



Plot-based, growth performance of space-planted mānuka (*Leptospermum scoparium*) on marginal land, and vulnerability to erosion

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Executive Summary

Project and Client

- At two study sites, above-ground growth metrics were collected for three age classes of space-planted mānuka to determine the effect of planting density on the time (years after planting) required for such plantings to provide an effective erosion control function when established on marginal land.
- This project was co-funded by The Ministry of Primary Industries and Landcare Research New Zealand Ltd.

Objectives

- Locate and secure access to established plantation-style, space-planted, mānuka at Lake Tutira and Puketoro Station.
- Identify and map landform units present within these study sites.
- Establish Permanent Sample Plots on the different landform units and collect above-ground growth metrics.
- Assess when (years after planting) effective protection by a closed-canopy could reduce the “vulnerability” of these sites to erosion.

Methods

- Three (20 × 20 m) Permanent Sample Plots (PSP) were established across each of the most frequent landform units within an area planted at Lake Tutira in 2012; and one plot was established in an area planted in 2011. A further three plots were established on each of three different landforms within an area planted on Puketoro Station in 2013.
- Above-ground measurements including tree height, diameter at breast height, root collar diameter and canopy spread (diameter) were measured for individual trees within each plot. Dead and missing trees were counted.
- Data from PSP plots on each of the different landforms were averaged and the results used to assess possible site influences on mānuka growth performance.
- A regression analysis was performed comparing root collar diameter and tree height for space-planted mānuka with similar-aged kānuka from a naturally reverting stand.
- For two different planting regimes, assumed canopy growth increments were used to estimate the approximate time required for space-planted mānuka to reach canopy closure.

Results

- A total of 19 plots were established on a total of 5 different landform units, across both study sites.
- At Lake Tutira, the metrics used for measuring above-ground growth performance (tree height, DBH, root collar diameter, canopy spread) of mānuka planted in 2012, indicate there is no significant difference in the growth performance across the different landforms. On account of the greater root collar diameter but stunted stature of the 2011 plantings, it would appear they were slower to establish because of the greater altitude and/or exposure of this permanent sample plot.
- At Puketoro Station, the above-ground growth performance of mānuka established on slump topography was similar to stable sites. Growth on earthflows was inhibited by increased wetness, ground movement, and light suppression by tall sedge-like plants associated with such sites.

- At both properties there was no statistically significant difference in the rate of mortality across the different landform units; however, this was largely due to the high variability in mortality between replicates on each landform, in particular on the landslide scars and earthflows.
- Mānuka mortality was high and generally unsatisfactory on the wetter and more mobile earthflow sites at Puketoro Station ($51\pm 20\%$), and the thin-soiled landslide scars at Lake Tutira ($36\pm 19\%$).
- Mānuka mortality has been less on the more stable landforms, averaging $9\pm 2\%$ at Tutira and $28\pm 8\%$ on ridges, and $32\pm 5\%$ on slump topography at Puketoro Station.
- Overall, the planting density on the latter landforms at Lake Tutira averages 1000 stems ha^{-1} , and at Puketoro Station, 1100–1200 stems ha^{-1} based on the number of live trees present at monitoring. This achieved the target density, given the mortality during establishment.
- At Lake Tutira, canopy closure for plantings spaced at 4 m (between rows) by 3 m (within row spacing between plants) could occur within 7 to 8 years after planting, and, although patchy, will likely occur simultaneously across much of the planted area.
- At Puketoro Station, canopy closure of the regular 3×3 m plantings on the more stable landforms may well occur within 6 to 7 years of planting. However, for plantings on earthflows, canopy closure will likely take considerably longer due to the typically high mortality rate. Additional influences, including elevation and associated climatic factors (e.g. exposure, snow), at Puketoro Station will likely adversely affect growth rates and further increase the time (years after planting) required for plantings on earthflows to achieve canopy closure.
- At this early stage of growth (2–4 years after establishment), the above-ground growth performance of space-planted mānuka at Lake Tutira and Puketoro Station is of the same order of magnitude as for individual trees within a naturally reverting kānuka stand of comparable age but higher density. However, the level of erosion mitigation against landslide initiation once canopy closure has occurred will not be as effective as has been shown for stands of naturally reverting mānuka and kānuka because of the lower stocking density. Space-planted mānuka will therefore remain vulnerable to storm influences for some undefined time after canopy closure.

Recommendations

- As there are few records of the above-ground growth performance of mānuka and kānuka established as low-density, plantation-style plantings, further data collection of growth metrics (e.g. DBH, collar diameter, tree height, canopy diameter) from the permanent sample plots established at Lake Tutira and at Puketoro Station is recommended. Further data are required to model the rate of canopy closure for mānuka at the respective planting spacing established on the different landforms associated with these two study sites.
- Consider the inclusion of below-ground metrics to better understand the effect that planting density (spacing) has on the time (years after planting) it takes for mānuka to provide effective root-soil occupancy and slope reinforcement function.
- Extend the study to other regions where significant areas of marginal land have been or are likely to be planted in mānuka, e.g. Northland, Taranaki, Waiararapa, and Manawatu-Wanganui, and where regional variations in growth could influence the timing of canopy closure, effective root-soil occupancy and thus the vulnerability of slopes to storm effects.
- With the introduction of a new Afforestation Grant Scheme (AGS), and the potential for further establishment of mānuka for honey production, plot-based data of above- and below-ground mensuration rates, particularly during the early growth period following

planting, will be of value to the national carbon (C) inventory system, and policy to reduce net greenhouse gas emissions. Growth metrics from these plots would provide data for the development of mānuka-specific allometric equations for calculating carbon sequestration more accurately than is possible using generalised mixed-species equations developed for older natural forest stands.

- As a means of promoting rates of mānuka growth and survival, evaluate the effectiveness of practices used to suppress grass competition (e.g. pre-plant spot spraying, post-plant release spraying), and trial the periodic grazing of mānuka to prevent the development of rank grass.
- Plant mānuka at densities that will achieve the desired final stocking, allowing for mortality on sites affected by past and current erosion.

1 Introduction

In the East Coast Region of the North Island, the space-planting of mānuka is considered to be a legitimate erosion mitigation measure for which funding is available through the Erosion Control Funding Programme (ECFP), formerly the East Coast Forestry Project, and approved by the Ministry for Primary Industry (MPI). Here, the ‘worst of the worst eroding land’, identified as Land Overlay 3 in Gisborne Council’s District and Regional Plan, is dominated by deeper-seated earthflow and slump failures. Elsewhere throughout New Zealand, space-planted mānuka is being established on steep and marginal hill country, which in many places is susceptible to surface erosion processes, particularly shallow landslides. Typically, and on account of their high current erosion rates, these areas are classified in the New Zealand Land Resource Inventory (National Water and Soil Conservation Organisation 1975) as Class VII. The expectation is that space-planted mānuka will provide effective and long-term, erosion control.

While not disputing claims that plantation-style plantings of mānuka will in time reduce the erosion susceptibility of marginal land, there is little quantitative evidence, especially for different plant spacing specifications, with which to establish the time (years after planting) slopes are likely to remain ‘at most risk’ to storm-related damage. High planting density specifications are likely to have an economic impact on honey and oil extraction incurred by the additional establishment costs, and reduced levels of production, with canopy closure occurring earlier than if planted at a wider spacing. The overlapping of individual tree canopies and eventual canopy closure will likely suppress flowering development, and thus honey production is expected to decline and then plateau thereafter. Conversely, the erosion control effectiveness of mānuka will likely be compromised if the planting density is too low. Thus in areas of marginal land where erosion susceptibility is high, a tension exists between driving economic gains from honey and oil extraction, and the erosion control effectiveness of these plantings.

Much of the research relevant to understanding the erosion control effectiveness of mānuka has largely been derived from investigations of ‘stands’ of naturally reverted scrub and/or of individual trees extracted from these stands. At the stand level, previous studies have included investigations of water balance components (e.g. interception of rainfall) (Aldridge & Jackson 1968; Rowe et al. 1999), the mitigation of storm-effects (e.g. landslide prevention) by closed-canopy stands of scrub (Marden & Rowan 1988, 1993; Hicks 1991; Bergin et al. 1995), and their use as a bio-engineering agent on roadsides and in mining rehabilitation (Watson et al. 1998). Studies of individual trees have involved the measurement of root growth (spread, depth and biomass) (Watson & O’Loughlin 1985; Watson et al. 1994), rates of root decay (Watson et al. 1997, 1999) and of root tensile strength (Watson & Marden 2004). Thus, previous attempts to model soil–root reinforcement and slope safety factor (Watson & O’Loughlin 1985; Ekanayake et al. 1997, 2004; Watson et al. 1999) are based largely on data from fully stocked stands of scrub where the tree density is initially high, and for young regenerating stands can be as high as 97 000 stems ha⁻¹ (unpublished data).

To our knowledge there have been no studies of a similar nature undertaken of stands or of individual plants established as widely spaced plantings, let alone for plantings established on marginal land. As there was no published research data currently available on the growth rates (both above- and below-ground) of space-planted mānuka with which to determine when (years after establishment) such plantings are likely to provide an effective erosion control function, a pilot study was initiated. The aim of this study was to establish Permanent

Sample Plots [PSP] on marginal land at two study sites with contrasting landforms, and from which mensuration data could be collected over successive years.

These data will greatly assist in understanding the effects of planting density, survival rates and landform on the efficacy of space-planted mānuka to reduce the “vulnerability” of marginal land to slope failure through effective root-reinforcement, and protection by a closed canopy. In addition, with the introduction of a new Afforestation Grant Scheme (AGS), and the potential for further establishment of mānuka for honey production, plot-based data of above- and below-ground mensuration rates, particularly during the early growth period following planting, will be of value to the national carbon (C) inventory system, and to policy to reduce net greenhouse gas emissions.

2 Study site

Lake Tutira (Fig. 1) and Puketoro Station (Fig. 2) were selected as study sites to assess the erosion control effectiveness of space-planted mānuka. Both sites are classified as Class VII marginal land in the New Zealand Land Resource Inventory (NZLRI) and each has landforms that are susceptible to different erosion processes. Importantly, mānuka had already been established at these sites a year (Puketoro Station), and for several successive years (Lake Tutira) before this study began. The physical site characteristics at these study sites are listed in Table 1.

Table 1 Physical site characteristics from the New Zealand Land Resource Inventory (NZLRI), Sheet N 114 (Lake Tutira), Sheet N80 (Puketoro Station)

	Lake Tutira	Puketoro Station
LUC Class	7e3	7e13
Slope group	E (21–25) & F (26–35)	E (21–25)
NZ Soil Classification ¹	Typic Immature Pallic	Typic Orthic Allophanic
Geology ²	Pliocene-age mudstone, sandstone, limestone	Mélange of the East Coast Allochthon
Erosion severity and type	Extreme shallow landsliding, slight tunnel gullyng	Extreme earthflow, very severe gully, moderate slump
Vegetation type	Low producing pasture	High producing pasture
Elevation (asl)	200–375 m	600–700 m
Aspect	West facing	North facing

¹ Hewitt (2010)

² Mazengarb & Speden (2000)

For the planted areas, landscape units were identified and mapped. At Lake Tutira, three landforms have been identified: (i) landslide scars with thin, skeletal soil/colluvium cover bed materials, predominantly located on mid-slopes (11.5 ha, 27.4% of study area); (ii) colluvial slopes where landslide debris comprising thick deposits of mixed soil and colluvium has accumulated (4.9 ha, 11.5% of study area) (Fig. 3); and (iii) stable sites, largely interfluvial ridges and spurs, with little sign of slope instability and where thick forest soil and volcanic ash cover beds have remained intact (22.3 ha, 53% of study area). Plots were not established on areas of alluvial valley floor (0.65 ha, 1.5% of study area) or on slopes so ‘disturbed’ it was difficult to identify a specific landform unit on which to locate a permanent sample plot (2.78 ha, 6.6% of study area).

