University of Canterbury

Assessing the Level of Unproductive Area in Production Forestry Sites in the South Island of New Zealand

Blakely Pacific

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Executive Summary

This paper presents the findings of a study carried out assessing the level of unproductive area in harvest sites within the South Island of New Zealand.
There have been few studies carried out into the amount of unproductive area in forestry in New Zealand. The efficiency of land use has potential to impact the level of profitability of forestry operations in NZ and is therefore of concern. This study has been appointed by Blakely Pacific, but the findings may be of interest to harvest planners, managers as well as other researchers.

Unproductive area is defined as area of roads plus the area of compacted landings including regenerated landings and therefore eroded sections are excluded. Initially slash is excluded from unproductive area, but it is later included to assess if it has a significant effect on a linear regression and final results.
The study sampled 41 harvesting sites from around the South Island, finding an average unproductive area ratio of 4.82% excluding slash and 5.09% including slash. Assuming an unknown total number of harvest sites this gives a confidence in the average unproductive area ratio excluding slash of 80% with a 10% interval.

The samples were separated into regions; each region was allocated a number of samples depending on the level of forestry by area within that region. Regions were defined following those set out by Ministry for Primary Industries (MPI). This gave 13 samples for Nelson/Marlbourgh, 3 samples for the West Coast, 16 samples for Otago/Southland and 9 samples for Canterbury. The overall average is therefore expected to represent the South Island as a whole.

Harvest site samples were assessed for harvest system used, level of crown cover and location. These variables along with total harvest area were input into linear regression models with unproductive area and unproductive area ratio as dependent variables in order to model how different factors contribute to the overall level of unproductive area. This was completed with limited success finding one model that had a reasonable significance and accuracy; however harvest area was the only independent variable that was managed to be incorporated into the model.
Many factors influence unproductive area in a harvest sites and a post-harvest aerial photograph analysis is only able to recognise several of these, such as harvest location and harvest system used. Comprehensive stand and harvest information is required in order to produce reliable models.
The successfulness of the regression was also limited by sample size. With a much larger sample size it would be expected that variables such as harvest system used have an influence on the level of unproductive area.

The average landing size found in the study was compared with other publications from around New Zealand. It is found that the results obtained are reasonable and therefore it can be concluded that the overall unproductive area ratios are also reasonable.
Mabazza, A (2014, unpublished) found the unproductive area ratio of harvest sites within the North Island to be 4.2% with a similar mythology. This supports backs the findings of this study.

From analysis of distributions of unproductive area ratios found it is believed that in the South Island the unproductive area ratio varies from around 2-8% depending on several variables which could not be successfully modelled.

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1.0 Introduction

Production forestry is a sustainable resources, with large international markets where logs are sold for structural timber, multiple wood products including pulp and furniture as well as a basic energy source. Due to its sustainability it is expected to be an ongoing and potentially expanding global industry with research going into new uses such as biofuels.
In New Zealand production forestry has an annual gross income of around $5 billion, which contributes around 3% to the GDP. The industry supplies the Asia Pacific with 9% of wood by volume or 20% by value (MPI, 2012/2013).
The amount of volume being harvested annually is expected grow massively over the next ten years as huge stocks planted in the 90's begin to mature. Many of the stands maturing are newly established plantations that are under first rotation and due to this have no pre-existing infrastructure, and will therefore require infrastructure in order to harvest and extract logs.
There are models for landing size requirements however there have been very few studies carried out that look at the efficiency of use of plantation forestry land area.
This is an area of concern because a more effective use of space means that the portion of productive area is higher, which would be expected to have beneficial results such as greater returns due to the relative proportion of volume being higher per hectare, assuming similar extraction costs.

By analysing and modelling how independent variables such as harvest area and different harvest systems affect the ratio of unproductive area a deeper perspective can be gained on what trade-offs lead to optimal spatial efficiency. The trade-offs can then be weighed up and more informed decisions can be made when designing forest infrastructure and harvest plans.

Blakely Pacific has requested a study that assesses the level of unproductive area within plantation forests in NZ. This paper aims to assess the level of unproductive area in the South Island and has been carried out concurrently with a study done by Mabazza, A (2014, unpublished) which aims to assess the level of unproductive area in the North Island adopting a similar mythology.

New Zealand has a net plantation stocks of 1.7 million hectors, 30% of this area lies in the South Island. Therefore the South Island alone has significant enough area to warrant an independent study.

Over 40 aerial photographs of harvest sites from all regions of the South Island of New Zealand have been analysed using GIS (Geographic Information System). In order for averages to be representative of the South Island as a whole, the number of samples in each region is weighted depending on the proportion of total plantation forest area growing in that location. The findings are summarised and discussed in this paper.

2.0 Objective

To calculate the amount of long term unproductive area as a proportion of harvested forestry area of forestry operations within the South Island of New Zealand.

3.0 Definitions

Unproductive area: defined as landings and permanent forestry roads.
Productive area: any area which is not defined as unproductive.
Total area: The total area which lies within the harvest perimeter and is also equal to unproductive area + productive area.

Unproductive Area Ratio: is defined as the unproductive area divided by total area expressed in percent.
Harvest area perimeter: this is defined as the connection of furthest points that within this area wood will flow to one of the selected landings. This is easily defined if the landings are within a newly regenerated forest, surrounded by mature (or different species) trees, however when the landings are surrounded by clear cut (or other circumstances) the harvest perimeter is found using professional judgement.
Landing area perimeter: This is defined as compacted area due to earthworks that is obviously been used as a landing. Where the boundary around the landing is blurred due to erosion, slash or other reasons, only the boundary of the compacted landing is found.
In the case of a road running through a landing the landing area **includes** the road going through it, however the road is only recorded as running up to the landing boundary (easily findable on GIS), and dues not run through it, and therefore the total unproductive area is not overestimated due to methodological error.
Permanent forestry road: is defined as a road which is the main access to skid/landing sites from public road networks or other skid/landings. This road must be permanent and therefore not replanted.
Regenerating Landing: is any landing that has a grid of trees that have been purposely planted.
Slash: is piles of tree stumps or branches dumped in a recognizable pile, which is connected to a landing.
Harvest System: the system employed to extract logs broken into two categories, ground based logging or cable based logging. Whichever system is believed to be have been used to extract greater than 50% of area will define the system for that map.
Crown cover: the degree to which the view of roads and landings is obstructed by crown cover, separated into three categories none, low/scattered or mid. Note: sites with high level of crown cover are rejected.

4.0 Critical Review of Literature: Productivity of Replanted Landings

Forestry landings are compacted prior to use in order to increase strength, minimising deformation under the large loads applied by heavy vehicles and logs during operation. Due to their compaction it is expected that growing on landing sites doesn't produce the same levels of growth as a normal density site. Replanted sites can be separated into two categories, rehabilitated and not rehabilitated. Rehabilitated sites are landings that have had efforts to improve soil conditions such as "tillage, topsoil conservation and replacement, and application of soil amendments" (Bulmer, C.E. and Krzic, M) or other efforts such as "winged subsoiling and grass/legume seeding" (Plotnikoff, M.R, Bulmer, C.E, Schmidt, M.G.). Most of the literature available on landing productivity was found in studies carried out in Canada, in particular British Columbia. For the scope of this study the productivity of landings is an important consideration when deciding whether to include regenerated landings in the calculation of productive area.

Rehabilitation programs were carried out in British Columbia in three forestry growing districts of Boundary, Kalum and Kispiox. The results of the efforts were analysed by more than one team and it was clear that the level of productivity on landings varied significantly.

In the Boundary district it was found that 5th year tree heights on landings were not significantly different to those in adjacent plantations. The growth increments in the 5th year were also similar. (Plotnikoff, M.R, Bulmer, C.E, Schmidt, M.G.). While in 1999 (Plotnikoff, M.R, Bulmer, C.E, Curran, C.) it was found that trees on the rehabilitated sites were growing as well if not better than trees on adjacent plantations.

In Kalum District landings with excess of 20% clay had "lower stocking densities, tree heights, and probe depths" (Plotnikoff, M.R, Bulmer, C.E, Schmidt, M.G.) compared to landings with less than 20% clay content. Trees growing on landings were 66% as tall as those growing on adjacent plantations (Plotnikoff, M.R, Bulmer, C.E, Curran, C.).

In Kispiox District the average 5th year heights and growth increments were lower on landings than on plantations. As with landings is Kalum, landings in Kispiox with excess of 20% clay had lower growth rates than that of landings with below 20% clay content. Of the three districts, Kispiox had the least probe (density test) depth and the greatest difference in height and increments between landings and plantations "supporting field reports of poor decompaction effectiveness there" (Plotnikoff, M.R, Bulmer, C.E, Schmidt, M.G.). A previous study (Plotnikoff, M.R, Bulmer, C.E, Curran, C.) showed that only trees on landings were only 51% as tall as trees on the adjacent plantation. The 2001 study (Plotnikoff, M.R, Bulmer, C.E, Schmidt, M.G.) concluded that "operationally feasible techniques for soil rehabilitation can create conditions suitable for establishment of a new forest on sites that otherwise would be considered non-productive", such as "Winged subsoiling and grass/legume seeding followed by planting of lodgepole pine(*Pinus contorta* var. *Latifolia)…",* which *"* …generally resulted in successful re-established of forest cover on landings."

In northern British Columbia it was found that six years after rehabilitation efforts were applied "60% of rehabilitated landing plots had more than 1000 stems ha–1, while 17% had fewer than 600 stems ha–1" (Bulmer, C.E. and Krzic, M). Therefore only around 60% of the landings that were being replanted would be considered of a similar productivity, in terms of stocking as other plantations. It was found that the"...average height of undamaged lodgepole pine trees on rehabilitated landings was consistently lower than for trees of the same age on plantations"(Bulmer, C.E. and Krzic, M).

In conclusion it is possible for a landing to have the same (or better) productivity than an adjacent stand, however the productivity of replanted landings varies significantly, improved drastically when there is low clay content and sufficient rehabilitation efforts. Due to the methods of samplings in this study, differentiating between successfully rehabilitated landings and just simply replanted landings or only partial rehabilitative efforts is impossible to identify. Therefore, because of the variability in growth on landings it would not be a fair representation of productive area to include replanted landings in this category outright, however there is some level of productivity and it would also not be a fair representation to include in unproductive area, and thus a sub category will be made for replanted landings which will be including in productive area but summarised in its own category.

5.0 Method

Computer Program Used for Sampling: GIS

For this project, GIS (ArcMap 10.1, Arc Catalog10.1) was used for the gathering of sample data. Google earth was a potential option, but the Google earth software needed to be brought, and the demo trial can only be used for seven days. Google earth however is good for scanning and locating harvesting sites. The aerial photos used to project onto GIS for analysis were acquired from LINZ Data Service.

All aerial photos and shape files, as well as any other layers were analysed after projecting the "NZGD 2000 New Zealand Transverse Mercator" coordinated system onto the layer.

Step 1: Choose Sample Plots

5.1 Amount of Samples Required For Confidence

For an unknown population, or in this case an unknown number of recently harvested forestry sites in the South Island, the following formula can be used to calculate how many samples will be required to gain a certain level of confidence, within a certain confidence interval:

$$n = \frac{z^2 \times p(1-p)}{d^2}$$

Where: n = sample size
z = z-value, dependant on confidence level, and summarised in table 1 below.
p = expected prevalence (as fraction of 1)
d = relative desired precision (confidence interval)

Level Of Confidence	Z - Value
80%	1.28
85%	1.44
90%	1.645
95%	1.96
98%	2.33
99%	2.58

Table 1: Z values associated with different confidence levels.

When expected prevalence is unknown (due to no previous data or other reasons) then the worst case scenario should be used, i.e. p=0.5, figure 1 on page 6, shows how the prevalence value chosen affects the number of samples required, in this case it is done for 95% confidence with a 10% interval, however the trend holds true for all confidence levels and intervals.

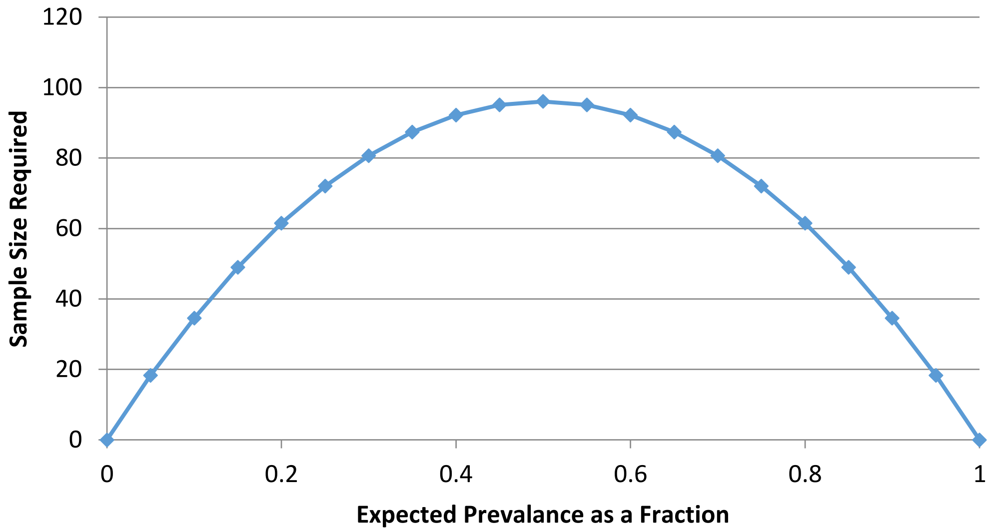


Figure 1: Effect of Prevalence on Sample Size Required

The table below summarise the number of samples required for different levels of confidence and within different confidence intervals for an unknown population size.

