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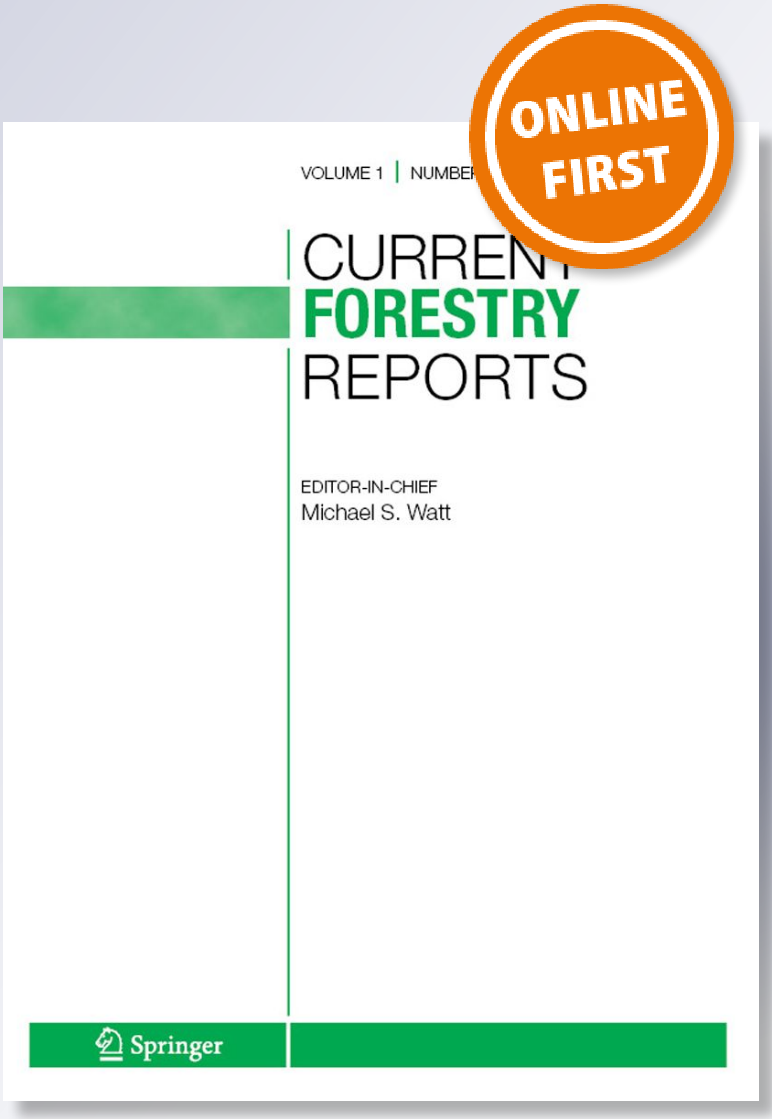

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New Zealand Cable Logging 2008–2018: a Period of Change

Hunter Harrill[1] · Rien Visser[2] · Keith Raymond[3]

Abstract

Purpose of Review Logging practices change and evolve over time to accomplish forest management goals considering constraints related to physical feasibility, economics, and social acceptability. Relative to its size New Zealand has a large and productive plantation forest estate and a well-established forest industry. In recent years, New Zealand has undergone significant changes to its timber harvesting methods, especially on steep terrain. The purpose of this paper is to qualify and quantify some of the changes in New Zealand cable logging practices over the last decade and discuss the impact of these changes.

Recent Findings There has been an increase in the volume of wood harvested in New Zealand and the proportion which is harvested from steep terrain. The need to improve safety, productivity, and costs associated with steep terrain harvesting has led to the development and implementation of new mechanized equipment and systems.

Summary Technological innovation has led to increased mechanization in many aspects of cable logging. While mechanization has in many cases improved aspects of safety and productivity, there are new challenges surfacing in the industry that will require another step change in harvesting systems.

Keywords Forest harvesting · Yarding · Mechanization · Safety · Productivity · Cost

Introduction

Historically, the majority of New Zealand's land base was covered in indigenous forests. While Maori used fire for hunting resulting in some forest loss, when the first European settlers arrived in the mid 1800s, forests were cleared and burned for agricultural purposes. Deforestation was so rapid that concerns arose about the country's future timber supply. In 1925, the state created financial incentives to establish plantations of introduced (exotic) forest species throughout the country to reduce the pressure on native forests. *Pinus radiata*, which was imported from California to form wind breaks on farms, proved to grow larger and faster than other species trialed and soon became the species of choice for afforestation. Mass plantings in the first half of the twentieth century created the plantation forest industry that exists today, with trees grown on rotations of 28–30 years [1].

Today, forests cover 35% of New Zealand's land, about 29% of which is native forest and 6% is plantation forests. Over 90% of the plantation forests are *Pinus radiata*, and 6% is frost tolerant Douglas-Fir (*Pseudotsuga menziesii*) at higher elevations. The net stocked forest area is 1.7 million hectares, with an annual harvest of approximately 45,000 ha [2•]. The average tree size is around 1.6 to 2.3 m^3, depending on silvicultural regime and the typical average volume per hectare ranges from 524 to 784 m^3. The forest industry has prospered in recent years with increased availability of mature trees reaching harvest age as a result of a planting boom in the mid-1990s and high log prices due to increased log demand, especially from China. The annual harvest volume has increased from approximately 20 million m^3 harvested in 2010 to more than 30 million m^3 in 2018 [2•]. The sector generated nearly $5.5 billion in export revenue and was the country's third largest export earner in 2018.

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The increased plantings in the 1990s, when between 50,000 and 100,000 ha of new land were planted, have resulted in almost 500,000 ha of forests in the 19–25-year-old age class. These forests are now reaching maturity and will be harvested in the next 10 years, which will further increase the annual harvest volume, up to 35 million m^3. However, many of these forests are termed small "farm forests" or "woodlots" (areas of less than < 100 ha) which are owned by more than 14,000 owners. These small forests are often located in steep and remote areas with little infrastructure, which represent additional challenges to logistics and costs as compared to larger corporate forest plantations [3].

Modern cable logging was introduced into plantation forests in the 1950s and has continued to be the preferred method of extracting timber on steep slopes that limit conventional ground-based equipment. There have been numerous developments in the methods of cable logging, and practices differ worldwide [4•]. Cable yarding is also preferred due to its environmental benefits over ground-based harvesting systems such as reduced road infrastructure due to longer extraction distances, reduced soil disturbance as a result of the partial or full suspension of logs during extraction, and machinery not required to traverse the harvest area [5, 6]. However, new systems are being developed to push the limits of ground-based machinery on steep terrain, such as the relatively new practice of winch-assisted felling and extraction [7].

