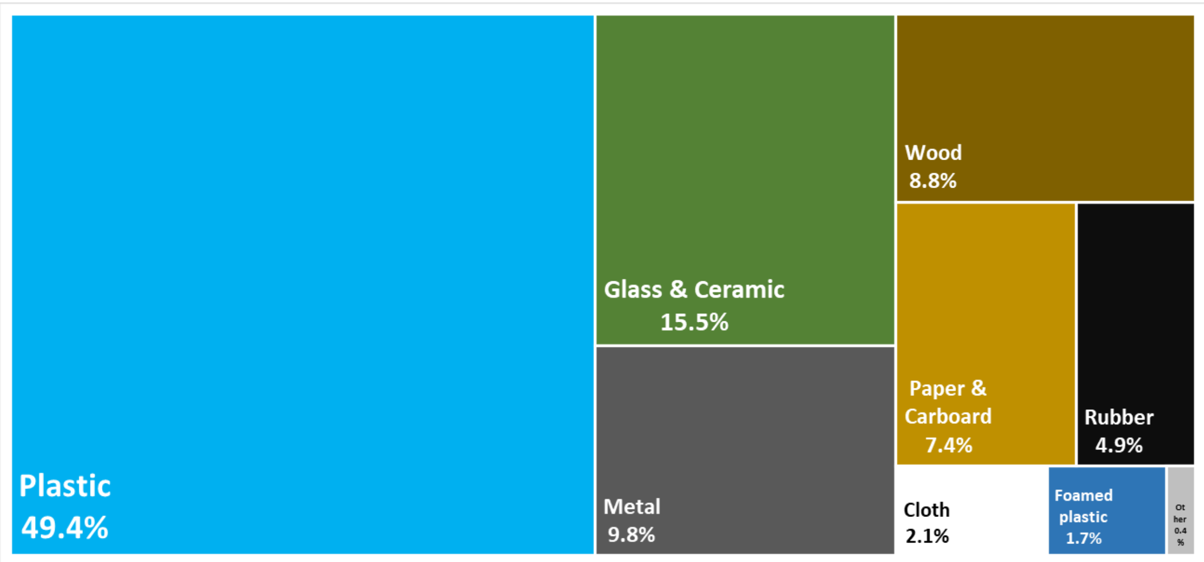

Figure 7: Composition (by dry mass, kg) of litter items captured by LittaTraps™ across Northland in 2021. The total count of litter items determines the cell size of each category.

Regardless of the type of land use category, litter items captured by traps were primarily made of ‘plastic’ (≥ 50%), ranging from 53.6% (n = 713) in ‘Park/Playground/Skate Park’ to 97.7% (n = 42) in ‘Hotel/motel’ land use (Figure 8). The highest proportions of ‘Glass & ceramic’ items were found in

‘Tertiary education’ (33.4%, n = 245) and ‘Park/Playground/Skate Park’ (29.4%, n = 391) land uses. The highest proportions of ‘foamed plastic’ items were found in ‘Residential’ (23.3%, n = 58) and ‘Transport, Postal, & Warehousing’ land uses (19.2%, n = 548; Figure 8).

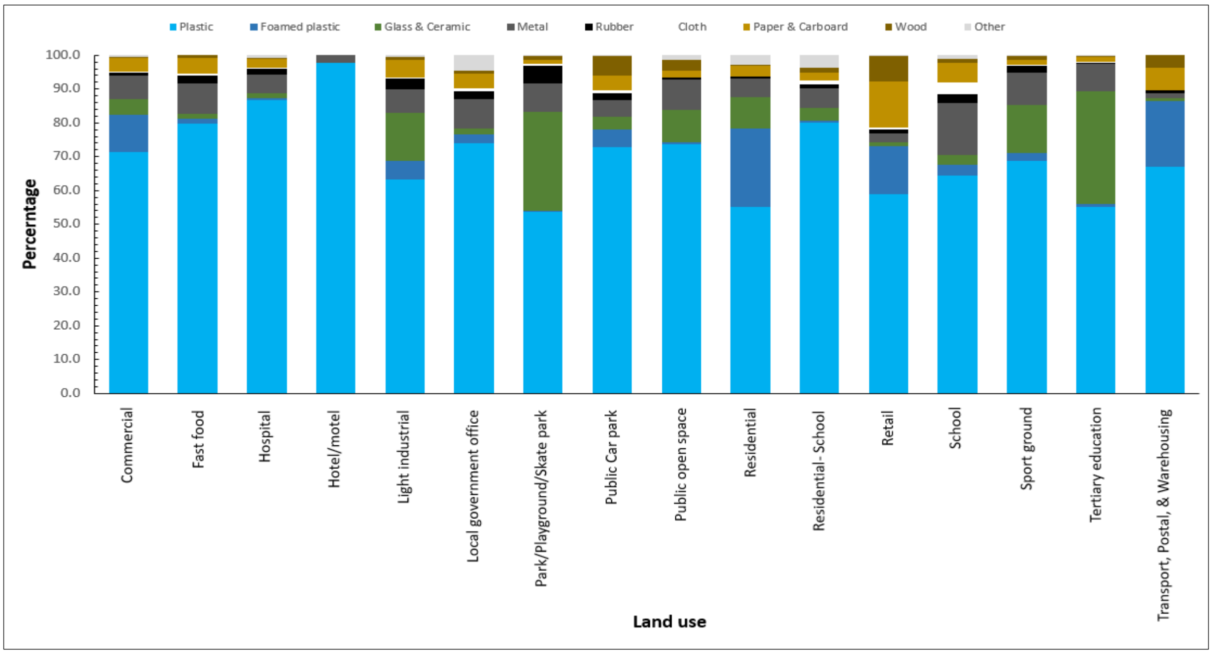

Figure 8: Composition of litter captured by LittaTraps™ across various land use types in Northland between December 2000 and December 2021.

Organic material

Organic material (Figure 9) constituted 98.6% of gross pollutants captured by the 51 traps by dry mass (361.1 kg) and 89.6% by volume (580.5 L). Traps captured a median of 0.266 kg of organic matter and minerals ha^{-1}. day^{-1} (IQR = 0.097 – 0.556; LTs = 49, n = 242) and 1.164 L of OMM ha^{-1}. day^{-1} (IQR = 0.489 – 2.643; LTs = 49, n = 96).

Figure 9: Example of organic material captured by several LittaTraps™ in Northland between December 2000 and December 2021 on drying beds before weighing (Photo: E. Martinez).

Top litter items

Among the 21,006 litter items captured by the 51 traps, cigarette butts were the top litter item (32.8%, n = 6,868), followed by fragments of soft plastics (17.8%, n = 3,734). These two items were either the top item or second item captured at all 16 land uses, indicating just how ubiquitous these items are (Table 3). At the 'Hospital' land use, cigarette butts accounted for 72.6% of all items, with a total of 2,371 cigarette butts captured in the five traps on 'Hospital' grounds.

Table 3: Top two litter items captured by LittaTraps™ in Northland in 2021 according to land use.

Catchment Type	Top item	Second item
Fast Food	Cigarette butts, filters 49.0% n = 867	Soft plastic fragments 18.9% n = 334
Commercial	Hard plastic fragments 25.1% n = 148	Cigarette butts, filters 16.5% n = 97
Hospital	Cigarette butts, filters 72.6% n = 2,371	Soft plastic fragments 6.1% n = 200
Hotel	Cigarette butts, filters 37.2% n = 16	Soft plastic fragments 27.9% n = 12
Light Industrial	Soft plastic fragments 21.6% n = 43	Cigarette butts, filters 13.6% n = 27
Local Government Office	Cigarette butts, filters 34.6% n = 233	Soft plastic fragments 18.6% n = 125
Park, Playground, Skate Park	Glass fragments 20.3% n = 270	Cigarette butts, filters 17.1% n = 227
Public Car Park	Cigarette butts, filters 33.1% n = 1,397	Soft plastic fragments 20.2% n = 854
Public Open Space	Cigarette butts, filters 28.6% n = 106	Soft plastic fragments 21.0% n = 78
Residential	Polystyrene fragments 30.5% n = 54	Soft plastic fragments 14.7% n = 26
Residential-School Zone	Hard plastic fragments 22.8% n = 108	Soft plastic fragments 18.1% n = 86
Retail	Cigarette butts, filters 20.0% n = 387	Soft plastic fragments 19.9% n = 386
School	Soft plastic fragments 11.9% n = 55	Foil wrappers & packaging 6.5% n = 30
Sport Grounds	Cigarette butts, filters 32.7% n = 598	Soft plastic fragments 12.1% n = 221
Tertiary Education	Glass fragments 33.4% n = 245	Cigarette butts, filters 31.9% n = 234
Transport, Postal, & Warehousing	Soft plastic fragments 39.8% n = 1,136	Polystyrene fragments 18.5% n = 528

Other items of interest: Plastic nurdles

Plastic nurdles or pellets were only captured in one trap installed at a 'Transport, Postal, & Warehousing' site (LT10; 5.9% of total items). The proportion of nurdles would have been higher because most nurdles found in the traps were smaller than 5mm so were not included in the analysis.

Litter loading rates

Land use categories

The 51 traps captured a median of 15.8 litter items $ha^{-1}.\ day^{-1}$ (IQR = 6.7 – 46.5; LTs = 49, n = 197) and 0.005 kg. $ha^{-1}.\ day^{-1}$ (IQR = 0.002 – 0.015; LTs = 51, n = 197). Loading rates (Figure 10) varied significantly between land use categories by items (Kruskal-Wallis, H = 77.86, d.f. = 15, $p < 0.001$;) and dry mass (Kruskal-Wallis, H = 75.497, d.f. = 15, $p < 0.001$). Pair-wise comparisons using Dunn-Bonferroni test indicated that the several land-use categories had significantly higher loading rates than others (adjusted p-value < 0.05) (Appendix 2). For example, traps installed in both 'Fast food' and 'Hospital' areas captured more litter per day than those in 'Commercial', 'Hotel/Motel', and 'Residential' areas by item (Appendix 2A) and dry mass (Appendix 2B).

When taking account both the number of items and dry mass in relation to land use, the following land use categories had the highest median litter loading rates (*i.e.,* above Q3; Figure 10):

- 'Hospital' grounds (68.1 n. $ha^{-1}.\ day^{-1}$, 0.015 kg. $ha^{-1}.\ day^{-1}$; n = 21)
- 'Fast food' (51.9 n. $ha^{-1}.\ day^{-1}$, 0.016 kg. $ha^{-1}.\ day^{-1}$; n = 12)
- 'Retail' (47.4 n. $ha^{-1}.\ day^{-1}$, 0.022 kg. $ha^{-1}.\ day^{-1}$; n =11)

'Park/Playground/Skatepark' and 'Transport, Postal, & Warehousing' were in the top quartile for litter loading rate by weight.

