Exploring opportunities for bio-oil within the New Zealand forestry industry

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

For any forest harvesting operations, either chainsaws or barsaws in harvesting heads are pivotal tools for felling and processing the trees. These cutting chains can only run on the bar if they are lubricated to avoid excessive wear and deterioration of the machinery. Lubrication of chainsaws and harvesting heads work on a total loss system, meaning that any chainbar oil will be discharged into the environment. Mineral oil is currently predominantly used in New Zealand as lubricants, but mineral oil can be toxic to the natural ecosystems, and the people who use it. This highlights the need to investigate alternative, more environmentally friendly lubrication options for cutting systems within the forestry industry such as bio-oils made from plant material (usually rape seed). Benefits that are claimed for bio-oil include a reduction in oil flow by up to 50% without any added wear, that it is more environmentally friendly and degrades within 28 days, is better for the machinery, and people that use them. Bio-oil is however almost double the price of standard mineral oil deterring many contractors from considering using it.

In this study nine contractors from around New Zealand trialled bio-oil for a one-month period. There were surveys sent to the contractors to get pre-trial and post-trial data on the bio-oil; the contractor's oil usage for both mineral and bio-oils and any other benefits they saw from the change to bio-oil. The second part of this study involved measuring the heat produced off the tip of the bar of the chainsaw to see what effect the two different oils had on cutting temperature. The flow of both oils on to the chain and bar was reduced to test the extent that oil-flow can be reduced before added wear becomes a risk.

All crews were able to reduce lubrication oil consumption with an average of 39%. However, there was a large variance in oil reduction, ranging from the maximum reduction seen was 51% to a low of 16%. From this an average cost saving from the contractor trial was 6%, with a maximum saving of 19%.

In the chainsaw trials where bar heat was measured under standardised test conditions, the lubrication was reduced for both oil types. The bio-oil was able to be reduced by 50% before an increase in heat was seen. The mineral oil however, was unable to be reduced from full flow before temperature increased. When the bio-oil flow was reduced by 50%, and the mineral oil unchanged at 0%, they ran at very similar temperatures (p-value of 0.48). This demonstrated that the bio-oils were able to be made cost competitive against mineral oils whilst not adding any extra wear to the chainsaw.

This study highlights the benefits of bio-oil and the possibilities of its industry application. It demonstrates a local example to New Zealand contractors of how bio-oil can be used in operations without any added wear or stress on machinery, in addition to its cost saving and environmental benefits. This dissertation can also be used as a basis for bio-oil policy within New Zealand forest management companies; especially in high risk areas such as waterways or near native remnants.

Acknowledgements

I would first like to mention my mum. Even though you're not here, you've shaped me to who I am today, and I can never thank you enough for that. You may be gone, but you will never be forgotten.

I would like to thank Dad for giving me a place to stay and his on-going encouragement throughout the length of my degree. He has offered wholehearted support and it would've been a different story without him. Thanks to all the grandparents, and Ryley and Emma, for your continued support throughout my university studies. You have all helped me pull through when times have been tough and stressful, and I thank you very much for that.

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Thanks to LubEco for supplying the infrared thermometer and the bio-oil, and Total Oils for supplying the mineral oil. Also, thanks to all of the contractors that participated in this trial and put up with my relentless emails and calls.

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1 Introduction

This dissertation explores the opportunity for bio-oils within the New Zealand forestry industry. It seeks to investigate what opportunities surround bio-oil and what possibilities it has within the industry. Chainsaw consumption of chainbar oil is on average 0.33 litres of standard mineral oil per productive machine hour (Schaffer & Buchschacher, 2002). Considering that these chainsaws work on a total loss system, a considerable amount of harmful oil spills out into the environment each year. This can pose an environmental issue for the forestry industry.

This study is supported by PF Olsen Ltd, a forestry-management company who have offices around New Zealand from Southland to Northland. PF Olsen currently manages 157,106 ha of plantation forest (Forest Owners Association, 2016) and have supported this study in order to encourage their own contractors, and the industry, to consider changing perceptions and policies and to begin utilising bio-oils in their operations.

1.1 What are the effect of mineral oils?

Used mineral oils are known to be harmful to the environment due to having a high ecotoxicity, which poses a considerable threat to the environment (Schneider, 2006). Based on a range of studies, every lubricant is harmful to the environment (Stanovsky, et al., 2013; Bartz, 1998; Schneider, 2006). However, lubricants produced from biological compounds have a significantly less harmful effect than those of fossil origins (Stanovsky, et al., 2013; Schaffer & Buchschacher, 2002). Used mineral oil can be contaminated with toxic chemicals, carcinogenic substances, volatile hydrocarbons and heavy metals during use, changing the properties of the oil (Enviromental Protection Authority, 2014). The disposal of used oil that “may cause contamination of the ground, and ground water, migrate to watercourses, contaminate air or have negative impacts on humans, plants, animals or other organisms”, is in direct contravention of the requirements under the HSNO Act, the Resource Management Act as well as the National Environmental Standards (Enviromental Protection Authority, 2013). The use of a total loss system with a chainsaw could be in violation of these acts. Bio-oil can remove some of this risk as it degrades at a rapid rate.

1.2 What is Bio-Oil?

Bio-oils are organic-based substitutes for mineral-based lubricants. LubEco's bio-oil is being used in this trial. LubEco uses rapeseed, which is pressed to extract the oil. The residue from this process is sold back to the rapeseed farmers as feed for their stock. The oils are then processed further to create a range of oils such as chain bar oil, hydraulic fluid and engine oils. LubEco has placed significant focus on ensuring their compliance with all international environmental standards (ISO: 9001, ISO: 14001), in addition to the EU Ecolabel (a certification scheme of environmental excellence). Bio-oils are far more environmentally friendly than traditional mineral oils as they break down at a faster rate, releasing water and carbon dioxide instead of harmful chemicals. LubEco's products are carbon neutral, as the carbon dioxide emitted during decomposition equals the carbon dioxide captured when the oil was originally produced (Orton, 2017).

1.3 Past bio-oil problems

Forestry crews have previously been hesitant to use bio products due to their high cost, limited access, efficacy and potential to damage equipment. Kimberly Evison's (PF Olsen Bio Oil Survey, 10th June 2014) survey of several contractors in the Central North Island region identified that contractors were concerned about the oil damaging their machines, as they had heard it had happened to others who were trialling bio-oils. This may be due to the first generation of bio-oil not performing well enough at high temperatures (oxidation, sludge formations) or at low temperatures (gel formation, loss of fluidity). Evison's study also highlights cases of materials within the hydraulic hoses reacting with the oil, leading to broken hoses and leaks (Norrby & Kopp, 2000). Stanovsky et al. (2013) in a trial conducted at Zvolen University in Croatia, found that the level of wear sustained on chainsaws was less when utilising bio-oil products, as opposed to greater wear when not using bio-oil products.

The bio-oil price is significantly higher than the mineral-oil price on a per litre basis (Damjanovic, Davidovic, & Spasojecvic-Santic, 2016). However, due to the increased lubricity of bio-oil, the amount of oil usage can be reduced by up to 60% (Karatzos, McMillan, & Saddler, 2014; LubEco, 2017). This can make bio-oil an economically viable option for New Zealand contracting crews. The availability of bio-oils has also increased dramatically within the past decade, with large brands such as Stihl ($8.27/L) and Husqvarna ($8.98/L) supplying their own bio-oil labels.

1.4 International policies around the use of bio-products

The European Commission has set goals for all European countries to develop a resource-efficient and low-carbon economy by 2050 (Scarlat, Dallemand, Monforti-Ferrario, & Nita, 2015). Increasing the use of bio-products is integral to achieving these goals. This progression can be observed in the European lubricant market, where bio-lubricants were forming 6.7% of the market in 2002 (van Broekhuizen, Theodori, Le Blansch, & Ullmer, 2003) while in 2013, bio-lubricants formed 15.6% of the total lubricant market in Europe (Bart, Gucciardi, & Cavallaro, 2013). From 2013 – 2018, the compound annual growth rate for Europe on average will exceed 5% (Aslanian, 2015). Austria has expanded on these goals and has banned the use of any petroleum-based chainsaw oil (Rudnick, 2017).

The Coordinating European Council (CEC) has established a testing method for the biodegradability of different oils. The test measures the amount of oil that biodegrades over a 21-day period. The standard is CEC-L-33-T-82 (Coordinating European Council, 2009). Bio-lubricants biodegrade at a much faster rate than petroleum-based oils. Tests against the CEC-L-33-T-82 standard have shown that some mineral oils do not degrade at all, with a biodegradability rate on average of 0-40% in the 21 days. In comparison, nearly all bio-lubricant products completely degraded in the 21 days, with a biodegradability rate of 70-100%. (Aluyor, Obahiagbon, & Ori-jesu, 2009; Damjanovic, Davidovic, & Spasojecvic-Santic, 2016).

In the United States of America, the 2006 government committed to increasing bio-energy three-fold through their Energy Independence and Security Act of 2007 (Energy Independence and Security Act of 2007, 2007). This act attempts to encourage the USA to become more energy independent (reduce the requirements on importing fuels and internationally processed oils) as well as increasing the production of clean, renewable fuels and the efficiency of products using renewable measures such as bio-lubricants and oils. This has resulted in a 6.8% compound annual growth rate for bio-oils within America from 2007 – 2014, which is expected is to increase to 7.2% from 2014 – 2020 (Allen, 2014).

1.5 New Zealand policies around bio-oils

New Zealand currently provides limited government incentives to encourage bio-product implementation, with neither a mandate nor any target for biofuel use in place (Suckling, 2015). In a survey conducted by Millan Visser (Bio-oil council survey, 21st November 2017), out of all the New Zealand Regional Councils, no council body that was surveyed had any plans to implement bio-oil policies in the foreseeable future. This places New Zealand well behind the global movement towards more environmentally friendly fuel production and usage. However, a small proportion of councils will consider linking bio-oils in to their biofuel plans which will be revised in the next 5 – 10 years. New Zealand's 'clean and green' image is currently often exaggerated. The use of sustainably produced bio-products would further enhance this reputation (Bioenergy Association of New Zealand, 2015). However, for this to be successful, there needs to be active engagement and a plan of action in place from regional councils and central government.

1.6 Bio-oil in forestry applications

When using a chainsaw, the bar and chain of the saw need to be lubricated to avoid wearing and blunting the teeth of the chain. Chain bar lubricants are consumed on a ‘total loss system’, and as such, the lubricant contaminates the ground (Milners Oil, 2014). In New Zealand, most commercial operators are still using petroleum-based oils (Ministry of Agriculture and Forestry, 2016). When a chainsaw is used, virtually all this oil is discharged into the environment. The exposure to petroleum-based oils can also have negative health effects on the users (Bartz, 1998). This highlights the need for bio-lubricants to be used for chainsaws. Hydraulic oils also play a significant role within forestry applications on an international level. As harvesting and forestry work become more mechanically based, this provides the potential for more environmentally harmful oils to be spilt onto the ground and into the environment. This can occur through burst lines, incorrect usage and lack of care (Yun Hsien, 2015). However, if bio-products are used in place of mineral hydraulic oils, the environmental effects will not be as severe, as bio-lubricants have a significantly reduced effect on the environment due to their plant base and/or woody biomass (Garrett, 1998).

1.6.1 Chainsaw use

A chainsaw is a basic operational instrument in a large number of forestry operations. These include felling, thinning, log making and pruning (Stanovsky, et al., 2013; Harkonen, Nilsson, & Forshed, 1979). Chainsaws have an oiler that keeps the chain and bar continually oiled. This is to increase the life of the chain and bar, and also increases cutting power (Donaldson, 2013). The oiler can be adjusted on most modern chainsaws to allow for a higher or lower flow of oil onto the chain and bar. There is a screw on the bottom of the chainsaw that allows for this to happen (Stihl, 2011). This oil is separate to that used in the fuel tank. As part of the total loss system, the lower the oil-flow is set, the less oil will be spilt out into the environment (Bartz, 1998). However, with most current mineral oils, they require the chainsaw to be on full oil usage (Syahir, et al., 2017). The new generation of bio-oils aims to change the amount of oil required to operate the chainsaw efficiently (LubEco, 2017).