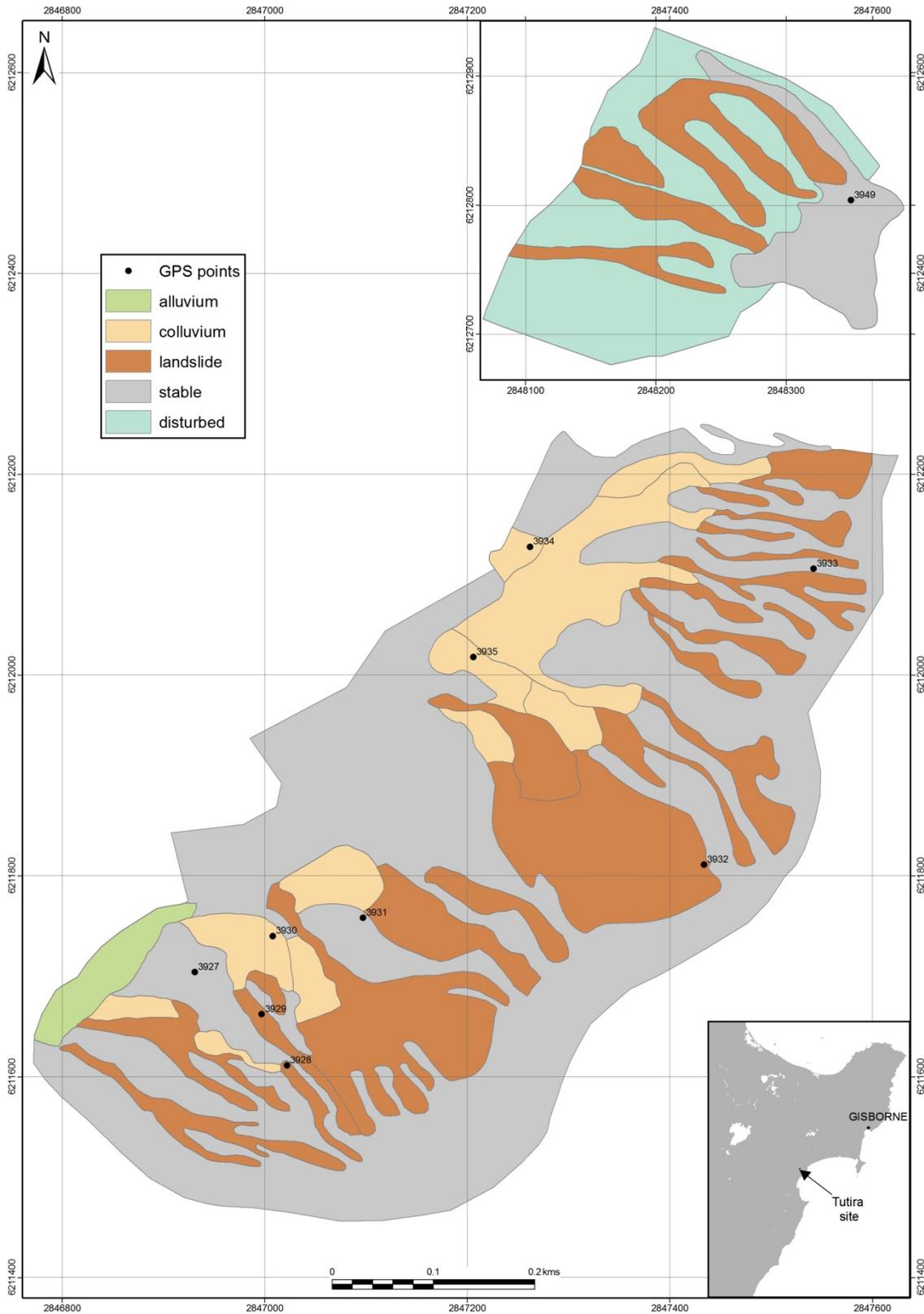


Figure 1 Map showing the location of permanent sample plots established within space-planted mānuka plantings established in 2011 (inset) and 2012 (large area), relative to the different landform units at Lake Tutira.

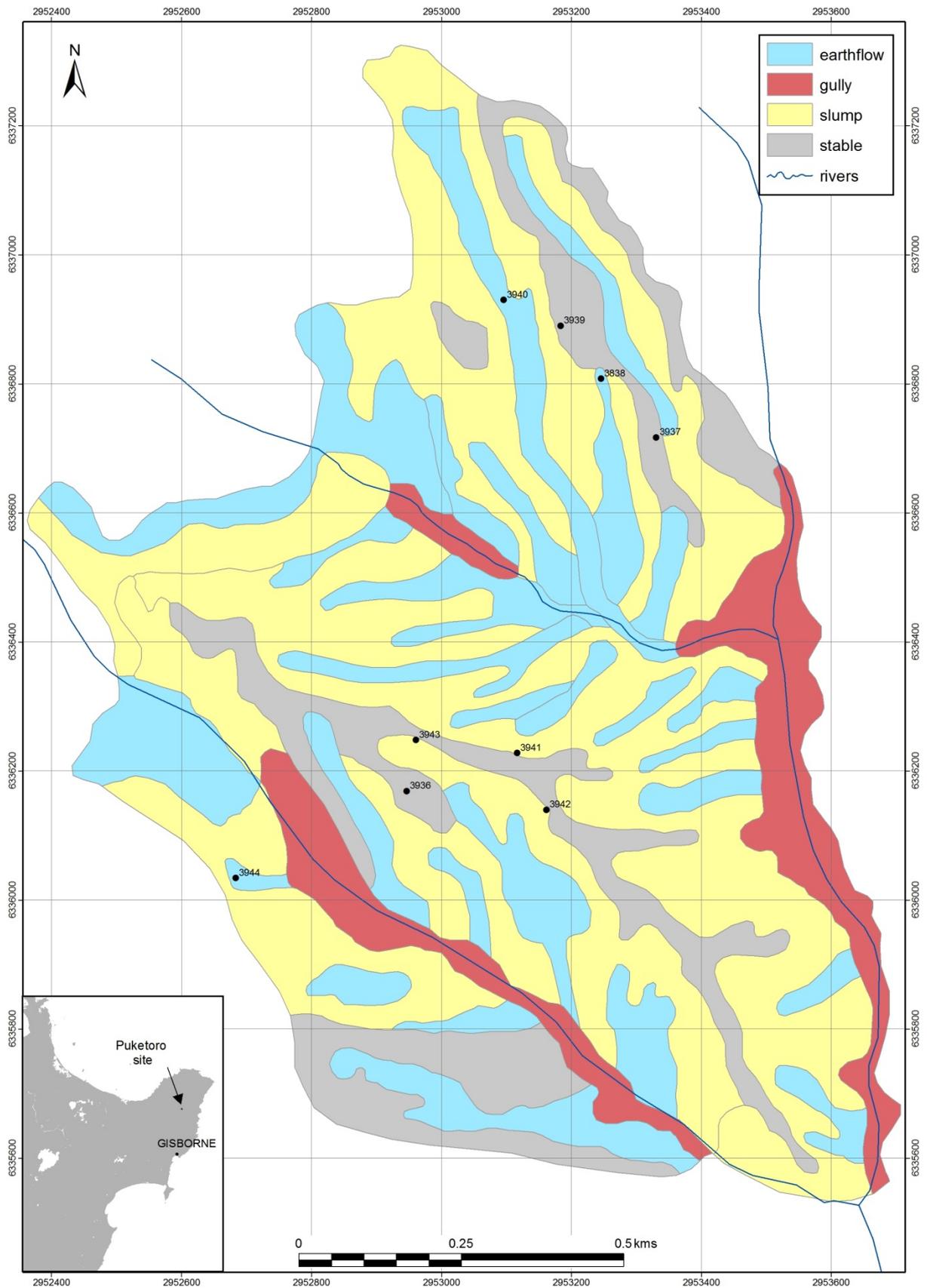


Figure 2 Map showing the location of permanent sample plots established within space-planted mānuka plantings established in 2013, relative to the different landform units at Puketoro Station.



Figure 3 Mānuka planted in 2012 on a colluvial foot slope at Lake Tutira. The colluvial soils have been derived from the landslide scars further upslope.

At Puketoro Station, landforms include: (i) earthflows, overgrown with sedge-like vegetation and where downslope surface displacement is likely during winter months (37.4 ha, 27.5% of study area) (Fig. 4); (ii) slump topography showing signs of slope movement, both past and present (64.2 ha, 47.2% of study area); and (iii) stable sites comprising interfluvial ridges (20.6 ha, 15.2% of study area). Actively eroding gullies comprising 10.1% of the study area were not planted in mānuka.



Figure 4 Mānuka planted in 2013 on earthflow terrain (foreground) at Puketoro Station.

3 Permanent Sample Plots (PSP plots)

At Lake Tutira, three permanent sample plots (each 20 × 20 m) (Hurst & Allen, 2007) have been established on each of three different landforms within an area planted in 2012 and one plot was established within an area planted in 2011 (Fig. 1). Similarly, at Puketoro Station, three replicate plots have been established on each of three different landforms within an area planted in 2013 (Fig. 2).

Plots were established between March and May (2015). The centre point of each plot is marked with a wooden post. An aluminium tag with an identification number (Appendix 1) was nailed to the top of the post. A tall, white fibreglass rod was placed next to the post. The location of the centre point of each plot was fixed using Global Positioning System technology (GPS); GPS coordinates for the PSP plots are listed in Appendix 1.

Within each plot, all live trees were measured for diameter at breast height (DBH at 1.4 m above ground level on the upslope side of each tree), root collar diameter (RCD, measured at ground level), plant height, and maximum projected canopy spread (measured in two directions and averaged). Plants that had died since planting were counted. For multiple-stemmed plants, DBH, RCD, and height of each stem were recorded. Table 2 presents details of the number of plots established per landform, trees measured, and the total number of measurements at each of the two study sites.

Table 2 Summary of the number of plots established per landform, trees measured and number of measurements collected at the two study sites

	Lake Tutira		Puketoro Station
Age class	2011	2012	2013
Landforms	1	3	3
Plots per landform	1	3	3
Number of plots	1	9	9
Trees measured	39	346	378
Total number of measurements	590	3838	1896

4 Results

4.1 Planting density at the time of establishment

4.1.1 Lake Tutira

Mānuka was contracted to be planted at 4×3 m spacing (James Powrie, pers. comm., Hawke's Bay Regional Council), that is, at a planting density of $833 \text{ stems ha}^{-1}$. However, field data for PSP plots indicates the planting spacing may have been closer to 3×3 m. The mean number of live plants measured in the three PSP plots, accounting for gaps where trees were probably planted but are now missing, suggests the actual planting density at the time of establishment was $1075 \text{ stems ha}^{-1}$ for the stable ridges/spurs, $1275 \text{ stems ha}^{-1}$ for the depositional colluvium sites, and $1300 \text{ stems ha}^{-1}$ on the areas identified as former landslide scars..

4.1.2 Puketoro Station

Mānuka was contracted to be planted at 3×3 m spacing, that is, at a planting density of $1,111 \text{ stems ha}^{-1}$. As per Lake Tutira, field data from PSP sites indicates a higher density at the time of establishment. This likely averaged $1750 \text{ stems ha}^{-1}$ on the stable ridges, $1325 \text{ stems ha}^{-1}$ on slump topography, and $1600 \text{ stems ha}^{-1}$ on areas identified as earthflows.

