# Identifying sites for potential afforestation across erodible landscapes of the Hawke's Bay region

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## Abstract

Identifying the right landscape in which to establish a plantation species is critical for economic and environmental sustainability. Hawke's Bay, like the rest of New Zealand, has a range of landscapes from the fertile low-lying alluvial plains through to elevated steep land. As the landscapes become increasingly elevated and steep, so do environmental issues related to commercial forestry operations. Typically, with higher elevations and steeper landscapes soils can become increasingly eroded and skeletal, leaving them vulnerable to degradation when not protected by woody vegetation. In this paper we identify landscapes that are skeletal, eroded, vulnerable and suffering from climatic extremes, which are best suited to retirement plantings that will retain environmental quality and hold these landscapes together. Conversely, we also identify landscapes that have potential for commercial forestry. This project's mapping approach utilises Land Use Capability (LUC) to delineate tree landscape (TreeScape) classes by identifying locations where commercial afforestation is suitable, compared to landscapes that should be retired. Greater mapping detail is gained by combining the LUC maps with the erosion, slope and direction of intense storm events maps.

## Introduction

The planting of trees across New Zealand's most vulnerable and unstable landscapes provides benefits, including reducing soil erosion. The potential for plantation forestry to reduce erosion by up to 95% is well documented. This occurs after an initial six to eight-year window of vulnerability until the newly planted crop develops and canopy closure takes place (Marden & Rowan, 1993; Baillie & Neary, 2015).

To ensure the right tree is in the right place, for the right purpose, the Hawke's Bay region requires a strategy that identifies: (1) the purpose of the afforestation (e.g. commercial, erosion protection, water filtration, carbon sequestration, biodiversity); (2) which tree species we should plant (e.g. exotic or native, their potential for surviving in different environments, disease resistance, resistance to drought and low nutrient substrates); and (3) where these plantings can or should take place (e.g. landscape position, erodible landscapes, riparian setbacks).

In this paper we divide the landscape at a broad level using the New Zealand Land Use Capability (LUC) classification, supported by expert knowledge and statistical approaches to delineate the landscape at a finer scale than that possible with the broad 1:50,000 LUC mapping. The aim was to partition the landscape into: Afforestation Groupings that are suitable for commercial plantation forestry for timber; and other groupings more suited to a permanent forest cover and the provision of other ecosystem services, such as erosion control or non-timber forest products like honey production.

## Methods

### Partitioning the landscape – LUC spatial data

LUC classifications enable the land to be described according to its capacity to support long-term sustained production based on an assessment of factors, such as climate, the effects of past land use and the potential for erosion (Lynn et al., 2009). The New Zealand LUC comprises eight classes with lower classes (1, 2, 3, 4 and 5) generally suitable for a wide range of land uses, such as dairying, cropping and horticulture. Higher classes (6, 7 and 8) are generally less suitable for intensive agriculture, with production forestry usually confined to low-producing pasture on classes 6 and 7, whereas class 8 is generally better suited to indigenous protection forests.

The LUC classification maps were developed at coarse (>1:50,000 map scale) spatial resolutions. In other words, 1 cm on a map represents 50,000 cm (500 m) on the Earth's surface, which is considered to represent the regional level. Although this information is extremely useful in the delineation of erodible land suitable for forestry at a coarse scale, deriving information useful at the 'farm-scale' remains problematic.

Using the New Zealand Land Resource Inventory and LUC extended legends for the Hawke's Bay and local expert forestry knowledge, we developed the Afforestation Groupings 1 to 9 (Table 1 and Figure 1). Generally, lower values occur across down lands and alluvial landscapes where gentle slopes and erosion are minimal, and where there are few limitations to commercial forestry for timber. However, as grouping values increase, so does the risk and severity of erosion across steeper landscapes where rock and soil types are prone to erosion.

Skeletal soils have been specifically identified as generally unsuited to large-scale afforestation for timber harvesting as they are vulnerable to mass failure (e.g. shallow landslides), resulting in debris flows such as during intense and/or prolonged periods of rainfall. As these problems are likely to become more frequent with changing climate patterns, much of the land in Group 7 should be retired. Group 8 lands (non-productive, high altitude and highly eroding landscapes) should also be retired and permitted to revert to native forest.

