Log residues from storage stacks and the possible effect on air quality: A case study at the Port of Tauranga.

A dissertation submitted in partial fulfilment of the requirements for the degree of Bachelor of Forestry Science with Honours by:

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Abstract:

Air quality has been a concern of the Mt. Maunganui Industrial Area mainly due to dust emissions. The Mt. Maunganui Industrial Area has breached rule 17 regarding PM_{10} in the NES-AQ bringing these environmental issues to the forefront. Residue from log storage is a known source of fugitive dust. However, the implications of log storage on air quality is unknown.

A line transect sampling method with $1m^2$ quadrants was used to measure residues less than 4mm x 4mm in log rows (g/m^2). There were four treatments analysed separating bark-on and debarked log rows both before and after sweeping.

Bark-on rows have higher amounts of residue both before (447 g/m^2) and after (119 g/m^2) sweeping and scraping compared to debarked rows (119 g/m^2 and 19 g/m^2 respectively). On average the sweepers and scrapers removed 91% of fine residue from bark-on rows and 84% of fine residue from debarked rows. Debarked rows post cleaning on average had half the residue (19 g/m^2) of bark-on rows (40 g/m^2). This residue remaining in exposed rows could potentially become airborne fugitive or nuisance dust.

From the four samples tested, the particle size range analysis indicated that 1.3% of the samples were under PM_{10}, and 13.7% was <60 µm which is the fraction which can become airborne for prolonged periods of time. Additionally, on average 72% of the dry weight was inorganic particulate matter.

Some considerations for improving dust management and suppression include reducing time periods where log rows are exposed, increasing the amount of debarked wood supplied, ensuring rows are cleaned before new logs are reloaded in and improving machine design.

This study showed that large volumes of residues are left immediately after logs are removed, however the current cleaning mechanisms remove large proportions, with only a fraction of what is remaining being < PM_{10}.

Key words: *air quality, log storage, raw wood material storage, debarked logs, bark-on logs, log residue, diffuse dust, fugitive dust,* PM_{10}, *Tauranga, New Zealand.*

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Contents:

1. Introduction

Air quality at the Mt. Maunganui Industrial Area (MMIA) is of concern mainly due to dust emissions (Omundsen, 2019). Air quality has been below acceptable levels on many occasions over the past several years though it is now becoming a priority issue for the Bay of Plenty Regional Council. The number of industrial air emissions have increased significantly over the past decade and correspond to an increase in activity in the MMIA (Omundsen, 2019). The MMIA includes the Port of Tauranga (PoT) as well as other industrial and commercial businesses located within a close proximity (Figure 1). The PoT itself has many different lessees. Activities range from light and heavy industry, commercial ventures and the large area of the PoT at which bulk cargo is loaded and unloaded. Not only is the Mt. Industrial area complex in terms of the range of activities, the operations and environments surrounding the area are extremely sensitive in all directions, and include recreation areas with ecological reserves, residential areas, commercial areas and the ocean used for fishing.

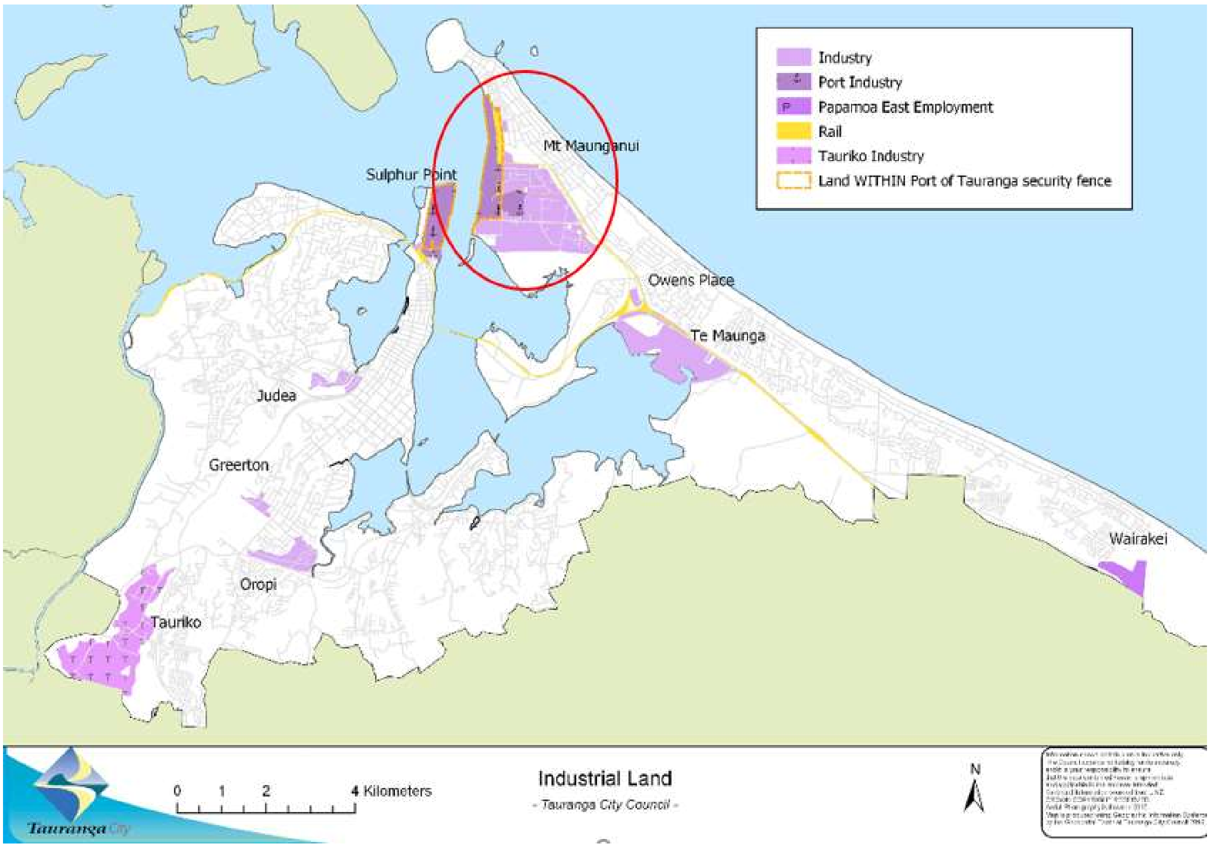

Figure 1. Mount Maunganui Industrial Area. Sourced: Anon, 2018.

The key air quality concerns in the Mt. Maunganui area have been dust, odour and the use of Methyl Bromide as a fumigant (Omundsen, 2019). There has been an increasing number of complaints from the public on air quality; there were over 147 complaints directly related to air quality in 2018 alone but not all directly related to log and bulk operations. Assessing air quality in a complex operating environment such as the MMIA is extremely difficult due to the multitude of sources with which the contaminant could be derived from. Many of these particles have similar signatures (plant material and mineral soil) making it difficult to attribute any dust event to a particular source or operation.

Air quality that does not meet the national environmental standards start a process whereby a regional council must improve air quality directly or set in place an air shed which constrains any further activities that might have a cumulative effect on the poor air quality. An air shed is a volume of air in a certain area which activities discharge into (Ministry for the Environment [MfE], 2002). It can be designated by any of the unitary authorities, regional or district councils (responsible for managing air quality) which is then gazetted by the Minister (Ministry for the Environment [MfE], 2016). Currently there is no air shed in place in the Mt Maunganui or greater Tauranga region. This is currently being reassessed. At present all operations within the MMIA must follow and comply with the National Environmental Standards for Air Quality (NES-AQ), and Regional Natural Resources Plan, Plan Change 13 – Air Quality. These require that PM_{10} levels must not exceed 50mg/m^3 on average over a 24 hour period and for SO_2, it must not exceed 350mg/m^3 average over the period of an hour (Ministry for Primary Industries [MPI], 2004).

PM_{10} is particulate matter under 10 microns (μm) which can cause serious short- and long-term health conditions if inhaled because once it is in the lungs it stays there (United States Environmental Protection Authority [US EPA], 2019). The BOPRC expanded their PM_{10} and SO_2 monitoring in late 2018 and now have a total of 9 PM_{10} monitoring stations located around the MMIA (Rata St, Totara St, Rail Yard South, Whareroa Marae and Sulphur Point) (Bay of Plenty Regional Council [BOPRC], 2019). After the installation of these monitors the Bay of Plenty Regional Council have reported 13 exceedances on their website from the 9th of November 2018 through to the end of August 2019, of which 9 have been PM_{10} and 4 have been SO_2. This means that the MMIA has breached the ambient air quality standards of the NES-AQ permitting one exceedance annually (MPI, 2004).