4.2 Mortality since establishment

Of the older 2011 plantings established on a stable site at Lake Tutira, 5% had died by 2015 (Table 3, Fig. 5). Of the 2012 mānuka plantings, mortality was $9 \pm 2\%$ on the stable sites, $16 \pm 7\%$ on the colluvial sites, and $36 \pm 19\%$ on landslide scars (Table 4, Fig. 5). Due to the large variability in mortality between the replicates on each landform, there was no significant difference between the landforms with respect to mortality.

Table 3 Number of live trees, growth parameters and mortality of mānuka planted in 2011 and 2012 at Lake Tutira. (Figures in parentheses are percent mortality)

Landform/Plot No.	No. of live trees measured	No. of bases measured	No. of DBH measured	No. of heights measured	No of Canopies measured	Number of dead/missing trees = mortality
<i>2011 Stable site</i>	39	63	425	63	39	2 (5)
<i>2012</i>						
<i>Landslide scar</i>						
3928	40	60	87	60	40	27 (40)
3929	29	69	224	69	29	3 (9)
3932	32	61	127	61	32	26 (45)
<i>Totals</i>	101	190	438	190	101	56 (36)
<i>Colluvial slope</i>						
3930	30	88	245	88	30	3 (9)
3934	52	138	376	138	52	10 (16)
3935	43	73	320	73	43	13 (23)
<i>Totals</i>	125	299	941	299	125	26(16)
<i>Stable sites</i>						
3927	48	119	115	119	48	3 (6)
3931	28	85	195	85	28	3 (10)
3933	44	83	251	83	44	5 (10)
<i>Totals</i>	120	287	561	287	120	11 (9)
<i>Total</i>	346	776	1940	776	346	93 (21)

Table 4 Number of live trees, growth parameters and mortality of mānuka planted in 2013 at Puketoro Station. (Figures in parentheses are percent mortality)

Landform/Plot No.	No. of live trees measured	No. of bases measured	No. of DBH measured	No. of heights measured	No of Canopies measured	Number of dead/missing trees = mortality
<i>Earthflow</i>						
3938	39	87	0	87	39	38 (49)
3940	38	78	0	78	38	18 (32)
3944	17	38	0	38	17	43 (72)
Total	94	203	0	203	94	99 (51)
<i>Slump</i>						
3941	44	84	4	84	44	25 (36)
3942	41	104	0	104	41	15 (27)
3943	50	50	0	50	50	23(32)
Total	135	238	4	238	135	23 (32)
<i>Stable sites</i>						
3936	57	131	0	131	57	17 (23)
3937	47	89	18	89	47	15 (24)
3939	45	82	10	82	45	27 (38)
Total	149	302	28	302	149	59 (28)
Totals	378	743	32	743	378	181(32)

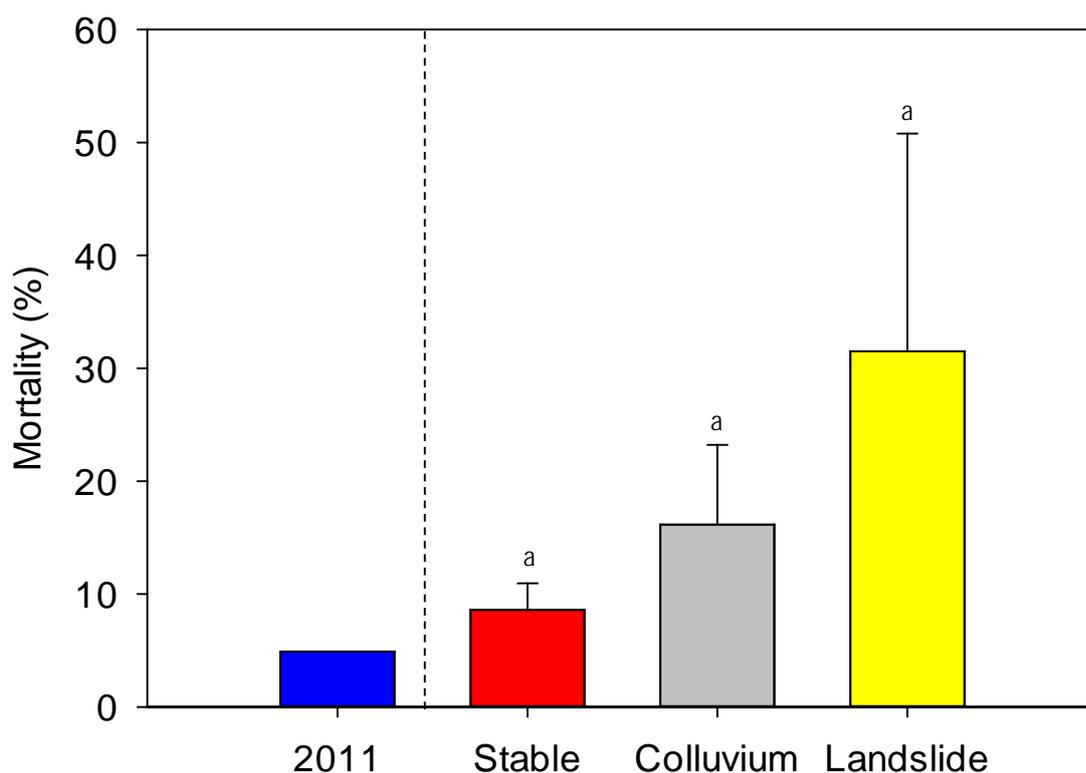


Figure 5 Mānuka mortality (%) on a stable site planted in 2011, and on the three landforms planted in 2012 at Lake Tutira. Bars represent standard deviation. Bars with different letters were significantly different ($P < 0.05$). The 2011 data were not included in the statistical analysis of mortality at Lake Tutira as they consist of a single data point.

At Puketoro Station, of the 2013 plantings, mortality on earthflows was $51 \pm 20\%$, while losses were $28 \pm 8\%$ on the more stable ridges, and $32 \pm 5\%$ on the slump topography, respectively (Table 4, Fig. 6). As for the sites at Lake Tutira, there were no significant differences with respect to mortality at Puketoro Station due to large inter-replicate variability.

Overall, (all landforms combined) and subsequent to planting, 5% of the 2011 and 21% of the 2012 mānuka plantings at Lake Tutira had died by 2015. Similarly, by 2015, 32% of the 2013 plantings at Puketoro Station died. At both sites, mānuka suppression by rank grass contributed to most of the post-establishment losses; however, at Puketoro Station, even heavier losses were associated with the wetter earthflow sites overgrown with sedges, and where periodic downslope movement toppled and buried plants. Stock damage by sheep and cattle was observed at both sites, but with the exception of one plot location at Puketoro Station, was not a major factor contributing to plant mortality.

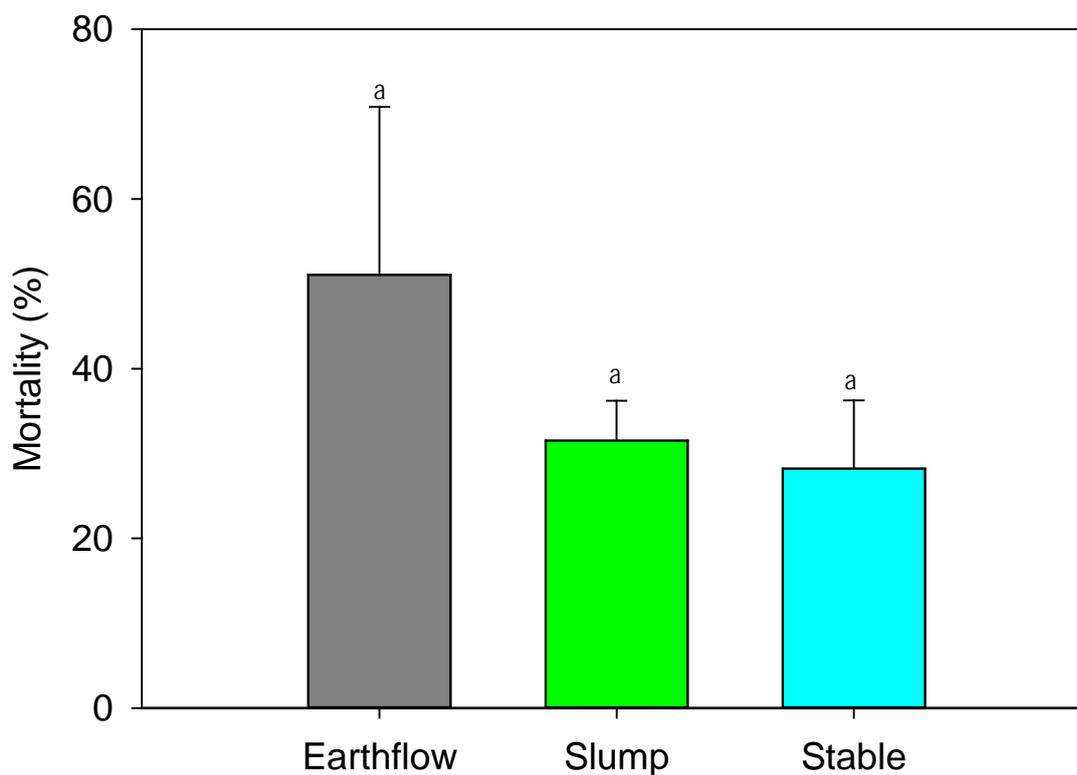


Figure 6 Mānuka mortality (%) of 2013 plantings on the three landforms at Puketoro Station. Bars represent standard deviation, bars with different letters were significantly different ($P < 0.05$).

4.3 Current planting density

Based on the number of live trees found within the 20×20 m permanent sample plots on the different landforms at Lake Tutira, the current plant density ranges between $833 \text{ stems ha}^{-1}$ for the poorer landslide scars with thin or no soil cover to $1000 \text{ stems ha}^{-1}$ for the stable ridges/spurs (thicker undisturbed soils), and $1042 \text{ stems ha}^{-1}$ for the colluvial sites with thick but disaggregated and mixed soils. A similar trend can be seen at Puketoro Station where the current planting density is poorer on the more mobile and heavily vegetated (sedges) earthflows at $784 \text{ stems ha}^{-1}$ compared with $1125 \text{ stems ha}^{-1}$ on the slump terrain, and $1242 \text{ stems ha}^{-1}$ on the most stable terrain where soils have remained relatively undisturbed.

The data suggest that at both Lake Tutira and Puketoro Station the current density of surviving (live) plants met the required planting specification, as more seedlings were initially planted. Only the poorer sites such as earthflows at Puketoro ($784 \text{ stems ha}^{-1}$) have current plant densities lower than the design density.

4.4 Growth performance

4.4.1 Tree height

At the time of establishment mānuka seedlings planted at Lake Tutira were ~0.2 m high. As at March 2015, the ~2-m mean height of plants established in 2011 and 2012 was not significantly different (Fig. 7). At Puketoro Station the 2013 plantings reached a mean tree height of ~1 m by 2015. Again, there was no significant difference in plant height between landforms (Fig. 8).