'Earthflows' are deeper-seated forms of mass failure, and although widespread they are slow moving. Large-scale tree planting options, including poplars and willows, are well proven in these areas subject to other constraints and landowner objectives.

Table 1: Afforestation Groupings overview

| Group | Area (ha) | Description | Potential predominant use |
|---|---|---|---|
| 1 | 233,568 | Generally alluvial valleys or terraces, fertile, lower altitude | Commercial timber forests |
| 2 | 98,180 | Generally rolling-to-steep on hard geology, fertile and lower altitude | Commercial timber forests |
| 3 | 74,289 | Rolling-to-steep, prone to some forms of sheet, rill or gully erosion | Commercial timber forests |
| 4 | 42,656 | Area with varying topographies and climatic, altitudinal and erosion limitations | Commercial timber forests |
| 5 | 273,235 | Moderate-to-steep landforms that are prone to soil slip or sheet and gully erosion under pasture | Commercial timber forests |
| 6 | 14,560 | Limited productivity under grazing on steeper terrains and prone to gully erosion | Commercial timber forests |
| 7: Skeletal | 319,777 | Limited productivity under grazing, thin soils on steeplands, vulnerable to debris flow/debris avalanche initiation | Permanent forest cover |
| 8: Reversion | 323,210 | Generally steep uplands subject to high rates of natural or induced erosion | Permanent forest cover |
| 9: Earthflow | 125,630 | Generally moderate-to-rolling hill country subject to deep-seated mass earthflow erosion | Commercial timber forests |

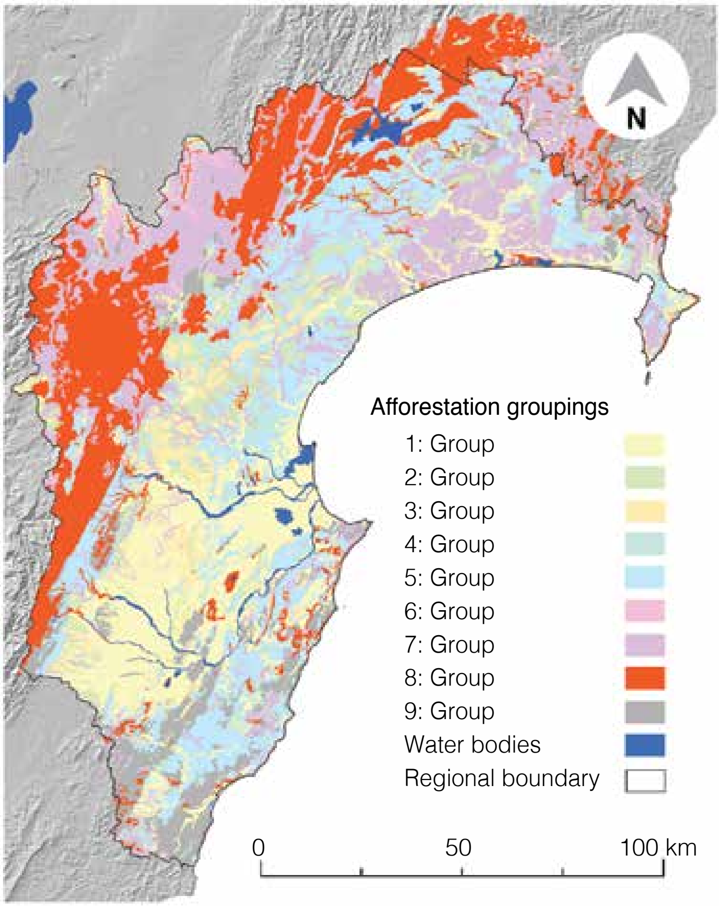


Figure 1: The nine Afforestation Groupings representing the Hawke's Bay region catchments developed by grouping LUC units

## Refining the Afforestation Groupings using fuzzy logic

An analysis using the LUC data at the regional level is appropriate for assessing regional trends, but it is unable to delineate forestry information at the land user level desired in this project. Consequently, we explored methods that could provide improved spatial representation of erosion relevant to afforestation.

