Awapapa Station Landslip Analysis

Spatial analysis on drivers of landslips for Awapapa and Dumgoyne Stations

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Environmental Science

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Executive summary

Landslips or landslides are an enduring problem for Hawke's Bay and the greater East Coast of the North Island. Erosion is a natural process and is influenced by slope, geology, soil type, aspect, and rainfall. In addition to these natural processes, landslip erosion can also be exacerbated by unsuitable land use, loss of land cover, and poor land management. Reducing the impact of these latter drivers of erosion has long been identified as an effective way to reduce landslips on vulnerable hill country.

Land management practices to keep topsoil where it is, and to reduce erosion, are well-engrained in many of Hawke's Bay's rural communities given previous adverse weather events. One method of trying to reduce erosion in steep hill country is by planting trees, and poplar and willow poles have proven popular for erosion control. The trees' root systems improve the stability of hillsides, while also providing livestock shelter and potentially forestry income.

Awapapa and Dumgoyne Stations in the Hangaroa Catchment of northern Hawke's Bay and Gisborne have been extensively planted for poplars for the last four decades. Currently 30% of Awapapa Station is planted in trees, and planting at Dumgoyne got underway more recently. Cyclone Gabrielle, provided an opportunity to assess the efficacy of poplar poles at reducing the number of landslips on his properties.

An investigation was commenced to determine the efficacy of planting trees as a method of erosion mitigation on two farms. The analysis follows Cyclone Gabrielle in February 2023 and previous recent adverse weather events dating back to March 2022. This study compared the occurrence of landslips on these properties and analysed the impact of landcover, land use capability, soil type, slope, rainfall, aspect and vegetation on landslip areas and counts, or spatial frequency. It found that the presence of trees at Awapapa Station likely influenced a reduction in slips by 71% when adjusting for farm size and slope. Adjusting for farm size alone, vegetation reduced slips by 45% across the two farms. Grassland is the least stable vegetation cover and is the dominant cover in which slips occurred on both properties. Awapapa had less than half the rate of slips per hectare at 1.63, whereas Dumgoyne had 3.66 slips per hectare.

In addition to vegetation cover, slope had a discernible influence on landslips, with soil type and rainfall just outside the bounds of statistical certainty. Therefore, as expected slope is a critical contributing factor to landslips. Space-planting slopes above 8° in trees is effective to reduce the likelihood of erosion during severe weather events.

1 Introduction

Landslips are an enduring problem for Hawke's Bay and the greater East Coast of the North Island (HBRC, 1996). Alongside natural influences on erosion, such as slope, soil type, aspect, and rainfall, are anthropogenic drivers such as land use, land cover and land management. All of these are critical factors that influence landslip susceptibility (Smith et al., 2021, 2023; Spiekermann et al., 2022). Controlling anthropogenic drivers has long been identified as necessary to mitigate adverse outcomes in vulnerable areas (HBRC, 1996). Stakeholders can implement measures to reduce the erosion of sediment from rural areas by planting susceptible slopes, reducing grazing rates, or retiring blocks from production. These practices are well entrenched in many rural communities on the East Coast and in Hawke's Bay (Hawke's Bay Catchment Board & Regional Water Board, 1988), however, anecdotal evidence alone of successful mitigation implementation is often not enough to garner government financial support, policy change or modify industry practices that lead to successful interventions. Therefore, a case study is used here to analyse factors influencing landslips following the devastating Cyclone Gabrielle. This approach applies spatial and regression analysis to quantify drivers of landslips across two contrasting farms.

2 Background

Hawke's Bay Regional Council (HBRC) was approached to undertake an empirical investigation on two farms that are managed in the Hangaroa Catchment.

1) Awapapa Station has been extensively planted with poplar poles that are well-established in certain areas. An initial survey by Gisborne District Council calculated the vegetated extent of Awapapa Station at 30% (E. Perez Garcin, personal communication, May 2023).
2) Dumgoyne Station, a predominantly grassland farm with half of it currently undergoing planting as part of the operation.

Given this situation, a hypothesis was developed to discover 'the influence of vegetation cover on erosion mitigation' using the two farms for analysis.

3 Method

The analysis involved two parts, 1) spatial regression analysis of variables that may influence slips, and 2) a weighted statistical investigation into the presence of slips by farm given the outcome of Part 1.

Before the statistical analysis, all visible landslips on the two farms were mapped alongside vegetation cover. Landslips were mapped at 1:600 scale and vegetation at 1:1200 scale. Note that the landslip area includes both scar and depositional tail given the difficulty to discern between the two in imagery taken recently after the Cyclone Gabrielle event. Slips are not confined to this event but may also include some that formed in preceding events in March 2022 and Cyclone Hale in January 2023. Other datasets analysed were: land cover, land use, soil type, geology, slope, aspect, rainfall, waterways and aerial photography provided by Gisborne District Council. Geology was subsequently dropped from the analysis as it was somewhat homogenous across the farms. Similarly, waterways were also dropped given the complexity of the relationship with landslips. Statutorily the farms reside in the Gisborne District, nonetheless, they fall within the Wairoa River catchment of Hawke's Bay. Figure 1 shows the location of the farms and the visual assessment of vegetation coverage.