Number of Samples Required For Different Levels of Statistical Significance							
		Level Of Confidence:					
		80%	85%	90%	95%	98%	99%
	2.50%	655	829	1082	1537	2172	2663
Confidence Interval:	5.00%	164	207	271	384	543	666
	10.00%	41	52	68	96	136	166

Table 2: amount of samples required of an unknown population to gain a certain level of confidence with a certain confidence interval.

Due to time constraints, only a total of 41 samples were taken around the South Island giving an 80% level of confidence with a confidence interval of 10%. 30% by area of plantation forest within New Zealand are located in the South Island, if the same method was carried out for North Island it would result in 136 samples giving an overall confidence of 98% with a 10% interval.

The results must be representative of the South Island as a whole and therefore the number of samples in each region (as set by MPI) will be split based on the proportion of forest area in that region, summarised in table 3, page 7.

Region	Forest Area (Ha)	Share of South Island Total Plantation Area	Samples Required
Nelson/Marlborough	168600	32.74%	13
West Coast	32500	6.31%	3
Canterbury	110100	21.38%	9
Otargo/Southland	203800	39.57%	16
Totals:	515000	100.00%	41

Table 3: amount of samples required in each region of NZ to give an accurate representation of that region.

Choosing the sample plot has several important aspects that must be accounted for:

1) Firstly the area must not be too small, therefore the number of landings was defined as at least 8 which was expected to give a minimum harvest area of approximately 100ha, as found from a preliminary analysis.

2) Secondly, the forest must be reasonably young so that the crown cover of trees is not covering the roads and landings. Similarly the sample must not be so recently cut that the landing and road boundaries have become very blurred due to erosion and slash. As long as the sample does not have substantial crown cover or erosion on landings and roads, which will affect the reliability of the results, then the sample is acceptable on this basis.

Once a sample was identified the map was then extracted and projected so it can be used on GIS. The map was given a numerical name so that it is easier to keep track of which map is which. The location associated with the map number was also recorded in a spreadsheet.

<u>Step 2</u>: Identify the landings to be investigated.

This was done by choosing landings with the most easily identifiable harvest area (minimum of 8). The landing was defined as compacted soil, and therefore slash and other waste around the landing or eroded dirt form harvest operations was not including in the area as it will be more than likely re-established. Landing areas were recorded in two categories; clear landings and regenerating landings.

<u>Step 3:</u> Identify the Harvest Boundary

Ideally there was a section of regenerating forest which had been recently clear cut, surrounded by established forest, which made the harvest area and boundary easily identifiable. However, when this was not the case professional opinion is used to find the harvest area boundaries. The area contained within this boundary is defined as total forest area in the sample.

<u>Step 4</u>: Identify roads and road classes

Only roads that serve as access to landings for logging trucks were incorporated and therefore skid trails were intentionally excluded. Road classes were identified based on road width. Roads of uniform width were put into the same road class.

<u>Step 5</u>: Take width samples of road class

Width samples were taken approximately every 100 - 150m along each road class. If the visibility of small sections of roads was heavily obscured then the sample was taken up or down the road from this point in order to help give a more repressive average of road width, however care was taken not to be biased and samples were taken at regular intervals. The average road width of each road class was extracted to a spread sheet in order to calculate road buffer width. Only permanent roads were accounted for, i.e. skid trails are deliberately excluded.

Step 5: Using GIS to find Areas
GIS polygon tool was used to calculate landing areas as well as harvest area. The road lengths were calculated using the line tool and the area was found by creating a buffer around each road class. Roads on the edge of the harvest area were included if they serve as direct access to the harvest site, and the harvest site runs right up to the roads edge. The buffer width is equal to half the average road width, of the respective road class.

Step 6: Extracting and recording
After all areas were identified the following was extracted from GIS and recorded for later data analysis:
1) Region of Sample as well as exact location (longitude and latitude)
2) Total harvest area
3) Total landing areas
4) Number of landings
5) Road area
6) Harvest System Used
7) Crown Cover

5.2 Results from Preliminary Study

Sampler	Map #	Location	Roads	Landings	Total
Kurt:	1	Otago	1.00%	2.10%	3.10%
	2	Nelson	2.50%	2.44%	4.94%
	3	Tasman	2.22%	4.06%	6.28%
	4	Tasman	2.31%	2.56%	4.87%
	5	Malborough	1.78%	2.71%	4.49%
		Average:	1.96%	2.78%	4.74%

Table 4: Results from preliminary study.

6.0 Results and Discussion

6.1 Location of Samples

Maps were selected in each region, trying to spread the selections out where possible. The map below shows the location each sample was extracted from.

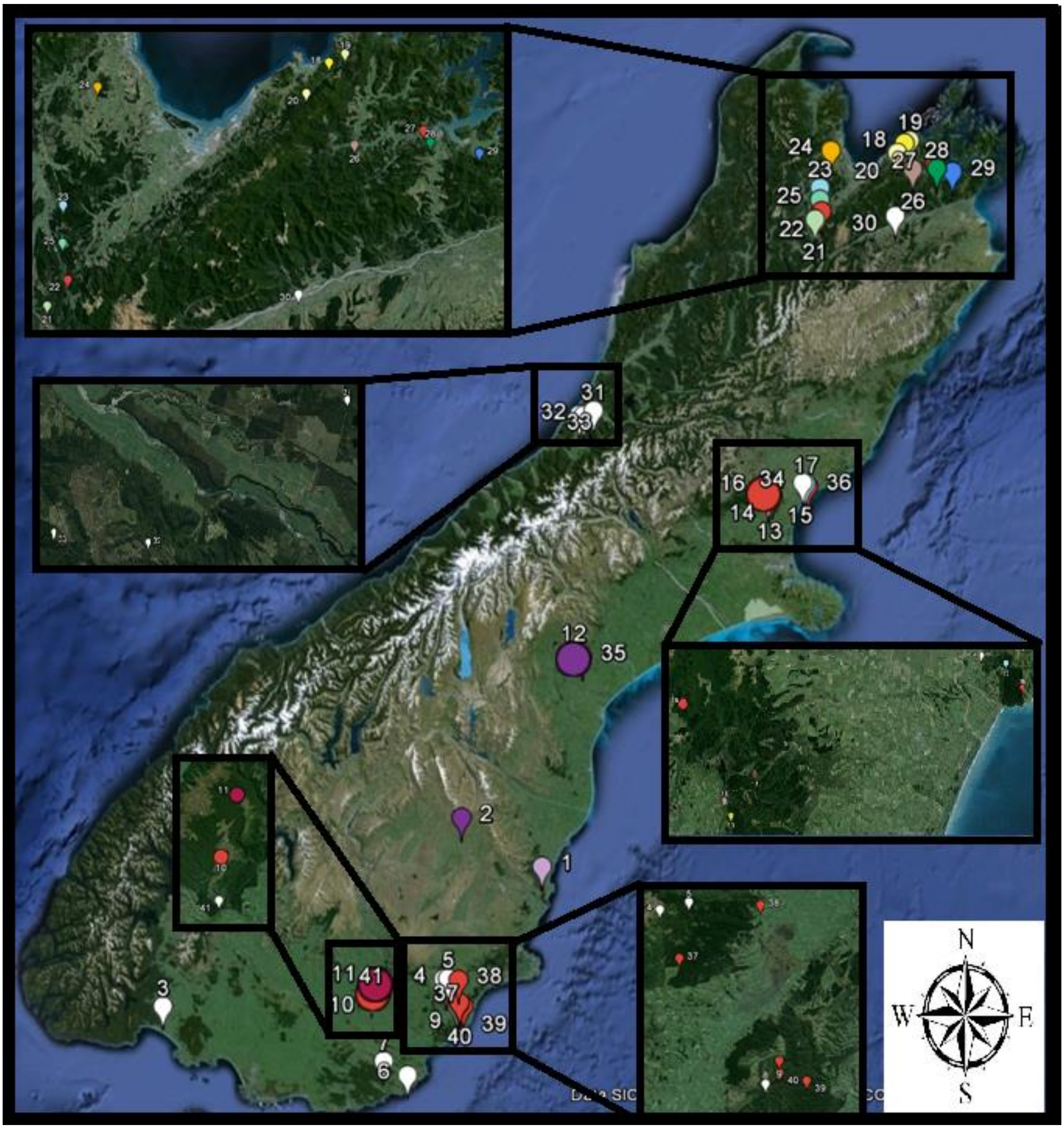


Figure 2: Map showing location where each sample was taken from. The amount of samples in each region is representative of the area of plantation forest in that region.

The data from the GIS study was analysed twice, first unproductive area was analysed assessing different models. It was found that the best model was a function of harvest area, which is expected. Second the unproductive area was analysed taking into account slash in order to see if slash plays a

significant part in unproductive area ratio.
It was found that the average amount of unproductive area in the South Island is 4.82% excluding slash and 5.09% including slash after outliers had been omitted from the average.
The unproductive area ratio excluding slash confirmed preliminary findings, and was also to close to the findings of Mabazza, A (2014, unpublished) in the North Island, found to be 4.2% with a similar mythology. The difference could be attributed different location, more cable logging occurring in the North Island or very possibly slight differences in personal interpretation of aerial photographs.

6.2 Statistical Analysis of Data: Excluding Slash

Data was statically analysed using IBM SPSS Statistics 2.0. Before a regression model could be built the outliners in the data needed to be omitted. The method for omission of outliers differs depending on the kind of distribution of data. The unproductive area ratio is expected to have a normal distribution; however this was first confirmed before proceeding. The histogram below shows the distribution frequency of unproductive area ratio. It can be seen that the distribution follows a relatively normal trend.

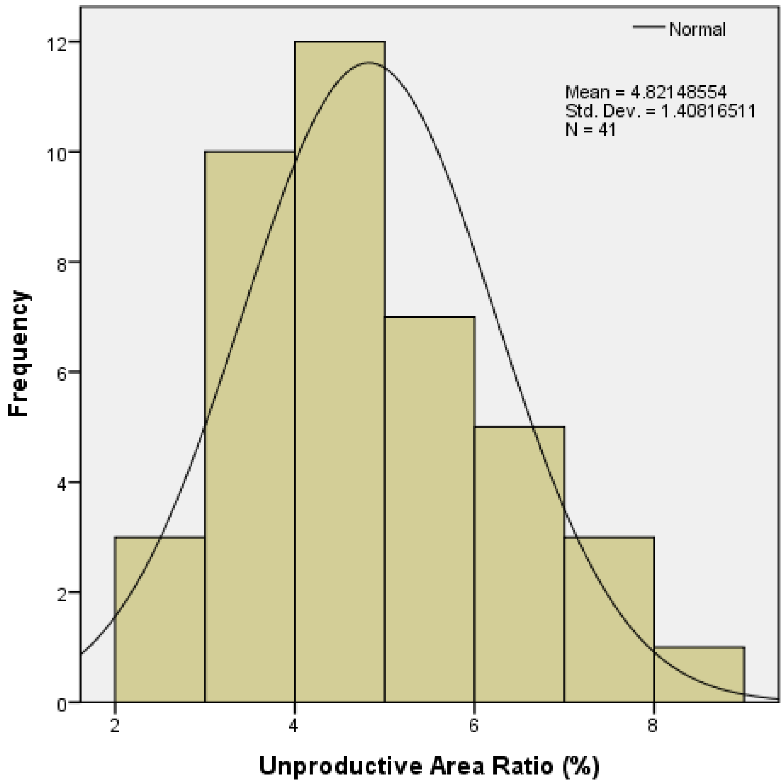


Figure 3: Histogram showing distribution of unproductive area ratio of the harvest sites sampled

6.2.1 Method for Defining Outliers

An outlier is defined using the Outlier Labelling Rule (Hoaglin, D. C., Iglewicz, B., 1987). Using this method the 75th and 25th percentiles (upper and lower quartiles) are found and the difference is multiplied by a factor (g), added and subtracted from the mean to find the upper and lower demarcation limits. The 25th and 75th percentiles were found to be 3.8% and 5.7% respectively. This shows that 50% of the observed unproductive ratios fell within a 1.8% range.
Using a g-factor of 2.2 as described by (Hoaglin, D. C., Iglewicz, B., 1987) as best practice when dealing with small samples size, the lower and upper demarcation points were found to be -0.2% to 9.7%. A negative limit is not possible in this case; therefore it was set to zero. It was found that all points fell within these limits.
In this case the demarcation points are unpractical, as obviously some infrastructure (unproductive area) is required to extract trees. Previous to the release of this paper, and still common practice by many statisticians a g-factor of 1.5 is used. This gave more practical upper and lower demarcation points of 8.4% and 1.1% respectively. Using this factor all points still fall within the upper and lower limits. The plot below shows the unproductive ratios found from the investigation.