Drivers for Change

Steep country forests contribute more than 50% of New Zealand's annual harvest [9] and are forecast to rise to over 60% in coming years [8]. With increased global competition in supplying wood fiber, the industry faced the challenge of remaining profitable. The forestry sector identified steep country harvesting as the key bottleneck in achieving greater profitability in forestry. Primarily, because the costs of harvesting on steep terrain are on average more than 40% higher than harvesting costs on flat terrain [9]. Harvesting and transport costs are typically 40–60% of the delivered costs of logs, yet prior to 2010, harvesting methods on steep terrain, such as cable logging, had changed little in 50 years [8]. Little research had been conducted in this area in New Zealand since the late 1990s when the former Logging Industry Research Organization (LIRO) was disestablished. If New Zealand was to remain competitive in international log markets, then improvements in cable logging operations in terms of harvesting productivity and cost were necessary. Despite its wide use and environmental benefits, cable logging is expensive and is more complex than ground-based methods, such as tractor or skidder logging. Cable logging also poses a high risk of accidents to workers and is generally less productive than ground-based methods of harvesting timber [10]. Additionally, New Zealand would require more forest workers and machines to harvest the increasing annual volumes. A survey by Visser [11] found that on average two cable yarders a month were being imported to New Zealand, and each of these machines required a crew of eight people on average.

Due to the multitude and complexity of the challenges identified (e.g., economics, labor, and safety), an industry research organization was established to guide forest operations and engineering research efforts. In 2007, Future Forests Research Ltd. (FFR) was formed (now called Forest Growers Research Ltd. (FGR)). Later in 2010, FFR was successful in forming a Primary Growth Partnership (PGP) with the government called the Steep Land Harvesting Program. This $7.6 million 7-year program had the goal of improving profitability by decreasing harvesting costs and increasing productivity with a heavy emphasis on mechanization and modern technology development and commercialization [8].

The concern over safety in harvesting operations heightened in 2013 when 10 workplace fatalities were recorded, approximately twice the long-term average and spurred the New Zealand forest industry to improve safety performance immediately, which culminated in the launch of a combined industry-government inquiry into safety [12]. The Independent Forestry Safety Review (IFSR) considered ways to reduce workplace harm to forestry and drove a number of initiatives to improve harvesting safety, including:

- Improved leadership through the formation in 2015 of the Forest Industry Safety Council (FISC) with representation from forest management companies, contractors, and workers
- Launch of the "Safetree" forestry safety website to elevate awareness, improve communication, and boost safety resources
- Setting up a comprehensive injury prevention program based on risk assessment, improved incident data and accident investigation and review processes

As a result of these initiatives, and developments in the Steepland Harvesting PGP program and other developments outside the program, forestry companies, harvesting contractors, and local machinery manufacturers implemented new mechanized harvesting technology.

Improving Understanding

The future of the New Zealand industry depended on cable logging to accomplish a step change to cost-effectively harvest the greater proportions of steep terrain logging [10]. Improvements started by gaining a better understanding of the status quo. Therefore, the industry deemed it important to quantify the cost and productivity of harvesting operations by establishing a database to annually benchmark current and future operations [13, 14]. More specific surveys were also conducted to further understand the current fleet of yarders, future demand for yarders, operating methods, and the most appropriate application of various methods [11, 15–17]. More broadly, practitioners were interested in how steep country harvesting was practiced in other parts of the world and what could be applied to New Zealand [18]. To aid the search for worldwide solutions to steep country harvesting, a technology watch article series was introduced by FFR in 2008.

A key interest area was in the mechanization of felling on steep slopes to not only improve productivity and safety but also improve subsequent cable yarding productivity [7, 19, 20]. Increasing operational costs continued to be of concern, particularly fuel costs for New Zealand logging operations which were expected to increase with higher proportions of harvesting on steep slopes [21]. Fuel efficiency was of particular concern as fuel costs are higher in New Zealand than nations that use similar machines and systems, like the USA and Canada. Therefore, an attempt was made to quantify fuel consumption (l/m^3) and efficiency (l/kWh) for New Zealand operations to compare to other countries and benchmark against future changes [22]. Results from the study confirmed that cable logging was less fuel efficient than ground-based operations and that cable logging fuel consumption averaged just over 3 l/m^3 and was greater than that observed in other countries. Another concern relating to not only cost but also environmental disturbance was the characteristics and size of landings constructed, which were found to have doubled in size over a period of less than 25 years and what was causing the increase [23].

With the government and industry co-funded research program established, a literature review into previous cable logging research relevant to New Zealand was conducted by Harrill and Visser [24] to inform the industry of the main research areas pertaining to cable logging and highlight where specific gaps in knowledge existed. One such gap identified was understanding around wire rope tension behavior during cable logging operations. A first investigation into the differences in tension between rigging configurations was simulated using a model yarder [25], which found there were significant differences in tension behavior even between slight variations in methods and when all other factors where controlled. Later, tensions in skylines were recorded and compared across a variety of actual logging operations in a series of case studies. The case studies indicated that safe working loads were often exceeded and that tension monitors provided benefits in respect to not only safety but also productivity through improving payload efficiency; the use of tension monitors in cable logging operations remained low, and they were not as effective as they could be in providing useful information [26, 27]. Arising from the fundamental work at University of Canterbury in monitoring operating tensions of wire ropes in both cable logging and winch-assisted machines, a tension monitoring "App" was developed which better displayed tension data visually in the yarder operator's cab and recorded the data for later review [28]. The App has subsequently been commercialized as the Falcon Tension Monitoring App, and a similar version is now standard in Falcon winch-assist machines.

European yarding technology became of interest to New Zealand due to reductions in required labor and fuel, but there were concerns about the smaller size machines and their capability in extracting New Zealand trees. Further studies on the tension monitoring of chokers attempted to quantify the forces required to "break out" a log during cable yarding to aid future yarder design, a limitation which was identified when a European yarder was previously trialed in New Zealand [29, 30].

