OPPORTUNITIES FOR OPTIMISING THE SUPPLY OF DEBARKED LOGS IN THE EXPORT SUPPLY CHAIN

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Forest Engineering Honours Project 2023
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Abstract

Logs are a significant export for New Zealand, ranking third by value. Log exports have been increasing for the past 15 years and are expected to remain high until around 2030. New Zealand is the world's largest softwood log exporter. Phytosanitary requirements in importing countries focus on preventing pest transfer, primarily bark beetles. Debarking is an approved method for minimising bark beetle transfer to China, so is important as methyl bromide fumigation is phased out.

This study aims to help exporters optimise the supply chain of debarked logs. There are three intentions. First, to publish data on the size and utilisation of log ships used in New Zealand. Second, to examine the effect of seasonal differences in log density on the debarked volume carried on a ship. Third, to understand factors affecting debarker productivity as it relates to export.

The study shows two ship classes dominate log exports from New Zealand ports. 82% of ships are either, Handysize and Handymax- a deadweight range of 32,000 to 42,000 tonnes. Data showed that most ships were slightly under-loaded. It also showed there is capacity for more debarked volume, particularly if stanchions were added to ships that do not have them currently.

Logs arrive at port 9% denser in winter than in summer in the North Island, and 6% denser in Port Chalmers. Port Chalmers receives denser logs year-round compared to the North Island ports. This shows that Southland logs experience reduced drying during processing and transit.

The percentage of debarked cargo loaded onto ships exhibits some correlation with the time of year. A model has been created to compare the anticipated volume of exported debarked timber across different months. This model was calculated based on the average proportion of debarked cargo carried in each month. At the Port of Tauranga, there is approximately a 4% increase in total volume carried during March compared to September or a 19% increase in the debarked volume.

An analysis of logs at the Murupara debarker examines the impact of log size on the production rate. The results demonstrate that larger logs yield higher debarker throughput, while the availability of the largest logs sets the limit on maximum production. Medium-diameter, long logs, and large-diameter, short logs, limit throughput similarly. The highest production shifts include less than 20% of these sizes in the throughput. Smaller classes significantly restrict production, and none of the most productive shifts had more than 5% small diameter logs.

A linear production line model revealed that diameter should have a more pronounced effect than length, implying that shorter logs lead to more delays.

This study provides a model of the monthly variation in debarked volume carted. This can be used to more accurately forecast the volume of debarked timber that will be needed to load a booked ship. It also identifies short logs as a source of unnecessary delays in the debarker and suggests that reducing lost time caused by gaps could boost overall volume throughput.

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Acknowledgements

I'd like to express my gratitude to:

- John Gardner and the PFP team for their continuous support during the project.
- Gareth Bowen and TLL for sharing insights on the debarker and assisting with site visits.
- Lance Riddell and ISO Ltd. for their assistance with port operations.
- Andrew Peddie and Ian Brown for their time and guidance.
- Professor Rien Visser for critical project feedback and supervision.

Whāia te iti kahurangi ki te tūohu koe me he maunga teitei

Seek the treasure you value most dearly: if you bow your head, let it be to a lofty mountain

1 Introduction

Logs are the third largest export by value in New Zealand, behind dairy products and meat (OEC, 2022). Forestry exports are very important to the forest industry, representing 62% of the total volume harvested in 2019 (MPI, 2022a). Exports of logs have been climbing for the past 15 years and are forecast to remain high until around 2030. New Zealand is the largest exporter of softwood logs worldwide (UNFAO, 2023).

Importing countries have phytosanitary requirements on the shipment of goods, which limit the likelihood of the transfer of pests. On New Zealand logs, the main pests importing countries are worried about are bark beetles and fungi (Ball, 2011; Pawson et al., 2014). Methyl bromide has been the standard in phytosanitary treatment, but in 2020 New Zealand restricted the use of methyl bromide to operations that capture or destroy the gas after use (MPI, 2021).

Debarking is one method of phytosanitary risk management. China is the only major market that accepts debarked logs, but since China makes up 87% of New Zealand's export volume (OEC, 2022) demand for debarked wood is still high. Debarking removes bark beetles, one of the main pest organisms, as they live in or just under the bark.

Logs dry out according to climatic conditions. In summer, logs dry faster than in winter (Simpson & Wang, 2003; Visser et al., 2014), so logs should arrive at the port lighter in summer. Ships can carry a certain weight before they become unstable, so the volume they can carry varies throughout the year. Ships are normally weight-limited, not volume-limited. Ships always fill their holds (which are fumigated with phosphine), so it is the on-deck, debarked volume that fluctuates.

The objective of this study is to assist exporters in improving the efficiency of the debarked log supply chain, focusing on three primary goals. Firstly, it aims to provide data on the size and utilisation of log ships employed in New Zealand. Secondly, it seeks to investigate the impact of seasonal variations in log density on the volume of debarked logs transported on ships. Lastly, the study aims to gain insights into the factors influencing export debarker productivity.

1.1 Reasons for phytosanitary treatment

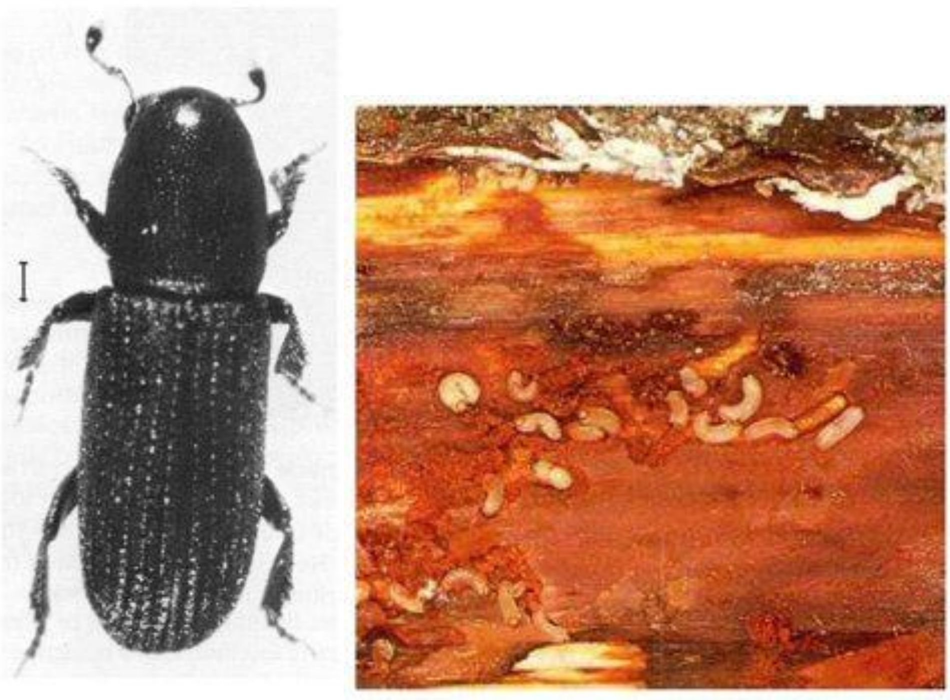
Natural disturbances such as pests, drought, and fire, have a profound impact on the health of forest ecosystems. Forest insect outbreaks alone damage around 35 million hectares (around 1%) of temperate and boreal forests annually (Ball, 2011). Non-indigenous pests accidentally introduced through trade in forest products and live plants have the potential to cause even more damage, as they have no natural control agents that keep populations in balance (Pawson et al., 2014).

1.1.1 Phytosanitary pests

A pest is “Any species, strain or biotype of plant, animal or pathogenic agent injurious to plants or plant products” (UNFAO, 2018). In terms of logs, the New Zealand forest industry is concerned about preventing the spread of pests from local forests, overseas.

Pests on the Quarantine Pests List include insects, arachnids, nematodes, bacteria, fungi, viruses and plants (MPI, 2023). For logs, key among these is preventing the spread of the *Hylastes* (**Figure 1**) and *Hylurgus* bark beetles, and *Arhopalus ferus*, the burnt pine beetle (STIMBR, 2005).

Figure 1:
Hylastes ater (left) and larvae (right) *(Milligan et al., 2009).*



As an example of the impact a phytosanitary pest can have, the European woodwasp (*Sirex noctilio*) was introduced to New Zealand through the movement of untreated timber. It was native to Asia, Europe and Northern Africa, but in the rest of the world, had no predators or parasites controlling it. In the 1940s in New Zealand, it caused losses of approximately 30% of all plantation trees (Ball, 2011).

1.1.2 Costs of phytosanitary failure

A breach in phytosanitary treatments can have substantial environmental consequences, as discussed above. In theory, trading partners can issue a Suspension of Trade for breaching phytosanitary requirements (Pawson et al., 2014). If China were to issue one, this would cut about 3.6 billion dollars in export sales (MPI, 2022b), and drive domestic log prices down as domestic log prices are set by the export market, as log sellers will sell to whoever gives the higher price (MPI, 2022a).

In 2009, a one-year suspension of trade was estimated to cost forest owners between $369 million and $3 billion (Self & Turner, 2009). Exports have tripled since then (MPI, 2022b), so losses can be expected to have increased proportionately (Pawson et al., 2014).

1.1.3 How phytosanitary treatment works

Phytosanitary treatment removes or kills phytosanitary pests. The main methods in use are fumigation and debarking. Current research is looking at joule heating as an alternative.

Fumigation works by sealing logs under a tarpaulin (**Figure 2**) or in a ship's hold, then pumping in a lethal gas. The gas permeates the logs, killing any organisms living on or in (in the case of methyl bromide) them. When fumigation is finished, the gas is vented into the atmosphere, recaptured (**Figure 3**), or destroyed (Molloy, 2017). Historically, this gas has been methyl bromide, but alternatives, such as phosphine, are increasingly being used (STIMBR, 2005). Each country has requirements on how much fumigant is needed and how long it should be applied for (MPI, 2023).

Figure 2:
Logs undergoing methyl bromide fumigation under a tarpaulin (Pawson et al., 2014).

Figure 3:
Methyl bromide recapture unit (Genera Biosecurity, 2017).

Debarking is not considered a phytosanitary treatment; it is a risk-reduction process aimed at eliminating the bark layer where bark beetles reside. The logs pass through a debarker, a machine that strips off the bark (**Figure 4**), and any pests residing within that layer.

Figure 4:
Logs with bark on (left) and debarked (right) (Murphy, 2016).

Heat treatment is another treatment method that is approved in some markets. It works by heating the log to a temperature beyond what pests can survive. In most cases, this is 56°C in the centre of the wood for 30 minutes (Heffernan, 2017). It is not used in New Zealand due to the prohibitive energy requirements of heating millions of tonnes of logs.

1.1.4 Phytosanitary requirements of importing countries

There is a significant number of standards and information available on the international trade of logs, with an emphasis on phytosanitary requirements and the trade of endangered species. These standards and information are provided by relevant governments and organisations (e.g., UNFAO). For instance, New Zealand publishes phytosanitary requirements for logs for each of the countries it exports to on the Ministry for Primary Industries (MPI) website. This study will focus on the commercial species aspect, as this is most relevant to New Zealand's log exports. Since almost all of New Zealand's export timber comes from plantation forests, the trade of endangered species is not a concern.

The MPI importing country phytosanitary requirements (ICPRs) show the phytosanitary treatments approved by both New Zealand and the importing country, for New Zealand’s main log export markets. Methyl bromide is an established treatment method in the countries listed in **Table 1**. However, in New Zealand, its use is being phased out except for container fumigation. Therefore, in **Table 1**, methyl bromide treatment is not included except when it is applied to individual containers of logs, which is still permitted (MPI, 2023).

Table 1:
Major log export destinations and their accepted phytosanitary treatments.

Country	Relative market size (OEC, 2022)	Treatments approved in hold	Treatments approved on deck
China	87%	Phosphine.	Debarking.
South Korea	7%	Fumigation on arrival.	Fumigation on arrival.
Japan	1%	Inspection, fumigation if required.	Inspection, fumigation if required.
Taiwan	1%	Inspection, fumigation if required.	Inspection, fumigation if required.
India	0.5%	Containerised methyl bromide, heat treatment (infeasible).	Containerised methyl bromide, heat treatment (infeasible).

The focus of this report is on logs being exported to China, as this is the only market that currently accepts debarked logs. The emphasis is placed on the on-deck volume, as these are the only logs that undergo the debarking process due to the lower cost of phosphine fumigation.

China recognises that debarked logs have lower phytosanitary risk due to the reduced habitat (the bark layer) for pest species (Pawson et al., 2014). This is why no additional treatment is required for these logs. For logs to be classed as debarked, no log may have more than 5% bark coverage, and no consignment (a group of logs, such as a stack or shipment) may have more than 2%.

To ensure compliance with phytosanitary regulations, a phytosanitary certificate is required for every shipment of logs. This certificate is issued by an independent verification agency (IVA), confirming that the logs meet the necessary phytosanitary standards. The IVA is responsible for measuring the bark area on each shipment and ensuring compliance with other phytosanitary measures such as phosphine application below deck. The process of measuring bark involves inspectors visually examining and measuring the visible area of logs at the end of a stack. If any logs exceed the 5% threshold, they will be identified and reclassified as bark-on. In cases where the visible logs collectively exceed the 2% requirement, a sample of logs from the stack will be selected and measured. If this sample fails, the entire row of logs may need to be reclassified. If both the logs and the stack meet the standards, a phytosanitary certificate will be issued. The purchaser in China receives this certificate, and the sale is contingent upon the acceptability of the phytosanitary treatments.

Chinese officials conduct their own inspections upon the arrival of logs. In case the logs fail to meet the requirements, complaints will be lodged. If the issue persists, the respective governments will intervene.