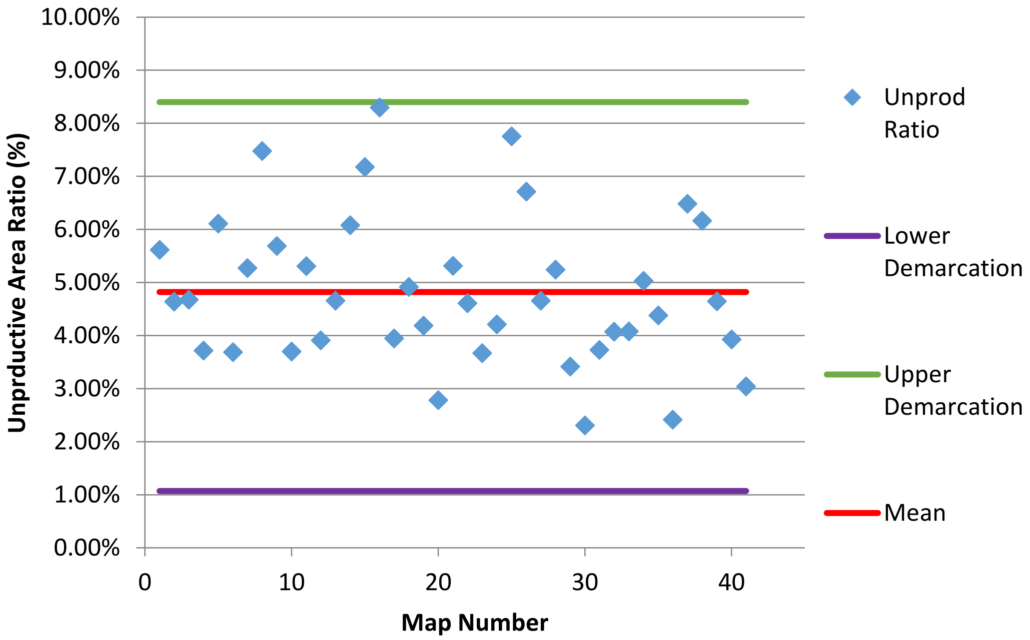


Figure 4: Scatterplot show unproductive area ratio against map (sample) number. Upper and lower demarcation points as well as the mean are shown.

Map 16 almost exceeds the upper limit with an unproductive ratio of 8.29%. Map 16 can be seen in the Maps section on page 23. Observing the map it can be seen that the north western landing is very large, most likely due to it being used as a cable yarding landing and the yarder being moved down the landing, to get trees in the valley. Potentially logs were processed at the landing as they were dropped by the cable yarder. Using skid vehicles to transport logs from the yarder to a central processing area could have resulted in a much smaller landing. Yarding rigging configurations with a wider corridor could have also improved unproductive area ratio by decreasing the number (or width) of landings required. This is because rigging configurations that allow lateral movement such as North bend mean that the yarder doesn't physically have to be moved as much as it has I wider corridor. The roads on this site are also rather wide which contributed further to unproductive ratio. Although this map seems unrepresentative of the average harvest site in the South Island it cannot be rejected on these grounds alone as it doesn't exceed the upper demarcation point, and therefore would be bias to aim of the investigation.

6.2.2 Linear Regression of Sample Data

When analysing statistical significance the following table defines interpretation of p-value (significance).

Interpretation of P-Value	
P>0.10	Not Significant
P<0.10	Marginal
P<0.05	Fair
P<0.01	Good
P<0.001	Excellent

Table 5: interpretation of p-values for significance.

A linear regression was carried out to model unproductive ratio as a dependent variable and harvest area, harvest system, region and crown cover as independent variables. Each category of harvest system (cable or ground), region (Canterbury, West Coast, Otargo/Southland and Nelson/Marlborough) and crown cover (none, low/scattered, mid) was broken down into their respective sub categories and given a logical (Boolean) variable with 1 representing true and 0 for false.

The regression excluded all variables apart from harvest area. The model was found to have a significant F-static but an adjusted r^2 of only 0.115. The model found that total harvest area was significant to a p-value of 0.017, which is consider fair and a p-value of $4.72x10^{18}$ for the constant (6.178) which is excellent. The regression gave the following model below, equation 1. The upper and lower bounds were added due to uncertainty of behaviour beyond these points.

$$Uproductive\ Area\ (\%) = 6.178 - 0.008\ (HarvestArea) \qquad (1)$$

For, 80 < Harvest Area (Ha) < 300

The model will therefore accurately predict the unproductive area ratio based on harvest area alone just 13.7% of the time. The summary of the SPSS output can be found in the appendix under section 10.4, page 33. Figure 5 on the following page shows harvest area vs unproductive area ratio.

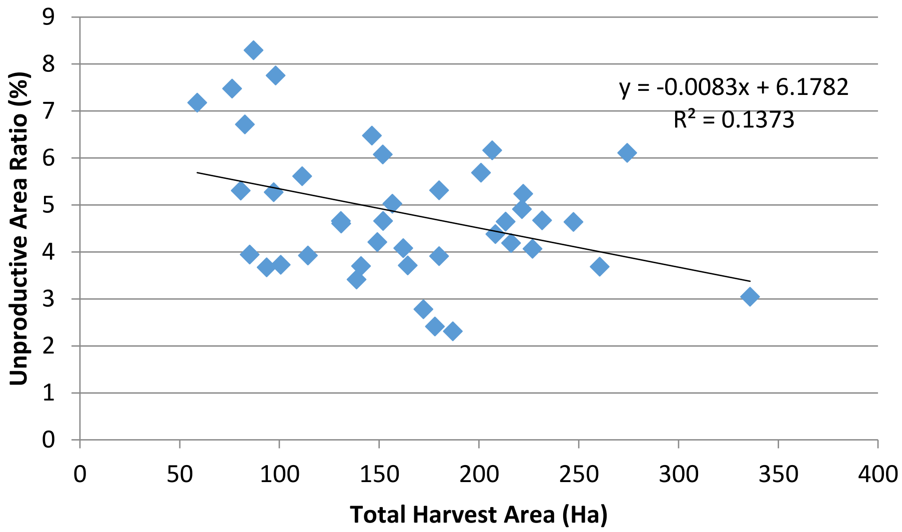


Figure 5: Efficiency of Land Use: Scatterplot showing unproductive area ratio against total harvest area.

In order to find a better model a regression of unproductive area dependant on harvest area, location, harvest system and crown cover was tested. The model again rejected location, harvest system and crown cover. The F-statistic for the model has an excellent significance (<0.001). Total harvest area had excellent significance but the constant was marginal with a significance of 0.073. The regression gave the following model below:

$$Unproductive\ Area\ (Ha) = 1.625 + 0.036\ (Harvest\ Area\ (Ha)) \qquad (2)$$

For, 80 < Harvest Area (Ha) < 300

The model will therefore predict the unproductive area in hectors based on total harvest area alone 57% of the time, with reasonable significance. The SPSS regression outputs for the model can be seen in the appendix under section 10.5, page 35. Figure 6 below shows unproductive area plotted against harvest area.

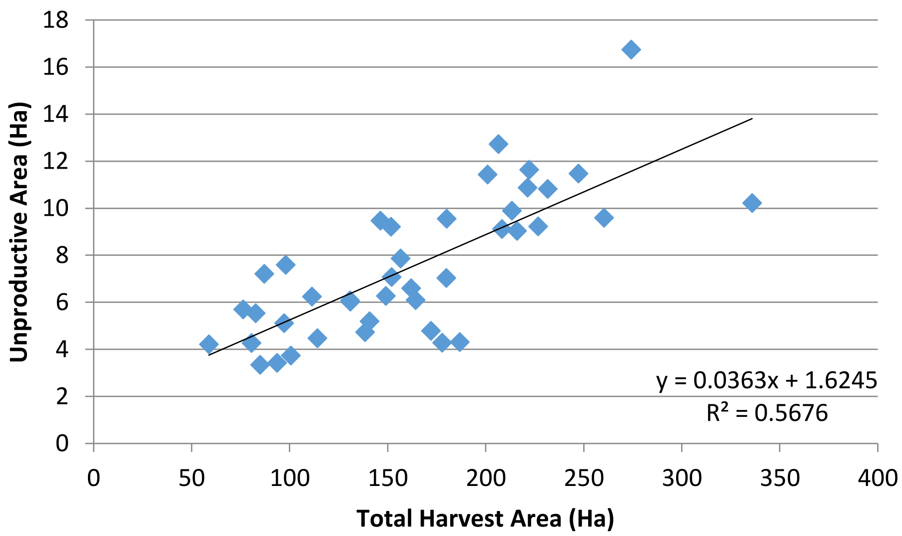


Figure 6: Relationship between total harvest area observed from harvest site and unproductive area.

Unproductive area would be expected to increase as harvest area increases, the constant in the equation accounts for smaller plots having proportionally larger unproductive areas; this could be partly due to minimum spatial requirements for log processing. Upper and lower limits have been placed on both equations as the behaviour of the curve beyond these limits is unknown.

There must be a lower limit associated with unproductive area ratio; this could potentially be at the lower end of the proposed normal distribution, which is expected to be around 1-2%. Similarly an upper limit of around 8% is expected.

Observing the prediction chart on page 13 it appears that the plotted data points are creating an envelope that converges to a central point of 1.6ha on the unproductive area axis. The lower limit of the envelope could potential represent the change in unproductive area with harvest area following the most efficient practices, while the upper limit could represent inefficient practice. However in reality there is likely to be other factors influencing such as harvest system, density of volume per unit area, productivity requirements or log sorts.

6.3 Statistical Analysis of Data: Including Slash

The same approach as part 6.2.1 was taken to define outliers. Again the distribution was confirmed to be normal and the upper and lower quartiles found in order to define demarcation points, using a g factor of 1.5 as with before. Below is a histogram showing the initial distribution before outliers are omitted. It can be seen that it is relatively normal however there is a cluster of data that is far above the mean. This suggests that perhaps slash doesn't help to make the unproductive area ratio distribution more normal as first hypothesised.

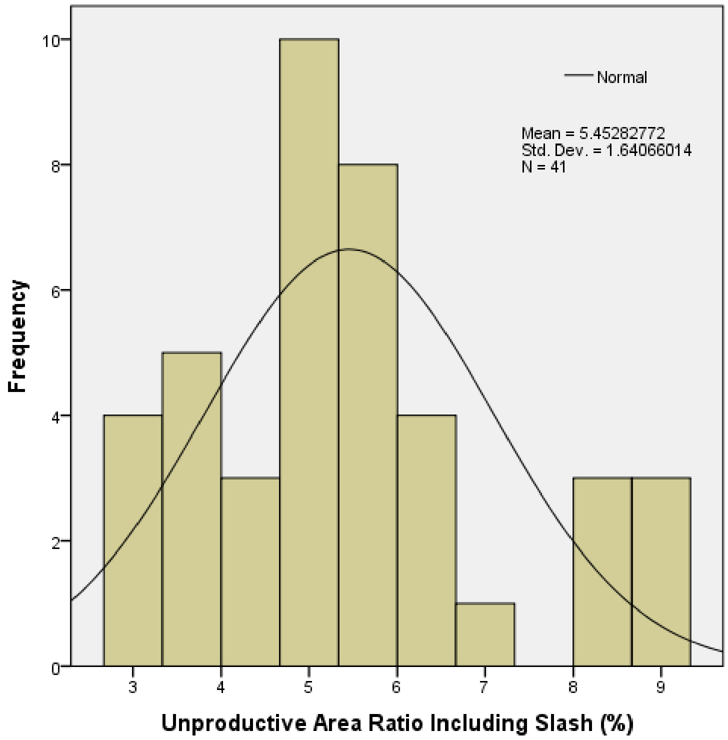


Figure 7: Histogram showing distribution of unproductive area ratio (including slash) of the harvest sites sampled

Plotting unproductive ratio with demarcation points produces the following graph. It can be seen that there are four points above the upper demarcation limit, these points were omitted.