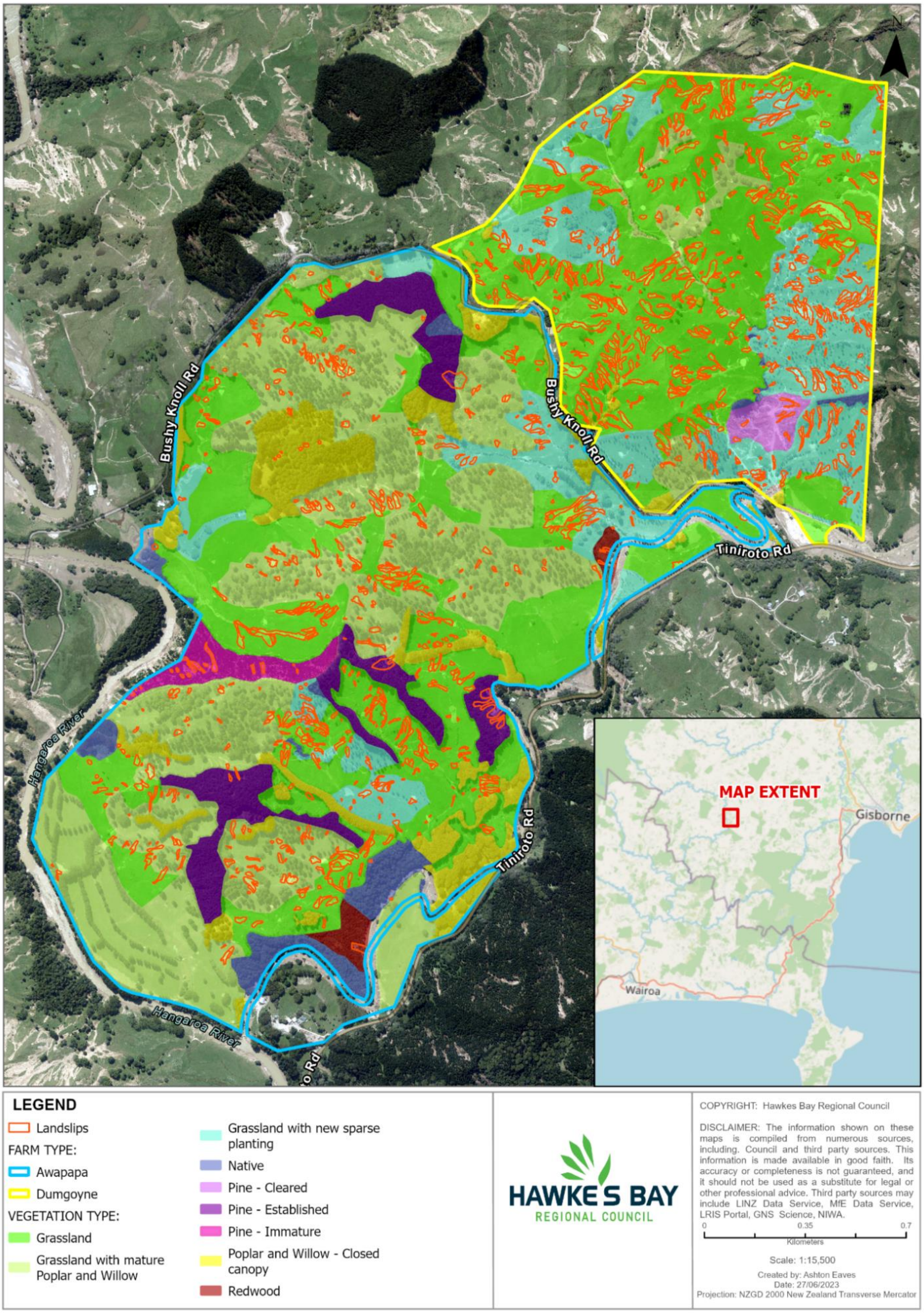

Figure 1 Farm location map with the landslip area and vegetation layer used for spatial analysis.

3.1 Part 1

Part 1 utilised regression analysis in Python on mapped landslips and mapped possible drivers, or influencers, of landslips. Landslip size was set as the dependent variable against the independent variables of:

- Farm (FarmLookup for Awapapa or Dumgoyne)
- Landcover (LCDB5Lookup defined by the Land Cover Database Version 5, Manaaki Whenua Landcare Research (MWLR))
- Land use capability (lcorrclass defined by MWLR)
- Soil type (SoilLookup defined by MWLR in S-Map)
- Slope
- Rainfall (RainGridcodeSynth which analysed antecedent rainfall between the 20th of February 2022 and the 20th of February 2023 with synthetic data for the Hangaroa station)
- Aspect
- Vegetation (VegetationLookup defined by desktop survey).

An influence was determined by having a statistical significance equal to or less than 0.05, or the probability that landslips are influenced by a variable is 95% or greater ($P \leq 0.05$). Regression analysis on the above-mapped outputs in Python determined p-values alongside other useful metrics such as the R-squared, a 'goodness of fit' measure for variable relationships. The base code of spatial regression in Python was adapted from Rey et al. (2020). The code is available on request from the author.

3.2 Part 2

Part 2 utilised weighted statistical analysis and normalisation to study the influence of vegetation and slope as two statistically significant drivers of landslips derived from Part 1. Thus, landslip areas and frequency counts were reported by farm area, vegetation cover and slope. See Appendix A for the various spatial output tables and Appendix B for the mathematical logic to determine the land use influence.

The analysis applied a weighting approach to extrapolate the influence of vegetation cover. Here both farm size and slope were weighted and normalised to account for their influence. –For example, Awapapa Station makes up 68% (364 ha) of the area, and Dumgoyne only 32% (170 ha). Equation 1 illustrates the calculation for weighting slip area as a function of the farm area. Equation 2 applies the weighting to the slip area. Then Equation 3 converts this result into a ratio for later application.

$$WF_{AD} = \left\{ \frac{F_{A,D}}{\left(\frac{F_A + F_D}{2}\right)} \right\} \quad (1)$$

Where: $WF_{A,D}$ = Weighted farm at an aggregated level
$F_{A,D}$ = Farm area (Awapapa or Dumgoyne, ha)

$$WA_{A,D} = \left(WF_{A,D} \times A_{A,D}\right) \quad (2)$$

Where: WA = Weighted slip area
$A_{A,D}$ = Slip area (ha)

$$WSR_{A,D} = \left(\frac{WA_{A,D}}{\sum WA_{A,D}}\right) \quad (3)$$

Where: $WSR_{A,D}$ = Weighted slip area as a ratio

Next, vegetation requires aggregation to define grassland against vegetated cover. Equation 4 illustrates this for grassland and Equation 5 for areas with vegetated cover.

$$V1_{A,D} = \left(\sum_{i=1}^{2} i\right) \quad (4)$$

Where i = Vegetation type
V1 = Vegetation class grassland (Awapapa or Dumgoyne)

$$V2_{A,D} = \left(\sum_{i=3}^{9} i\right) \quad (5)$$

Where: V2 = Vegetation class vegetated cover (Awapapa or Dumgoyne)

Next, adjusting for slope applies similar steps as above to weigh the proportion of slips that occurred in each slope band per farm. For example, there were 196 ha of land classified in the 8 – 15° band with 20 ha of landslips occurring. There are 6 slope bands for Awapapa and 5 slope bands for Dumgoyne. Equation 6 is similar to Equation 1 to define the slope weight. Equation 7 then multiplies the slope weight by the slope area to define the slope-weighted area. Again, this is turned into a ratio for later comparison in Equation 8. Next, Equation 9, multiplies the slip area by the slope weighted ratio (slope influence) by the weighted slip ratio (farm influence).

$$SW_{AD} = \left\{ \frac{ST_{A,D}}{\left(\frac{\sum_1^6 ST_A + \sum_1^5 ST_D}{11}\right)} \right\} \quad (6)$$

Where: $SW_{A,D}$ = Slope Weight
$ST_{A,D}$ = Slope Type (Awapapa or Dumgoyne, ha)

$$SWA_{A,D} = (SW_{A,D} \times SA_{A,D}) \quad (7)$$

Where: SWA = Slope Weighted Area
$SA_{A,D}$ = Slope Area (ha)

$$SWR_{A,D} = \left(\frac{SWA_{A,D}}{\sum SWA_{A,D}}\right) \quad (8)$$

Where: $SWR_{A,D}$ = Slope weighted area as a ratio

$$SAA_j = \left(A_j \times SWR_{A,D} \times WSR_{A,D}\right) \quad (9)$$

Where: j = Slope Type
SAA = Slip area adjusted to slope ratio & farm ratio

Finally, the matrix is summed to reveal the difference between the two farms, as outlined in Equation 10. Here *i* summarises the two vegetation types by farm (2 types on Awapapa and 2 on Dumgoyne) and *j* summarises the 6 slope bands into one.

$$T = \sum_{i=1}^{2}\sum_{j=1}^{6}(SAA_D - SAA_A) \quad (10)$$

Where: T = Totalled difference between Dumgoyne and Awapapa stations

For context, Figure 2 shows the quantification of vegetation cover by area for each farm in the analysis.