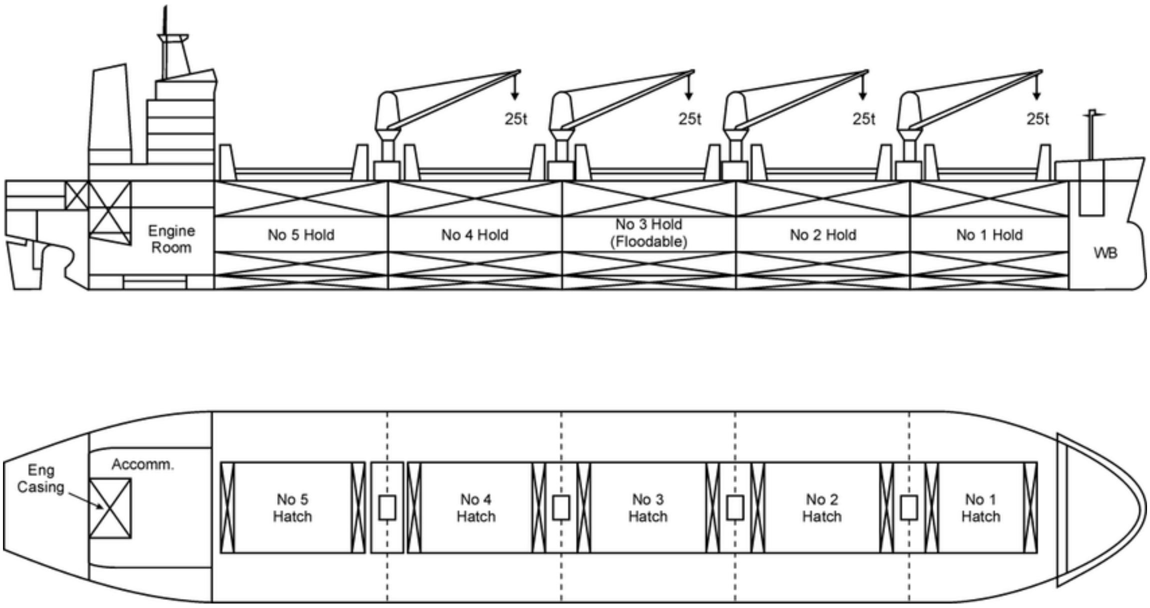
1.2 Carrying capacity of ships

1.2.1 Types of ship

Log ships are bulk carriers (bulkers), with multiple open holds into which logs are stacked by excavator (**Figure 5**). Most are self-discharging (have cranes on board) to enable loading at smaller ports that do not have wharf cranes (**Figure 6**).

Figure 5:
Excavator with grapple stacking logs in the hold of a ship at the Port of Tauranga.

Figure 6:
Plans of a self-discharging Handymax bulk carrier (Açık & Başer, 2018).



Ships are categorised into different classes based on their carrying capacity. In New Zealand, common log ship classes are Handysize (with an approximate deadweight tonnage of 32,000 to 38,000 tonnes) and Handymax (38,000 to 42,000 tonnes). Panamax (62,000 to 65,000 tonnes) and Post-Panamax (92,000 to 96,000 tonnes) ships are just beginning to be used. Deadweight tonnage refers to the total weight a ship can carry, including cargo, fuel, and ballast. It does not include the mass of the ship itself. Anecdotal information suggests that most log ships in New Zealand are Handysize.

Ships are often designed to carry denser loads than logs so holds are filled before deadweight is reached. Log ships are fitted with stanchions (**Figure 7**) that enable logs to be loaded above the holds, increasing the volume that can be carried. It is in this area that the debarked volume is loaded. 30-40% of the volume is stored above deck. While the volume of logs the ship can carry increases, there are a couple of disadvantages. First, you cannot fumigate logs not stored in a hold, as the fumigant will blow away. Second, the centre of gravity of the ship is raised, which can affect the stability if the ship is loaded incorrectly (Maritime NZ, 2011). A ship that is unstable in this way is called 'tender'- if pushed off a neutral axis it takes a long time to return.

Figure 7:
Loaded ship, showing above-deck volume being supported by stanchions.

Because ship design varies, the overall volume carried varies, as well as the percentage stored above and below deck.

1.3 Metrics for measuring density

Several metrics can be used to measure the density of the wood (WPMA, 2020). Each is useful in different scenarios.

- Basic Density: The ratio of oven-dry wood weight to saturated volume. This is the most absolute density - both oven dry weight and green volume are fixed for a certain piece of wood.
- Oven Dry Density: Oven dry wood weight divided by its corresponding oven-dry volume.
- In-situ Density: In-situ weight divided by in-situ volume. This is the metric that changes seasonally as the drying rate varies.
- Bulk Density: The density of logs in a stack or hold, including voids. Also called packing density. Important for exporters who are trying to load the maximum amount of logs on a ship.

All of these can be expressed in terms of different volume units. While domestic logs are measured in metric units (metres cubed), export logs are measured in Japanese Agricultural Standard (JAS) metres cubed. This is a scaling process that approximates the log as a rectangular prism using the length and smallest and largest small end diameters (SED). It is similar to true metres cubed, but can vary depending on the shape of the log (Ellis et al., 1996). Unless otherwise stated, this paper deals with JAS metres cubed in the shipping section and true metres cubed in the debarking section.

1.3.1 Geographical variation in density

Pinus radiata wood density varies according to location in the country. The general trend is that the further north the tree and the lower the altitude it grew at, the higher the density. As is shown in **Figure 8**, the areas with the highest density are therefore the lowland areas of the Waikato, Bay of Plenty, Auckland and Northland. Southland has the lowest values (Palmer et al., 2013). In this study, this means we would expect the lowest density out of Port Chalmers, and the highest density out of Marsden Point and Tauranga. Indications are that annual temperature and summer rainfall are major contributors to log dry density (Palmer et al., 2013).

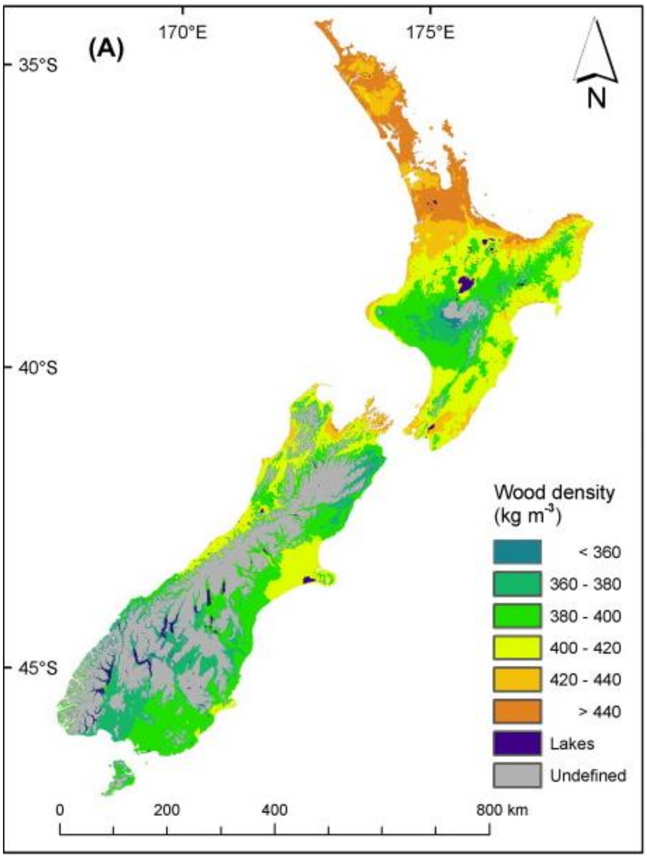


Figure 8:
Spatial variation in Pinus radiata density (Palmer et al., 2013).

1.3.2 Effect of cargo bulk density on log ship design

The bulk density of cargo plays a significant role in understanding how ships are loaded and their carrying capacity. Ships are often designed to transport heavy cargo, so when they are tasked with transporting lighter logs, the ship's holds are filled before the ship reaches its deadweight.

Iron ore has a very high bulk density, both because the rock is very dense, and because the particles are irregular, meaning they can pack more tightly. Iron ore, cement and minerals are common cargos for bulk ships, so most ships are designed for heavy loads (Bulk Carrier Guide, 2010). Wood is far less dense, and logs have a regular, non-tessellating shape. This means there are a lot of gaps (from the report data, the volume of logs is 80-85% of the hold volume), which means the cargo has low bulk density. It is also why so much effort is put into stacking logs in the holds (**Figure 5**). Consequently, when logs are loaded onto ships designed for iron ore transport, the holds reach volumetric capacity before the ship reaches its weight limit.

To address this issue, small and medium-sized ships have used stanchions to load logs on deck. This approach allows for the efficient use of available space and weight capacity by stacking logs above the holds in the open air. By doing so, they maximise their cargo capacity in terms of both volume and weight, resulting in more cost-effective transportation.

Large ships often do not employ this strategy, as they have not been used much for logs before, so there has been no demand to fit them with stanchions. The first of these larger ships have been loaded in the last couple of years, with sight to using them more in the future.

1.4 Seasonal variation in log density

1.4.1 Log drying

Wood is hygroscopic, meaning it can absorb and release water vapour, depending upon various factors. These factors include the moisture gradient between the air and the timber, wind speed, temperature, log length and diameter, debarking, and exposure time (Simpson & Wang, 2003; Visser et al., 2014).

The moisture gradient denotes the difference in moisture content between the wood and the surrounding air. Wood strives to reach an equilibrium moisture content (EMC) with its environment, so absorbs and releases water according to this (Simo-Tagne & Bennamoun, 2018).

Higher wind speeds enhance the rate of evaporation from the wood's surface, thereby hastening the drying process. Lower wind speeds, result in a boundary layer of moist air around the wood, slowing the drying process (Simo-Tagne & Bennamoun, 2018).

Temperature influences the hygroscopic behaviour of wood. Higher temperatures increase the rate of moisture release by increasing the movement of water molecules. Lower temperatures slow the moisture exchange, leading to longer moisture retention in the wood (Simo-Tagne & Bennamoun, 2018).

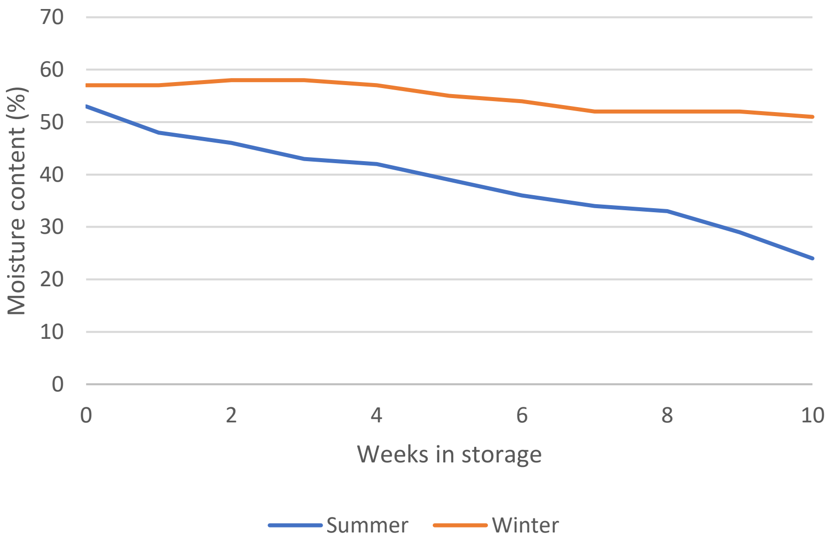
The dimensions of the wood, such as log length and diameter, impact its hygroscopic properties. Smaller pieces have more surface area per unit volume, so dry more quickly than larger pieces (Simo-Tagne & Bennamoun, 2018; Simpson & Wang, 2003; Visser et al., 2014).

Debarking, the removal of the outer bark from the wood, can affect its hygroscopic behaviour. The bark acts as a protective barrier (e.g., covering a log stack), limiting the moisture exchange between the wood and the environment. Removing the bark exposes the wood's surface, enabling more efficient moisture absorption or release.

Exposure time refers to the duration that wood is subjected to a particular moisture environment. Longer exposure times provide the wood with more time to reach its EMC, and so correlates to more drying (Visser et al., 2014).

The effect of climate on log drying can be seen in **Figure 9**.

Figure 9:
Log moisture content over time in summer versus winter (Visser et al., 2014).