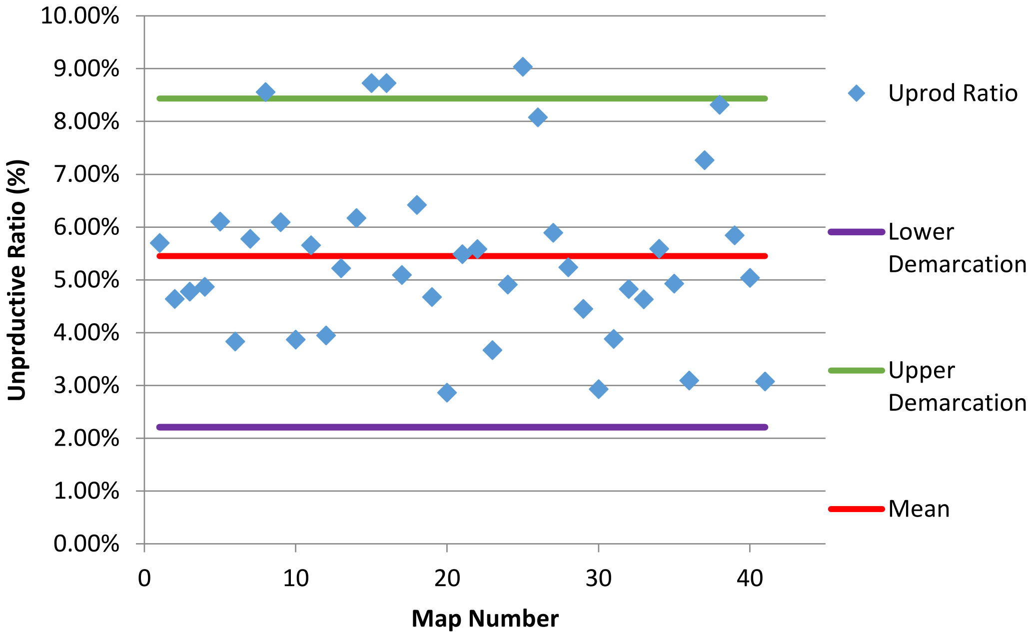


Figure 8: Scatterplot show unproductive area ratio (Including Slash) against map (sample) number. Upper and lower demarcation points as well as the mean are shown.

Re-plotting produces the histogram below. The histogram is taking on a more normal distribution; however, there are gaps in what would be expected to be a bell curve.

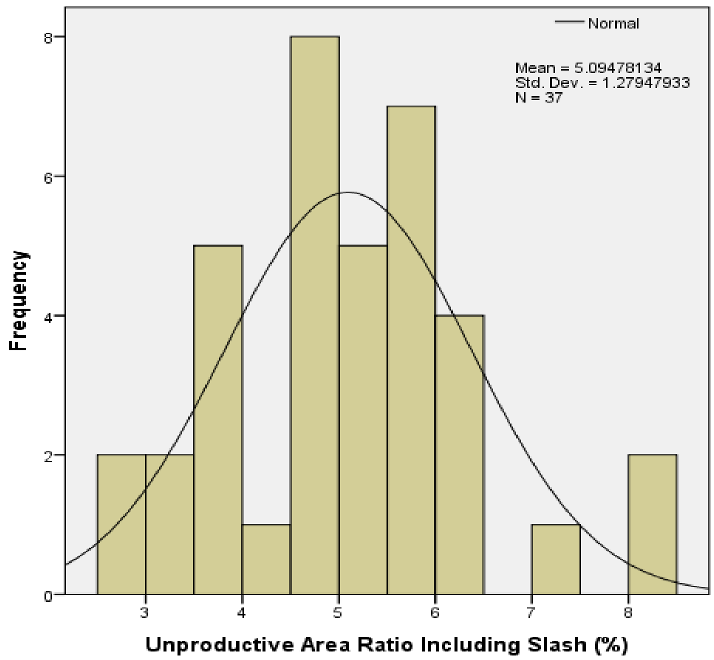


Figure 9: Histogram showing distribution of unproductive area ratio (including slash) of the harvest sites sampled after outliers have been omitted.

6.3.1 Linear Regression of Data

A linear regression of the data was carried out with the same approach as part 6.2.2. Including slash into the unproductive area resulted in lower adjust r^2 values for unproductive area including slash ratio, however statistical significance could not be found for either regression, and therefore the models are rejected. Omitting outliers meant that there was a decrease in sample size allegeable for regression. This coupled with an already relatively weak relationship between variables is believed to be the cause of for the large drop in statistical significance.

The following two graphs show the plotted findings when slash is included in unproductive area, with outliers omitted.

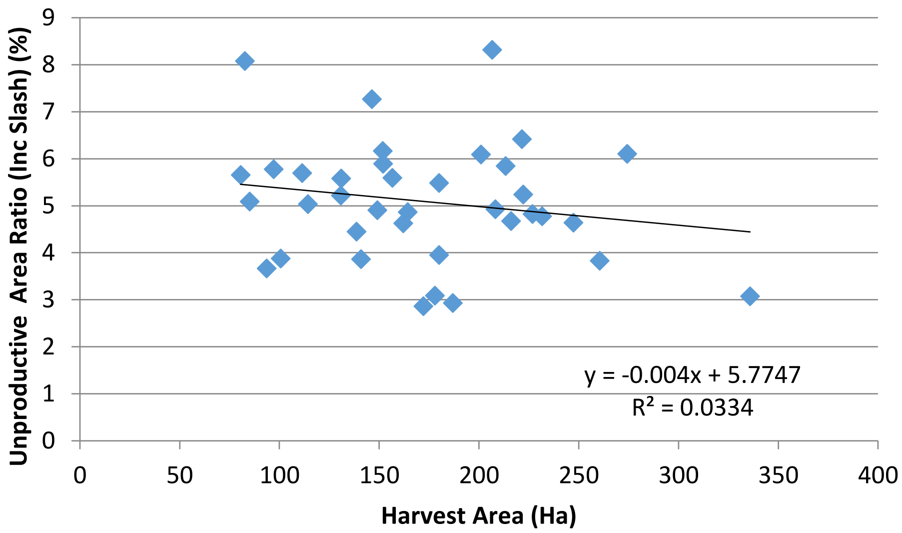


Figure 10: Efficiency of Land Use: Scatterplot showing unproductive area ratio (including slash) against total harvest area.

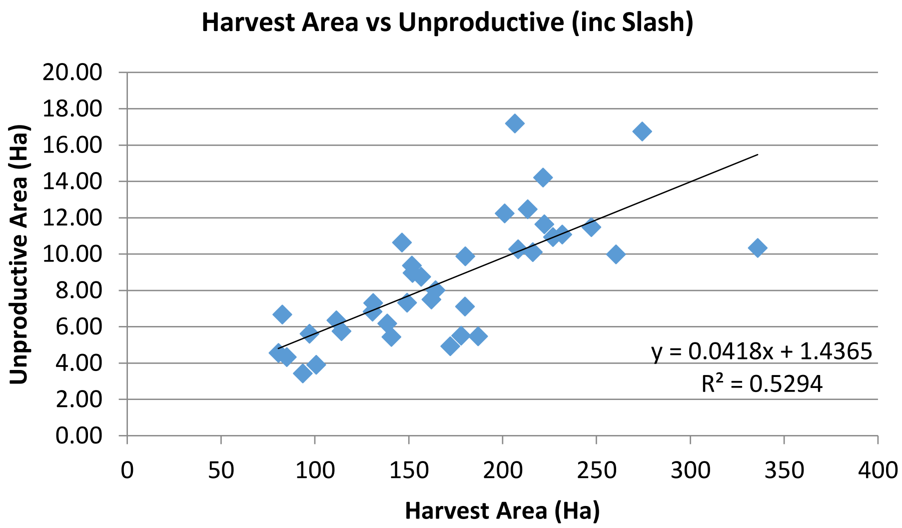


Figure 11: Relationship between total harvest area observed from harvest site and unproductive area (including slash).

6.4 Comparison of Results With Previous Publications

There have been no previous publications quanitifying the net amount of unproductive area in NZ platation forests, however there has been several studies on landing size. For example Raymond, K. A. (1987) found that there was a varience of landing sizes throughout different regions in NZ. Landing were different sizes depending on loader operated, log sorts produced as well as construction costs. If construction costs are high then there is a stronger motive to keep landings small. Construction costs on soils such as clay types can require stabilisation and this increases constructions costs significantly.

A general overview of the findings is that the average landing size was around 0.2-0.25 Ha, the range followed a normal trend ranging from 0-0.4 (ha).

Figure 12 below shows the distrubution of average landing sizes found in this study. The outlier calcualtions was done using a g-factor of 2.2 in this case, all values fell within the upper and lower demacation points. It can be seen on figure 12 that there is a normal distrubution with a mean of 0.31 Ha. This average is slighty higher than the findings of Raymod, K. A (1987), however it is certainly a reasonable figure, given the small sample sizes in both studies, varriation of locations and the amount of time between studies.

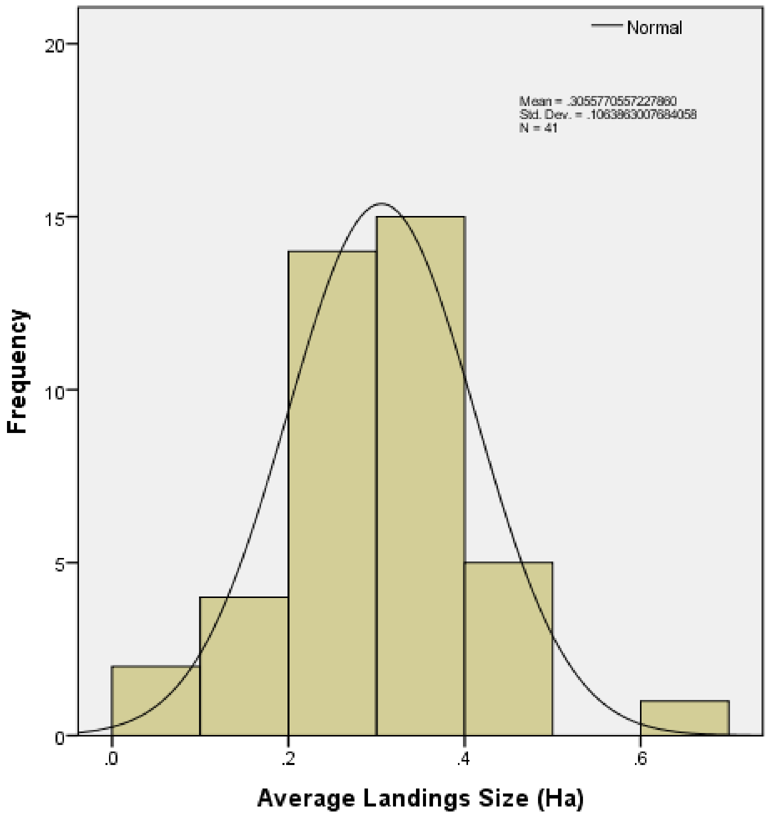


Figure 12: Histogram showing distribution of average landing size of each harvest site sampled.

Larger landing areas could also be attributed to the relativily huge drop in log prices since 1987 (when the study was carried out). A larger landing size is required for higher producitity and more complicated log sorts. With a lower log prices, value optimastion (log sorts) and productivity with low extraction costs has becomes more critical.

7.0 Conclusion

The aim of this study was to assess unproductive area as a proportion of productive area. This was done it two ways, firstly the average ratio of unproductive area of harvest sites within the South Island was found with predetermined levels of confidence, and secondly to incorporate different variables into a model that allows one to find expected unproductive area based on the influence of these variables.

An average unproductive area was successfully found to be 4.82% of harvest area for the South Island. This average is found with 80% confidence and a 10% confidence interval. When incorporating slash area as unproductive it was found that there was 5.09% (outliers omitted) unproductive area on average.

Two limited models were constructed that allow prediction of unproductive area based on harvest area alone. The first model had high significance but very low accuracy. This negative correlation could potentially be an exaggerated effect due to the methodology used for unproductive area selection and sample size. As part of the method, when including roads running along the boundary of a harvest site, the road is included, if it serves as access to the harvest sight and the harvest area runs up to the edge of the road (e.g. map 12). With smaller sites it's possible that the boundary roads contributed a significant amount to unproductive area and therefore exaggerated the effect. For very small sites it is expected that unproductive area would be relatively large due to minimum spatial requirements for operation, however the methodology tried to eliminate this effect coming into play by stating a minimum of 8 landings, which was believed to be around 100ha form preliminary results, however it was later confirmed that this was closer to 70-80ha in many cases.

The second model has reasonable significance and moderate accuracy, being accurate 57% of the time. The regression confirmed that harvest area is an extremely significant variable in not only total unproductive area but also the unproductive area ratio, which suggests that the efficiency of land use increases as harvest area increases.

Harvest system, harvest region and crown cover were not able to be incorporated into the models as variables. Harvest system was expected to be variable in both models however, this was not the case. With more samples potentially these variable may be able to be incorporated into a model.