The Bay of Plenty Regional Council are currently considering whether to apply for a gazetted air shed/normal air shed for the MMIA to impose a cap on emissions, to aim to identify the source of the discharges and to control and reduce emissions. However, prior to taking this step, Council are actively engaged with emitters to manage and reduce their emissions. By obtaining a resource consent these industries are committing to the council that they will actively manage what they are emitting. In the case of the log yard operations this means identifying their current cleaning mechanism and how they are getting residue from A to B in the most efficient and environmentally sound way possible.

While the overall issue is complex, this study aims to characterise the type and amount of debris coming off logs at the port after storage (Figure 2), thus giving insights into how it may contribute to dust issues, as well as understanding and assessing the minimising and mitigating mechanisms currently in place.

Figure 2 Residue remaining from a bark-on row (left) and residue remaining from a debarked row (right) at the Port of Tauranga.

As we are targeting residues that are likely to cause air quality problems, the focus is on smaller residue which is less than 4mm by 4mm. Larger woody debris (i.e. large pieces of bark) are unlikely to become airborne and are not included in this study, however it is acknowledged and recognised that large woody debris can contaminate water if not managed or contained.

2. Literature Review

2.1. Sources and characterisation of dust

Dust derived from industrial environments is undesirable as a pollutant resulting in a need for effective management (Igathinathane et al., 2009). The storage of raw wood material in log yards is a known source of diffuse dust emissions (Stubdrup et al., 2016). Log yards are typically paved to reduce and prevent further contamination of soil and grit whilst easing cleaning processes (Stubdrup et al. 2016). Diffuse emissions are extremely common when the raw materials are handled and are exposed to wind velocity (Igathinathane et al., 2009; Stubdrup et al., 2016). It has also been acknowledged that there are increased dust emissions in the hotter summer months and in dry climates especially on high wind days (Stubdrup et al. 2016). The process of debarking is another potential source of fugitive dust that has been identified (Stubdrup et al., 2016). However, depending on the type of debarker, the dust and residue is contained.

Industrial dust can pose many different issues relating to respiratory conditions, organ/skin irritation, health effects, equipment damage, spontaneous combustion (explosions and fire), vision impairments, unpleasant odours and lastly issues regarding to community relations (Igathinathane et al., 2009).

Depending on the source of the dust, it can either be classed as organic or non-organic matter and can have vast differences in particulate size (Igathinathane et al., 2009). For developing management strategies and developing dust handling machinery (Figure 3), it is essential to understand the relative particle size distribution of the dust particles that is being dealt with (Igathinathane et al., 2009).

Figure 3 Row after it has been swept and scraped irrespective of bark treatment at the Port of Tauranga.

When talking about particulate matter or particle sizes we are referring to the particles aerodynamic diameter as the geometric shape does not explain how the particle behaves when airborne (World Health Organisation [WHO], 1999; New South Wales Environmental Protection Agency [NSW EPA], 2019). An aerodynamic diameter is the diameter of a spherical particle with a density of one g/cm^3 and behaves in the same manner as air (NSW EPA, 2019). This expression is appropriate as it closely relates to the particles ability to penetrate and settle at different locations of the respiratory tract (WHO, 1999). The term particulate matter (PM) is essentially a mixture of solids and liquid droplets suspended in air (MfE, 2016; US EPA, 2019).

Particle size guides have been derived from the particulate matter that is discharged which is relevant to log storage. With regards to dust particle size, the greatest particle size that can be suspended in the air for long durations of time due to wind velocity is 60 µm (which to put in context is roughly the diameter of a human hair) (Cecala et al., 2012). However particles which range from 60-2,000 µm can become airborne, although they can only reach heights of less than 1m before they fall back down. The particulate matter which is 2,000 µm typically creeps/rolls along the ground as a result of wind speed. (Cecala et al., 2012).

When dust particles become airborne, the settling velocity (the rate of the particle falling to ground) is relative to the size of the particle (MfE, 2016). For example for a particle less than 10 µm in diameter, the settling velocity could be 0.5 cm/sec under calm conditions. However for particulate matter around the size of 100 µm, the settling velocity would roughly be around 45 cm/sec in still conditions (MfE, 2016). PM_{10} particles can stay airborne for minutes or even hours and travel from 100 m through to 50 km (NSW EPA, 2019). $PM_{2.5}$ (any particulate matter less than 2.5 µm in diameter) alternatively can remain airborne for days or even weeks and can potentially travel hundreds of kilometres (NSW EPA, 2019).

Small dust particles (depending on particle density) can potentially become airborne and then pose more severe issues in comparison to larger particles which tend to settle easier (Igathinathane et al., 2009). With respect to the impacts on human health, particulate matter <10 µm is categorised as respirable and is the proportion of the particle range that get deep into the lungs and may get into the blood stream (Igathinathane et al., 2009; US EPA, 2019). To further breakdown that fraction, material less than $PM_{2.5}$ (really fine particulate matter) has been identified as having the greatest risk to health (US EPA, 2019). Anything greater than 10 µm is regarded as inhalable (up to a certain particle size) (Igathinathane et al. 2009) and are substantial in size to be able to settle relatively quickly in the atmosphere providing it is under the influence of gravity (Harrison, 2004).

Larger coarser particles however are customarily the cause of nuisance dust through the ability to deposit on horizontal surfaces resulting in dust soiling as well as the finer fractions being a health hazard (Harrison, 2004). Particulate matter greater than 50-100 µm is identified as visible to the human eye and is more likely to be identified as a nuisance (Das, 2008; MfE, 2016).

2.2. Dust management techniques

Debarking is a known source of fugitive dust and the potential discharge has been estimated using emission factors. Emission factors are essentially represented values associated with a certain activity to try to quantify the amount of pollutant being released into the atmosphere (US EPA, 2019). The debarking process has estimated emission factors for PM_{10} of 0.006 kg/tonne log and 0.003 kg/tonne log for $PM_{2.5}$ (United States Environmental Protection Authority [US EPA], 2014). It could be argued however that the positive trade-off from debarking (removing bark, dirt etc.) outweighs the negatives of producing very small amounts of residue through the debarking process.

Little has been published with regard to managing dust from log storage practices. Most dust management literature relevant to log storage and bulk handling is from open cast mining; where large amounts and piles of excavated material are being handled and transported from one location to another in an open exposed environment.

Open cast mining can have moderate to severe impacts on air quality however some of the issues the mining and export industries face are similar (i.e. impeded air and water quality, noise and occupational health (Katoria et al., 2013)). Some of the methods this industry minimises and mitigates dust issues is through using fixed and mobile water sprayers on roads with traffic. Additionally sealing or asphalting roads can also decrease impacts on air quality (Katoria et al., 2013).

The blasting process should be undertaken under cover with the use of a compressed air water blaster simultaneously which can reduce dust levels by 99% (Williamson and Shugert, 1950). Additionally, dry piles or matter should have water applied to dampen which reduces the exposure (Williamson and Shugert, 1950).

2.3. Mitigation recommendations

A dust audit undertaken in 2016 of the PoT (Anon, 2017) identified a few key areas to improve for dust management. These include:

- *Significantly increasing the amount, and efficacy, of sweeping/vacuuming services;*
- *Installing a logging truck wash at the Hewlett's Road entrance;*
- *Using effective water sprays to control fine dust when handling logs and bulk cargo;*
- *Undertaking a systematic review of bulk cargo handling dust mitigation options;*
- *Increasing the height of the bund for the sweepings stockpile; and*
- *Reducing vehicle speeds.*

The 2016 audit also identified that increased monitoring would be essential for bulk cargo handling activities at the Port of Tauranga (Anon, 2017). To minimise the spread of fugitive dust, transport paths, storage areas as well as vehicles should be cleaned on a regular basis (Stubdrup et al., 2016). Cleaning these areas not only helps to mitigate airborne dust emissions but also decreases the amount of woody material and particulate matter in surface run-off (Stubdrup et al., 2016).

Wetting logs as a management technique is a detriment due to the additional increase in weight resulting in less logs being loaded per vessel in addition to the PoT log yard being so large it would be difficult to achieve. Contrary to other industries, logs are not applied with water to minimise fugitive dust (Stubdrup et al., 2016) as there is no advantage to having wet logs in fact wet logs are a disadvantage for exporters and potential storm water runoff into the harbour.