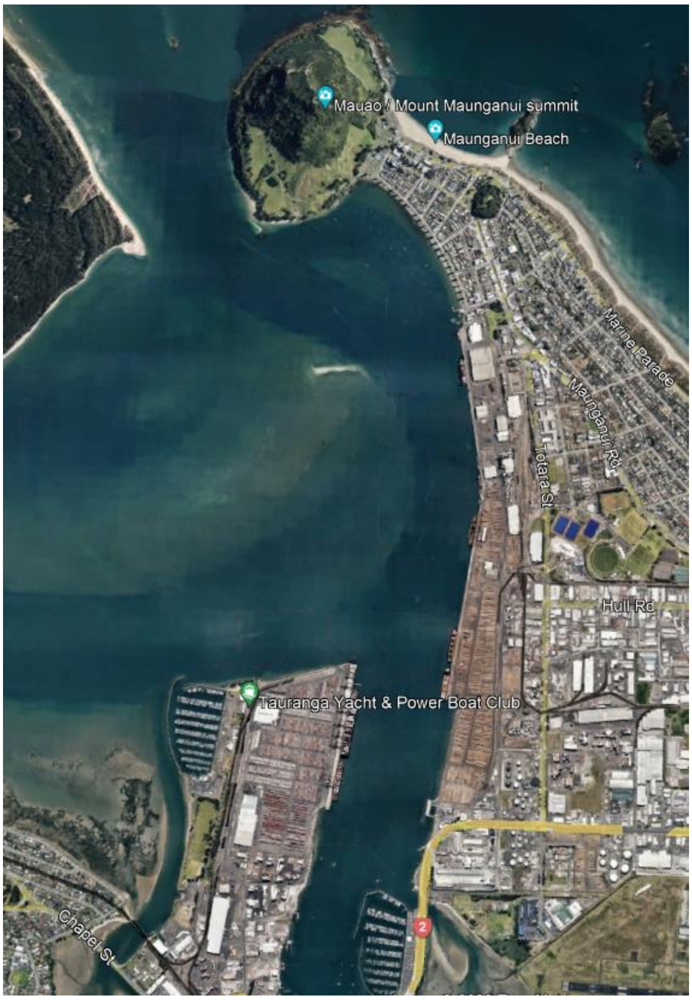
The available information on the seasonal weight variation of Pinus Radiata at the port is from weighbridge data, which is not publicly accessible. The impact of this seasonal weight variation on the on-ship volume is not known due to the influence of other factors such as shrinkage and bark removal. Other confounding factors include weather conditions and storage time, which affect drying time. The moisture content of logs can change up to 3% per week in ideal conditions, but may not change in wet, cold conditions (Visser et al., 2014).

1.4.2 Effect of weather patterns at the Port of Tauranga

Tauranga has sheltered and sunny weather patterns due to the surrounding high country on three sides. Most rainfall occurs when tropical airflows are forced up over these high areas. Because weather is dependent on non-prevailing airflows (those coming from the east), weather patterns are variable (Chappell, 2013).

Average wind speeds in Tauranga are highest in spring, followed by summer and winter, which are similar, and autumn, which has the lowest wind speeds. Wind speeds are highest mid-afternoon, which is also the warmest time of day (Chappell, 2013). Weather data was recorded at Tauranga Airport, within two kilometres of the log yard. The log yards are on the right side of the harbour in **Figure 10**, while the airport is the grassy area in the bottom right corner.

Figure 10:
Port of Tauranga, with log yards on the right and the container berths on the left.



Rainfall is highest in winter, followed by autumn and spring, then summer. Winter months are less variable than summer, due to the summer rainfall being influenced by cyclonic weather patterns. Tauranga experiences an average of 112 days annually where rainfall measures 1 mm or higher (Chappell, 2013).

Comparing information shows that the weather in Tauranga (Chappell, 2013) is similar to the trials done by Visser et al. (2014) (**Table 2**).

Table 2:

Comparison of weather conditions at Tauranga airport and in Visser et al. (2014).

	Summer test	Winter test	January Tauranga	July Tauranga
Average air temperature (°C)	13	7	20	10
Average relative humidity (%)	76	85	73	84
Average rainfall (mm/week)	9.8	20.0	17.6	29.1
Average total evaporation (mm/day)	3.2	1.4	5.2	1.0
Average daily windspeed (m/s)	3.7	2.8	3.9	3.6

Because of this, drying patterns should be similar to those shown in **Figure 9** - we expect faster drying in summer than in winter, with logs arriving at the port lighter.

1.5 Debarking machines

A debarker is a machine that strips the bark off a log or stem to expose the wood inside (Murphy & Logan, 2016). They are used across the wood processing industry, for pulp, sawmills, and exporting. In general, the objective is to produce two value-added products. When it comes to exports, the primary goal is to meet phytosanitary requirements (Murphy, 2016).

1.5.1 Types of debarker

A debarker used for export timber needs to have a very high level of bark removal to meet phytosanitary requirements. It also needs to have minimal log damage to retain log value and volume (Murphy, 2020). There are many types of debarker, each with advantages and disadvantages. These include chain-flail, drum, cradle, Rosser head, and rotary ring (Chahal & Ciolkosz, 2019).

A chain flail debarker passes the log past a series of spinning chains, which whack the bark off the logs. This is a low-cost debarking method with simple mechanisms but is not useful for the export industry because there is too much log damage and not enough bark removal. It is primarily used in the pulp industry, where log damage is not so important (Chahal & Ciolkosz, 2019).

The drum and cradle debarkers work in similar ways, where logs are agitated against each other, which rubs the bark off. A drum debarker has a large rotating slotted drum which rolls and tosses the logs. The drum is mounted on a slope so that the logs slide through, and the bark falls out through the slots (Chahal & Ciolkosz, 2019; Isokangas et al., 2006). A cradle debarker uses conveyors to lift and drop the logs (Acrowood, 2015). Both methods remove the bark through abrasion against other logs and the surface of the machine. They can process very large volumes of wood, and diameter does not affect volume production like methods where one log is debarked at a time. They are not used for log export due to inconsistent bark removal and wood damage (Chahal & Ciolkosz, 2019).

Rosser head debarkers use a spinning head to grind the bark off as the log slowly rotates. They achieve good levels of bark removal in uniform logs (Chahal & Ciolkosz, 2019). They are slower than other debarking types, so are not used in New Zealand for export, where high volume is a priority.

Rotary ring debarkers (**Figure 11**) pass logs through an array of rotating swing-arm knives that scrape the bark off the log (Chahal & Ciolkosz, 2019). They have the advantage of high-quality debarking with less log damage compared to other methods. This is true on logs with good form. They can also have lower installation costs and power requirements than drum debarkers (Koch, 1985). A rotary ring debarker is in use at Kaingaroa Timberlands and is where the data for this report was collected.

Figure 11:
A rotary ring debarker shown scraping a log (Progress Industries, 2018).

Bark is also removed in the forest with the use of mechanised processing heads and static delimbers. These provide 40-80% bark removal- insufficient to meet phytosanitary requirements (MPI, 2023; Murphy & Logan, 2016).

1.6 Automated data collection process

1.6.1 Data collection at the Port of Tauranga

When a truckload of logs arrives at the port, each log has a ticket stapled to it. This ticket details the origin of the log and the grade, among other things. The truck then drives to an automatic JAS scaling robot, which measures each log by taking photos of the truckload and assigns the ticket a volume. The truck then drives to the port, where the logs are unloaded into stacks.

When a ship arrives, the logs are unstacked and taken to the dock. Another machine takes photos of the tickets, thus knowing each log that is loaded on the ship.

All this information is automatically entered into a database, as well as times and other relevant information. From this, the overall volume that was loaded can be calculated, as well as other statistics used in this project, such as the percentage of the overall volume made up of debarked logs.

1.6.2 Data collection at the Murupara debarker

The Murupara debarker collects and stores information about each log it debarks within an online database. Data such as length and diameter is stored as the log passes through the debarker. This database is constantly updated, enabling real-time analysis of the debarker's performance. Data for this report was sourced from this database.

1.7 Gaps in current research

Research on debarking as a solution to export requirements includes relative costs of fumigation and debarking (Molloy, 2017), the quality of certain debarkers (Murphy, 2020), minimum phytosanitary requirements (MPI, 2023) and whether they are met (Murphy & Acuna, 2017).

Research has been conducted on the drying rates of Radiata pine in various scenarios (Simpson & Wang, 2003; Visser et al., 2014). The focus of this research is understanding the drying process itself and how it varies with changing environmental conditions and piece size. Often the focus is biomass. To date, there has been a lack of interpretation regarding the impact of drying on wood exports. There has been no research on the seasonal variability in the log volume that is loaded on a ship.

No data has been published on the sizes of log ships that are used in New Zealand.

Molloy (2017) also discusses the comparative cost of debarking various grades. This report will focus on the rate, as opposed to the cost, of the debarking. Information is needed on how log size affects the rate of debarking.

2 Study objectives

The overall aim of this paper is to help exporters optimise the supply chain of debarked logs. As part of this, there are three objectives, as follows.

1. Examine the effect of size and utilisation of log ships used in New Zealand on debarked volumes.

Analysing ship size and utilisation is important to the debarked supply chain because improving ship utilisation is the main reason that debarked timber is carried. By understanding the types of ships used to cart logs in New Zealand, we can better discern the volume of debarked timber that will be required. It also enables identification of opportunities to carry more debarked timber and begin increasing the capacity of the debarking supply chain as required.

2. Examine variation in above-deck volume loaded on a ship due to seasonal differences in log moisture content.

Enhancing knowledge of seasonal volume variations loaded on ships between summer and winter leads to improved volume forecasting. This reduces under and overproduction, aiding exporters in reducing on-port debarked log stockpiles. It promotes environmental and health benefits by minimising the use of methyl bromide, generally used to make up the difference between debarked log availability and demand.

3. Analyse how log size impacts the throughput of Kaingaroa Timberlands' Murupara debarker and compare it to a linear production line model.

Finding the effect of log size on productivity allows differences between theoretical and actual production to be observed. This allows the identification of areas where the debarker is not performing as well as a model, and therefore areas for improvement. The end goal of this is to enable higher production.

3 Methods

Two sets of data were analysed, one from PFP and one from TLL. Objectives 1 and 2 were met using the data from PFP, while Objective 3 used data from TLL.

3.1 Ship data collection and sorting

3.1.1 Robotic data collection process at the Port of Tauranga

Upon the arrival of a truckload of logs at the port, each log gets a ticket (label) attached which bears its origin and grade. The truck then proceeds to a JAS scaling robot, where the logs are measured through photos. The robot assigns a volume to each log's ticket. Following this process, the truck goes to the port, where the logs are unloaded into stacks.

When a ship arrives, another machine captures images of the tickets associated with each log as they are loaded, creating a record of the logs loaded on the ship. All pertinent information, including timestamps and other relevant data, is integrated into a database.

Because this process is mechanised, there is no human error. Computer error is minimised by having a human check the phases where computer vision is used, such as the JAS scaling machine.

All data is automatically entered into the PFP database.

3.1.2 Collating data from the PFP database

Data for this report was sourced from PFP's historical ship dispatch records – the database referred to above. The data used was from the period beginning 1st January 2021, and ending 3rd July 2023 – 2.5 years. PFP's representation of the entire market was assumed.

The historical data from Pacific Forest Products encompassed ship details, loading locations, wood types (bark-on, oversize bark-on, debarked, oversize debarked and antisapstained, debarked and antisapstained), dates, ship sizes, and weight/volume conversion factors.

In this section, units of volume are JAS m^3.

3.1.3 Sorting and filtering shipping data

It was acknowledged that grade ratios can influence the bulk density of the logs in the hold- i.e., having a lot of small logs may lower the bulk density. The assumption made was that grade mixes were similar across all ships, a notion confirmed by PFP.

Data was supplied in multiple datasets as each set was requested. To combine them for analysis, Visual Basic code was used by referencing the unique shipment number. If the code was written incorrectly, this is a source of error. Only a small sample of the shipments could be manually checked.

The day and month of the ship's departure, excluding the year, were extracted from the date data. This allowed for the overlay of data spanning multiple years, resulting in denser data points and simplified interpretation. It was assumed that the year did not significantly influence the cargo volume carried, although this assumption could not be verified since potential year-related factors were not formally documented.

Because of significant data variability, attempts were made to identify patterns causing this variability. This process involved PFP and TLL, and their insights enabled groups of data that did not apply to be removed. Removing outliers from established patterns without reason was dismissed due to this resulting in a misrepresentation of the data.

Solely bulkers where the whole ship was loaded by PFP were used- ships shared between multiple exporters were excluded. This is because the data supplied contained the volume of logs PFP loaded, therefore not representing a whole ship.

The analysis was carried out in MS Excel.

3.2 Graphing size distribution of log ships

Creating a histogram of deadweight facilitated ship classification, revealing distinct ship classes. This is displayed in the results section (**Figure 12**). This enabled the exclusion of Panamax and

Post-Panamax ships, which generally lack stanchions and therefore debarked volume, for certain calculations. No other ship classes were deemed appropriate to remove, as they did not have any clear trends in the proportion of debarked volume loaded and should all have had stanchions.

These results could then be analysed according to the objectives, including identifying potential opportunities for better utilisation.

3.3 Calculating and graphing variation in above-deck volume

3.3.1 Weight factor

Weight factor, being the density of the logs, was calculated from weighbridge data for truckloads arriving at the port and then averaged over the logs loaded on an entire ship. This enabled the density of the logs at different times of the year to be compared for different ports. This is related to the volume carried, so was used to display the expected pattern for overall volume.

3.3.2 Calculations and graphing proportion debarked

The volume data supplied was in more categories than necessary, so categories were combined to create two: debarked and bark-on. The total debarked volume was calculated as:

$$Debarked\ volume = D + OT + T \tag{1}$$

Where D is debarked, OT is oversized, debarked and antisapstained, and T is debarked and antisapstained.

The bark-on categories were calculated as follows:

$$Bark\ on = B + OB \tag{2}$$

Where B is bark-on, and OB is oversized bark-on.

There were two categories of timber used in the analysis, such that:

$$Total\ volume\ loaded = Debarked\ volume + Bark\ on \tag{3}$$

The proportion debarked was calculated as a percentage of the overall volume loaded on the ship.

$$Proportion\ debarked = \frac{Debarked\ volume}{Total\ volume\ loaded} \tag{4}$$

It was suspected that some ships in the database were not fully loaded and that this was the cause for low debarked volumes. To test this, each ship's weight factor and deadweight were utilised to calculate the weight of logs as a fraction of the deadweight of the ship (proportion loaded).

$$Total\ weight\ loaded = Total\ volume\ loaded \times Weight\ factor \tag{5}$$

$$Proportion\ loaded = \frac{Total\ weight\ loaded}{Deadweight} \tag{6}$$

$$Proportion\ loaded = \frac{Total\ volume\ loaded\ \times Weight\ factor}{Deadweight} \tag{7}$$

Weight factor has units of tonnes per JAS m^3, and deadweight is in tonnes.