In contrast, the following land uses had the lowest litter loading rates (*i.e.,* below Q1; Figure 10):

- 'Hotel/motel' (3.7 n. $ha^{-1}.\ day^{-1}$, 0.001 kg. $ha^{-1}.\ day^{-1}$; n = 4)
- 'Residential' (4.4 n. $ha^{-1}.\ day^{-1}$, 0.010 kg. $ha^{-1}.\ day^{-1}$; n = 16)
- 'Commercial' (6.0 n. $ha^{-1}.\ day^{-1}$, 0.001 kg. $ha^{-1}.\ day^{-1}$; n = 16).

High-risk land uses

High risk land uses were identified as land uses where the loading rate by number of items was more than double the median loading rate of 15.8 litter items $ha^{-1}.\ day^{-1}$. Using this metric, 'Hospital', 'Fast food', 'Retail', 'Park/Playground/Skate Park', 'Transport, Postal, & Warehousing', and 'Public Car Parks' were identified as high-risk land uses (Figure 10). Interestingly, all these land uses also had loading rates by weight, more than double the median loading rate of 0.005 kg. $ha^{-1}.\ day^{-1}$ (Figure 10).

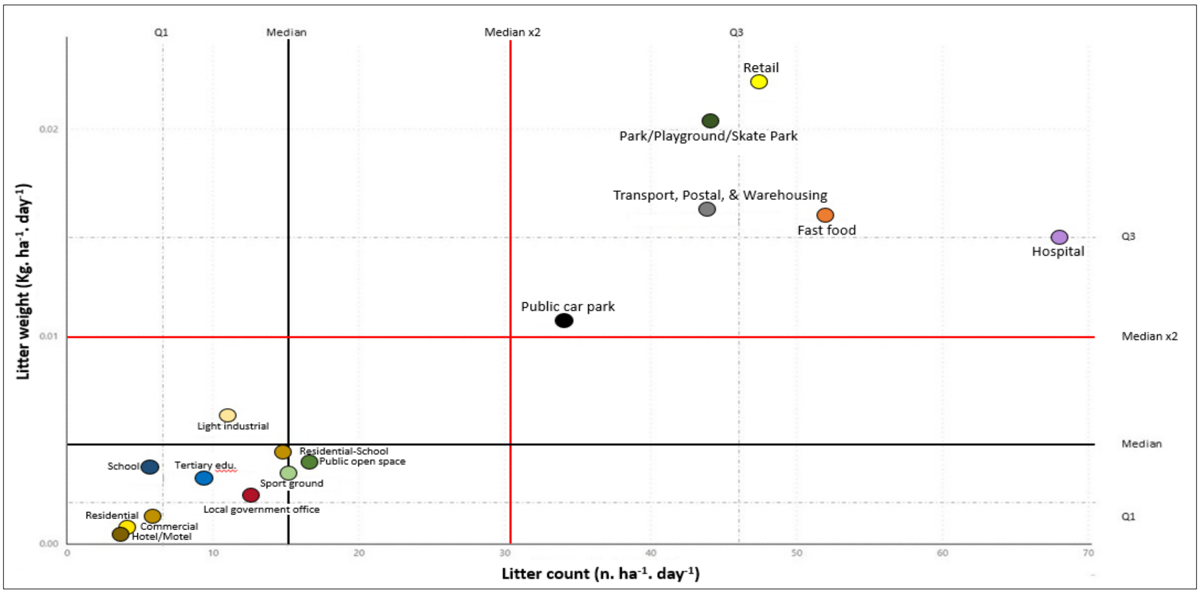

Figure 10: Median loading rates by item (n. ha-1. day-1), dry mass (kg. ha-1. day-1), and land use category of litter items captured by LittaTraps™ in Northland in 2021.

Plastic litter loading rates

'Plastic' items had the highest median loading rates by item (11.1 n. ha^{-1}. day^{-1}, IQR = 5.2 – 33.8) and dry mass (0.0029 kg. ha^{-1}. day^{-1}, IQR = 0.0011 – 0.0080), followed by metal (1.3 n. ha^{-1}. day^{-1}, IQR = 0.5 – 3.2; 0.0007 kg. ha^{-1}. day^{-1}, IQR = 0.0002 – 0.0014). Loading rates (Figure 11) of plastic items also varied significantly between land use categories by both number of items (Kruskal-Wallis; 84.825, d.f. = 15, $p < 0.001$) and by dry mass (Kruskal-Wallis; H = 72.788, d.f. = 15, $p < 0.001$). Pair-wise comparisons using Dunn-Bonferroni test indicated that the several of these land-use categories had significantly higher loads than others (adjusted p-value < 0.05) (Appendix 2D). For example, traps installed in both 'Fast food' and 'Hospital' areas captured more litter per day than those in 'Commercial' and 'Residential' areas by item (Appendix 2D) and dry mass (Appendix 2E). These differences were consistent with loading rates for overall litter.

When taking into account both the number of items and dry mass in relation to land use categories, the following land uses had the highest median plastic loading rates (*i.e.,* above Q3; Figure 11):

- 'Hospital' (median: 59.1 n. ha^{-1}. day^{-1}, 0.010 kg. ha^{-1}. day^{-1}; n =21)
- 'Fast food' (median: 45.1 n. ha^{-1}. day^{-1}, 0.009 kg. ha^{-1}. day^{-1}; n = 12)

In contrast, the following land uses had the lowest plastic loading rates (*i.e.,* below Q1; Figure 11):

- 'Hotel/motel' (3.5 n. ha^{-1}. day^{-1}, 0.0004 kg. ha^{-1}. day^{-1}; n = 4)
- 'Commercial' (3.3 n. ha^{-1}. day^{-1}, 0.00035 kg. ha^{-1}. day^{-1}; n = 16)
- 'Residential' (2.3 n. ha^{-1}. day^{-1}, 0.00035 kg. ha^{-1}. day^{-1}; n = 16).

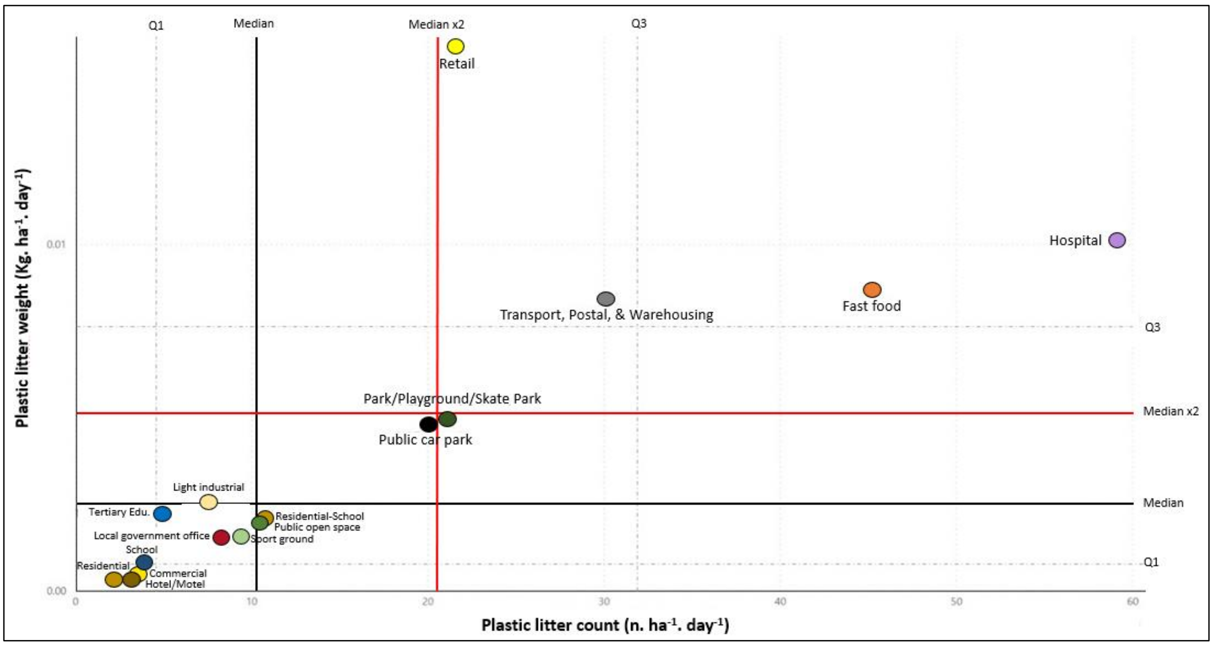

Figure 11: Median loading rate by item (n. ha-1. day-1) and dry mass (kg. ha-1. day-1) and by land use of plastic litter items captured by LittaTraps™ in Northland in 2021.

Organic material

Organic material loading rates by dry mass varied significantly between land use categories (Kruskal-Wallis, H = 48.78, d.f. = 15, $p < 0.001$). Pair-wise comparisons using Dunn-Bonferroni test indicated that several land-use categories had significantly higher loads than others (adjusted p-value < 0.05). For example, traps installed in both 'Public open space' and 'Park/Playground/Skate Park' land uses captured more organic material than those in 'Commercial', 'Hospital', 'Retail', and 'Transport, Postal, & Warehousing' (Appendix 2C).

Top items

In terms of loading rate by item (n. ha^{-1}. day^{-1}), results indicated that cigarette butts were the top item in the region with 3,031 filters captured per hectare per year, followed by fragments of soft plastics (1,648 n. ha^{-1}. day^{-1}; Appendix 3C. This is consistent with results by quantity (or proportion). Except for glass, all the other items in the top five list were made of plastic (Appendix 3C). When considering the loading rates of the top ten items by dry mass (kg. ha^{-1}. day^{-1}), cigarette butts were again the top item in the region (0.484 kg. ha^{-1}. day^{-1}). followed by fragments of glass (0.292 kg. ha^{-1}. day^{-1}), and fragments of soft plastics (0.265 kg. ha^{-1}. day^{-1}; Appendix 3D).

Identification of hotspots

Nine sites captured more than 50% of the 21,006 litter items (Figure 12 & Table 4). The top two sites, located at a 'Transport, Postal, & Warehousing' site and a 'Public Car Park', captured 20% of all litter items. These top nine sites or 'hotspots' were all located in 'Transport, Postal, & Warehousing', 'Public Car Park', 'Hospital', 'Retail' or 'Park/Playground/Skate Park' land uses (Table 4). These five land uses were all identified as high-risk land use categories (Figures 10 & 11). Interestingly, 21 traps (41% of all traps) captured 80% of all items and at the other extreme, the 'best' five sites captured less than 1% of all items, indicating that there would be diminishing returns if traps were installed universally (Table 4; Appendix 4).

