SCION
Next generation biomaterials

# Forest harvest practices in and around sensitive areas – a literature review

www.scionresearch.com

SCION
Next generation biomaterials

**REPORT INFORMATION SHEET**

| | |
|---|---|
| *REPORT TITLE* | Forest harvest practices in and around sensitive areas – a literature review |
| *AUTHORS* | BRENDA R. BAILLIE |
| *SCION TECHNICAL PUBLICATION NUMBER* | S0001 |
| *ISBN:* | 978-0-478-11039-1 |
| *SIDNEY OUTPUT NUMBER* | 46520 |
| *SIGNED OFF BY* | BRIAN RICHARDSON |
| *DATE* | JUNE 2010 |
| *CONFIDENTIALITY REQUIREMENT* | PUBLICLY AVAILABLE |
| *INTELLECTUAL PROPERTY* | © NEW ZEALAND FOREST RESEARCH INSTITUTE LIMITED ALL RIGHTS RESERVED. UNLESS PERMITTED BY CONTRACT OR LAW, NO PART OF THIS WORK MAY BE REPRODUCED, STORED OR COPIED IN ANY FORM OR BY ANY MEANS WITHOUT THE EXPRESS PERMISSION OF THE NEW ZEALAND FOREST RESEARCH INSTITUTE LIMITED (TRADING AS SCION). |

# EXECUTIVE SUMMARY


## Objective

Harvesting activities have the potential to adversely impact environmental values, particularly in sensitive forest areas such as; steep unstable erodable terrain, compactable soils, wetlands, water bodies, and riparian areas. Because of their environmental sensitivity, these areas often require alternative harvesting systems to achieve environmentally acceptable standards or are left unharvested because costs outweigh the value of the timber. The objective of this literature review was to collate and examine information on international harvest systems, practices, tools and equipment that allow limited harvesting activities in these environmentally sensitive areas.

## Key Results

The review has identified a range of systems and practices with the potential to allow restricted harvesting activities in environmentally sensitive areas:

- alternative systems that extend ground-based systems into areas with limited or restricted access i.e. limited tracking and use of synthetic ropes in riparian areas, wide-tyred skidders, long-reach feller bunchers and harvesters, forwarders, walking forestry harvesters, and air-cushioned vehicles;
- alternative systems that extend ground-based systems into steep sensitive areas, traditionally harvested using hauler systems i.e. long reach feller bunchers and harvesters, small crawler tractors;
- hauler systems that extend hauler operations into areas that are currently inaccessible or have limited roading access i.e. long-distance cable systems;
- alternative hauler systems that extend hauler operations into sensitive areas traditionally harvested used ground-based systems i.e. skyline systems in flat wetland areas;
- use of aircraft (helicopters) for areas with no roading access, high value timber and high environmental values;
- tools and techniques that extend ground-based and hauler operations into existing limited or inaccessible areas i.e. excavator-assisted felling, batwing, synthetic ropes; and
- implementation of the latest regulatory and non-regulatory rules, Best Management practices (BMPs) and guidelines which would underpin all these alternatives.

## Conclusions

While the review identified a range of systems, machinery and equipment capable of harvesting in and around sensitive areas, little was found in the way of new developments. With the exception of air-cushioned vehicles and the walking forestry harvesters, most of the alternatives identified in this report such as wide-tyred skidders, long-reach harvesters, long-distance skyline systems, helicopter logging and synthetic ropes, have been investigated in New Zealand by the Logging Industry Research Organisation (LIRO) and others in the 1980's and 1990's.

However, in the last 10-15 years the environmental performance of harvesting machinery, tools and equipment has continued to improve. The potential exists to re-evaluate some of these alternative methods using the latest machinery, equipment and best management practices (BMPs), to identify those most suitable for New Zealand conditions, piece size characteristics and harvesting configurations. Emphasis should be on steep erodable terrain and around riparian areas and waterways, as these sensitive areas attract the highest environmental compliance costs in New Zealand. Greatest potential gains are where alternative methods reduce the need for roading, tracking, skid sites and landings which are expensive to establish and maintain, and are the main source of sediment in harvesting operations.

# Forest harvest practices in and around sensitive areas – a literature review

**Brenda R. Baillie**
Scion, Private Bag 3020, Rotorua 3046, New Zealand

June 2010

## Table of Contents

# Introduction

Research over a number of decades has identified the adverse effects that forestry activities, particularly harvesting, can have on soil, water, aquatic biota and other environmental values (Campbell & Doeg, 1989; Baillie, Collier, & Nagels, 2005). At risk are the more sensitive areas in forest estates. Sensitive sites are those that are considered susceptible to disturbances from harvesting activities and require additional management beyond the standard operating procedures. Sensitive sites include areas such as steep unstable terrain, erodable soils, wetlands, lakes, waterways, riparian areas, archaeological sites, remnant indigenous vegetation, areas containing rare and endangered species or ecosystems and sensitive landscapes (Figure 1). Sensitive areas, by their nature tend to be in the more isolated and inaccessible areas of the harvesting block. Winching and haul distances are longer, machinery access is often difficult or prohibited and the associated risks and costs are higher. Forest companies often avoid or abandon harvesting in these areas because the costs outweigh the value of the timber.

Alternative systems or methods are often used to harvest these areas (Krag, 1991; Bennett & Eng, 1996; Stokes & Schilling, 1997; Sauder, 1998). Logging systems, equipment and practices are considered ‘alternative’ if they differ from the usual conventional methods and can include practices such as helicopter logging, wide-tyred skidders, and long-distance cableway systems. Alternative systems can provide options to harvest sensitive areas to environmentally acceptable standards while achieving a satisfactory economic return. The objective of this literature review was to collate and examine international harvest systems, practices, tools and equipment that allow limited harvesting activities in these environmentally sensitive areas.

