Alternatives to clearfelling for harvesting of radiata pine plantations on erosion-susceptible land

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Woodside Forest. Photo courtesy of Ryan McDonald (MoMac)

Abstract

Approximately one-quarter of New Zealand's plantation forest estate is on erosion-susceptible lands. There is a 'window of vulnerability' to increased erosion after clearfelling of these plantations and before the replanted crop begins to re-occupy the site. This paper explores alternatives to clearfelling (small-coupe harvesting and continuous cover forestry) which reduce these erosion risks arising from the window of vulnerability. The technical, operational and financial implications of these alternatives are discussed. The costs and difficulties associated with adopting these alternatives need to be balanced against the risks of continuing to harvest large clearfell coupes on land with high or very high erosion susceptibility.

Introduction

New Zealand's plantation forests, whether small or large, are mostly comprised of single-species, even-aged stands managed on clearfell regimes. Radiata pine is the main species, making up 90% of the planted area (NZFOA, 2019). Approximately one-quarter of this plantation forest estate is on erosion-susceptible lands (Te Uru Rākau, 2019a). While plantation forest generally mitigates erosion on these erosion-susceptible lands, there is a window of vulnerability to erosion after clearfelling and before the replanted crop begins to re-occupy the site. Here harvest earthworks, removal of the tree canopy, and the subsequent death of the root system all render the site more susceptible to erosion during high-intensity rainfall events. This window of vulnerability lasts until approximately six years after clearfelling, assuming another radiata pine crop is replanted immediately (Phillips et al., 2012).

Clearfell harvesting has large aesthetic impacts and significantly alters ecosystem attributes, such as species diversity and microclimate, as well as hydrological and erosion processes (Pawson et al., 2006). For this reason, in many countries clearfelling coupes may be regulated as to size and location, to mitigate erosion and flooding risk as well as the adverse effects on habitat, landscape and riparian environments. This is also the case in the harvesting of privately-owned New Zealand indigenous forest under the Forests Amendment Act 1992, where coupe sizes generally may not exceed 0.5 ha.

In contrast, there are no explicit regulatory controls on coupe sizes in New Zealand plantation forests and sizes are usually dictated by operational requirements. Thus, a coupe area may be dictated by the size of a contiguous area which has reached optimal rotation age. Since many New Zealand plantation forests were created by buying farm properties, the need to minimise the holding cost of land once it was acquired has resulted in most newly-acquired land being planted within a few years. This has created large plantation forest areas of uniform age, likely to be clearfelled within a relatively short period (less than five years). Some of these forest areas are on land which is highly susceptible to erosion.

In New Zealand, erosion susceptibility of plantation forest lands is described by the Erosion Susceptibility Classification (ESC), a decision support tool that is incorporated into the National Environmental Standard for Plantation Forestry or NES-PF (Te Uru Rākau, 2019b). A recent geospatial analysis of private (non-corporate) forests in the Wairarapa District showed that 58% of the total area of land classified as very high erosion susceptibility under the NES-PF was in large (>50 ha) even-aged blocks. Stands between 20–50 ha provided a further 17% of the total area. Therefore, 75% of the private forest area on very high ESC land was made up of stands >20 ha, each of which is likely to be completely clearfelled within a five-year window (Table 1).

Table 1: Size of even-aged stands on very high ESC land, Wairarapa District private forest estate. Source: Vega Xu (unpublished data)

Stand area (ha)	No. of stands (n)	% of n	Total area (ha)	% of area
<5 ha	174	55%	413	8%
5–10	55	18%	377	7%
10–20	39	12%	582	11%
20–50	29	9%	922	17%
>50 ha	17	5%	3197	58%
Total	**314**	**100%**	**5490**	**100%**

However, on high or very high ESC land, large areas of clearfelled forest mean a significant risk of landslides and other forms of erosion. Amishev et al. (2014) identified three alternatives to large clearfelling coupes for New Zealand plantation forests on erosion-susceptible land:

1. **Harvesting over longer rotations with radiata pine or a slower-growing species such as Douglas-fir**

   This requires stands to be clearfelled at rotation lengths that are significantly longer than the normal (approximately 28 years) clearfelling age for radiata pine in New Zealand. In the case of radiata pine, growing stands on longer rotations means an increased risk of windthrow or, on some sites, toppling. Furthermore, radiata pine stands grown at relatively low stockings on rotations >40 years will result in very large tree diameters, and logs may become too large for conventional harvesting or processing equipment to handle.