It is also likely that there are other contributing variables that have not been accounted for, such as types and sizes of machines, log sorts cut and size and experience of logging crews operating and harvest planners designing the extraction process.

The study is a post-harvest analysis with no information on the stand harvested and could therefore be misleading in some cases as it doesn't take into account the density of volume in the area and therefore level of wood flows going to the landing. Only harvest area alone is taken into account.

The investigation is also limited as it is a snapshot approach. As an example in some cases roads that are used to extract volumes from other parts of the forest such as arterial roots may be wider to allow for higher density traffic. The additional volume running through the site isn't accounted for, and as a result the unproductive area ratio for the site is higher, which doesn't necessarily reflect efficiency of land use in the forest.

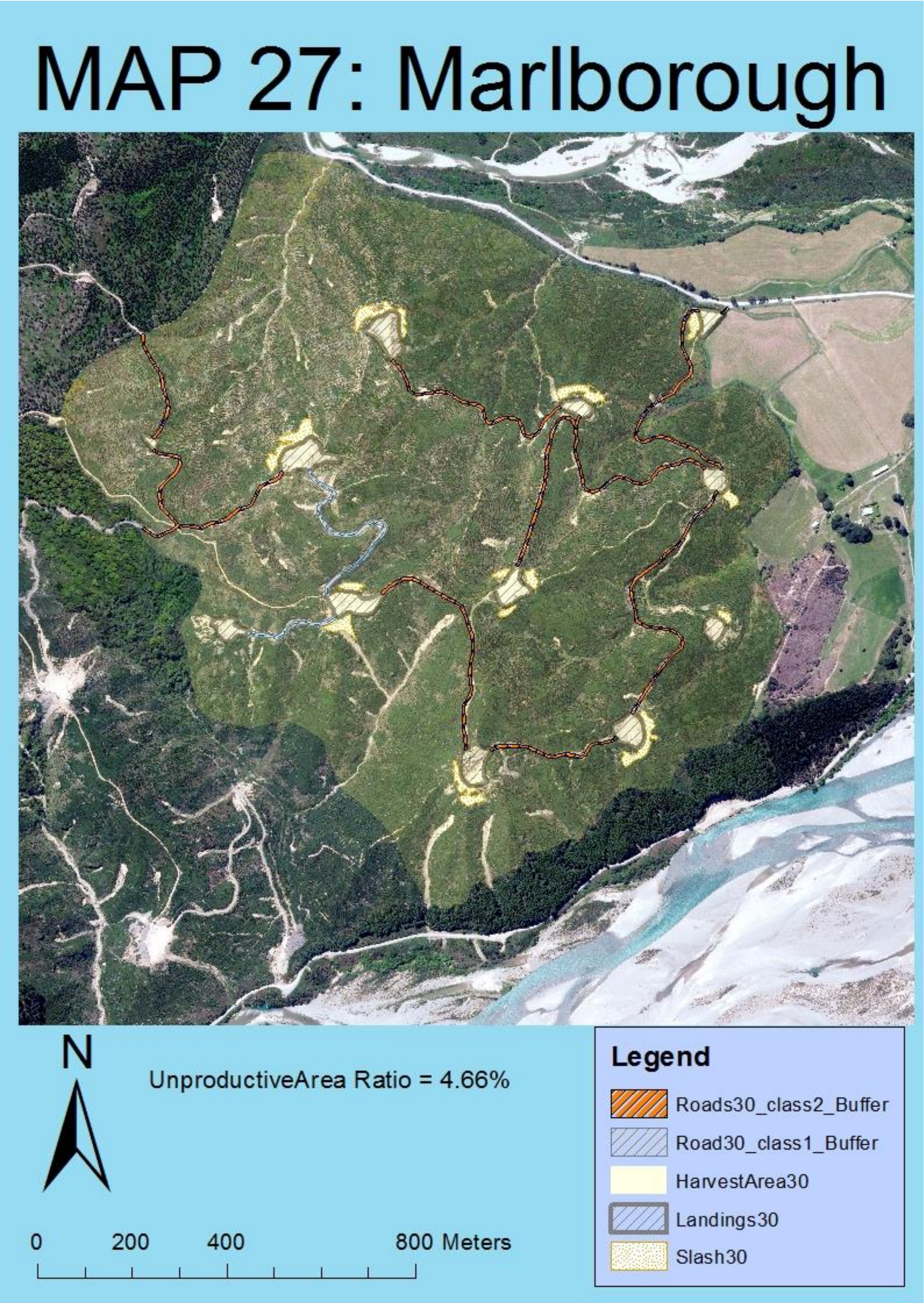
In conclusion the models found are very limited and comprehensive information about the stands cut would be required to build a reliable model.

The average unproductive area ratio found of 4.8% is very reasonable when comparing with Mabbazza, A (2014, unpublished), which found 4.2% for the North Island, and considering the average landing sizes found also fell within the ranges found in previous studies in NZ.

In order to gain true perspective on unproductive area more samples are required. It would be expected that with sufficient samples an almost prefect normal distribution could be reached. From figure 3 (page 10) it can be seen that the distribution is normal, however due to a small sample size there is gaps in this distribution.

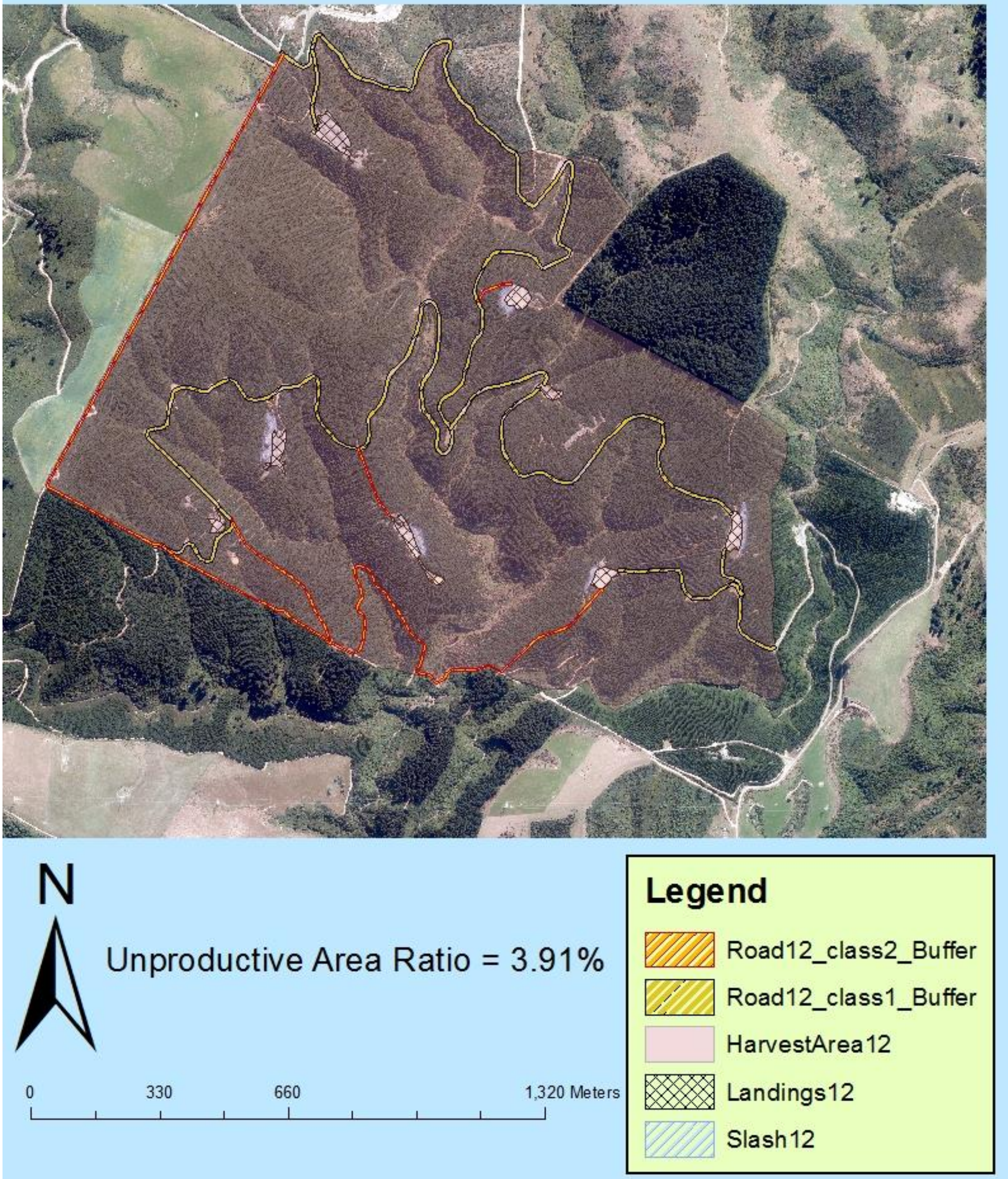
In conclusion the true unproductive area ratio is expected to be around 4-5% of total harvest area on average.