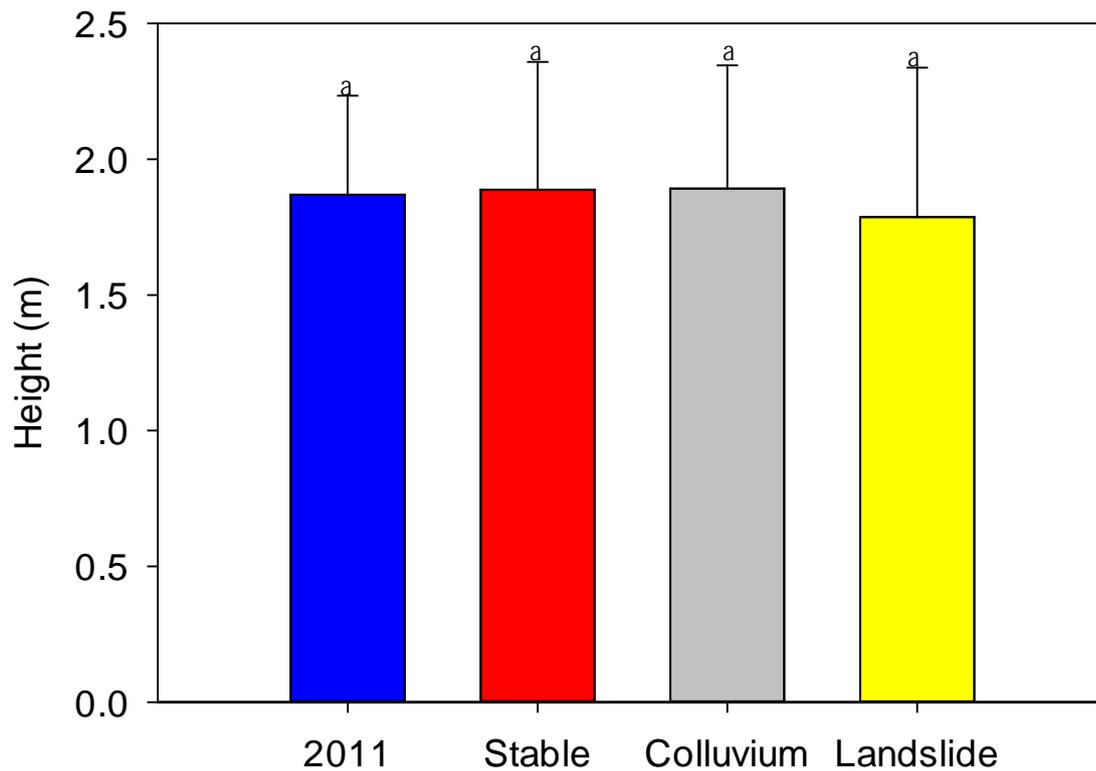


Figure 7 Mean height of 2011 mānuka plantings (stable site) and 2012 mānuka plantings on the three landforms at Lake Tutira. Bars represent standard deviation, bars with different letters were significantly different ($P < 0.05$).

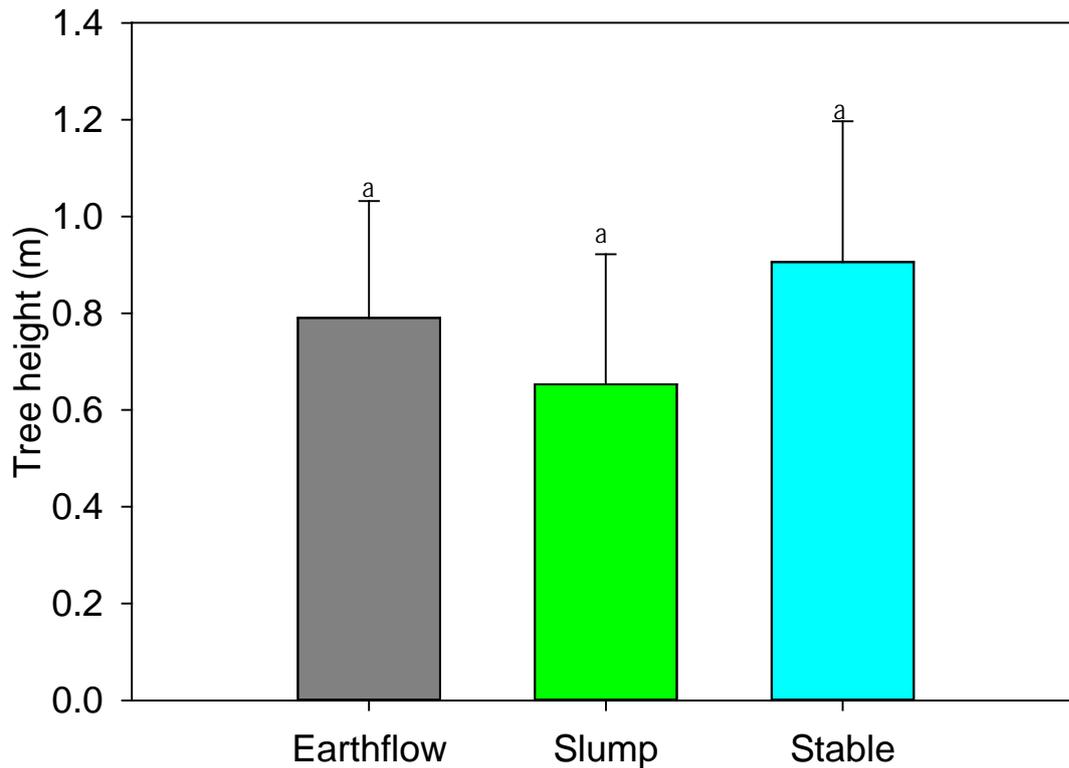


Figure 8 Mean tree height of 2013 mānuka plantings on the three landforms at Puketoro Station. Bars represent standard deviation, bars with different letters were significantly different ($P < 0.05$).

4.4.2 Root collar diameter (measured at ground level)

At the time of establishment the mānuka seedlings planted at Lake Tutira had a collar diameter of ~3–4 mm (James Powrie, pers. comm.). Within 2 years, the root collar diameter of the 2013 plantings increased to a mean of 18 mm (Fig. 9), and 4 years after planting had increased to 40 mm. At Puketoro Station mean root collar diameter 2 years after establishment was just 4 mm (Fig. 10). At both Lake Tutira and Puketoro Station there was no significant difference in mean root collar diameter between the different landforms.

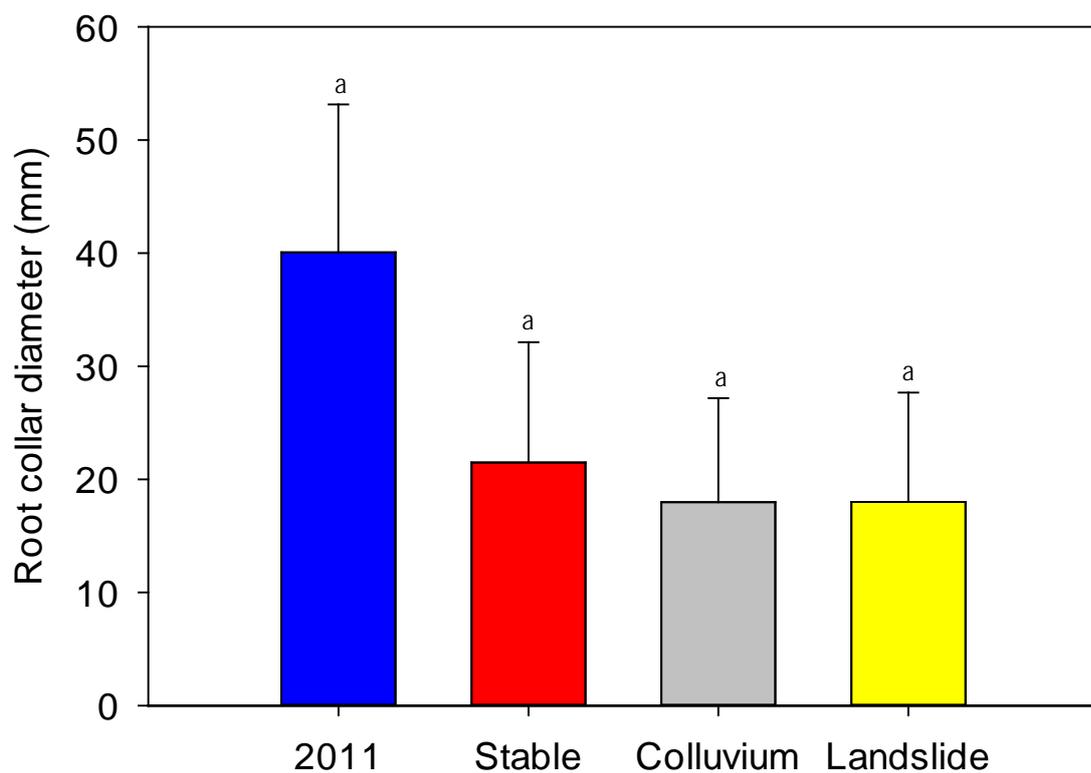


Figure 9 Mean root collar diameter of 2011(stable site) and 2012 plantings on the three landforms at Lake Tutira. Bars represent standard deviation, bars with different letters were significantly different ($P < 0.05$).

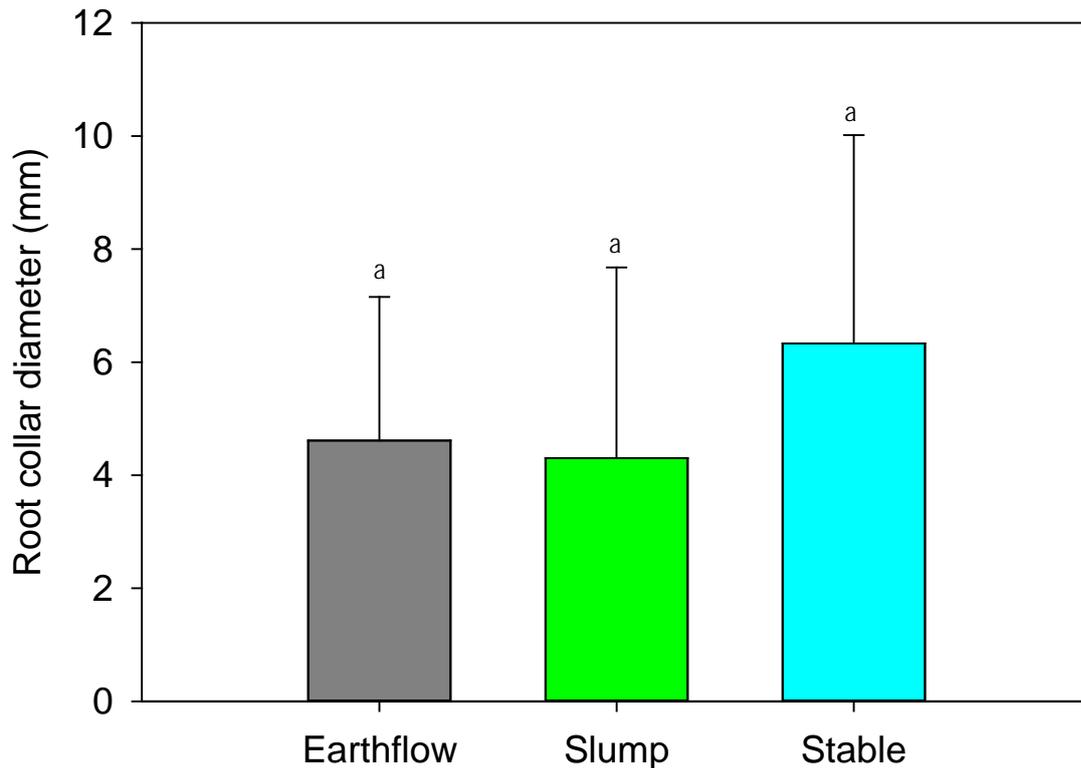


Figure 10 Mean root collar diameter of 2013 plantings on the three landforms at Puketoro Station. Error bars represent standard deviation, bars with different letters were significantly different ($P < 0.05$).