2. **Small-coupe clearfelling**

   Here risks from clearfelling are mitigated by limiting the area harvested within a specified time period and therefore the area within the window of vulnerability. However, harvesting managers and contractors prefer large coupes as these minimise shifting times between coupes and thus overall harvesting costs. Conversion of a large even-aged stand to smaller coupe clearfelling may initially also impact on rotation length, as clearfelling will need to be staged in order to create a set of stands with different ages where once there was a single age-class.

3. **Continuous cover ('permanent') forests**

   These avoid the window of vulnerability since they are not clearfelled at any time in the life of the stand, and timber is partially-harvested in a series of thinnings. Therefore, continuous cover forests may be an option where erosion susceptibility is very high and clearfelling creates an unacceptably high risk of landslides. However, partial harvesting on steep erosion-susceptible land is technically demanding, and suitable logging systems and experienced loggers are not widely available in New Zealand.

All three options will also involve delays in the harvest age for at least part of the forest crop compared with clearfelling. Since forest investments are evaluated using discounted cashflows, these delays in harvesting will reduce the present value of the crop.

Despite the financial and technical limitations to adoption of continuous cover forestry (CCF), longer rotations or small harvest coupes, they are all realistic alternatives to large clearfelling coupes. Large coupes result in very high risks of landslides on erosion-susceptible land. These risks are increasingly seen by regulators and wider society as unacceptable.

Alternative harvesting systems

Small-coupe clearfell harvesting

Clearfell coupe size limits and/or adjacency constraints are intended to prevent large contiguous areas of clearfelled or recently established young trees. Adjacency constraints are requirements for the 'green-up' of a clearfelled site before further clearfelling can be undertaken in an adjoining stand. Examples of clearfell coupe size limitations and adjacency constraints relevant to New Zealand are reviewed in Visser et al. (2018):

- In the US, Sustainable Forestry Initiative (SFI, 2015) certification limits average clearfell harvest areas to 50 ha. This is similar to the maximum clearfell size for steep terrain in Washington State (60 ha) but higher than in California (15 ha)

- In central Europe, Austria restricts clearfell coupes to 0.5 ha, with an exemption allowing a harvest up to 2 ha. In comparison, Germany and Italy restrict all clearfells, generally allowing only patch-cuts, thinning or single tree selection
- Visser et al. (2018) quote the adjacency rule for Washington State:

> *For harvesting operations that remove all or most of the largest trees, operators shall ensure that no more than half the area of high landslide hazard locations on a single ownership within the drainage or hillslope directly above the affected structure or road are in a 0 to 9 year-old age class or with reduced canopy closure in other age classes.*

A review of the literature suggests that coupe size limitations or adjacency constraints will mitigate landslide hazard and/or soil erosion and consequent downstream sedimentation. Bathurst and Iroume (2014) assembled data for paired catchment studies in temperate forests (51 catchments including 16 controls) where post-logging sediment yield was compared with both the pre-logging period and an undisturbed control catchment. They found that the maximum increase in specific sediment yield (SSY – the sediment yield per unit of catchment area) following logging could be up to an order of magnitude above the control SSY. This applied at both the annual and storm event scales, even under normal circumstances of best management practice.

In general, total sediment yield from a catchment is a function of SSY and catchment area (A). Thus, an increase in SSY caused by the clearfell harvesting of forests will result in a larger increase in sediment if it occurs over a larger area. Restricting clearfell coupe size limits the increase in total sediment yield by controlling the area of logged forest, but it does not control the increase in SSY on the logged site itself.

