Forests and erosion protection – getting to the root of the matter

Chris Phillips, Michael Marden and Les Basher

Abstract

Tree roots reinforce soils and contribute to reducing the risk of slope failure. When trees are harvested the potential for failure to occur increases until the new crop reaches canopy closure. Managing this 'window of vulnerability' is becoming an increasingly important consideration for steepland forest managers.

Introduction

One of the key decisions relating to forest establishment and re-establishment following harvesting is what species to plant. For most forest companies in New Zealand that decision is *Pinus radiata*. However, for some sites, particularly those on steep and difficult erosion-prone terrain that are subject to high risk of storm-induced landsliding and debris flows, the question of what to plant needs further consideration. Do you plant the same species, in the same configuration, at the same density, with the same management regime in expectation of getting a similar level of economic return?

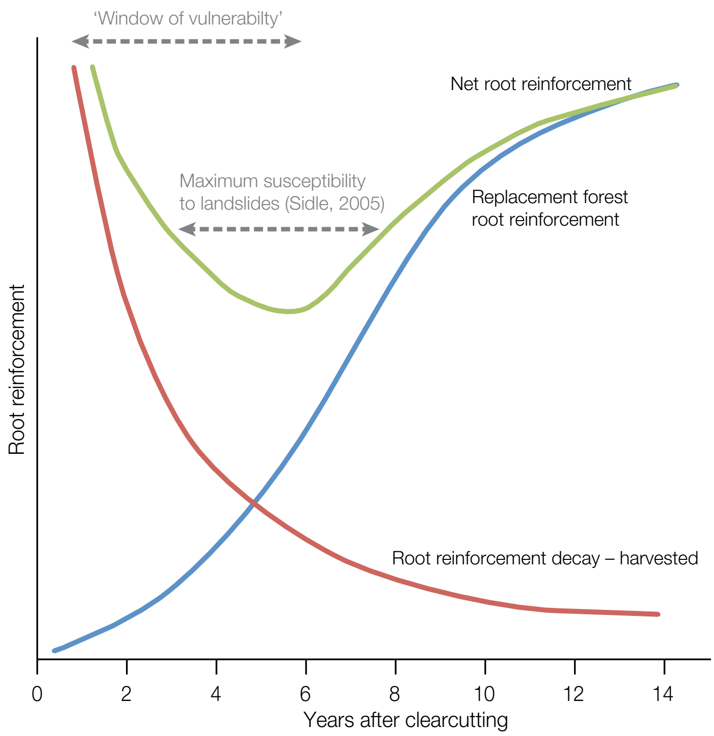

Figure 1: An example of typical changes in forest vegetation root strength or root reinforcement after timber harvesting showing the 'window of vulnerability' (see Phillips et al. 2012 for more details)

One other relevant question is: 'Will the new vegetation provide the erosion control function the existing forest currently provides, and when after planting will it become effective?' The nature of the increased risk of landsliding and debris flows is partly a result of the trees being removed at harvest, i.e. what has been termed the 'window of vulnerability' (e.g. Phillips et al., 2012) (Figure 1). Many of our steepland forests were planted as 'erosion control' forests. When they are cut down the landscape, which had been protected for about 25 years, is exposed and at risk to the forces of nature. This 'window of vulnerability' is a function of both the potential loss of the soil-reinforcing effects of the vegetation's roots and the forests' ability to affect aspects of the hydrological conditions that may contribute to promoting landsliding, as well as the inherent erosion susceptibility of the site (see Basher, 2015).

As outlined in the introduction to this special feature, the New Zealand forest estate is dominated by one species – *P. radiata*. This species can establish easily and grow well across the country (Maclaren, 1993) and, as such, provides the benchmark against which to compare aspects of tree performance. However, in future, alternatives to this ever-present forest species may well emerge, particularly on steep erosion-prone hill country. Whatever alternatives are proposed the question remains, 'Can the alternatives perform as well as *P. radiata*?' In this short opinion piece we focus on what we know about the below-ground aspects of the tree – its root system – and how it relates to issues of inter-rotational forest management and erosion protection.