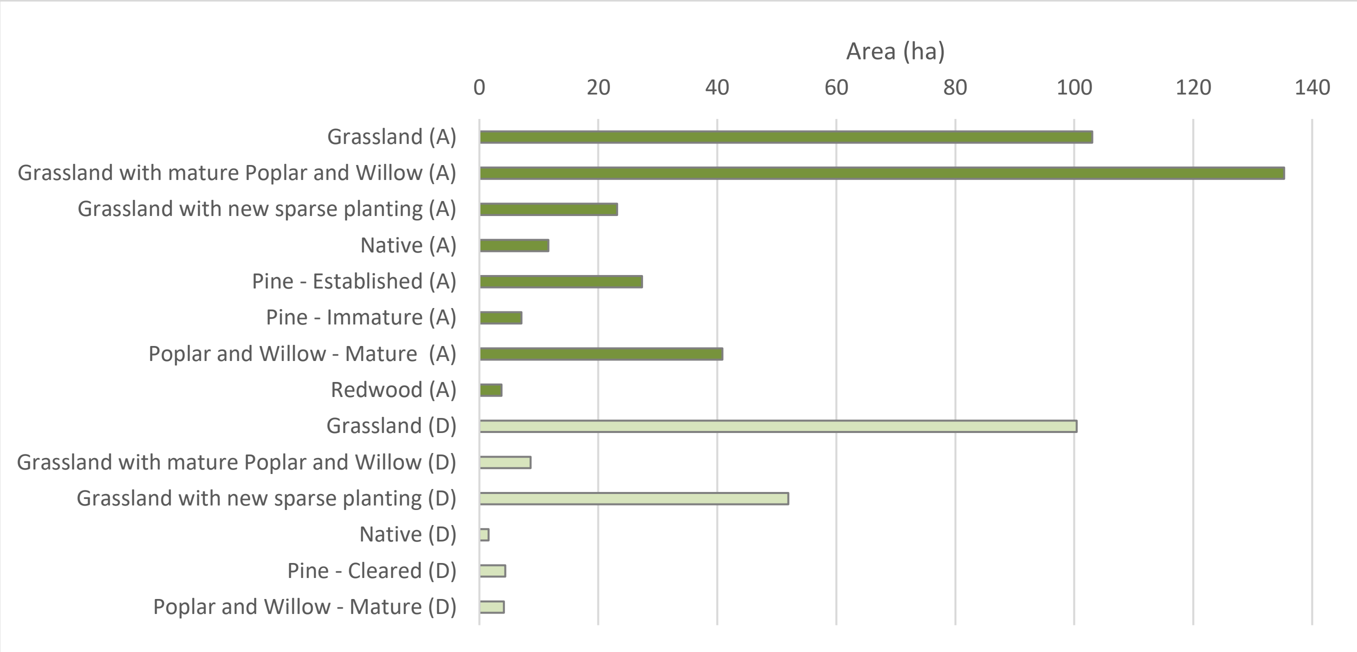

Figure 2 Vegetation cover by area and farm type. (A) represents Awapapa Station and (D) represents Dumgoyne. Grassland between the two farms is similar, yet mature poplar and willow plantings are significantly more on Awapapa Station.

Similarly, Figure 3 shows the quantification of the slope by area for each farm to provide context for the results. Slopes of 8 – 15° are most common, particularly for Awapapa Station.

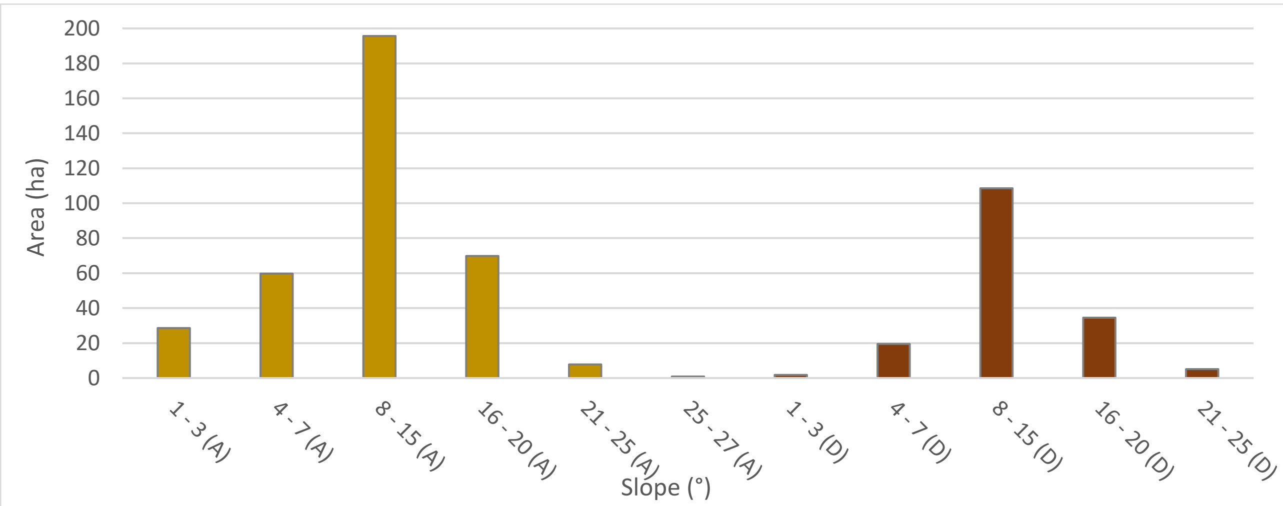

Figure 3 Slope by area and farm type with categorisation by Land Use Capability guidelines. (A) represents Awapapa Station and (D) represents Dumgoyne.

4 Results

Similarly, the results are in two parts, 1) spatial regression analysis, and 2) a statistical investigation into the presence of slips by farm and driver.

4.1 Part 1

The regression analysis highlights two main findings, as shown in Table 1. Firstly, slope and vegetation are statistically significant with p-values less than 5% ($p < 0.05$). Secondly the R-squared value of 0.056 suggests a very weak relationship, whereby these factors explain only a small proportion of the total variability.

Given the first finding, we can conclude that the area of landslips is influenced by the presence of steeper slopes ($p < 0.001$) and vegetation cover ($p < 0.001$). Soil type ($p = 0.06$) and rainfall ($p = 0.09$) illustrated that there is a relationship, but they are just outside acceptable statistical bounds. The small study area and coarse-resolution datasets applied at the farm scale possibly led to poor statistical significance for these and the other variables tested. Conversely, the aspect had a relatively fine spatial resolution but also produced an insignificant result which requires further investigation.