1.6.2 Effect of bio-oil in forestry applications

In a study conducted by the Forest Engineering Institute of Canada (FERIC), bio-oils were found to perform well when compared to the mineral oils being used to lubricate the hydraulics (Jokai, 1995). The operator claimed that the response of bio-oils was quicker and more profound at extreme temperatures, compared to the mineral oil they had changed from. However, the report does reinforce how the bio-oil made the brakes slippery due to its increased lubricity, while the cost was 120% more expensive that regular mineral oil (Jokai, 1995).

Utilising bio-oil and lubricants in chainsaws has been significantly researched in Europe, as these countries continue to progress in moving away from using mineral oils. Research has been conducted into the running temperatures of the chainsaws with bio-oils and mineral oils. A notable finding pertaining to this research describes how on average, bio-oil performs better in terms of retaining a lower temperature (Skoupy, Klvac, & Hosseini, 2010; Ignea, Ghaffaryian, & Borz, 2017). The only measure where bio-oil appeared to perform worse was in softwoods. This is potentially due to their higher resin content, or lower density, where the heat produced exceeded that of mineral oil (Stanovsky, et al., 2013). While the outcome of this study sustained that both oils are suitable for use in chainsaws, from an environmentally conscious perspective, bio-oil is much more beneficial (Stanovsky, et al., 2013; Ignea, Ghaffaryian, & Borz, 2017).

2 Problem Statement

PF Olsen observes that on an international level, the New Zealand forestry industry is not currently aligned with their international counterparts in terms of bio-product utilisation in forestry applications. PF Olsen have been encouraging their forestry contractors to use bio-oil products for the past decade. The premise behind this study is that bio-oil products are claimed to be superior to mineral oils in terms of their reduced negative impacts on the natural environment, the people and machines that use them. There are currently an estimated 2 – 2.5 million litres of chain bar oil spilt into the New Zealand environment each year (Kadlec, 2018). However, due to a range of issues that bio-oil products have caused in the past including clogging and build up around the chain, the cost of the oil and improper lubrication, forestry contractors are sceptical about using these products, especially if it may put their machinery at risk of being damaged.

Understanding the factors that influence the decision made by contractors to not use bio-oil will help to identify what barriers are stopping their uptake, and to identify ways to resolve them. The use of bio-oils may provide opportunities that are currently not achievable with mineral oils, such as reducing the amount of oil used on chainsaw bars without having a detrimental effect on the tool. A lower price may also be achieved due to a reduction in the amount of oil required for effective machine operation, while the quality of the bio-oil may also be found to exceed that of the mineral oils. Contractor health is also extremely important when assessing the change from mineral oil to bio-oils.

3 Research Questions

- Are bio chain bar oils as cost-effective as standard mineral oils?
  - What is the price difference?
  - How can they be made to be competitive?

- How much can you reduce the chainsaw's oil use for bio-oils and mineral oils?
  - At what point (%) of oil reduction does temperature and wear become an issue?
  - Do the chainsaws require less maintenance (i.e. chain sharpening)?

- What other benefits are seen from a shift to bio-oil?
  - Does contractor health improve?
  - Is there less oil spilt out into the environment?

4 Methods

The trial of the bio-oil was set to be completed over the course of a month, and PF Olsen subsidised the crews to carry out the trial. This subsidy covered the cost for the contractor to pay the extra cost of the bio-oil. Each crew received the subsidy to choose either up to 400L of chain bar oil to trial with their chainsaws, or with their processing heads, or both. There are 9 crews that volunteered to participate in this trial (locations detailed in appendix (figure A4).

This project engaged the use of two different analytical methods to determine what effects the bio-oils had on the chainsaws, the surrounding environment and the costs of the operation, compared to what effect the more commonly used mineral oil had. The first method of analysis involved collecting evidence from contractors, such as the price of oil and their oil usage. The second method of analysis was conducted on a recently harvested skid site in Canterbury to measure other aspects of the chainsaws that would have been too dangerous to try and complete during a logging operation.

4.1 Data from contractors and suppliers

The data that was collected from contractors and suppliers helps to create a large-scale, industry-wide level of the benefits and disadvantages of utilising bio-oils in the field, rather than just focusing on controlled chainsaw results. The data that has been gathered has had all contractor's names removed for confidentiality purposes, and each contractor has been prescribed a number ranging from 1 to 9. Price lists have also been accessed, both from data provided by the contractors, as well as publicly available data from a range of different suppliers.

4.2.1 Evidence from contractors

Initially, a survey was sent out to the nine contractors who agreed to participate in the trial. This survey asked for data concerning their previous oil usage for the past two years, the price they were paying for the oil across the same time period, the brand and bar length of the chainsaws that were going to be used in the trial and the maintenance requirements on them i.e. chains and bars. The final question only applied to the contractors who were going to use bio-oil in their processing heads. This question asked about downtime and amount of chains used in the head. Once this data was collected it was compiled to produce the results in section 5 of this report. The initial survey can be found in the appendix under section A2. Any comments from contractors throughout the trial were noted and acted upon if necessary. Any comments that proved to be helpful have been quoted within section 5 of this report. During the trial, I made site visits to the crews in the Central North Island as well as in the Gisborne region. At these visits I collected anecdotal evidence, as well as some temperature readings to compare against the results that were found in the field tests. The final stage with the contractors was sending them a survey at the end of the trial. This survey can be found in the appendix under section A3. The survey asked contractors to provide their bio-oil usage for the month that the trial had been conducted, as well as a range of other questions which would gather some anecdotal evidence to help reinforce findings found through the chainsaw tests.

4.2 Testing of the chainsaws

The testing of chainsaws was done in two different environments. The first test was completed on finished skid sites in the Canterbury region where logs had been left. The second part of the testing was conducted in a paddock under controlled conditions. In both of these locations the temperature of the bar of the chainsaw was measured whilst using the different oils.

4.2.1 Materials used

There were two oils chosen to be tested. The mineral oil selected proved to the most predominantly used by the contractors, which was Total MTC 150 Chain Bar oil. The bio-oil that has been used in this trial is LubEco Chain and Bar Oil 150. The characteristics of each oil are detailed below.

Table 1: Characteristics of oil used in testing

Characteristic	Total MTC 150 Chainbar	LubEco Chain and Bar Oil 150
Pour point, ^{0}c	-12	-45
Flash point, ^{0}c	204	>250
Density (at 15 ^{0}c), g/cm^3	879	945
Kinematic viscosity (at 40 ^{0}c), mm^2/s	150	150

The chainsaw selected for measurements in this trial, was the Stihl MS 660. It is commonly used by contractors in the New Zealand forestry sector. The main characteristics of this chainsaw are demonstrated on the table below.

Table 2: Chainsaw characteristics

Characteristic	Stihl MS 660
Displacement, cm^3	91.6
Performance, kW	5.2
Weight, kg	7.4
Oil tank volume, ml	360
Idle speed, rpm	2,500

The thermal measurements were taken with a DT-480 infrared thermometer, and a stop watch for timing the intervals.

4.2.2 Temperature data gathering

The temperatures of the chain bar were measured to see which oil would maintain the lower temperature under the same conditions, in turn having a less-wear effect on the chainsaw. The test was conducted at skid sites that had recently finished harvesting and logs had been left. The testing of the chainsaws was based on a similar study conducted by Stanovsky et al in 2013.

The tests were done to give an indication of how the oils performed under perfect conditions. The amount of bio-oil & mineral oil used was reduced between each cut to see if less oil usage was possible. The species used in all these trials was *Pinus radiata,* New Zealand's main production species. The amount of oil used on the bar was also reduced systematically by 25% between each measurement cycle. This was to test how far the oil usage could be reduced before temperature and wear became a problem.

The thermal measurements were split into two parts:

A. Measurements without a cutting load
B. Measurements with a cutting load

4.2.2.1 Measurements without a cutting load

The temperature measurements were taken at a range of time intervals. The measurement cycle for the oils without a cutting load were as follows:

1. A thermal measurement of the bar without movement from the chain. This was to indicate the standing temperature of the chainsaw.
2. A second measurement was taken after the chainsaw had been under full engine load for 1 minute.
3. The third measurement was taken after the chainsaw had been under full engine load for 2 minutes.
4. The final measurement was taken after the chainsaw had been under full engine load for 3 minutes.

Between each step in the measurement cycle there was a maximum of a 15 second pause to allow the chainsaw to get as hot as possible. Between each measurement cycle the chainsaws were rested and the oil usage was reduced by 25%, until they made it back to the original standing temperature in step 1.

4.2.2.2 Measurements with a cutting load

The second measurement cycle for the chainsaw was when the chainsaw was under a cutting load. These measurements consisted of 4 steps:

1. A thermal measurement of the bar without movement from the chain. This was to indicate the standing temperature of the chainsaw.
2. A second measurement was taken after the chainsaw had been under full engine and cutting load for 1 minute.
3. The third measurement was taken after the chainsaw had been under full engine and cutting load for 2 minutes.
4. The final measurement was taken after the chainsaw had been under full engine and cutting load for 3 minutes.

The process of testing the chainsaws was to adjust the oil flow, complete the cut for the trial and then change the oil. The oil flow was then reduced, and the process was repeated. This meant that the oil-flow adjustment was equal for both oils.

Both cycles were repeated thirteen times for the different types of oil. If the chainsaw had already finished the cut before the allocated time, the operator moved as quickly as possible on to the next cut. Again, there was a maximum of a 15 second pause between the steps in the cycle, and between each cycle the oil was reduced by 25% and the chainsaw allowed to cool.

The temperature was measured within the red circle on figure 1 below. This is the point on the saw where the most friction happens, and the most heat should be generated.

Figure 1*:* Where the temperatures were measured

5 Results

5.1 Contractor survey data

5.1.1 Oil usage by crews

The initial survey sent to contractors was to see their current oil usage and find the contractors opinions on bio-oil before they tried it. This was to determine a benchmark of oil usage, to see whether their oil usage can be reduced and, investigate if the bio-oil is cost-effective. From the 9 crews that participated, two were already using bio-oil. One provided data from before the switch and then their current usage with the bio-oils.

As well as asking about their current oil usage, the survey also asked about the type of chainsaws and the bar length they use, as well as the amount of chains and bars replaced over the past year. The final question in the survey asked the contractors why they hadn't tried bio-oil before. Table 3 below demonstrates the machinery that was used in the trial.

Table 3: Chainsaw and processing heads used in the trial

Chainsaw/ Processing Head	**Numbers used in trial**
Stihl 660	6
Stihl 661	4
Log Max 7000	2
Waratah 625C	2
Woodsman 800 Processor	1
Satco 630	1
Satco 225T	1

As the table shows there was an array of different chainsaws and processing heads utilised in the trial. Given that the Stihl 660 was a common chainsaw in use, this was used in the temperature trials.

The oil usage of crews for a two-month period (1 mineral oil, 1 bio-oil) is demonstrated in Figure 2. Noticeably, there is a significant statistical difference between the nine-crew's oil usages over both months (p-value of 0.02). The oil measurements here are measuring the machines and/or chainsaws that were using bio-oil for the length of the trial, in order to have a direct comparison over their change in oil usage. Some crews were not convinced about the bio-oil and didn’t want to put all their machinery at risk.