In contrast, Eastland Wood Council (2015) stated that:

> *In a forest estate producing a continuous yield, the smaller the harvest site the more sites there will be open and vulnerable to storms at any given time. Given the very small size of landslide initiation points and their narrow initial flow paths, small-coupes may reduce the risk if an intense rainstorm is very localised but may increase the risk if the rain storm is more broad based. It's a probability game in which no one knows the final outcome.*

However, the logic of this statement is incomplete. It is correct to say that a specific outcome (in this case the scale and severity of erosion) of any single probabilistic event, such as a future rainfall event, is unknown. Nonetheless, an expected value (number of occurrences of that specific outcome) can be calculated from the probability of the outcome arising from an

Debris flow and logging slash material from a clearfell site in the Bay of Plenty. Photo courtesy of Sally Moore

event multiplied by the number of times the event happens. In the long term, with many rainfall events the number of occurrences of a specified outcome (an erosion-triggering rainfall event) will tend towards the expected value.

Therefore, over time the driver of sedimentation from clearfell sites is not the number of clearfelled sites or their individual size, but the total clearfelled area multiplied by increases in SSY due to clearfelling and also harvesting earthworks. The effect of coupe size limitations and adjacency constraints is to limit the area within a specific catchment where SSY is increased. This will mitigate total sediment yield from that catchment in a storm, whether storms are localised or regional in scale.

Finally, the analysis by Eastland Wood Council (2015) does not account for scale effects. Effects of landslides increase with landslide size according to a power function (Galli & Guzzetti, 2007; Lin et al., 2017), so that large landslides have a much higher potential for catastrophic damage. All things being equal, a larger clearfell coupe will generate more sediment during an erosion event and therefore is more likely to generate large debris flows or debris floods, which will have an exponentially larger capacity to cause damage.

Estimating coupe size limits and adjacency constraints

While the relationship between clearfell coupes and increases in erosion and sedimentation is clear, there appears to be no formal analysis used to determine the clearfell coupe size limits reported by Visser et al. (2018) or in any other literature, at least in terms of mitigating erosion and sedimentation.

The following is an attempt to estimate suitable coupe size limits based on some simple relationships between land cover and catchment hydrological response. The aim here is to do a 'desktop' analysis, to see how coupe size restrictions might impact on harvesting parameters, such as harvesting age and harvested areas. The results of this analysis are indicative and are not a recommendation for policy or management.

One rule of thumb is that changes in vegetation cover of less than 20% of a catchment area have no measurable effect on catchment hydrology (Bosch & Hewlett, 1982; Davie & Fahey, 2005). While this relates to streamflows, in the absence of any other guideline this threshold could be applied as a constraint on the amount of forest or catchment area that is within the one to six-year window of vulnerability. Using a 50 ha maximum coupe size, and a constraint that no more than 20% of larger catchments (>250 ha) should be in the window of vulnerability, Table 2 shows the effect of these limitations on the rotation age of plantation forests.

Table 2: Effects of 50 ha coupe size and 20% catchment area limitations on clearfell areas and stand rotations

	Clearfell area		
Catchment area (ha)	Total (ha)	% of total area	Max. rotation (years)
50	50	100%	28
100	50	50%	34
150	50	33%	40
200	50	25%	46
250	50	20%	52
300	*60	20%	52
350	*70	20%	52

*Must be logged in two non-adjacent coupes, each ≤50 ha

In small catchments (50–200 ha), the 50 ha maximum coupe size means that more than 20% of the catchment may be clearfelled in one coupe. Because the catchment area is relatively small the effects are likely to be local. Sedimentation and landslide effects may be mitigated by processes such as the downstream mixing of suspended sediment and the deposition of erosion debris. However, once catchments become large there will be an increasing scale of sedimentation effects, and erosion debris from multiple sources may coalesce, creating large debris flows or debris floods. For catchments ≥250 ha, clearfelled areas should be limited to ≤20% of the catchment area. There is an opportunity to harvest >50 ha while still remaining below the limit of 20% of the catchment area. However, this larger area must now be in two coupes (separated by an adjacency constraint) since any single coupe cannot exceed 50 ha.

Where less than 100% of the forest can be harvested, then harvest must be delayed by six years (the length of the window of vulnerability) until another area can be clearfelled. For a large forest within a catchment, the 20% of catchment area constraint means that forest may need to be logged in up to four additional stages, resulting in a 4 × 6 = 24-year delay between the initial clearfell and the final clearfelling operation. This equates to a rotation age of 28 years for the first stage and 52 years for the final stage.