We used fuzzy logic to improve the spatial resolution of the LUC units and the Afforestation Groupings. Fuzzy logic approaches are used to manage vague and fuzzy concepts and potential uncertainty. Fuzzy membership (fuzziness) provides an indication as to what degree a property of interest belongs to a class, or degree of membership (DOM). In geospatial terms, fuzzy logic can be used to manage uncertainty and vagueness in a property where a statement can be true (value = 1.0), false (value = 0.0), or somewhere in-between.

Both the literature and expert knowledge have suggested that prime candidates for use in the fuzzy logic approach were degree of slope, direction or aspect and sediment yields. The workflow used in this project is illustrated in Figure 2.

## Effect of slope – slope fuzzy membership

Erosion can occur to some slight degree on slopes less than 5°, then increases substantially from around a 15° slope to a maximum between a 35° and 40° slope according

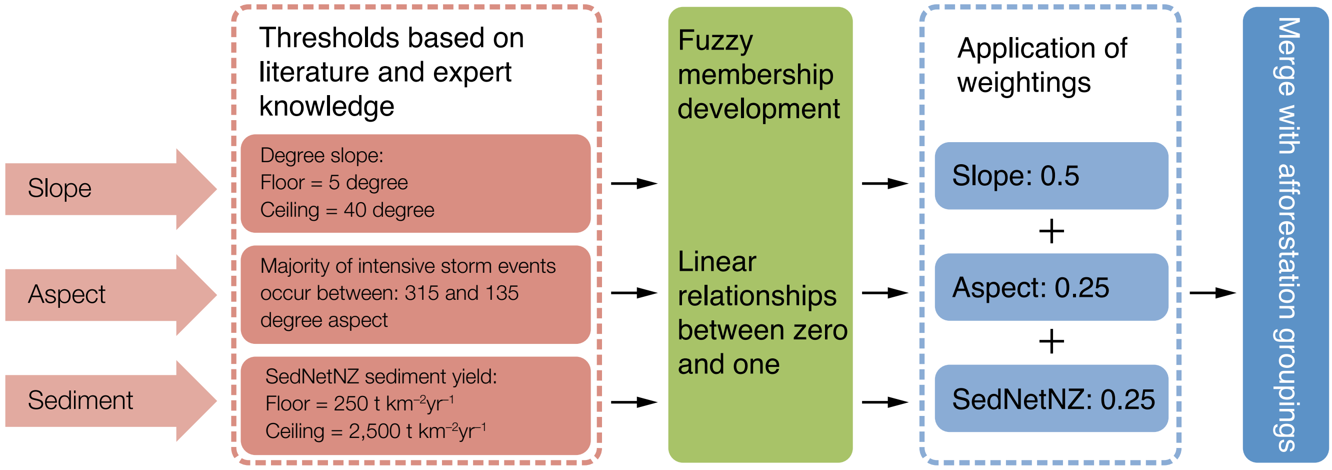


Figure 2: Workflow used in the development of greater detail for LUC and the Afforestation Groupings

to the New Zealand erosion literature (Betts et al., 2017; Dymond et al., 2006). This is shown as a theoretical response curve in Figure 3, which is based on expert knowledge and represents what is considered the typical or expected impact of slope on erosion suitable for use in fuzzy membership calculations. Where slope is below a floor of 5°, erosion is unlikely to occur (degree of fuzzy membership = 0.0 false); above a 40° ceiling, erosion will definitely occur (degree of fuzzy membership = 1.0 true).

## Effect of the direction storms approach from – aspect fuzzy membership

Historic data for the North Island of New Zealand (Hancox & Wright, 2005; Marden & Rowan, 1995) and erosion experts suggest that most intense storms approach from the northwest to southeast aspects (M. Marden, pers. comm., 2019). However, for the East Coast region, the dominant direction tropical cyclones arrive from is the northeast. Southerly storm events have less impact on slope failure and erosion contribution.