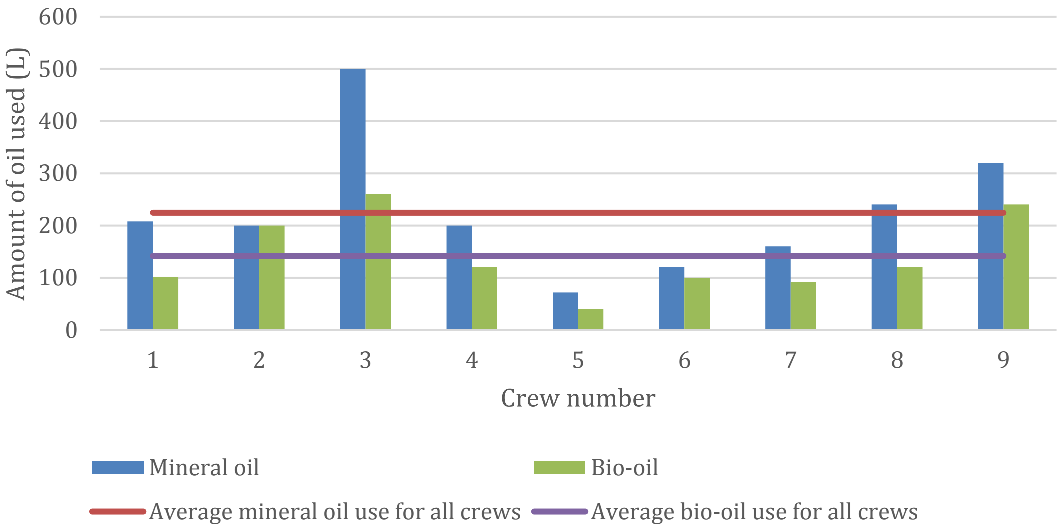

Figure 2: Oil usage per crew for each month’s trial

As shown in figure 2 there is a significant difference between the amounts of oil used each month on a per-crew basis. On average, between all the crews, a 39.6% decrease was seen in oil usage when moving to bio-oils, as demonstrated in table 4 below. In all average calculations crew number 2’s results have been removed to avoid a biased result. Each crew managed to reduce their oil usage by winding down the oil-flow rate as low as they felt comfortable without experiencing any added wear.

Table 4: Change in oil usage on a crew basis

Crew Number	Mineral Oil Used (L)	Bio-Oil Used (L)	Percentage Change (%)
1	208	100	51%
2	200	200	0%
3	500	260	48%
4	200	120	40%
5	70	40	42%
6	120	100	16%
7	160	92	42%
8	240	120	50%
9	320	240	25%
Average	**227**	**134**	**39%**

As figure 2 and table 4 demonstrate, there is a significant fluctuation in the amount of oil each crew reduced their usage by. A maximum reduction of 51% was seen by crew number 1. The minimum reduction in oil usage was 16%. This crew noted that ‘too much wear was noticed at half the mineral oil amount and we had to increase it to three-quarters of the amount to get the same result’. This was contrary to what many of the other crews said about the oil and is considered more in section 5.1.3 of this report.

5.1.2 Price analysis

As mentioned earlier into the report, all the contractors that participated in the trial also provided the current price of the oil they purchase. Unfortunately, most of the contractors did not want their prices published, and due to this, all comparisons below are conducted on a percentage or average basis.

Figure 3 demonstrates the change in cost from changing from the mineral oil to the bio-oil for each contracting crew.

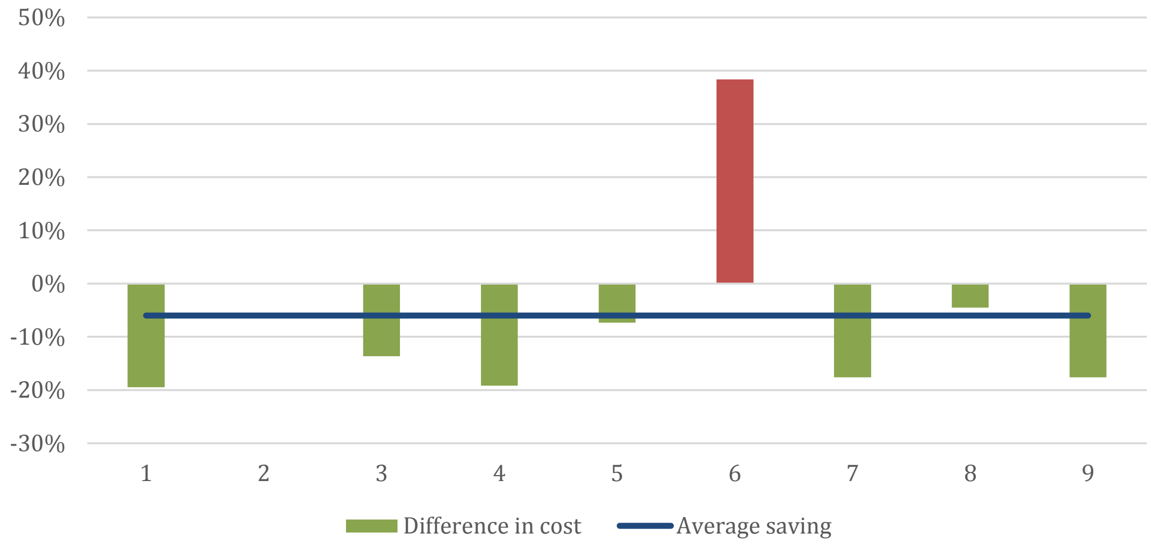

Figure 3: Cost comparison between the bio-oils

Crew 6 are highlighted here – they were the only crew in the trial not to reduce their costs but instead saw an increase in cost of 38%. They were, however, one of the crews paying the least for their mineral oil. The maximum cost savings were 19% by crew 1 and crew 4. The difference in savings can be attributed to the current cost that the contractors were paying for their mineral oil. All bio-oil prices were kept constant for all the contractors, but the mineral oil price had a range of $2.60 – $3.80/litre which affects the savings by each crew considerably when the cost of the bio-oil was set at $4.45/ litre. The average savings for the crews in the trial was 6%.

5.1.3 Contractor data

The surveys also included other questions asked about the change in bio-oil. Interestingly, the trial changed many of the contractor's views on the oil. The survey asked the contractors on a scale of 1 – 10 to rate their opinion of the bio-oil before and after the trial (1 being a very low opinion, 10 being a very high opinion), figure 4 depicts these results.

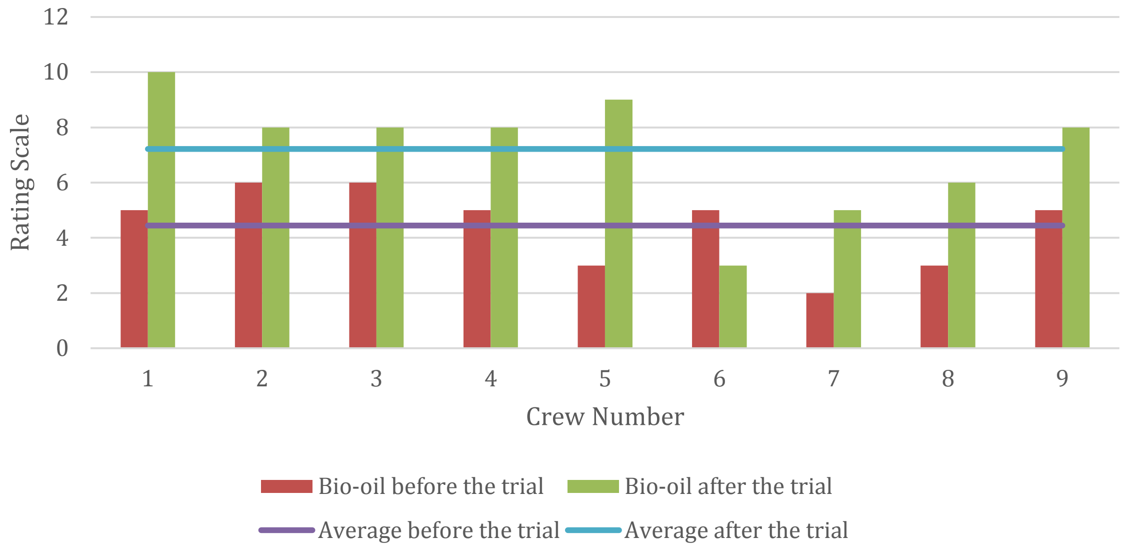

Figure 4: Contractor opinions of bio-oil before and after the trial

As shown, there were significant increases in the opinions of bio-oils from the crews. Crew 6 again had a negative view of the bio-oil, however, this was to be expected after the results they found with it. Crew 1 had an outstanding opinion after the trial, and they have now converted their whole operation to bio-oil, including all hydraulics. The average rating across all crews before using the bio-oils for the month period began at just over 4/10, so a relatively negative opinion. The opinion of bio-oils across these crews now is a 7/10, which is a significant increase.

The feedback on the oil ranged from extremely positive to quite negative. However, there was more positive feedback than negative, as proven by figure 5, which shows that two-thirds of the contractors are continuing to use bio-oils after the trial. The other two crews, that did not continue to use bio-oil, did so because they did not want to risk their machinery without further testing, and they were still slightly sceptical about the oils. A proportion of the contractors are also considering trialling bio-oil to replace their current mineral hydraulic oils.

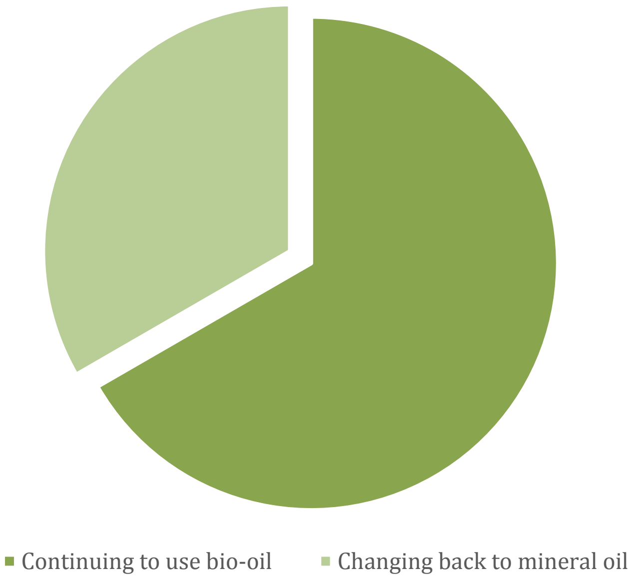

Figure 5: Uptake of bio-oils

There were a range of comments from the contractors during the length of the trial. A comment of note from two of the contractors in this trial, and one from Kimberly Evison's trial, was 'They [possums] clean up where the lube is every night. They are starting to scratch at my hoses on the harvester. I'm concerned about damage they might do'. This crew were trialling the bio-oil in their harvesting head and had recently begun to try it in their hydraulic hoses. As the crew had said, they are concerned about the possums eating away their hydraulic hoses, however, they were not concerned about the possums at the head of the machine because every morning they came back, and the machine was licked clean. Figure 6 below demonstrates a possum on the harvesting head at the skid site, while figure 7 shows what the possums are doing to head when bio-oil is left over. As seen, wherever the bio-oil is left the machine is licked extremely clean. The other crew that were utilising bio-oil and found a similar issue said 'our two cans have been found with scratch marks around the caps. These cans contain a two-stroke fuel mix in one end and a bio-oil in the other. The crew believes the marks are caused by possums. This never occurred with mineral oils".


Figure 6: Possums on harvesting head **Figure 7:** Possums clean up on harvesting head

The contractor who contributed to the negative results of the trial had multiple comments on the oil. One of these comments was: '…wound back usage but noticed increased wear, had to increase flow to three-quarters of mineral oil to get the same result'. As seen in the earlier figures, all the other contractors reduced their oil usage and cost, and this was the only crew who did not see the benefits of the bio-oil. This can be attributed, once again, to the low price they are currently paying for their mineral oil.

5.1.4 Contractor health

Contractor health was also important to consider when exploring the opportunities for bio-oil within the New Zealand forestry industry. The measurement of contractor health was only conducted through asking questions in the surveys, and as such – the only measurable aspects of contractor health were anecdotal.

Six of the contractors noted how much nicer it was on their hands as it did not dry them out as much as normal mineral oil did once washed off. Two of the contractors noted how much ‘less toxic’ the smell was after a cut was completed. However, the results look promising, as the contractors were noticing a difference between the two oils, with bio-oil appearing to be the healthier option.

Nearly of all the contractors, however, noted how their clothes were cleaner at the end of the day, and the sawdust did not stick to their chaps as much as it did with mineral oils. The operation, as a whole, appeared to be cleaner.

5.2 Chainsaw testing

The following section reports on the testing of chainsaws and measuring bar temperatures whilst reducing the oil flow. This measures if bio-oil use can be made cost-competitive by reduced oil usage (as claimed by the manufacturers), whilst not increasing the wear on the chainsaw. The operator of the chainsaw used in the testing was extremely competent. His experience was also used in measuring the wear of the chainsaw through the blunting of the chain.