4.4.3 Diameter at breast height (measured at 1.4 m above ground level)

The mean diameter at breast height of ~4 mm for plantings established at Lake Tutira in 2011 was not significantly different from that on any of the landforms planted in 2012 (Fig. 11). At Puketoro Station none of the 2013 mānuka established on earthflows reached DBH height, while on slump and stable terrain the mean diameter at breast height was 2 mm, and was not significantly different between these two landforms (Fig. 12).

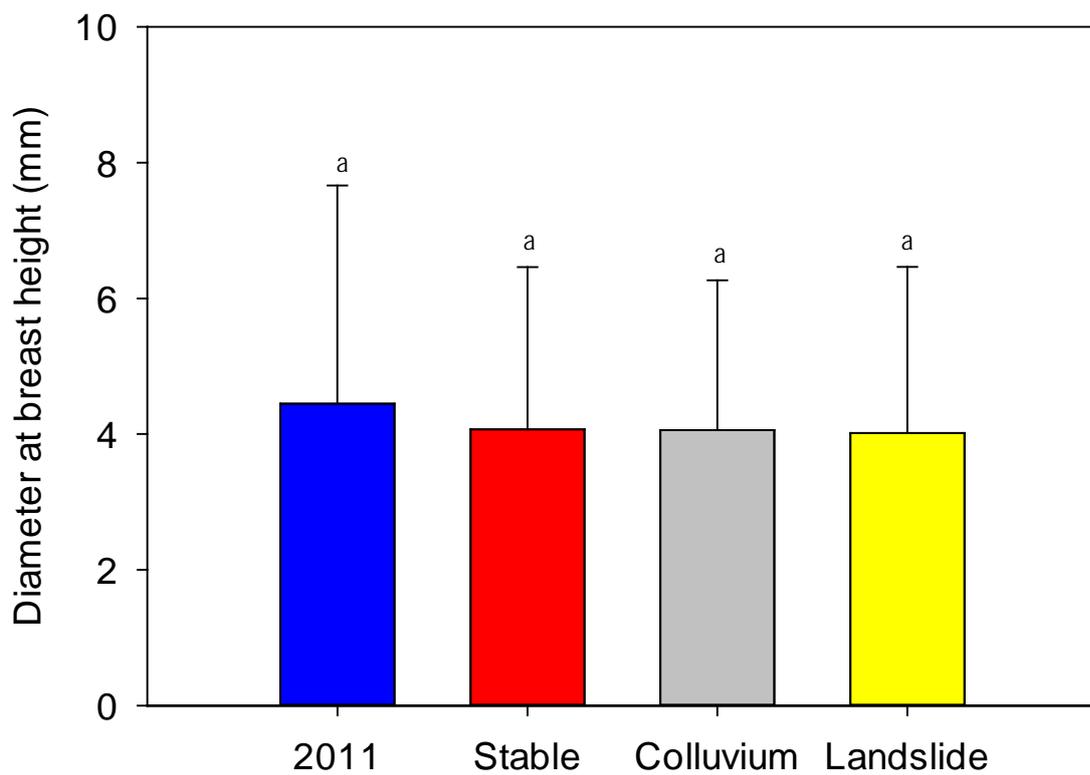


Figure 11 Mean diameter at breast height of 2011 plantings (stable site) and the 2012 mānuka plantings established on the three landforms at Lake Tutira. Error bars represent standard deviation, bars with different letters were significantly different ($P < 0.05$).

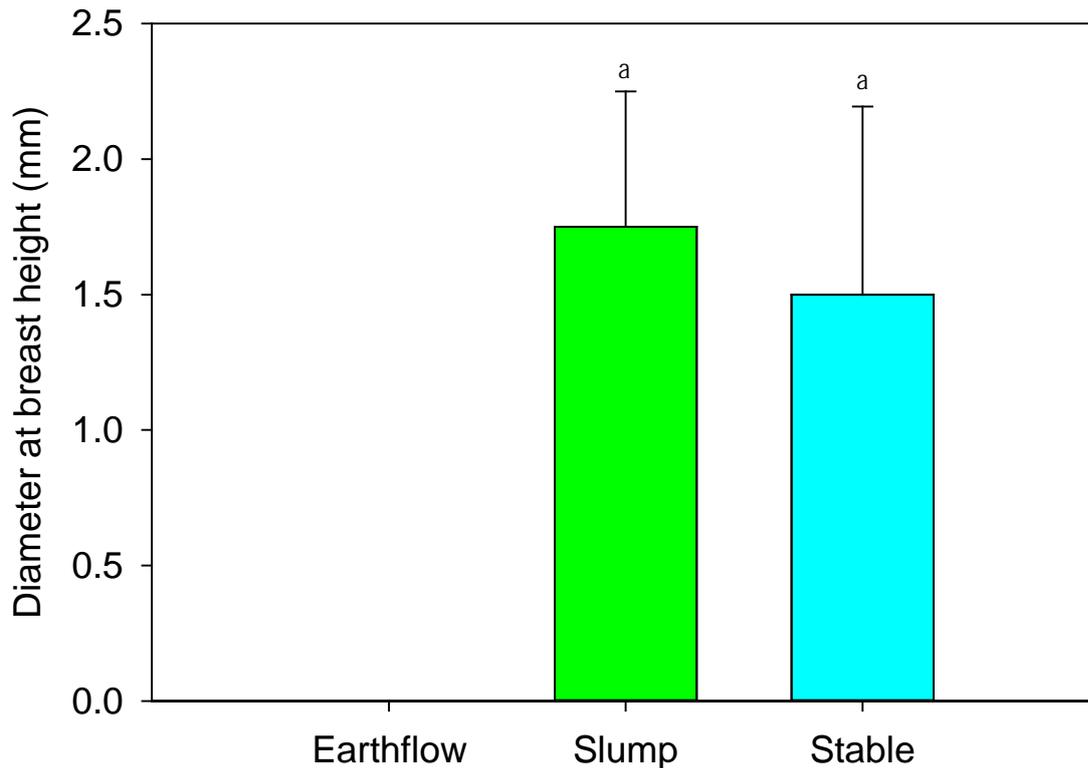


Figure 12 Mean diameter at breast height of 2013 mānuka plantings on the tree landforms at Puketoro Station. Error bars represent standard deviation, bars with different letters were significantly different ($P < 0.05$). Note: no plants established on earthflows reached dbh height.

4.4.4 Canopy diameter

Mean canopy diameter of the 2011 and 2012 mānuka plantings at Lake Tutira was ~1.1 m and ~1.2 m respectively (Fig. 13), but there was no significant difference between 2011 and 2012 plantings established on any of the landforms. Within the 2012 plantings, the mānuka established on landslides had a significantly lower ($P < 0.001$) canopy diameter than trees established on the remaining landforms (Fig. 13). At Puketoro Station the mean canopy diameter of the 2013 plantings was ~0.5 m, and there were no differences in canopy development between any of the landforms (Fig. 14).

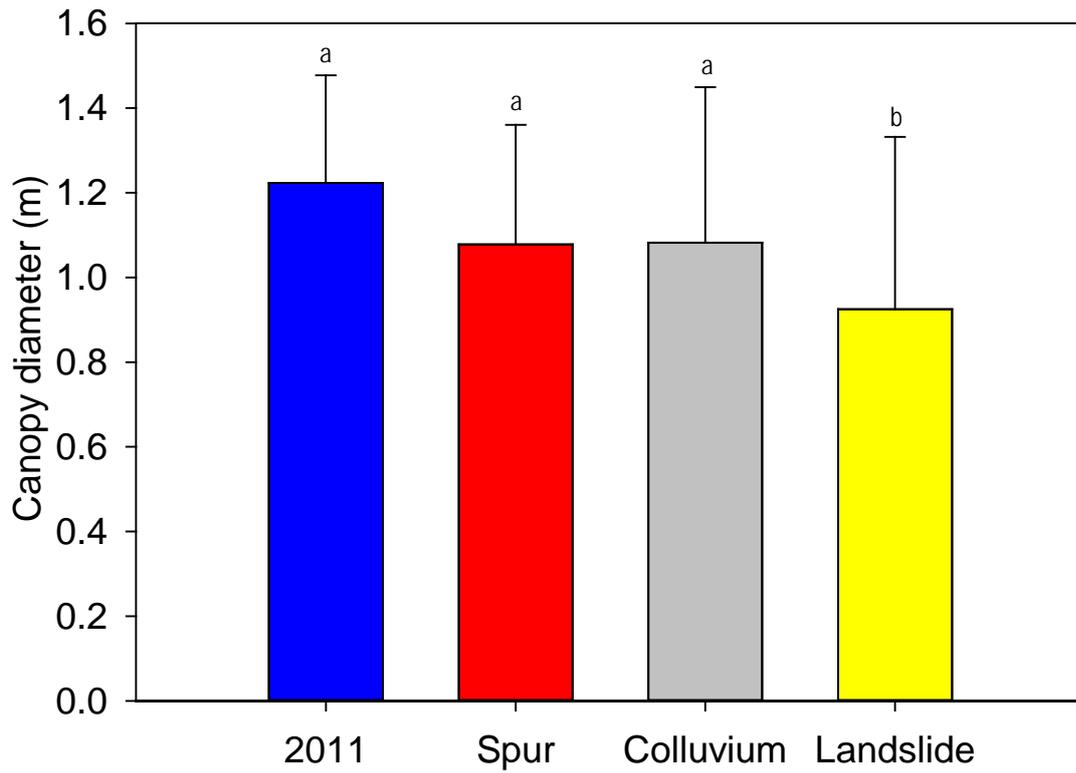


Figure 13 Canopy diameter of mānuka planted in 2011 (stable site) and 2012 on the three landforms at Lake Tutira. Error bars represent standard deviation, bars with different letters were significantly different ($P < 0.001$).

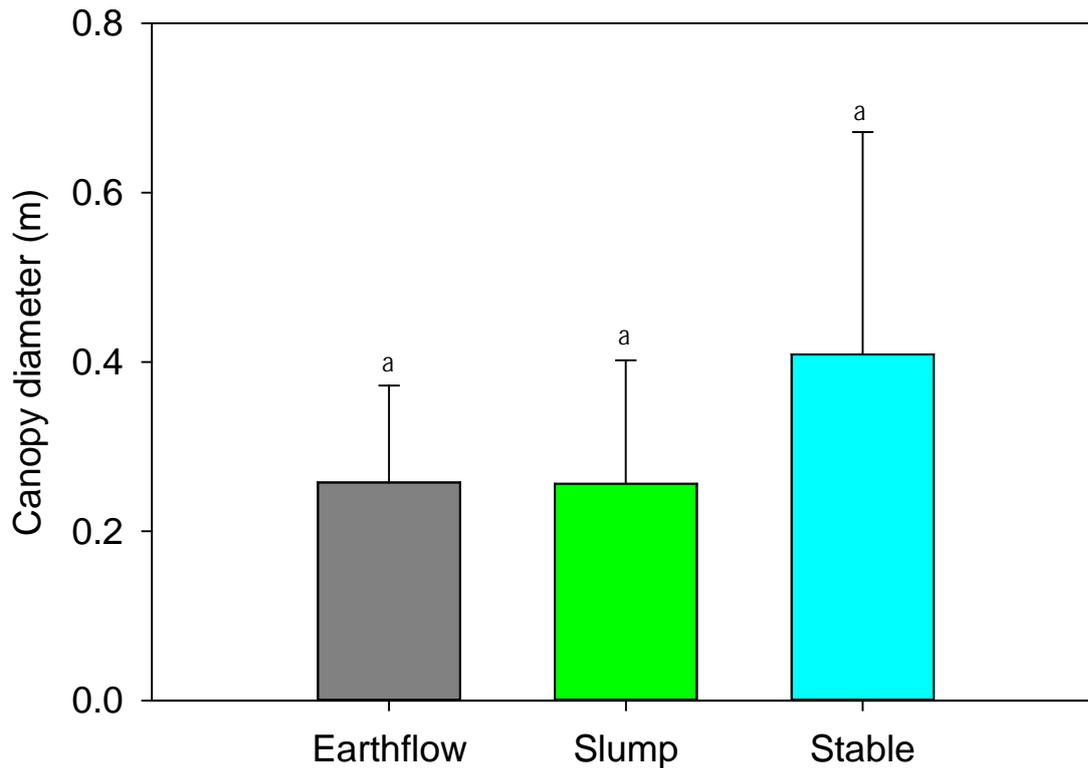


Figure 14 Canopy diameter of 2013 mānuka plantings on the three landforms at Puketoro Station. Error bars represent standard deviation. Error bars represent standard deviation, bars with different letters were significantly different ($P < 0.05$).