We therefore assumed the DOM for aspect would be highest for northeasterly-facing slopes, i.e. the aspect has an impact that is true (value = 1.0 true). West, south and southwest-facing slopes were assumed to have a low DOM, but as there is still likely to be some erosion risk on these slopes we used 0.04 to reflect this low risk. In-between slope aspects were assigned intermediate DOMs (see Figure 4 for details).

## Effect from the level of sedimentation – sediment fuzzy membership

The SedNetNZ model predicts the mean annual suspended sediment for each sub-catchment throughout a river network (Palmer et al., 2013). Land with SedNetNZ yields greater that 1,000 t $km^{-2}$ $yr^{1}$ is considered highly erodible (Betts et al., 2017; Dymond et al., 2016). Using SedNetNZ sediment yield, we developed a sediment response curve where sediment yields <250 t $km^{-2}$ $yr^{1}$ were valued as zero (degree of fuzzy membership = 0.0 false) along a continuum rising to a ceiling of 2,500 t $km^{-2}$ $yr^{1}$ (degree of fuzzy membership = 1.0 true) (Figure 5), to identify locations that would benefit from the planting of protective forests.

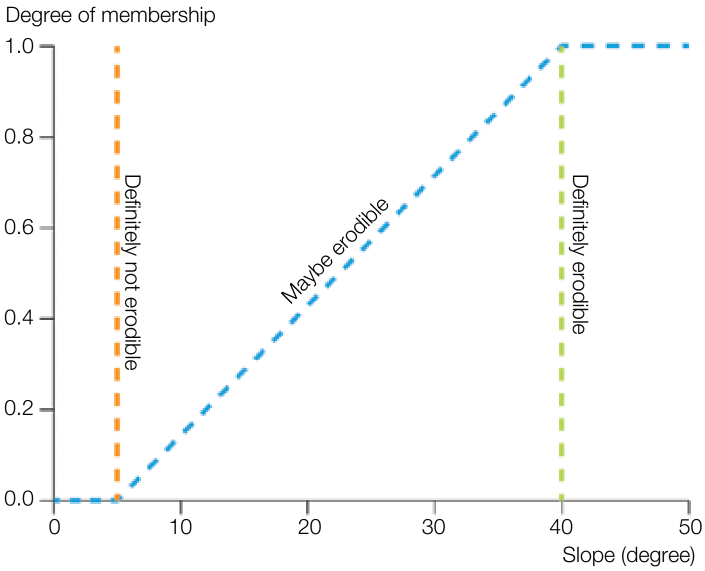


Figure 3: Response curve development for slope in relation to erosion showing a theoretical floor (5° slope) and ceiling (40° slope)

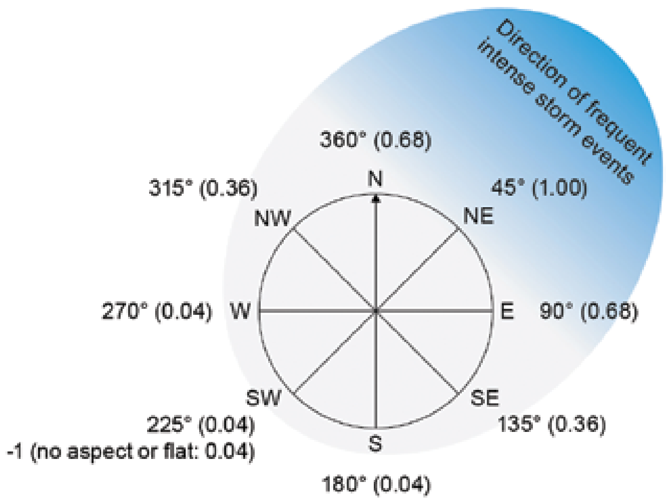


Figure 4: The predominant direction that frequent intense storm events approach the Hawke's Bay region. Fuzzy membership values associated with the degree of truth are given in brackets