5.2.2 Temperature data

The chainsaw was tested by two different methods: one with the chainsaw running at full speed and not in contact with wood, the other at full throttle while cutting through logs. These were conducted in parallel to get a well-rounded study that removes the potential bias caused by the logs that were being cut (for example: wetness, sap content, DBH). The tests were conducted thirteen times each. The first test conducted was the chainsaw under no load, trialling both oils whilst reducing the oil flow and, in turn, usage. This was then repeated with the chainsaw with a cutting load. The average diameter of the pieces of wood that were used was 42.8cm.

Figure 8, below, demonstrates all of the starting temperatures of the 52 different tests done for this part of the trial. This is the standing temperature of the chainsaw bar and was made to be the same for each of the trials conducted. The temperatures of the bar at the beginning of each test were all kept within 2.5 degrees to make sure of a non-biased trial.

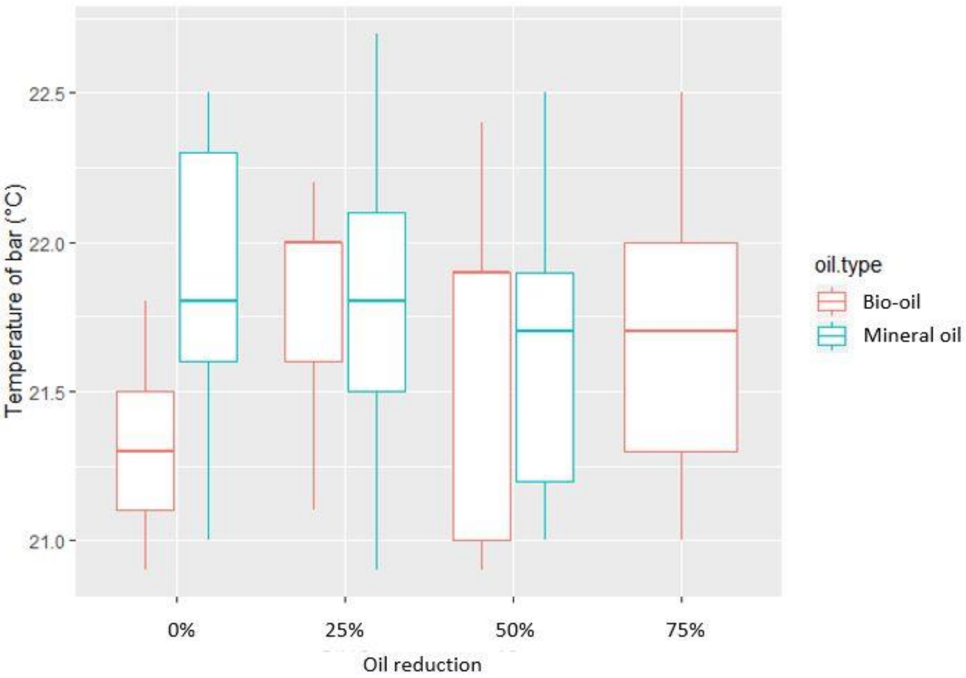

Figure 8: Standing temperature of chainsaw during initial no-load testing

5.2.2.1 *Chainsaw without a cutting load*

The chainsaw measurements were first measured without a cutting load. The method of how the chainsaw was measured and set up is shown in figure 9, below.

Figure 9: No-load temperature testing design

As seen, the chainsaw is on top of a workbench with the bar over the edge. It was then run for the interval times, and the temperature reading was taken.

The results of the chainsaw without a cutting load meant that the only effects on temperature were by the oil, and by the reduction of the oils. Figure 10, below, shows the results from the testing. The red dots signify the bio-oil, and the blue dots signify the mineral oils. Notably, the bio-oil runs cooler at all oil reductions and all intervals.

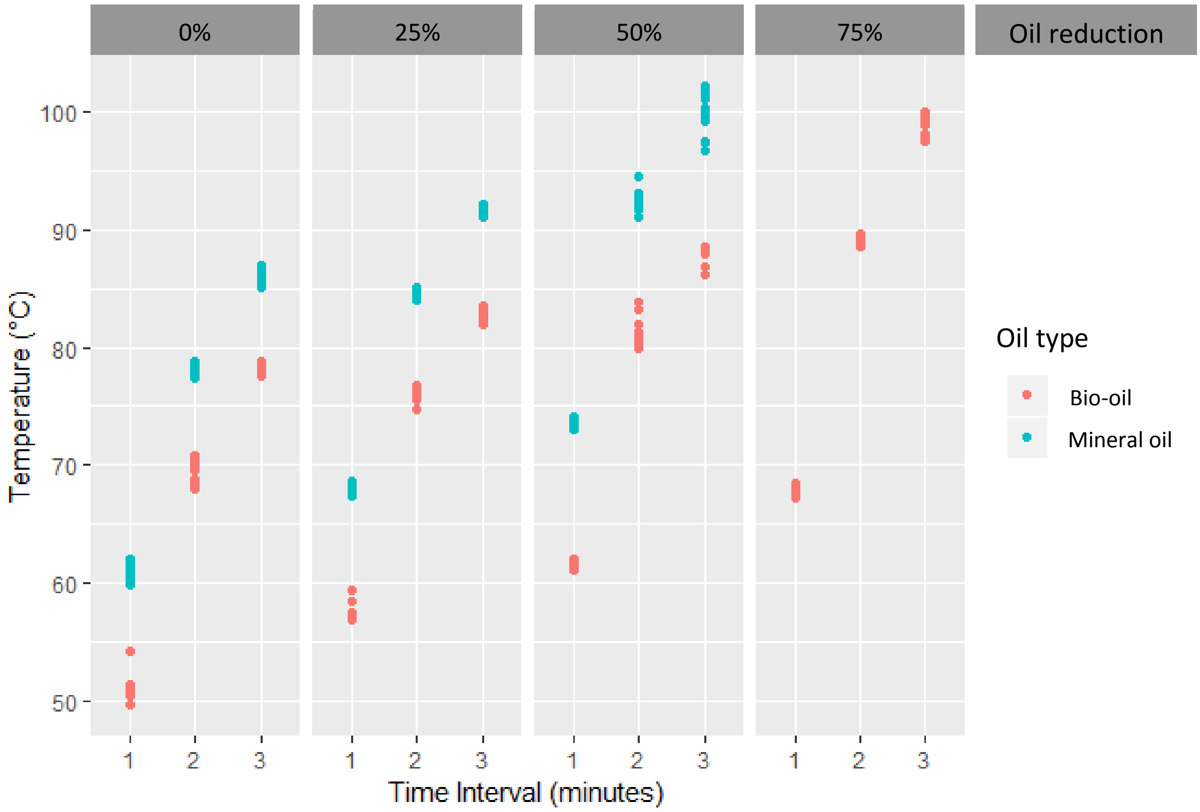

Figure 10: Chainsaw temperatures without a load

Mineral oil was not tested at 75% reduction as the temperatures looked to be getting high and the oils had not been designed to run at such a reduced flow. An interesting point observable from figure 10, is that the bio-oil temperatures almost match the previous mineral oil temperature at a lower oil flow. This will be explored further into the report.

The first test involved measuring the bar temperature at a 0% reduction in oil. The results of this test are displayed in figure 11, below. This magnifies the results seen from figure 10. As can be seen, there is a significant difference in temperature between the two oils running at the same flow. On average, the bio-oil ran 8.9^{0}C cooler than the mineral oil. Through an ANOVA, it can be determined that there is a statistically significant difference between the bio and mineral oil temperatures, whilst testing at p-value of 0.05, the result of the test is 0.00141, showing a strong statistical difference.

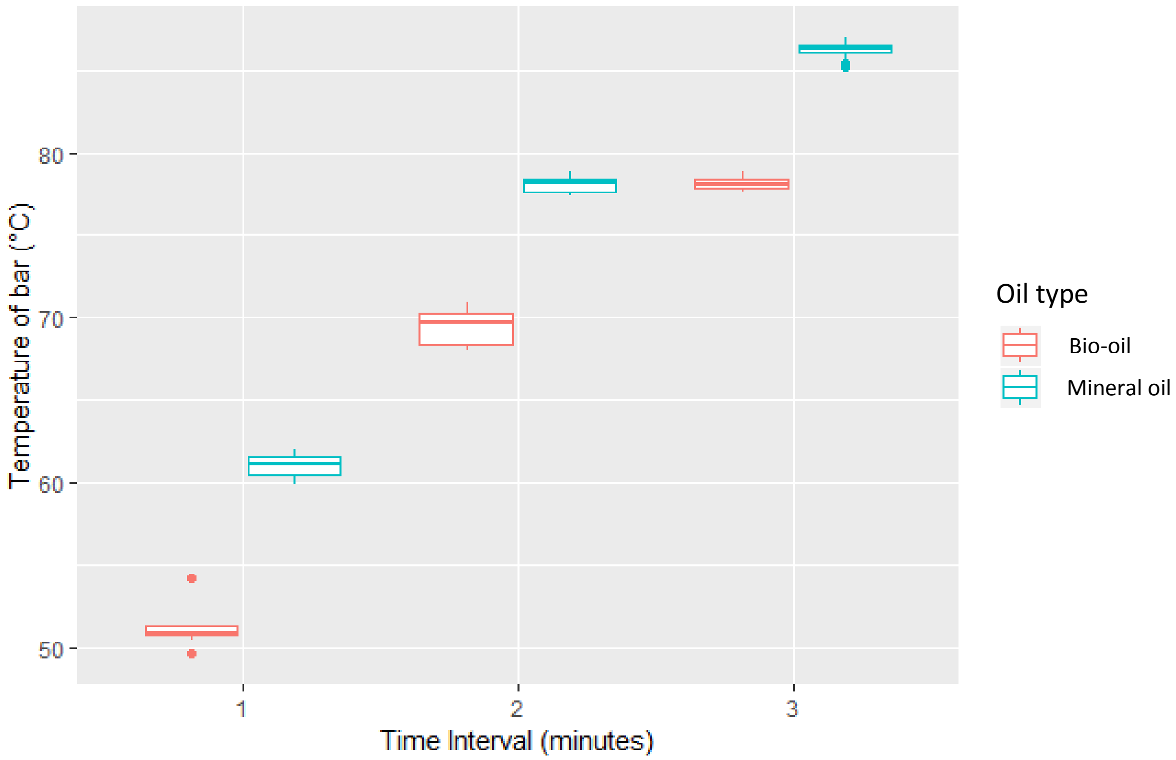

Figure 11: 0% oil reduction results (without load)

The results from the oil flow being reduced by 25% can be seen in the appendix on figure A5. The temperatures show a linear increase as the oil is reduced. When the oil flow was reduced by 50% the following figure (figure 12) demonstrates the results.

As can be seen it follows a similar pattern to what was found when the temperatures were running at 0% oil flow reduction. This is expected, as the only variable change between the two was the amount of oil. A point of note, however, is the higher deviations seen within this data set to the 0% reduction. At 0% reduction the average standard deviation was 1.0 degree across all mineral oil intervals, and at the 50% reduction the average standard deviation was 1.6 degrees. This may be due to the oil not being designed to flow at such a reduced rate (Table 1) and due to the oil's lower density, resulting in a lower tackiness, meaning it runs off the chain and bar easier.