Increasing Productivity

In addition to reduced harm, increasing productivity and reducing costs was the main goal of the PGP Steep Land Harvesting program. Planning for cable logging operations is critical, especially when setting up a yarder where it will have enough cable deflection. While deflection is easily measured via maps, GIS, and payload analysis software during the design phase of planning, it can be difficult to estimate in the field and cumbersome to measure. New approaches to measuring deflection in the field ensuring that the desired design deflection was achieved were investigated using photo techniques from the power line industry, and eventually, an easy to use calculator was converted into an App [31, 32]. Once the desired deflection is achieved, adequate payloads are key to productivity in cable logging, but hard to estimate visually and can be time consuming or dangerous to measure during operations [33]. One such technique for estimating payloads is to use a tension monitor [34]; a concept which had been previously investigated when monitors were first introduced in the early 1990s [35]. While tension monitors were historically thought of as primarily improving safety of operations, they also have a real potential to improve productivity through payload optimization [27].

Other studies on technology integration into yarders occurred during this period such as on board computer systems for measuring carriage outhaul distance, monitoring productivity, and electronic controls to aid in collecting the data and to improve ergonomics through simplification of controls [36–39]. The interest grew further to investigate the potential of alternative power sources for yarders and to perform multiple functions such as processing as used in Europe or even to dispose of residues by installing a chipper on the yarder [40–42].

Interest from the forest sector on technology employed in European yarders resulted in several trips overseas to ascertain whether the systems could be appropriate for New Zealand conditions [43–46]. Eventually, a European yarder, the Koller 602H, was imported to New Zealand and investigated in several productivity studies. There were also new yarders being developed in New Zealand, like the Active 70 which was similarly studied [29, 47–49]. Excavator-based yarders were also becoming more popular in New Zealand such as the New Zealand produced HarvestLine and Alpine Shovel Yarder from South Africa [50, 51], with interest growing around their application particularly in small forests and woodlots.

One project involved investigations into different yarders and methods, led by workshop discussions to generate ideas to create an entirely new and innovative yarding system. A literature review of innovative systems, followed by structured workshops to generate ideas, was conducted [52, 53]. The ideas generated were evaluated by an expert panel, and then a feasibility analysis was performed [54, 55]. Eventually, one idea, the Skyshifter carriage, was brought to prototype stage for field evaluation [56, 57].

All together, sector-wide benefits arising from the commercialization of these new products and processes out of the PGP program and from other industry related efforts have resulted in increased productivity as measured by the FGR benchmarking database, managed by University of Canterbury (Fig. 1).

Grappling with Changes

One practice, which has widely been adopted in New Zealand over recent years, is grapple yarding [58]. Grapple yarding was highly desired by the forest industry because it achieved the dual goals of mechanizing the extraction process and improving both safety and productivity of cable logging operations. The increased uptake of grapple-capable swing yarders and excavator yarders fuelled this shift, and the simultaneous development of motorized grapple carriages extended this capability to tower yarders [10]. Early interests in grapple yarding were highlighted by a literature review of international grapple carriage developments and improved control systems for operating them [59, 60]. New and simple ideas were trialed like a restraint system of springs to better control the movement of conventional mechanical grapples, making the process of grappling easier for the operator [61].

New motorized hydraulic grapple carriages were developed during this period such as the Falcon Forestry Claw and the Alpine Grapple Carriage. The Alpine, developed in South Africa, is a remote controlled light weight hydraulic log grapple designed for two or three-drum yarders. Both these grapple carriages were the focus of extensive trials and several production studies as grappling grew in popularity [26, 62–65]. Other innovative motorized grapple carriage concepts were also investigated but were not successful in commercialization [66]. Grapple carriages provided opportunities to reduce labor and even extend working hours [67]. However, the carriages also highlighted some concerns with wire rope wear and early fatigue, so new types of wire ropes for their use were trialed [68].

Changes to Felling on Steep Slopes

One of the major outcomes of New Zealand innovations in harvesting has been the implementation of new equipment and processes for winch-assisted felling machinery on steep slopes [19]. To date, the industry uptake of winch-assisted felling machinery on steep slopes and increased uptake of grapple yarding as an improved method of extraction have achieved increases of 25% in cable harvesting productivity since 2012 (23.5 t/h in 2012 vs. 29.4 t/h in 2016) [69]. Mechanized felling is now replacing motor-manual tree fallers wherever possible in forests throughout New Zealand. Since commercialization of the ClimbMAX harvester in 2012 [70] and widespread uptake of over 90 other winch-assisted machines over the last 7 years, the level of mechanized tree felling in yarder operations has increased to 35% of

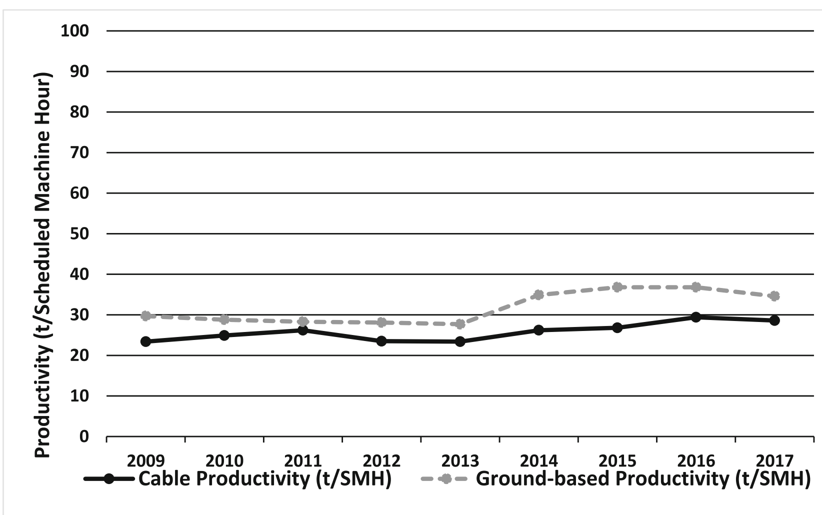


Fig. 1 Average harvesting productivity by system, New Zealand 2009–2017 [56]

operations, up from only 1% in 2010 (Fig. 2), as reported by Raymond [71•, 72•] in his summary reports of the FFR Steepland Harvesting Program. Uptake of mechanized felling in ground-based operations has also increased to over 80% of operations. Over all harvesting operations, the proportion of mechanized felling has increased from 23% of all operations in 2009 to about 57% of operations in 2017 (Fig. 2).

A more radical project involved the concept design, development, field testing, and demonstration of a prototype robotic tree-to-tree felling machine, a new mobility system using movement from tree-to-tree to traverse steep terrain [73].