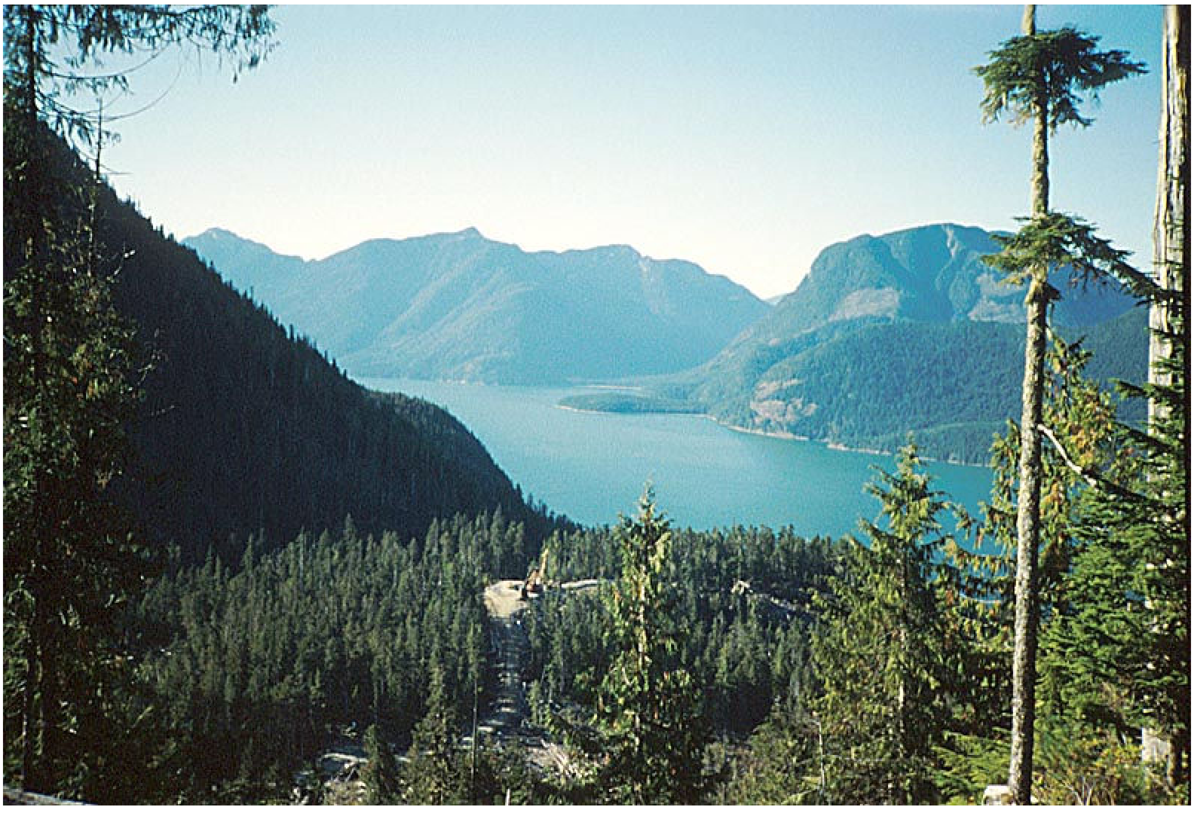

**Figure 1:** Partial cutting in old growth on visually sensitive landscapes in Coastal British Columbia, Canada. Photo courtesy of FPInnovations FERIC division.

# Methods

The literature review was undertaken using the Scopus, the ISI web of Knowledge, Google Scholar and Treesearch search engines, and the New Zealand National Forestry Library database. Follow-up searches were carried out from leads identified in the initial searches.

# Results and Discussion

## Wide-tyred and track machines – flatter topography

Wide tyred and tracked machines are traditionally used to reduce soil disturbance and compaction on sensitive soils on relatively flat land. Conventional track and tyred machines are often unsuitable for soft, low-strength, waterlogged soils because of excessive soil disturbance, soil compaction, scarification, mixing and rutting. Production losses occur through machine downtime with bogged machines and a reduction in the number and size of loads. Soil disturbance and compaction can affect site productivity into the next rotation (Parker, 2007).

While wide-tyred machines show little or no advantage over traditional tyres on dry, stable soils (Spiers & Cody, 1985), machines equipped with wide, flexible, low pressure, high flotation tyres can improve productivity and environmental performance on sensitive soils (Figure 2). Studies in New Zealand and overseas have demonstrated a reduction in soil disturbance and compaction using wide-tyred machines (Spiers & Cody, 1985; Hall, 1998; Stokes & Schilling, 1997; Prebble, Blundell, & Robertson, 1989). Soil disturbance can be further reduced with the retention or placement of logging slash along access routes (McMahon & Evanson, 1994).


**Figure 2:** Example of a wide-tyred skidder extracting timber after a 44 mm rainfall event.

Wide-tyred large forwarders have been used to extract timber on sensitive soils and where roading access is limited or undesirable. These machines can transport loads over several kilometres, reducing roading requirements and the number of passes over a site, extending the harvesting season in areas with wet, sensitive soils, while reducing environmental damage to the site (Stokes & Schilling, 1997). Other advantages of wide-tyred machines include improved fuel consumption, increased travel speed, extended access to previously inaccessible areas using conventional methods, increased productivity, and increased stability on side slopes and when winching.

However, care is needed in the use of these machines. Aust, Reisinger, Stokes & Burger (1991) showed that while wider tyres reduced soil disturbance and compaction, the impact could still be significant. At one site, wide-tyred machines increased the area of soil disturbance because of their ability to access a greater proportion of the total site. Trials on a range of forest soils in British Columbia, Canada also found that while wide-tyres reduced soil compaction, levels were still high enough to potentially affect site productivity into the next rotation (Rollerson, 1990). Wide tyres are more expensive than traditional tyres, and they can reduce machine manoeuvrability. There can be difficulties in fitting the wider tyres to existing machines and the extra weight increases the stress on the machine. Although suited to New Zealand’s terrain and conditions, at the time of Hall’s (1998) report wide tyres were not commonly used in this country.

**Figure 3:** Trans-Gesco TG88C operating on moist fine-textured soils, Alberta Canada. Photo courtesy of FPInnovations FERIC division.

Tracked machines have also been used to harvest sensitive sites on flatter topography such as the example in Figure 3. In the central North Island of New Zealand, stands of old-growth Lawson cypress and Douglas Fir were located in the headwaters of an ecologically important river. The site contained water-logged soils, endangered plant species and remnant indigenous bush (Jayne, 1994). Skidders, feller-bunching and cable logging were unsuitable options for this environment. Instead the logs were shovel logged using a grapple head mounted on 20 or 30-tonne excavator bases. The heavier machine was able to handle the larger piece size, and used fewer passes than the skidder. The wider tracks of the excavator and the use of corduroy tracks to transport timber reduced environmental damage to the soils. While less productive and more expensive than conventional operations on dry soils, these machines worked more consistently, and year round, accessing a greater proportion of the stands.

Tracked feller-bunchers have been used in felling operations on sensitive, wet soils (Stokes & Schilling, 1997). While more expensive than the conventional skidder they can reduce environmental impacts by using wide tracks or tyres, and the machines ability to bunching stems can reduce the impacts of extraction.

The super snorkel is a retractable 45-metre boom, attached to a regular boom equipped with a grapple and mounted on a tracked carrier. It is used to extend the reach of roadside timber extraction (Kell, 1988; Canadian Forest Industries, 1991). The super snorkel follows behind the initial roadside clearing operation pulling all timber within its reach to the roadside, and is particularly effective in down hill yarding operations. It can be very productive but requires a skilled operator. The main disadvantage is the time taken to dismantle the snorkel although the development of a hinged version is improving this.