2.4. Measuring fine residue

The log yard at the PoT is potentially hazardous due to the quantity and size of mobile plant operating simultaneously. Therefore getting a multitude of replicates manually on a large scale is challenging and is not currently common practice.

A line transect sampling method is commonly used when assessing sedimentation and erosion levels in forests caused by ground extraction harvesting, thinning, mechanical land preparation as well as to assess cutovers (McMahon, 1995). This method involves setting out line transects and conducting point samples along them at designated intervals. The line transects additionally are spaced at intervals specified by an equation which accounts for the surveys area (ha) and the number of classification points:

$$Required\ transect\ spacing\ (m) = \left(\frac{survey\ area\ (ha)}{no.of\ classification\ points}\right) \times 10{,}000$$

The number of classification points are determined based off the percentage of absolute error. Once the line transect has been laid out and established, the first sample should be conducted within 1 m of the beginning and the line transect should also cover the entire area (McMahon, 1995). In order to increase accuracy, the surveying method should be as consistent as possible (McMahon, 1995).

With the increase in environmental awareness and pressure, there has been more research into impacts of industry on natural resources. There are different methods and techniques used to suppress and manage dust which are applicable to Port activities. However, some may need to be adapted to suit operations at the PoT as well as improving the efficacy of these methods to meet environmental demands and regulations. There is an evident gap in literature with regards to the environmental impacts of logs throughout the operational exportation process. There has been little research invested into the impact of log storage for both bark-on logs and debarked logs. It is also unknown what particle size or organic/inorganic content are derived from the log storage process. Although it is acknowledged logs and debarking are a source of dust, the impacts of log storage are unknown and would be beneficial to understand from an air quality perspective.

3. Research Questions

The overall goal is to characterise the type and amount of residue from log storage at the PoT and to assess the dust suppression and removal systems in place. These are assessed through the following questions:

1. How much residue is left after log storage?
2. Is there a difference between residues produced from bark-on log rows vs debarked log rows?
3. Is the current log residue removal system effective?

4. Methods

4.1. Experimental Layout and Site Selection

4.1.1. Port of Tauranga log Yard

The log yard is located at the Port of Tauranga in the Mt. Maunganui Industrial Area in the Bay of Plenty region (Figure 4). There are two separate log storage areas. The first is the main large log storage area (45 ha) (pictured north-west in Figure 4) and the smaller Hewletts Road storage area (5 ha) (pictured south in Figure 4). The main log yard which is 45 ha has 29 hectares of that land occupied by log storage (excluding area for the debarker, railway area, berths and roading). For the purpose of this study, all sampling was undertaken in the larger main log yard.

Figure 4 The Port of Tauranga Log Yards. The main storage area is north-west and the smaller Hewletts Road storage area is south. Source: Google Earth Pro 2019.

The log yard is 100% sealed, predominantly pavement with a small portion being covered with cobbles. Within the log yard, logs are separated into rows based off their length, grade, bark treatment type as well as by company of ownership (as different parts of the log yards are allocated to different companies). Some rows have book-ends which are large metal structures positioned at the ends of rows, enabling rows to be stacked higher allowing them to maximise port capacity and area. The maximum height log rows can be is 6m high. The general operational process that occurs at the Port of Tauranga is that logs arrive via truck or rail, they are loaded into a row, stored for a designated period of time, and then they are loaded out of the row. The scraper comes through and removes the large woody debris then finally the sweeper comes through and removes the finer particulate matter remaining (Figure

5). Some logs rows can have logs added and removed multiple times throughout the duration of storage before the row is completely emptied. The ‘before’ and ‘after’ sampling points are further explained in section 4.2.

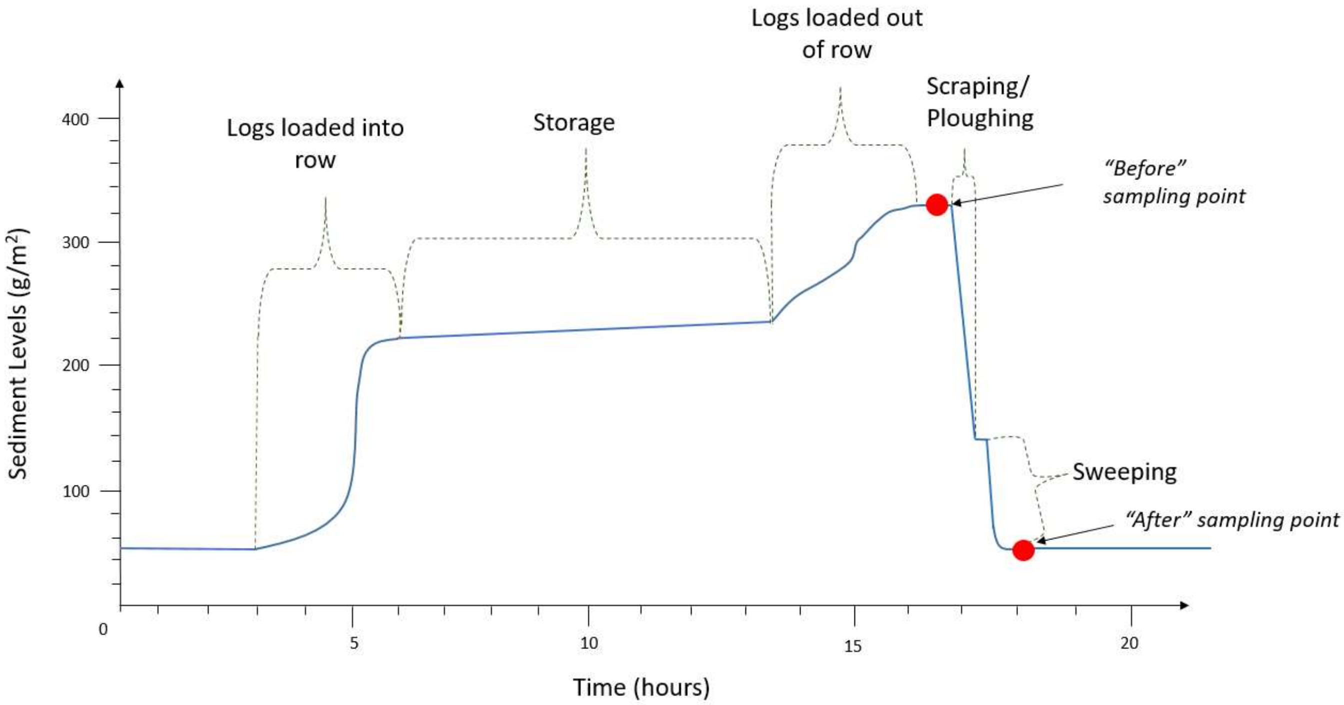

*Figure 5 Hypothetical timeline of row op*erations with sampling points for *the Port of Tauranga.*

At the Port of Tauranga during the period of sampling (summer of 18/19), there was one scraper/plough (as pictured in Figure 6) and one front end bucket loader. The front end bucket loader had a dual use for both scraping (using the front edge of the tilted bucket to scrape along the ground) and collecting and removing existing piles of residue. The scrapers drive around the PoT log yard and scrape the large debris into multiple small piles.

Figure 6 Daltons sweeper truck which are currently used at the Port of Tauranga (left) and a scraper/plough used at the Port of Tauranga (right). Source: https://www.daltons.co.nz/careers-daltons.

The front end bucket loader then collects these piles of residue and transfers them into an open-top truck trasnporting the debris from the open and exposed log yard into an enclosed shed (Figure 7). Therefore the front-end bucket loader and open-top truck work in tandem at all times.

Figure 7 Truck used for transporting woody debris from the open log yard to an enclosed shed. Source: Daltons https://www.daltons.co.nz/careers-daltons.

Two sweeper trucks operated throughout the duration of the summer. The machines are designed with spray nozzles at the front underneath the truck. Directly following these are rotating brushes which rotate inwards towards the truck so the particulate matter is directed inwards underneath the truck minimising the amount of airborne dust. Two vacuums on the left and right side of the truck are then positioned directly after the rotating brushes removing as much of the fine dust as possible. The residue vacuumed is sucked into a hopper inside the truck which is then emptied when full.