Looking into finding 2, the low R-squared value of 0.056 shows how the independent variables collectively explain only a small proportion of the total variability in the dependent variable of landslip area. This could be explained by 1) the small spatial scale of a farm leading to weaker relationships in the data. 2) There may be missing variables from the regression model that have a meaningful relationship with the landslip area. 3) Multicollinearity could also be a factor here as there is likely a high correlation among independent variables which leads to significant p-values for the individual coefficients, but a low overall R-squared value. Further investigation is needed across more sites.

Table 1 Spatial regression analysis in Python for Awapapa and Dumgoyne Stations.

```
----------
SUMMARY OF OUTPUT: ORDINARY LEAST SQUARES
----------------------------------------
Data set            :     unknown
Weights matrix      :        None
Dependent Variable  :  Shape_Area                Number of Observations:        1216
Mean dependent var  :    273.8672                Number of Variables   :           9
S.D. dependent var  :    368.6440                Degrees of Freedom    :        1207
R-squared           :      0.0564
Adjusted R-squared  :      0.0501
Sum squared residual:155803826.593                F-statistic           :      9.0182
Sigma-square        :  129083.535                Prob(F-statistic)     :   4.393e-12
S.E. of regression  :     359.282                Log likelihood        :   -8875.987
Sigma-square ML     :  128128.147                Akaike info criterion :   17769.975
S.E of regression ML:    357.9499                Schwarz criterion     :   17815.904

------------------------------------------------------------------------------------
            Variable     Coefficient       Std.Error     t-Statistic     Probability
------------------------------------------------------------------------------------
            CONSTANT     306.2153902     219.2718183       1.3965105       0.1628176
          FarmLookup       3.5632512      27.5079986       0.1295351       0.8969558
         LCDB5Lookup      -2.4660159       9.1417911      -0.2697519       0.7873972
          lcorrclass     -22.8013877      22.1794926      -1.0280392       0.3041374
          SoilLookup     -16.1771744       8.6644758      -1.8670690       0.0621342
               Slope      13.1026957       3.0696084       4.2685235       0.0000212
              Aspect       0.0806553       0.0972438       0.8294135       0.4070345
    VegetationLookup      30.5686579       6.6204648       4.6172978       0.0000043
   RainGridcodeSynth      -0.1166295       0.0699513      -1.6672950       0.0957152
------------------------------------------------------------------------------------
```

4.2 Part 2

As mentioned earlier, Part 2 measures the influence of vegetation and slope on the occurrence of landslips. Results are reported as either count per hectare, percentage area, percentage count or normalised values of the two.

Figure 4 shows the number of slips per hectare by each farm. Notably, the rate of slips for Dumgoyne Station is 3.66 ha^{-1} whereas for Awapapa the rate is lower at 1.63 ha^{-1}. Most slips in Dumgoyne occur in grassland, whereas on Awapapa, slips predominantly occur in both grassland and grassland with mature poplar and willow. Note that the areas in pine, native and redwood were not large enough to confidently conclude.

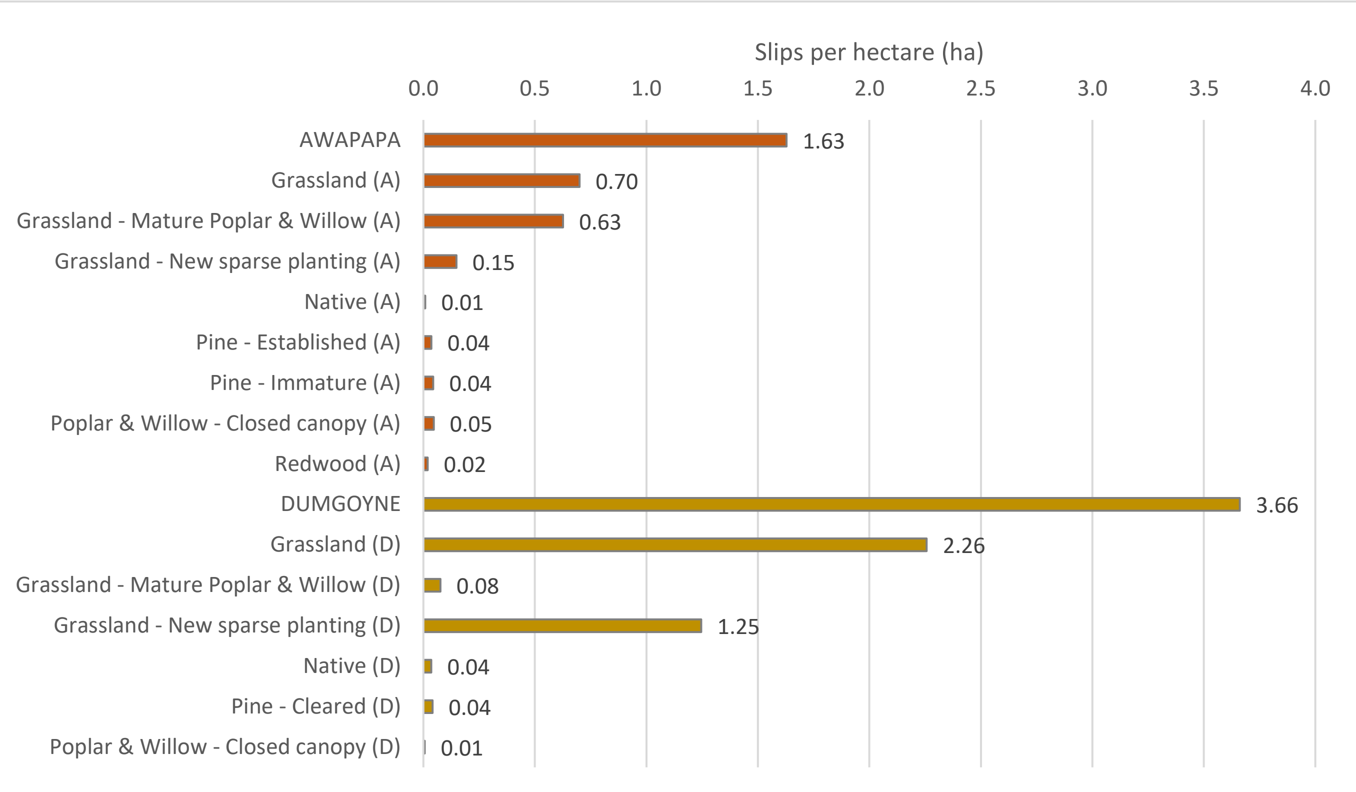

Figure 4 The number of slips per hectare for each farm and by vegetation type.

The difference between the two farms in an aggregated form is shown in figure 5. The quantum of landslips at Awapapa Station covered 15 ha, whereas Dumgoyne had 18 ha coverage, giving a total of 33 ha. Noticeably, Awapapa Station is significantly bigger than Dumgoyne but has a smaller area of slips covering its surface, hence the need for weighting by area. Similarly, looking at the number of slips, Dumgoyne has a slightly higher count of slips (612 or 51% compared to 593 or 49%). However, when weighted by area, Awapapa Station has a noticeably smaller area covered by landslips (27.6% compared to 72.4% on Dumgoyne) and count of slips (30.8% compared to 69.2%). Thus, when weighting by farm area alone, the quantum of landslips by area was 44.8% less (and 38.4% less by count) on Awapapa Station compared to Dumgoyne.