A similar desktop analysis was carried out by Visser et al. (2018), but with more lenient constraints (60 ha maximum coupe size and an area limit of 25% of a major catchment within a four-year window of vulnerability). These limits result in a shorter maximum rotation than in Table 2 (40 years compared with 52 years), but the 25% catchment area limit and four-year delay between harvests used by these authors are pragmatic guidelines and cannot be justified on any technical grounds.

In most cases, small-coupe clearfell harvesting where coupe sizes are limited to 50 ha should not be technically any more difficult than unrestricted clearfell harvesting. A typical hauler setting in steep country is approximately 20 ha, so it may be possible to harvest several settings in one 50 ha coupe before the need to shift the harvesting crew to another location. However, small-coupe clearfelling will:

- Require more frequent location shifts by harvesting crews; and
- During the transition to small-coupes, require that some parts of larger forests experience long delays before they may be harvested, with the possibility that trees may become very large and difficult to harvest with conventional machinery.

Continuous cover forestry (CCF)

CCF regimes involve managing productive forests by harvesting in a way that mimics natural tree mortality and regeneration processes, so that the forest canopy cover is always maintained at one or more levels. In practical terms, this means managing forests without large-scale clearfelling but rather by selective harvesting of very small areas or individual trees. Felling of areas wider than two tree heights is avoided, therefore felling coupes are less than 0.25 ha (Barton, 2008). CCF systems focus on producing high-quality trees and harvesting them at a size and consistent rate that suits target markets.

The introduction of a CCF system into an even-aged plantation can lead eventually to the transition to an uneven-aged stand structure (Vitkova & Dhubháin, 2013), where harvesting can be carried out on a small scale on a regular basis.

In contrast to clearfelling regimes, CCF stands by definition function in a relatively 'steady-state'. As a result, not only can they produce a regular income stream for owners, but they also maintain forest ecosystem values (including a more-or-less stable carbon reservoir) in perpetuity without the oscillations that result from clearfelling.

However, CCF systems generally have more expensive harvesting costs than clearfelling and require skilful operators and additional management input. In this respect, they are well suited to more intensivelymanaged forests and so are ideal for smaller forests. The skills, infrastructure and machinery needed for CCF are scarce but do exist in New Zealand. There are various examples of successful CCF systems (see Barton, 2008), mainly in indigenous forests but also in plantations of exotic species, including radiata pine.

One CCF system that has proved successful in a New Zealand radiata pine forest is target diameter harvesting (TDH), which is the selective felling and extraction of individual trees once they reach a specified target diameter. Natural regeneration of the crop species occurs within the gaps created as trees are harvested. This natural regeneration can be enriched by planting if the distribution or quantity of the new crop is inadequate. The naturally regenerated crop requires a different approach to management than a conventional plantation crop, but the end product (high-quality logs) is the same as in any well-managed forest. As with other CCF systems, TDH can lead to the conversion of an even-aged plantation to an uneven-aged forest; the forest can then be managed on a sustainable continuous cover basis, with regular selective harvesting, in perpetuity.

A successful and well-known TDH system based on radiata pine is found at John and Rosalie Wardle's property, Woodside, located near Oxford in North Canterbury (Perry et al., 2015; Wardle, 2016; 2019). Here, the forest owners have spent some 15 years implementing TDH in a 30 ha radiata pine plantation. Harvesting occurs annually at 60 cm target diameter and logs are sold into a range of standard markets.

An independent study of the TDH system at Woodside (Perry et al., 2015) compared the economics of TDH with a conventional clearfell system. The study included an on-site inventory of the plantation followed by detailed economic analysis. The study concluded that the TDH system was less profitable than a clearfelling system, but still made a positive return at a 7% discount rate. There was no attempt to incorporate any non-timber values, including ecosystem services, despite that they were acknowledged by the authors as a significant additional advantage of CCF systems.

TDH case study in the Greater Wellington region

Can the TDH system used at Woodside be applied to other even-aged radiata pine forests? A recent Sustainable Farming Fund (SFF) project looked at alternatives to clearfelling for privately-owned radiata pine forests (Bloomberg et al., 2019). TDH and small-coupe harvesting were evaluated for four representative radiata pine forests of varying size, three in the Greater Wellington region and one in Hawke's Bay (Table 3).