Walking forestry harvesters (Figure 4) have been under development for over 10 years. These six-legged machines have the ability to access difficult and sensitive terrain with a lower footprint than tracked or wheeled machines by optimising the weight distribution over the six foot pads. The machines ability to move in any direction and turn on the spot allows it to access timber in confined areas. It can also sense and step over obstacles in its path. These machines are being promoted as a new technological solution for harvesting steep country, (Billingsley, Visala & Dunn, 2008). However they are not in use commercially and would need to consider remote control in situations too risky for human operators in the cab.

**Figure 4:** Timberjack walking forestry harvester. www.newlaunches.com. Downloaded 25th March 2010.

Both tracked and wheeled machines are used to harvest riparian areas. These areas can be particularly sensitive because of their proximity to waterbodies and associated soil, water and biological values. The environmental performance of machinery in riparian areas was investigated in the southeastern United States by comparing the visual soil disturbance between manual felling cable/skidder winching systems and feller buncher/grapple skidder systems (Hodges, 2006). The manual operation was less expensive than the mechanised system and the machine remained outside the riparian area, whereas the mechanised system eliminated the need to skid logs within the riparian area, and was safer and more productive than the manual system. While there were no significant differences in the levels of visual soil disturbance between the two methods (both averaged 26% soil disturbance), the manual system produced more ruts and retained more logging slash cover than the mechanised system.
The potential of long-reach harvesters to harvest riparian areas was trialled in Quebec, Canada. A Valmet 901 was successfully used to thin streamside protection strips in Quebec (Meek, 1994). The three operational methods that allowed differing levels of machine access into riparian areas all resulted in very low levels of severe soil disturbance.

In another study, the installation of a 1995 FMG 746 single-grip head mounted on the end of a stroke delimber boom, extended the reach of the harvester machine to 17 m (Desrochers, 2007). The harvester was restricted from entering the riparian zone (approx 25 m in width) but was able to access just over 70% of the riparian area. A second trial allowed short access tracks, averaging 4 m in length into the riparian zone. A 2004-model Waratah 450 head mounted on a Denis telescoping delimber boom extended the reach of the harvester to 17.5 m. The harvester was able to access the full depth of the reserve and achieved the target residual stocking of around 500 s.p.h. over a large proportion of the reserve. In both cases damage to remaining trees and soil disturbance was minor, with most soil disturbance occurring from machine travel along the outside boundary of the reserve. The productivity of the two operations compared favourable with conventional single-grip harvester operations, partly because of the higher tree density and larger tree size at both sites and a shorter travel distance at one site, which off-set the lower machine utilisation and the longer travel distances usually associated with harvesting riparian areas. At the time of this report, Quebec was going to include riparian zones as part of the allowable cut, commencing in 2008 (Desrochers, 2007). Based on the results of this study, the author suggested a review of regulations restricting machine use in these areas to allow limited access with restrictions on the type of machinery, design of access tracks and providing there was minimal soil disturbance by machinery travel.

In New Zealand, the use of long-reach harvesters in sensitive areas is limited by the machine and boom capacity, and cutting head size to cope with the larger piece size of mature *Pinus radiata* (0.9 – 3.1 $m^3$).

## Wide-tyred and track machines – steeper topography

Cable-yarder systems are traditionally used to harvest steep slopes because of their lower soil disturbance levels compared with rubber tyred skidders and crawler tractors and their ability to work slopes inaccessible to ground-based machinery. While tracked and wheeled machines are traditionally used on flatter land, those with acceptable environmental performance and ability to navigate steep slopes are extending into steeper terrain traditionally harvested with hauler systems (Figure 5).

For example, the increased climbing ability and side slope stability from using wide tyres on skidders, increases the potential to use these machines on steeper country (Spiers & Cody, 1985; Prebble et al., 1989). In coastal British Columbia Canada, wide-tyred skidders were used to harvest an area traditionally harvested using grapple yarding (Sauder, 1998). By using random skidding patterns on coarse textured soils and designated skid-trail networks on finer-textured soils, along with close supervision in wet weather conditions the site was harvested more economically, and with fewer roads than conventional grapple yarding, without compromising water quality. Another comparative study in Newfoundland Canada, between conventional and wide-tyred machines operating on steep side slopes ranging from 31-48% (18-28°) found that the wide tyres significantly reduced ground disturbance (Pickett, 1986).

Research in North America has also investigated the use of tracked machines (particularly small crawler tractors) on steeper slopes traditionally harvested by cable yarders (McMorland, 1980; Krag & Webb, 1987; Krag, 1991; Sauder, 1998). A study on small crawler tractors in British Columbia, Canada, operating on slopes up to 40°, and using contour tracking 30 m apart, found site disturbance by these machines was approximately one-third less than conventional skidders and tractors (McMorland, 1980). The authors attributed most of this to the narrower tracks and wider spacing of the track network. Small crawler tractors were most cost-effective on slopes greater than 17°.


**Figure 5:** John Deere 903J tracked feller buncher operating on steep terrain. www.deer.com downloaded $25^{th}$ March 2010.

Another field trial compared the productivity and soil disturbance levels of cable-yarder and rubber-tyred skidders on steep slopes, with small crawler tractors, to assess their suitability as an alternative to traditional ground-based and cable-yarder systems (Krag & Webb, 1987). Operational costs were highest for the cable-yarding system ($18.60/$m^3$) followed by the small crawler-tractor system at $13.25/$m^3$, and the conventional rubber-tyred skidder operation was cheapest at $11.34/$m^3$. Based on the assumption of equal roading and landing densities for each of the three systems, only the yarder operation maintained total soil disturbance levels at or below the standard of 10% set by the British Columbia Ministry of Forests and Lands. A photographic survey indicated that road and landing density was substantially higher in the yarder operations compared with rubber-tyred skidders in similar terrain, suggesting that the levels of soil disturbance were overstated for the ground-based systems and understated for cable-yarder systems.

In an Oregon operation, a Valmet 500T single grip harvester and a 548 forwarder were used to harvest Douglas Fir stands on slopes around 30% (17°) (TimberWest, 1993). The operator utilised 26 ft (8 m) of a 34 foot (10.5 m) slide boom to harvest trees with average diameters in the 14-18 inch (35-50 cm) range, achieving 4% stand damage and 8% ground disturbance.

In Quebec, a conventional cable yarder operation in very steep country using motor-manual felling and breaking out, was combined with mechanized felling and bunching and cable extraction on slopes of 0-30%. A feller buncher was used on the hill top along with a grapple skidder to transport trees to the cable yarder (Hillman, 2001). More than 90% of the harvested area was either undisturbed or only slightly disturbed. Operational costs of the combined cable yarder and mechanised felling and bunching component of the operation were around two-thirds that of the conventional cable operation. Productivity of the combined cable yarder and mechanised system was twice that of the conventional yarder operation and productivity of the hill top operation was over four times that of the conventional cable operation. The author considered an integrated operation such as this a viable option for harvesting high-quality stands on steep slopes.