Health and Safety

As highlighted by the IFSR in 2014, harvesting health and safety was a concern facing both harvesting contractors and forest managers [12]. Investigations into safer and more ergonomic ways of harvesting begun earlier were starting to bear fruit, and some innovations were already being trialed. A literature review of the uptake of human factors and ergonomics research, published by Hide and others [74], found that there were shortcomings and areas of health and safety which had not been addressed through research. Effective training was also recognized as important for the safety of workers in forest operations. A comparison of steep terrain training programs in several countries was used for evaluating current domestic training programs [75].

New innovative ways of training, like the use of video from cameras mounted on workers, were tested as a means of training for some of the highest risk jobs, such as choker setting [76]. Since choker setting and tree felling were identified as the highest risk jobs, many of the developments around the country focused on making these jobs safer and less demanding. There were a few studies which investigated the cardiovascular workload on choker setters through heart rate monitoring and found it was demanding and strenuous by international standards and rated above sugar cane cutting [47, 77].

One difficult task for choker setters is pulling wire rope either to hook up logs for extraction or during the setup of a cable yarder. Synthetic ropes commonly used in European operations were investigated through a literature review for appropriate applications in New Zealand [78]. Synthetic ropes have started to find their way into harvesting operations in New Zealand and have even been used in conjunction with UAV's to fly straw line for cable yarder setup. The conventional physically demanding process usually requiring several workers and a few hours presents many slip, trip, and fall hazards, which can now be accomplished in approximately one-half hour with one to two people and minimal effort [31].

Camera systems have also found their way into many operations, with cameras mounted on various types of grapple carriages, which are now produced by several equipment manufacturers. Another application, called the CutoverCam, incorporates a new vision system using a high-definition camera located in the harvest area to provide the yarder operator with full vision of the choker setters and the log extraction (Fig. 3). The CutoverCam development was the focus of several studies and has since been commercialized [79–81].

The national drive towards fully mechanized operations with winch-assisted felling, followed by grapple yarding, has seen many workers removed from the two most hazardous tasks of motor-manual tree felling and choker setting. It has been calculated that from 2012 to mid-2018, about 213 workers have been removed from these two hazardous roles [72•].

Even more striking is the rate of serious harm incidents per million cubic meter of wood production, which has dropped to less than one-third of the rate in 2012, from 7.2 to 2.4 (Fig. 4).

Serious harm incidents are measured against annual round wood removals from data collected by Ministry for Primary Industries and the number of serious harm incidents as recorded by WorkSafe NZ. Over this period, annual forest harvest volumes have lifted from 26.0 million m^3 per annum in 2012 to 30.6 million m^3 in 2017 (+ 18%).

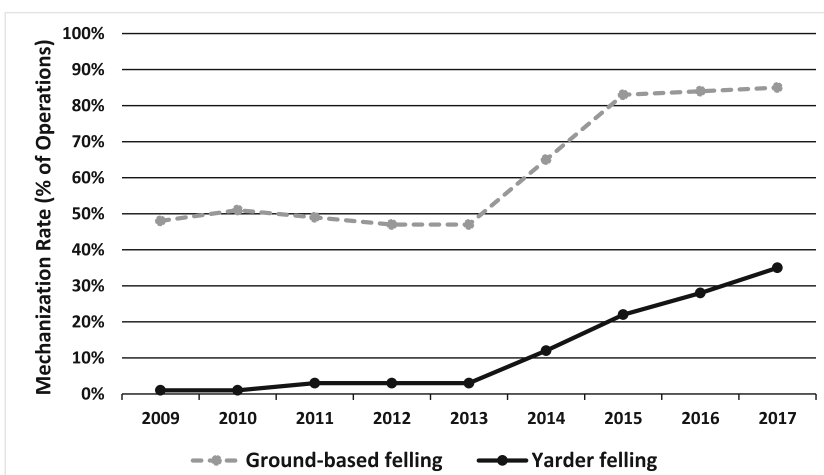


Fig. 2 Increase in mechanized felling by system, New Zealand 2009–2017 [70]

Fig. 3 Cutover camera showing a cable yarder operator a view of trees to be extracted [source: Applied Teleoperation Limited]

The innovations discussed are providing forest owners and contractors with solutions to improve productivity and reduce the exposure of workers to hazards on steep terrain. However, manual tree fallers will still be required in some circumstances. One solution to aid motor-manual tree felling has been attempts to develop a new type of felling wedge, which acts like a jack to guide tree falling in the desired direction [82]. The jack has been the focus of several studies and is seen as a desired tool when felling trees that are large and/or have a significant lean [83, 84].

Environmental Concerns

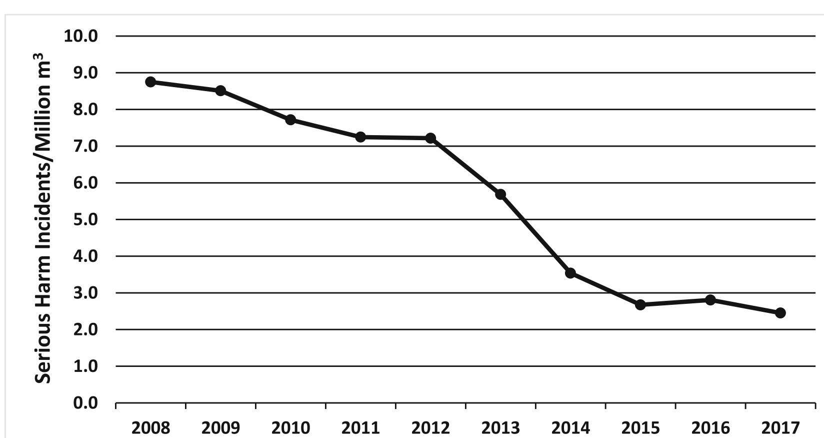
Although mechanization has clear and obvious benefits in terms of safety and productivity, more machinery covering more ground, especially on steep terrain, also leads to higher levels of ground disturbance. For plantation forests, soil disturbance or related compaction shows little impact on longer-term crop productivity [85]. However, soil disturbance studies showed that poor yarding practices such as excessive ground lead [86] can lead to unacceptable results. The greater concerns are related to impacts on water quality and degradation of waterways through sedimentation.