4.1.2. Row Definition and Selection

A row is specified as an area of the log yard that consists of a log stack which is logs of the same grade and length stacked together in an organised manner and that logs are positioned parallel to each other. An empty row subsequently is an area in the log yard that has recently had a log stack removed and that all residue is remaining on the ground surface. For both row types, there is a standard 1.5 m between them to allow individuals to walk between for log inspection and fumigation purposes.

Throughout this report reference to bark treatments are either as bark-on or debarked rows. Bark-on rows consist of logs that have only been processed by a harvester and/or processer and have had no further treatment. Debarked log rows alternately have logs which have been harvested and/or processed and then are put through a debarker either at Murupara before delivery to PoT or through the debarker located at the PoT main log yard.

A suitable row for sampling was an empty row that had recently had a log stack removed in which all residue was remaining on the ground (i.e. has not been scraped or swept) (Figure 2). Row selection was a difficult process due to two main factors. The first is regarding health and safety as part of the standard operating procedures states you have to be working at least two rows away from a machine. The second implication was that during the summer of 2018/19, the log yard was extremely full, implying that when rows became free and empty to sample, the marshaller's and loader operators wanted to put logs straight back into the row.

4.1.3. Line Transect sampling with Quadrants

An adapted line transect sampling method was used with quadrants to get a representation of the whole row to help account for variability across the row (Figure 8). Each row was subject to variability due to wheeled loaders or log pushing bark in different directions creating areas more dense in debris, but other areas slightly lighter in debris.

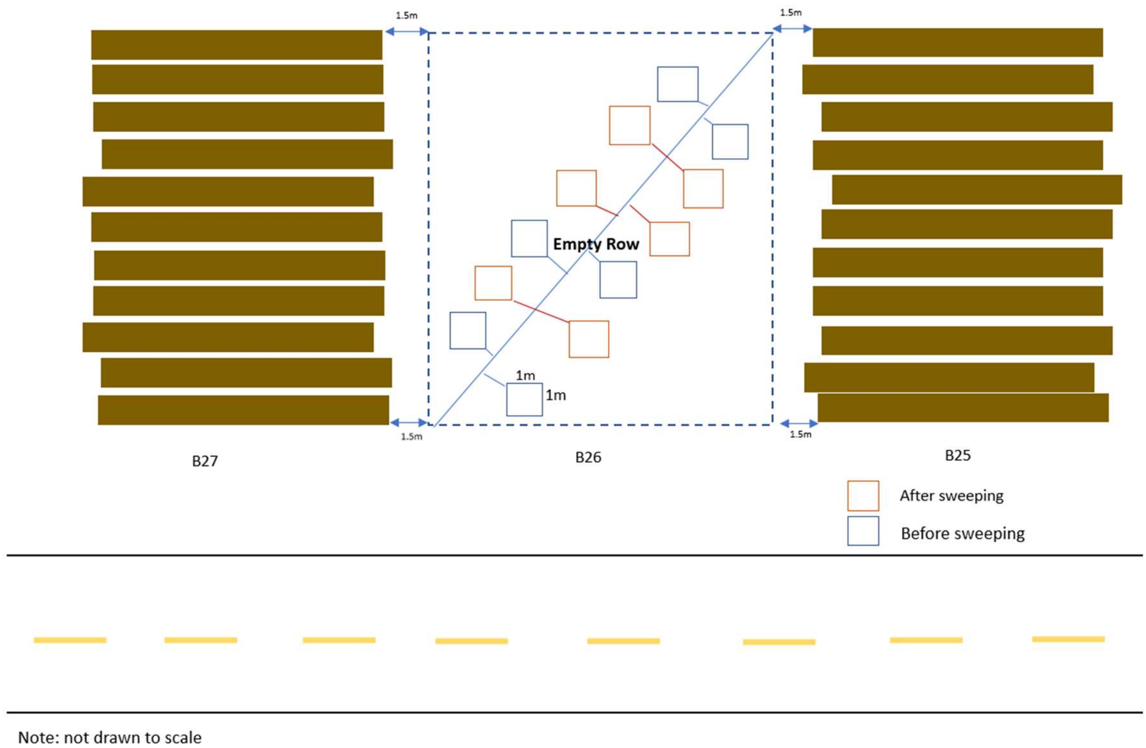

Figure 8 Line transect sampling method with quadrants for an empty row at the Port of Tauranga.

With regards to the survey area for this study, although the whole log yard is 45 ha (29 ha of actual log storage area) each row was treated individually. Each setting is defined as a single row due to the empty rows for sampling not being continuous (i.e. they are not located directly next to each other) resulting in a fragmented study area. The line transect was placed diagonally from one corner to the opposite corner of the row to eliminate bias. With respect to line transect spacing, using McMahons (1995) equation, often the spacing would exceed the perimeter of the row so therefore only one line transect was placed for each row.

The number of samples taken per row was decided based off multiple factors. With the disturbance surveys, at each point along the line transect, a quick visual inspection occurs to classify the level of disturbance as characterised in a table. These sample or classification points occur every 1 m along these transects as they are quick visual categorisations. The sampling for this study was considerably more time consuming and is required to be carried out in a dangerous environment. Therefore a general rule of thumb was established that if a row length was less than 40 m in length, 6 quadrant samples were taken both before and after sweeping and scraping. However if the row was greater than 40 m in length then 8 quadrant samples were taken.

4.2. Data Collection (Sampling)

With each row, both the length and width measurements were taken to calculate the total row area. Additionally, the previous log stack grade and row volume was noted down to endeavour to determine if any of these factors had an effect on residue levels.

The first step was to place a 1m x 1m quadrant systematically on the ground along the diagonal line transect. Large pieces of woody debris were then removed from around the edge of the quadrant. Each quadrant had the corners marked with spray-paint to avoid resampling the same location for sampling post sweeping and scraping (Figure 9). All residue inside the quadrant was then swept up and placed into a sieve with 4mm x 4mm holes which was placed on top of a bucket. The plastic sieve used had holes at regular intervals with a hard plastic surface in-between. This meant that when the residue was extremely fine and dry, the residue would descend into the bucket and if it was still airborne, there was less chance that the airborne residue would resurface back out the holes. Instead it would be intercepted by the plastic and remain in the bucket (Figure 9). This was more time consuming however, it was an effective method of containing the dust to ensure accurate recordings were achieved.

Figure 9 1m x 1m quadrant with spray painted corners (left) and residue being sieved into a bucket during sampling (right) at the Port of Tauranga..

The sieve was then shaken thoroughly but gently to minimise the disturbance of dust and to make sure as little as possible escaped into the air. Once all fine particles had been separated from the large debris in the bucket, the large debris was discarded away and downwind from the sample to avoid impacting other samples along the line transect. If samples were undertaken on cobbles, a handheld rechargeable vacuum was used to get the fine dust stuck in the grooves. This was repeated until the entire quadrant had been successfully sieved. The remaining fine residue in the bucket was then measured using electronic scales. This gave the amount of residue which was measured in grams per metre squared (g/m^2). This process was repeated 6-8 times depending on the length of the row (Figure 8).

The whole process was again repeated post sweeping and scraping (sampling points located in Figure 5), avoiding areas with spray paint that had previously been sampled. All sampling was undertaken when there had been no rain for at least two consecutive days. If light rain occurred whilst logs were still in the row, there is a low chance the water reached the ground surface, therefore the row was still viable to sample. Sampling was only to be undertaken when wind was less than 20 km/hr.

4.3. Data Analysis

4.3.1. Fine Residue Analysis

The data was entered using Microsoft Excel. A linear mixed model was then undertaken in Rstudio to understand if any of the variables had any random or fixed effects on row residue level. The random variables were rows and residue level and the fixed variables were the different treatment levels (bark-on before, bark-on after, debarked before and debarked after).

Then an estimated marginal means (least-square means) was then undertaken using Rstudio. This was used to estimate the means of the four treatment types (bark-on before, bark-on after, debarked before and debarked after) from the mixed model.

4.3.2. Particle Size Range Detection

Four samples (two from bark-on after and two from debarked-on after) were sent away to the School of Science department at the University of Waikato, New Zealand to determine the particle size range distribution. The samples sent away were from after the sweeper and scraper had been through to give a more accurate representation of what is likely to be exposed for the longest period of time. This process involves mixing 4 g of residue with water then using the Malvern Mastersizer 3000 v3.50. This instrument uses laser diffraction (differences in light scattering) to measure the particle size distributions ranging from 0-3,500 µm. This piece of instrument delivers fast and accurate particle size distribution (microns (µm)) for the wet dispersion samples giving results as a percentage of the total initial sample volume.