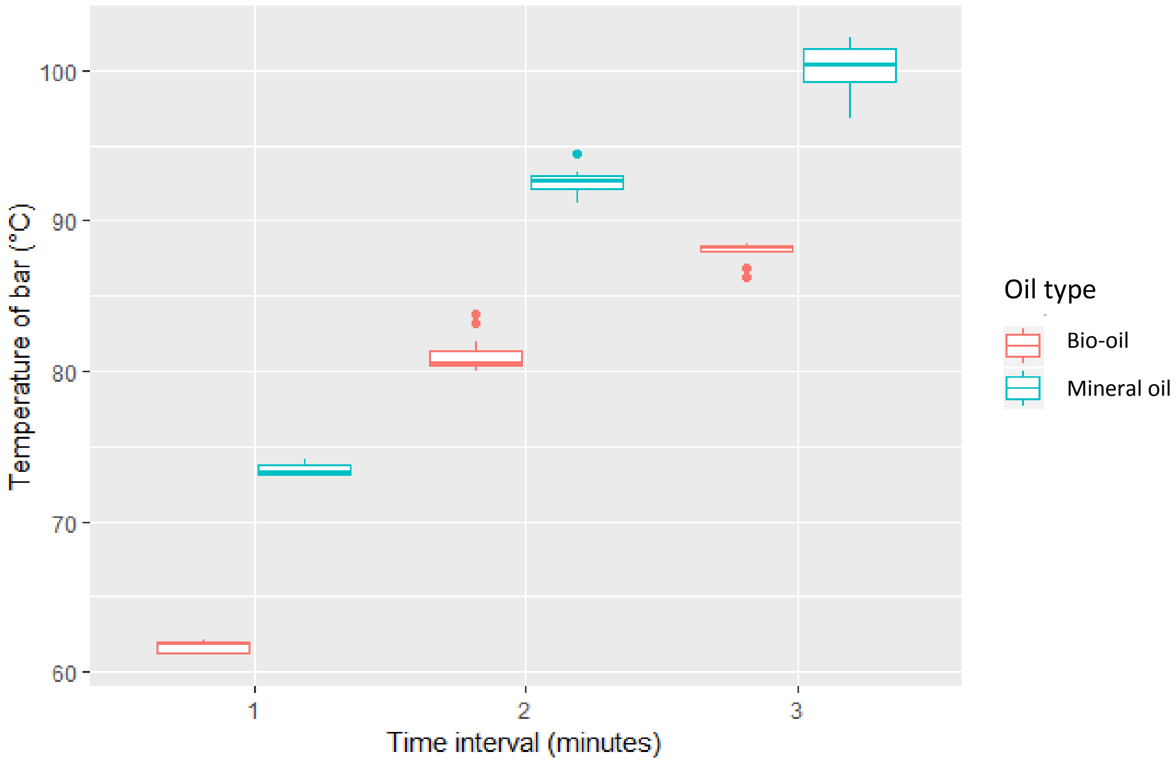

Figure 12: 50% oil reduction results (without load)

Figure 13 clearly demonstrates a significant temperature difference between the bio and mineral oils. (ANOVA test produced a p-value of <0.001), showing an even stronger significant difference between the two oils.

As aforementioned, a point of note was the temperature of bio-oil and mineral oil being similar when the bio-oil was reduced by 50% and the mineral oil at a 0% reduction. This can be seen in figure 11. What this means for the bio-oil is that it has the potential to be made cost-competitive with the mineral oils.

An ANOVA test was conducted on this idea of 50% bio-oil running at the same temperature as 0% reduction of the mineral oils. The results of the ANOVA show a p-value of 0.4798, signifying that there is no statistically significant difference between the running temperatures of the two oils.

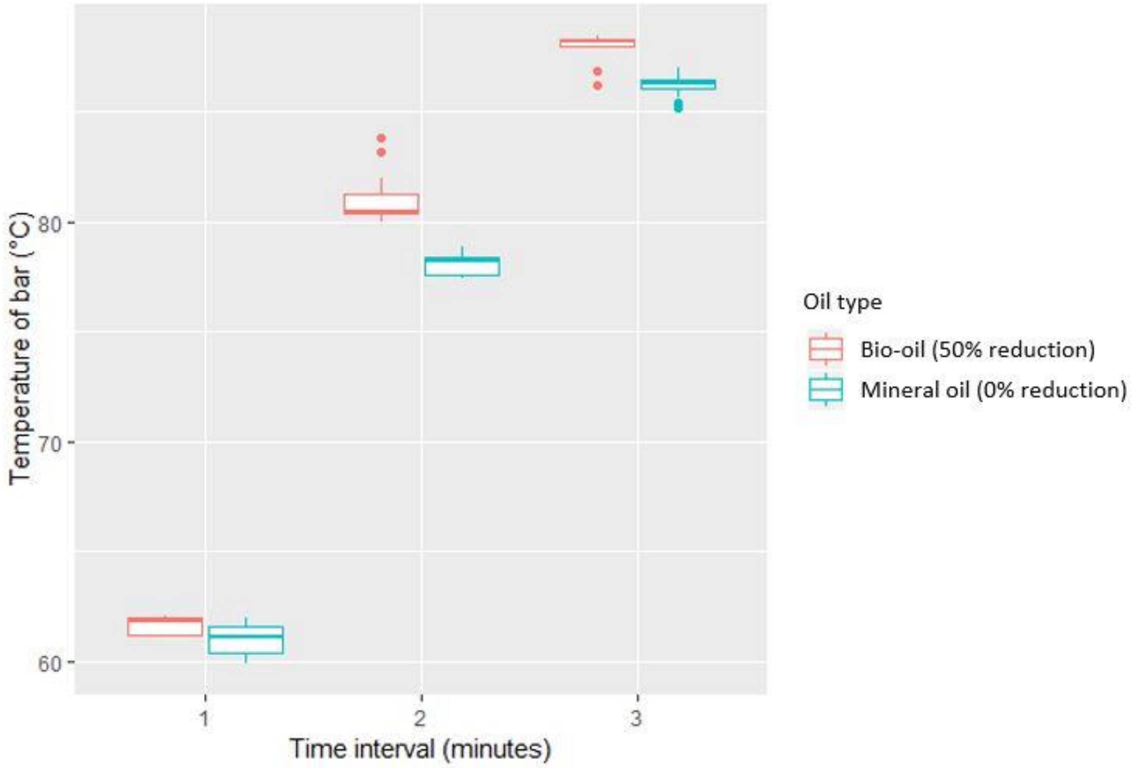

Figure 13: Bio-oil, mineral oil comparison (no load)

5.2.2.2 Chainsaw with a cutting load

This trial was conducted to test the different oils and reductions whilst the chainsaw was making a cut (or multiple) into a log. Figure 14, below, demonstrates how this test was carried out on bin wood, left over from a recently harvested skid site.

Figure 14: Temperature testing design

The temperature of the chainsaw bar was once again measured for all the tests and were kept within 2.5 degrees before each test was begun. This was again used as a base to begin the testing, and to make sure there was no bias and the test was a fair and representative test of both the oils at different flows. The average standing running temperature of the chainsaws across both trials was 21.8°C. The standing temperatures of the saw can be seen in figure 15.

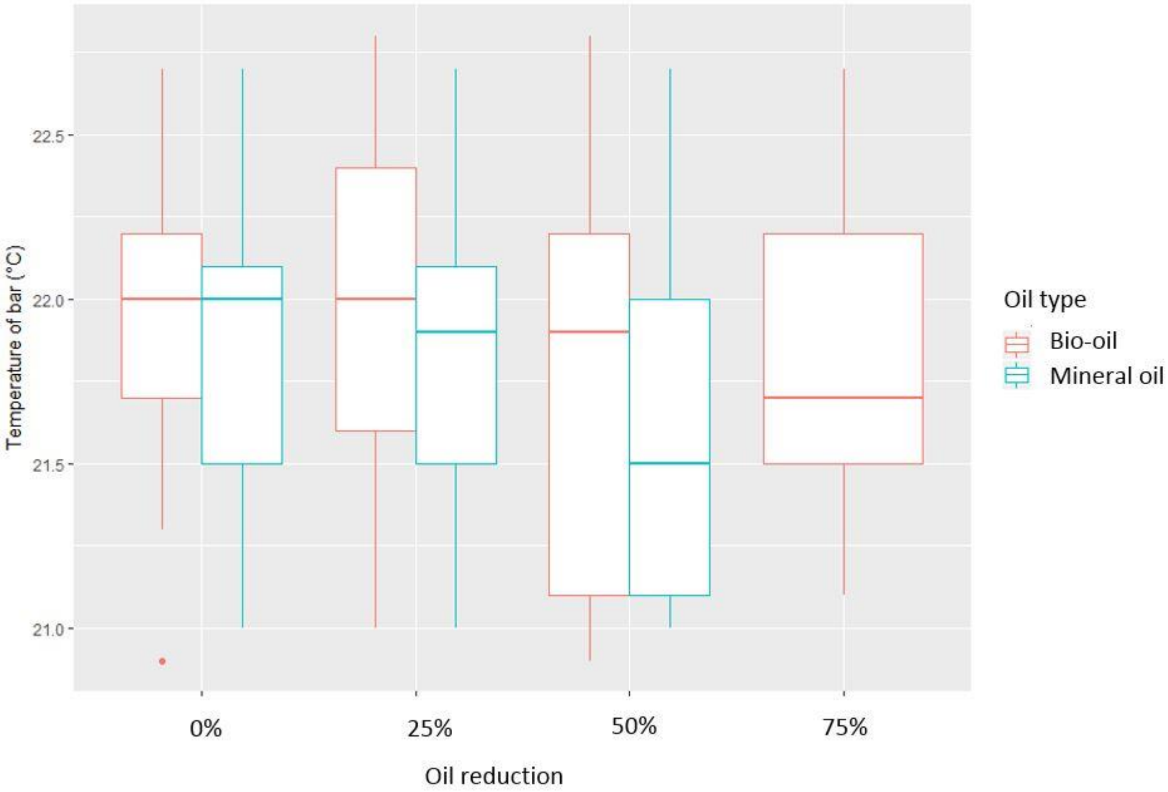

Figure 15: Standing temperature of chainsaw during testing

This trial's results tend to have a larger standard deviation due to the logs also having a direct effect on the saw, whereas the previous trial only had the oil variable. Some logs may have been damper than others, or knots may have been present causing a cooler cutting surface or more resistance on the chain. However, the results still give a clear outline of the trends of both the oils and a good indication of running and cutting temperatures. Figure 16, below, demonstrates the total results of the trial whilst the chainsaw was under load.

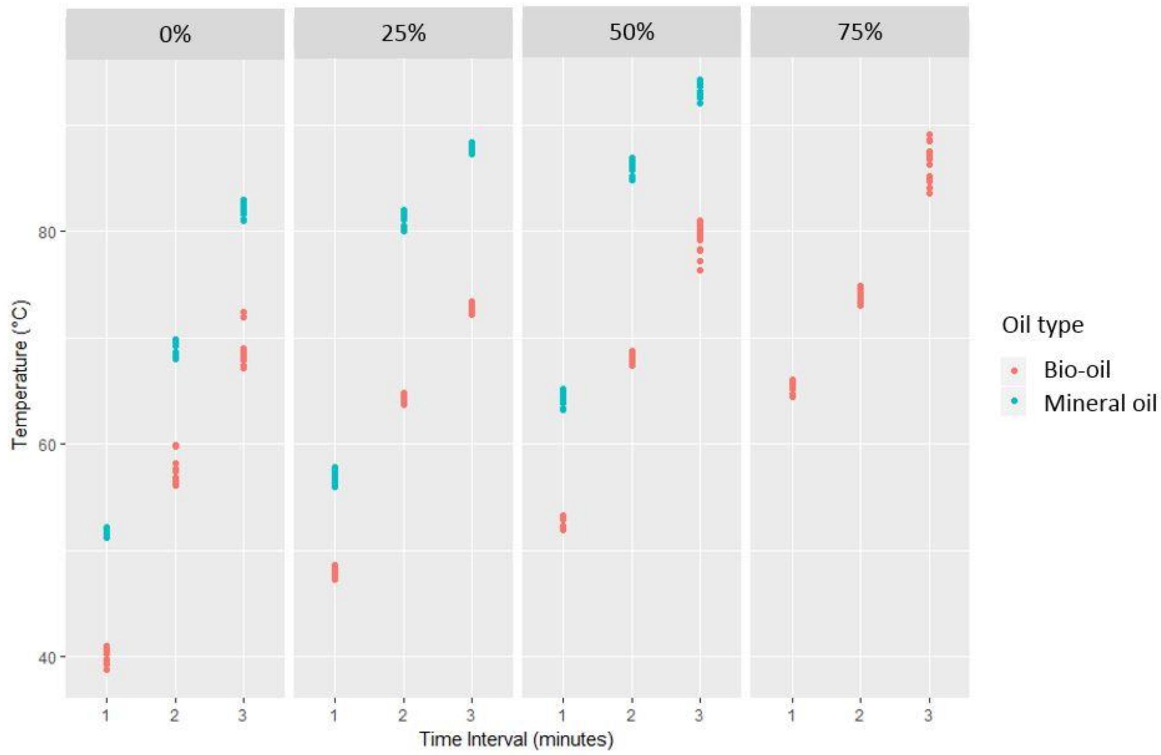

Figure 16: Results from chainsaw testing (with load)

Both oils were originally trialled at 100% (0% reduction) oil flow on the chainsaw, the flow that mineral oil is designed to work at.