What we know about soil reinforcement by tree roots

It is well known that vegetation, and in particular trees, improve slope stability and reduce erosion (e.g. Greenway, 1987; Norris et al., 2008). Tree roots reinforce soil, making it stronger, and the tree canopy tends to make the soil drier (through hydrological processes of interception and transpiration), which also increases soil strength. Both these factors tend to reduce the potential for slopes to fail. Species composition, tree spacing and age influence the nature and magnitude of

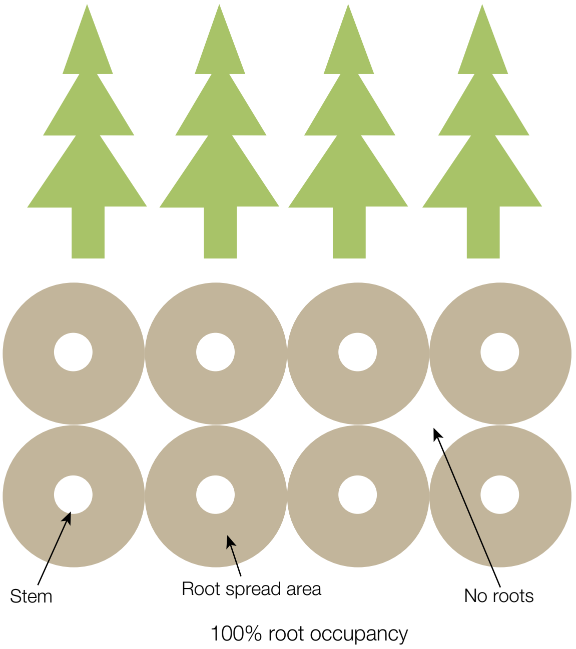

Figure 2: Root site occupancy occurs when the roots of adjacent trees overlap (touch). However, there will be areas between the trees that are not occupied by roots (the white spaces at the very least, and also there will be parts of the shaded circles where no roots exist for species that have an asymmetric root distribution). Once trees reach this 'theoretical' value of site occupancy, roots will continue to grow and occupy the soil as they seek resources so that with time the whole site tends to contain some roots much like a natural forest (from Phillips et al. 2011)

these processes. Species that have fast growth rates and/or are planted at densities that enable canopy closure and root overlap in the shortest time are likely to be better for protection than those that take many years to reach that point. The point at which roots overlap is referred to as 100% root site occupancy (Phillips et al., 2011) – see Figure 2). Similarly, species that have wide environmental tolerances are also likely to be preferred over species that are less widely tolerant. The morphologies of roots and root systems are closely determined by the soil physical conditions, particularly stoniness, site and soil drainage conditions, depth to water table, bedrock conditions and the strength and permeability of strata.

Roots and the root system create both lateral and vertical soil reinforcement. Roots also bind soil particles at the ground surface to reduce the rate of surface soil erosion that may otherwise lead to undercutting and instability of slopes. Metrics used to compare the performance of this erosion 'protection' or reinforcement function (Stokes et al., 2009) by different species include: root biomass, spread, depth and form; individual live, dead and decaying root strength; hydrological effects (canopy interception etc); allometric growth models relating root collar diameter (RCD) or diameter at breast height (DBH) to other metrics; and modelled factors of safety of different vegetation treatments on slope stability.

The usefulness of these parameters is generally limited by the availability of field data. Most root information is hard won particularly for larger plants, because the trees have to be fully removed from the soil and that is time-consuming, physically difficult and costly. This helps explain why root data sets are often limited to younger plants (i.e. those less than about five years) and are limited in the numbers of plants studied. This is why statistical relationships and models based on these data have wide variance and often low statistical power. We have listed some species differences for key parameters for which data exists (Table 1; see first and second photos).