Graphs presented in the Results/Discussion section were derived by plotting subsets of this data against each other. Some graphs incorporate data filters to enhance interpretability. These filters, and the reasons they are applied, are explained with the relevant graph.

3.4 Modelling debarker productivity

3.4.1 Data collection

The dataset collected by the Murupara debarker included information about every individual log. From this extensive dataset, shift summaries were compiled for each shift, excluding reject logs. Each shift represents one day's worth of work. The summaries provided data on the overall volume processed and the volume categorized by diameter and length. The dataset spans a duration of four years, ending February 2023. The data arrived in separate sets, with one set for each size classification and an additional set encompassing the overall statistics. Visual Basic code was employed to amalgamate these datasets for analysis.

3.4.2 Classifying logs for debarker analysis

Logs were sorted into six classes. Three divisions were made by SED (<210 mm, 210-310 mm, >310 mm) and two by length (greater than and less than 4.5 m, referred to as Short and Long). From now on, these will be referred to as the diameter class, followed by the length code. For example, 210-310 Long would be logs with SED of 210-310 mm, and length greater than 4.5 m. Note that volume units in this section are true metres cubed, rather than JAS metres cubed.

While the option to filter the data was considered, it was decided not to remove shifts that produced volumes below a certain threshold. Instead, graphs were generated to visualize the data. This results in a better representation of the data.

3.4.3 Process of modelling theoretical maximum debarking rate

Theoretical calculations were carried out to determine the impact that log size, the gap between logs, and the line speed of the debarker would make. For this, two cases were supplied: a normal case, where the line speed was 100 m/min and the gap between logs was 0.2 m, and a best case, where the line speed was 130 m/min, and the gap was 0.1 m (Bowen, 2023).

By using the formula below, the volume could be calculated as factors are varied.

$$V = \left(\frac{D}{2}\right)^2 \times \left(v - G \times \frac{v}{G + L}\right) \tag{8}$$

Where V is the volume produced (m^3/min), D is the log diameter (m), v is the linear speed of the debarker (m/s), G is the gap size (m), and L is the log length (m).

This enables analysis of how each of these factors affects production.

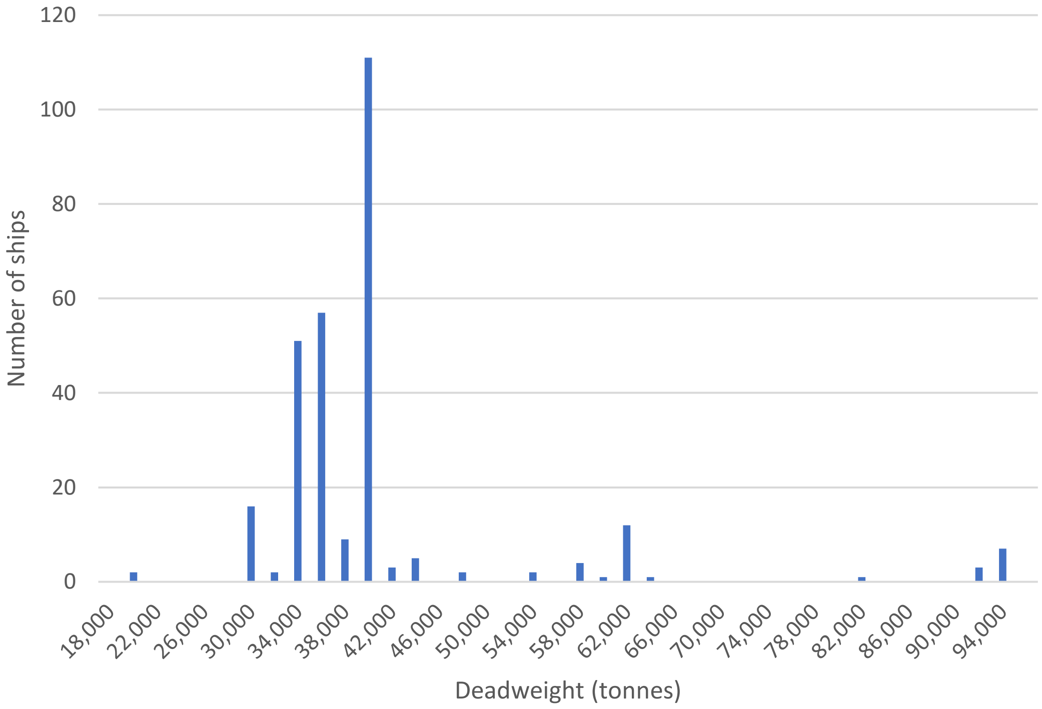
4 Results/Discussion

4.1 Size and utilisation of log ships

4.1.1 Ship deadweight

The clearest measure for ship size is its deadweight- the amount of variable load it can carry. Deadweight, as booked by PFP, ranged from 18,000 tonnes to 93,000 tonnes, but 82% were in the range of 32,000 tonnes to 42,000 tonnes. To classify log ships, a histogram based on deadweight was plotted (**Figure 12**).

Figure 12:
Histogram of the deadweight of the ships booked by PFP.



Clear delineations in ship size appear above, with large numbers of ships occurring in small bands of deadweight, and few ships in between. These are related to the classes in Section 1.2.1. The delineations made, as well as the number of ships that fall into each, can be found in **Table 3**. These will be referred to further in this report.

Table 3:
Ship classifications, and number of ships in each.

Ship type	Deadweight >= (tonnes)	Deadweight < (tonnes)	Count
Very small	18,000	27,000	2
Small	27,000	32,000	18
Handysize	32,000	38,000	111
Handymax	38,000	42,000	119
Large	42,000	62,000	15
Panamax	62,000	65,000	13
Post-Panamax	92,000	96,000	10
Total			288

Some of the classifications made are ‘catching’ classifications, picking up ships that do not fall into a predefined class. ‘Very small’ and ‘Large’ are examples of these.

Other classes are much clearer. Handysize and Handymax are classes that span just 6000 and 4000 tonnes, respectively, but represent 82% of the total number of ships, and 76% of the total volume. Likewise, the ‘Panamax’ category spans just 3000 tonnes but represents 6% of the total volume.

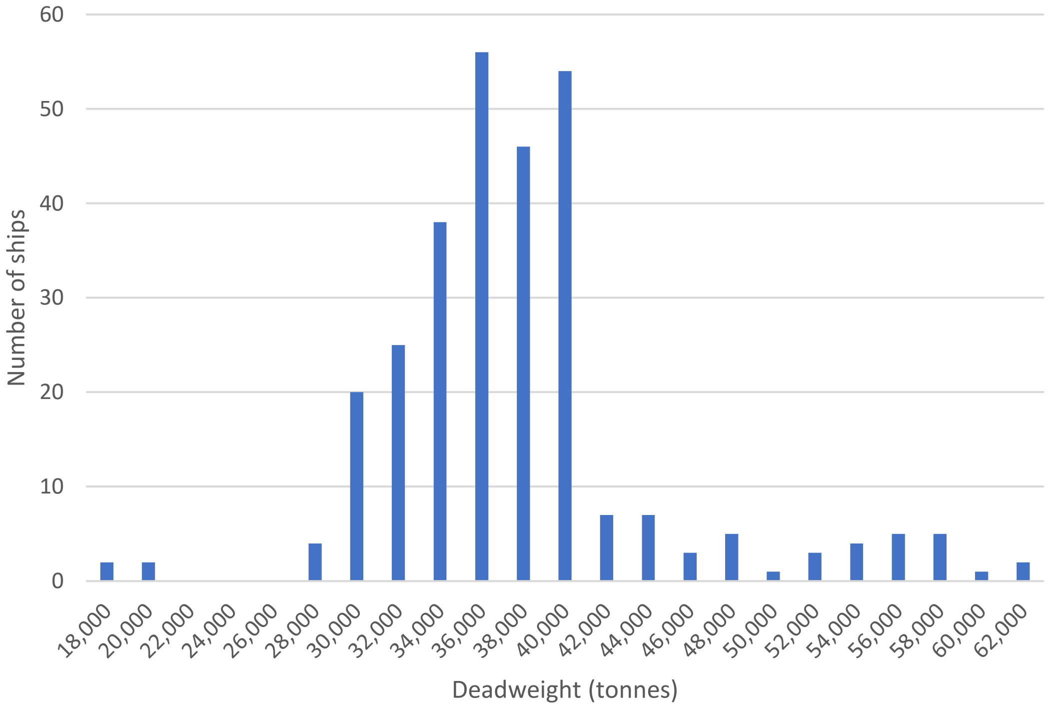
A fourth peak is noted at 30,000 tonnes, this is represented by the ‘Small’ class. These smaller ships are loaded at a small port (Marsden Point, Gisborne, Napier, Port Chalmers), before topping off with debarked cargo in Tauranga.

This data shows that the most common ship class is Handymax, representing 40% of the total volume carted, followed by Handysize, with 36%. This goes against the anecdotal information supplied in Section 1.2.1, which stated that Handysize were the most common. Given that they are close, this is understandable. It is also possible that other exporters use more Handysize ships. That these two classes are most common is also understandable, as a ship this size does not require a large port and does not require maximising the port's stockpiles to fill a ship. This data suggests most loggers (ships fitted with stanchions for carrying logs) are this size.

4.1.2 Utilisation of deadweight

The actual weight of logs loaded on the ship is not necessarily the same as the deadweight. **Figure 13** shows the actual weight of logs loaded on ships.

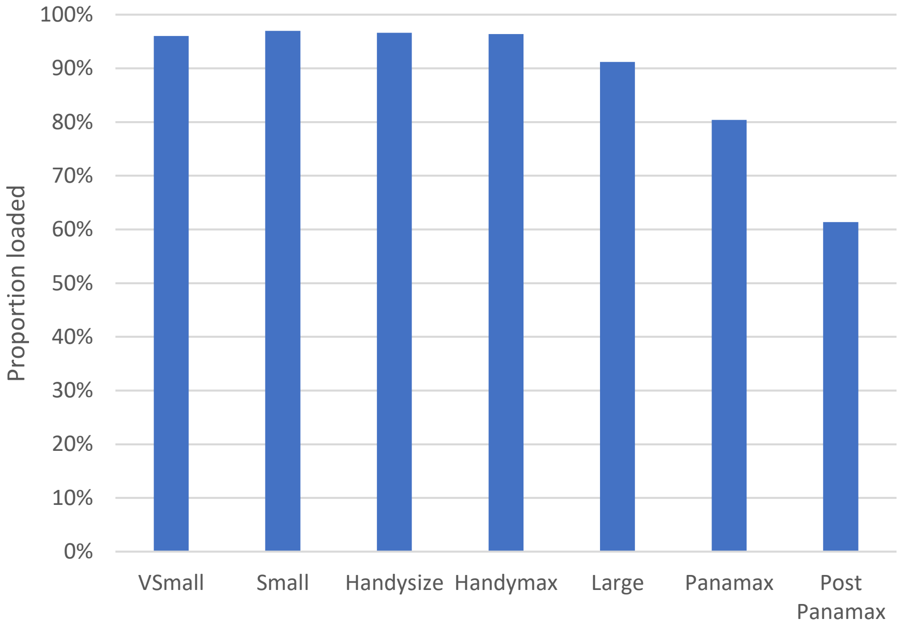
Figure 13:
Histogram of the total weight of logs loaded on the ships booked by PFP.



If all ships were fully loaded according to their deadweight, the series in **Figure 12** and **Figure 13** would be the same. They are not- the spikes in **Figure 12** were much more defined.

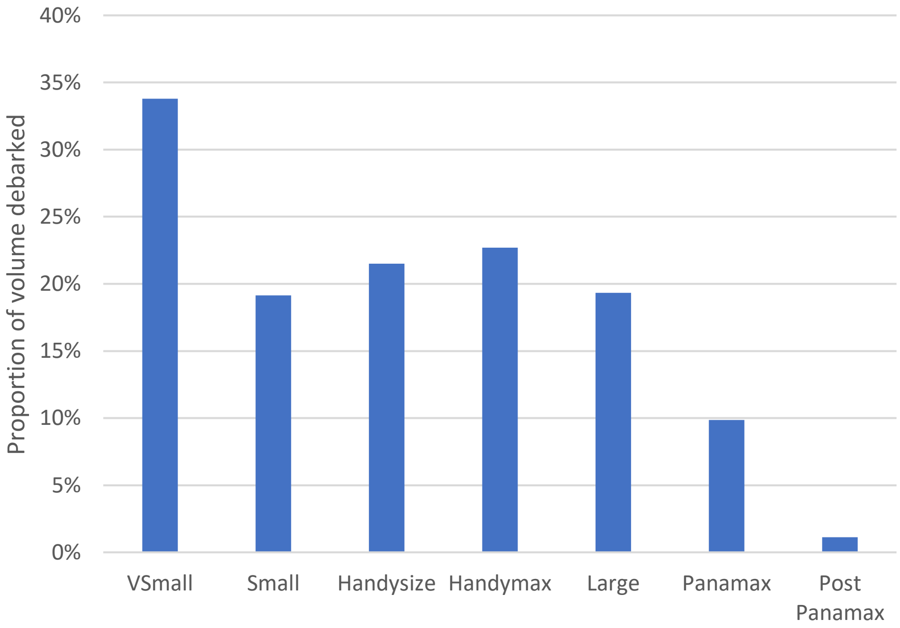
Both the Handysize and Handymax classes are generally slightly under-loaded, however deadweight includes other variable loads, like fuel, so they are most likely loaded accurately. Average loading is 97% when ships under 90% loaded are excluded, and 94% when including all values. The average loading for the Panamax and Post-Panamax ships is 72% (**Figure 14**).