However, a comprehensive study by Kockx and Krag (1993) examining a range of ground-based operations harvesting on steep slopes in British Columbia, Canada, found that productivity, costs and environmental performance varied widely, a reflection of variation in organisational, operational and site factors. Overall, lower levels of skidding disturbance were associated with more moderate slopes, mechanised harvesting systems, winter harvesting on snow and/or the use of crawler tractors to build skid roads. These operations were working on side slopes averaging 31-48% (18-28°) in trees averaging 25-44 cm DBH and 25-34 m in height.

Skidders and tracked machines are more economic and versatile than haulers, requiring less specialised skills to operate. These studies have shown that with careful planning and placement of roads, tracks and landings, some of these machines can operate on steeper country traditionally harvested by haulers to acceptable environmental standards. This is achieved mainly by reducing the depth and extent of soil disturbance, and width of skid trails of more conventional tracked and wheeled machines. The ability to utilise these alternate wheeled and tracked machines on moderate slopes, in tandem with cable yarders on steeper slopes has the potential to improve economic performance as long as environmental standards are maintained. Options such as these offer a compromise that allows economic recovery of timber in an environmentally satisfactory manner, potentially opening up areas for harvesting which are uneconomic using conventional methods.

## Air-cushioned vehicles (ACV)

**Figure 6:** An air-cushioned landing craft at Camp Pendleton, California, U.S.A.

Advancements in air cushion technology, have lead to the development of the air-cushioned landing craft, a modern variation on the amphibious landing boat, which is used extensively by the United States Navy to access soft sandy beaches, wetlands and loose surfaces (http://en.wikipedia.org/wiki/Air-cushioned_landing_craft, accessed 14th February, 2009) (Figure 6).

There is the potential to harvest sensitive sites using these machines (Garrett & Studier, 1997; Stokes & Schilling, 1997) although this remains theoretical at this point in time. Air-cushioned vehicles (ACV) have minimal environmental impact and could be used in combination with cable systems or tow machines to extract timber across streams, rivers, wetlands and other sensitive areas, reducing the need for roads and extraction tracks.

## Skyline hauler systems

**Figure 7:** An example of full suspension using a Wyssen skyline system. South coastal British Columbia, Canada. Photo courtesy of FPInnovations FERIC division.

Skyline hauler systems are commonly used overseas (Figure 7) and in New Zealand's steep terrain to harvest particularly sensitive areas. In one example in New Zealand, a skyline system was used to harvest a sensitive area of steep dissected terrain, with erodable soils, remnant indigenous vegetation in the gullies and streams flowing into a trout fishery river (Palmer, McMahon, Fraser, & Visser, 1996). The lateral pulling ability of an Eagle II motorised slack pulling carriage meant that only one extraction corridor was needed across the gully to harvest the 5.5 ha block. By achieving full suspension across the gully, damage was limited to 3% of the vegetation, the stream was protected and soil disturbance confined to a spur beneath the skyline.

A small skyline yarder was used in New York State, U.S.A. in an area where harvesting was a politically and environmentally sensitive issue, particularly the visual aspects when harvesting in close proximity to urban areas (Koten & Peters, 1985). If economically and environmentally successful the skyline yarder had the potential to extend the area of harvesting into steeper slopes to access timber normally not accessible by conventional ground-based methods. While the trial showed minimal environmental damage using this system (tree damage was within acceptable levels, roading and landings reduced and mineral soil exposure minimal) the operation was not economic largely because of under utilisation from machine breakdown. If normal utilisation rates could be achieved, the authors thought the operation was potentially economic.

In Italy, a trial using mini-yarders for uphill and downhill extraction in small-scale forestry operations on steep terrain showed that these machines could provide a viable alternative to other options such as light tower yarders, although wear and tear is expected to be higher (Spinelli, Magagnotti, & Lombardini, 2010) (Figure 8). There is also the risk associated with downhill extraction of funnelling water runoff.

While skyline systems are traditionally used on steeper terrain, they have been modified and trialled for use in wetland areas in Canada, USA, Colombia and Papua New Guinea (Aulerich, 1990). Most operations involve motor-manual felling, and for smaller stems, manual preparation of logs into bundles for extraction. In Colombia, two modified skyline systems (modified North bend and a skyline rigged in the Tyler configuration) worked together to extract bundles of wood to a road side. A standing skyline system with a double-tree support was used in Oregon to extract timber from the wet area with numerous drainage ditches and dykes and in Ontario Canada, partial harvesting in flat water logged areas was achieved with a Highland Trailer Alp yarder. In Papua New Guinea, high rainfall and sensitive soils required most skid roads to be corduroyed. The use of a live skyline system with intermediate supports to gain lift over the terrain and extend lateral yarding capabilities, reduced the roading network required to harvest the block (Aulerich, 1990). In most instances these systems appeared to be handling small piece sizes. High lead cable logging on flat wet areas was used in New Zealand up until the mid-1980’s to extract timber from areas unsuitable for ground-based operations (pers. comm., P. Hall, Scion).

**Figure 8:** Timber extraction using a mini-yarder in Italy equipped with synthetic rope. Photos courtesy of CNR IVALSA.

Skylines have the advantage of reducing roading requirements and creating less soil disturbance than ground-based systems (Hotta, Kayama, & Suzuki, 2007), but are more expensive and require a more specialised skill set to operate. In flatter wet areas, establishing roading networks and extracting timber using ground-based methods is limited, expensive and often prohibitive. However skyline systems are also expensive and require the use of intermediate spars to gain the required lift to extract timber from the flatter terrain and suitable tailhold locations to achieve full suspension.

## *Long-distance cableway systems*

Long-distance cable way systems are used extensively in Europe (Bennett & Eng, 1996) and have been used in North America since the 1950's in areas where environmental constraints or difficult terrain prohibit or limit roading networks to support more conventional tower systems. A standard configuration for a long-distance cableway system includes a sled yarder or winch, fitted with the mainline, positioned at a high point in the block alongside, but offset from the skyline (Figure 9). Intermediate supports are often used to provide additional elevation above the terrain. The mainline runs from the yarder through a block on the skyline down to the carriage. Logs are suspended under the carriage and travel under gravity down to the landing.