4.3.3. Particulate Matter Characterisation

Four samples (two from bark-on after and two from debarked-on after) were sent away to Hill's Laboratory in Hamilton Waikato, New Zealand to determine the organic versus inorganic content. This is achieved by taking 100g of residue then placing it in an oven to remove all moisture. The new dry weight is taken and then the remaining dry sample is burnt in a furnace at 550°C for six hours. This burns off all the organic content leaving ash remaining. The ash is the inorganic content which is then subtracted off the initial dry weight. Organic content is any woody material (wood, bark, foliage and other particulate matter such as palm kernel). Ash and inorganic material is essentially anything else (dirt, stone, rubber from tyres etc.).

5. Results

5.1. Fine Residue Analysis

In total, there were 836 individual samples taken from a total of 30 debarked rows and 34 bark-on rows. The results from the raw data found in Table 1 are fine residue quantities at the row level. Before sweeping and scraping, the minimum and maximum values were significantly higher for bark-on rows compared to debarked rows (62-1,980 g/m^2 and 9-559 g/m^2 respectively). Post sweeping and scraping, the minimum values for bark-on and debarked rows are comparable (1 g/m^2 and 0 g/m^2 respectively). However, post cleaning for bark-on rows the 97.5% confidence interval is 97 g/m^2 higher than debarked rows and the maximum is 198 g/m^2 higher than debarked rows.

Table 1 Summary statistics from raw data of rows for both bark-on and debarked samples before and after sweeping at the Port of Tauranga.

Bark type	Pre-post sweeping /scraping	N°. of Rows (n)	N°. Sub plots	Minimum	2.5%	Median	97.5%	Maximum
Bark On	Before	34	222	62.0	80.7	336	1,503	1,980
Debarked	Before	30	196	9.00	24.9	103	324	559
Bark On	After	34	222	1.00	1.00	16.0	207	393
Debarked	After	30	196	0.00	1.86	11.0	110	195

Figure 10 illustrates the results of the average log row residue levels for the four different treatment types. The graph demonstrates that there is a significant difference between bark-on rows before and after sweeping and scraping. The plot also illustrates that there is more residue left in a row immediately after logs are removed for bark-on rows compared to debarked rows. Bark-on rows pre sweeping and scraping have the largest amount of variation. Debarked rows post sweeping and scraping have the smallest level of variation. There was also a reduction in average residue levels for both bark-on and debarked rows after sweeping and scraping however the difference for bark-on rows is more prominent. It appears that debarked rows after sweeping may have less residue remaining in the row compared to bark-on rows. The differences between these two treatments is further explained in the results from the estimate means from mixed models in Tables 1 & 2.

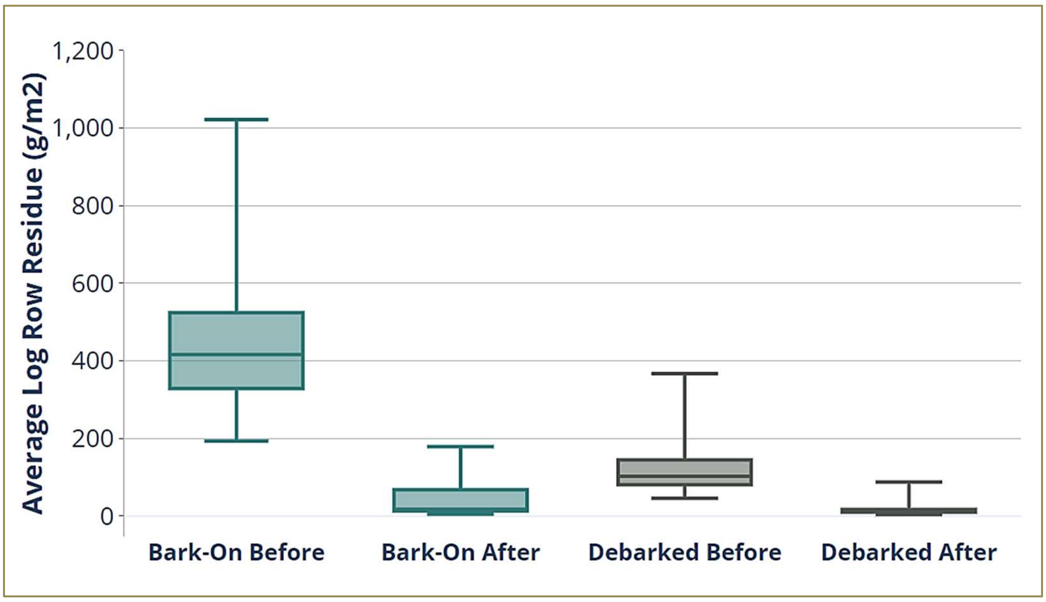

Figure 10 Boxplot showing average residue distribution from the four treatment types (Bark-on before, bark-on after, debarked before and debarked after).

The estimate means from mixed models was used as it takes into account that each unit (row) has multiple subplots (individual 1m^2 samples). To compare the debarked and bark-on after sweeping and scraping, the estimated average values indicate that bark-on rows on average have twice as much residue remaining in a row per m^2 compared to debarked rows (Tables 2 & 3). After sweeping and scraping there was an average reduction in residue of 91% and 84% for bark-on rows and debarked rows respectively. Bark-on rows before sweeping and scraping have the highest average mean (447 g/m^2) which is 3.7 times the average amount for debarked rows immediately after logs have been removed from a row (Tables 2 & 3). The average row area sampled was 193 m^2.

Table 2 Estimate means from mixed model results for bark-on rows in g/m^2 (3 s.f.)

Bark on:	**Mean**	**Lower C.I. (2.5%)**	**Upper C.I. (97.5%)**
Before (g/m^2)	447	417	476
After (g/m^2)	40.1	10.4	69.9

Table 3 Estimate means from mixed model results for debarked rows (3 s.f.).

Debarked:	**Mean**	**Lower C.I. (2.5%)**	**Upper C.I. (97.5%)**
Before (g/m^2)	119.3	87.3	151.2
After (g/m^2)	19.0	-13.0	50.9

The results from the estimated means from mixed models calculated the effect on average residue levels under each treatment type were consistent with the boxplots in Figure 10.

To scale these values up from a per metre squared basis to per row basis, after logs have been immediately removed from a bark-on row, using the estimated means and average row area (193 m^2), there is potentially 86 kg of fine residue remaining in a row. After sweeping and scraping however, this is reduced to on average 7.74 kg per row. This is significantly higher than a debarked row having on average 23 kg pre sweeping and scraping and is reduced to 3.67 kg afterwards.

Moreover, when looking at the respective 95% confidence intervals for these two treatments, there is no overlap indicating that there is a statistically significant difference between debarked and bark-on rows post sweeping and scraping.

Furthermore, log grade, row area and row volume were analysed with respect to residue levels using the linear mixed model. Within the model it indicated that there was no meaningful effects or statistical significance of these factors on log residue levels.

5.2. Particle Size Range Analysis

The particulate matter size range outputs from the Malvern Mastersizer instrument, as prepared by the University of Waikato are given in % of sample volume under a certain particulate matter size in microns (µm). This illustrates that a large proportion of the volume for the four samples are under 1000 µm in size (Figure 11).

There is a steep increase in particulate volume in the fine fragments of the particle range (<100 µm). The Malvern Mastersizer separates the particles into 37 different particle size brackets under 1 µm as the instrument is designed to target and determine the volumes in the extremely fine ranges of the spectrum increasing congestion under 100 µm. There appears to be little observable difference between the two debarked and two bark-on samples. Additionally one of the samples (bark-on 1) only had particulate matter in the sample that was less than 1,900 µm.