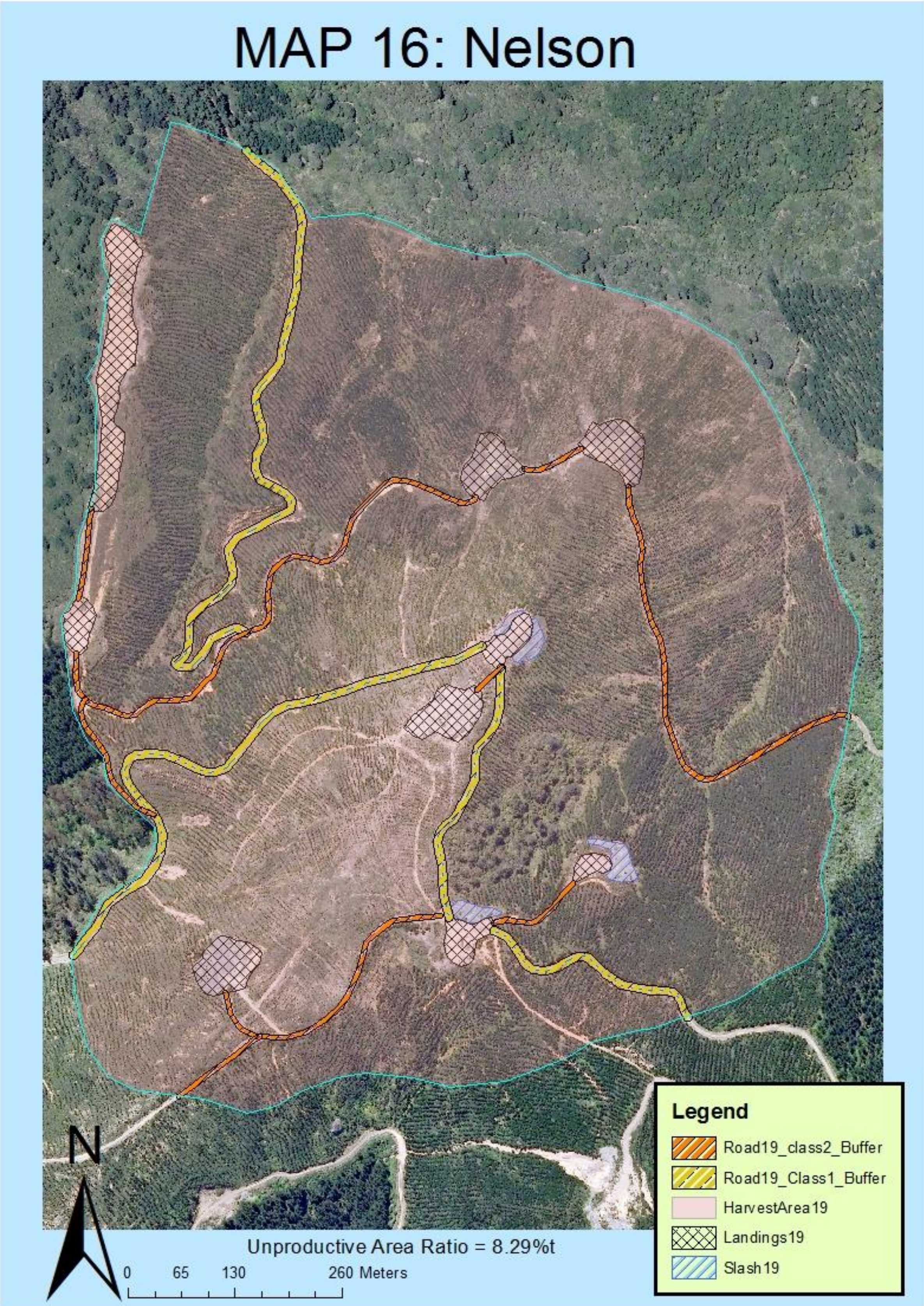
8.0 Example Maps



MAP 13: Canterbury

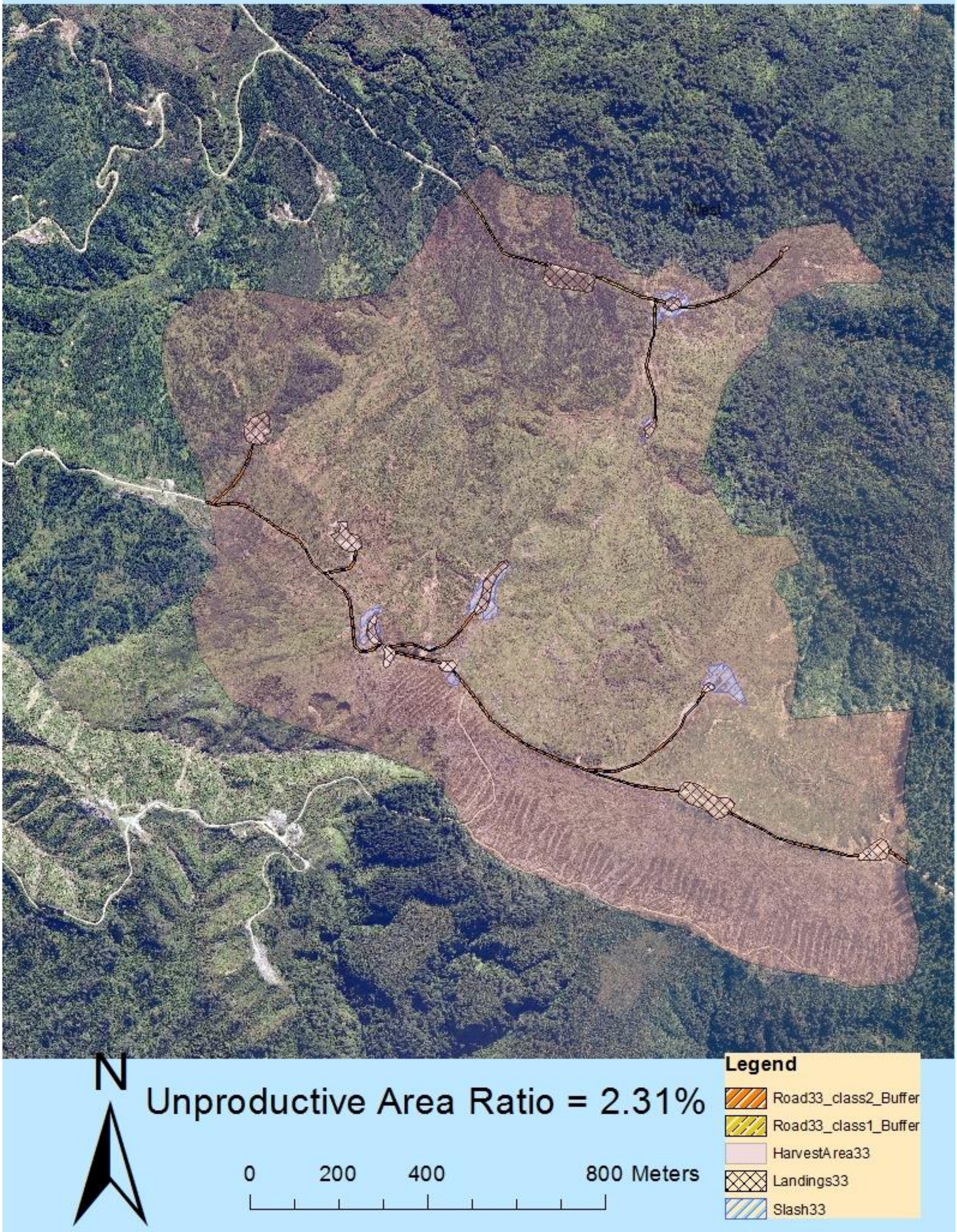
Map 12: Canterbury

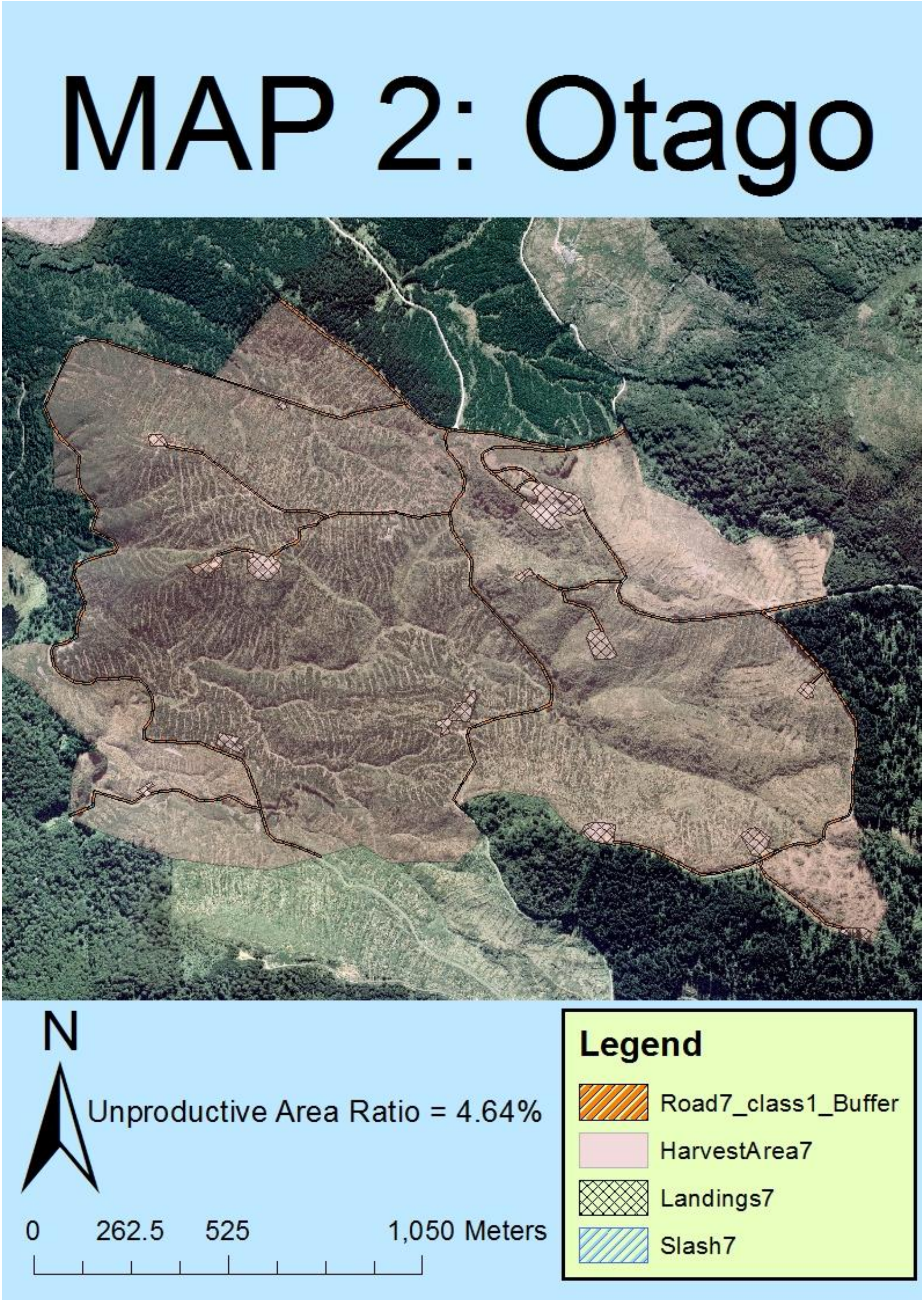


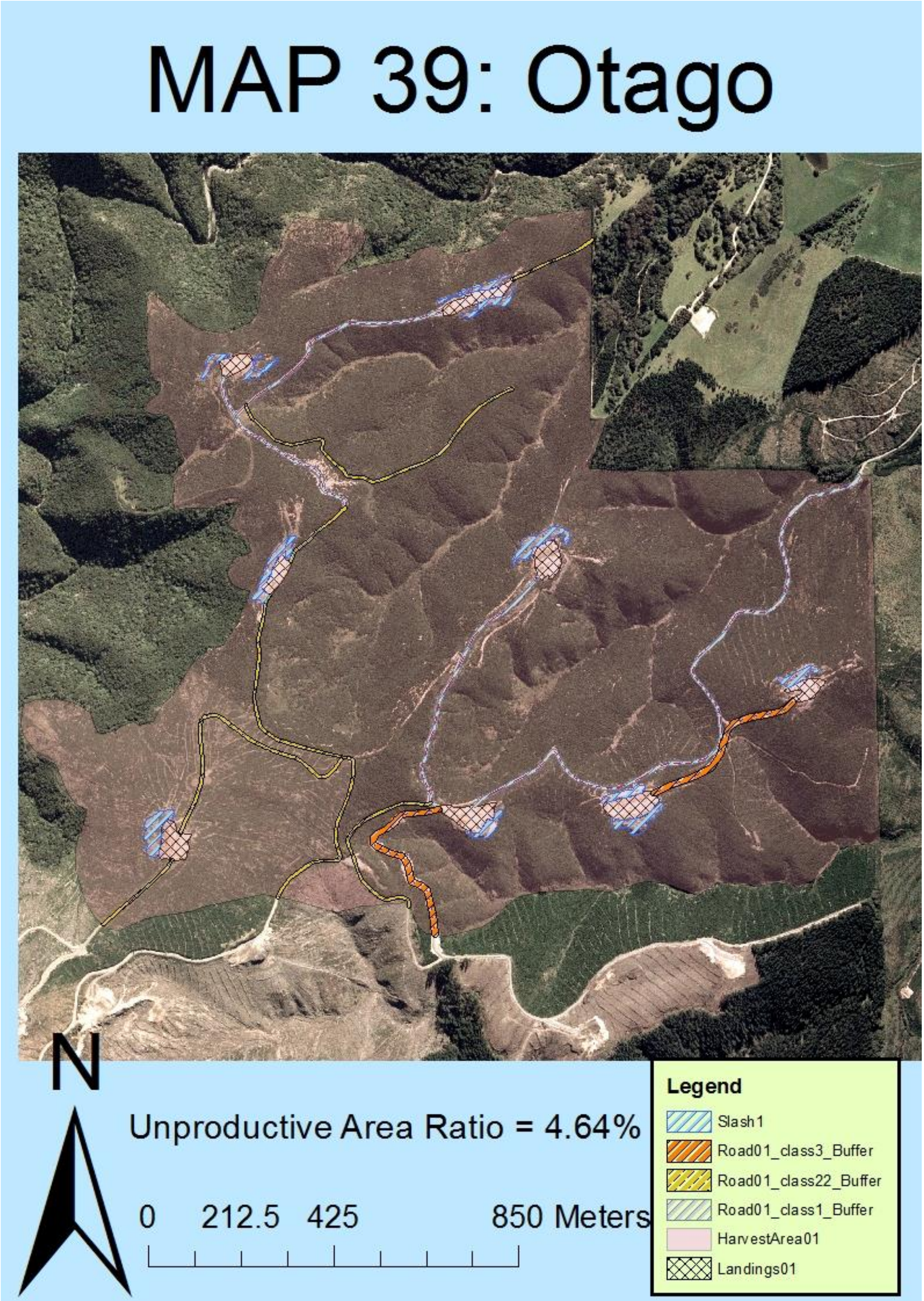


MAP 16: Nelson
Legend
Road19_class2_Buffer
Road19_Class1_Buffer
HarvestArea19
Landings19
Slash19
N
Unproductive Area Ratio = 8.29%t
0
65
130
260 Meters