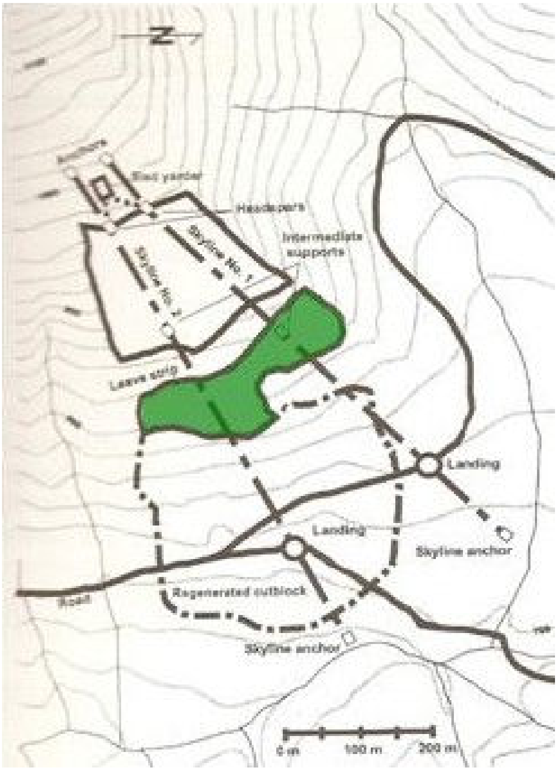


**Figure 9:** Example of a long-distance cableway plan (Bennett & Eng, 1996)

The advantage of this system is that the sled yarder can be winched upslope into position or flown in by helicopter, accessing areas where roading isn't an option. It can achieve full load suspension, minimising soil and vegetation disturbance and disturbance to sensitive areas such as waterways, wetlands, remnant indigenous vegetation or highly erodable soils. This system can provide a steady flow of wood, unimpeded by adverse weather conditions. Capital costs are comparatively lower than tower systems. However, it is more labour intensive and expensive to operate than the traditional tower systems and experienced riggers are needed to install and maintain the system. In small blocks, the cost of installing and dismantling the yarder can contribute a high proportion of unit costs but is off-set by the high unit costs of roading in these sensitive or inaccessible areas.

Figure 10 shows a long-distance cableway system in Europe with a new Seik carriage developed for forestry operations. The double hoisting winch allows full tree suspension in sensitive areas.

**Figure 10:** Long-distance cableway system in Europe using a Valentini 1500 tower with a newly designed Seik carriage allowing full tree suspension. Photo courtesy of CNR IVALSA.

A long-distance cableway system with a 10-tonne payload capacity was used to harvest two blocks in an environmentally sensitive watershed, providing water supply to the Vancouver area in British Columbia, Canada (Bennett & Eng, 1996). The primary objectives were to protect and enhance water quality, protect regenerating cutover and at one site to protect a strip of forest cover stabilising an area with a moderate risk of slope instability (Figure 9). Skyline lengths ranged from 1000-1200 m with a maximum haul distance of 700 m. The average number of logs and volume per load were 4.2 and 7.1 $m^3$ respectively. The haul distance and lateral haul distance were two key components of the operation affecting productivity and costs, along with the proportionally high costs to set up and dismantle the yarder in these small blocks (11.0 and 6.1 ha respectively). The capacity of this system to lift loads directly up and out of gullies and to fully suspended loads en route to the landing, minimised soil and vegetation disturbance and prevented the accumulation of logging slash in gullies.

Long-reach skyline systems have been used in New Zealand to harvest in sensitive areas (Neilson, 1979; Robinson, 1993; McConchie & Robinson, 1996), but not extensively. These systems have some advantages over more standard skyline systems, such as lower capital investment, long reach capability, effectiveness in broken and convex terrain, reduced soil disturbance through full suspension and reduced roading requirements. However, their lower productivity, requirement for intermediate supports and higher rigging and setup time, along with the existing roading network in most New Zealand's forests has seen the industry favour more traditional hauler and skyline systems. Long reach skylines have been used in New Zealand to extract and transport wood in the Marlborough Sounds, where roading in steep terrain close to the coast was not a viable option (Robinson, 1993; McConchie & Robinson, 1996) and in pulpwood thinning operations on the central North Island (Neilson, 1979).

Long-distance cableway systems are an option in sensitive areas where roading access is prohibited or limited, and the use of the more conventional tower systems is not an option

(Figure 10). When comparing the costs effectiveness of this system with other alternatives, the economic benefits from reduced roading costs should be included in the process.

## Helicopters

Helicopters are one of the more expensive systems used to harvest sensitive areas (Figure 11). While the environmental impact is low, high operating costs limit its potential as an alternative for many sensitive areas. This is off-set to some extent by their potential high productivity. To maximise the production potential of helicopters careful planning and management is needed to ensure smooth running of the operation. Positioning of landings as close to the timber source as possible and ensuring the personnel and machinery capacity and landing design are optimised to deal with the higher extraction volume and to maintain wood flow are critical to the economic success of helicopter operations (Kirk & Smith, 1992). There are costs savings and environmental benefits from reduced roading and landings, environmental benefits from reduced soil compaction and disturbance and landslides and the advantage of accessing timber conventional harvest systems can't reach, either through economic, operational or environmental constraints (Kirk & Smith, 1992; Roberts, Ward, & Rollerson, 2004). Economics are also improved where high value timber is being extracted or when market prices are favourable.

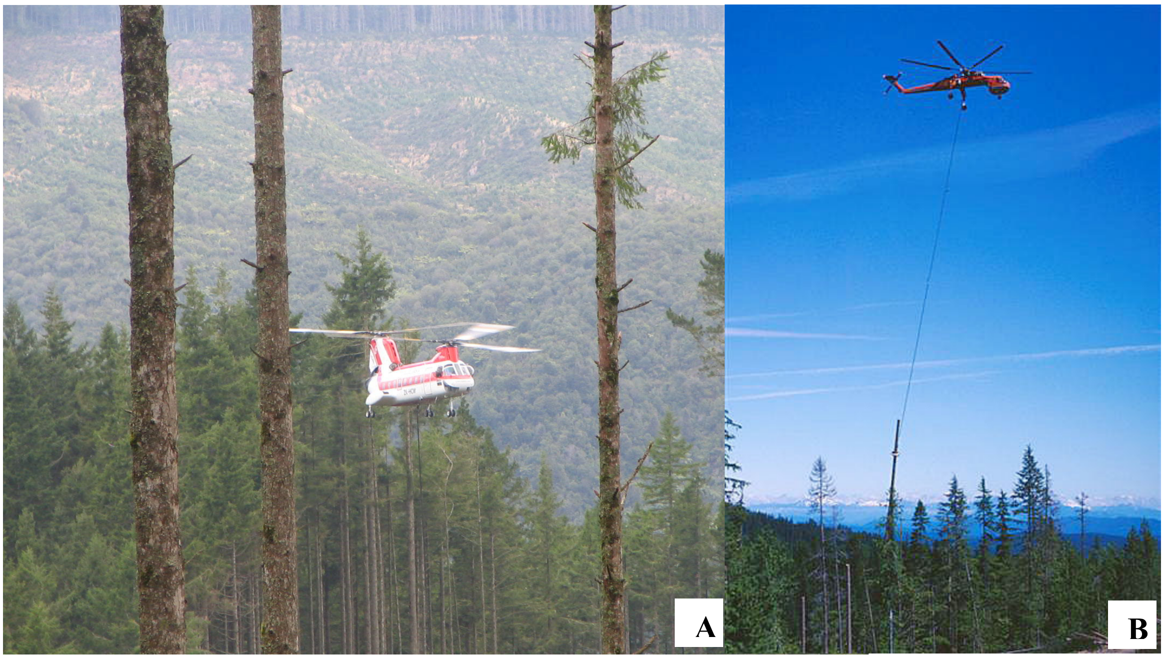


**Figure 11: A** - Helicopter thinning operation along the margins of a lake in New Zealand. Photo courtesy of Timberland Limited. **B** – Sikoroski (now Erikson) S-64E skycrane lifting a prepared stem from a riparian reserve. Note the tops of prepared stems are also visible. Photo courtesy of FPInnovations FERIC division.