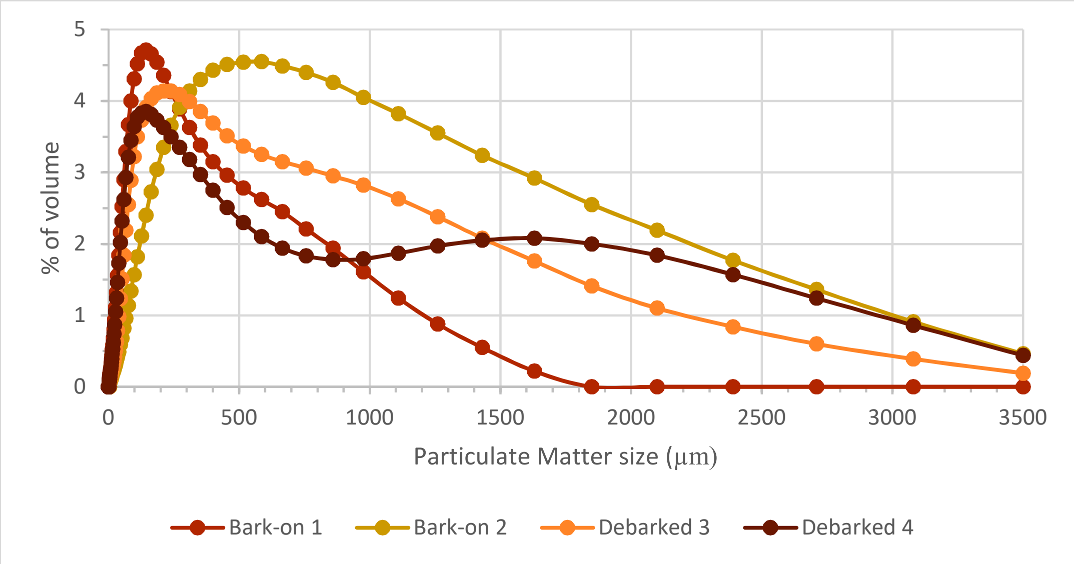

Figure 11 Particle size range distribution of the four samples analysed by the Malvern Mastersizer Instrument in February 2019.

The data has a maximum value of 3,500 µm as this is the limit of the Malvern Mastersizer instrument. There may be particles larger however they weren't detected and analysed in these samples. The particle size cut offs are different to what we typically use in New Zealand i.e. the Malvern Mastersizer gives you a percentage of residue under 11.2 µm whereas we typically classify things under 10 µm therefore interpolation was used.

Using the particle size characterisation ranges as specified in Cecala et al., (2012), the particulate matter ranges for the four samples were separated accordingly. Figure 12 represent the average across the four samples by particle size range class. The results indicated that on average 83% of the volume sampled were in the 60-2,000 µm particle range. This means that large volumes can become airborne however they only reach heights of 1 m before falling back to the ground again. On average only 1.3% were under the respirable PM_{10} (0-10 µm) range. This was further broken down and across the four samples, on average only 0.035% of the samples analysed were less than $PM_{2.5}$. Some 12% of the average volume were between 10-60 µm which is the matter which can become airborne for prolonged periods of time. Some 13.7% of the samples < 60 µm could potentially become airborne for long periods of time and travel long distances. Lastly the larger sized particulate matter (2,000-2,500 µm) only represents a very small fraction of the samples analysed.

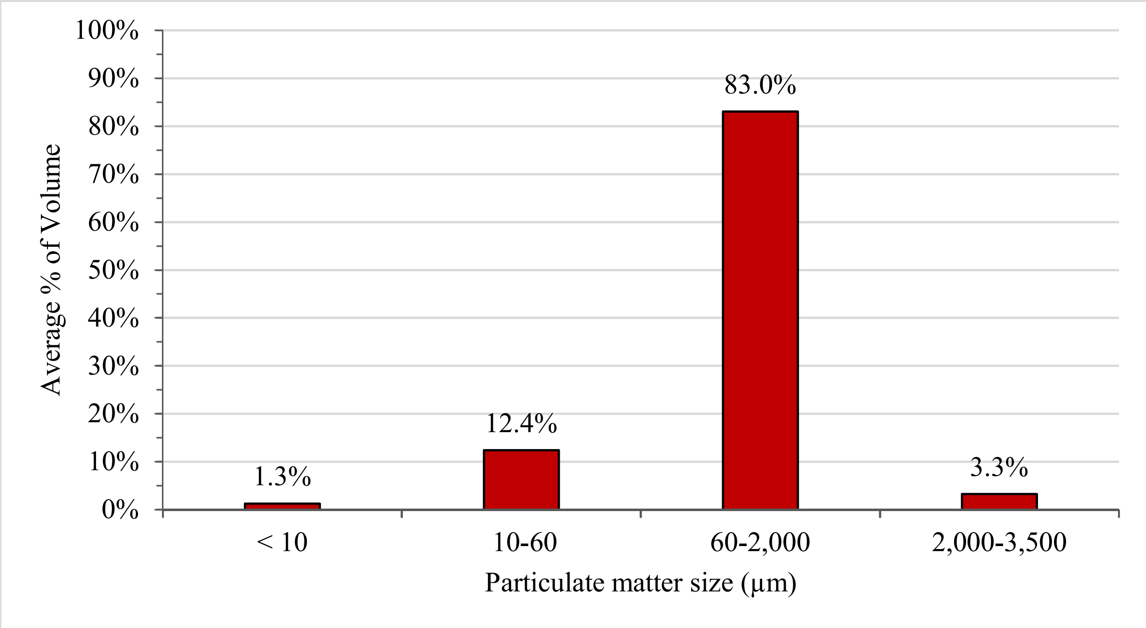

Figure 12 Average percentage of volume in categorical particle size ranges for all samples (as specified by Cecala et al. 2012.)

5.3. Particulate Matter Characterisation

Across the four samples, on average 72% of the original dry weight was inorganic indicating that majority of the residue remaining in rows after sweeping and scraping is either dirt, stone or other inorganic material (e.g. rubber from tyres etc.). The debarked samples analysed had somewhat lower ash particulate matter of the starting 100g dry weight interestingly, indicating that the rows on average had slightly higher organic material.

6. Discussion

6.1. Fugitive dust mitigation:

The results from the estimated means from mixed models for both pre and post sweeping and scraping indicate that the more material and particulate matter that is in a row to begin with, the more is going to be have to removed and consequentially the more that will remain and be exposed to the elements. For bark-on rows there was on average 447 g/m^2 prior to sweeping and scraping which is significantly higher than the 119 g/m^2 for debarked log rows. This was a similar trend post sweeping and scraping as the estimated average values were 40 g/m^2 and 19 g/m^2 for bark-on and debarked rows respectively.

The increased residue levels may have an indirect relationship with bark-on logs. This is not necessarily saying that bark is the sole cause for increased residue levels, however, a visual observation was that dirt, stone and other inorganic and organic material tend to stick or get trapped in the crevasses of bark. Further, the material and particulate matter brought into the premises of the PoT has a higher probability of being stripped off logs through handling or weathering. This subsequently means more matter can be broken down and crushed into further smaller particles due to heavy traffic of mobile plant.

As mentioned in section 5.1., bark-on samples before sweeping and scraping had the most variability. The bark-on logs themselves had varying levels of bark and inorganic matter still remaining on the logs. This variability may be a result of harvesting, as different harvesting methods and harvesting heads are used depending on the source and company the logs are supplied from. Newer and more technological harvesting heads tend to remove more bark than older harvesting heads or mechanical methods of harvesting. There are other factors that may play a potential role in increased residue levels such as where in the forest the logs were stored, the duration of storage in forest, season and many others, all in which could be explored further. Having clean logs could partially mitigate this issue through either debarking, storing logs in dryer places in forests or transporting logs from the forest to the port as quick as possible post-harvest.

Through the debarking process, most bark, dirt, stone or other particulate matter has been removed therefore residue levels are unlikely to increase once the logs are in the respective rows. When the logs are handled, material still comes off the logs however they are typically of the coarser particulate matter size such as wood splints and wood chips which are removed by the scraper and sweeper. Some residue may arise from the debarker located at the PoT, however based on observation in comparison to the remainder of the yard, residue emissions appears to be minimal. This may partially be due to being slightly sheltered by infrastructure, however, further exploration of this would be beneficial.

The cleaning mechanisms (sweeping and scraping) would be considered effective as they remove on average 91% of residue from bark-on rows and 84% of fine residue from debarked rows. Within each bark treatment types, sweeping and scraping reduce residue levels down to a homogeneous level that is proportionate to the amount of variability and the mean of residue immediately after logs have been removed from a row. Between the treatment types however the sweepers and scrapers did not reduce it down to a homogeneous level. It appears that the sweepers can only remove a certain amount of particulate matter indicating that the more you start with the more you are going to be left with at the end. As seen by the minimum values in Table 1, it is possible to reduce bark-on row residue levels down to extremely low levels after sweeping and scraping however there is more variability.