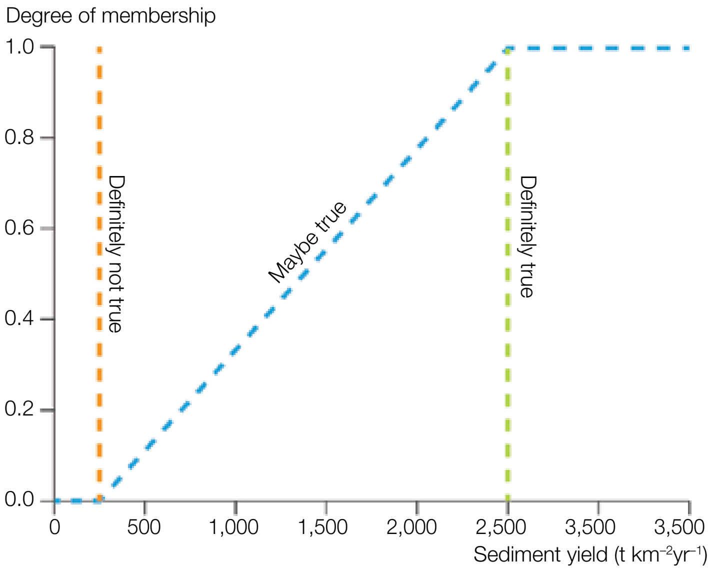


Figure 5: Fuzzy membership response with a sediment yield floor of 250 t $km^{-2}$ $yr^{-1}$ through to a sediment yield ceiling of 2,500 t $km^{-2}$ $yr^{-1}$

The Hawke's Bay Regional Council believes that sediment yields greater that 1,000 t $km^{-2}$ $yr^{1}$ is a reasonable target above which to aim for protection from some type of woody vegetation (Barry Lynch, HBRC, pers. comm., 2019).

## Weighting of fuzzy values in the development of Afforestation Groupings

For slope, aspect and sediment yield we used the floor and ceiling values defined above, and normalised the remaining data to values between zero and one, to develop digital surfaces at a 25 m cell size resolution with a New Zealand Transverse Mercator (topological) projection.

The three variables – slope, aspect and sediment – will have different degrees of effect on the refined groupings and need to be weighted to reflect that. Therefore, we applied a weighting to each layer or raster, based on the authors', industry and local expert knowledge, and used Equation 1 to bring the fuzzy membership rasters together into one value.

*Total fuzzy membership weightings = (slope x W) + (aspect x W) + (sediment yield x W)* (1)

*where W refers to the weighting for each property*

As an example, the slope weighting was set to 0.50, and aspect and sediment both set to 0.25 to generate Afforestation Groupings for the area around Lake Tutira (Figure 6).

## Results and discussion

Using the fuzzy data, we were able to refine the Afforestation Groupings to a finer scale. Note that fuzzy membership relationships were not applied to Afforestation Grouping 9, earthflow erosion, as it is driven by different erosion factors compared to other erosion types.

An example of the Hawke's Bay area around Lake Tutira demonstrates the impacts of including fuzzy membership (Figure 6) in identifying areas that could benefit most from afforestation to control erosion (darker blue and purple areas). Local, industry and spatial experts attending a workshop in May 2019 assessed the results and stated that the Afforestation Groupings with fuzzy membership were a substantial improvement providing spatial detail of erosion risk not available from the LUC classes alone.