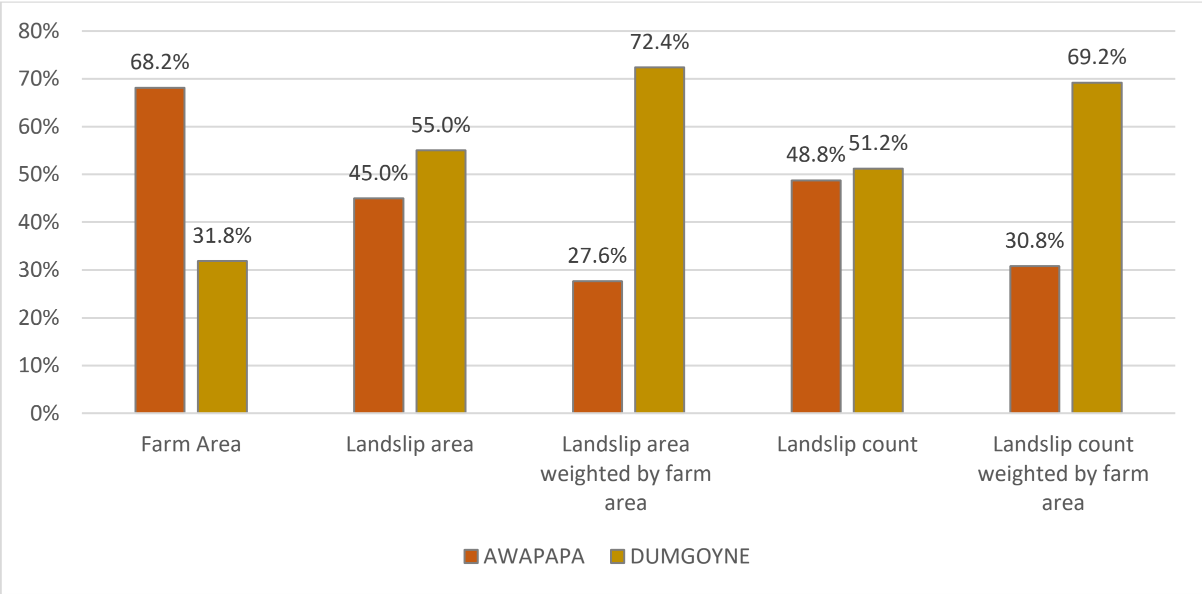

Figure 5 Aggregated farm proportions for landslip areas and counts, raw and weighted.

When looking at the type of land cover in which landslips occurred, it is useful to normalise against the predominant land cover type for comparison against the other types. Here the other land covers are compared to Awapapa grassland as the control (100%). Thus, if a landcover reduces the presence of slips, it will have a smaller landslip area relative to the grassland control. Figure 6 shows a reduction in slips on Awapapa of 45% where grassland has mature poplars and willows and a 98% reduction where there is a closed canopy. Conversely, Dumgoyne grassland is 60% more likely to slip than Awapapa grassland. Therefore, grassland on Dumgoyne Station is by far the dominant vegetation cover in which slips occur. This is understandable given its shallow root structure and anecdotal evidence from the farming community. However, desktop surveys (such as this one) introduce an uncertain level of bias as not all slips under trees can be captured given obscuration by canopy cover. Nonetheless, debris tails exiting closed-canopy vegetation were mapped and extended into the vegetation to define an approximate the shape.

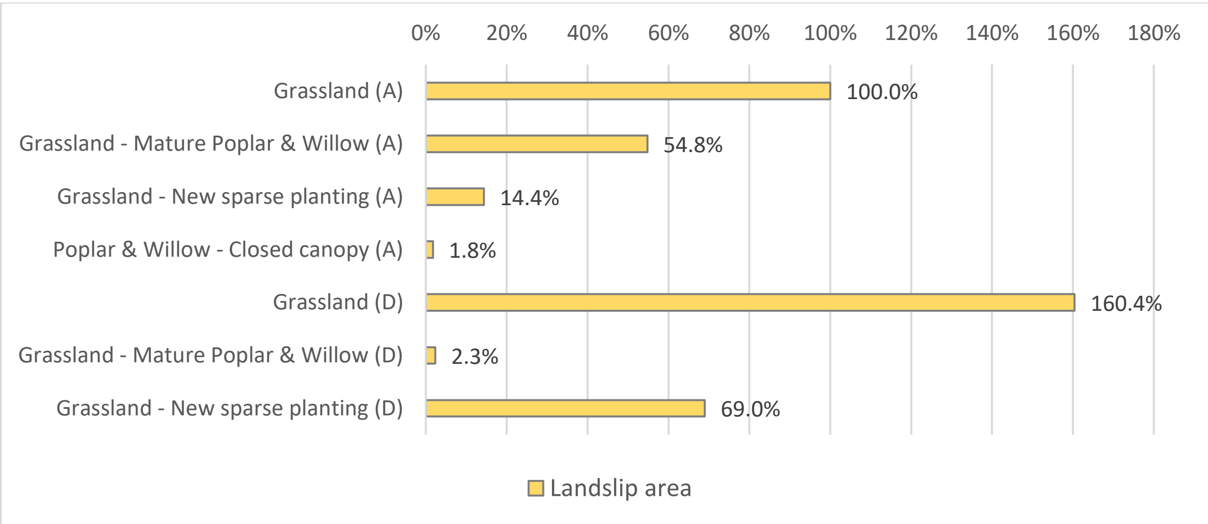

Figure 6 The influence of land cover on landslip areas normalised to Awapapa grassland for Awapapa (A) and Dumgoyne (D) Stations.

The slope is also a critical contributing factor to landslips. Figure 7 shows the quantum of an area that has slipped normalised to Awapapa grassland by farm type and slope in degrees. Interestingly, slopes between

8° and 15° on Dumgoyne Station are most likely to fail, with an 86.3% higher failure rate. Awapapa also had its highest number of failures at this slope with 5.9 ha of landslips. More slips did not occur at higher increments because the most common slope typology on the farms is 8° – 15° totalling 304 ha (57%). Why there is such a significant difference between the two grassland types needs further investigation to discover the possible differences.