Even though the current cleaning mechanisms remove 80-90% of the fine residue on a grams per m^2 basis, there is still on average 19-40 g/m^2 remaining. When you scale this up to the 29 ha of log storage there is still a considerable amount of residue which could become fugitive dust considering the average row area sampled was 193 m^2. However it is extremely unlikely that the full 29 ha will be exposed at the same time as that would assume there are no logs present in the log yard.

One question that still needs to be defined is an acceptable level of residue at the PoT. As shown in Table 1, 97.5% of the bark-on samples post sweeping and scraping were under 207 g/m^2. Therefore a proposal would be to set the maximum acceptable level at 207 g/m^2 immediately after sweeping. From the results it appears that debarked rows will consistently be less than this threshold however there is a small chance some bark-on rows (2.5%) may be over this threshold. This target level is based off what is achievable for the current sweepers and scrapers and is a reasonably low level of residue. This however should not be a long term definite level. As technology improves, mechanisms change and the level of knowledge increases, it is a reasonable expectation that the acceptable level of residue would decrease.

One of the issues in the hotter summer months is that even when rows have been swept and scraped, fine dust and residue which is already airborne can be deposited into these freshly cleaned rows creating a new blanket of residue which may not necessarily be caused from log storage (i.e. wind can transport other material such as palm kernel or other particulate matter sourced externally from the PoT into these rows). This is extremely hard to minimise however this can be mitigated through increasing the frequency of sweeping for each exposed row.

Log yard and roadways are cleaned multiple times daily which is a current integral part of dust suppression and management at the PoT. Stubdrup et al., (2016) noted that cleaning of vehicles is also important to minimise the spread of fugitive dust. At the PoT, the cleaning of mobile plant and vehicles does occur however the frequency and intervals to which they are cleaned are left to the users or owners discretion. A dust audit undertaken in 2016 of the Port of Tauranga suggested that an automated truck wash station should be installed at the Hewletts road entrance (Anon, 2017). This has not yet been actioned (October 2019).

As the PoT leases their land out, the land users (exporters) become the parties who are responsible for particulate discharge into the environment. They then become at risk from a fugitive dust regulation perspective at the district and regional council level and must comply with all air and water quality standards. Because of this, there is a strong vested interest from all exporting parties into improving the dust suppression and management techniques. One of the positives is that it is highly achievable to improve the dust management at the PoT through both implementing measures and developing technology.

6.2. Particulate Size and Characterisation:

6.2.1. Particle size range analysis

From a human health perspective, the fact that only 1.3% of the samples analysed were under 10 µm is a positive result for the storage of logs at the PoT. As mentioned in section 3, particulate matter which is less than 2.5 µm is most harmful to health (US EPA, 2019) in which the samples analysed only showed that 0.035% of the average volume were under this size. Particles greater than 100 µm that are visible to the human eye are present in large volumes proportionately of the samples. The large percentage (84.5%) of particulate matter in the 60-2,000 µm still can potentially cause visual nuisance fugitive dust (Harrison, 2004) as high wind velocities can still transport the material off-site. However it is more likely that the 13.7% < 60 µm will become airborne for long periods of time and travel long distances.

6.2.2. Particulate matter characterisation

One of the factors that contributes to the high inorganic material is that when bark-on logs are transported to the PoT, they often carry varying levels of dirt and other material that are attached to logs. With the bark remaining on logs there is greater chance that dirt and mud will stay in the crevasses for prolonged periods of time. Another factor that may help explain part of the higher proportion of inorganic residue is due to other importing countries phytosanitary requirements. Depending on the importing country, a requirement for log exportation is that all logs must be inspected and free of (or have minimal) soil or other foliage, fungi etc. prior to leaving the border. Therefore all logs are inspected and log ends are water blasted in their rows in the log yard before being loaded onto vessels. This results in dirt and residue from the water blasting eventually making its way to the ground surface.

Seasonality may also be a factor that impacts the ratio of organic vs inorganic. In the winter months there is increased rainfall which creates waterlogged areas on landings and in forests where logs are generally stacked and stored prior to being trucked or railed to the log yard. Logs could be lying in mud for time periods up to weeks which results in increased sediment on the surface area of logs.

For the inorganic vs organic testing, it would be interesting to see whether there were differences in content for before and after sweeping and scraping. Logically, a hypothesis would be that the scraper may remove more of the larger coarse or super coarse woody debris in rows leaving the finer inorganic material which are naturally finer. These results for both particle size range analysis and organic versus inorganic characterisation presented are indicative as there was only four samples sent away for analysis.

6.3. Considerations for improving dust management

At present, the dust management and mitigation mechanisms that are in place include:

- Two scraper trucks and 3 sweeper trucks operating.
- Water spray trucks operating on berths
- Wind netting on the perimeter fences facing public industrial areas.
- Set speed limit within the bounds of the log yard of 20 km/hr.
- Enclosed dumping station for both sweeper and open top trucks

These elements provide the basis of the current dust management plan, however through the process of carrying out this research, they also denote what further actions could possibly be taken at the PoT. These measures that could be taken or implemented to improve dust management include:

a. Reducing the critical time delay periods of the sweepers and scrapers,
b. Having the right ratio of sweepers to scrapers,
c. Ensuring each row is swept and scraped before new logs are loaded into the row,
d. Making sure mobile plant operators should stick to the designated roadways and maintain the appropriate speed limit of 20 km/hr,
e. Improving the design of the sweeper trucks, and
f. Increasing the amount of debarked wood.

One of the observed key factors to consider (a) would be to minimise the time delay between scraping and sweeping. Figure 13 represents a hypothetical timeline for a row at the PoT.

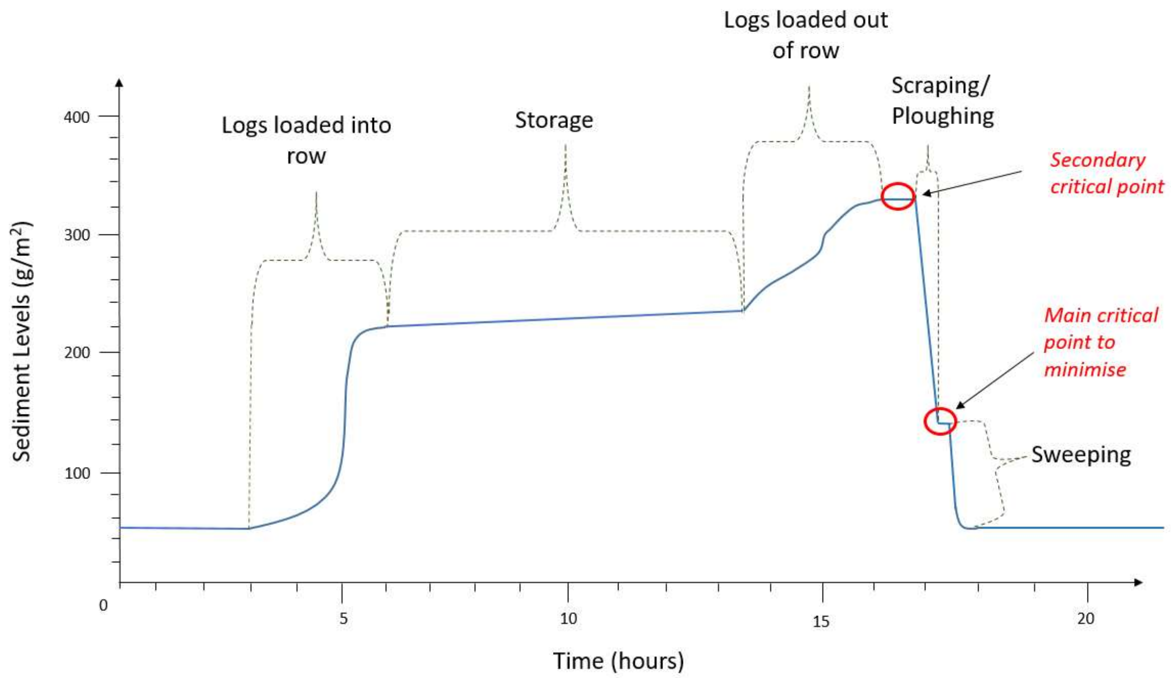

Figure 13 Hypothetical row operations timeline with critical points identified for the Port of Tauranga.