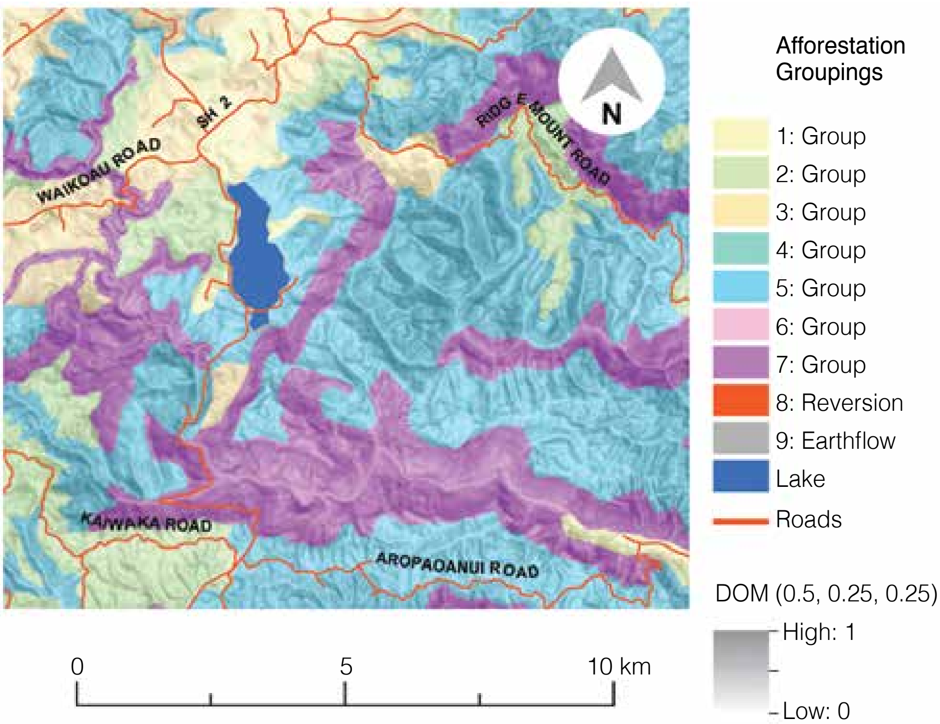


Figure 6: Close-up map of Lake Tutira area showing the effect the Afforestation Groupings together with fuzzy membership weightings of slope 0.5, aspect 0.25 and sediment yield 0.25

Other spatial datasets that represent erosion are all derivatives to some degree of the LUC and Land Resource Inventory (LRI) data that we used to develop the Afforestation Grouping layers. Therefore, to use the Highly Erodible Land (Dymond et al., 2006) the New Zealand Empirical Erosion Model (Dymond et al., 2010), or the Erosion Susceptibility Classification (ESC) (Bloomberg et al., (2011), would likely over-represent erosion during any fuzzy membership analysis.

In the future, should a national modelling of Afforestation Groupings be required then a possible candidate to replace the SedNetNZ erosion data (as national coverage is not available) would be the ESC (Bloomberg et al. 2011). The

ESC has the advantage that it represents a continuum of erosion severity, it has been updated in recent years to reflect forestry management needs, and it is recognised for its applicability in national environmental standards for plantation forestry.

Sediment generation and delivery using SedNetNZ currently operates at a 15 m cell size resolution. SedNetNZ utilises data that is dependent on the information originally associated with the coarse resolution (~1:50,000 map scale) LUC units, as do most New Zealand erosion models and surfaces. The development of slope and aspect at finer resolutions has the potential to improve representation of the landscape and erosion modelling. To improve sediment, or more generally erosion modelling, requires future work that could utilise new remote frontier technologies. For example, this could be achieved through the capture of LIDAR data, with enough ground returns to represent the landscape at cell size resolutions between 5 m and 10 m.

## Conclusion

The Afforestation Groupings we have developed will help landowners and regional bodies make informed decisions around the right tree in the right place in the landscape. The fuzzy membership approach was used to improve the spatial resolution at which soil erosion risk can be mapped, and therefore the protection that could be obtained from forests established on these landscapes. With visual inspection of the Afforestation Grouping fuzzy membership maps, the improvement seems realistic.

The overarching premise for developing the Afforestation Groupings from the LUC units was to identify locations in the Hawke's Bay suited to afforestation with commercial plantings, compared to sites with limitations that may require:

- Approaches such as retirement, reversion or potentially carbon sinks with permanent forest cover, or
- Other ecosystem services, such as the filtration of water and erosion reduction. Afforestation Groupings will provide a useful resource in the decision-making process for positioning the right tree, for the right purpose, in the best position in New Zealand's landscape.

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