4.4.5 Regression analyses

For the Lake Tutira data, the linear regression analysis fitting RCD and tree height (Fig. 15), with r^2 ranging between 0.3 and 0.5, reflects the wide variation in both RCD and height measurements of predominantly multi-stemmed plants. The larger root collar diameter but stunted stature of the 2011 plantings, suggests that mānuka within the area of this permanent sample plot were slower to establish because of its higher altitude and greater exposure to climatic influences. All regressions were highly significant ($P < 0.001$; Table 5).

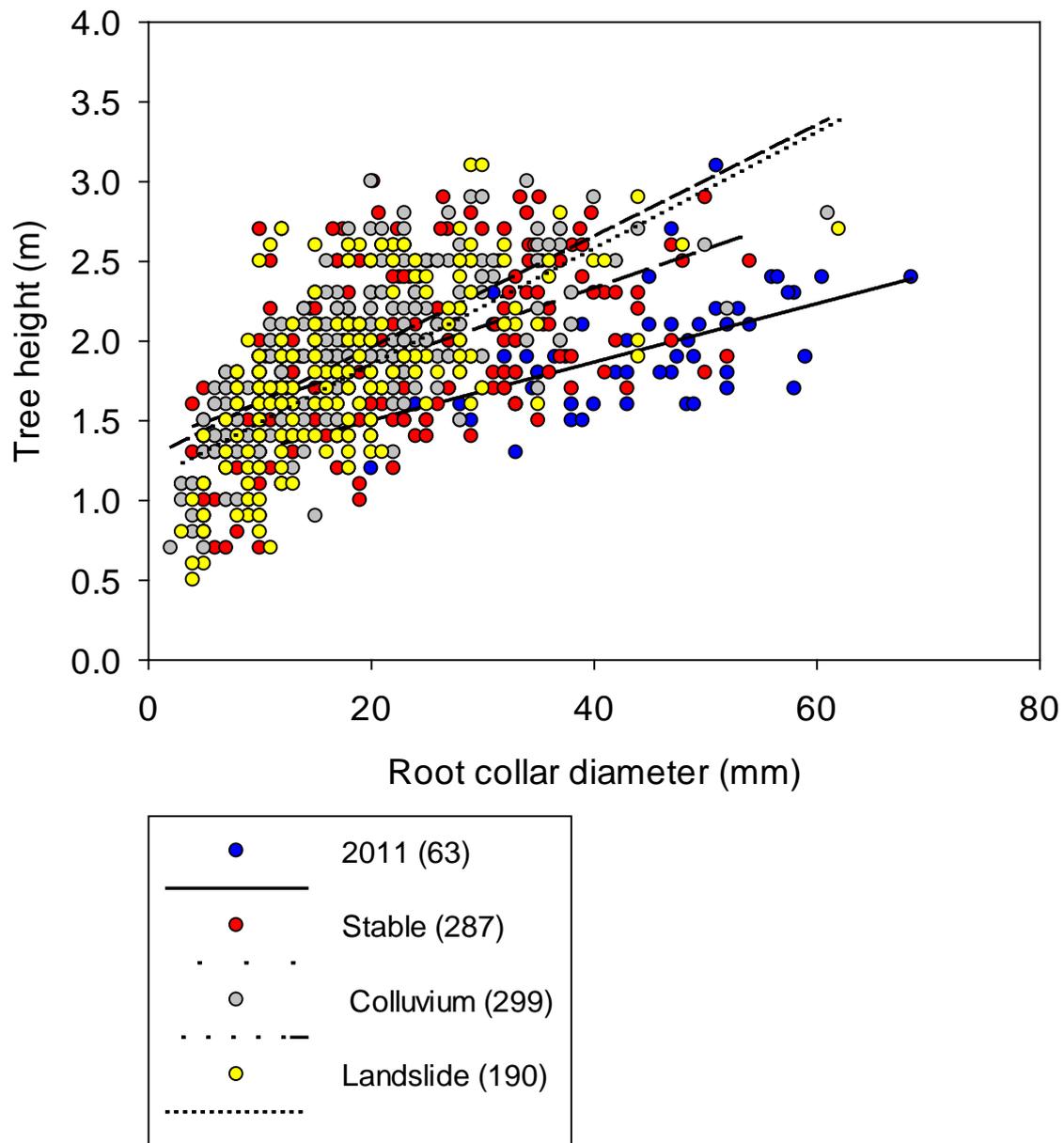


Figure 15 Linear regression of root collar diameter against tree height for mānuka planted at Lake Tutira in 2011 and 2012, with respect to landform. Numbers in parentheses are the numbers of mānuka stems measured. Regression statistics (slope, intercept, r^2 , standard error of estimate), respectively, are given in Table 5.

Table 5 Regression statistics for root collar diameter against tree height for mānuka planted at Lake Tutira in 2011 and 2012, with respect to landform

Age and landform	r ²	P	Slope	Intercept	SEE*
2011 Stable	0.44	<0.001	0.018	1.14	0.28
2012					
Stable	0.30	<0.001	0.036	1.12	0.40
Colluvium	0.50	<0.001	0.035	1.27	0.32
Landslide	0.43	<0.001	0.024	1.40	0.42

*Standard error of the estimate

For the Puketoro Station data, the linear regression analysis fitting RCD and tree height (Fig. 16), with r² ranging between 0.57 and 0.62, reflects minimal growth within the 2-year post-establishment period with only minor differences in the growth performance across the three landforms. All regressions were highly significant ($P < 0.001$; Table 6).

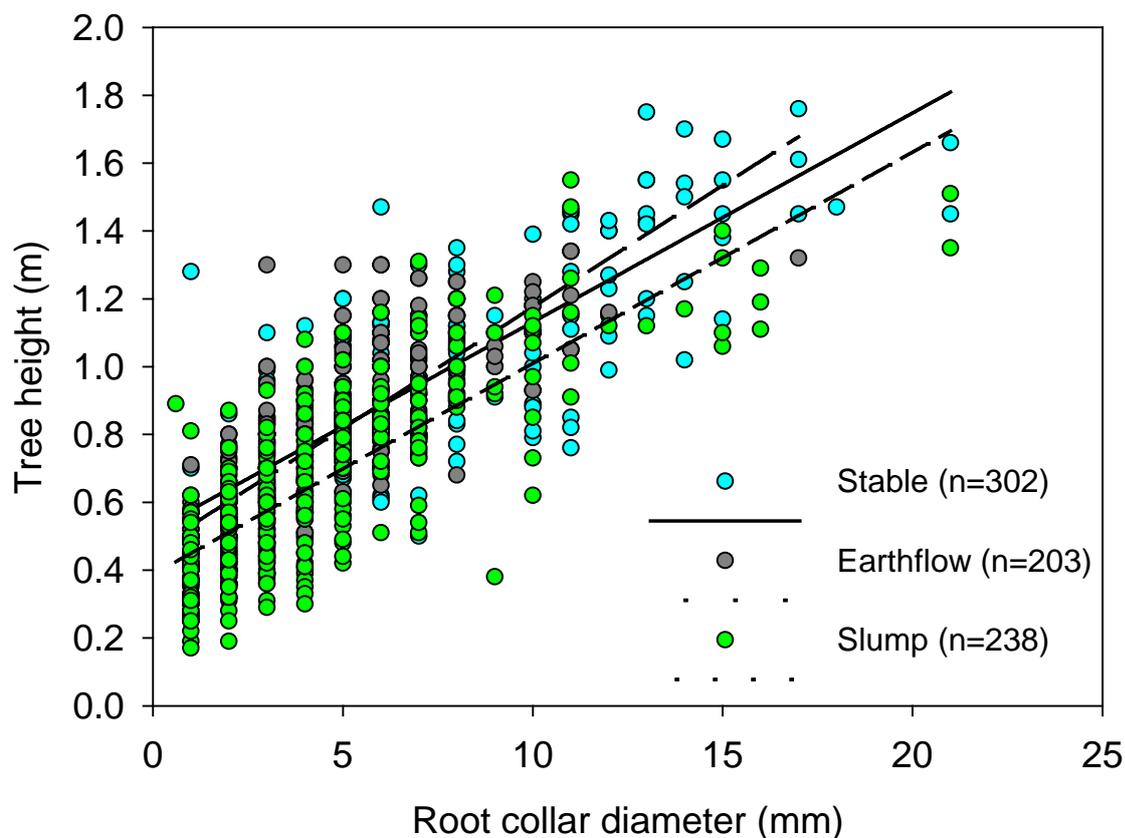


Figure 16: Linear regression of root collar diameter against tree height for mānuka planted in 2013 at Puketoro Station, with respect to landform. Numbers in parentheses are the numbers of mānuka stems measured. Regression statistics (slope, intercept, r², standard error of estimate), respectively, are given in Table 6.

Table 6 Regression statistics for root collar diameter against tree height for mānuka planted at Puketoro Station in 2013, with respect to landform

Landform	r^2	P	Slope	Intercept	SEE*
Stable	0.61	<0.001	0.062	0.52	0.18
Earthflow	0.57	<0.001	0.072	0.46	0.16
Slump	0.62	<0.001	0.062	0.39	0.17

*Standard error of the estimate

A comparison of the linear regression analysis fitting RCD and tree height for space-planted mānuka ($r^2 = 0.4$), and for naturally reverting mānuka ($r^2 = 0.6$), suggests that for any given RCD, the mānuka within a naturally reverting stand will likely be taller than its space-planted counterpart (Fig. 17). This is likely due to the higher stand density associated with naturally reverting stands increasing competition for light, producing a thinner and taller tree form. Conversely, for space-planted mānuka there is little competition between plants for space or nutrients at this early stage of growth thus individual plants tend to be shorter and bushier. All regressions were highly significant ($P < 0.001$; Table 7).