In a New Zealand case study a 53 ha block of trees on broken, steep, unstable erosion prone land, adjacent to a main highway was successfully harvested using a Bell 214 ST helicopter (Kirk & Smith, 1992). Close proximity of the landing to the block minimised cycle times, maximising productivity and the helicopter was able to extract timber which was uneconomic by other more traditional methods. Environmental benefits included fewer roads and landings, full suspension of loads, minimal soil disturbance and compaction, and a short harvest period which facilitated rapid re-establishment of the block, minimising exposure to surface erosion and run-off. A comparative study of helicopter operations versus conventional cable-based harvested in British Columbia, Canada found higher rates of open slope landslides on cable harvested sites compared with sites harvested using helicopters (Roberts et al., 2004). In southern USA, helicopters are being used to a limited extent to harvest wet sites (Stokes & Schilling, 1997).

## Tools, Equipment, Practices

### *Synthetic Ropes*

**Figure 12:** Demonstration of synthetic rope on a skidder to a group of cable loggers in Quebec, Canada. Photo courtesy of FPInnovations FERIC division.

Replacing steel wire rope with synthetic rope is gaining some acceptance in the forestry industry, particularly in North America and Europe. While primarily used in ground-based operations (Figure 12), synthetic ropes are extending into other areas such as chokers, securing loads on trucks and as guylines and other static line in cable harvesting operations (Ewing, 2003; Pilkerton, Garland, & Hartter, 2004; Hartter, Leonard, Garland, & Pilkerton, 2006; Spong & Wang, 2008) (Figure 8).

Synthetic ropes are also being used in riparian and other sensitive areas where the use of machinery is either prohibited or impractical. Where machinery is prohibited in riparian zones, some operators are motor-manual felling and delimbing trees within the riparian area before winching out the stems to a machine positioned outside the riparian area (Ewing, 2003). In two trials in New Brunswick and Quebec, the mainline wire rope was replaced with synthetic rope. The lighter synthetic rope made it easier for operators to haul out rope, extending the distance into the riparian area, and accessing trees not normally reachable using standard wire rope. Damage to residual trees was ≤2% and mineral soil exposure was <2% with the exception of one site where it reached 4-6% where stems crested the upper reaches of the slope. In both trials the synthetic rope was used until the end of the operating season, in spite of a few failures requiring knotting of the rope and working with a shortened rope. This system was also used to harvest short steep slopes unsuitable for mechanised harvesting.

In the Appalachians, harvesting is predominantly ground-based. In a trial to extract timber from a power line right-of-way in an area of rocky uneven ground, the wire winch rope on a bulldozer was replaced with an ultra-high molecular weight polyethylene rope. There was no noticeable difference in the strength or ability of the synthetic rope compared with the wire rope, and operators found it lighter and easier to work and splice (Spong & Wang, 2008).

Synthetic rope has other potential environmental benefits:

- reduced skid trail density;
- used as skyline extension to improve lift of logs over stream and riparian areas;
- increased lateral distance may decrease the number of corridors through streams and riparian areas; and
- synthetic rope mainlines or even skylines could improve payloads and increase the lift needed to extract logs from sensitive areas (Pilkerton et al., 2004; Hartter et al., 2006).

The key advantage of some synthetic rope is its similar strength to wire rope of a similar diameter while only a fraction of the weight (approximately 1/9$^{th}$). More synthetic rope can be spooled on to winch drums compared with wire rope because of its improved spooling and compaction. It also lacks the torsional energy of wire rope and doesn't have sprags. Operators find synthetic ropes easier to handle and less energy is required to haul rope out across difficult terrain making it easier to haul these ropes out over greater distances than conventional wire rope (Ewing, 2003; Pilkerton et al., 2004) (Figure 13). In conventional ground-based operations replacing the main winch rope with synthetic rope is estimated to increase productivity by around 10% through the increase in number of drags per day, the reduction in machine positioning time because of the greater haul distances achievable with synthetic rope and fewer delays in spooling rope onto the winch drum (Pilkerton et al., 2004).

**Figure 13:** Synthetic rope - showing ease of haul out up a steep slope. Photo courtesy of CNR IVALSA.

The main disadvantage of synthetic rope is its cost, 2-5 times that of steel wire rope. Synthetic rope suffers more breakage from abrasion, cuts and strain, particularly from sharp pieces of metal on the winch and other parts of the machinery. However, synthetic rope can be quickly respliced in the field, a new skill that operators need to learn (Spong & Wang, 2008). In one study (Ewing, 2003); the rope was coated with polyurethane to improve abrasion resistance. A main failing point was the abrasion caused by the sliders that connect chokers to the mainline during skidding and in one trial the section of concentrated abrasion was replaced by wire rope, spliced in at the end of the synthetic rope. While there has been development of end connectors suitable for synthetic rope, the numbers are limited. Synthetic rope may require equipment modifications and new designs and the new product has yet to build up a supporting infrastructure of expertise and training systems (Hartter et al., 2006).

## *Assisted directional felling*

A range of tools and techniques have been used to assist in felling trees away from sensitive areas. These trees are often of low timber quality and can be difficult to fell because of the direction of lean, heavy branching and location. The time taken to fell and extract these trees can be uneconomic, but prescription standards sometimes require their removal. The most efficient tools and techniques to harvest these trees are those that utilise the existing harvesting configuration with minimal adaption.

In a comparative study of four techniques to fell streamside trees in a ground-based operation, the two machine-assisted felling techniques (an excavator with a grapple head and a skidder winch) were more productive, safer and achieved higher environmental standards than motor–manual felling and motor-manual felling using tree jacks (Baillie & Kirk, 1997). However the machine assisted felling techniques were more costly to use.

**Figure 14:** Felling along a stream edge using a batwing

Another piece of equipment used to assist directional felling in hauler operations, particularly along stream edges, is the batwing (Canadian Forest Industries, 1991; Baillie, 1997). The batwing is either a set of wings attached to either side of a carriage, or a winged device in place of the butt rigging and is used in cable hauler operations to assist with directional felling of trees (Figure 14). The advantages of the batwing were the degree of control over fall direction, (it was nearly impossible for the tree to fall backwards), it could be positioned higher up the tree than strops which increased leverage, and was quicker than cable-assisted falling using strops even allowing for change-over time to set up the system. The batwing reduced the hazards to the faller when felling heavily leaning trees, and minimised environmental impacts.The disadvantages included the need for skilled fallers, the batwing was inefficient for small groups of trees, a mobile tail was required to provide sufficient lift to position the batwing, and the risk associated with the proximity of the falling tree to the suspended ropes.