This study assessed the operational, marketing and economic feasibility of applying TDH to each forest. In each case, pre-harvest forest inventory was undertaken followed by modelling to grow the forests forward and simulate harvests over 20 years using:

- TDH, or
- As a baseline, a clearfell operation at the time of optimum net present value (NPV) for all forests, regardless of coupe size limitations.

Three of the properties (B-D) had single age-classes, but property A was a larger forest with multiple stands planted at different dates.

Table 3: The four case study properties

Property	Size class	Age	Description
A Wairarapa	>100 ha	14–25	Multiple age-class radiata pine resource but with most areas planted 1992–2004. Highly erodible land type, rolling to steep. Long cartage distances
B Hawke's Bay	20–50 ha	24	Mature, well-tended forest on rolling terrain, close to port
C Wairarapa	5–20 ha	25	Mature forest, rolling terrain, easy access
D Upper Hutt	<5 ha	25	Small mature block on flattish land, part of a much larger forest. Low roading and cartage costs

The financial analysis did not include income from carbon. The Emissions Trading Scheme (ETS) is currently under review, and the expectation is that any changes to the scheme will go through the required parliamentary process in 2019–20. At the time of analysis, the ETS was not specifically designed to accommodate a commercial plantation continuous cover system.

In all four case study properties, TDH was predicted to result in a profitable harvest, albeit with a significantly lower NPV than the clearfell, with a 50 cm limit TDH resulting in reductions ranging from 11–22% of NPV under a clearfell regime (Figure 1). This result is not unexpected and is consistent with previous studies on TDH in New Zealand radiata pine plantations (Perry et al., 2015; Dickson & Bloomberg, 2003). We know that optimal financial performance of radiata pine forestry is achieved by clearfell harvesting at optimum rotation age and promptly replanting the next crop. The economic difference between TDH and clearfell regimes can be viewed as the trade-off between optimising the economic return from harvested wood versus the value of regular cashflow and non-market benefits such as sustained ecosystem services.

Note that the reduction in NPV occurs during the transition period from even-aged forests to a mixed-age structure. Once the transition is complete and assuming that TDH harvest costs are only 30% more expensive than for clearfelling, the annual cashflow from a forest managed under TDH harvesting may be similar to a 'normal' forest managed under clearfell harvesting. This is because higher harvesting costs could be balanced by lower growing costs