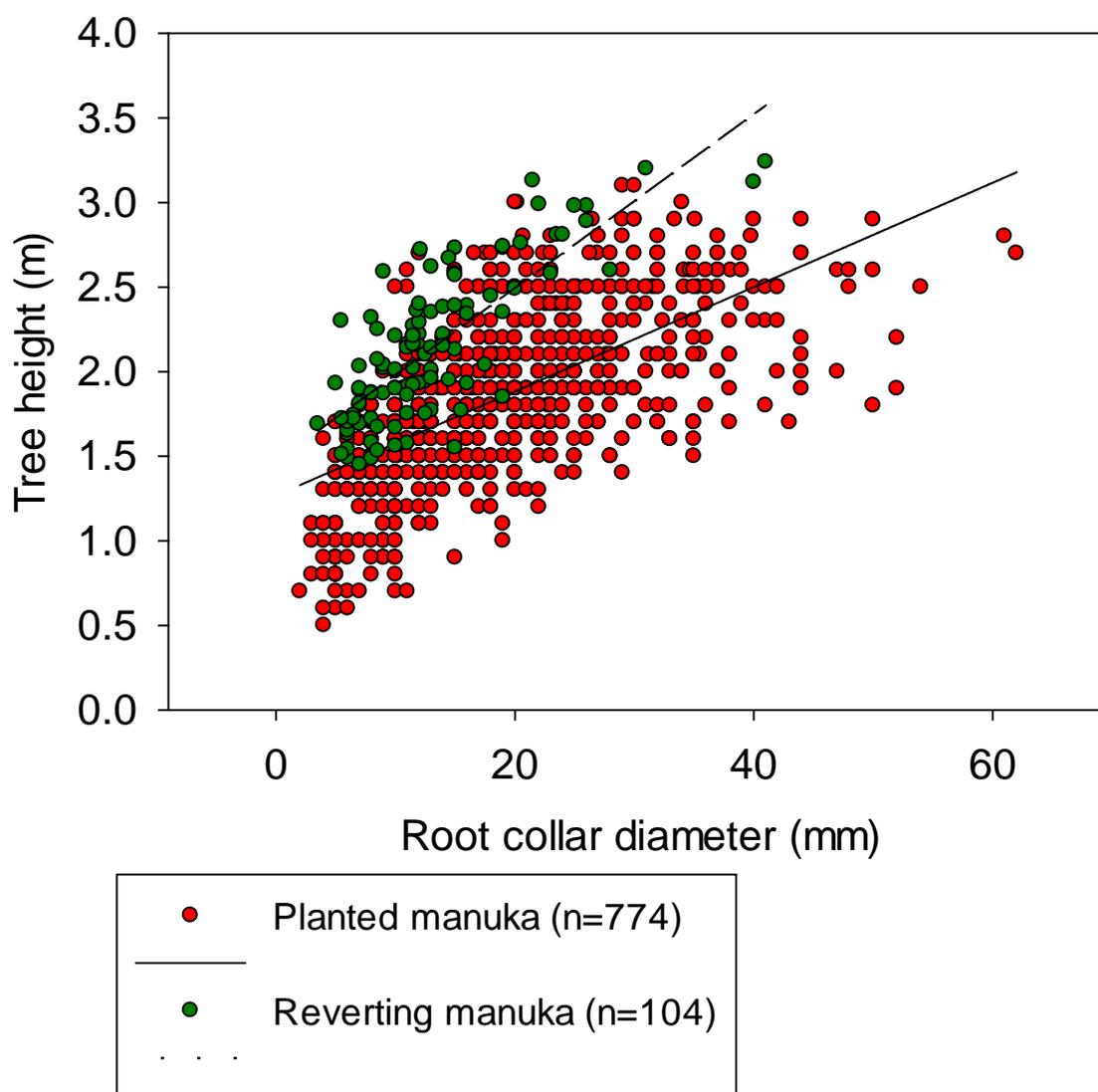


Figure 17 Linear regression of root collar diameter against tree height for space-planted mānuka at Lake Tutira and Puketoro Station combined, and for naturally reverting mānuka. Numbers in parentheses are the numbers of mānuka stems measured. Regression statistics (slope, intercept, r^2 , standard error of estimate), respectively, are given in Table 7.

Table 7 Regression statistics for root collar diameter against tree height for space-planted mānuka at Lake Tutira and Puketoro Station combined, and for naturally reverting mānuka

	r^2	P	Slope	Intercept	SEE*
Space-planted mānuka	0.404	<0.001	0.031	1.25	0.38
Natural reversion	0.621	<0.001	0.051	1.47	0.27

*Standard error of the estimate

4.4.6 General observations

Stem configuration

The majority of mānuka seedlings at the time of establishment were multi-stemmed with some plants having as many as 8 individual stems each with a separate root system. The supplier of the seedlings planted at Lake Tutira confirmed that no attempt was made to reduce the number of individual seedlings transplanted from seed trays to root trainers and that some of the plants are multi-stemmed before being planted in the field.

Grass suppression

Waist-high, rank grass and blackberry at Lake Tutira likely suppressed growth and/or have deformed the stature of mānuka seedlings with many displaying a bent lower stem. This was particularly evident on the landslide scars where mānuka has been slower to establish than the grasses and blackberry. Anecdotally, the large area of pre-planting release spraying may have given the blackberry a competitive edge over the mānuka. At Puketoro Station, areas of active earthflow displacement were deliberately left unplanted, and where sedge-like grasses were well established, no attempt was made to plant through these areas. This may account, in part, for the lower than prescribed planting densities on these sites.

Soil characteristics

Soil textures on earthflows at Puketoro tend to be heavier (silty clay loam or clay loam) compared with non-earthflow terrain (silt loam or sandy loam). Topsoil depths tended to be shallower on the earthflows (mean 0.1 m) compared with non-earthflow terrain (mean 0.157 m), but only at some sites. The differences were not significant at Puketoro (Owetea site of Basher et al. 2013).

On undisturbed sites at Lake Tutira, silt loams comprise a 0.2-m thick A-horizon underlain by a 0.15-m thick B-horizon of volcanic ash (Waimihia Lapilli), and 0.4 m of older finer-grained tephra of mid-Holocene age giving a mean depth of ~0.75 m. They are free-draining with tunnel gullies forming within the Waimihia Lapilli. Soils overlie a highly weathered C-horizon of mudstone and/or sandstone and limestone. In contrast, the mean soil depth on recent landslide scars is ~0.1 m, and on older scars is ~0.3 m. The deepest soils ~1.0 m occur on colluvial slopes where storm-initiated landslide debris has accumulated over many years (Preston 1999).

5 Implications of findings

It is well known that vegetation and in particular trees, improve slope stability and reduce erosion (e.g. Greenway 1987). Several above- and below-ground growth metrics are used to compare the performance of different species for performing this erosion “protection” or reinforcement function (Stokes et al. 2009).

Tree roots reinforce soil making it stronger. The tree canopy, through hydrological processes of interception and transpiration, tends to make the soil drier, which increases soil strength. Together, both factors tend to reduce the potential for slopes to fail. Species composition, growth rates, tree spacing and age influence the time (years after planting) at which plantings afford effective protection against the initiation of shallow landslides. Tree canopy closure is regarded as a key indicator of slope stability. Species that have fast growth rates and/or are planted at densities that enable root occupancy and canopy closure in the shortest time are intuitively likely to provide protection earliest.

However, without time series data on tree canopy growth (diameter) over a number of years, with which to model the rate of canopy closure, our best guesstimates are based on measurement of canopy dimensions from 3-year and 4-year old mānuka at Lake Tutira, and 2-year old mānuka plantings at Puketoro Station, relative to measurements of canopy dimensions of individual 1–8-year-old kānuka from naturally reverting stands (Fig. 18).

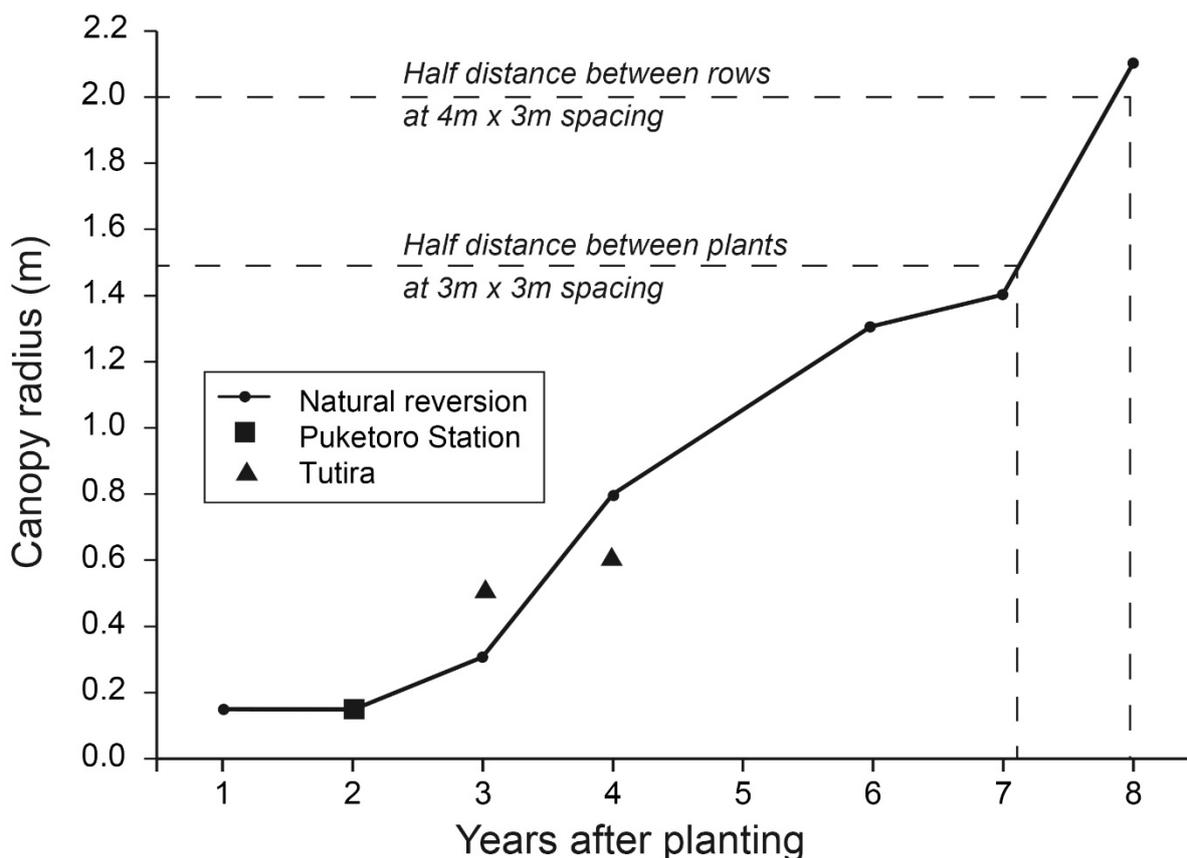


Figure 18 Mean, plot-based, canopy dimensions for space-planted mānuka at Lake Tutira and Puketoro Station relative to equivalent-aged canopy dimensions of kānuka from naturally reverting stands. Dashed lines indicate approximate time required by canopies of individual mānuka to cover half the distance between plants at an even spacing of 3 m by 3 m, or half the distance between rows planted 4 m apart, to attain canopy closure.

At Lake Tutira, for the mānuka plantings established on the best performing sites (stable ridges and spurs) in 2011 (4 years old), and 2012 (3 years old), the mean canopy diameter was measured at ~1.2 m (i.e. radius of 0.6 m). Assuming the actual spacing at the time of planting was 4 m between rows and 3 m between plants within a row, and assuming a conservative canopy growth rate of ~0.4 m (radius) per year to date and in the years to come, canopy closure between rows is likely 7–8 years after establishment (Fig. 18). Similarly, at Puketoro Station, for the mānuka plantings established on the best performing sites (stable ridges and spurs) in 2013 (2 years old), the mean canopy diameter was measured at just ~0.5 m (i.e. radius of 0.25 m). At 3 × 3 m spacing, canopy closure may well occur on the stable sites within 6–7 years of planting (Fig. 18).