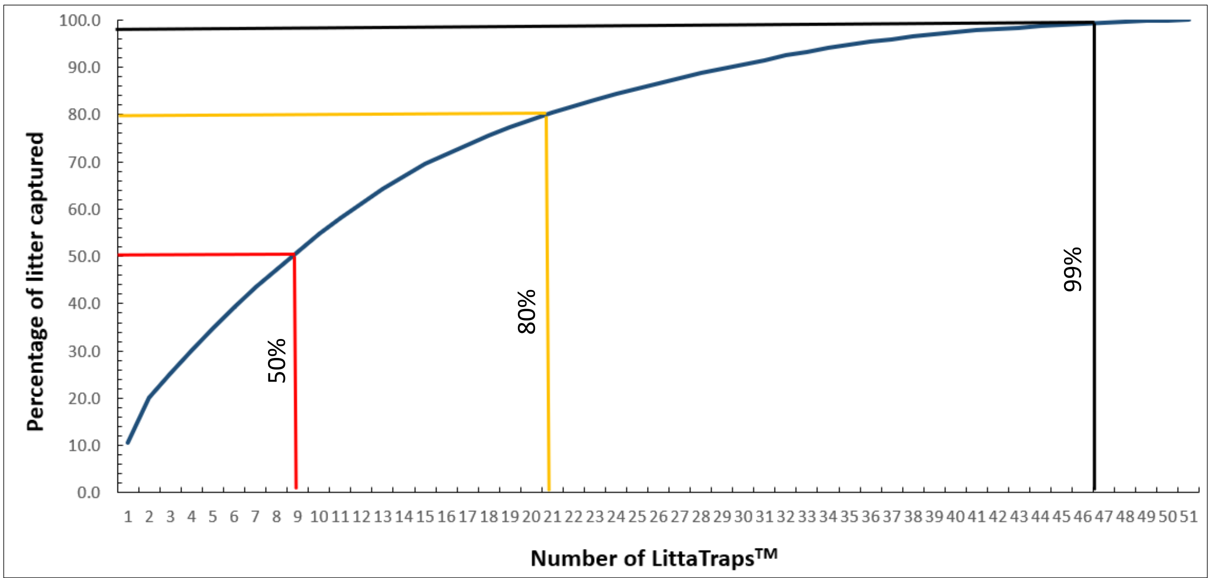

Figure 12: Cumulative amount of litter captured by LittaTrap™ installed in Northland in 2021 based on standardised data. Lines represent the total litter captured (50%, below the red line; 80% below the orange one, and < 1% above the black one).

Intra-site and land use variability

Several sites had more than one trap installed, which allowed for analysis of potential intra-site differences. At a retail and a commercial site, the differences between loading rates were very large (Table 5). In the customer car park of a retail store (LT12) just 122 items were captured compared to 1,100 items in the goods inward/loading bay to the rear of the store (LT 13) (Table 5). A similar result was recorded at the commercial site, where the customer car park (LT17) had a much lower loading rate than the rear staff car park next to waste disposal area (LT18; Table 5). A high number of cigarettes found in the staff car park indicates that this might be an area where smokers congregate. In contrast, at a sports ground (LT21 & LT22) and at a fast-food site (LT01 & LT02) where two traps were installed at each location, loading rates were similar. At the hospital, loading rates tended to be higher in traps near building entrances (LT 24, 25, & 28), where there is high foot traffic with lower loading rates in the car parks. The entrances to buildings may also be areas where people congregate to smoke (Table 5).

Table 4: LittaTraps™ with the highest (≥ 50%; n = 9) and lowest (< 1%; n = 5) count of the total litter captured in a year in Northland in 2021.

	LittaTrap™ Number	Land Use	Count .year^{-1}	% total count	n. ha^{-1}. day^{-1}
50% of all litter captured by the 'worst' nine sites	LT10	Transport, Postal, & Warehousing	2,409	10.5	78.6
	LT18	Public car park	2,178	9.5	351.8
	LT29	Hospital	1,166	5.1	62.7
	LT28	Hospital	1,150	5.0	148.7
	LT13	Retail	1,100	4.8	73.0
	LT41	Park/Playground/Skate Park	989	4.3	47. 4
	LT24	Hospital	951	4.2	120.9
	LT07	Public car park	892	3.9	37.4
	LT34	Retail	863	3.8	51.2
<1% of all litter captured by the five 'best' sites	LT32	Hotel/Motel	44	0.2	3.5
	LT51	Local Government Office	36	0.2	2.6
	LT31	Commercial	33	0.1	2.2
	LT30	Commercial	27	0.1	1.6
	LT39	Residential	23	0.1	1.0

Table 5: Intra-site loading rates of LittaTrap™ (LT) installed in different land use categories in Northland in 2021.

Intra-site & land use		n. ha^{-1}.day^{-1}	kg. ha^{-1}.day^{-1}
Hospital			
LT28	Maternity entrance)	148.7	0.022
LT24	Emergency entrance)	120.9	0.024
LT25	Mental Health Entrance)	100.2	0.010
LT29	Car park near Kitchen unit)	62.7	0.023
LT26	Car Park #8)	12.3	0.002
LT27	Car Park #16)	3. 8	0.003
Sport grounds			
LT21	Whangarei Hockey Centre (Marist Sports)	16.1	0.004
LT22	Whangarei Hockey Centre (Toilet)	11.8	0.005
Retail site			
LT13	Loading zone	73.0	0.048
LT12	Customer car park	3.6	0.002
Commercial			
LT18	Rear car park next to waste disposal area	351.8	0.069
LT17	Customer car park	114.9	0.007
Fast food			
LT03	Customer car park	84.6	0.020
LT01	Customer car park	53.1	0.017
LT02	Customer car park	47.9	0.012

Residential land use

Another pattern that was identified was a higher median loading rate at residential sites close (< 200m) to schools (5,512 n. ha^{-1}. yr^{-1}, 4.015 kg. ha^{-1}. yr^{-1}) than those with no school (1,351 n. ha^{-1}. yr^{-1}, 0.365 kg. ha^{-1}. yr^{-1}; Table 6). The only exception was LT35, but this site had an extremely small catchment so although a relatively small number of items were found at this site the loading rate for this site was high. However, no significant difference was found.

Table 6: Loading rates for LittaTrap™ (LT) installed in residential land use in Northland in 2021.

Land-use	n. ha^{-1}.day^{-1}	kg. ha^{-1}.day^{-1}
Residential		
LT35	23.4	0.005
LT36	2.6	0.0002
LT39	1.0	0.001
LT45	8.6	0.001
Residential (School)		
LT47	17.4	0.004
LT40	12.6	0.010

Seasonality

Over the course of one year, a total of 19,068 litter items (6.8 kg) were captured in the 46 traps with data available for all four seasons. Across the region, most litter items (32.8%) were captured in winter, followed by autumn (24.9%), and the least in spring (20.1%; Table 7). The seasonal variation was significant (Pearson's chi-square χ^2, d.f. 3 = 710.169, $p < 0.0001$).

Table 7: Number of traps installed, total number of litter items captured in LittaTraps™, and the percentage of litter items collected per season in Northland in 2021.

Number of traps	Summer	Autumn	Winter	Spring	Total items
46	**22.1%**	**24.9%**	**32.8%**	**20.1%**	**19,068**

Interestingly, when this same analysis was performed between loading rates according to season for both items and dry mass, no statistical significance ($p > 0.05$) was detected.

Comparison of litter collected by LittaTraps and shoreline surveys along the Hātea River in Whangārei

The composition of litter collected in shoreline surveys at the Hātea River and Onerahi were relatively consistent with the litter captured by the traps in Whangārei. Litter was dominated by items made of plastic, followed by foamed plastic. The proportions of these two types of material captured by traps in Whangārei (71.9% & 6.5%) were similar to the proportions of these items surveyed at Onerahi (78.6% & 11.3%) (Figure 13). However, at the Hātea River shoreline site, a much higher proportion of foamed plastic (34.2%) and a smaller proportion of plastic was recorded (50.6%) when compared to the LittaTraps in Whangārei and the shoreline surveys at Onerahi (Figure 13).

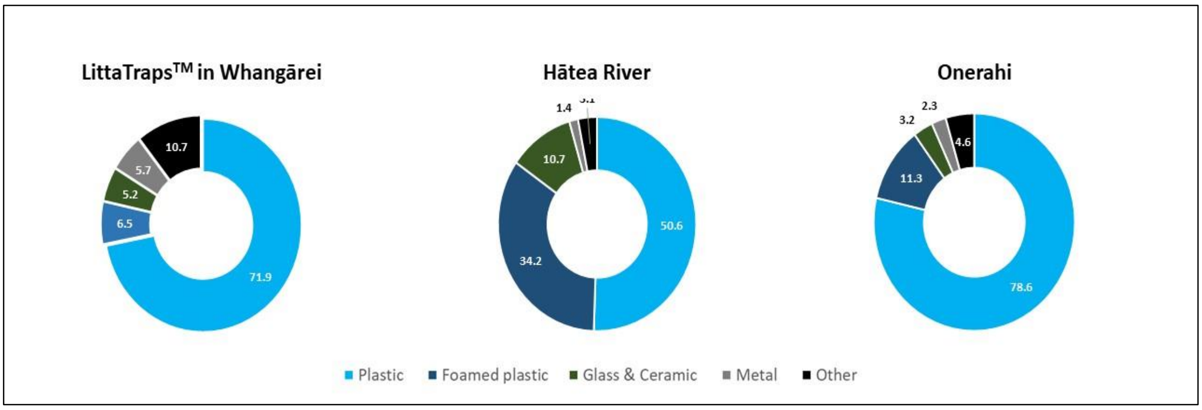

Figure 13: Composition of litter captured by LittaTraps™ in Whangārei in 2021 compared to litter surveys conducted by Council at a Hātea River site (2021) and by TTTDMP at Onerahi (December 2019 – November 2020), Northland.