## *Rules/BMPs/Guidelines*

While it is not within the scope of this literature review to identify all the Best Management practices (BMPs) and guidelines used in harvesting sensitive areas, in most countries, harvesting operations in sensitive areas have to operate within a mix of regulatory and non-regulatory rules, guidelines and BMPs. Collectively, they can be considered a tool or practice used to harvest in sensitive areas.

A review of BMPs used in harvesting and site preparation in the Eastern United States indicated that in most circumstances BMPs were effective in minimising impacts on water quality and site productivity (Aust & Blinn, 2004). Two example studies in Australia and the USA, demonstrated the effectiveness of BMPs in reducing adverse impacts of harvesting in sensitive areas. In West Virginia, areas harvested using BMPs reduced sediment loss and showed minimal adverse effects on water quality (Kochenderfer & Hornbeck, 1999), and a catchment experiment in new South Wales Australia found no significant changes in a number of water quality parameters following harvesting of two small catchments using the states BMPs (Webb, Jarrett, & Turner, 2007).

## Conclusions

The review has identified a range of systems and practices with the potential to allow restricted harvesting activities in environmentally sensitive areas:

- alternative systems that extend ground-based systems into areas with limited or restricted access i.e. limited tracking and use of synthetic ropes in riparian areas, wide-tyred skidders, long-reach feller bunchers and harvesters, forwarders, walking forestry harvesters, and air-cushioned vehicles;
- alternative systems that extend ground-based systems into steep sensitive areas, traditionally harvested using hauler systems i.e. long reach feller bunchers and harvesters, small crawler tractors;
- hauler systems that extend hauler operations into areas that are currently inaccessible or have limited roading access i.e. long-distance cable systems;
- alternative hauler systems that extend hauler operations into sensitive areas traditionally harvested used ground-based systems i.e. skyline systems in flat wetland areas;
- use of aircraft (helicopters) for areas with no roading access, high value timber and high environmental values;
- tools and techniques that extend ground-based and hauler operations into existing limited or inaccessible areas i.e. excavator-assisted felling, batwing, synthetic ropes; and
- implementation of the latest regulatory and non-regulatory rules, Best Management practices (BMPs) and guidelines which would underpin all these alternatives.

While the review has identified a range of systems, machinery and equipment to harvest in sensitive areas, little was found in the way of new developments. With the exception of air-cushioned vehicles and the walking forestry harvesters, most of the alternatives identified in this report such as wide-tyred skidders, crawler tractors, long-reach harvesters, long-distance skyline systems, helicopter logging and synthetic ropes, have been investigated in New Zealand mainly by LIRO in the 1980's and 1990's. In fact many of the reports and papers in this review, refer back to this era (see reference list).

However, over time there are on-going developments in machinery, system components, tools and equipment. There is the potential to re-evaluate some of these alternate methods using the latest machinery, equipment and BMPs with a particularly focus on steep erodable sites and around riparian areas and waterways, as these sensitive areas attract the highest environmental compliance costs in New Zealand (Baillie, 2010). Further investigation is also needed in evaluating the applicability of some of these alternatives to New Zealand conditions, piece size characteristics and harvesting configurations. Greatest potential gains are where alternate methods (i.e. limited access in riparian areas) reduce the need for roading, tracking, skid sites and landings. Roads, tracks skid sites and landings are expensive to establish and maintain, attract high environmental compliance costs (Baillie, 2010) and are the main source of sediment in harvesting operations.

The negative impacts of harvesting have been well documented. Future research should focus on harvesting solutions that produce good environmental outcomes that will assist the forestry industry in the sustainable management of its resources.

## Acknowledgements

This research was funded by Scion’s Capability Fund. I would like to thank Sarah Heine, Tony Evanson and Peter Hall for reviewing the draft report.

## References

Aulerich, S. P. (1990). *Applying cable logging systems to wetlands.* Paper presented at the Managing forestry operations in a changing environment: proceedings of the Council on Forest Engineering 13th annual meeting, Outer Banks, North Carolina.

Aust, W. M., & Blinn, C. R. (2004). Forestry best management practices for timber harvesting and site preparation in the eastern United States: An overview of water quality and productivity research during the past 20 years (1982-2002). *Water, Air, and Soil Pollution: Focus, 4*(1), 5-36.

Aust, W. M., Reisinger, T. W., Stokes, B. J., & Burger, J. A. (1991). *Wide-tired skidders operating on wetland sites - preliminary results.* Paper presented at the Forestry and Environment Engineering Solutions, New Orleans.

Baillie, B. (1997). *The batwing - An option for cable-assisted directional felling*. Logging Industry Research Organisation Report 22(3). Rotorua, New Zealand. 7p.

Baillie, B.R. (2010). Impacts of environmental compliance on harvesting operations in New Zealand – results of a survey. Scion Publically Available Technical Publication. New Zealand Forest Research Institute Limited, Rotorua, New Zealand.16p.

Baillie, B., & Kirk, P. (1997). *An evaluation of four streamside felling techniques used in ground-based operations*. Liro Limited Report 22(13). Rotorua, New Zealand. 6p.

Baillie, B. R., Collier, K. J., & Nagels, J. (2005). Effects of forest harvesting and woody debris removal on two Northland streams, New Zealand. *New Zealand Journal of Marine and Freshwater Research, 39*, 1-15.

Bennett, D. M., & Eng, P. (1996). *Harvesting sensitive sites with a long-distance cableway system: Productivity and costs*. Forest Engineering Research Institute of Canada TN-238. Vancouver, Canada. 13p.

Billingsley, J., Visala, A., & Dunn, M. (2008). Robotics in agriculture and forestry. In B. Siciliano & O. Khatib (Eds.), *Springer handbook of robotics* (pp. 1065-1077). Berlin, Heidelberg: Springer-Verlag.

Campbell, I. C., & Doeg, T. J. (1989). Impact of timber harvesting and production on streams: a review. *Australian Journal of Marine & Freshwater Research, 40*, 519-539.

Canadian Forest Industries. (1991). Holy directional felling it's the batwing. *Canadian Forest Industries*. Quebec, Canada.

Canadian Forest Industries. (1991). Roadside snorkelling: Yarding logs faster than you can load them. *Canadian Forest Industries*. Quebec, Canada.

Desrochers, L. (2007). *Mechanized harvesting in riparian zones using a long-reach single-grip harvester*. FPInnovations Feric division, Advantage 9(1). Pointe-Claire, Canada. 8p.