At a 0% reduction in oil flow, the bio-oils were once again seen to perform at a considerably lower temperature, as witnessed. The average temperature difference between the two oils was 12.1°C, the bio-oil running considerably cooler than the mineral oil at all intervals. This is reinforced by an ANOVA test that returns a p-value of 0.001, showing a strong result and that there is a significant difference in the two oils running temperatures. This can be seen clearly in figure 17.

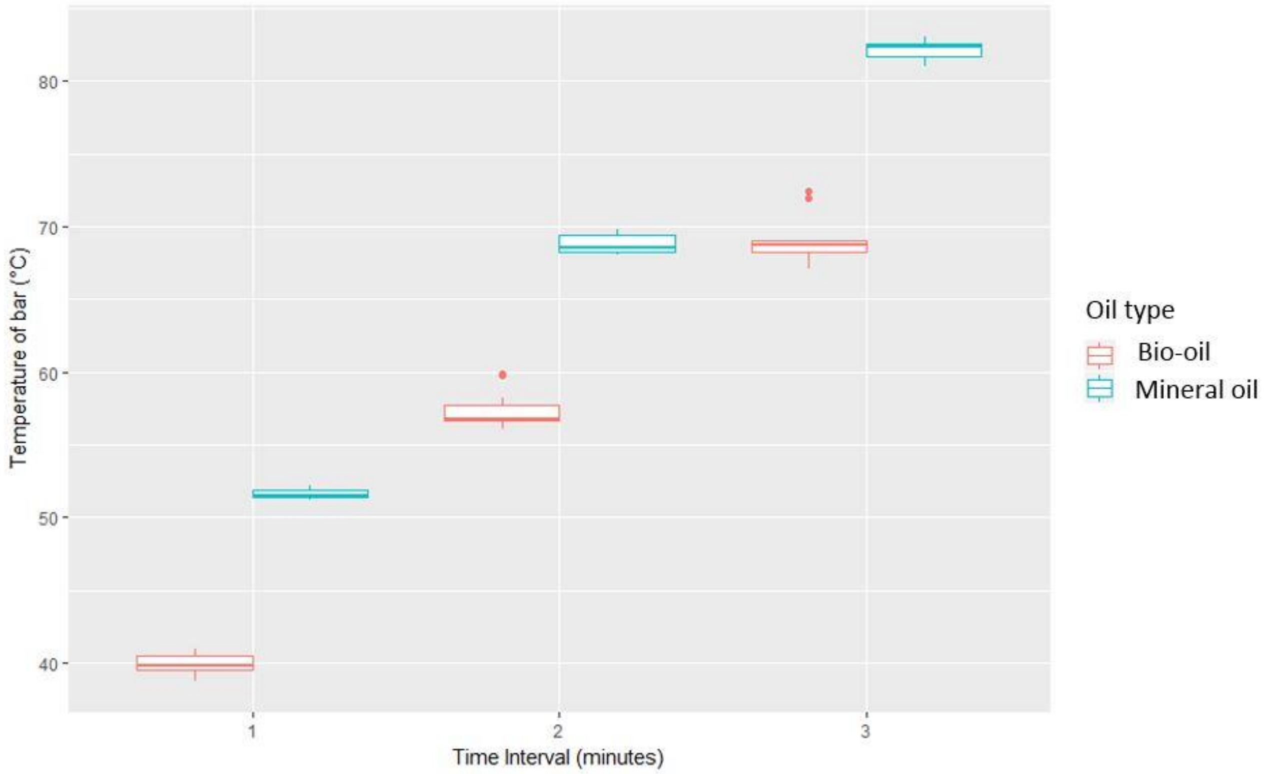

Figure 17: 0% reduction results (with load)

Both oils were again tested at a 25% reduction in oil. The results from this part of the trial are attached in the appendix as figure A6. The bio-oil, once again, ran significantly cooler than the mineral oil at all intervals.

The final test was between both oils when the oil flow was reduced by 50%. The mineral oil is not designed to flow at this reduced amount (figure 18), due to the high temperatures that the bar is reaching. At the three-minute interval, the chainsaw bar is reaching a maximum temperature of 94.3°C with mineral oil. This is considerably hotter than the bio-oil which reaches a maximum temperature of 79.9°C. This highlights that mineral oil is not designed to run at these low flow rates. In undertaking an ANOVA test a p-value of 0.0002 was calculated, showing a strong statistical difference between the two oils at this flow rate.

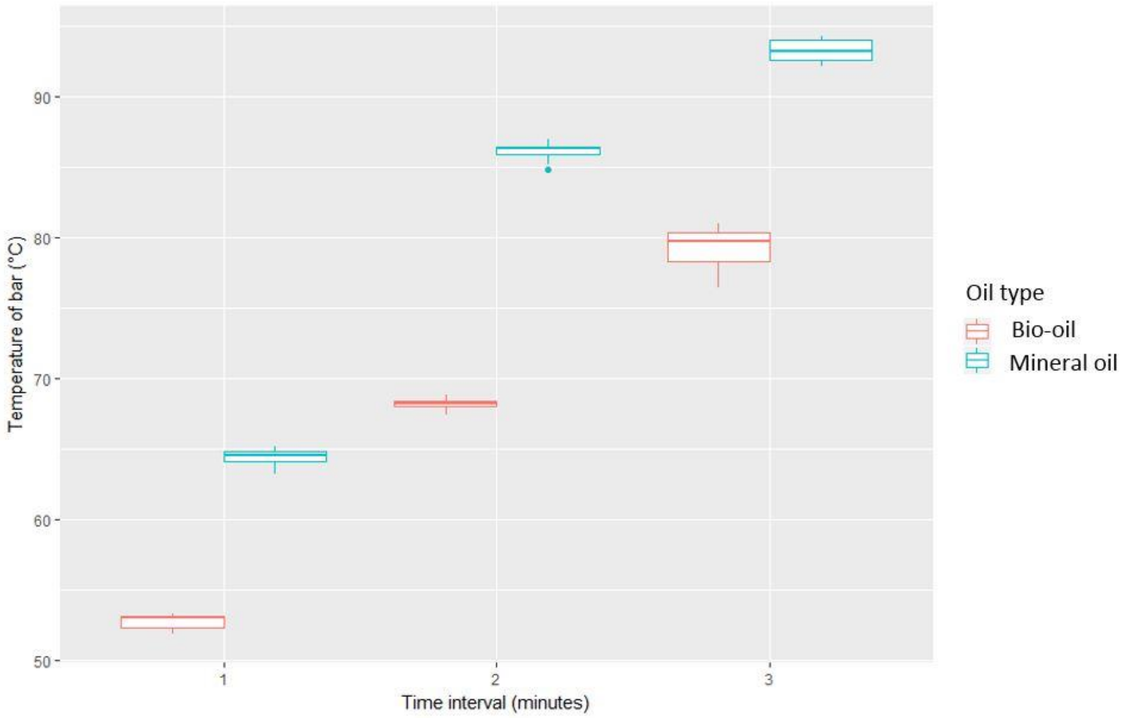

Figure 18: 50% oil reduction results (with load)

LubEco, the bio-oil manufacturer, claimed that the bio-oil can run at 50% less oil than mineral oil does, whilst seeing no detrimental effects on the tool. The following figure (figure 19) tests if this claim can be substantiated.

On the boxplot, mineral oil at full flow is tested against bio-oils at a 50% oil flow reduction. The results clearly show that there is no significant difference between the two. An ANOVA comparison of the two oils at their different flow rates reinforces this with a p-value of 0.7864, which means there is no statistical difference between the two oils and running temperature of the bar. This results in the claim from LubEco being substantiated.

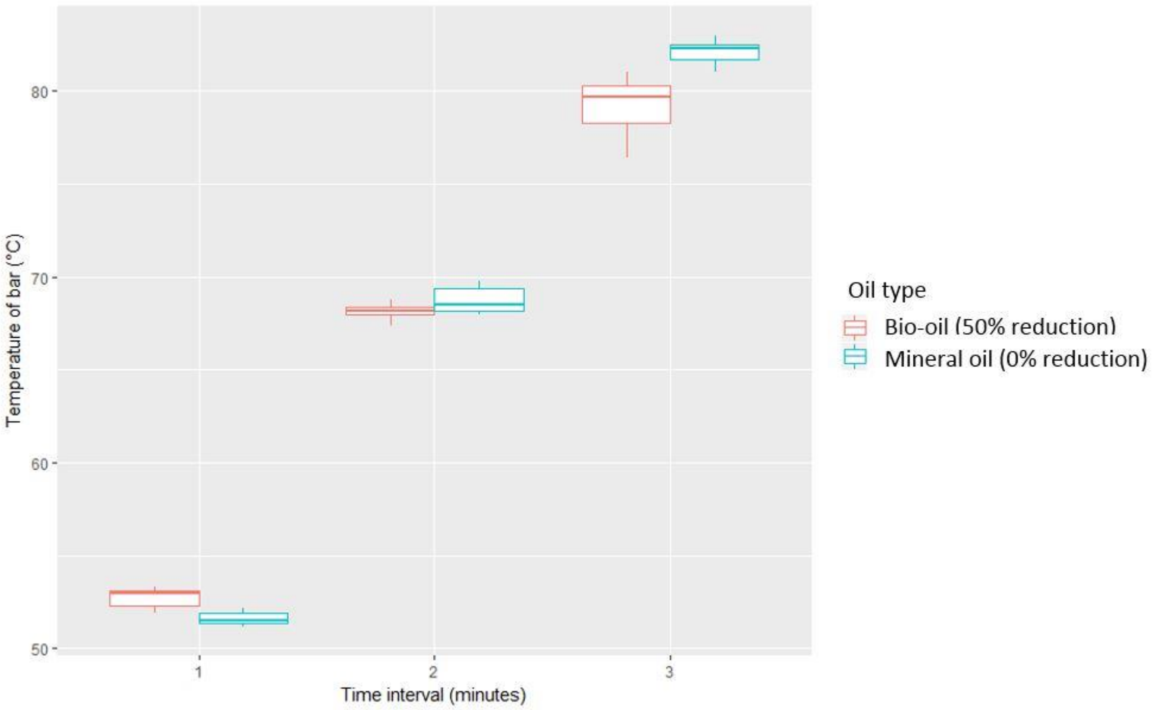

Figure 19: Bio-oil, mineral oil comparison (with load)

5.2.2.3 Chainsaw wear

When the mineral oil was reduced from its current setting of full oil flow, the chainsaw operator noted that there was faster wear on the chain at all reduction levels trialled. It was observed that when the flow was reduced by 25%, the wear was not significant and was manageable but required some extra sharpening to what was needed at full flow. But, when the mineral oil was reduced by 50% the operator noted that the chain was wearing exceptionally quickly. This is what was found to be the reason for the sudden increase in the temperature at the second interval. They also noted that the chainsaw, whilst using the bio-oil at 50%, did not feel any different to the mineral oil at a 0% reduction. However, when the bio-oil was reduced by 75%, the operator noticed significant wear. The temperature from this section of the trial can be seen in figure A7 & A8 in the appendix.

6 Discussion

The use of bio-oils in the forestry industry is not a new concept on an international level. Contractors in New Zealand have trialled bio-oils at their own accord (or at managements request) before (such as Kimberley Evison's Trial (2014), but these oils were known as first generation bio-oils. First generation bio-oils they were not as refined as they needed to be and hence gave the oil a bad name within the New Zealand forestry industry. However, as the results from these contractors show, the bio-oils are improving through their ability for the oil flow to be reduced, and contractors are more willing to trial them in other parts of the operation and with different machinery applications, such as their hydraulic fluids, once they can be reassured that the oils are not going to damage their equipment.

The chainsaw tests conducted as part of this study are also the first of its kind in New Zealand. This part of the study aims to reinforce the results obtained from surveying contractors who were utilising the bio-oils in the forest operationally, rather than having a controlled-environment test as they were for the chainsaws. This section of the study was similar to a study conducted by Stanovsky et al., (2013), however in their study they did not attempt to reduce either oil but kept them both at full flow and measured temperature as a function of wear.