Extrapolation of litter reaching waterways in Northland

From the extrapolation of results, it is estimated that approximately 7.5 million litter items are discharged annually from the Whangārei stormwater network into the aquatic environment (Table 8 & Appendix 5A), including 5.0 million items of plastic. This is equivalent to 136.2 litter items. yr^{-1}. $person^{-1}$ (or two items per week) and 90.2 plastic items. yr^{-1}. $person^{-1}$ (Appendix 5B). The total number of litter items reaching the aquatic environment from the six urban centres in the region was estimated to be approximately 13.2 million litter items, including 8.7 million plastic items (Table 8 & Appendix 5).

Table 8: Estimates of the annual number of litter and plastic items discharged from six urban stormwater networks in Northland, based on data captured by 51 LittaTraps™ in 2021.

Locations	Total catchment area (ha)	Median estimated annual litter load	Median estimated annual plastic load
Whangārei	1,294.8	7,478,911	4,951,331
Kaitāia	214.6	1,239,459	820,570
Kerikeri	317.3	1,832,596	1,213,250
Kaikohe	147.0	849,174	562,186
Mangawhai	101.2	584,693	387,090
Dargaville	204.9	1,183,480	783,510
Total	**2,279.8**	**13,168,313**	**8,717,936**

Summary/synthesis

This study investigated the composition and loading rates of litter, from urban stormwater in Northland. LittaTraps™ were installed in different land uses that are representative of the urban areas in Northland to estimate the total load of litter and plastic entering the coast. These traps are a type of catch basin inserts already used in New Zealand and (Cornelius *et al*., 1994; Tiddy et al., 2021) and globally (*e.g*., Allison and Chiew, 1995; Lamont *et al*., 2019; Weideman *et al.,* 2020; Pasternak *et al.*, 2021) to reduce land-based litter inputs into the aquatic environment. A secondary aim was to identify 'hotspots' and high frequency litter items so that mitigation measures and education could be more targeted to reduce the amount of litter reaching Northland's coastal environment.

Litter quantity and composition

Between December 2020 and December 2021, a total of 21,006 items were captured by the 51 traps installed across the three districts. 'Plastics' were the most common type of material by count (71.1% of all items) and by dry mass (49.4% of kgs), followed by 'Glass & Ceramic' (6.4% of items and 15.5% of kgs).

Top item: Cigarette butts

The most common plastic items were cigarette butts and filters, with 6,868 captured during the 12-month study period (32.8% of all items). This result is consistent with other studies using catch basin inserts or retention booms both in New Zealand (*LittaTrap™-City of Hamilton,* n.d; Tiddy *et al.,* 2021) and overseas (Carson *et al*., 2013; Weiderman *et al*., 2020; Pasternak *et al.*, 2021). The high amount of cigarette butts is not surprising given that, globally, they are considered one of the most common forms of personal litter in coastal (Curtis *et al.*, 2017) and terrestrial environments (KNZB, 2019). In this study, particularly high proportions of cigarette butts were found at 'Hospital' (72.6%) and 'Fast Food' (49.0%) land uses. The high number of cigarettes (2,371) found at the hospital land use is particularly surprising given that the hospital is a smoke free area.

The high abundance of cigarette butts in urban discharges is concerning because discarded cigarette butts contain carcinogenic and toxic substances (*e.g*., nicotine, tar, arsenic, polycyclic aromatic hydrocarbons or PAHs, and heavy metals) and release microplastic fibres, which can pollute the soil, the water, and also be harmful to the biota (Slaughter *et al*., 2011; Araújo & Costa, 2019; Dobaradaran *et al*., 2019; Oliva *et al.,* 2021; Shen *et al*., 2021).

Organic material

Between December 2020 and December 2021, the majority of gross pollutants captured by traps across the region were a mixture of organic matter and minerals (OMM), both by dry mass (98.6%, 361.1 kg, median: 0.266 kg of OMM ha^{-1}. day^{-1}) and volume (89.6%, 580.5 L, median: 1.164 L of OMM ha^{-1}. day^{-1}). The high proportion of OMM captured by traps is consistent with other studies monitoring gross pollutants in stormwater networks (Allison & Chiew, 1995; Weideman *et al*., 2020). The proportion of OMM varied by land use categories, with ´Park/Playground/Skate Park' and 'Public open space' areas, for example, having significantly more OMM by dry mass and volume than 'Commercial', 'Retail', and/or 'Transport, Postal, & Warehousing' grounds. This is not surprising given that Park/Playground/Skate Park' and 'Public open space' areas are likely to have more trees and landscaping than commercial and retail sites. This finding has important implications for the installation of new traps and ongoing maintenance of gross pollutant traps.

Weideman *et al*. (2020) found least amount of OMM in industrial areas. While outside the scope of this report, other studies have indicated that OMM or 'green litter' can add to the nutrient load, including nitrogen and phosphorus, in waterways (*e.g*., Madhani *et al*., 2009). Excess nutrient in our freshwater ecosystems is an issue that was highlighted by the Ministry for the Environment (MfE & Stats NZ, 2020).

Litter loading rates & high-risk land uses

In this study traps captured a median of 15.8 litter items ha^{-1}. day^{-1} (5,767 items ha^{-1}. yr^{-1}) and 0.005 kg. ha^{-1}. day^{-1} (1.825 kg. ha^{-1}. yr^{-1}). These loading rates are much lower than those estimated by Weideman *et al*. (2020) in Cape Town South Africa, between 2018 – 2019 (261 items ha^{-1}. day^{-1} or 95,375 items ha^{-1}. yr^{-1}; 0.165 kg. ha^{-1}. day^{-1} or 60.225 kg. ha^{-1}. yr^{-1}).

Litter loading rates varied significantly between land use categories, and several land use categories had significantly higher loading rates than others. Six high-risk land uses were identified: 'Fast food', 'Hospital', 'Playgrounds/skateparks', 'Car parks', 'Retail', and 'Transport, postal and warehousing', where the loading rates were double the median overall loading rate. In contrast 'Hotel/motel', 'Residential' and 'Commercial' land uses had the lowest litter loading rates.

Interestingly, traps in 'Residential-School' areas had a higher median loading rate by item than those in 'Residential' areas although this trend was not significant. This can be expected given the higher traffic level (by foot and vehicles) in residential areas within the vicinity of a school.

There is, unfortunately, a paucity of data available on loading rates from different land use categories in the literature. A study on stormwater discharge in Auckland (Cornelius *et al*. ,1994) indicated that 'Commercial' areas produced a higher litter loading rate (1.4 kg. ha^{-1}. yr^{-1}) than 'Residential' areas (0.5 kg. ha^{-1}. yr^{-1}), which is consistent with the loading rates found in this study ('Commercial': 1.5 kg. ha^{-1}. yr^{-1}; 'Residential': 0.4 kg. ha^{-1}. yr^{-1}) and a study in Coburg, Melbourne, Australia ('Residential': 0.5 kg. ha^{-1}. yr^{-1}; Allison & Chiew, 1995).

According to a national audit conducted by KNZB (2019), 'Industrial' sites were the most littered, followed by 'Retail'. 'Residential' and 'Car Park' areas had moderate densities of litter per 1,000m^2, while 'Public Recreational' sites contributed the least. In Northland, however, 'Retail' sites had the highest number of litter items, followed by 'Residential', 'Industrial', and 'Car Park' sites (KNZB, 2019). 'Industrial' and 'Retail' sites were also associated with the largest litter weights per 1,000 m^2. Findings in this study were not always consistent with the 2019 national audit. This can be expected given the different methodologies employed to assess litter. Differences in the definition of land use categories might also be confounding the results. In this study 'Commercial', 'Fast food', and 'Retail' are all treated as separate land uses. 'Parks/Playground/Skatepark' is also treated as a separate land use to 'Public Open Space'.

Plastics

In terms of material type, 'Plastics' had the highest loading rates by items (11.1 items. ha^{-1}. day^{-1}, 4,033.3 items. ha^{-1}. yr^{-1}) and dry mass (0.0029 kg. ha^{-1}. day^{-1}, 1.059 kg. ha^{-1}. yr^{-1}). These results are consistent with KNZB (2019) litter audits by number of items. But, in their study, KNBZ found that plastics had moderate loading rates by dry mass while glass items contributed the most by weight. This difference is not unexpected given the size and weight of glass bottles, which are often stopped by the grate. No glass bottles were captured in all 51 traps in this study, which would explain why 'Glass & Ceramic' had a much lower loading rate by weight.

Plastic loading rates were significantly higher by items and dry mass in 'Fast food' and 'Hospital' areas, than in 'Commercial', 'Hotel/motel', and 'Residential' land uses. In both 'Fast Food' and 'Hospital' land uses, cigarette butts and filters, which are considered a plastic item, were the prominent litter item (49.0% and 72.6%, respectively). With the addition of soft and hard plastic fragments, these three litter items accounted for 67.9% and 81.5% of litter, at these land uses respectively. Most of the food and beverage packaging sold by fast food chains are used on-the-go and are single-use plastics (Ncube *et al*., 2021). Straw plastic wrappers, for example, represented a further 3.2% of litter.

Hotspots

In this study, nine traps (17.7%) collected more than 50% of the total litter items based on raw count data. These nine hotspots were all located in 'Transport, Postal, & Warehousing', 'Public car park', 'Hospital', 'Retail', 'Fast food' or 'Sports grounds'. Two of these traps (LT10 and LT18) captured disproportionally higher litter items than other traps and accounted for 20% of all litter. LT10, which captured 10.5% of all items was installed in a loading zone at a 'Transport, Postal, & Warehousing' site and LT18, which captured 9.5% of all items was in a 'Public car park' that is surrounded by industrial businesses, which includes loading zones. Another 'hotspot' (LT13), which accounted for another 4.8% of the total litter captured, was located in a good inwards area of a 'Retail' site. Tiddy *et al*. (2021) also found a hotspot in a location with several amenities (*e.g.,* bus stop, cafes, loading zones, etc.), which accounted for 11% of the total litter captured in LittaTraps™ on Waiheke Island. These results indicate that areas such as goods inwards and loading zones, where goods are packaged and unpackaged, are particularly high-risk areas for litter loss.

In contrast the 'best' five sites captured less than 1% of all litter. These five traps were in 'Residential', 'Commercial', 'Local government', and 'Hotel/motel' land uses. All five sites collected less than 50 items a year and the 'best' site captured just 26 items.

Seasonality

Litter quantities were not uniform across the year. The proportion of litter items was significantly ($p < 0.001$) higher in winter by count (32.8%) and lowest in spring (20.1%). In a study using the same type of trap, conducted on Waikehe Island near Auckland, Tidy *et al*. (2021) detected highest gross pollutant quantities in autumn (31%). The authors attributed the findings to natural factors such as an increase in rainfall. Madhani *et al*. (2009) observed that as little as 2.6 mm of rainfall can be adequate to provide a transport mechanism for gross pollutants, such as litter. Social factors also affected gross pollutant loads on Waiheke Island, with the area being a popular tourist location, especially in summer. The difference between the studies highlights the importance of monitoring litter at a local scale, whenever possible.