Figure 14:
Percentage of the deadweight that is logs, for each ship class.



Panamax and Post-Panamax ships have much lower utilisation. This is because they do not normally carry debarked volume, so cannot fit enough cargo to fully utilise their deadweight. The proportion of cargo carried on each ship type that is debarked is shown in **Figure 15**.

Figure 15:
Percentage of the overall volume that is loaded above deck (debarked).



Handysize and Handymax ships have approximately the same percentage of their cargo being debarked. This makes planning easier, as 82% of ships can expect to have similar volume being debarked.

If log ships did not have stanchions, their carrying capacity would be limited by the volume they could carry. An example of this is the Post-Panamax ships- they are not fully loaded by weight (**Figure 14**) although their holds are full. Adding stanchions removes the volume constraint, which is why the smaller ships are fully loaded according to weight.

The use of large ships is in its infancy, but if their use increases in the future, there may be a drop in the proportion of the overall export volume that is debarked, as these ships do not have stanchions. If stanchions begin to be added to these larger ships, there will be an increase in the volume of debarked timber required. This is something exporters should be aware of when making decisions around ship booking.

4.1.3 Fuel savings in large ships

Smaller and medium-sized ships use stanchions for on-deck log loading, optimising space and weight capacity. Larger ships have not adopted this practice due to the limited use of these ships for logs in the past (**Figure 15**). Larger ship classes have lower overall loadings (**Figure 14**) of this.

With recent trials of larger ships and potential future use, there arises a commercial opportunity. Equipping a Panamax or Post-Panamax vessel with stanchions could further reduce their already low shipping rates, allowing full utilisation of their deadweight capacity. As indicated by the report data, a Panamax or Post-Panamax ship is typically loaded to about 70% of its deadweight capacity. Equation 9 showed that loading to full capacity would lead to an 11% reduction in fuel consumption per tonne and subsequently lower shipping rates (Bialystocki & Konovessis, 2016).

$$Fuel\ burn_{Design} = Fuel\ burn_{Actual}\left(\frac{Design\ deadweight}{Actual\ deadweight}\right)^{\frac{2}{3}} \tag{9}$$

4.1.4 Reasons for variable loading

The 10 largest ships all have deadweight above 92,000 tonnes. By comparison, the 10 largest weights loaded range from 56,000 tonnes to 61,000 tonnes. This is because cargo ships are designed for cargo denser than logs, so the holds fill up before the deadweight is reached. While smaller ships utilise their full deadweight by using stanchions to carry more cargo above the holds, Panamax and Post-Panamax ships lack stanchions so cannot sail at their deadweight. This is one reason that the highest data points in **Figure 13** are more concentrated than in **Figure 12**.

It was hypothesised that having more logs loaded above deck would raise the centre of gravity, making the ship less stable and able to carry less (Maritime NZ, 2011). If this were the case, the proportion loaded would be less in summer. To test this, the potential impact of the time of year on the proportion loaded was examined. It was speculated that during summer, more debarked cargo would be loaded above deck, leading to a higher centre of gravity, so lower overall loading. This hypothesis was rejected- no relationship was observed.

One potential reason is that other loads on the ship vary. A ship’s deadweight includes fuel and ballast, so if the ship had just refuelled less cargo could be carried. This accounts for some of the variability.

Multiple ships seem to be sailing partly loaded. Panamax and Post-Panamax ships make up approximately half of these data points, which is understandable as they do not have stanchions. It is unknown why there are others.

There could be inaccuracies in the recording or storing of the data, which meant the received data was inaccurate. This was deemed unlikely given that PFP bills its customers in China based on the volume of logs on the ship, so it is important these numbers are correct.

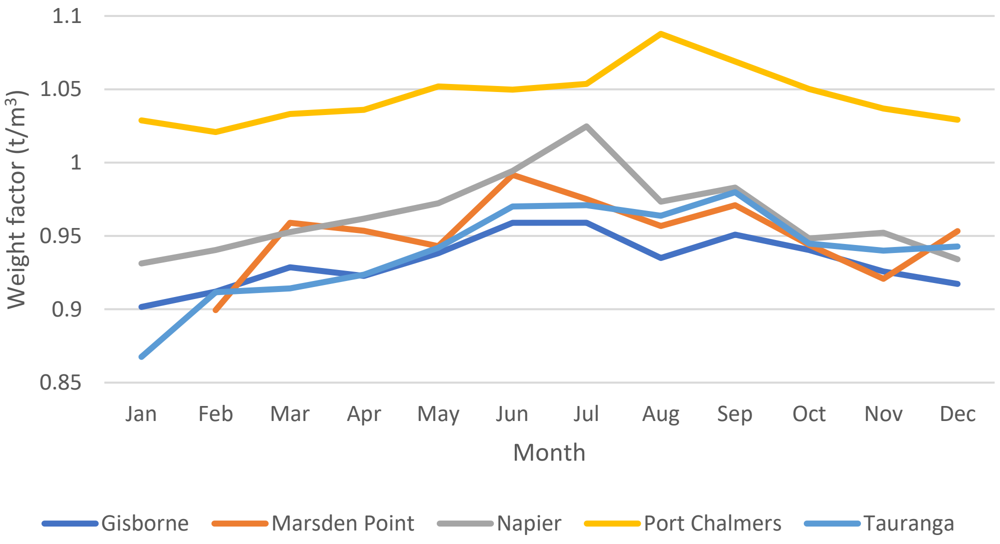
It is possible that there are inaccuracies in the loading of the ship. The ship is loaded based on displacement measurements, which are lines on the sides of the ship. This ensures that the ship is loaded evenly (there are marks on each corner that prevent one part of the ship from being loaded more heavily than another), but these are also quite crude measurements, so there may be small variations in the overall loading of the ship.

4.2 Variation in above deck volume

4.2.1 Weight factor

Weight factor (log density) was expected to vary throughout the year. Logs dry faster in summer (Visser et al., 2014), so should arrive at the port with a lower moisture content, and hence lower weight. This is the trend shown in **Figure 16**, with the weight factor being lowest in January (the warmest and one of the windiest months (Chappell, 2013; Marca, 2013)), when the most drying would occur in the stacks and on the truck.

Figure 16:
Monthly average weight factor of logs arriving at each port.



There is a relationship between the weight factor and the time of year the shipment was made. At the North Island ports, the mean weight factor in January is 0.889, while in July, the mean is 0.976, meaning logs are shipped 9% heavier in winter than in summer.). The difference for Port Chalmers is 6%- the maximum is in August with 1.08 and the minimum is in February with 1.02. There is some variance around the mean (the standard deviation for any given month is approximately 0.05.

There is a clear separation of logs shipped from Port Chalmers (Dunedin, at the bottom of the South Island) and the North Island ports (Tauranga, Marsden Point, Gisborne, Napier). Logs are arriving at the port heavier in Dunedin than at any of the other ports. This is the opposite of the trend in growing trees (Palmer et al., 2013), where we would expect the densest timber in the north of the country. The difference is assumed to be because the climate is causing the logs to dry less before being shipped (Chappell, 2013; Marca, 2013; Visser et al., 2014). This is supported by there being a smaller difference in weight from summer to winter in Port Chalmers, as logs that had dried less would always be closer to their green moisture content.

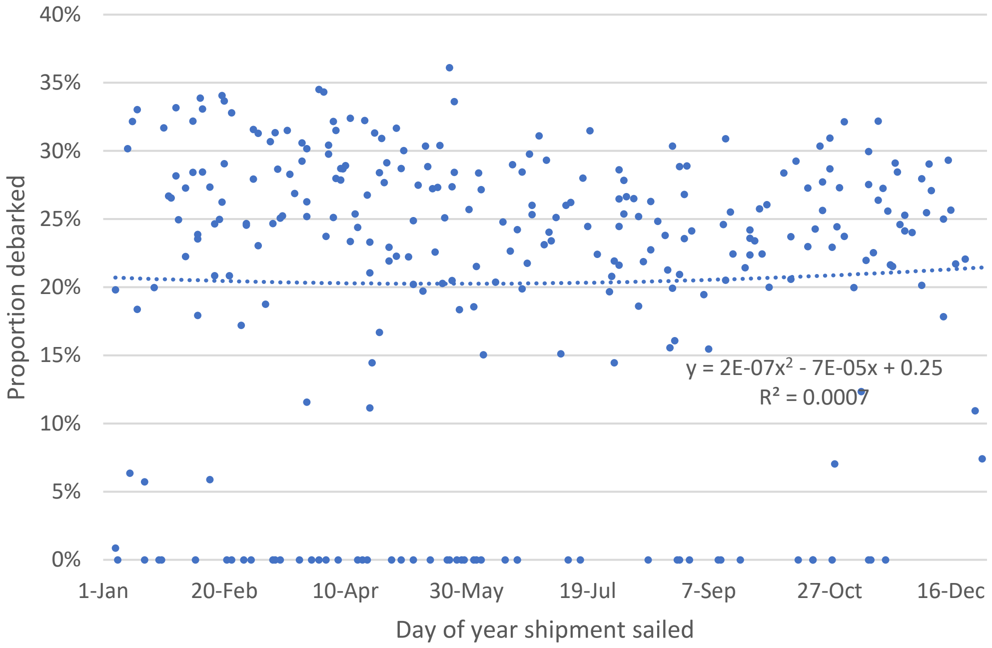
The lowest and highest weight factors occur in different months at different ports. This can be used to the exporter's advantage, as by loading out ports when they have a lower weight factor, they would increase the amount of logs a ship can carry. An example of this could be shipping more volume from the Tauranga, and less from Port Chalmers in January, but more from Port Chalmers in July, before the August peak. This would be limited by storage capacity.

4.2.2 Proportion of cargo that is debarked

The proportion of the total volume of cargo loaded on a ship that is debarked was plotted against the day of the year that the ship sailed. This dataset was noisy and challenging to find trends in. All PFP ships that sailed internationally are shown in **Figure 17**.

Figure 17:

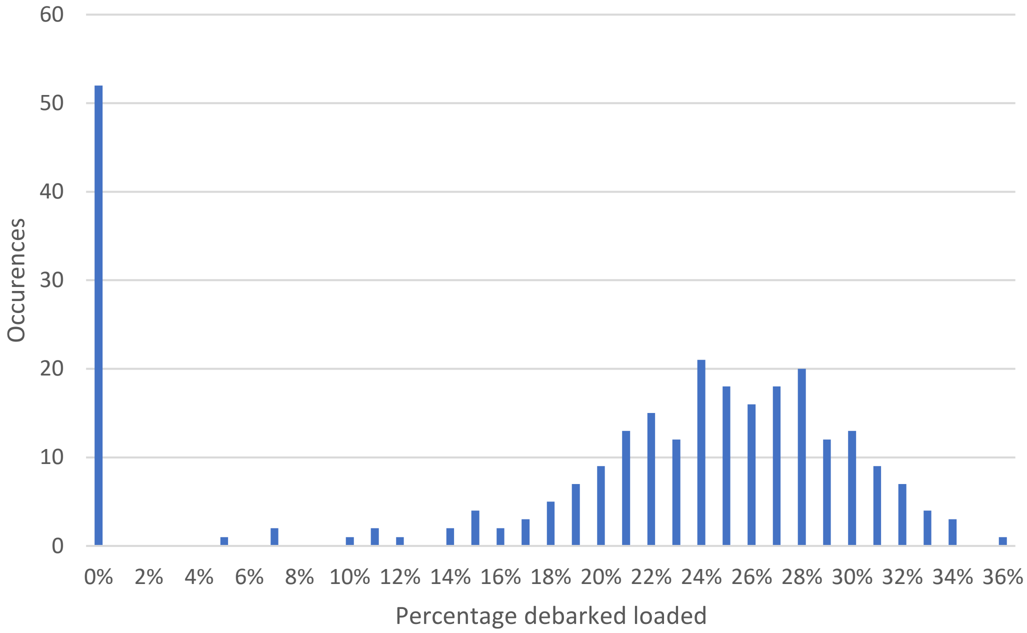
Proportion debarked over the year with all sailings included.



This dataset is variable - the standard deviation for any given month ranged between 30% and 77% of the mean. This shows that drying is not the only factor affecting the amount of debarked timber loaded.

It was assumed that some domestic sailings (for example sailing from Napier to Tauranga to fill the remainder of the space on-board) were included in this dataset. This was backed up by PFP representatives stating no ships sailed internationally part full (Gardner, 2023). Removing partly full sailings was trialled, but this had no significant effect. The distribution was approximately normal, ($\mu = 25\%,\ \sigma = 10.7\%$), excluding zero values (**Figure 18**).

Figure 18:
Histogram of the proportion of the total cargo that is debarked.