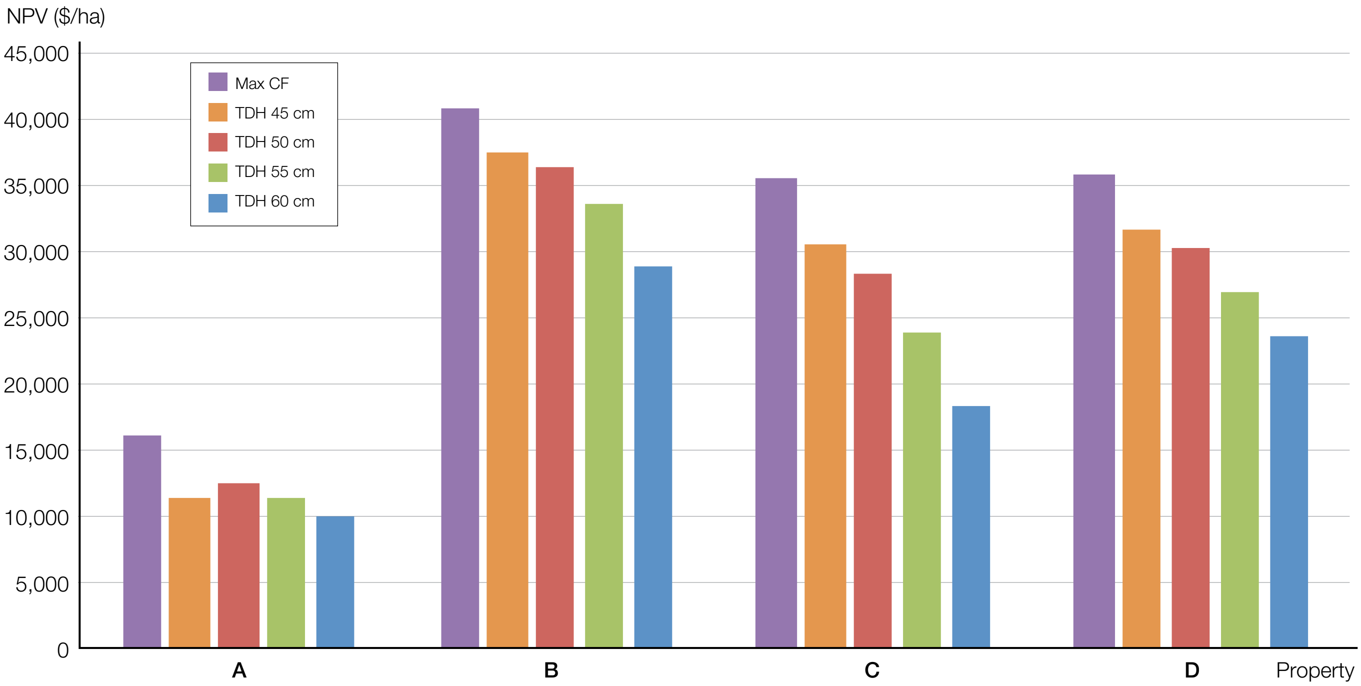

Figure 1: NPV ($/ha) for different target diameters (TDH in cm) at each case study site. 'Max CF' is the NPV from clearfelling at the optimal rotation age and is the maximum possible profitability for the forest on the case study site. Actual NPV values varied between properties due to different crop ages, site productivities, and harvesting and transport requirements. Source: Modified from Bloomberg et al. (2019)

of mixed-age forests and also higher log revenues, since harvests from TDH have a higher percentage of valuable log grades and less pulpwood than a clearfelling harvest.

Conclusions

Almost all New Zealand plantation forests are managed on short (28-year) rotations before they are clearfell harvested and replanted. In many cases, clearfell coupes are large and coupe sizes are not regulated for New Zealand planted forests. On land with a high or very high erosion susceptibility, large clearfelling coupes create a high risk of sedimentation and landslides during the six-year window of vulnerability that occurs after clearfell harvesting. These risks will scale with the size of the clearfelling coupes, although this relationship is probabilistic rather than deterministic.

Alternatives to large clearfell coupes on land with high erosion susceptibility include small-coupe harvesting, coupled with longer rotations, and a CCF system such as TDH harvesting. While these can be effective ways to avoid or mitigate erosion risks for plantation forests, they will require delays in harvesting during the transition period from large clearfelling systems. Financial returns to forests are typically calculated using discounted cashflow methods, such as NPV, so any delays in harvesting will result in reductions to the NPV of forests. In addition:

- CCF will require changes to existing clearfell-based harvesting systems, including investment in new harvesting machinery
- Growing species such as radiata pine on longer rotations may result in trees that are too large for conventional harvesting and processing, and which may be prone to windthrow and toppling.

Forest owners may therefore be reluctant to adopt small-coupe or CCF harvesting.

Nonetheless, the costs and difficulties associated with adopting these approaches need to be balanced against the risks of continuing to harvest large clearfell coupes on land with high or very high erosion susceptibility. In particular, there is a risk that governing society may impose restrictions on large clearfell coupes in plantation forests, in the same way that strong restrictions were imposed on harvesting practices in privately-owned indigenous forest. If the forest industry decides that it needs to find alternatives to large clearfelling coupes, there is scope for further research in a number of areas related to CCF and small-coupe harvesting systems:

1. Small-coupe harvesting alternatives – if TDH is too difficult and expensive to be feasible, what other harvesting alternatives could be tried?
2. The potential for CCF on steep slopes using either winch-assisted or hauler-based harvesting systems; also a review of small-scale harvesting machinery and logistics options which might be applied in CCF systems. This could be linked to ongoing work by Forest Growers Research looking at alternative harvesting systems.
3. The willingness of owners to try CCF or small-coupe harvesting systems. Linked to this is the need for a better understanding of factors affecting forest owners' decisions around harvesting. Forest owners may take the decision to harvest based on

other financial indicators, needs or risk factors, and the NPV of an investment may not be the 'be all and end all' of the decision.

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