Comparison to other sites around Whangārei and to other studies

Overall, results from this study were similar in terms of litter composition with data from shoreline surveys at sites around Whangārei (Hātea River and Onerahi) as well as with studies both at the national and international level. Plastic items dominated shoreline audits conducted along the Hātea River (50.6%; Litter Intelligence, unpublished data) and at Onerahi (78.6%, TTTDMP unpublished data). Across Northland, Martinez and Bamford (2021) estimated that 70.4% of marine debris were made of plastics, which is consistent with the rest of the country (70% in 2021; Stats NZ, 2022). The KNZB (2019) audit also identified plastics as the most frequently identified items in the region and in New Zealand. This is further corroborated by litter audits conducted at several sites around New Zealand using traps (*e.g.*, *LittaTrap™-Manfreight*, n.d; *LittaTrap™-Toyota*, n.d; *LittaTrap™-Medical Plastics*, n.d). In South Africa, Weideman *et al*. (2020) also found that plastics were the most prevalent type of litter both numerically (64%) and by mass (52%). Globally, plastic typically represents 60 – 100% of floating debris in estuaries (*e.g., Sadri et al*., 2014; Galgani *et* al., 2015) and in coastal environments (*e.g*., Derraik, 2002; Cunnigham & Wilson, 2003; Lavers *et al.*, 2017; MfE & Stats NZ, 2019; Pasternak *et al*., 2017; van Gool *et al*., 2021)

Litter loads entering aquatic environments

Annually, an estimated 13.2 million items of litter (95% CI: 10.1 – 16.9 million), including 8.7 million plastic items (95% CI: 6.9 – 11.2), is discharged from the stormwater networks in Whangārei, Kerikeri, Kaitāia, Kaikohe, Dargaville, and Mangawhai. This estimate confirms findings from other studies that have shown that litter from non-treated stormwater discharges can act as a large litter contributor to aquatic and coastal environments (*e.g*., Armitage and Rooseboom, 2000a; Willis *et al*., 2017; Chitaka and von Blottnitz, 2019; Weideman *et al.,* 2020; Pasternak *et al.*, 2021; van Gool *et al*., 2021), including microplastic contamination in sediments across Northland (de Lena *et al*., 2021).

Study limitations

This study had several limitations, which were identified as follows:

- Because of logistical and safety limitations, primarily related to weather conditions and staff availability, the sampling interval ranged from nine to 16 days. Sampling for the winter audit was also delayed by up to three weeks because of COVID-19 level 4 lockdown. This might explain the significantly higher proportion of items in winter compared to spring.
- Although effort was taken to represent as many land use categories as possible (n = 16), not all were included (*e.g*., 'Airport', 'State highways'). Furthermore, due to financial constraints, some land use categories had a very low sample size (e.g., Hotel/motel had only one trap).
- This study was conducted during the COVID-19 pandemic, with different levels of restrictions and regulations imposed by the New Zealand government, which included a hard lockdown (Level 4) in August 2021. Between December 2021 and December 2021, Northland experienced all four Alert Levels ("*Unite Against COVID-19*", 2022). Crises such as the COVID-19 pandemic are known to affect consumption patterns and retail mode (online vs offline) as well as pedestrian traffic (Hall *et al*., 2021; Dyason *et al.,* 2022). Therefore, results presented here may not be representative of litter levels in a typical year. Abiotic factors known to affect gross pollutant loading such as wind and rainfall (*e.g.,* Alam *et al.,* 2017; Pasternak *et al*., 2021) and social-economic levels of residential suburbs (Marais *et al*., 2004) were not included here as it was beyond the scope of this study.
- Finally, there is no standardised protocols and methodologies to audit litter captured in traps and catch basin inserts and assess loading rates, including the type and definition of land use categories. In addition, there is a limited amount of scientific literature on litter captured in traps or catch basin inserts, which made comparison with other studies, including in New Zealand, challenging. A lack of a standardised protocol and methodology has been highlighted as an issue in the assessment of plastic and litter pollution (Vermeiren *et al*., 2016).

Recommendations

Litter, including plastics, as gross pollutants

Litter pollution, particularly plastics, is not only a global issue but a "planetary threat" (Borrelle *et al*., 2020). The New Zealand waste and recycling industry is listed as one of the least efficient of all developed countries (OECD, 2017). The reduction of plastic pollution requires an urgent transformative change with a move towards a more circular economy model (Jambeck *et al*., 2018; Borrelle *et al*., 2020; Lau *et al.,* 2020; Shamsuyeva & Endres, 2021). Borrelle *et al*. (2020) provide examples of actions that can be taken to achieve each of the three following strategies: a) reducing waste generation (*e.g.,* ban on single-use plastics); b) improving waste management (*e.g.,* capture and containment of plastic waste); and c) environmental recovery (*e.g.,* clean ups). The recovery of plastic waste needs to be a sustained priority to minimise adverse effects on species and ecosystems (Bucci *et al*., 2020). This study has identified that a significant amount of litter and plastic is reaching the region's coastline each year, and that discharges from urban stormwater is likely to be an important source of litter reaching the coast.

Litter loads do usually correlate with the level and type of human activities, whether that litter is generated intentionally or by accident (Tidy *et al*., 2021). This study has identified six high-risk land uses, where litter loading rates are double the median loading rate and identified nine 'hotspots', which together contributed more than 50% of all litter. Characteristics of these hotspots can be used to identify other potential hotspots. For example, goods inwards, loading zones and areas near waste disposal facilities are likely to have high litter loading rates. These findings can be used to target education and mitigation measures.

Many solutions to reduce plastic pollutions in urban stormwater discharges have been suggested (refer to Armitage, 2007; Weideman *et al*., 2020). Some of these solutions can be implemented relatively easily. For example, high risk land use categories and hotspots can be targeted for education or treatment of stormwater by installing traps or other capture devices to reduce litter reaching the coast. If the 51 traps deployed in this study were all re-deployed to 'hotspots', these could be expected to capture approximately 66,300 items annually compared to the 21,006 items captured in this study. Targeted installation of traps at high-risk land uses such 'Transport, Postal, & Warehousing', and 'Fast food', which also cover relatively small areas of the total urban areas, could achieve relatively high reductions in overall litter loads. Highly selective installation of LittaTraps™ could lead to even larger reductions. For example, installing traps in loading areas or waste disposal areas at retail land use is likely to achieve a much great reduction in litter load than installing traps in the customer car parks. Furthermore, traps and catch basin inserts can reduce sediment build-up in pits and, therefore, on-going maintenance in downstream pipelines (Alam *et al*., 2017). Helinski *et al*. (2021) provides a framework to select plastic pollution capture devices for use in freshwater systems (*e.g.,* booms, receptacles, watercraft devices).

In addition to installing traps in high-risk areas, the amount of litter entering the environment via urban discharges could also be drastically reduced by implementing the following measures (refer to Armitage, 2007; Armitage & Rooseboom, 2000a; Weideman *et al*., 2020; Pasternak *et al*., 2021):

- Improving public awareness and education, including being personally responsible for the waste generated ('Kaitiakitanga'). Japan could be used as an example where strong civic ethic has taught people to respect and keep areas clean for themselves and others (Ong & Sovacool, 2012).
- Placing more bins in areas with particularly high litter loads;

- Improving solid-waste collection services (*e.g*., closed recycling bins); and
- Evaluating street and private areas cleaning operations currently undertaken by local authorities or businesses (*e.g*., increasing the frequency of cleaning efforts and ensuring cleaners collect litter items rather than sweep them into stormwater drains).

Cigarette butts

Cigarette butts contributed more than a third of the total litter pollution in Northland. This category of litter should, therefore, receive more attention in the frame of waste reduction and future policies at the local, regional, and national level. Whangārei parks, playgrounds, outdoor dining, and all other public places are designated as smokefree and vapefree (WDC, 2018), in support of the Central Government's goal of a 'Smokefree Aotearoa 2025' (Ministry of Health, 2021). This study clearly demonstrated that the current policies put in place by Councils and Te Whatu Ora- Health New Zealand Te Taitokerau (formerly Northland District Health Board, NDHB) need to be improved if the region plans to achieve the 2025 government goal. This trend is likely national. In Hamilton, for example, despite an area enforcing a full smoking ban, cigarette butts were still the main item captured in a trap (*LittaTrap*™*-City of Hamilton*, n.d.). Better education and awareness campaigns to strengthen consumer responsibility could be one of the solutions as studies have shown that most smokers do not know that filters are made of synthetic plastic, which are not fully biodegradable (Epperson *et al*., 2021; Kotz & Kastaun, 2021). Smokers holding the belief that cigarette butts are not litter are also more likely to discard them in the environment, including in sewers and gutters (Rath *et al*., 2012). A successful education campaign could, therefore, lead to a significant reduction in the amount of litter and plastic reaching the region's coast. Cigarettes butts accounted for 32.7% of all litter captured in this study so if the number of cigarettes littered was reduced by 50% that could stop over 2.2 million items reaching the coast each year.

Organic matter

Effort should be taken to avoid installing traps near trees and other vegetation within their catchment area to minimise maintenance. Should traps be required in such areas, these must be checked at shorter regularly interval as these might fill up quicker than other traps. Real-time monitoring of traps using sensors could improve the management of such assets (*e.g.*, *Gross pollutant trap sensors,* n.d.). Leaf collection could also be included as part of street cleaning programs, if not already in place. The frequency of these programs could be enhanced in autumn when the production of organic material is high. Alternatively, leaf removal should be conducted prior to precipitation events (Selbig, 2016). This would minimise nutrient transport into streets and stormwater networks as well as reduce the nutrient load in regional waterways (*e.g.*, Janke *et al*., 2007).

Conclusion

This study presents the first empirical survey on the composition and loads of gross pollutants, focusing on litter, from urban stormwater in Northland. Consistent with global trends, results indicated most of the 21,006 litter items were made of plastic (~70%), with cigarette butts being the most discarded item (~30%). Litter loading rates varied significantly between land use categories and six high risk land uses: 'Fast food', 'Retail', 'Hospital', 'Playgrounds/skateparks', 'Car parks' and 'Transport, postal and warehousing', were identified. This study estimated that annually over 13.2 million litter items are discharged from six urban stormwater networks in Northland, including 8.7 million plastic items, indicating that non-treated urban discharges are an important source of litter and plastics to aquatic environments.