6.1 Are chain bar oils cost effective?

The trial conducted through the contractors allowed an understanding to be gained around their original hesitance to use bio-oil. This study aimed to understand the contractors' hesitancy and aimed to overcome them. From this, the initial question of this study was "Are bio chain bar oils as cost-effective as standard mineral oils?". It was found that bio-oils (LubEco) are on average, double the price of standard mineral oils for the contractors in this trial. Due to this, for the bio-oil to be price competitive, the bio-oil usage needed to be reduced by 50% whilst seeing no diminishment in the wear or power of the chainsaw and processing head. As most contractors found, the bio-oil was successfully able to be reduced to 50% of the full flow of mineral oil. Some of the contractors even reduced their oil usage enough to be saving money on their chain bar oil compared to what they currently paid. As mentioned in the results section, the maximum saving by a contractor by switching oils was 19%.

The cost-effectiveness of the bio-oils was also reinforced by the chainsaw trials conducted. It was found that bio oil was able to be reduced enough to make the bio-oils cost-effective without increasing wear. This will be discussed further in the following section.

6.2 How much can oil flow be reduced before temperature and wear become an issue?

The initial message to the contractors when they first received the bio-oil, was to attempt to reduce the oil usage as much as possible without suffering any extra wear on the chainsaw or head that they were using the oil on. Notably, the contractors managed to reduce their oil usage on average by 39.6%. The chainsaw tests were also conducted, with tests finding that both oils lubricate the bar and chain adequately, reducing friction between individual components, the cutting system and the wood that is being cut at full oil flow (no oil reduction). The chainsaw test demonstrated that as it reduced the oil flow on to the bar, the temperature began to increase in a near linear fashion. When the bio-oil was reduced by 50% it was found that the temperature was almost identical to the running temperature of mineral oil at no reduction. From this, it can be concluded that the bio-oil can be reduced at between 40% - 50%, which for most contractors makes the oil cost-effective. The mineral oil was seen to be causing extra wear when it began to be reduced from anything other than 100% oil flow. At 25%, the operator noticed that he was having to put more time into the cuts, and the chain was blunter than it usually would be at 100%. By 50% reduction, and the third interval, the chain was extremely blunt, and the operator was having to spend a long time sharpening between trials. Therefore, the trial stopped after the 50% reduction of mineral oil. This research also disproves many contractors' theories that the bio-oils have a negative effect on wear due to the oil.

6.3 What other benefits were seen in a shift to bio-oil?

Other benefits were also seen in a shift to bio-oil for the crews that participated. Due to the length of the trial length, contractor health was difficult to measure. Some of the contractors, however, did notice an improvement in health and a much cleaner operation, with the amount of saw dust and oil stuck to their chaps at the end of the day being significantly less than it was with their mineral oils.

Both oils are suitable to use in chainsaws in regarding the wear and friction of the saw as also found by Stanovsky, et al., (2013) in their trial. From this study, bio-oil appears to be more suitable than the mineral oils at reduced flows. Bio-oil should begin to be considered as the oil of choice due to a range of factors. Namely, there is less oil spilt out into the environment, the oil is not as toxic and degrades within 28 days meaning there is less effect on the environment. Considering a range of criteria, it is a cleaner, healthier operation for the contractors with comments to confirm this such as, ‘less build up on the side covers’ and ‘feels much nicer when you spill it on your hands than ordinary mineral oil’.

Due to the oil being kinder on the environment, councils and managers alike should begin to consider regulation or policy around the use of bio-oils. Especially around high-value areas such as waterways.

6.4 Research limitations

Although this research was carefully organised and prepared, there are a range of limitations in applying and considering the data gained from this study. All the research and measurements for this study were conducted within two months which is not a long enough period to measure things such as downtime due to the oils, as well as potential added wear on the saw. It could have been beneficial to the study if the trial was conducted over a longer period to measure these factors. However, to what degree this would have affected the study is up for debate.

Another limitation to the study is the relatively small data set gained (13 measurements at each interval and at each reduction), and only one saw was trialled. This gives an indication of what results to expect from a larger sample size. If another study was to be conducted, more trials at smaller reduction intervals and trialling more chainsaws could be beneficial to the overall result.

7 Recommendations & conclusion

Overall, recommendations can be made from this study to councils and forestry managers, as well as contractors:

Regulation or policy for the use of bio-oils should be investigated more thoroughly by both councils and forestry management companies. High risk areas, such as near waterways, when total loss oil systems such as the chainbar oils in both manual and mechanical felling systems are being used should especially be considered. This report proves that bio-oil does not have the problems that the first generation bio-oils had, and it can begin to be investigated further in order to start adding regulations to council plans, and for forestry companies to begin adding bio-oil clauses in to their environmental policies, even if it is in a stepped process, beginning with more stringent protection of the waterways.

The findings of this study establish the recommendation that contractors should seriously consider utilising bio-oils. As this study demonstrates, bio-oils have the potential to reduce oil usage, save costs, as well as helping to save the environment in the process. If 2.5 million litres of chain bar oil are currently spilt into the environment, there is the potential for this to be halved by using less toxic oils that will degrade within 28 days. If this starts with the contractors, rather than having to be enforced down from managers and councils alike, it would be an advantageous step forward for the New Zealand forestry industry.

I can also recommend for further study to be conducted into researching other bio-oils, such as hydraulic oils and other oils that have a high chance of being spilt into the environment. New Zealand already has a ‘clean green’ image, it’s now up to the New Zealand forestry industry to reinforce this image of New Zealand and back it up with cleaner, more environmentally friendly operations.

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9 Appendix

Council Bio-Oil Policy Survey November 2017

Council Name: ______________________

1. **Does your council currently have bio-oil policies in place?**

☐ **Yes** ☐ **No**

If no, are there plans to implement one?

☐ **Yes, within a year** ☐ **I don't know**

☐ **Yes, within 5 years** ☐ **No plans at this stage**

☐ **Yes, within 10 years**

Comments:

2. **Are the policies enforced?**

☐ **Yes** ☐ **No**

If no, why not?

If yes, how are they enforced?

Any other comments or concerns on the idea of bio-oils used in a forestry setting:

Please attach any policy documents on the use of bio-oils in your region as an attachment in the email reply.
Thank you for your participation.

A1: Survey sent to all New Zealand Regional Councils regarding bio-oil

Bio-oil Trial 2017/2018

- **The brand of oil you are currently using as chain bar oil?**

  ____

- **The cost of the oil you are using ($/L)?**

  _____________ ($/L)

- **The amount of oil you are using (Chainbar):**

  _____________ L September 2017

  _____________ L October 2017

  _____________ L November 2017

  _____________ L December 2017

-

Brand of chainsaw:	**Number of chains used over the past year** (if known)	**Number of bars replaced over the past year:** (if known)

If trailing the bio-oil in the felling or processing head:

	Brand of header
Felling	
Processing	

- **What problems have you had with changing to bio-oils in the past, or why haven't you tried?**

____
____
____

A2: Pre-trial survey sent to contractors

Crew name: ______________________________

- **Have you noticed a change in the health of you or your staff due to the change in oil?**

  ☐ YES ☐ NO

  Comments:

  ____
  ____
  ____

- **When cleaning/ conducting preventative maintenance do you notice there is less oil mess? I.e. engine block, oil canals, oil/ grime around the chain sprockets, chain.**

  Comments:

  ____
  ____
  ____

- **Do the chainsaws appear to be wearing less?**

  ☐ YES ☐ NO

  Comments on how? I.e. less bar breakages, not using as many chains etc.

  ____
  ____
  ____

- **Is there less downtime now, compared to when you were using mineral oils?**

  ☐ YES ☐ NO

- **Is the operation noticeably cleaner now? I.e. chaps are not being covered in oil etc.**

  ____
  ____

- **Have you tried winding the oil usage back?**

  ☐ YES ☐ NO

  - **If so, by how much and are they performing just as good, better or worse?**

  ____

- **How much oil are you using on a weekly basis with bio-oils?**

  Weekly: ______________Litres

- **At the conclusion of this trial will you continue to use bio-oil?**

  ☐ YES ☐ NO

  - Why or why not?

  ____
  ____
  ____

- **On a scale of 1 – 10 (1 = very low opinion and 10 = very high opinion) what did you think of:**
  - Bio-oil products before the trial **1 2 3 4 5 6 7 8 9 10**
  - Bio-oil products after the trial **1 2 3 4 5 6 7 8 9 10**
  - Its performance **1 2 3 4 5 6 7 8 9 10**

- **Would you consider using other bio-oil products (e.g. hydraulic oils) in your machines?**

  ☐ YES ☐ NO

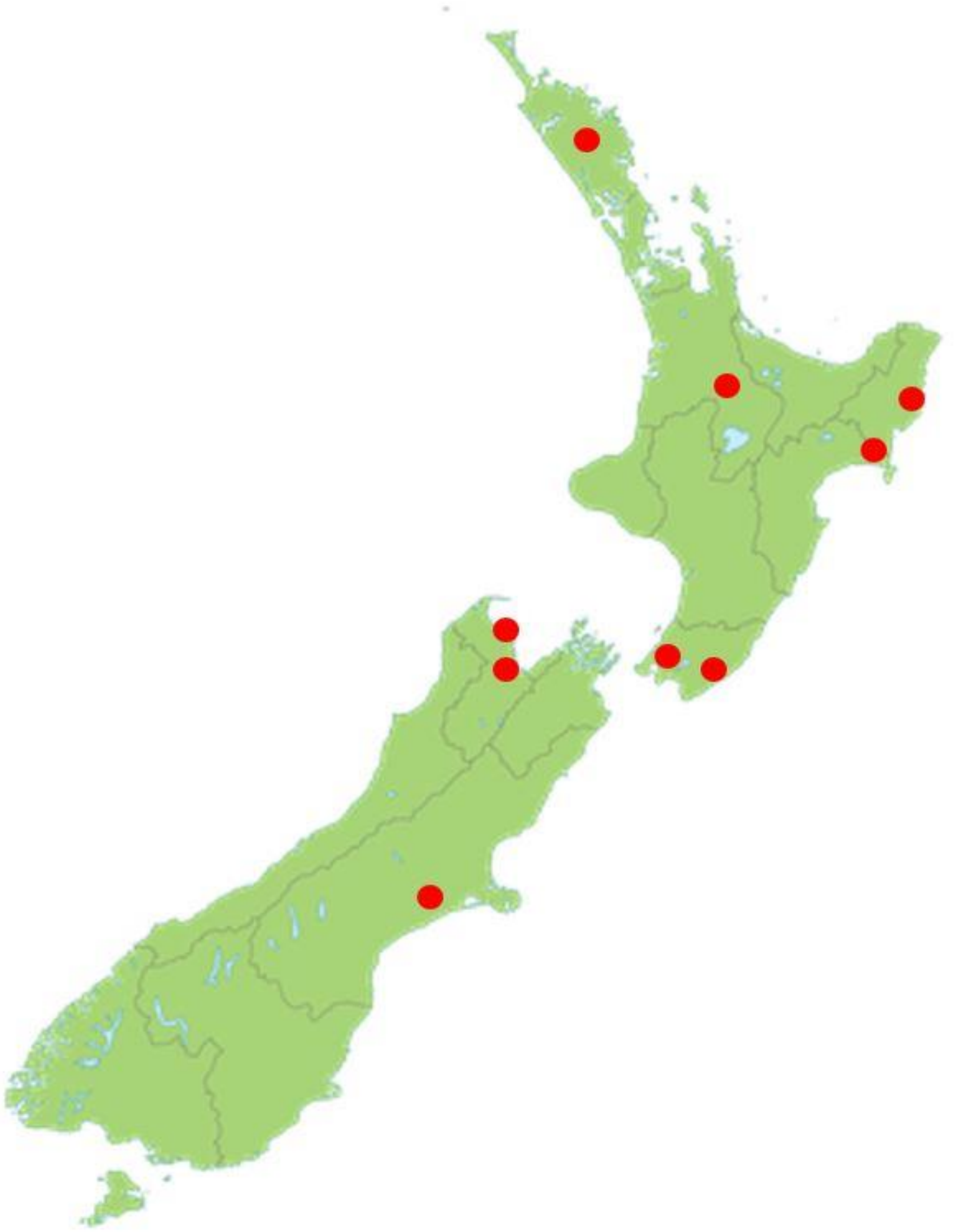
- **Has using the oil changed your perception around bio-oils? (i.e. price and performance)**