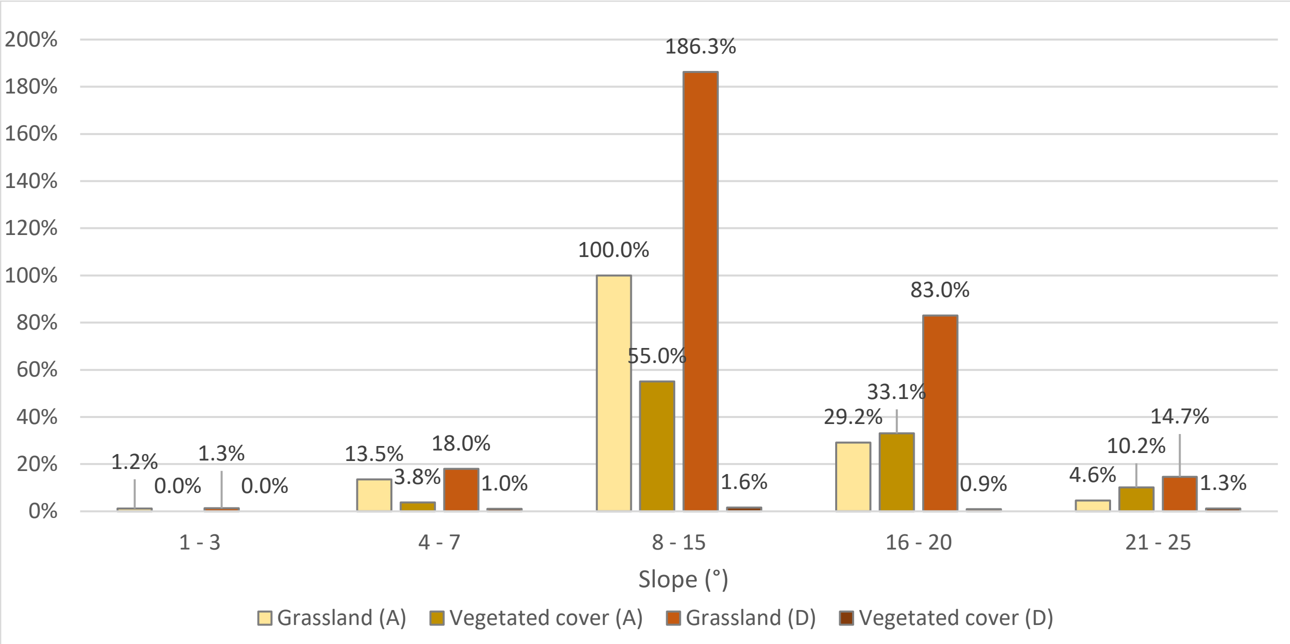

Figure 7 Landslip areas normalised to Awapapa Station grassland with a slope of 8 – 15°. Awapapa grassland sustained 5.9 ha of landslips at this slope.

Next, Figure 8 sums up the normalised proportion of landslip area by land cover with totals for each farm. The normalisation accounts for farm size and slope. Landcover is aggregated into grassland or vegetated cover, except for 'grassland with poplar and willow' which is subsumed into vegetated cover to help define the influence of vegetation. Therefore, when accounting for the difference in farm size and accounting for the difference in slopes prone to failure on each farm, it is estimated that the vegetation cover of trees likely influenced a reduction in slips by 71% on Awapapa Station.

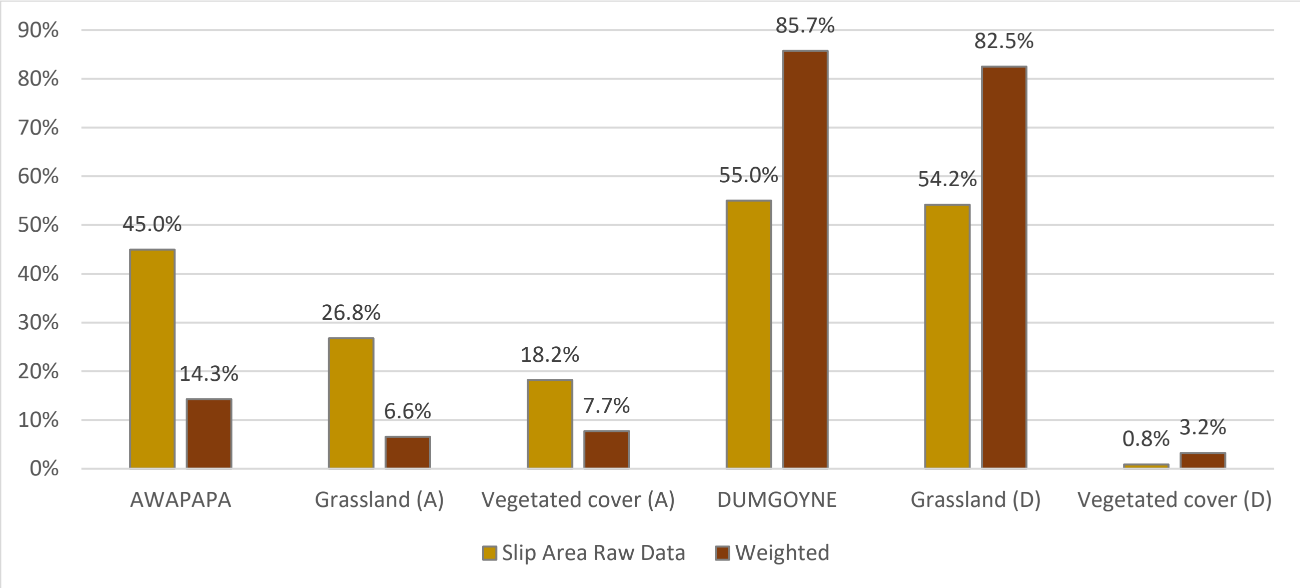

Figure 8 Slip area by land cover normalised by slope and farm area for Awapapa (A) & Dumgoyne (D) Stations. The raw data is added to the weighted data for comparison.

Finally, to justify this value it is useful to visualise the slip density. Kernel density estimation (KDE) was conducted to see whether this result correlates spatially. KDE is a non-parametric technique used to estimate the probability density function (PDF) of a random variable based on a given set of observations. It works by placing a kernel function on each observation and summing them up to obtain the overall estimated density. Here, point locations for each slip were used to determine the spatial density for both farms allowing us to visually infer that Dumgoyne Station has been significantly impacted more than Awapapa (Figure 9).