The findings in the study can be used to target education and mitigation measures to reduce the amount of litter reaching the coast. The identification of cigarette butts as a high frequency item and six high-risk land uses can be used to target education and mitigation. An educational campaign targeting littering (particularly cigarette littering) combined with the provision of bins, regular site cleaning, and installation of LittaTraps™ or similar devices at high-risk land uses could lead to significant reductions in litter loads reaching Northland's coast.

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Data availability

Whenever possible, data collected from each LittaTrap™ were shared with Litter Intelligence, a project from Sustainable Coastlines, which can be accessed online.

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Appendices

Appendix 1: Auditing of the LittaTraps^{TM} between February and December 2021

Table 1A: Sampling timeline of LittaTraps^{TM} content in all three districts of Northland (Far North, Kaipara, and Whangārei) between March and December 2021.

	Summer	Autumn	Winter	Spring
	48	51	50*	48
	28/02/2021 to 07/03/2021	02/06/2021 to 09/06/2021	13/09/2021 to 20/09/2021	30/11/2021 to 01/12/2021
	26/02/2021 to 15/03/2021	11/06/2021	28/09/2021 to 30/09/2021	14/12/2021
	02/03/2021	08/06/2021	29/09/2021	15/12/2021

* Covid-19 level 4 lockdown (18/08/2021 – 02/09/2021)

Appendix 2: Results of Dunn-Bonferroni tests

Table 2A: Results of a Dunn-Bonferroni test (significant results only, $p < 0.05$) conducted to detect differences in litter loading rates by item (n. ha^{-1}. day^{-1}) captured by LittaTraps™ located in various types of land use in Northland in 2021.

District	Test Statistic	SE	Std. Test Statistic	p-value
Commercial - Hospital	-64.2	18.92	-3.39	0.011
Fast food - Commercial	85.7	21.77	3.94	0.001
Fast food - Hotel/motel	122.42	32.92	3.72	0.003
Fast food - School	112.21	23.28	4.82	< 0.001
Fast food - Residential	111.54	21.77	5.12	< 0.001
Fast food - Light industrial	81.92	26.02	3.15	0.026
Fast food - Tertiary education	87.92	26.02	3.38	0.012
Hospital - Hotel/motel	100.92	31.1	3.24	0.019
Hospital - School	90.71	20.63	4.4	< 0.001
Hospital - Residential	90.04	18.92	4.76	< 0.001
Park/Playground/skate park - Commercial	78.2	23.76	3.29	0.016
Park/Playground/skate park - Hotel/motel	114.92	34.26	3.35	0.013
Park/Playground/skate park - School	104.71	25.14	4.16	< 0.001
Park/Playground/skate park - Residential	104.04	23.76	4.38	< 0.001
Public car park - School	80.13	20.16	3.98	0.001
Public car park - Residential	79.46	18.4	4.32	< 0.001
Retail - Residential	67.47	22.33	3.02	0.04
Transport, Postal, & Warehousing - Commercial	78.91	24.69	3.2	0.022
Transport, Postal, & Warehousing - Hotel/motel	115.63	34.91	3.31	0.015
Transport, Postal, & Warehousing - School	105.42	26.02	4.05	0.001
Transport, Postal, & Warehousing - Residential	104.75	24.69	4.24	< 0.001

Table 2B: Results of a Dunn-Bonferroni test (significant results only, $p < 0.05$) conducted to detect differences in litter loading rates by dry mass (kg. ha^{-1}. day^{-1}) captured by LittaTraps™ located in various types of land use in Northland in 2021.

District	Test Statistic	SE	Std. Test Statistic	p-value
Commercial - Hospital	-61.137	18.862	-3.241	0.019
Fast food - Commercial	86.292	21.706	3.975	0.001
Fast food - Sports ground	66.698	21.706	3.073	0.034
Fast food - Hotel/motel	128.792	32.816	3.925	0.001
Fast food - Local Government office	74.604	21.706	3.437	0.009
Fast food - Tertiary education	83.104	25.944	3.203	0.022
Hospital - Hotel/motel	103.637	31.008	3.342	0.013
Park/Playground/skate park - School	81.681	25.064	3.259	0.018
Park/Playground/skate park - Residential	119.910	23.683	5.063	<.001
Park/Playground/skate park - Commercial	88.097	23.683	3.720	0.003
Park/Playground/skate park - Hotel/motel	130.597	34.156	3.824	0.002
Park/Playground/skate park - Local Government office	76.410	23.683	3.226	0.02
Park/Playground/skate park - Tertiary education	84.910	27.619	3.074	0.034
Public car park - Residential	89.417	18.345	4.874	<.001
Public car park - Commercial	57.604	18.345	3.140	0.027
Public car park - Hotel/motel	100.104	30.697	3.261	0.018
Retail - Residential	91.778	22.263	4.123	0.001
Retail - Hotel/motel	102.466	33.187	3.087526	0.032
Residential - Fast food	-118.104	21.706	-5.441	<.001
Residential - Transport, Postal, & Warehousing	-98.438	24.612	-3.400	<.001
Residential - Hospital	-92.949	18.862	-4.928	<.001
School - Fast food	-79.875	23.205	-3.442	0.009
Transport, Postal, & Warehousing - Hotel/motel	109.125	34.807	3.135	0.027

Table 2C: Results of a Dunn-Bonferroni test (significant results only, $p < 0.05$) conducted to detect differences in organic matter and minerals loading rate by dry mass (kg. ha^{-1}. day^{-1}) captured by LittaTraps™ located various land use categories in Northland in 2021.

District	Test Statistic	SE	Std. Test Statistic	p-value
Commercial - Park/Playground/skate park	-83.16	25.31	-3.29	0.016
Commercial - Public open space	-85.47	24.18	-3.53	0.007
Fast food - Retail	72.63	23.31	3.12	0.029
Fast food - Transport, Postal, & Warehousing	92.06	25.49	3.61	0.005
Hospital - Park/Playground/skate park	-79.61	24.69	-3.22	0.02
Hospital - Public open space	-81.92	23.54	-3.48	0.008
Local Government offices - Public open space	-76.69	24.18	-3.17	0.024
Park/Playground/skate park - Retail	95.5	27	3.54	0.006
Park/Playground/skate park - Transport, Postal, & Warehousing	114.94	28.9	3.98	0.001
Public open space - Retail	97.81	25.95	3.77	0.003
Public open space - School	80.19	25.49	3.15	0.026
Public open space - Transport, Postal, & Warehousing	117.25	27.92	4.2	<.001
Tertiary education - Transport, Postal, & Warehousing	86.06	27.92	3.08	0.033

Table 2D: Results of a Dunn-Bonferroni test (significant results only, $p < 0.05$) conducted to detect differences in plastic litter loading rates by item (n. ha^{-1}. day^{-1}) captured by LittaTraps™ located in various types of land use in Northland in 2021.

District	Test Statistic	SE	Std. Test Statistic	p-value
Commercial - Fast food	-96.667	21.772	-4.440	< 0.001
Commercial - Hospital	-72.131	18.919	-3.813	0.002
Commercial - Park/Playground/skate park	-74.639	23.756	-3.142	0.027
Commercial - Public car park	-57.542	18.401	-3.127	0.028
Commercial - Transport, Postal & Warehousing	-79.750	24.687	-3.230	0.02
Fast food - Hotel/motel	115.167	32.917	3.499	0.007
Fast food - Light industrial	94.4797	26.023	3.6301	0.005
Fast food - Residential	126.1357	21.77	5.793	<.001
Fast food - School	119.250	23.276	5.123	< 0.001
Fast food - Sports ground	72.604	21.77	3.335	0.014
Fast food - Tertiary education	99.042	26.023	3.806	0.002
Hospital - Residential	101.600	18.919	5.370	< 0.001
Hospital - School	94.714	20.632	4.591	< 0.001
Hospital - Tertiary education	74.506	23.688	3.145	0.027
Local Government office - Residential	63.781	20.157	3.1644	0.025
Park/Playground/skate park - Residential	104.108	23.756	4.383	< 0.001
Park/Playground/skate park - School	97.222	25.140	3.8676	0.002
Public car park - Residential	87.010	18.401	4.723	< 0.001
Public car park - School	80.125	20.157	3.975	0.001
Residential - Retail	-70.673	22.331	-3.165	0.025
Residential - Transport, Postal & Warehousing	-109.219	24.687	-4.424	< 0.001
School - Transport, Postal & Warehousing	-102.333	26.023	-3.933	0.001

Table 2E: Results of a Dunn-Bonferroni test (significant results only, $p < 0.05$) conducted to detect differences in plastic litter loading rates by dry mass (kg. ha^{-1}. day^{-1}) captured by LittaTraps™ located in various types of land use in Northland in 2021.

District	Test Statistic	SE	Std. Test Statistic	p-value
Commercial - Fast food	-96.073	21.766	-4.414	< 0.001
Commercial - Hospital	-69.490	18.914	-3.674	0.004
Commercial - Public car park	-59.281	18.396	-3.223	0.02
Commercial - Transport, Postal & Warehousing	-74.844	24.680	-3.033	0.039
Fast food - Hotel/motel	113.667	32.907	3.454	0.009
Fast food - Local Government office	73.510	21.766	3.377	0.012
Fast food - Residential	126.479	21.766	5.811	< 0.001
Fast food - School	98.625	23.269	4.239	< 0.001
Fast food - Sports ground	72.448	21.766	3.329	0.014
Hospital - Residential	99.896	18.914	5.282	< 0.001
Hospital - School	72.0417	20.626	3.493	0.008
Park/Playground/skate park - Residential	98.451	23.749	4.146	0.001
Park/Playground/skate park - School	70.597	25.133	2.809	0.08
Public car park - Residential	89.688	18.396	4.876	< 0.001
Public car park - School	61.833	20.152	3.068	0.034
Residential - Retail	-88.108	22.324	-3.947	0.001
Residential - Transport, Postal & Warehousing	-105.250	24.681	-4.2651	< 0.001
School - Transport, Postal & Warehousing	-77.396	26.016	-2.975	0.047

Appendix 3: Loading rates of the top 10 ten litter items per land use category

Table 3A: Loading rates by item (n. ha^{-1}. day^{-1}) and land use category of the top 10 litter items captured by LittaTraps™ in Northland in 2021. Cigarette butts, the top item in the region is highlighted.