As identified on the timeline in Figure 8, there are two critical points that should be prioritised to minimise. The more critical period of time to minimise occurs at post scraping and pre sweeping. At this point in the timeline, the scraper has come through and removed all the large woody debris from the row essentially exposing large surfaces of fine residue. Any wind or water that comes through is going to turn that fine residue into either airborne fugitive dust or surface run-off. The second point to acknowledge is immediately after the logs have been loaded out of a row. Although there is the large woody debris remaining, if wind or water is present it will still collect moderate proportions of residue. Therefore these two periods of time should be prioritised to clean, minimising the effect of residue on both air and water quality. The time delays at these two critical points could be anywhere from seconds to an hour.

With the dust suppression and removal systems, it is important that there is the right ratio of sweepers to scrapers in addition to having them operating 24/7 (b). With regards to the ratio, upon observation, the scrapers are considerably quicker than the sweepers. Therefore it takes more sweepers to keep up with the scrapers to help reduce the delay between the processes. Since the sampling was undertaken, a third sweeper truck has been introduced to the log yard for this purpose. It is also important for the operators of the sweepers to empty their trucks regularly to maintain and increase the effectiveness of the trucks. Water trucks are used at the PoT however they are primarily positioned on the berths to minimise and mitigate the many points of handling potentially creating airborne dust. The main routes with high traffic could also benefit from the occasional treatment of water trucks if dust and residue levels are high.

Following on from this point, each row should be scraped and swept before new logs are loaded into the row (c). Otherwise if logs are loaded on top of existing residue, once the next lot of logs are removed, you potentially have double the amount of residue available for air and water pollution. This factor is at biggest risk when log yards are nearing maximum capacity due to loader operators wanting to immediately use that open space to store logs.

With respect to the loader operators, one aspect to recognise is that all drivers should keep to the designated roads within the different areas of the log yard. This is an important factor as drivers often cut through empty uncleaned areas to shortcut however what this does is transfer particulate matter and residue from uncleaned rows and areas onto clean roads and areas of the log yard from their wheels. Additionally it is common knowledge that mobile plant and other vehicles at the PoT should reduce their speed to minimise the disruption and impact on dust (Anon, 2017). Therefore all machinery should comply with the PoT's maximum permitted speed within the log yard of 20 km/hr as anything below this would significantly impact and hinder productivity. Furthermore, when the sweeper vacuums are in operation, the speed of the truck should be reduced to allow for the airborne particulate matter to settle inside the hopper in the truck.

Daltons and the PoT are also currently in communication to discuss potentially attaching a scraping blade on the front of a sweeper truck. This would eliminate the time delay between sweeping and scraping. However this is still in deliberation and has not yet been implemented or trialled to date (2019).

Lastly, one of the factors to consider based off the results of this study would be to increase the amount of debarked wood delivered to the PoT. The new debarker installed at Kaingaroa Timberlands Murupara log yard has been estimated to produce 660,000 tonnes of debarked wood in 2019. This has the potential to be increased to 1 million tonnes in 2020 (S. Milligan personal communication, July 2, 2019). The debarker currently at the PoT has some limitations as it can only debark 1,000 JAS per day and can't debark either small diameter logs or really large logs. It is unrealistic to expect all logs to be debarked however increasing the amount will help to reduce residue levels in the log yard. Debarking can be more expensive and also can raise logistical challenges (Bay of Plenty Regional Council, 2018).

However, in more recent times debarking is becoming more economic and feasible due to economies of scale combined with pressures of alternative fumigation treatments to Methyl Bromide.

While it is understood there are costs associated with each of these factors, and carrying out all options initially may be cost prohibitive, selecting some of these options will undoubtedly help reduce fine residue levels and mitigate dust issues at the PoT.

6.4. Future Research:

As this study only scratches the surface, there are other important avenues that could be explored. The first beneficial study would be to do a full analysis of the particle size distribution. As only four samples were analysed for this study, sending away multiple samples of the four different treatments would be beneficial to further understand the effects on air quality.

Another important area to look into especially for the BOPRC would be to collect samples from the current monitoring stations around the MMIA when exceedances occur. These samples could then be taken back to a lab to completely characterise the particulate matter to then accurately attribute the source of the exceedance. It would also be useful to analyse samples captured from log rows to get a full breakdown and characterisation of the particulate matter. This would help identify what is derived from logs (bark and wood chips), and other potential sources (I.e. palm kernel, rubber for tyres, stone, dirt etc.).

As this study primarily focused on the impacts of logs and log storage on air quality, it would also be valuable to understand the effects of these on water quality.

Lastly, it would also be interesting to analyse whether the type of machinery used e.g. high stackers and trailers vs wheeled loaders and bunks would have any effect on the amount of residue produced. The process of wheeled loaders and bunks has additional points of handling which as mentioned in 2.1. is likely a source of additional dust. Therefore it is reasonable to expect this method of log marshalling to produce more dust and residue compared to the use of high stackers and trailers.

6.5. Limitations:

One of the limitations present in this study is that there was a chance that dust and residue may have become airborne and been removed from the row prior to sampling. Alternatively, there is also potentially the opposite effect in that there is the possibility for airborne dust and residue from other areas to settle in the designated row to be sampled. A way this was minimised was when possible, we would standby and wait for the row to be unloaded so that once the machinery had left, we immediately commenced working on the row and sampled as promptly as possible.

A further limitation of the sampling process was that there was the potential for residue and dust to escape during sieving. The sampling is essentially disturbing fine particulate matter resulting in residue becoming airborne. This was minimised through only sampling on days where wind speeds were less than 20 km/hour and the dust could only escape back up the holes in the sieves in which was trapped by the larger woody debris which couldn't fit through the holes. As the sampling process involved separating the fine residue from the large woody debris through sieving, there is a chance that some residue could stick to the bark pieces even after thorough separation of fine and course material. There was undoubtedly some residue lost however with regards to mass (g) per m^2 it would likely be minimal. Further fine particles lost with larger matter are more likely to remain fixed to the bark and be of less risk to the air quality. It was possible that sieving also created more fine particles than would be present naturally. Following on from that, within the 1m by 1m quadrants, there was possibly small amounts of fine residue which could have been stuck to and remain on the pavement and therefore not included in the analysis.

Although there was a sufficient sample size for the main analysis, additional row samples of different log grades and volumes may have been beneficial to try to further determine any effects on fine residue. However due to time constraints and logistical difficulties just the 64 rows were collected. Further to this, debarked rows were the hardest to sample purely because there is less volume and rows of debarked logs at the Port of Tauranga and therefore less rows become available to sample.

7. Conclusion

From this study it was evident that there was a contrasting significant difference in fine residue between bark-on and debarked log rows immediately after logs are removed from a row (447 g/m^2 and 119 g/m^2 respectively). Even post scraping and sweeping, bark-on rows still had on average twice the amount (21 g/m^2 more) of residue remaining in a row in comparison to debarked rows. The sweepers and scrapers would be deemed effective as they remove on average 80-90% of the residue. The results indicated that the less residue you have in a row to begin with, the less the scrapers and sweeper are going to have to remove which then flows onto having less residue in rows post sweeping and scraping. This then reduces the overall risk and volume of fine residue that can become potential fugitive dust.

The remaining residue left in exposed empty rows present risks as they could turn into fugitive dust. As there is still on average 19-40 g/m^2 after sweeping and scraping, when scaled up to multiple empty rows at any one time (highly variable), across the 29 ha yard, the residue levels remaining still need to be managed.

Further the particulate matter testing indicated that on average 72% of the sample volume dry weight was inorganic material. Additionally, only 1.3% on average of the sample volume was under the PM_{10} range which is detectable by the BOPRC monitors. There are however large potential proportions (84.5%) that could potentially become fugitive and nuisance dust.

With current practices, the export users at the PoT are already reducing the amount of residue that can be fugitive dust through both debarking and sweeping and scraping which is a significant positive improvement. The fact that there is room for improvement of dust management at the PoT is also positive. Further minimisation and mitigation can be achieved through implementing regulations and decreasing the exposure periods, adapting and introducing new machines and technology and through increasing the amount of wood that is debarked.

This study aimed to understand the basis of what impact logs and log storage potentially have on air quality. This has been explored and addressed throughout the report however it is worth noting that there are many other pathways that could further be explored. This could include a full particle size range analysis, physical characterisation of particulate to be able to attribute which source is responsible for specific exceedances, the impacts on water quality and if the type of machinery used in the marshalling process has any impact. Management and understanding of environmental impacts of log exports and storage is becoming increasingly important and will continue to do so in the future.

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