Ewing, R. (2003). *Harvesting riparian zones using cable skidders equipped with Spectra® synthetic-fiber mainlines*. Forest Engineering Research Institute of Canada, Advantage 4(20). Pointe Claire, Quebec. 6p.

Garrett, S., & Studier, D. (1997). *Logging with air-cushioned vehicles*. United States Department of Agriculture Forest Service 9724 1201-SDTDC. United States of America. 10p.

Hall, P. (1998). *Wider tyres reduce logging costs*. Liro Limited TN - 35. Rotorua, New Zealand. 2p.

Hartter, J., Leonard, J., Garland, J. J., & Pilkerton, S. (2006). Research on synthetic rope and its future in timber harvesting. *New Zealand Journal of Forestry, August*, 23-30.

Hillman, D. (2001). *Productivity of a cable yarder teamed with a feller-buncher and a grapple skidder*. Forest Engineering Research Institute of Canada, Advantage 2(36). Pointe Claire, Quebec. 6p.

Hodges, C. L. (2006). *Logging in the streamside management zone: Effects of harvesting system and intensity on visual soil disturbance.* Unpublished Masters, Virginia Polytechnic Institute and State University, Blacksburg, United States of America. 57p.

Hotta, N., Kayama, T., & Suzuki, M. (2007). Analysis of suspended sediment yields after low impact forest harvesting. *Hydrological Processes, 21*, 3565-3575.

Jayne, V. (1994). Just walking the log: soft footprint harvesting. *New Zealand Forest Industries, 25,* 17-18.

Kell, B. (1988). Super snorkel hustles logs on MacMillan Bloedel job. *Timber Harvesting*. Alabama, U.S.A.

Kirk, P., & Smith, M. (1992). *Helicopter logging: An environmental logging case study*. Logging Industry Research Organisation Report 17(7). Rotorua, New Zealand. 6p.

Kochenderfer, J. N., & Hornbeck, J. W. (1999). *Contrasting timber harvesting operations illustrate the value BMPS.* Paper presented at the 12th central hardwood forest conference February 28, March 1-2, Lexington, Kentucky, U.S.A.

Kockx, G. P., & Krag, R. K. (1993). *Trials of ground-skidding methods on steep slopes in the east Kootenays, British Columbia: productivities and site impacts*. Forest Engineering Research Institute of Canada SR-89. Vancouver, Canada. 23p.

Koten, D. E., & Peters, P. A. (1985). *Cable yarding on environmentally sensitive areas in New York State.* Paper presented at the 8th annual conference on forest engineering meeting August 18-22, Tahoe City, California, U.S.A.

Krag, R. (1991). Options for reducing soil disturbance during timber harvesting. *Canadian Forest Industries,* Quebec, Canada. 60-64.

Krag, R. K., & Webb, S. R. (1987). *Cariboo Lake logging trials: A study of three harvesting systems on steep slopes in the central interior of British Columbia*. Forest Engineering Research Institute of Canada TR-76. Vancouver, Canada. 48p.

McConchie, M., & Robinson, D. (1996). *Extraction with long reach standing skylines*. Logging Industry Research Organisation Report 21(2). Rotorua, New Zealand. 7p.

McMahon, S., & Evanson, T. (1994). *The effect of slash cover in reducing soil compaction resulting from vehicle passage*. Logging Industry research Organisation Report 19(1). Rotorua, New Zealand. 8p.

McMorland, B. (1980). *Skidding with small crawler-tractors*. Forest Engineering Research Institute of Canada TR-37. Vancouver, Canada. 89p.

Meek, P. *Thinning in streamside protection strips with the Valmet 901*. Forest Engineering Research Institute of Canada FN-22, Quebec, Canada. 2p.

Neilson, D. (1979). *Intermediate supports*. Logging Industry Research Organisation Report 4(4). Rotorua, New Zealand. 4p.

Palmer, D., McMahon, S., Fraser, D., & Visser, R. (1996). *Skyline logging to minimise impacts on native vegetation*. Logging Industry Research Organisation Report 21(16). Rotorua, New Zealand. 5p.

Parker, R. T. (2007). Monitoring soil strength conditions resulting from mechanical harvesting in volcanic ash soils of Central Oregon. *Western Journal of Applied Forestry, 22*(4), 261-268.

Pickett, D. (1986). *Wide tire trial on steep slopes in western Newfoundland*. Government of Newfoundland and Labrador Forest Products Development Report 38. Canada. 23p.

Pilkerton, S. J., Garland, J. J., & Hartter, J. (2004). *Applications of synthetic rope for improved ergonomic, ecomonic and environmental performance in mountainous logging.* Paper presented at the 2004 International Mountain Logging Conference 13-16 June, Vancouver, British Columbia, Canada.

Prebble, R., Blundell, W., & Robertson, E. (1989). *A project to investigate the use of wide tyres on a skidder in New Zealand.* Logging Industry Research Organisation PR 45. Rotorua, New Zealand. 105p.

Roberts, B., Ward, B., & Rollerson, T. (2004). A comparison of landslide rates following helicopter and conventional cable-based clear-cut logging operations in the Southwest Coast Mountains of British Columbia. *Geomorphology, 61*, 337-346.

Robinson, D. (1993). *Wood transport using a long reach skyline*. Logging Industry Research Organisation Report 18(20). Rotorua, New Zealand. 8p.

Rollerson, T. P. (1990). Influence of wide-tire skidder operations on soils. *Journal of Forest Engineering, 2*(1), 23-30.

Sauder, E. A. (1998). The benefits of using alternative logging systems for harvesting sensitive sites. *Canadian Forest Industries, 108,* 51, 54-55.

Spiers, J. J. K., & Cody, A. O. (1985). *High Flotation Tyres*. Logging Industry Research Organisation Digest 9(1). Rotorua. 4p.

Spinelli, R., Magagnotti, N., & Lombardini, C. (2010). Performance, capability and costs of small-scale cable yarding technology. *Small-scale Forestry 9*, 123-135.

Spong, B. D., & Wang, J. (2008). *Synthetic rope applications in Appalachian logging.* Paper presented at the 16th Central hardwood Forest Conference, West Lafayette, Indiana.

Stokes, B. J., & Schilling, A. (1997). Improved harvesting systems for wet sites. *Forest Ecology and Management, 90*(2-3), 155-160.

TimberWest. (1993). With a forester in the cab of a Valmet 500T, More Logs is thinning a steep, dense fir stand with only 4 percent stand damage and 8 percent ground disturbance. *TimberWest, April,* Washington, U.S.A. 28-32.

Webb, A. A., Jarrett, B. W., & Turner, L. M. (2007). *Effects of plantation forest harvesting on water quality and quantity: Canoblas State Forest, NSW.* Paper presented at the 5th Australian Stream Management Conference. Australian rivers: making a difference, Thurgoona, New South Wales, Australia.