Land use	1st item	2nd item	3rd item	4th item	5th item	6th item	7th item	8th item	9th item	10th item
Commercial	Hard plastic fragments 3.618	**Cigarette butts 2.371**	Other plastics 1.931	Soft plastic fragments 1.687	Polystyrene insulation or packaging 1.491	Construction material (Glass) 0.489	Unidentified paper & cardboard 0.464	Foil wrappers & packaging 0.464	Unidentified metal fragments 0.244	Plastic label 0.196
Fast food	**Cigarette butts 26.393**	Soft plastic fragments 10.167	Foil wrappers & packaging 3.288	Hard plastic fragments 3.075	Unidentified paper & cardboard 1.248	Unidentified metal fragments 0.913	Cardboard boxes & fragments 0.852	Glass fragments 0.731	Plastic label 0.731	Chewing gum 0.639
Hospital	**Cigarette butts 24.526**	Soft plastic fragments 2.069	Hard plastic fragments 1.096	Other metal 0.838	Foil wrappers & packaging 0.786	Other plastic 0.507	Chewing gum 0.445	Unidentified paper & cardboard 0.424	Plastic food wrappers 0.352	Construction material (Glass) 0.331
Hotel/Motel	**Cigarette butts 1.507**	Soft plastic fragments 1.130	Hard plastic fragments 0.377	Plastic tape 0.188	Plastic food wrappers 0.188	Plastic bottle caps & lids 0.188	Metal bottle caps & lids 0.094	Plastic rope, twine, & string 0.094	Plastic film 0.094	Plastic cable ties & zip ties 0.094
Light industrial	Soft plastic fragments 2.101	**Cigarette butts 1.319**	Hard plastic fragments 0.977	Glass fragments 0.880	Foil wrappers & packaging 0.537	Plastic bags 0.537	Construction material (Glass) 0.489	Unidentified paper & cardboard 0.391	Polystyrene insulation or packaging 0.391	Plastic cable ties & zip ties 0.244
Local gov. office	**Cigarette butts 11.431**	Soft plastic fragments 6.132	Hard plastic fragments 3.974	Foil wrappers & packaging 2.257	Other-No other categories 1.374	Other plastics 1.128	Unidentified paper & cardboard 1.030	Polystyrene insulation or packaging 0.834	Unidentified metal fragments 0.442	Plastic food wrappers 0.442
Park/Playground/Skate Park	Glass fragments 9.529	**Cigarette butts 8.011**	Hard plastic fragments 6.917	Soft plastic fragments 5.152	Construction material (Glass) 4.270	Foil wrappers & packaging 2.647	Rubber fragments 2.082	Other plastic 1.341	Plastic bottle caps & lids 0.776	Plastic label 0.671
Public car park	**Cigarette butts 15.329**	Soft plastic fragments 9.371	Hard plastic fragments 3.830	Processed timber & pallet crates 1.964	Foil wrappers & packaging 1.898	Polystyrene insulation or packaging 1.854	Other plastics 1.547	Glass fragments 1.053	Unidentified paper & cardboard 1.020	Construction material (Glass) 0.691
Public open space	**Cigarette butts 4.253**	Soft plastic fragments 3.130	Hard plastic fragments 1.605	Glass fragments 1.164	Foil wrappers & packaging 0.963	Plastic label 0.441	Plastic food wrappers 0.441	Wooden utensils 0.401	Construction material (Glass) 0.241	Plastic bottle seals & liners 0.201

Residential	Polystyrene insulation or packaging 0.804	Soft plastic fragments 0.387	Hard plastic fragments 0.298	Other plastics 0.268	**Cigarette butts 0.209**	Construction material (Glass) 0.164	Foil wrappers & packaging 0.134	Glass fragments 0.119	Unidentified paper & cardboard 0.060	Unidentified metal fragments 0.045
Residential-School zone	Hard plastic fragments 3.416	Soft plastic fragments 2.720	Other plastics 2.340	**Cigarette butts** 1.929	Foil wrappers & packaging 0.791	Other-No other categories 0.506	Construction material (Glass) 0.411	Unidentified paper & cardboard 0.380	Synthetic stuffing 0.348	Plastic bottle caps & lids 0.348
Retail	**Cigarette butts** 6.252	Soft plastic fragments 6.236	Polystyrene insulation or packaging 4.297	Unidentified paper & cardboard 2.956	Processed timber & pallet crates 1.971	Hard plastic fragments 1.809	Plastic label 0.743	Cardboard boxes & fragments 0.678	Foil wrappers & packaging 0.646	Plastic sheeting 0.630
School	Soft plastic fragments 0.727	Foil wrappers & packaging 0.397	Unidentified paper & cardboard 0.317	**Cigarette butts** 0.278	Natural rope, line, or string 0.198	Plastic food wrappers 0.172	Rubber bands 0.106	Plastic film 0.093	Glass fragments 0.079	Hard plastic fragments 0.053
Sports grounds	**Cigarette butts** 5.808	Glass fragments 2.146	Soft plastic fragments 2.146	Hard plastic fragments 1.573	Other plastics 1.389	Foil wrappers & packaging 1.195	Construction material (Glass) 0.321	Polystyrene insulation or packaging 0.321	Plastic food wrappers 0.243	Other metal 0.233
Tertiary education	Glass fragments 3.227	**Cigarette butts** 3.082	Hard plastic fragments 0.869	Soft plastic fragments 0.593	Foil wrappers & packaging 0.382	Other plastics 0.263	Unidentified metal fragments 0.171	Unidentified paper & cardboard 0.132	Plastic food wrappers 0.119	Plastic bottles < 2L 0.053
Transport, Postal, & Warehousing	Soft plastic fragments 26.083	Polystyrene insulation or packaging 12.123	**Cigarette butts** 4.133	Hard plastic fragments 3.949	Plastic nurdles 3.720	Plastic sheeting 3.490	Unidentified paper & cardboard 2.778	Processed timber & pallet crates 2.273	Foil wrappers & packaging 0.895	Paper 0.827

Table 3B: Loading rates by dry mass (kg. ha^{-1}. day^{-1}) and land use category of the top 10 litter items captured by LittaTraps^{TM} in Northland in 2021. Cigarette butts, the top item in the region is highlighted.

Land use	1st item	2nd item	3rd item	4th item	5th item	6th item	7th item	8th item	9th item	10th item
Commercial	Hard plastic fragments 0.00090	Construction material (Metal) 0.00057	Other plastics 0.00051	**Cigarette butts** 0.00032	Construction material (Glass) 0.00023	Soft plastic fragments 0.00021	Plastic film 0.00018	Metal bottle caps & lids 0.00017	Unidentified metal fragments 0.00015	Plastic bottle caps & lids 0.00009
Fast food	**Cigarette butts 0.0040**	Soft plastic fragments 0.0018	Plastic bottle caps & lids 0.0010	Wipes 0.0008	Other metal 0.0006	Foil wrappers & packaging 0.00054	Hard plastic fragments 0.00053	Chewing gum 0.00052	Cigarette lighters 0.00049	Construction material (Metal) 0.00046
Hospital	**Cigarette butts 0.00451**	Construction material (Glass) 0.00093	Construction material (Metal) 0.00053	Soft plastic fragments 0.00051	Chewing gum 0.00041	Plastic tape 0.00036	Hard plastic fragments 0.0023	Other plastics 0.00023	Foil wrappers & packaging 0.00017	Plastic food wrappers 0.00011
Hotel/Motel	Plastic bottle caps & lids 0.00040	**Cigarette butts 0.00026**	Plastic tape 0.00006	Soft plastic fragments 0.00004	Plastic food wrappers 0.00004	Metal bottle caps & lids 0.00003	Plastic film 0.00001	Hard plastic fragments < 0.00001	Stuffing & alternative down < 0.00001	Plastic rope, twine, string < 0.00001
Light industrial	Construction material (Metal) 0.00065	Construction material (Glass) 0.00053	Soft plastic fragments 0.00053	Rubber fragments 0.00043	Unidentified paper & cardboard 0.00034	Glass fragments 0.00032	Hard plastic fragments 0.00029	Plastic bags 0.00028	**Cigarette butts 0.00024**	Plastic bottle caps & lids 0.00018
Local gov. office	Construction material (Glass) 0.00176	**Cigarette butts 0.00115**	Hard plastic fragments 0.00079	Soft plastic fragments 0.00041	**Cigarette lighters 0.00040**	Foil wrappers & packaging 0.00026	Unidentified metal fragments 0.00019	Plastic pens & stationery 0.00017	Plastic food wrappers 0.00016	Other- No other categories 0.00012
Park/Playground/Skate Park	Glass fragments 0.0161	Rubber footwear 0.0039	Construction material (Glass) 0.0021	**Cigarette lighters 0.0013**	Hard plastic fragments 0.0009	Plastic bottle caps & lids 0.0008	Foil wrappers & packaging 0.0007	Processed timber & pallet crates 0.0007	Soft plastic fragments 0.0005	Plastic pens & stationery 0.0004
Public car park	Processed timber & pallet crates 0.0041	**Cigarette lighters 0.0020**	Hard plastic fragments 0.0013	Soft plastic fragments 0.0012	Construction material (Glass) 0.0008	Plastic bottle caps & lids 0.0007	Glass fragments 0.0006	Foil wrappers & packaging 0.0005	Paper cups, food trays & wrappers 0.0004	Other plastics 0.0004
Public open space	Construction material (Glass) 0.00092	**Cigarette lighters 0.00051**	Wooden utensils 0.00037	Metal bottle caps & lids 0.00029	Glass fragments 0.00026	Soft plastic fragments 0.00025	Hard plastic fragments 0.00023	Plastic bottle caps & lids 0.00021	Plastic film 0.00019	Plastic food containers 0.00016
Residential	Construction material (Glass) 0.000128	Glass fragments 0.000088	**Cigarette lighters 0.000078**	Hard plastic fragments 0.000070	Aluminium & tin cans 0.000062	Paper cups, food trays & wrappers 0.000059	Corks 0.000059	Soft plastic fragments 0.000059	Paraffin or wax 0.000050	Other plastics 0.000045