Above left: A three-year-old alder (*Alnus rubra*) with a 7.7 m root spread and showing dense branching lateral roots with high root numbers (high root density and high root order)

Above right: A three-year-old radiata (*Pinus radiata*) with a 5 m root spread and showing long lateral roots with limited branching order, but with many short branch roots on the main laterals

Table 1: Metrics for some species (mean values except for * where only one tree; means usually of three to a maximum of 10 representatives)

Species	Age since planting (years)	Tree height (m)	Root collar diameter (mm)	Diameter at breast height (mm)	Total below-ground biomass including root bole (kg)	Total root length > 1 mm diameter (m)
Radiata[2]	3	2.67	103	71	2.05	128
Alder[2]*	3	6.43	129	80	8.96	1268
Redwood[3]	4	3.80	106	47	2.89	471
Poplar 'Veronese'[4]	1	5.71	103	73	4.58	254
Willow 'Hiwinui'[4]	1	5.73	121	75	6.97	533
Lemonwood[1]	5	2.97	61	27	1.55	197
Ribbonwood[1]	5	3.18	85	60	1.82	159
Cabbage tree[1]	5	3.10	121	70	2.70	100
Kanuka[5]	6	6.10	53	45	0.87	30**
Mānuka[1]	5	2.46	34	21	0.32	25
Mountain flax[6]	3	1.51	200	NA	0.62	265
Toe toe[6]*	3	1.90	300	NA	1.72	728
Carex[6]*	3	1.10	280	NA	1.32	959

[1]Marden et al. (2005); [2]Phillips et al. (accepted); [3]Phillips et al. (2013); [4]Phillips et al. (2014) – poles; [5]Watson et al. (1999) & unpublished data; [6]Unpublished data; ** total root length > 2 mm diameter

What we are doing

As part of the Scion MBIE research programme, Growing Confidence in Forestry's Future, we recently completed work assessing the root development of several exotic species that have the potential to be used in erosion control forestry in a trial site near Gisborne (Phillips et al., 2015)(see first and second photos). Similar work had been conducted at this site on a range of native species (Marden et al., 2005) and on poplars and willows (Phillips et al., 2014). In a related study, we showed that redwood trees, by virtue of having greater total root length, are possible plantation alternatives to radiata pine (Phillips et al., 2013). We have also just begun to take another look at mānuka root development, due to the recent surge of interest in this species for high Unique Mānuka Factor (UMF) honey and the potential win-win it provides for retirement of marginal land from pastoral grazing. Our investigations will build on previous work (Watson & O'Loughlin, 1985; Marden & Rowan, 1993; Ekanayake et al., 1997) and are centred around the questions of when a mānuka plantation at 1100 stems/ha provides a level of erosion protection, and how it performs compared to natural reversion of scrub (mānuka and kanuka).

Beyond trials and tree root excavations, we are also collaborating with the international root research community through ecorisQ (www.ecorisq.org/) in developing simple tools that can be used to explore a forest's influence on slope stability. For example, SlideforNET is an online tool that estimates the degree of protection from shallow landsliding a forest provides given the defined slope and forest conditions. It is based on a slope stability analysis that accounts for lateral reinforcement of tree roots. SoSlope is a new research tool that treats lateral root reinforcement within the soil as a fibre bundle (Schwarz et al., 2013) that will be validated for *P. radiata* information and New Zealand conditions over the next year or so, beginning in August 2015 with some preliminary work by a visiting Swiss student. These efforts are aimed at addressing the needs of researchers and practitioners dealing with the ecological mitigation of hillslope instability (Stokes et al., 2014), both in New Zealand and globally.

What still needs to be known

Scientists often suggest they do not have enough data and wish to collect more before they can definitively support or reject the hypothesis they are testing. In relation to model development, calibration and validation, we do not yet have enough information (field data, including root information) to confidently predict what will happen with different species and planting approaches in terms of assessing when a species becomes effective from planting and at what storm rainfall threshold the risk of slope failure becomes critical. However, we are working towards defining exactly what parameters are important for the models currently in the research domain that will, with time, become the management tools of the future.