MAP 30: West Coast

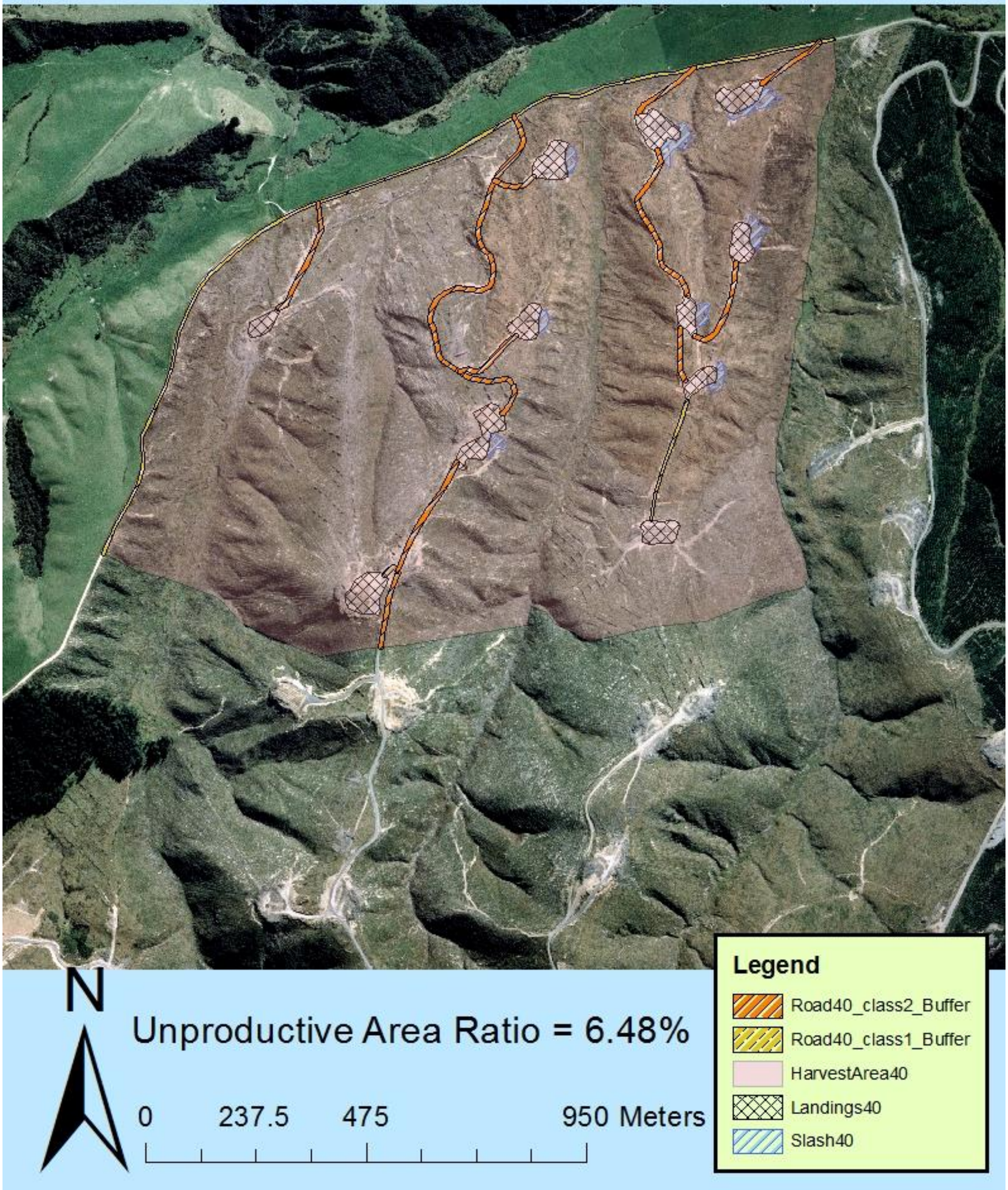


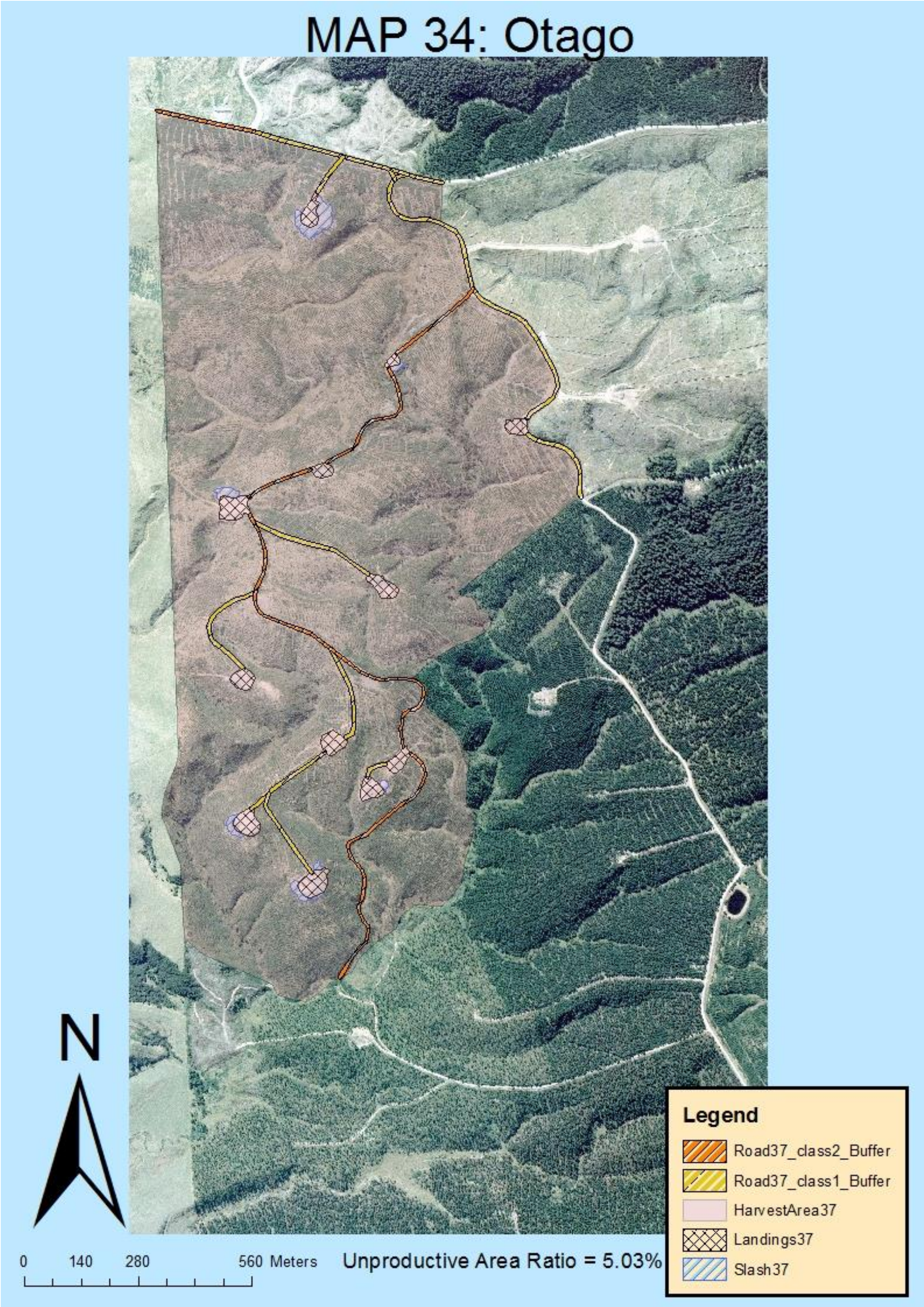

MAP 2: Otago
N
Unproductive Area Ratio = 4.64%
0
262.5
525
1,050 Meters
Legend
Road7_class1_Buffer
HarvestArea7
Landings7
Slash7



Note: not a mistake that both map 39 and 2 have same unproductive area ratio of 4.64% refer to appendix.

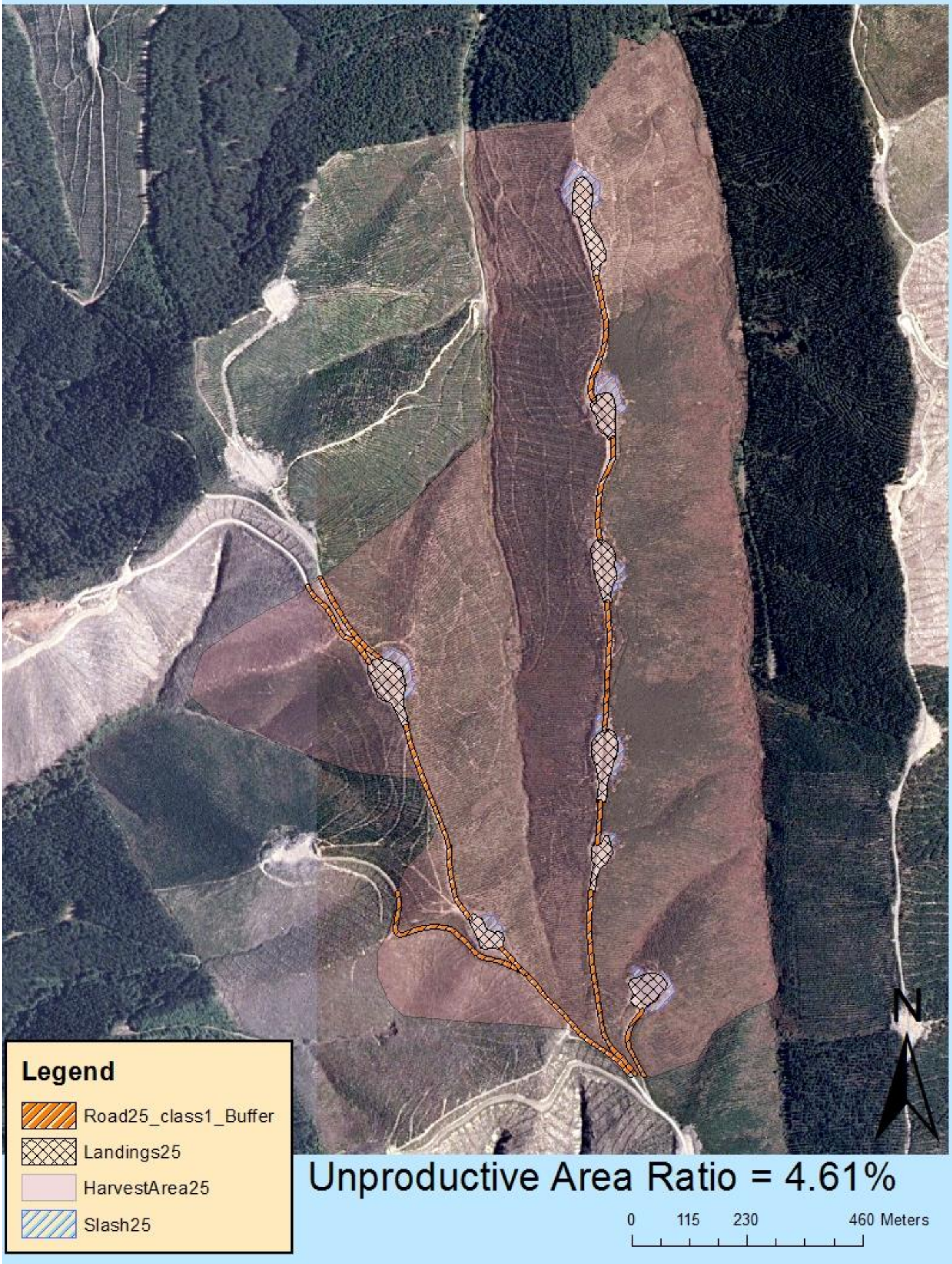
MAP 37: Otago


N
Unproductive Area Ratio = 6.48%
0
237.5
475
950 Meters
Legend
Road40_class2_Buffer
Road40_class1_Buffer
HarvestArea40
Landings40
Slash40



MAP 34: Otago
N
0
140
280
560 Meters
Unproductive Area Ratio = 5.03%
Legend
Road37_class2_Buffer
Road37_class1_Buffer
HarvestArea37
Landings37
Slash37

MAP 22: Tasman



9.0 References

-Bulmer, C.E. and Krzic, M (29/5/04) *"Soil properties and lodgepole pine growth on rehabilitated landings in northeastern British Columbia"*
-Plotnikoff, M.R, Bulmer, C.E, Schmidt, M.G. (28/5/01) *"Soil properties and tree growth on rehabilitated forest landings in the interior cedar hemlock biogeoclimatic zone: British Columbia"*
- Plotnikoff, M.R, Bulmer, C.E, Curran, C. (September 1999) *"Forest Productivity and Soil Conditions on Rehabilitated Landings: Interior British Columbia"*
-Hoaglin, D. C., and Iglewicz, B. (1987), Fine tuning some resistant rules for outlier labeling, Journal of American Statistical Association, 82, 1147-1149.
-Ministry for Primary Industries (MPI), *Facts & Figures* (2012/2013)
-Raymond, K. A, (1987) *Factors influencing landing size* NZ Logging Industry Research Assoc. Inc