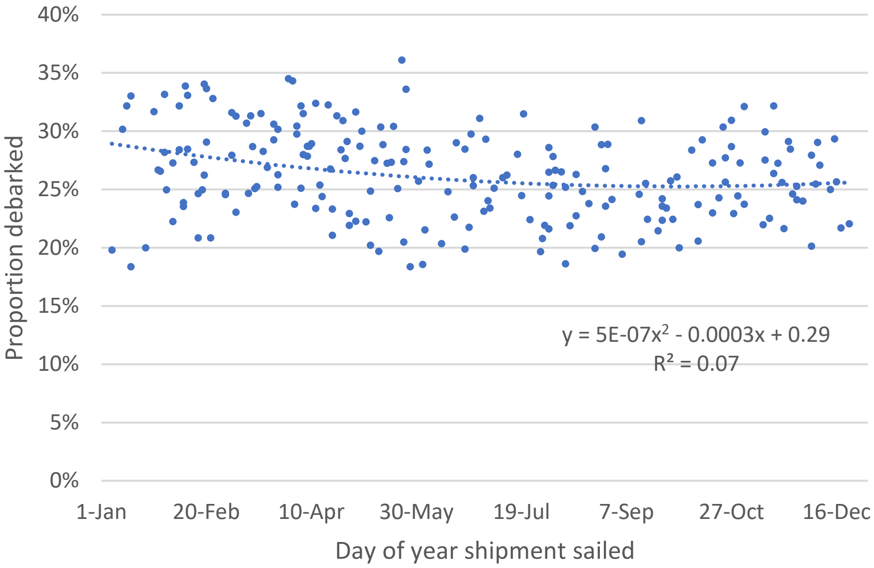


The amount of debarked timber loaded should be consistent, which means there are other factors affecting the dataset (Gardner, 2023). PFP considered that it would be appropriate to apply a flat limit to the low data points to demonstrate how much debarked volume varies.

Ships with a proportion debarked below 18% were excluded from **Figure 17** to create **Figure 19**. It was believed that cutting the value at this point represented Handymax and Handysize (the most common classes) ships that had their entire deck cargo loaded with debarked timber (Gardner, 2023). **Figure 19** displays the expected trend of having more debarked cargo loaded in summer than in winter.

Figure 19:

Proportion debarked, with ships below 18% debarked volume excluded.



The R^2 value in this chart is higher than **Figure 17**, but still low. This suggests other factors affect the relationship between time of year and proportion debarked. Among the ships that have similar debarked cargo, there is less debarked cargo loaded in winter.

When ships with less than 18% debarked cargo are excluded, the month with the lowest average volume of debarked cargo loaded is September, with 24% of the volume carried on the ship being debarked. The month with the highest average volume of debarked cargo loaded is March, with 28% of the volume carried on the ship being debarked.

In contrast, when all ships loaded 90% and above are included, the average is highest in February, with 24%, and lowest in January, with 20%. This showcases the variability of the dataset- January should be one of the months with the lowest proportion debarked, but it has a high number of low values, so has a low average overall.

4.2.3 Reasons for variability in proportion debarked

The proportion of a ship's cargo that was debarked logs was more variable than expected. Several factors explain these differences. Ship designs vary within a weight class, affecting the proportion of the total volume that is either deck space or in the cargo holds. As discussed in Section 1.3.2, this stems from the bulk density of the cargo that the ship was designed to carry. A ship that was designed to carry heavy cargo will have smaller holds, and hence a higher proportion of its cargo will be loaded above deck (Bialystocki & Konovessis, 2016). A ship that has been designed as a log-carrying ship may not have much above-deck cargo. Ship design was not recorded in the dataset, so this cannot be confirmed. This cannot be the only factor, though. Some ships returned several times, enabling direct comparison of debarked volumes that were carried on the same ship at different times of year (**Figure 20**).

Figure 20:
The proportion of debarked logs on the Enishi, the most frequently returning ship.

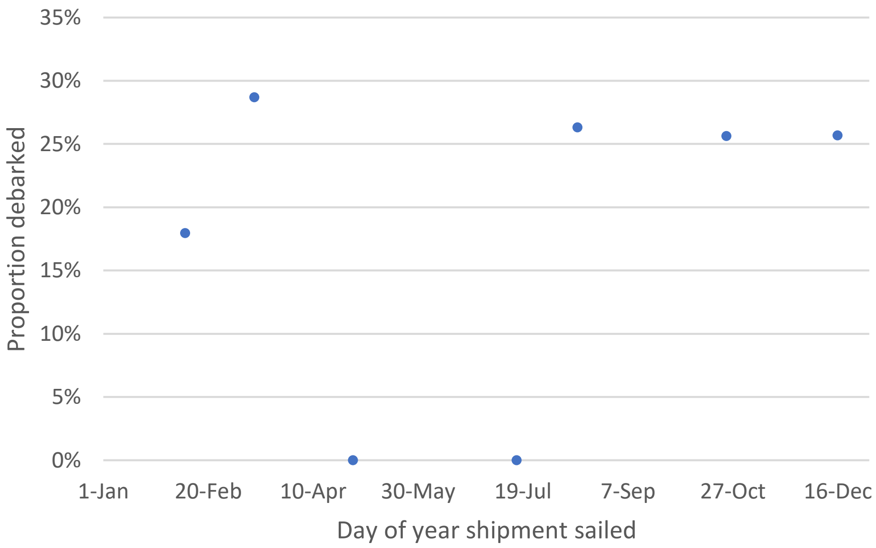


Figure 20 shows that even when the same ship is used, only some points follow a trend.

Another factor is that some ships may be enroute to other ports for additional on-deck cargo loading. For example, a ship may have filled its holds in Napier, then sailed to Tauranga to top off. It would then have no debarked cargo onboard. In theory, domestic sailings should have been excluded, but may not have been entirely.

Data accuracy represents a potential source of variability. Volume data is used by PFP to bill their clients, so it is checked thoroughly. There could be errors in the more detailed data, such as that mentioned in Section 3.3.2.

The mechanised process of data collection reduces the risk of human error (Section 3.1.1). Data is automatically entered into the PFP systems. The data used in the shipping section of this project is extracted from this automated process. Because of this, there should have been minimal chance of error in the data gathered.

4.2.4 Model of monthly variation in debarked volume

The relationship in **Figure 17** is not strong enough to create a useful model. Instead, based on the average proportion debarked each month the following relationships were formed. Data from the Port of Tauranga only was used, this being where most debarked cargo is loaded. Using the mean is reasonable given that the numbers follow a normal distribution (**Figure 18**).

The conversion factors in **Table 4** are useful for returning ships.

- The first column represents the month in which the ship has previously been loaded.
- The header row represents the month in which the ship is scheduled to arrive.
- The numbers are predictive conversion factors for the difference in volume carried between sailings in different months.

Utilise **Table 4** as follows.

1. Follow the row with the month in which the ship had previously sailed until you get to the column where the ship is scheduled to sail this time.
2. This value is a conversion factor; multiply the volume of debarked cargo carried on the last sailing by the factor to get the volume that is expected to be loaded this time.
3. If the ship has arrived multiple times before, this process can be repeated, and the average taken.

Table 4:
Relationships between the proportion of debarked cargo carried each month.

	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Jan	1.00	1.00	1.03	1.02	0.96	0.92	0.91	0.91	0.87	0.95	0.94	0.93
Feb	1.00	1.00	1.03	1.02	0.96	0.91	0.90	0.91	0.86	0.95	0.94	0.93
Mar	0.97	0.98	1.00	0.99	0.94	0.89	0.88	0.88	0.84	0.92	0.92	0.90
Apr	0.98	0.98	1.01	1.00	0.94	0.90	0.89	0.89	0.85	0.93	0.92	0.91
May	1.04	1.04	1.07	1.06	1.00	0.95	0.94	0.95	0.90	0.99	0.98	0.97
Jun	1.09	1.10	1.12	1.11	1.05	1.00	0.99	1.00	0.95	1.04	1.03	1.02
Jul	1.10	1.11	1.13	1.12	1.06	1.01	1.00	1.00	0.95	1.05	1.04	1.03
Aug	1.10	1.10	1.13	1.12	1.06	1.00	1.00	1.00	0.95	1.04	1.03	1.02
Sep	1.16	1.16	1.19	1.18	1.11	1.06	1.05	1.05	1.00	1.10	1.09	1.07
Oct	1.05	1.06	1.08	1.07	1.01	0.96	0.95	0.96	0.91	1.00	0.99	0.98
Nov	1.06	1.06	1.09	1.08	1.02	0.97	0.96	0.97	0.92	1.01	1.00	0.99
Dec	1.08	1.08	1.11	1.10	1.03	0.98	0.98	0.98	0.93	1.02	1.01	1.00

Note that due to the high variability in the proportion of debarked cargo carried, this model will provide approximations only. It should, however, enable exporters to forecast the amount of debarked cargo they will need at different times of the year with more accuracy, improving planning and reducing under and overproduction.

There is a maximum of 19% difference in the volume of debarked cargo carried, between March and September.

4.3 Debarker productivity

The goal of a debarker is to maximise the volume output while meeting other requirements (quality, safety, maintenance, etc.). Therefore, this section will focus on the ways that volume production could be maximised in a debarker. It identifies the effect of log size on production and makes recommendations of areas to focus on.

Achieving high-volume production in a debarker depends on line speed (the speed at which the logs move through the debarker), the size of the gap between logs, and the surface area-to-volume ratio, which is dependent on the diameter. Line speed dictates the overlap between debarking knife passes, influencing the number of rotations required per meter of log, but also the quality of debarking. Minimising gaps is crucial because they represent idle time for the debarker, reducing overall production.

4.3.1 Effect of log size on shift volume

The average volume produced in a shift was 1580 m^3, but this was highly variable, with a standard deviation of 950 m^3. >310 Long, >310 Short, and 210-310 Long averaged 27-29% of volume each, 210-310 Short averaged 13%, and <210 mm SED logs made up about 1% of logs debarked. See Section 3.4.2: Classifying logs for debarker analysis, for an explanation of size classification.

Some log sizes had a clear impact on the volume a debarker outputs in a shift, while others were more convoluted. Each size class and its effect on the volume produced in a shift are presented below, from smallest to largest.

Figure 21 and **Figure 22** show this for the smallest classes, logs with small end diameters less than 210 mm.

Figure 21:

Percentage of <210 mm SED Short logs against total volume debarked in that shift.

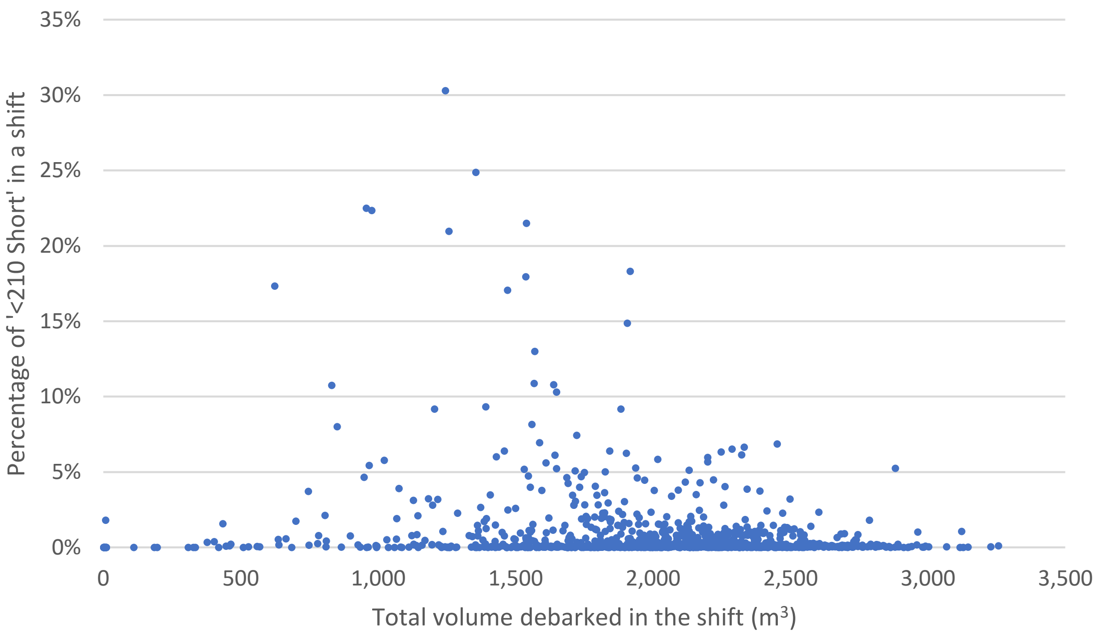
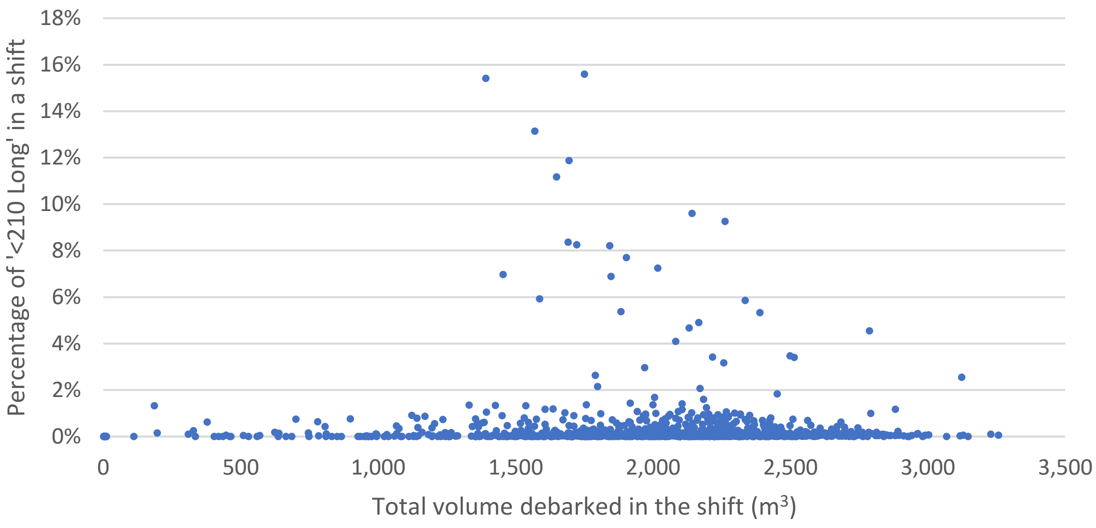


Figure 22:

Percentage of <210 mm SED Long against total volume debarked in that shift.