For radiata in particular, we do not yet have enough root distribution data from trees of different ages from different soil types, landform units, or regional climate zones. Much of our understanding of structural root system development in this species was carried out in the 1980s and little work has been done since (see third photo). Developing approaches that require minimal parameterisation with easily acquired field data remains a challenge. In recent years,

A 25-year-old radiata (*Pinus radiata*) excavated from Mangatu Forest in the 1980s

however, there has been a move away from whole tree root excavation towards more targeted data acquisition largely because of cost. Whether such 'point' data can fully represent the characteristics of the tree root system under examination remains to be seen.

As Basher et al. (2015) have pointed out, we definitely need a much better understanding of regional post-harvest landslide thresholds to different storm profiles. This would enable the development of risk-based maps – linking erosion susceptibility with slope reinforcement models to model forest scenarios for different storm profiles – and potentially provide the necessary input to the planning phase before the standing crop is harvested. We also need to understand the nature of the risk at different stages in the rotation, and perhaps under different management regimes.

Lastly, we believe it would be desirable in the future to link site characteristics to models of slope stability, species selection and economics (i.e. assess and account for different ecosystem services) to better understand trade-offs. This might improve the understanding of the beneficial role forestry plays in the economy of New Zealand and its contributions to the environment (e.g. Maclaren, 1996). It may also educate the public so that they understand that when situations occur that deliver wood on to beaches, slips on roads, and sediment in places where it is not wanted, that the industry has recognised the risk and done its best to manage what it can.

Implications for inter-rotational forest planning

Putting economic considerations aside, decisions about what to do next on the site need to be explored both at the time the pre-harvest inventory is conducted, but perhaps more generally at a strategic planning level. First, factors that might influence future alternative rotations are likely to include growth rates of the existing crop (i.e. if it is poor is there something else that could be used?), possible storm damage history over the life of the rotation(s) affecting the compartment or infrastructure, and so on. Secondly, the harvest plan may indicate small areas where it is difficult to extract trees and these areas might then be considered for abandonment (i.e. leave standing) or, if harvested, a species change or reversion. Finally, when the trees are harvested, consideration needs to be given to the volume recovery from different parts of the landscape, the cost of harvesting those difficult areas and the yield from them, and any health and safety aspects. There may also be other factors that contribute to tactical withdrawal from some places, such as proximity to streams, lakes and wetlands of high value, or encroachment of residential property.

A key part of any decision to continue with the incumbent species or to change or abandon it should include consideration of how long the 'window of vulnerability' will exist at the proposed planting density, and the probability during that period of a storm causing landslide-debris flows. If the planting density is low, the projected growth and survival rates are low, and the erosion susceptibility and risk from a storm is high, then future forestry on the site should be questioned. It is also about the overall risk profile of the forest. Longer rotations, changes in silviculture and species, and alternative harvesting methods will all have an impact on the forest's risk profile – either increasing or reducing overall risk.

In summary, it may well be that it is time to recognise that parts of our steepland landscapes may be unsuitable for production forestry, just as they were once deemed unsuitable for pastoral farming. Further, it may also be time for the forest industry and the wider public of New Zealand to formally recognise what risks foresters can and can't manage and acknowledge that nature often wins, despite our best efforts to manage her.

References

Basher, L.R., Phillips, C, Marden M. and Harrison, D. 2015. What Do We Need for a Risk Management Approach to Steepland Plantation Forests in Erodible Terrain? *New Zealand Journal of Forestry*, 60 (2): 7–10.

Ekanayake, J.C. and Marden, M. et al. 1997. Tree Roots and Slope Stability: A Comparison between *Pinus radiata* and Kanuka. *New Zealand Journal of Forestry Science*, 27(2): 216–233.

Greenway, D.R. 1987. Vegetation and Slope Stability. In Anderson, M.G., Richards, K.S. (Eds.), *Slope Stability*. Chichester, UK: Wiley, pp. 187–230.