  ____
  ____
  ____
  ____

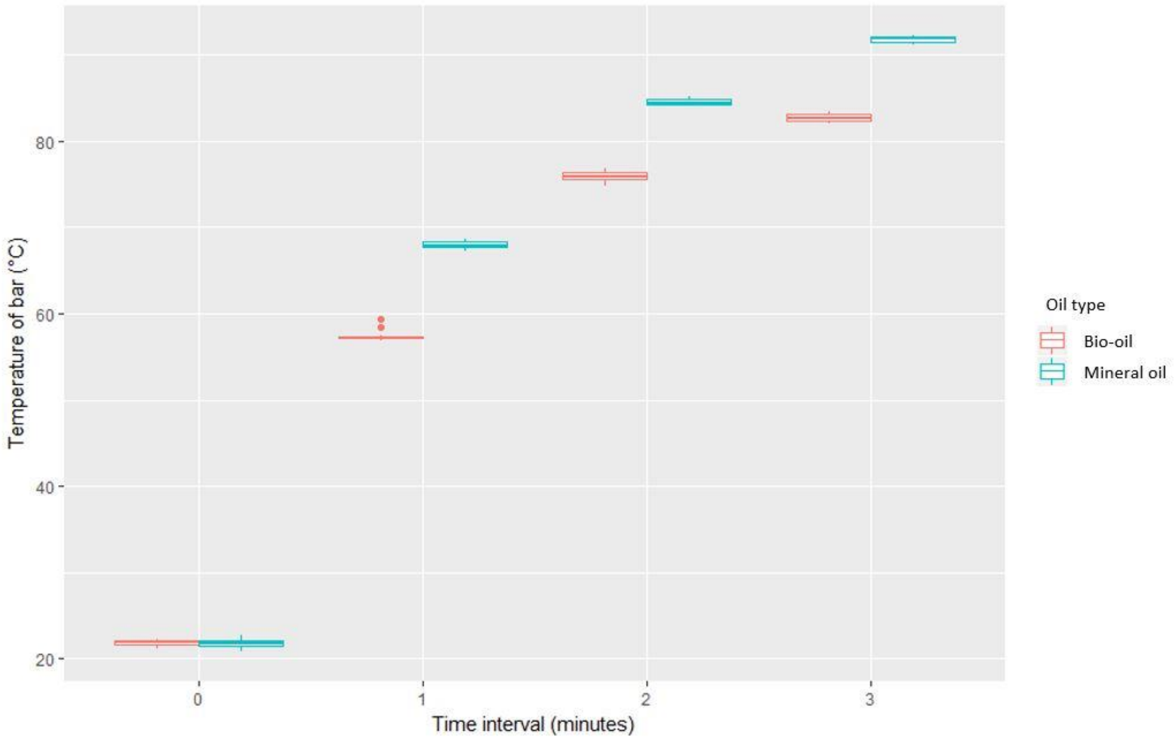
- **Any other comments or thoughts on the bio-oil?**

  ____
  ____

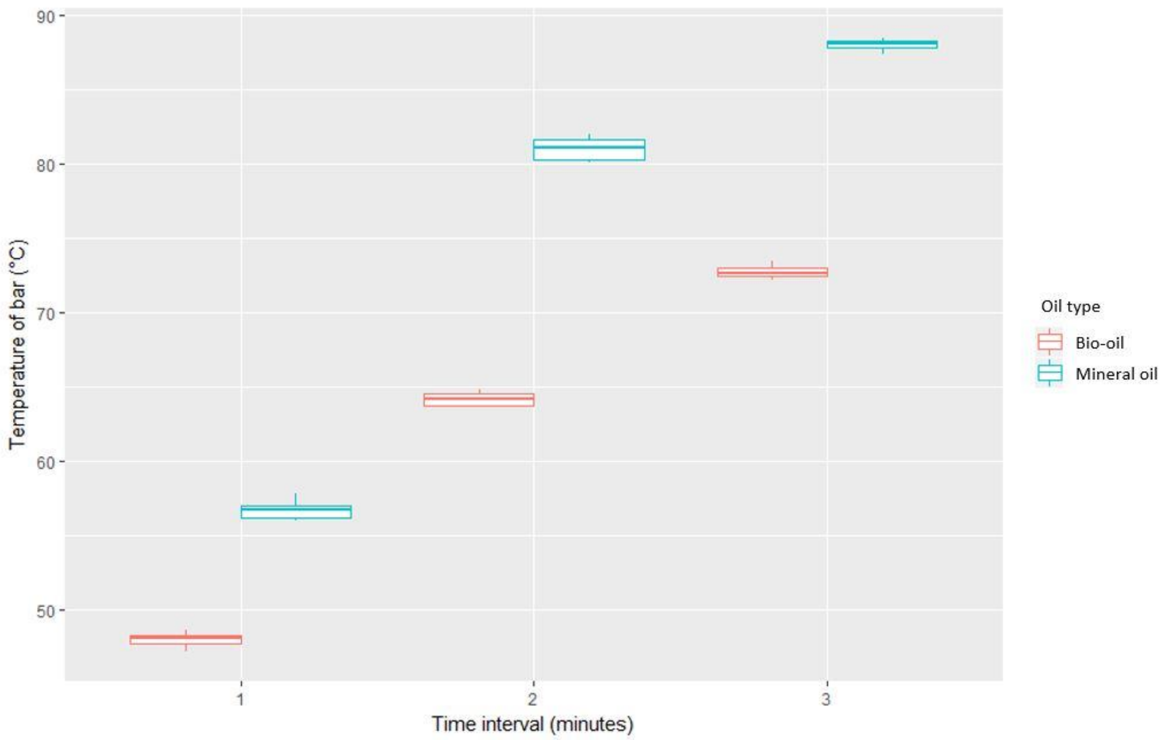
A3: Final survey sent to contractors



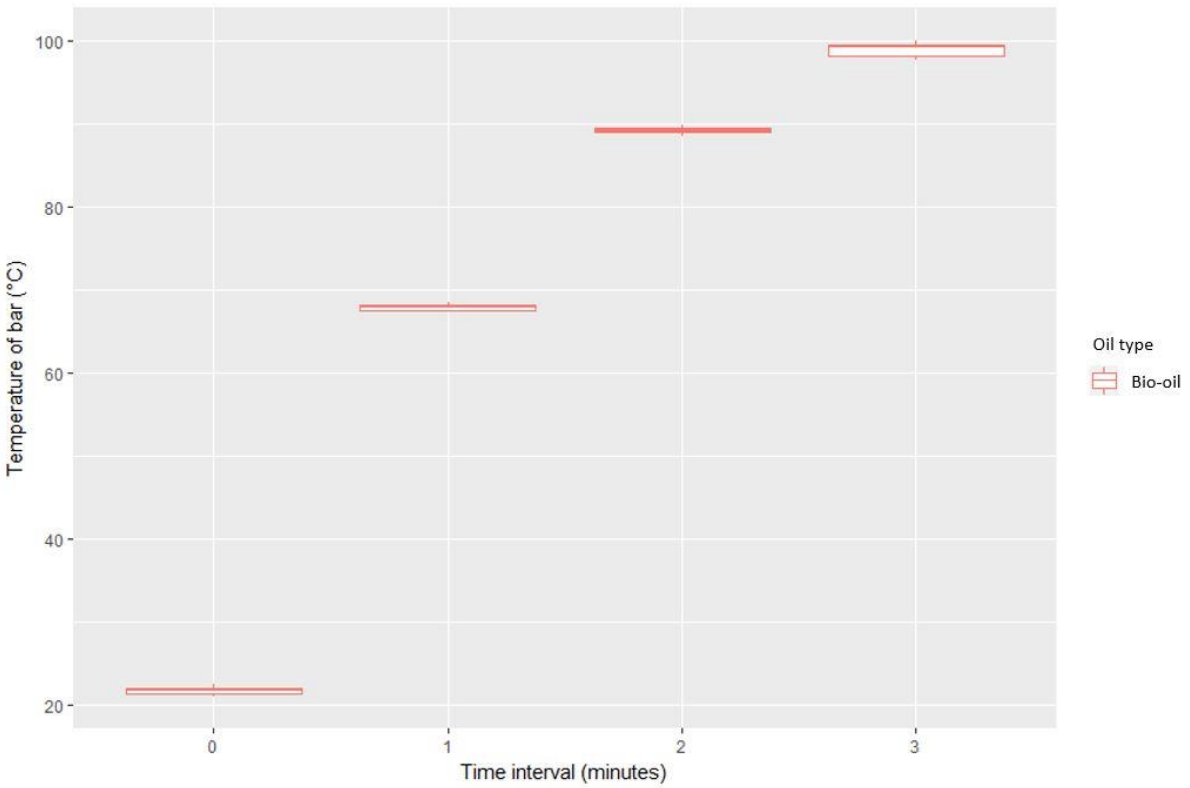
A4: Crews trialling bio-oil location



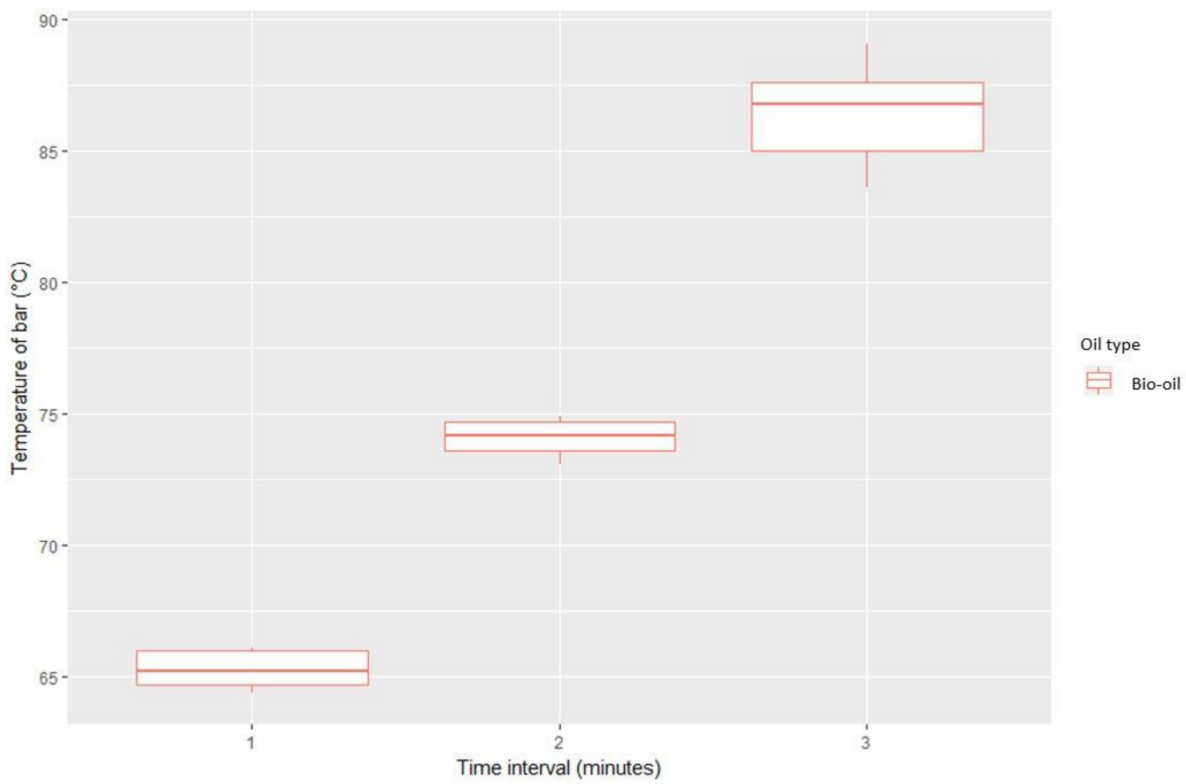
A5: 25% reduction results with no load



A6: 25% reduction results with load



A7: 75% reduction with no load



A8: 75% reduction with load