Patterns here are similar. Both form small portions of the overall debarked volume, and the reason for this can be seen in the graph. When there are higher proportions of these smaller logs debarked, the shift achieves moderate volumes overall (1200-2200 m^3). The highest volume shifts have low proportions of these small logs, suggesting that these logs slow production. This is because a greater log length needs to be debarked to produce the same volume.

Figure 23 and **Figure 24** show the same, for logs with diameters between 210 mm and 310 mm.

Figure 23:
Percentage of 210-310 mm SED Short against total volume debarked in that shift.

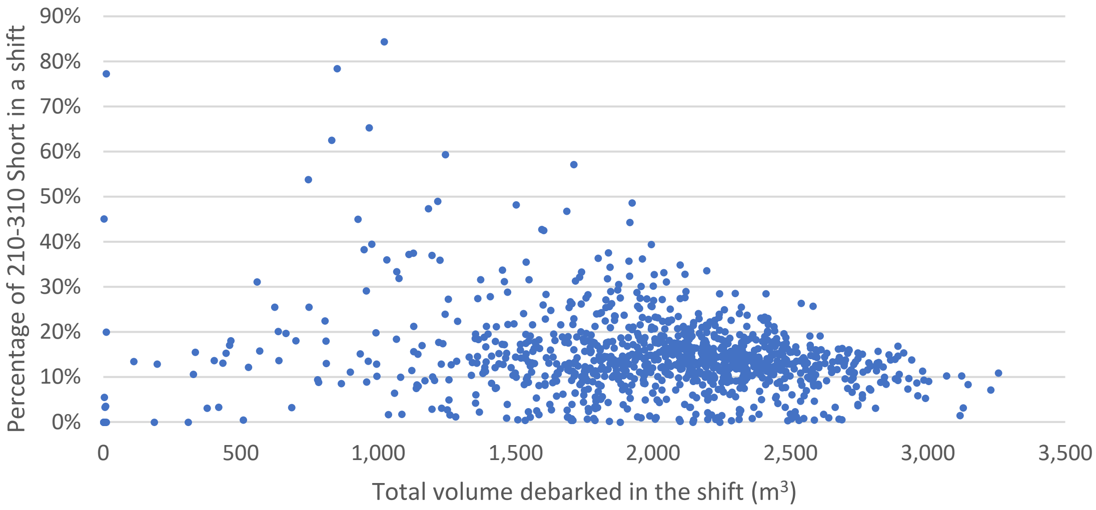
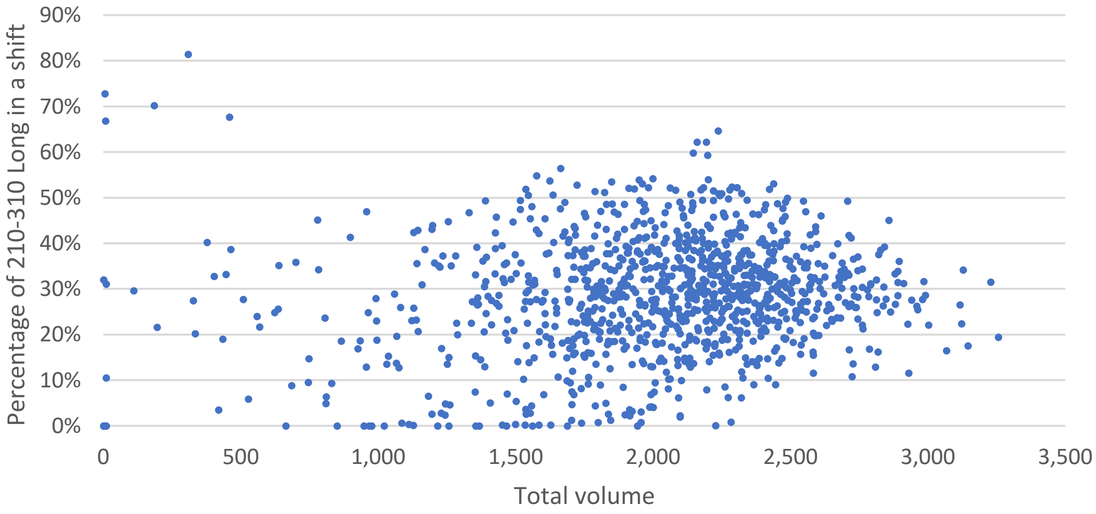


Figure 24:
Percentage of 210-310 mm SED Long against total volume debarked in that shift.



There are different trends here. 210-310 Short (**Figure 23**) shows the same pattern as the logs with diameters less than 210 mm (**Figure 21** and **Figure 22**), where increasing the proportion of this size decreases the overall volume, though not as strongly. The longer logs are different- the shifts that have produced the most volume have produced 20-40% 210-310 Long. This suggests that these larger logs are not as limiting to production, and sometimes debarking them is necessary to continue producing. The largest production days have 20-30% 210-310 Long, and 10% 210-310 Short.

Figure 25 and **Figure 26** show the relationship for the largest diameter class, logs with SED greater than 310 mm.

Figure 25:
Percentage of >310mm SED Short against total volume debarked in that shift.

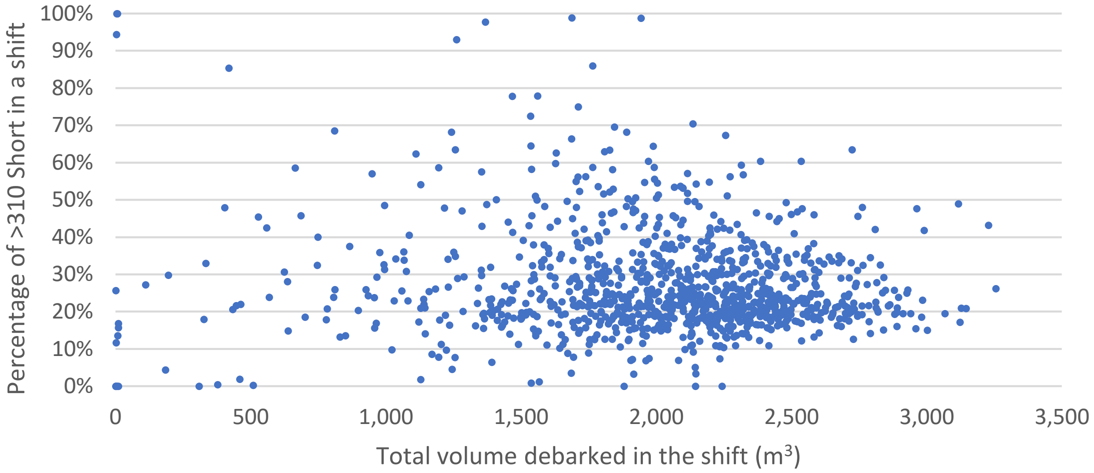
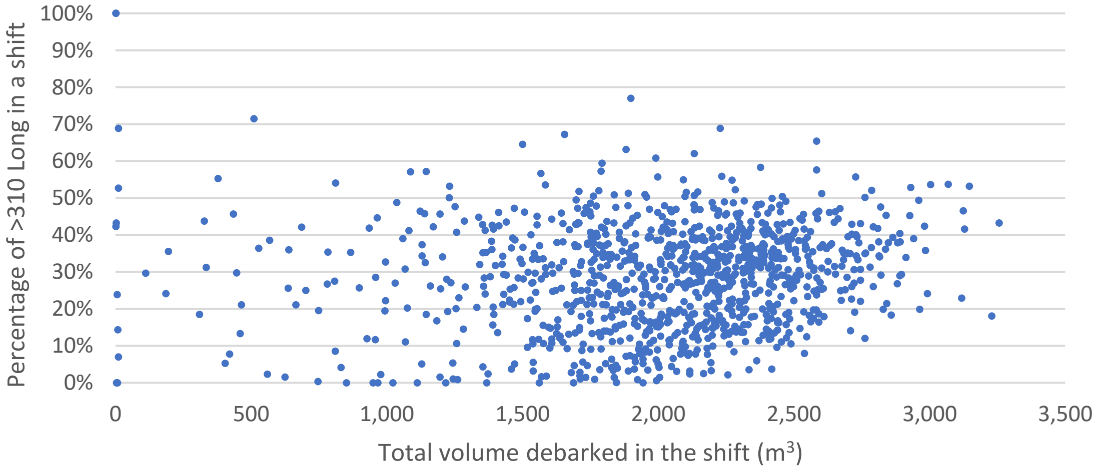


Figure 26:
Percentage of >310mm SED Long against total volume debarked in that shift.



The large-diameter, short logs show a similar trend to the smaller logs, whereby the production is limited if the volume of this class produced is too large. It appears that there is rarely enough logs to debark more than 50% >310 Long, but if there was, this would increase production- all the largest production days in **Figure 26** have at least 19% >310 Long, while most have around 50%. The largest production days have 15-35% >310 Short. Increasing the proportion of >310 Short too much appears to limit production, much like the smaller diameter logs. There is an insufficient quantity of the >310 Long to debark them all the time. Debarking too many >310 Short limits production comparatively.

Therefore, for maximum production, large diameter, long logs should be prioritised, followed by large diameter, short and medium diameter, long, which have a similar effect on the volume. Medium diameter, short and small-diameter logs limit overall production if they are produced extensively but are sometimes necessary to maintain production when there are no larger options.

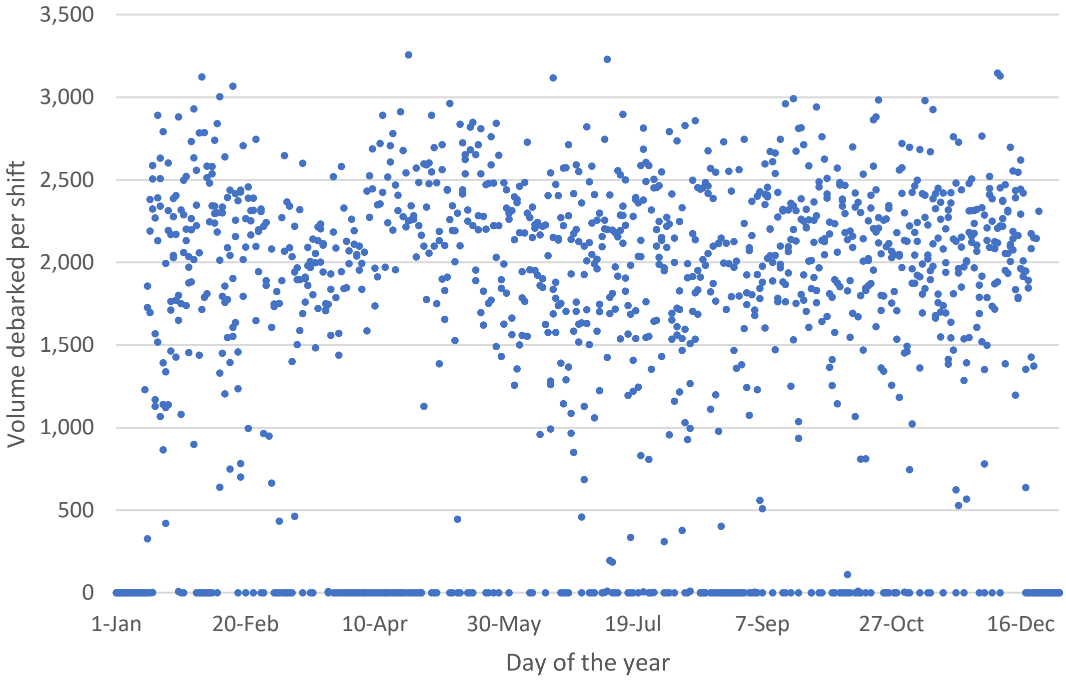
It was expected that each diameter class would result in a higher debarking rate (for example that >310 Short would have higher production than 210-310 Long). The only log class that enabled maximum production was the largest logs. All others resulted in a drop in productivity, which got greater as the log class decreased in size.

4.3.2 Variation in monthly production

Given that the volume of debarked cargo exported varies throughout the year, one would expect that debarking production would also vary. This is not the case, as **Figure 27** shows.

Figure 27:

Total production of each shift at the Murupara debarker over the year.



This corresponds with the manager's opinion that the debarker runs consistently throughout the year, excluding delays and scheduled maintenance. It is assumed that other debarkers, such as the ISO debarker at the port, provide the additional volume (Bowen, 2023). Methyl bromide is used where necessary. More data would be needed to verify this.

4.3.3 Dataset variability

Data for the debarker was collected automatically. Each log that passes is measured and collected in a database. The data was then collated into summaries by shift, and this could then be analysed. Therefore, there should be no human error in the data.

The Murupara debarker runs 13 shifts, then a scheduled maintenance shift. This is shown by the shifts where zero volume was produced in the graphs above. There are also quite a few shifts where a smaller volume of wood was produced. These can be explained as shifts that went overtime, so rolled into the night shift in the database (Bowen, 2023).