Residential-School zone	Construction material (Metal) 0.00526	Hard plastic fragments 0.00087	Plastic bottle caps & lids 0.00081	Construction material (Glass) 0.00056	Other plastics 0.00052	Wipes 0.00031	Plastic vehicle parts 0.00028	Unidentified paper & cardboard 0.00027	Soft plastic fragments 0.00026	**Cigarette lighters 0.00022**
Retail	Plastic sheeting 0.00232	Soft plastic fragments 0.00171	Processed timber & pallet crates 0.00170	Cardboard boxes & fragments 0.00113	**Cigarette lighters 0.00135**	Unidentified paper & cardboard 0.00113	Plastic tape 0.00089	Plastic bottle caps & lids 0.00070	Hard plastic fragments 0.00064	Plastic bags 0.00064
School	Construction material (Glass) 0.00054	Foil wrappers & packaging 0.00041	Other metal 0.00038	Soft plastic fragments 0.00029	Glass fragments 0.00024	Plastic food wrappers 0.00021	Plastic bottles < 2L 0.00020	**Cigarette lighters 0.00016**	Hard plastic fragments 0.00015	Plastic pens & stationery 0.00014
Sports grounds	Construction material (Glass) 0.00102	**Cigarette lighters 0.00092**	Paper cups, food trays & wrappers 0.00049	Glass fragments 0.00037	Hard plastic fragments 0.00034	Plastic bottles < 2L 0.00028	Plastic bottle caps & lids 0.00023	Foil wrappers & packaging 0.00023	Metal bottle caps & lids 0.00016	Soft plastic fragments 0.00015
Tertiary education	Plastic bottles < 2L 0.00102	Glass fragments 0.00073	Plastic toys, sport & recreation 0.00048	**Cigarette lighters 0.00037**	Aluminium & tin cans 0.00029	Processed timber & pallet crates 0.00017	Hard plastic fragments 0.00015	Other plastics 0.00013	Plastic tape 0.00013	Soft plastic fragments 0.00009
Transport, Postal, & Warehousing	Soft plastic fragments 0.0038	Plastic sheeting 0.0030	Hard plastic fragments 0.0017	Polystyrene insulation or packaging 0.0010	Construction material (Glass) 0.0009	Processed timber & pallet crates 0.0007	Ceramic fragments 0.0006	**Cigarette lighters 0.0005**	Paper 0.0004	Unidentified paper & cardboard 0.0004

Table 3C. Loading rates by item (n. ha^{-1}. day^{-1}) of the top 10 litter items captured by LittaTraps™ in Northland in 2021.

Location	Top item	2nd item	3rd item	4th item	5th item
Northland	Cigarette butts, filters 8.305 n.ha^{-1}.day^{-1} 3,031.1 n.ha^{-1}.year^{-1}	Soft plastic fragments 4.516 n.ha^{-1}.day^{-1} 1,648.2 n.ha^{-1}.year^{-1}	Hard plastic fragments 2.075 n.ha^{-1}.day^{-1} 757.5 n.ha^{-1}.year^{-1}	Glass fragments 1.180 n.ha^{-1}.day^{-1} 430.8 n.ha^{-1}.year^{-1}	Other plastics 0.828 n.ha^{-1}.day^{-1} 302.7 n.ha^{-1}.year^{-1}

	6th item	7th item	8th item	9th item	10th item
Northland	Unidentified paper & cardboard 0.732 n.ha^{-1}.day^{-1} 267.1 n.ha^{-1}.year^{-1}	Foil wrappers & packaging 0.714 n.ha^{-1}.day^{-1} 260.4 n.ha^{-1}.year^{-1}	Processed timber & pallet crates 0.537 n.ha^{-1}.day^{-1} 196.0 n.ha^{-1}.year^{-1}	Construction material (Glass & ceramic) 0.416 n.ha^{-1}.day^{-1} 151.8 n.ha^{-1}.year^{-1}	Polystyrene insulation or packaging 0.111 n.ha^{-1}.day^{-1} 40.6 n.ha^{-1}.year^{-1}

Table 3D. Loading rates by item (kg. ha^{-1}. day^{-1}) of the top 10 litter items captured by LittaTraps™ in Northland in 2021.

Location	Top item	2nd item	3rd item	4th item	5th item
Northland	Cigarette butts, filters 0.0013 Kg.ha^{-1}.day^{-1} 0.484 Kg.ha^{-1}.year^{-1}	Glass fragments 0.0008 Kg.ha^{-1}.day^{-1} 0.292 Kg.ha^{-1}.year^{-1}	Soft plastic fragments 0.0007 Kg.ha^{-1}.day^{-1} 0.265 Kg.ha^{-1}.year^{-1}	Processed timber & pallet crates 0.0007 Kg.ha^{-1}.day^{-1} 0.251 Kg.ha^{-1}.year^{-1}	Construction material (Glass & ceramic) 0.0006 Kg.ha^{-1}.day^{-1} 0.233 Kg.ha^{-1}.year^{-1}

	6th item	7th item	8th item	9th item	10th item
Northland	Hard plastic fragments 0.0006 Kg.ha^{-1}.day^{-1} 0.202 Kg.ha^{-1}.year^{-1}	Construction material (Metal) 0.0004 Kg.ha^{-1}.day^{-1} 0.132 Kg.ha^{-1}.year^{-1}	Plastic sheeting 0.0003 Kg.ha^{-1}.day^{-1} 0.125 Kg.ha^{-1}.year^{-1}	Plastic bottle caps & lids 0.0003 Kg.ha^{-1}.day^{-1} 0.110 Kg.ha^{-1}.year^{-1}	Foil wrappers & packaging 0.0002 Kg.ha^{-1}.day^{-1} 0.088 Kg.ha^{-1}.year^{-1}

Appendix 4: Litter captured in a year by each LittaTraps™

Table 4A: Percentage of total litter captured in a year in each of the 51 traps in Northland in 2021.

LittaTrap™ Number	Land Use	Count .year^{-1}	% total count	n. ha^{-1}. day^{-1}
LT10	Transport, Postal, & Warehousing	2,409	10.5	78.617
LT18	Public car park	2,178	9.5	351.810
LT29	Hospital	1,166	5.1	62.704
LT28	Hospital	1,150	5.0	148.708
LT13	Retail	1,100	4.8	73.007
LT41	Park/Playground/Skate Park	989	4.3	47.349
LT24	Hospital	951	4.2	120.915
LT07	Public car park	892	3.9	37.437
LT34	Retail	863	3.8	51.239
LT20	Sport grounds	840	3.7	29.450
LT01	Fast-food	781	3.4	53.066
LT25	Hospital	701	3.1	100.199
LT02	Fast-food	693	3.0	47.874
LT22	Sport grounds	623	2.7	11.806
LT09	Park/Playground/Skate Park	582	2.5	35.300
LT52	Tertiary education	481	2.1	8.965
LT55	Local Government Office	439	1.9	69.709
LT11	Transport, Postal, & Warehousing	438	1.9	34.097
LT05	Park/Playground/Skate Park	422	1.8	117.466
LT08	Public car park	346	1.5	53.218
LT06	Public car park	333	1.5	10.987
LT17	Commercial	320	1.4	114.848
LT27	Hospital	297	1.3	3.748
LT03	Fast-food	294	1.3	84.569
LT47	Residential-School zone	285	1.2	17.400
LT04	Public car park	264	1.2	16.406
LT53	Tertiary education	254	1.1	11.491
LT46	School	218	1.0	8.139
LT42	Public car park	216	0.9	26.331
LT38	Public open space	214	0.9	13.939
LT21	Sport grounds	213	0.9	16.086
LT16	Commercial	209	0.9	30.381
LT40	Residential-School zone	183	0.8	12.586
LT48	School	174	0.8	6.011
LT23	Sport grounds	167	0.7	16.790
LT19	Public open space	149	0.6	16.348
LT54	Local Government Office	131	0.6	23.794
LT12	Retail	125	0.5	3.632
LT37	Light industrial	122	0.5	7.599
LT26	Hospital	83	0.4	12.267
LT36	Residential	82	0.4	2.565
LT45	Residential	72	0.3	8.626
LT43	Light industrial	70	0.3	18.574
LT50	Local Government Office	69	0.3	14.546
LT33	School	69	0.3	3.544
LT35	Residential	66	0.3	23.423
LT32	Hotel/Motel	44	0.2	3.544
LT51	Local Government Office	36	0.2	2.565
LT31	Commercial	33	0.1	2.212
LT30	Commercial	27	0.1	1.581
LT39	Residential	23	0.1	1.034

Appendix 5: Extrapolations of litter reaching waterways in Northland

Table 5A: Estimates of the annual number of litter items released from urban stormwater with the 95% confidence intervals in Whangārei and other towns around Northland, based on data captured by 51 LittaTraps™ in 2021. Estimates of the annual number of litter items per person are also provided.

Locations	Total catchment area (ha)*	Median estimated litter yr^{-1} with 95% CI*	Median estimated litter yr^{-1} $person^{-1}$ with 95% CI*
Whangārei	1,294.8	7,478,911.4 (5,743,223.8 – 9,605,023.4)	136.2 (104.6 – 175.0)
Kaitāia	214.6	1,239,458.7 (951,808.1 – 1,591,813.2)	195.5 (150.1 – 251.1)
Kerikeri	317.3	1,832,596.1 (1,407,291.6 – 2,353,568.2)	227.4 (174.6 – 292.0)
Kaikohe	147.0	849,174.2 (652,099.9 – 1,090,578.2)	173.3 (133.1 – 222.6)
Mangawhai	101.2	584,692.9 (448,998.8 – 750,909.9)	453.3 (348.1 – 582.1)
Dargaville	204.9	1,183,479.8 (908,820.7 – 1,519,920.6)	225.9 (173.4 – 290.1)
TOTAL	**2,279.8**	**13,168,313.1 (10,112,243.0 – 16,911,813.6)**	

* Total value

Table 5B: Estimates of the annual number of plastic litter items released from urban stormwater with the 95% confidence intervals in Whangārei and other towns around Northland, based on data captured by 51 LittaTraps™ in 2021. Estimates of the annual number of litter items per person are also provided.

Locations	Total catchment area (ha)*	Median estimated plastic litter yr^{-1} with 95% CI*	Median estimated plastic litter yr^{-1} $person^{-1}$ with 95% CI*
Whangārei	1,294.8	4,951,330.6 (3,917,952.9 – 6,345,260.7)	90.2 (71.4 – 115.6)
Kaitāia	214.6	820,569.9 (649,311.2 – 1,051,582.0)	129.4 (102.4 – 165.9)
Kerikeri	317.3	1,213,250.0 (960,036.1 – 1,554,811.8)	150.5 (119.1 – 192.9)
Kaikohe	147.0	562,186.4 (444,854.1 – 720,456.7)	114.7 (90.8 – 147.0)
Mangawhai	101.2	387,089.5 (306,301.2 – 496,065.4)	300.1 (118.3 – 191.6)
Dargaville	204.9	783,509.7 (619,985.7 – 1,004,088.4)	149.5 (118.3 – 191.6)
TOTAL	**2,279.8**	**8,717,936.1 (6,898,441.2 – 11,172,265.0)**	

* Total value

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