Up to 2018, the regulatory setting in New Zealand required each region to develop its own plans and rules that guide all land use [87]. This was within an overarching environmental law called the Resource Management Act 1991 (RMA) that effectively prohibited regions from making land use specific rules. As such, regional rules were based around broader activities such as "vegetation clearance" and "earthworks." Around the time of the RMA introduction, a series of catchment scale studies showed forests to be a relatively positive land use in terms of water quality and erosion risk [88, 89], which in turn was well aligned with larger-scale and longer-term USA-based catchment studies [90, 91]. This led to a period of time for harvesting operations with few environmental restrictions, especially as cable logging was recognized as the preferred and lower-impact system for harvesting on steep slopes.

Given the complexity of adhering to different rules, the forest industry guided the government to a "National Environmental Standard for Plantation Forests" (NES-PF) with the goal of providing a consistent set of rules that address the risks of forestry activities and protects sensitive environments. Rules for the protection of waterways, as well as acceptable levels of water quality impacts, will affect cable logging operations. For example, the rule on water quality states that harvesting should not conspicuously change the color of water after reasonable mixing. There is also clear guidance on the need to fell trees away from waterways and the need to fully suspend when using cable logging systems over waterways.

With commercial forest areas planted *en masse*, harvesting typically is carried out on contiguous blocks using larger-scale North American style yarding systems carrying out clear-cut operations. In addition to exposing larger catchment areas to erosion risk, harvesting the plantation pine forests also yields larger volumes of harvest residues that are concentrated

Fig. 4 Serious harm incident rate per million cubic meter production, New Zealand 2008–2017 [70]



around the processing areas [92••]. With a large proportion of the commercial plantations being harvested from first-rotation, there is also considerable risk associated with the new infrastructure. Over 1300 km of new forest road is still being constructed each year, and about 40% of that is on terrain identified as either highly or very highly erodible [93].

A series of recent major storms has resulted in major depositions of both sediment and harvest residues on downstream properties and provides cause for concern as to current modus operandi [94, 95]. A series of reviews noted that it is not only the physical aspects but also the social license to operate that is at risk [96, 97]. It is expected that these environmental impact risks will change how we harvest in the near future, especially areas with slope stability issues. Raymond and Bawden [98] reflected on the fact that larger-scale debris flows are not new, but their sporadic nature means they are often forgotten.

By reviewing mass soil movement from storm events, Marden and Rowan [99] showed that pine forests with good ground cover (e.g. 8+ years) provided excellent protection, similar to mature indigenous forest. However, the review also highlighted a post-harvest period where harvested, or recently planted, areas are prone to mass erosion events. While some consideration is being given to managing the plantation forests using selective harvesting and natural regeneration [100], such practices are most likely to be cost-prohibitive [101]. Harvesting practices, such as constraining the scale of harvest in both temporal and spatial dimensions, were being implemented 25 years ago to address such risks [98].

While steep country harvesting has gone through a period of rapid change to meet safety and productivity demands, it will need to continue to develop in the near future to accommodate environmental performance expectations.

New Challenges

The Steepland Harvesting Program from 2010 to 2017 has been a catalyst for increased innovation in harvesting in New Zealand with new technology being developed and deployed, both from the program and outside of the program. Some examples include equipment not only winch-assist, teleoperation, and increased use of cameras but also the development of software to help manage operations on steep slopes.

One of the major challenges identified by the industry was to sustain a strong, safe, and healthy workforce. The outputs from all the innovations and ultimately the desired outcomes relating to safety are very relevant to the current high level of focus on worker safety in the New Zealand forest industry, primarily in harvesting activities. The new technology implemented has not presented major new challenges in terms of skills and training. Work is continuing in integrating new technology into the skills training and qualifications system.

The challenge now is to continue the momentum developed in the industry towards further innovation. A new PGP program "Te Mahi Ngahere i te Ao Hurihuri—Forestry Work in the Modern Age" has three major aims: to create value, improve profitability, and enhance sustainability across the forestry value chain through automation [102••]. The program aims to do this by developing a new integrated forestry value chain from harvest to market, incorporating new technologies (Fig. 5).

It builds on the successful development of forestry mechanization, remote control and teleoperation developed in the earlier PGP Steepland Harvesting program, and focuses on new automation and robotics technology.

The new program is led by the Forest Value Chain Consortium, a partnership of forestry companies, harvesting and logistics contractors, and machinery manufacturing firms. The Consortium proposes development of new log sort yards as a wood logistics solution which redesigns the harvesting, log manufacturing, and logistics process. The goal is that by 2030, over 20% of all harvesting operations will be fully automated, using products developed in this program.

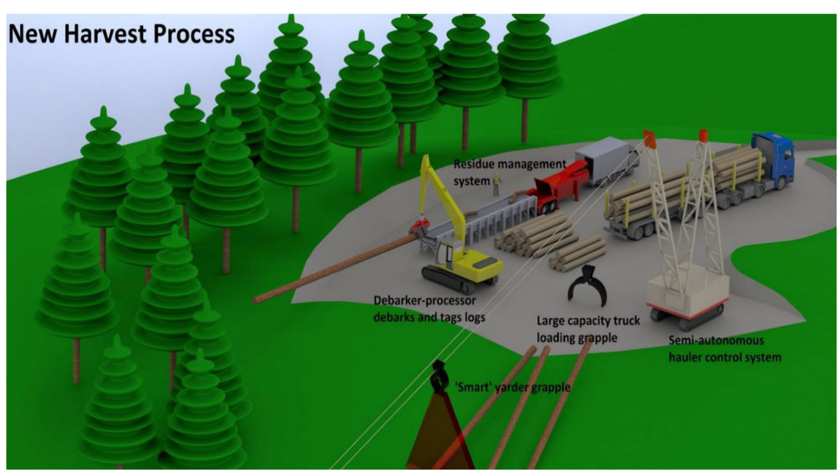


Fig. 5 Concept for a new harvest process involving automation [100]

Conclusion

The New Zealand forestry sector identified steep country harvesting as the main bottleneck to greater profitability and safety in forestry. Industry initiatives have achieved the development and implementation of innovative mechanized and remote-controlled harvesting technologies to realize substantial safety, productivity, and cost reduction gains and improve worker safety in steep terrain harvesting in New Zealand. A major contribution towards this goal was achieved through the investment in applied research, with a strong focus on commercialization. These efforts were led by Forest Growers Research, where industry formed a partnership with government (Ministry for Primary Industry) to remove manual workers from hazards in steep terrain harvesting operations and realize the vision of "no worker on the slope, no hand on the chainsaw."

The New Zealand forest industry has been, and will continue to be, in a significant period of change. Future innovations have the potential to further transform the forest harvesting industry substantially and to improve both economic and environmental outcomes in New Zealand plantation forestry. This transformation will be dependent on further commercialization and uptake of the outputs of forest engineering developments, combined with strong support from forest management companies and harvesting contractors in order to further drive adoption.

Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflict of interest.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

References

Papers of particular interest, published recently, have been highlighted as:
• Of importance
•• Of major importance

Note: The FFR (Now called FGR) reports, listed below, can be accessed through the FGR website (http://fgr.nz) or more specifically most can be found within the Harvesting and Logistics Theme page (https://fgr.nz/programmes/harvesting-and-logistics/).

1. NZFOA. Plantation Forestry in New Zealand: history. 2014. http://www.nzfoa.org.nz/plantation-forestry/plantation-forestry-overview. Accessed August 20th 2014.
2.• NZFOA. New Zealand plantation forest industry: facts and figures. 2017. https://www.nzfoa.org.nz/resources/publications/facts-and-figures. Accessed December 1st 2017. **This online document summarizes the latest available facts about the plantation forest industry in New Zealand, for researchers looking for such information.**
3. Raymond K. Innovation to increase profitability of steep terrain harvesting in New Zealand. In Proceedings of New Zealand Institute of Forestry Annual Conference; 2012; Christchurch, New Zealand.
4.• Visser R, Harrill H. Cable yarding in North America and New Zealand: a review of developments and practices. Croat J For Eng. 2017; 38(2): 209-217 **This review journal article summarizes the developments in cable logging technology and compares them between the trends and practices observed in Europe, New Zealand, and North America**.
5. Baillie B. Forest harvesting practices in and around sensitive areas: a literature review. Rotorua, New Zealand: Scion. 2010. Scion Technical Report No. S0001. 6.
6. Palmer D, McMahon S, Fraser D, Visser R. Skyline logging to minimise impacts on native vegetation. Rotorua, New Zealand: Logging Industry Research Organisation 1996. Report 21(16). 5.
7. Evanson AW, Amishev D. A steep slope excavator feller buncher. Rotorua, New Zealand: Future Forests Research Ltd. 2010. Report No.: HTN03-02. 8.
8. FFR. Four Corners May 2010. Available online at http://www.fgr.nz/2010/05/26/ffr-welcomes-funding-forest-harvesting-research/. Accessed 20 June 2019. 2010.
9. Visser R. Harvesting cost and productivity benchmarking: 2013 update. Rotorua, New Zealand: Future Forests Research Ltd. 2014. Report No.: HTN06-06. 6.
10. Harrill H. Improving cable logging operations for New Zealand's steep terrain forest plantations. PhD Thesis, University of Canterbury; 2014. 242.
11. Visser R. Survey of cable yarders used in New Zealand. Rotorua, New Zealand: Future Forests Research Ltd. 2013. Report No.: HTN06-03. 4.
12. Adams G, Armstrong H, Cosman M. Independent forestry safety review: an agenda for change in the forestry sector. 2014. http://hazelarmstronglaw.co.nz/wp-content/uploads/2017/09/FINAL-REPORT-Independent-Forestry-Safety-Review.pdf. Accessed September 15th 2018.
13. Visser R. Benchmarking harvesting cost and productivity. Rotorua, New Zealand: Future Forests Research Ltd. 2009. Report No.: HTN02-06. 8.
14. Visser R. 2010 Benchmarking of harvesting cost and productivity. Rotorua, New Zealand: Future Forests Research Ltd. 2011. Report No.: HTN03-10. 6.
15. Clarke A. Potential demand for haulers over the next 10 years. Rotorua, New Zealand: Future Forests Research Ltd. 2012. Report No.: HTN05-04. 6.
16. Harrill H, Visser R. Rigging configurations used in New Zealand cable logging. Rotorua, New Zealand: Future Forests Research Ltd. 2011. Report No.: HTN03-11. 6.
17. Harrill H, Visser R. Matching rigging configurations to harvesting conditions. Rotorua, New Zealand: Future Forests Research Ltd. 2012. Report No.: HTN04-06. 8.
18. Raymond K. Steep slope harvesting in British Columbia. Rotorua, New Zealand: Future Forests Research Ltd. 2013 Report No.: HTN06-05. 8.
19. Amishev D. Steep slope feller buncher: a feasibility study. Rotorua, New Zealand: Future Forests Research Ltd. 2011. Report No.: H007. 27.
20. Amishev D. Mechanised steep slope felling for New Zealand: current developments. Rotorua, New Zealand: Future Forests Research Ltd. 2012. Report No.: HTN04-07. 8.