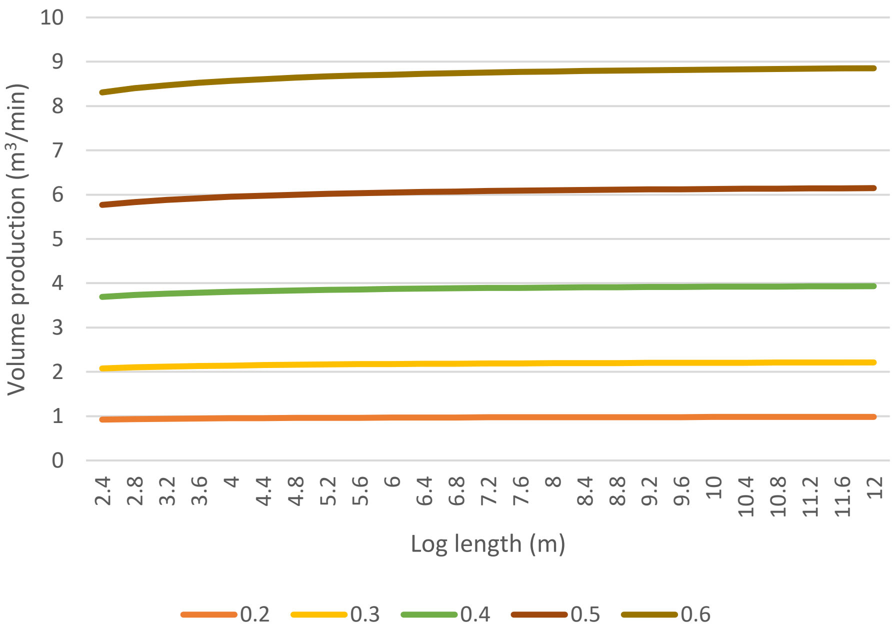
Other variability comes from the differences in piece size that were available for debarking. This variability was recorded in the data and helps determine how grade mix affects production. This is the main reason that production was not the same each day. If it were the only reason, though, we would expect linear relationships in **Figures 22-27**.

Another factor is unforeseen breakdowns and maintenance. Given that this information was not marked with the shift data, it was impossible to remove. Applying hard limits (for example, excluding shifts where less than 500 pieces were processed) was decided against to maintain a representation of the entire dataset.

4.3.4 Theoretical maximum debarking rate

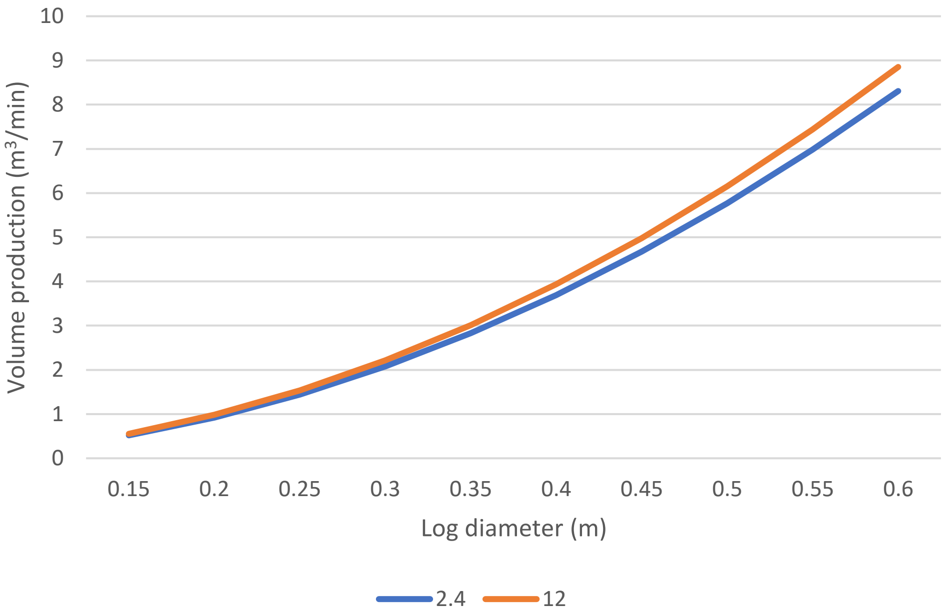
This section is based on a model of an ideal linear production line. It is useful to compare the actual performance of the Murupara debarker. **Figure 28** shows how the log length and diameter affect production. This uses the 'normal' values (see Section 3.4.3: Process of modelling theoretical maximum debarking rate). The gap size was 0.2 m, and the line speed was 100 m/min. Series in are diameter (m), while axis values are lengths (m).

Figure 28:
Log length against volume throughput. Legend values are diameter, in metres.



Each increase in diameter is a substantial step up in the potential volume production. Doubling the diameter quadruples production, for the range of diameters shown. Note how the lines in **Figure 28** never overlap - larger diameter logs should always be faster to debark, no matter the length. It also shows the minimal impact of increasing the log length. **Figure 29** shows the same pattern, but with the series representing a very short and a very long log length, and diameter on the x-axis. Note the small impact of increasing the log length from 2.4 m to 12 m.

Figure 29:
Log diameter against volume throughput. Legend values are length, in metres.



These figures show that log diameter has a large effect on production. Production increases exponentially as diameter increases due to the cube difference between diameter and volume. This shows that large-diameter logs should lead to the highest production.

Log length has a smaller impact. There is still a small increase in debarking production as logs get longer, but the increase is hyperbolic: the larger the log gets, the smaller the marginal increase in production. This is because the gap size becomes a smaller fraction of the overall log length, so decreasing it makes a smaller difference overall. Therefore, decreasing gap size will have the largest impact when running a lot of short logs.

Figure 30 and **Figure 31** show the impact of improving the gap and line speed on production.

Figure 30 shows the impact of increasing diameter, for logs of a 4.8 m length.

Figure 30:
Impact of improving gap and line speed with respect to log diameter.

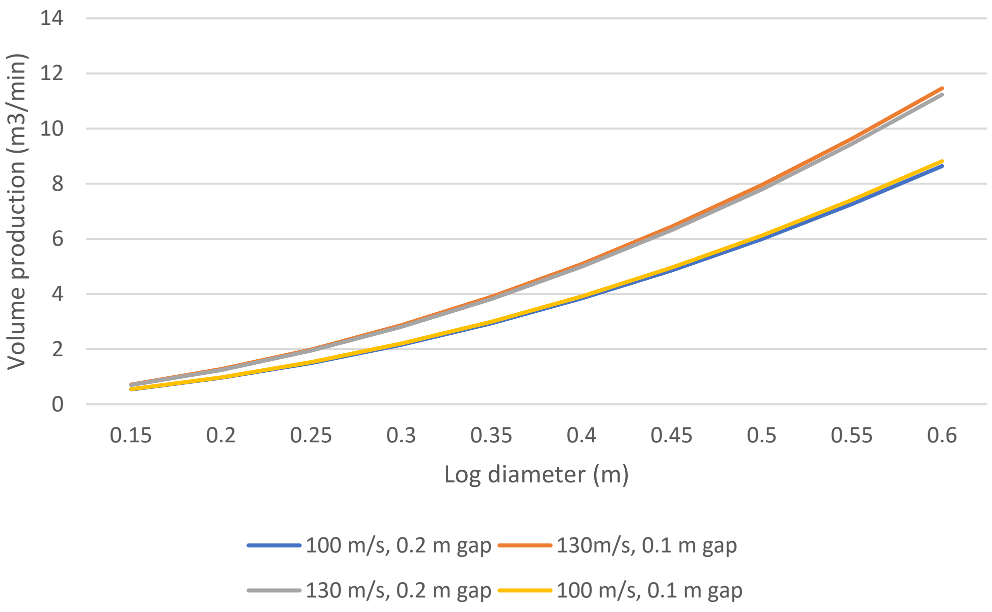


Figure 31 shows the impact of increasing length, for logs of a 0.25 m diameter.

***Figure 31**:*
Impact of improving gap and line speed with respect to log length.

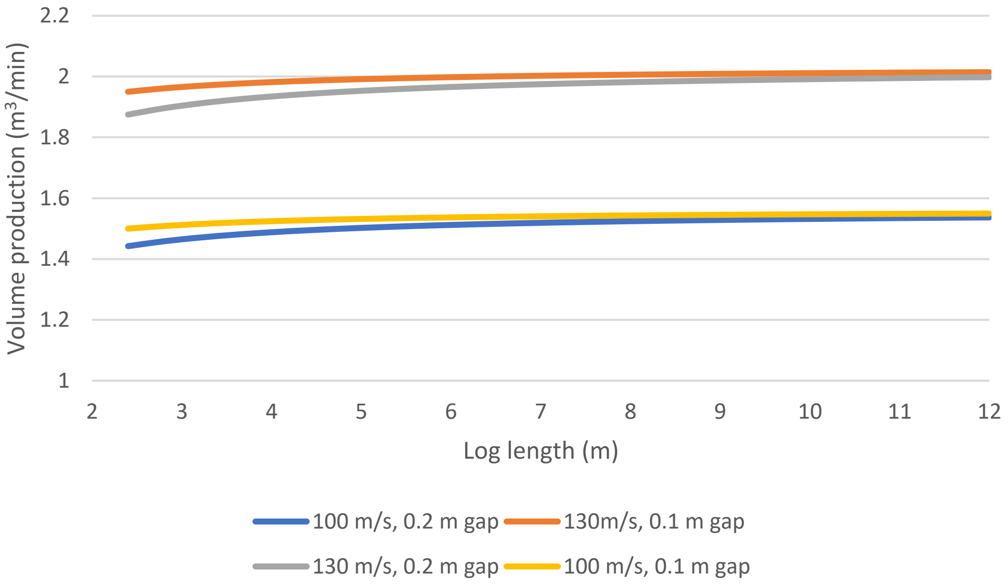


Table 5 shows the maximum, minimum and average increase between the 'normal' case and each of the other cases.

Table 5:
Difference between the 'normal' model and other cases.

	Increase	**Min increase**	**At**	**Max increase**	**At**
Normal to best case	32.2%	31.1%	12 m	35.2%	2.4 m
Normal to best speed	30.0%	30.0%	All	30.0%	All
Normal to best gap	1.7%	0.8%	12 m	4.0%	2.4 m

Increasing the line speed of the debarker has a proportional effect on the volume production - increasing the speed by 30% led to 30% more volume being produced. This happens regardless of the grade being run.

Decreasing the gap has the greatest effect on the smallest log length. Diameter does not affect the results. This is because the gap occurs most frequently in smaller log sizes. While the increase in production is small, it is still substantial for the smaller log lengths. The smaller gap is easier to run on smaller diameter logs as they tend to have less diameter variance, so the debarker needs less time to adjust. Larger logs may not be worth decreasing the gap size, as this will increase the number of poorly debarked logs, and there will be minimal gain (Bowen, 2023).

4.3.5 Implications of the modelled results

Section 4.3.2 suggests that log diameter should have a much larger impact on production than log length. Therefore, the logs that gave the most production should have been the >310 diameter class, then the 210-310 mm diameters, then the <210 mm diameters, regardless of the length. This was not the case in the real-world results.

The fact that log length had as much of an impact as diameter suggests that a larger gap between logs provided more of a delay than was thought. There are two potential reasons for this; either the gap size run in real life was larger than the one quoted, or there are more delays when you have to change logs in a real debarker. Examples of delays are logs jamming, poor debarking, and machine adjustments. This is possible, as the simple model used above does not allow for delays. If a certain proportion of log changes slowed the debarker, then increasing the number of logs would increase the delays. This accounts for the length and diameter having a similar effect.

For reference, a 0.6 m gap is when the length starts to have a similar impact on throughput as the diameter (in the theoretical model). This means that changing logs in the Murupara debarker is having the same impact as running a 0.6 m gap. If the delay is this large, then this would be a substantial area for improvement.

4.4 Further research opportunities

This study has provided numbers that represent the volume of logs debarked and loaded on a ship for export. Further research is needed to determine the reasons the dataset is so variable in both cases. This would enable a more accurate representation and prediction of the factors affecting the debarking supply chain.

This study determined that the Murupara debarker does not vary its production to match the variance in export volume. Further research could determine how much other debarkers vary their production, and what role methyl bromide still plays.

5 Conclusion

This study was conducted to aid exporters in optimising the supply chain of debarked logs. Three factors were examined; the effect of size and utilisation of log ships used in New Zealand on debarked volumes, the variation in debarked volume due to seasonal changes in log density, and the effect of log size on debarker productivity.

The study found that ships which exported logs came in a strong class distribution, with 82% having a deadweight between 32,000 and 42,000 tonnes. Most ships are slightly under-loaded, according to their deadweight. Data showed that most ships were slightly under-loaded. It showed there is capacity for more debarked volume, particularly if stanchions were added to ships that do not have them currently. Adding stanchions would enable them to carry an extra 40% of debarked cargo above deck (approximately), which results in an 11% lower fuel burn per tonne.

There is a 9% (or 6% for Port Chalmers) variation in the density (i.e., the weight factor) of logs arriving at the port between summer and winter. Port Chalmers has the heaviest logs arriving at the port, but the dry density of the log is lowest, suggesting that logs dry less there than at the North Island ports.

The percentage of debarked cargo being loaded on a ship was variable, which suggests that there are other factors affecting loading. A model comparing the expected volume of debarked timber carried in different months was produced. The model works off average volumes of debarked cargo carried for each month and suggests that there is up to a 4% difference in overall volume loaded on the ship, summer to winter. This translates to 19% of the debarked volume.

Logs at a key debarker were sorted into six classes to facilitate a comparison of the volume that was produced in a shift when different proportions of each log size were debarked. This showed that the larger the log, the more volume the debarker could throughput in a day. Throughput was limited by the number of the largest logs that were available. Of the smaller classes, the medium diameter, long logs, and the large diameter, short logs had a smaller effect on throughput, while the smallest classes limited production significantly. A linear production line model was used to show that log diameter should have a much larger effect on production than length. Potential reasons for the difference include extra delays caused by an increased number of gaps, or the gap size being larger than thought. This dataset was also variable, with factors affecting this assumed to be scheduled and unscheduled maintenance, as well as overtime shifts. These could not be excluded, so were left for the best representation of the original data.

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