10.0 Appendix

10.1 Raw Values

			………………….Roading…………………..			………Landings ………		
MAP Number	Location	GIS Number	Total Area Harvested (ha)	Length of Roads (km)	Area Roads (ha)	Area Normal (Ha)	Area Regen (Ha)	Slash Area (Ha)
1	Otago	6	111.38	4.74	3.20	1.73	1.33	0.10
2	Otago	7	247.23	10.81	6.73	4.74	0.00	0.00
3	Otago	8	231.64	6.41	5.75	5.07	0.00	0.25
4	Otago	9	164.28	3.08	2.62	3.49	0.00	1.90
5	Otago	10	274.24	9.27	10.93	5.82	0.00	0.00
6	Otago	11	260.39	4.86	4.85	4.75	0.00	0.39
7	Otago	4	97.08	2.55	1.68	3.44	0.00	0.49
8	Otago	5	76.19	2.50	2.03	1.83	1.83	0.82
9	Canterbury	12	200.99	11.10	9.04	2.39	0.00	0.81
10	Canterbury	13	140.75	4.50	3.40	1.80	0.00	0.24
11	Canterbury	14	80.49	2.46	1.70	2.57	0.00	0.28
12	Canterbury	15	179.89	4.92	3.58	3.46	0.00	0.07
13	Canterbury	16	130.70	4.86	3.17	2.92	0.00	0.73
14	Canterbury	17	151.67	5.99	4.04	4.03	1.15	0.14
15	Nelson	18	58.78	3.97	2.65	1.57	0.00	0.91
16	Nelson	19	86.98	4.56	3.82	3.39	0.00	0.38
17	Nelson	20	84.94	3.49	2.33	1.02	0.00	0.98
18	Tasman	21	221.41	8.28	6.62	4.26	0.00	3.33
19	Tasman	22	215.96	6.87	4.69	4.36	0.00	1.06
20	Tasman	23	172.09	2.45	1.92	2.87	0.00	0.14
21	Tasman	24	180.00	9.31	6.90	2.67	0.00	0.31
22	Tasman	25	130.95	2.87	2.74	3.30	0.00	1.28

23	Tasman	26	93.53	4.33	2.36	1.07	0.00	0.00
24	Marlborough	27	149.06	5.27	3.68	2.31	0.28	1.04
25	Marlborough	28	97.97	4.65	3.61	3.99	0.00	1.25
26	Marlborough	29	82.62	2.96	2.90	2.65	0.00	1.13
27	Marlborough	30	151.91	4.82	3.25	3.82	0.00	1.88
28	WestCoast	31	222.18	7.30	5.53	6.11	0.00	0.00
29	WestCoast	32	138.51	4.24	2.31	2.42	0.00	1.44
30	WestCoast	33	186.80	3.42	1.68	2.63	0.00	1.17
31	Canterbury	34	100.60	3.71	2.09	1.66	0.00	0.16
32	Canterbury	35	226.71	8.06	7.15	2.08	0.00	1.72
33	Canterbury	36	161.96	5.54	3.70	2.91	0.00	0.89
34	Otago	37	156.58	5.67	4.90	2.98	0.00	0.89
35	Otago	38	208.24	7.62	6.13	3.00	0.00	1.14
36	Otago	39	177.81	3.72	3.15	1.14	0.00	1.21
37	Otago	40	146.24	5.27	4.85	4.63	0.00	1.16
38	Otago	41	206.53	7.81	8.27	4.46	0.00	4.46
39	Otago	1	213.29	7.50	6.62	3.28	0.00	2.57
40	Otago	2	114.12	4.31	2.37	1.93	0.18	1.27
41	Otago	3	335.88	9.37	5.60	4.28	0.34	0.12

10.2 Totals

			UNPRODUCTIVE	
MAP Number	Total Area (ha)	Total Landing Area Inc Slash (Ha)	Total Unproductive (Ha)	Total Unproductive Including Slash (Ha)
1	3.05	3.15	6.25	6.35
2	4.74	4.74	11.47	11.47
3	5.07	5.33	10.82	11.08
4	3.49	5.39	6.10	8.00
5	5.82	5.82	16.75	16.75
6	4.75	5.14	9.60	9.99
7	3.44	3.93	5.12	5.61
8	3.67	4.49	5.70	6.52
9	2.39	3.20	11.43	12.24
10	1.80	2.04	5.20	5.44
11	2.57	2.85	4.27	4.55
12	3.46	3.53	7.04	7.11
13	2.92	3.66	6.09	6.82
14	5.18	5.32	9.22	9.36
15	1.57	2.48	4.22	5.13
16	3.39	3.77	7.21	7.60
17	1.02	2.00	3.35	4.33
18	4.26	7.60	10.88	14.22

19	4.36	5.42	9.04	10.10
20	2.87	3.00	4.79	4.93
21	2.67	2.98	9.56	9.88
22	3.30	4.57	6.03	7.31
23	1.07	1.07	3.43	3.43
24	2.60	3.64	6.28	7.32
25	3.99	5.25	7.60	8.85
26	2.65	3.77	5.55	6.68
27	3.82	5.70	7.08	8.96
28	6.11	6.11	11.64	11.64
29	2.42	3.86	4.73	6.17
30	2.63	3.80	4.31	5.48
31	1.66	1.81	3.75	3.90
32	2.08	3.79	9.23	10.94
33	2.91	3.80	6.61	7.50
34	2.98	3.86	7.87	8.76
35	3.00	4.14	9.12	10.27
36	1.14	2.35	4.29	5.50
37	4.63	5.79	9.48	10.63
38	4.46	8.91	12.73	17.18
39	3.28	5.85	9.90	12.47
40	2.11	3.38	4.48	5.75
41	4.62	4.74	10.22	10.34

10.3 Ratios

			Percentage of Harvested					
			Landings			Totals		
MAP Number	Slash	Roads	Normal	Regen	Both	*Exclude* regen	*Include* regen	Including Slash
1	0.09%	2.87%	1.55%	1.19%	2.74%	4.42%	5.61%	5.70%
2	0.00%	2.72%	1.92%	0.00%	1.92%	4.64%	4.64%	4.64%
3	0.11%	2.48%	2.19%	0.00%	2.19%	4.67%	4.67%	4.78%
4	1.16%	1.59%	2.12%	0.00%	2.12%	3.71%	3.71%	4.87%
5	0.00%	3.99%	2.12%	0.00%	2.12%	6.11%	6.11%	6.11%
6	0.15%	1.86%	1.82%	0.00%	1.82%	3.69%	3.69%	3.84%
7	0.51%	1.73%	3.54%	0.00%	3.54%	5.27%	5.27%	5.78%
8	1.08%	2.66%	2.41%	2.41%	4.82%	5.07%	7.48%	8.56%
9	0.40%	4.50%	1.19%	0.00%	1.19%	5.69%	5.69%	6.09%
10	0.17%	2.42%	1.28%	0.00%	1.28%	3.70%	3.70%	3.87%
11	0.35%	2.11%	3.19%	0.00%	3.19%	5.31%	5.31%	5.66%
12	0.04%	1.99%	1.92%	0.00%	1.92%	3.91%	3.91%	3.95%
13	0.56%	2.42%	2.23%	0.00%	2.23%	4.66%	4.66%	5.22%
14	0.09%	2.66%	2.65%	0.76%	3.42%	5.32%	6.08%	6.17%

15	1.55%	4.51%	2.67%	0.00%	2.67%	7.18%	7.18%	8.73%
16	0.44%	4.39%	3.90%	0.00%	3.90%	8.29%	8.29%	8.73%
17	1.15%	2.74%	1.20%	0.00%	1.20%	3.94%	3.94%	5.09%
18	1.51%	2.99%	1.92%	0.00%	1.92%	4.91%	4.91%	6.42%
19	0.49%	2.17%	2.02%	0.00%	2.02%	4.19%	4.19%	4.68%
20	0.08%	1.12%	1.67%	0.00%	1.67%	2.78%	2.78%	2.86%
21	0.17%	3.83%	1.48%	0.00%	1.48%	5.31%	5.31%	5.49%
22	0.97%	2.09%	2.52%	0.00%	2.52%	4.61%	4.61%	5.58%
23	0.00%	2.52%	1.15%	0.00%	1.15%	3.67%	3.67%	3.67%
24	0.70%	2.47%	1.55%	0.19%	1.74%	4.02%	4.21%	4.91%
25	1.28%	3.68%	4.08%	0.00%	4.08%	7.76%	7.76%	9.04%
26	1.37%	3.51%	3.20%	0.00%	3.20%	6.71%	6.71%	8.08%
27	1.24%	2.14%	2.51%	0.00%	2.51%	4.66%	4.66%	5.90%
28	0.00%	2.49%	2.75%	0.00%	2.75%	5.24%	5.24%	5.24%
29	1.04%	1.67%	1.75%	0.00%	1.75%	3.42%	3.42%	4.46%
30	0.62%	0.90%	1.41%	0.00%	1.41%	2.31%	2.31%	2.93%
31	0.16%	2.08%	1.65%	0.00%	1.65%	3.73%	3.73%	3.88%
32	0.76%	3.15%	0.92%	0.00%	0.92%	4.07%	4.07%	4.83%
33	0.55%	2.28%	1.80%	0.00%	1.80%	4.08%	4.08%	4.63%
34	0.57%	3.13%	1.90%	0.00%	1.90%	5.03%	5.03%	5.59%
35	0.55%	2.94%	1.44%	0.00%	1.44%	4.38%	4.38%	4.93%
36	0.68%	1.77%	0.64%	0.00%	0.64%	2.41%	2.41%	3.09%
37	0.79%	3.31%	3.17%	0.00%	3.17%	6.48%	6.48%	7.27%
38	2.16%	4.00%	2.16%	0.00%	2.16%	6.16%	6.16%	8.32%
39	1.20%	3.10%	1.54%	0.00%	1.54%	4.64%	4.64%	5.85%
40	1.11%	2.08%	1.69%	0.16%	1.85%	3.77%	3.93%	5.04%
41	0.04%	1.67%	1.27%	0.10%	1.38%	2.94%	3.04%	3.08%

10.4 Unproductive Area Raito Regression Outputs

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	Total Area Harvested (ha)	.	Stepwise (Criteria: Probability-of-F-to-enter <= .050, Probability-of-F-to-remove >= .100).

a. Dependent Variable: Unproductive Ratio UPR

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.371[a]	.137	.115	1.32459995549

a. Predictors: (Constant), Total Area Harvested (ha)

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	10.889	1	10.889	6.206	.017[b]
	Residual	68.428	39	1.755		
	Total	79.317	40			

a. Dependent Variable: Unproductive Ratio UPR

b. Predictors: (Constant), Total Area Harvested (ha)

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t
		B	Std. Error	Beta	
1	(Constant)	6.178	.583		10.605
	Total Area Harvested (ha)	-.008	.003	-.371	-2.491

Coefficients[a]

Model		Sig.
1	(Constant)	.000
	Total Area Harvested (ha)	.017

a. Dependent Variable: Unproductive Ratio UPR

Excluded Variables[a]

Model		Beta In	t	Sig.	Partial Correlation	Collinearity Statistics
						Tolerance
1	LOW/SCATTRED	-.006[b]	-.038	.970	-.006	.787
	NONE	.188[b]	1.214	.232	.193	.908
	MID	-.145[b]	-.943	.351	-.151	.935
	Cable	.040[b]	.265	.792	.043	1.000
	Canterbury	-.125[b]	-.834	.409	-.134	.993
	Nelson/Marlborough	.098[b]	.617	.541	.100	.892
	WestCoast	-.204[b]	-1.381	.175	-.219	.992
	Otargo/Southland	.147[b]	.927	.360	.149	.885
	ground	-.040[b]	-.265	.792	-.043	1.000

a. Dependent Variable: Unproductive Ratio UPR

b. Predictors in the Model: (Constant), Total Area Harvested (ha)

10.5 Unproductive Area Regression Outputs

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	Total Area Harvested (ha)	.	Stepwise (Criteria: Probability-of-F-to-enter <= .050, Probability-of-F-to-remove >= .100).

a. Dependent Variable: Unproductive Area

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.753[a]	.568	.557	2.005171248211531

a. Predictors: (Constant), Total Area Harvested (ha)

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	205.872	1	205.872	51.203	.000[b]
	Residual	156.808	39	4.021		
	Total	362.680	40			

a. Dependent Variable: Unproductive Area

b. Predictors: (Constant), Total Area Harvested (ha)

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t
		B	Std. Error	Beta	
1	(Constant)	1.625	.882		1.842
	Total Area Harvested (ha)	.036	.005	.753	7.156

Coefficients[a]

Model	Sig.

1	(Constant)	.073
	Total Area Harvested (ha)	.000

a. Dependent Variable: Unproductive Area

Excluded Variables[a]

Model		Beta In	t	Sig.	Partial Correlation	Collinearity Statistics
						Tolerance
1	LOW/SCATTRED	-.079[b]	-.663	.511	-.107	.787
	NONE	.211[b]	1.983	.055	.306	.908
	MID	-.097[b]	-.884	.382	-.142	.935
	Cable	-.012[b]	-.109	.914	-.018	1.000
	Canterbury	-.032[b]	-.301	.765	-.049	.993
	Nelson/Marlborough	.026[b]	.229	.820	.037	.892
	WestCoast	-.128[b]	-1.223	.229	-.195	.992
	Otargo/Southland	.083[b]	.734	.467	.118	.885
	ground	.012[b]	.109	.914	.018	1.000

a. Dependent Variable: Unproductive Area

b. Predictors in the Model: (Constant), Total Area Harvested (ha)