21. Amishev D. A Review of fuel consumption in New Zealand harvesting operations. Rotorua, New Zealand: Future Forests Research Ltd. 2010 Report No.: HTN03-04. 5.
22. Oyier P, Visser R. Fuel consumption of timber harvesting systems in New Zealand. Eur J For Eng. 2016;2(2): 67-73.
23. Visser R. Landing size and characteristics. Rotorua, New Zealand: Future Forests Research Ltd. 2010. Report No.: HTN03-05. 6.
24. Harrill H, Visser R. A review of cable logging literature. Rotorua, New Zealand: Future Forests Research Ltd. 2014. Report No.: H019. 17.
25. Harrill H, Visser R. Simulating skyline tensions of rigging configurations. Rotorua, New Zealand: Future Forests Research Ltd. 2013. Report No.: HTN05-12. 8.
26. Harrill H, Visser R. Rigging configurations efficiency case studies. Rotorua, New Zealand: Future Forests Research Ltd. 2014. Report No.: H020. 89.
27. Harrill H. Improving yarding productivity using tension monitors. Rotorua, New Zealand: Future Forests Research Ltd. 2016. Report No.: HTN09-02. 7.
28. Visser R, Harrill H, Martin A. Development of a tension monitoring 'app'. Rotorua, New Zealand: Future Forests Research Ltd. 2016. Report No.: HTN09-01. 5.
29. Evanson AW, Hill S. The Koller 602H yarding system. Rotorua, New Zealand: Future Forests Research Ltd. 2015. Report No.: HTN08-01. 10.
30. Harrill H, Visser R. A study of breakout forces in cable logging. Rotorua, New Zealand: Forest Growers Research Ltd. 2017. Report No.: HTN09-06. 6.
31. Harrill H, Visser R, Campbell T. Technological developments in cable logging. In Proceedings of Annual Council on Forest Engineering Meeting; 2016; Vancouver, British Columbia. 8.
32. Harrill H, Visser R. Measuring skyline deflection with the LineSmarts app. Rotorua, New Zealand: Future Forests Research Ltd. 2016. Report No.: HTN08-07. 5.
33. Marshall H. Comparison of methods for estimating harvesting payloads. Rotorua, New Zealand: Future Forests Research Ltd. 2009. Report No.: HTN02-08. 4.
34. Evanson AW. Use of tension monitors to estimate payload. Rotorua, New Zealand: Future Forests Research Ltd. 2009. Report No.: HTN01-08. 6.
35. Hartsough B. Benefits of remote tension monitoring. Rotorua, New Zealand: Logging Industry Research Organisation. 1993. Report 18 (23). 13.
36. Evanson AW. A method to estimate yarding distance. Rotorua, New Zealand: Future Forests Research Ltd. 2009. Report No.: HTN02-04. 3.
37. Evanson AW. On-board monitoring systems. Rotorua, New Zealand: Future Forests Research Ltd. 2010. Report No.: HTN02-10. 4.
38. Evanson AW, Henderson B. Sauer-danfoss controllers in haulers. Rotorua, New Zealand: Future Forests Research Ltd. 2009. Report No.: HTN01-04. 3.
39. Marshall H. The integration of technology for productivity monitoring. Rotorua, New Zealand: Future Forests Research Ltd. 2010. Report No.: HTN02-11. 6.
40. Amishev D. Developing a multi-funtion hauler: a feasibility study. Rotorua, New Zealand: Future Forests Research Ltd. 2011. Report No.: HTN04-04. 6.
41. Amishev D. Using hauler engine power to drive a wood chipper. Rotorua, New Zealand: Future Forests Research Ltd. 2012. Report No.: HTN05-05. 8.
42. Milliken P, Amishev D. Alternative power sources for cable yarders. Rotorua, New Zealand: Future Forests Research Ltd. 2013. Report No.: HTN06-04. 6.
43. Amishev D. New logging technology. Rotorua, New Zealand: Future Forests Research Ltd. 2011. Report No.: HTW-008. 8.
44. Hill S, Raymond K. Valentini V1500 cable yarder. Rotorua, New Zealand: Future Forests Research Ltd. 2013. Report No.: HTN06-01. 6.
45. Raymond K. New logging technology. Rotorua, New Zealand: Future Forests Research Ltd. 2013. Report No.: HTW-012. 10.
46. Visser R, Spinelli R, Stampfer K. New developments in european yarder technology. Rotorua, New Zealand: Future Forests Research Ltd. 2011. Report No.: HTN04-01. 6.
47. Campbell T. Assessment of the opportunity of modern cable yarders for application in New Zealand. MS Thesis, University of Canterbury; 2016. 95.
48. Campbell T, Harrill H, Visser R. Productivity of the Active 70 tower yarder. Rotorua, New Zealand: Future Forests Research Ltd. 2016. Report No.: HTN08-05. 8.
49. Evanson AW, Hill S, Campbell T, Visser R. Productivity of the Koller 602h yarder in radiata pine. Rotorua, New Zealand: Forest Growers Research Ltd. 2017. Report No.: HTN09-04. 8.
50. Evanson AW. Excavator yarders for New Zealand. Rotorua, New Zealand: Future Forests Research Ltd. 2016 Report No.: HTW-17. 8.
51. Raymond K, Hill S. Alpine shovel yarder in New Zealand. Rotorua, New Zealand: Forest Growers Research Ltd. 2018. Report No.: HTW-18. 5.
52. Hill S. Innovative yarding systems: a review of literature. Rotorua, New Zealand: Future Forests Research Ltd. 2014. Report No.: HTN06-07. 6.
53. Hill S, Parker RJ. Innovative yarding systems: concept generation. Rotorua, New Zealand: Future Forests Research Ltd. 2013. Report No.: HTN05-09. 10.
54. Hill S. Innovative yarding system: technical and economic feasibility. Rotorua, New Zealand: Future Forests Research Ltd. 2014. Report No.: HTN07-01. 7.
55. Hill S, Parker RJ. Innovative yarding system: analysis of ideas. Rotorua, New Zealand: Future Forests Research Ltd. 2013. Report No.: HTN05-10. 6.
56. Hill S, Scott D. Skyshifter twin winch tail hold carriage: field trials. Rotorua, New Zealand: Forest Growers Research Ltd. 2017. Report No.: H031. 18.
57. Scott D, Hill S. Twin winch tail hold carriage: design and economic analysis. Rotorua, New Zealand: Future Forests Research Ltd. 2015. Report No.: H025. 20.
58. Harrill H, Visser R. Survey of yarders and rigging configurations: 2018. Rotorua, New Zealand: Forest Growers Research Ltd. 2018. Report No.: HTN10-04. 9.
59. Evanson AW. International grapple carriage developments: a review of the literature. Rotorua, New Zealand: Future Forests Research Ltd. 2011. Report No.: H004. 23.
60. Evanson AW. Deveolpment of an improved grapple carriage control system: a feasibility study. Rotorua, New Zealand: Future Forests Research Ltd. 2011. Report No.: H005. 19.
61. Evanson AW, Brown D. Improved grapple control using a grapple restraint. Rotorua, New Zealand: Future Forests Research Ltd. 2012. Contract No.: HTN04-10. 7.
62. Evanson AW. Improved grapple control: the alpine grapple. Rotorua, New Zealand: Future Forests Research Ltd. 2013. Report No.: HTN05-HTN08. 5.
63. Evanson AW. Alpine grapple carriage from prototype to production. Rotorua, New Zealand: Future Forests Research Ltd. 2014. Report No.: HTN06-09. 6.
64. McFadzean S, Visser R. Falcon forestry claw grapple: productivity and ergonomics. Rotorua, New Zealand: Future Forests Research Ltd. 2013. Report No.: HTN05-06. 7.
65. Milne S. Falcon forestry claw motorised grapple carriage: solving performance limitations. Rotorua, New Zealand: Future Forests Research Ltd. 2013. Report No.: H009. 17.