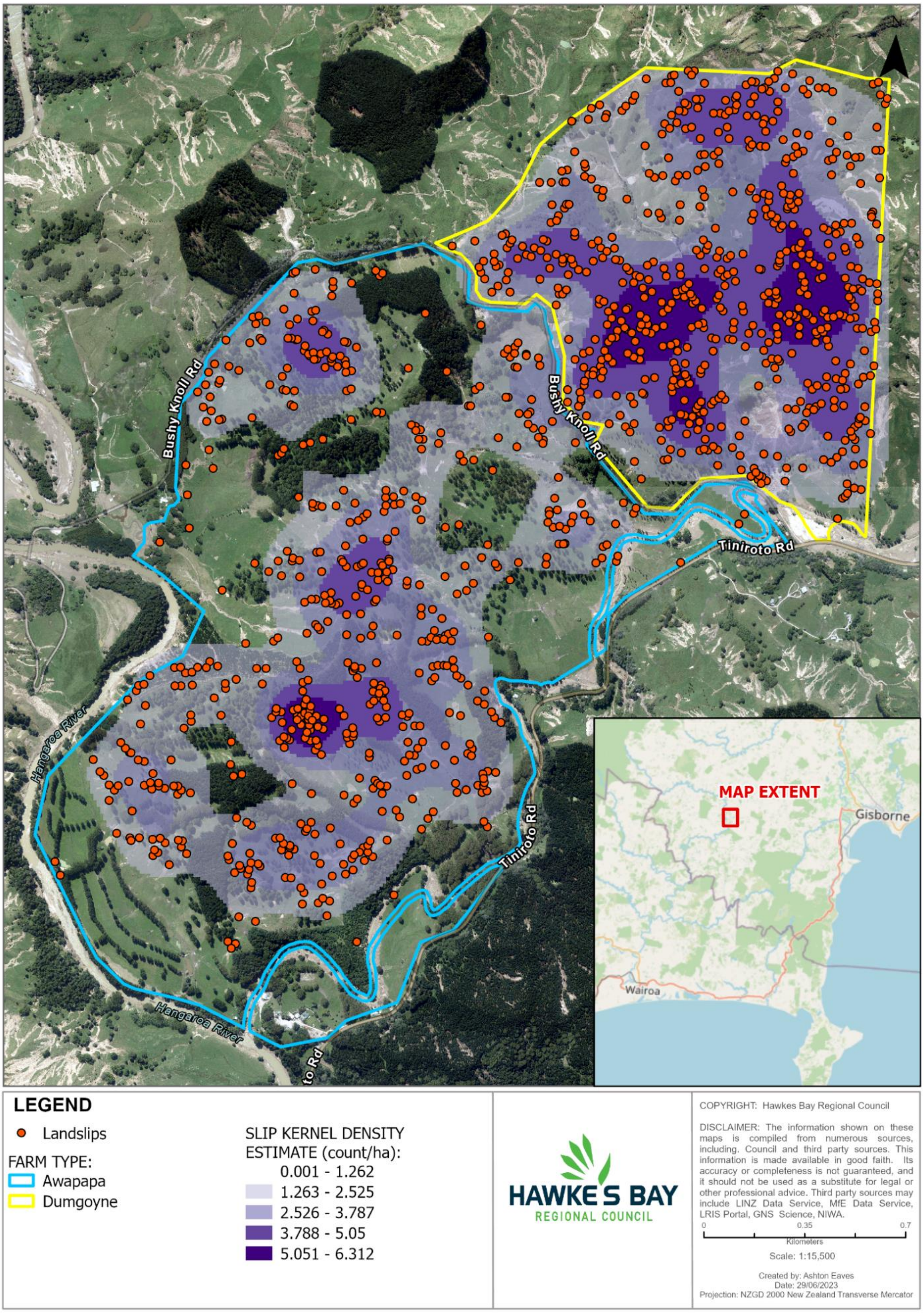

Figure 9 Kernel Density Estimates for Awapapa & Dumgoyne Stations. Density is calculated as the landslip count per hectare. Noticeably Dumgoyne is more heavily impacted by slips.

5 Conclusion

This investigation supports tree planting as an effective method of erosion mitigation. Grassland was the dominant vegetation cover in which slips occurred on these properties, and therefore grassland is the least stable vegetation cover. Awapapa Station has tree cover of approximately 30% and less than half the rate of slips per hectare than Dumgoyne Station. This analysis suggests that the presence of trees at Awapapa likely influenced a reduction in slips by 45% when adjusting for the difference in farm sizes alone. In addition to vegetation cover, slope also influenced the area of landslips on both properties. Of these, slope is a particularly critical contributing factor to landslips. Slopes between 8° and 15° had the highest failure rates on both farms given that the farms predominantly fall into this category. When adjusting for the differing slope profiles of the farms as well as the different farm areas, the reduction in slips due to vegetation cover increases to 71% for this study area. The findings of this report support planting slopes above 8° in trees for effective reduction in the likelihood of erosion during severe weather events.

6 References

Hawke's Bay Catchment Board, & Regional Water Board. (1988). *Sustainable Landuse After Cyclone Bola*. Hawke's Bay Catchment Board.

HBRC. (1996). *Sustainable Land: Protecting your farm from storm damage*.

Rey, S. J., Arribas-Bel, D., & Wolf, L. J. (2020). *Spatial Regression*. https://geographicdata.science/book/notebooks/11_regression.html

Smith, H. G., Neverman, A. J., Betts, H., & Spiekermann, R. (2023). The influence of spatial patterns in rainfall on shallow landslides. *Geomorphology*, *437*.

Smith, H. G., Spiekermann, R., Betts, H., & Neverman, A. J. (2021). Comparing methods of landslide data acquisition and susceptibility modelling: Examples from New Zealand. *Geomorphology*, *381*.

Spiekermann, R. I., Smith, H. G., McColl, S., Burkitt, L., & Fuller, I. C. (2022). Development of a morphometric connectivity model to mitigate sediment derived from storm-driven shallow landslides. *Ecological Engineering*, *180*, 106676. https://doi.org/10.1016/j.ecoleng.2022.106676

Appendix A Spatial output tables and the mathematical progression

Table of aggregated weighting at the farm scale. Weighting percentage change is used to define the difference in farms.

AreaType	Area (ha)	Area (%)	Count	Count (%)	SlipsPerHa	Weight	SlipPropFarm	Pcnt	Difference
Farms									
Awapapa	364.090	0.682	593	0.488	1.629	0.734	10.987	0.276	
Dumgoyne	170.150	0.318	623	0.512	3.661	1.570	28.772	0.724	
TOTAL	**534.240**	**1.000**	**1216**	**1.000**	**2.276**	**2.304**	**39.759**	**1.000**	**0.447**
Average Area	**267.120**								

Table of landslips - scars & debris tails totals and by vegetation type

Vegetation	Area (ha)	Area (%)	AreaWt	AreaWt Pcnt	Count	CntPerHa	CntPcnt	CntWt	CntWt Pcnt
AWAPAPA	**14.975**	**0.450**	**10.987**	**0.276**	**593**	**1.63**	**0.488**	**435.063**	**0.308**
Grassland (A)	7.797	0.234	5.720	0.144	255	0.70	0.210	187.085	0.132
Grassland - Mature Poplar & Willow (A)	4.271	0.128	3.133	0.079	228	0.63	0.188	167.276	0.118
Grassland - New sparse planting (A)	1.120	0.034	0.822	0.021	54	0.15	0.044	39.618	0.028
Native (A)	0.023	0.001	0.017	0.000	3	0.01	0.002	2.201	0.002
Pine - Established (A)	1.079	0.032	0.792	0.020	13	0.04	0.011	9.538	0.007
Pine - Immature (A)	0.356	0.011	0.261	0.007	16	0.04	0.013	11.739	0.008
Poplar & Willow - Closed canopy (A)	0.137	0.004	0.101	0.003	17	0.05	0.014	12.472	0.009
Redwood (A)	0.193	0.006	0.141	0.004	7	0.02	0.006	5.136	0.004
DUMGOYNE	**18.327**	**0.550**	**28.772**	**0.724**	**623**	**3.66**	**0.512**	**978.053**	**0.692**
Grassland (D)	12.505	0.375	19.631	0.494	384	2.26	0.316	602.845	0.427
Grassland - Mature Poplar & Willow (D)	0.183	0.005	0.287	0.007	13	0.08	0.011	20.409	0.014
Grassland - New sparse planting (D)	5.378	0.161	8.443	0.212	212	1.25	0.174	332.821	0.236
Native (D)	0.092	0.003	0.145	0.004	6	0.04	0.005	9.419	0.007
Pine - Cleared (D)	0.164	0.005	0.258	0.006	7	0.04	0.006	10.989	0.008
Poplar & Willow - Closed canopy (D)	0.005	0.000	0.008	0.000	1	0.01	0.001	1.570	0.001
TOTAL	**33.302**	**1.000**	**39.759**	**1.000**	**1216**		**1.000**	**1413.116**	**1.000**