However, as is the case for most native plantings, mānuka growth rates will increase exponentially during years 3 and 4, particularly as grass suppression decreases. Thus, at both these locations, canopy closure on the better sites may occur even earlier but for plantings on earthflows at Puketoro Station and on landslides at Lake Tutira, where gaps are created by high mortality rates, canopy closure will likely take considerably longer. At Puketoro Station, elevation and associated climatic factors are also likely to reduce growth rates and therefore the time (years after planting) to canopy closure. These estimates will also vary because of

differences in canopy form/shape that are unrelated to site differences between landform units (e.g. soil thickness, composition and texture, soil moisture, nutrients, aspect and altitude) but are instead potentially related to seed source genetics, and /or the ratio of single-stemmed to multiple-stemmed plants with the multiple-stemmed plants having a bushier and denser canopy than the more slender canopy of single-stemmed plants. Windthrow, toppling, and mānuka blight may also potentially delay canopy closure. Mānuka blight is caused by the scale insect *Eriococcus orariensis* Hoy and its accompanying sooty mold *Capnodium waited* Saccardo. Mortality due to mānuka blight can be high in drier East Coast areas, with the blight appearing 3–5 years after establishment. Additionally, the timing of canopy closure will be influenced by the rate of spread of self-sown seedlings derived from nearby mature stands of kānuka. At Tutira, such kānuka seedlings constituted up to 10% of the total number of seedlings present in some plots, particularly on colluvial slopes. There was no sign of self-sown regenerating mānuka or kānuka at the Puketoro Station sites.

As the canopy develops, evaporation of rainfall (interception and transpiration) and therefore its effects on the soil moisture regime of slopes (largely through hydrological processes, e.g. interception, evaporation, transpiration), will increase. In the East Coast of the North Island rainfall intercepted by the canopy of a closed stand of regenerating kānuka (*Kunzea ericoides* var. *ericoides*) accounted for 42% of the annual rainfall with interception losses higher in summer than during the winter months (Rowe et al. 1997). While interception loss as a percentage of rainfall is high compared with other interception studies of woody vegetation in New Zealand, the results are consistent with other studies if the annual losses are viewed in terms of annual rainfall, and the relationships between storm interception loss and rainfall are comparable with those for other vegetation communities including mānuka (Blake 1965; Aldridge & Jackson 1968), kāmahī (Jackson & Aldridge 1973), various forms of beech forest (Aldridge & Jackson 1973; Rowe 1975, 1979, 1983), and *Pinus radiata* (Fahey 1964; Pearce et al. 1987; Kelliher et al. 1992; Duncan 1995).

Although the above-ground growth performance of space-planted mānuka at these sites is of the same order of magnitude as for a naturally reverting kānuka stand of comparable age (Fig. 18), the level of erosion mitigation against landslide initiation at the time canopy closure is reached will not be as effective as has been previously shown for stands of naturally reverting mānuka and kānuka of similar age (Hicks 1991; Marden & Rowan 1995, Bergin et al. 1995). This is because: (i) the stand canopy is less dense (although individual canopy density and leaf area is likely higher), and will not be as effective in intercepting rainfall, throughfall will therefore be greater and as a consequence soils will remain wetter for longer; and (ii) as the stem density of space-planted mānuka is at least an order of magnitude less than for an equivalent aged stand of reverting mānuka/kānuka, the area of soil occupied by roots and the density of roots will be less, particularly between rows, and thus the soil–root reinforcement influences will be significantly less effective in preventing slope failure. Overall, these sites will remain vulnerable to storm events for longer.

6 Recommendations

- Canopy interception, soil–water utilisation, root biomass, and root development have been studied for naturally reverting stands of mānuka and kānuka but there is little quantitative information available for space-planted mānuka. With growing interest in the planting of mānuka on marginal land, there is a need for time-series data on changes in stand diversity, density, and in their above- and below-ground growth performance at the specified spacing prescribed for different marginal landforms.
- In particular, a time-series data base of below-ground growth metrics is required to better understand the effect planting density (spacing) and site factors have on the timing (years after planting) required for mānuka to provide an effective root-soil reinforcement function sufficient to ameliorate the impact of future storms.
- With the potential for further establishment of mānuka on marginal land (predominantly for honey production), and the introduction of a new Afforestation Grant Scheme (AGS), data on the above- and below-ground biomass sequestration rates by stands of mānuka established as low-density, plantation-style plantings will be of relevance to the national carbon (C) inventory system and policy to reduce net greenhouse gas emissions. Growth metrics from these plots would provide data for the development of mānuka-specific allometric equations for calculating carbon sequestration more accurately than is possible using generalised mixed-species equations developed for older natural forest stands. It is therefore proposed that additional PSP plots be installed in other regions where significant areas of marginal land representative of different landforms have been or are likely to be planted in mānuka, e.g. Northland, Taranaki, Waiararapa, and Manawatu-Wanganui, and where climatic and site factors could significantly affect growth rates.
- As a means of promoting rates of mānuka growth and survival, evaluate the effectiveness of practices used to suppress grass competition (e.g. pre-plant spot spraying, post-plant release spraying), and trial the periodic grazing of mānuka to prevent the development of rank grass.
- Plant mānuka at densities that will achieve the desired final stocking, allowing for mortality on sites affected by past and current erosion.

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8 References

- Aldridge R, Jackson RJ 1968. Interception of Rainfall by Manuka (*Leptospermum Scoparium*) at Taita New Zealand. *New Zealand Journal of Science* 11(2): 301–317.
- Basher L, Mc Neill S, Page M, Lynn I, Betts H, De Rose R, Marden M, Rosser B 2013. Soil carbon stocks and changes: carbon losses from erosion. Landcare Research Contract Report LC1563 prepared for Ministry of Primary Industries, Wellington. 42 p.
- Bergin D, Kimberley MO, Marden M 1995. Protective value of regenerating tea tree stands on erosion-prone hill country, East Coast, North Island, New Zealand. *New Zealand Journal of Forestry Science* 25(1): 3–19.
- Duncan, MJ 1995. Hydrological impacts of converting pasture and gorse to pine plantation, and forest harvesting, Nelson, New Zealand. *Journal of Hydrology (New Zealand)* 34: 15–41.
- Ekanayake J, Marden M, Watson AJ, Rowan D 1997. Tree roots and slope stability: A comparison between *Pinus radiata* (Radiata pine) and *Kunzea ericoides* (Kanuka). *New Zealand Journal of Forestry Science* 27(2): 216–233.
- Ekanayake JC, Phillips CJ, Marden M 2004. A comparison of methods for stability analysis of vegetated slopes. In: Barker DH, Watson AJ, Sombatpanit S, Northcutt B, Maglinao AR eds *Ground and water bioengineering for erosion control and slope stabilization*. Enfield, NH, Sciences Publishers. Pp. 171–181.
- Fahey BD 1964. Throughfall and interception of rainfall in a stand of radiata pine. *Journal of Hydrology (New Zealand)* 3: 17–26.
- Greenway DR 1987. Vegetation and slope stability. In: Anderson MG, Richards KS eds *Slope stability*. Chichester, UK, John Wiley. Pp. 187–230.
- Hicks D 1991. Erosion under pasture, pine plantations, scrub and indigenous forest: A comparison from Cyclone Bola. *New Zealand Forestry* 36(3): 21–22.
- Hurst JM, Allen RB 2007. A permanent plot method for monitoring indigenous forests: field protocols. Lincoln, Landcare Research New Zealand. 66 p.
- Jackson RJ, Aldridge R 1973. Interception of rainfall by kamahi (*Weinmannia mcemosa*) at Taita, New Zealand. *New Zealand Journal of Science* 16: 573–590.
- Kelliher FM, Whitehead D, Pollock DS 1992. Rainfall interception by trees and slash in a young *Pinus radiata* D. Don stand. *Journal of Hydrology* 131: 187–204.
- Marden M, Rowan D 1988. Protection value of different vegetation types in the East Coast Region after Cyclone Bola: a preliminary assessment. Unpublished Forest Research Institute Report. 14 p.
- Marden M, Rowan D 1993. Protective value of vegetation on Tertiary terrain before and during Cyclone Bola, East Coast, North Island, New Zealand. *New Zealand Journal of Forestry Science* 23: 255–263.

- National Water and Soil Conservation Organisation 1975. New Zealand Land Resource Inventory worksheets. Wellington, New Zealand, New Zealand Government Printer.
- Pearce AJ, O'Loughlin CL, Jackson RJ, Zhang XB 1987. Reforestation: on-site effects on hydrology and erosion, eastern Raukumara Range, New Zealand. *International Association of Hydrological Sciences Publication* 167: 489–497.
- Preston N 1999. Event-induced changes in land surface condition-implications for subsequent slope stability. *Zeitschrift für Geomorphologie* 115: 157–173.
- Rowe LK 1975. Rainfall interception by mountain beech. *New Zealand Journal of Forestry Science* 5: 45–61.
- Rowe LK 1979. Rainfall interception by a beech-podocarp-hardwood forest near Reefton, North Westland, New Zealand. *Journal of Hydrology (New Zealand)* 18: 63–72.
- Rowe LK 1983. Rainfall interception by an evergreen beech forest, Nelson, New Zealand. *Journal of Hydrology* 66: 143–158.
- Rowe LK, Marden M, Rowan D 1999. Interception and throughfall of kanuka (*Kunzea ericoides* var. *ericoides*), East Coast region, North Island, New Zealand, and implications for soil conservation. *Journal of Hydrology (NZ)* 38(1): 29–48.
- Stokes A, Atger C, Bengough AG, Fourcaud T, Sidle RC 2009. Desirable plant root traits for protecting natural and engineered slopes against landslides. *Plant Soil* 324: 1–30. doi: 10.1007/s11104-009-0159-y.
- Watson A, Marden M 2004. Live root-wood tensile strengths of some common New Zealand indigenous and plantation tree species. *New Zealand Journal of Forestry Science* 34(3): 344–353.
- Watson A, Marden M, Rowan D 1994. Tree species performance and slope stability. In: Barker DH ed. *Proceedings of Institute of Civil Engineers Conference, "Vegetation and slopes: stabilisation, protection and ecology"*, 29–30 September 1994, University Museum, Oxford, United Kingdom. Pp. 161–71.
- Watson AJ, Marden M, Rowan D 1997. Root-wood strength deterioration in kanuka after clearfelling. *New Zealand Journal of Forestry Science* 27(2): 205–215.
- Watson AJ, Phillips CJ, Simcock R 1998. Rooting depth investigations of indigenous plants: Tailings dam embankment-Martha Gold Mine, Waihi. Landcare Research Contract Report LC9798/90 prepared for Waihi Gold Mining Company Limited. 31 p.
- Watson A, O'Loughlin CL 1985. Morphology, strength and biomass of mānuka roots and their influence on slope stability. *New Zealand Journal of Forestry Science* 15(3): 337–348.
- Watson AJ, Phillips CJ, Marden M 1999. Root strength, growth, and rates of decay: root reinforcement changes of two tree species and their contribution to slope stability. *Plant and Soil* 217(1–2): 39–47.

Appendix 1 – Global Positioning System locations of permanent sample plots at Lake Tutira and at Puketoro Station

Plot distribution in relation to landform units is shown on Figs. 1 & 2.

Location	Year planted	Site number	Site code	Easting	Northing
Lake Tutira	2011	3949	Stable 1	E2848350	N6212804
		3927	Stable 1	E2846931	N6211704
	2012	3931	Stable 2	E2847097	N6211758
		3933	Stable 3	E2847542	N6212106
		3928	Landslide 1	E2847022	N6211611
		3929	Landslide 2	E2846997	N6211662
		3932	Landslide 3	E2847434	N6211811
		3930	Colluvial 1	E2847008	N6211740
		3934	Colluvial 2	E2847262	N6212128
		3935	Colluvial 3	E2847206	N6212018
		Puketoro Station	2013	3936	Stable 1
3937	Stable 2			E2953331	N6336717
3939	Stable 3			E2953184	N6336890
3938	Earthflow 1			E2953246	N6336808
3940	Earthflow 2			E2953096	N6336930
3944	Earthflow 3			E2952684	N6336034
3941	Slump 1			E2953117	N6336228
3942	Slump 2			E2953162	N6336140
3943	Slump 3			E2952961	N6336248