66. Snyman J. Scorpion grapple carriage: concept appraisal. Rotorua, New Zealand: Future Forests Research Ltd. 2014. Report No.: H016. 24.
67. Hill S. Logging after dark with an alpine grapple carriage fitted with lights. Rotorua, New Zealand: Future Forests Research Ltd. 2014. Report No.: HTN07-02. 6.
68. Harrill H, Visser R. Constructex wire rope: initial trials. Rotorua, New Zealand: Future Forests Research Ltd. 2016. Report No.: HTN08-08. 6.
69. Visser R. Benchmarking harvesting cost and productivity: 2017 update. Rotorua, New Zealand: Forest Growers Research Ltd. 2018 Report No.: HTN10-02. 4.
70. Evanson AW, Amishev D, Parker RJ, Harrill H. An evaluation of a ClimbMAX Steep Slope Harvester in Maungataniwha Forest, Hawkes Bay. Rotorua, New Zealand: Future Forests Research. 2013. Report No.: H013. 16.
71.• Raymond K. Steepland harvesting programme: final programme report. Rotorua, New Zealand: Forest Growers Research Ltd. 2017. Report No.: H032. 37. **This report summarizes the major outcomes from the PGP steepland harvesting program.**
72•. Raymond K. Steepland Harvesting Programme Post-Programme Report. Rotorua, New Zealand: Forest Growers Research Ltd. 2018. Report No.: 02. 23. **This report summarizes the major outcomes and benefits from the PGP steepland harvesting program.**
73. Parker RJ, Milliken P. Design of the robotic tree felling machine. Rotorua, New Zealand: Future Forests Research Ltd. 2013. Report No.: H011. 13.
74. Hide S, Parker RJ, Moore DJ. The uptake of human factors and ergonomics research. Rotorua, New Zealand: Future Forests Research Ltd. 2010. Report No.: H002. 138.
75. Harrill H, Visser R. International steep terrain training programmes. Rotorua, New Zealand: Future Forests Research Ltd. 2015. Report No.: HTN08-02. 9.
76. Parker RJ. Using video clips for training - breaking out. Rotorua, New Zealand: Future Forests Research Ltd. 2010. Report No.: HTN03-03. 6.
77. Triplow S. Heart-rate monitoring of breaker-outs. BE Thesis, University of Canterbury; Christchurch, 2010. 10.
78. Amishev D. Synthetic rope for use in cable logging: a review of the literature. Rotorua, New Zealand: Future Forests Research Ltd. 2009. Report No.: HTN01-06. 6.
79. Evanson AW, Milliken P. Hauler vision system: Testing of the cutover camera. Rotorua, New Zealand: Future Forests Research Ltd. 2012. Report No.: HTN05-03. 6.
80. Evanson AW, Parker RJ. Advanced hauler vision system: a feasibility study. Rotorua, New Zealand: Future Forests Research Ltd. 2011. Report No.: H006. 33.
81. Hill S. Production trials of the CutoverCam. Rotorua, New Zealand: Forest Growers Research Ltd. 2017. Report No.: HTN09-09. 6.
82. Vincent B. Development of an improved felling wedge for directional felling: initial trials. Rotorua, New Zealand: Future Forests Research Ltd. 2013. Report No.: H010. 21.
83. Vincent B. The Jackson Beckham lifting wedge and the Koller mechanical tree feller: comparison trials. Rotorua, New Zealand: Future Forests Research Ltd. 2015. Report No.: H022. 19.
84. Vincent B, Jackson D, Beckham M. Development of the Jackson Beckham felling wedge for directional tree felling. Rotorua, New Zealand: Future Forests Research Ltd. 2014. Report No.: H018. 25.
85. Murphy G, Firth JG, Skinner MF. Long-term impacts of forest harvesting related soil disturbance on log product yields and economic potential in a New Zealand forest. Silva Fennica. 2004;38(3):279–89.
86. McMahon S. Cable logging disturbance on an unstable slope: a case study, Rotorua: New Zealand Logging Industry Research Organisation. 1995. 40(12). 9.
87. Fowler C. The National Environmental Standards for Plantation Forestry – implications for the forestry sector. NZ J For. 2017;62(3):6–11.
88. Eyles G, Fahey BD. The Pakuratahi land use study: a 12 year paired catchment study of the environmental effects of Pinus Radiata forestry. In: Council HsBR, editor. New Zealand. 2006. 135.
89. Fransen P, Brownlie R. Historical slip erosion in catchments under pasture and radiata pine forest, Hawke's Bay hill country. N.Z. Forestry. 1995; November:29-33.
90. Bosch J, Hewlett J. A review of catchment experiments to determine the effect of vegetation changes on water yield and evapotranspiration. J Hydrol. 1982;55:3–23.
91. Hornbeck JW, Martin CW, Eager C. Summary of water yield experiments at Hubbard Brook experimental forest. Can J For Res. 1997;27:2043–52.
92.•• Visser R, Spinelli R, Brown K. Best practices for reducing harvest residues and mitigating mobilisation of harvest residues in steepland plantation forests. In: Council GR, editor. Christchurch, New Zealand: School of Forestry, University of Canterbury; 2018. 53. **This report commissioned after a recent storm event, reviews best practices from around the world regarding harvest residues and mobilization into waterways, and provides suggestions for the New Zealand plantation forest industry.**
93. Brown K, Visser R. Adoption of emergent technology for forest road management in New Zealand. NZ J For. 2018;63(3):23–9.
94. Cave M, Davies N, Lnagford J. Cyclone cook slash investigation. In: Council GD, editor. New Zealand. 2017. 105.
95. Payn T, Phillips C, Basher L, Garrett L, Harrison D, Heaphy M, et al. Improving management of post-harvest risks in steepland plantations. NZ J For. 2015;60(2):3–6.
96. Payn T. Future environmental challenges and New Zealand's planted forests. NZ J For. 2018;63(2):14–20.
97. Phillips C, Marden M, Basher L. Plantation forest harvesting and landscape response: what we know and what we need to know. NZ J For. 2012;56(4):4–12.
98. Raymond K, Bawden R. Steep land forest management: lessons from 25 years ago. NZ J For. 2019;63(4):17–24.
99. Marden M, Rowan D. Protective value of vegetation on tertiary terrain before and during cyclone Bolay, East Coast, North Island, New Zealand. N Z J For Sci. 1993;23(3):255–63.
100. Wardle J. Management of radiata pine using selective harvesting and natural regeneration. NZ J For. 2019;63(4):25–8.
101. Spinelli R, Visser R, Thees O, Sauter U-H, Kranjnc N, Rjond C, et al. Cable logging contract rates in the Alps: the effect of regional variability and technical constraints. Croat j For Eng. 2015;36(2): 179–87.
102.•• Raymond K. Te Mahi Ngahere i te Ao Hurihuri: Forestry work in the Modern Age. Rotorua, New Zealand: Forest Growers Research Ltd. 2018. Report No.: 00. 7. **This report outlines the new Primary Growth Partnership research program.**