Table of slope layer output

Slope	Area (ha)	Area (%)	AreaWt	AreaWtPcnt
1 - 3 (A)	28.607	0.054	1.691	0.016
4 - 7 (A)	59.715	0.112	0.810	0.008
8 - 15 (A)	195.634	0.368	0.247	0.002
16 - 20 (A)	69.826	0.131	0.693	0.007
21 - 25 (A)	7.802	0.015	6.199	0.060
25 - 27 (A)	0.897	0.002	53.909	0.518
1 - 3 (D)	1.811	0.003	26.709	0.257
4 - 7 (D)	19.514	0.037	2.478	0.024
8 - 15 (D)	108.535	0.204	0.446	0.004
16 - 20 (D)	34.548	0.065	1.400	0.013
21 - 25 (D)	5.099	0.010	9.485	0.091
TOTAL	**531.988**	**1.000**	**104.067**	**1.000**
Awapapa	**362.481**	**0.681**		
Dumgoyne	**169.507**	**0.319**		
Average Area	**48.363**			

Table of vegetation layer output

Vegetation	Area (ha)	Area (%)	AreaWt	AreaWtPcnt	SumVeg	SumVegPcnt
Grassland (A)	103.026	0.197	0.363	0.005	0.028	0.028
Grassland - Mature Poplar & Willow (A)	135.288	0.259	0.276	0.004	0.316	0.311
Grassland - New sparse planting (A)	23.150	0.044	1.614	0.023		
Native (A)	11.595	0.022	3.222	0.046		
Pine - Established (A)	27.341	0.052	1.366	0.019		
Pine - Immature (A)	7.068	0.014	5.286	0.075		
Poplar & Willow - Closed canopy (A)	40.850	0.078	0.914	0.013		
Redwood (A)	3.717	0.007	10.051	0.143		
Grassland (D)	100.415	0.192	0.372	0.005	0.016	0.015
Grassland - Mature Poplar & Willow (D)	8.607	0.016	4.340	0.062	0.656	0.646
Grassland - New sparse planting (D)	51.934	0.099	0.719	0.010		
Native (D)	1.546	0.003	24.169	0.344		
Pine - Cleared (D)	4.349	0.008	8.589	0.122		
Poplar & Willow - Closed canopy (D)	4.119	0.008	9.070	0.129		
TOTAL	**523.004**	**1.000**	**70.353**	**1.000**	**1.016**	**1.000**
Awapapa	**352.034**	**0.673**				
Dumgoyne	**170.969**	**0.327**				
Average	**37.357**					

Appendix B Mathematical logic to determine land use influence

1. Transpose of raw data

Typology (m²)	1 - 3	4 - 7	8 - 15	16 - 20	21 - 25	Blank	TOTAL
Grassland (A)	435.954	5217.574	53058.339	15316.478	2754.418	1185.676	77968.440
Grassland with mature Poplar and Willow (A)		1920.419	25362.718	15330.796		95.734	42709.666
Grassland with new sparse planting (A)	247.689	2770.801	6217.747	1962.543			11198.781
Native (A)		60.964	78.138	90.535			229.637
Pine - Established (A)			4378.301	3027.475	3388.938		10794.715
Pine - Immature (A)			52.060	873.892	2629.210		3555.162
Poplar and Willow - Mature (A)		201.999	891.090	276.841			1369.930
Redwood (A)		89.391	1836.034				1925.425
Grassland (D)	129.655	7446.765	79574.380	34926.587	2968.652		125046.040
Grassland with mature Poplar and Willow (D)		315.391	255.688	512.828	743.301		1827.208
Grassland with new sparse planting (D)	649.489	3200.069	30842.441	13486.797	4849.635	748.704	53777.135
Native (D)		303.406	619.441				922.847
Pine - Cleared (D)				756.870	886.646		1643.516
Poplar and Willow - Mature (D)			54.067				54.067
TOTAL	**1462.788**	**21526.778**	**203220.444**	**86561.643**	**18220.801**	**2030.114**	**333022.568**

2. Combine vegetation classes and convert to hectares

GRASS VEG SPLIT (ha)	1 - 3	4 - 7	8 - 15	16 - 20	21 - 25	Blank	TOTAL
Grassland (A)	0.068	0.799	5.928	1.728	0.275	0.119	8.917
Vegetated cover (A)	0.000	0.227	3.260	1.960	0.602	0.010	6.058
Grassland (D)	0.078	1.065	11.042	4.917	0.870	0.075	18.047
Vegetated cover (D)	0.000	0.062	0.093	0.051	0.074	0.000	0.280
TOTAL	**0.146**	**2.153**	**20.322**	**8.656**	**1.822**	**0.203**	**33.302**

3. Apply farm area weightings (as percentage)

GRASS VEG SPLIT	1 - 3	4 - 7	8 - 15	16 - 20	21 - 25	Blank	TOTAL
Grassland (A)	0.019	0.221	1.638	0.477	0.076	0.033	2.464
Vegetated cover (A)	0.000	0.063	0.901	0.542	0.166	0.003	1.674
Grassland (D)	0.056	0.770	7.990	3.558	0.630	0.054	13.060
Vegetated cover (D)	0.000	0.045	0.067	0.037	0.054	0.000	0.203

TOTAL	**0.075**	**1.099**	**10.597**	**4.614**	**0.926**	**0.090**	**17.401**

4. **Apply slope area weightings (as percentage)**

GRASS VEG SPLIT	1 - 3	4 - 7	8 - 15	16 - 20	21 - 25	Blank	TOTAL
Grassland (A)	0.000	0.002	0.004	0.003	0.005	0.000	0.014
Vegetated cover (A)	0.000	0.000	0.002	0.004	0.010	0.000	0.016
Grassland (D)	0.014	0.018	0.034	0.048	0.057	0.000	0.173
Vegetated cover (D)	0.000	0.001	0.000	0.000	0.005	0.000	0.007
TOTAL	**0.015**	**0.022**	**0.041**	**0.055**	**0.077**	**0.000**	**0.209**

5. **Tally up slope and vegetation by farm**

GRASS VEG SPLIT	Pcnt	Farm	PcntFarm	Difference
Grassland (A)	0.066			
Vegetated cover (A)	0.077	Awapapa	**0.143**	
Grassland (D)	0.825			
Vegetated cover (D)	0.032	Dumgoyne	**0.857**	
TOTAL	**1.000**			**0.715**