Maclaren, J.P. 1993. Radiata Pine Growers Manual. *FRI Bulletin No.184*. Rotorua, NZ: NZ Forest Research Institute Limited. ISSN 0111-8129, 140 p.

Maclaren, J.P. 1996. Environmental Effects of Planted Forests in New Zealand: The Implications of Continued Afforestation of Pasture. *FRI Bulletin No. 198*. Rotorua, NZ: NZ Forest Research Institute Limited. ISSN: 0111-8120, 180 p.

Marden, M. and 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.

Marden, M. and Rowan, D. et al. 2005. Stabilising Characteristics of New Zealand Indigenous Riparian Colonising Plants. *Plant and Soil*, 278: 95–105.

Norris, J.E. and Stokes, A. et al. 2008. *Slope Stability and Erosion Control: Ecotechnological Solutions*. The Netherlands: Springer, 287 p.

Phillips, C.J. and Ekanayake, J.C. et al. 2011. Root Site Occupancy Modelling of Young New Zealand Native Plants: Implications for Soil Reinforcement. *Plant Soil*, 346(1–2): 201–214. doi: 10.1007/s11104-011-0810-2.

Phillips, C. and Marden, M. et al. 2012. Plantation Forest Harvesting and Landscape Response – What We Know and What We Need to Know. *New Zealand Journal of Forestry*, 56(4): 4–12.

Phillips, C.J. and Marden, M. et al. 2013. Observations of Below-Ground Characteristics of Young Redwood Trees (*Sequoia Sempervirens*) From Two Sites in New Zealand – Implications for Erosion Control. *Plant and Soil*, 363: 33–48. doi: 10.1007/s11104-012-1286-4.

Phillips, C.J. and Marden, M. et al. 2014. Observations of Root Growth of Young Poplar and Willow Planting Types. *New Zealand Journal of Forestry Science*, 44: 15. doi: 10.1186/s40490-014-0015-6.

Phillips, C.J. and Marden, M. et al. 2015. Observations of "Coarse" Root Development in Young Trees of Nine Exotic Species from a New Zealand Plot Trial. *New Zealand Journal of Forestry Science* (accepted for publication).

Schwarz, M. and Giadrossich, F. et al. 2013. Modelling Root Reinforcement Using Root-Failure Weibull Survival Function. *Hydrol. Earth Syst. Sci. Discuss.*,10(3): 3843–3868. doi: 10.5194/hessd-10-3843-2013.

Sidle, R.C. 2005. Influence of Forest Harvesting Activities on Debris Avalanches and Flows. In Jacob, M. and Hungr, O. (Eds.), *Debris Flow Hazards and Related Phenomena*. Heidelberg: Springer-Praxis, pp. 345–367.

Stokes, A. and Atger, C. et al. 2009. Desirable Plant Root Traits for Protecting Natural and Engineered Slopes Against Landslides. *Plant and Soil*, 324: 1–30. doi: 10.1007/s11104-009-0159-y.

Stokes, A. and Douglas, G.B. et al. 2014. Ecological Mitigation of Hillslope Instability: Ten Key Issues Facing Researchers and Practitioners. *Plant and Soil*, 377: 1–23. doi: 10.1007/s11104-014-2044-6.

Watson, A.J. and O'Loughlin, C.L. 1985. Morphology, Strength, and Biomass of Manuka Roots and Their Influence on Slope Stability. *New Zealand Journal of Forestry Science*, 15(3): 337–348.

Watson, A. and Phillips, C. et al. 1999. Root Strength, Growth, and Rates of Decay: Root Reinforcement Changes of Two Tree Species and their Contribution to Slope Stability. *Plant Soil*, 217: 39–47.

Les Basher, Chris Phillips and Michael Marden are Research Scientists with Landcare Research NZ Ltd based in Nelson, Lincoln and Gisborne. Corresponding author: chris.phillips@landcareresearch.co.nz.