DEVELOPMENT OF A PROTOCOL FOR ECOEFFICIENT WOOD HARVESTING ON SENSITIVE SITES (ECOWOOD)

Quality of Life and Management of Living Resources Contract
No. QLK5-1999-00991
(1999-2002)

PROJECT DELIVERABLE D2 (Work Package No. 1) on

SELECTION AND OPERATION OF CABLE SYSTEMS ON SENSITIVE FOREST SITES

D. Tiernan†, P.M.O. Owende*, C.L. Kanali*, R. Spinelli‡, J. Lyons†, and S.M. Ward*

* Forest Engineering Unit, Agricultural and Food Engineering Department,
   University College Dublin, Earlsfort Terrace, Dublin 2, IRELAND
   Tel: (+353) 1 716 7351; Fax: (+353) 1 475 2119; email: forest.eng@ucd.ie
   ECOWOOD Project URL: www.ucd.ie/~foresteng

† Irish Forestry Board (Coillte Teoranta),
   Sullivan’s Quay, Cork, IRELAND
   Tel: (+353) 021 4964 366; Fax: (+353) 021 496 4072; email: john.lyons@coillte.ie

‡ Consiglio Nazionale Delle Ricerche (CNR),
   Instituto Per la Ricerca Sul Legno,
   Via Barazzuoli 23, I-I-50136,
   Florence, ITALY
   Tel: (+39 055) 661 886; Fax: (+39 055) 670 624; email: spinelli@mailbox.irl.cnr.it

February 2002
# Table of Contents

## List of Abbreviations

## List of Tables

## List of Figures

## Executive Summary

### 1. Introduction

1.1. Background on the ECOWOOD Project

1.2. Terrain Classification for Ecocefficient Wood Extraction

1.3. Challenges to wood harvesting and extraction under alpine conditions and other steep terrain

1.4. Challenges to wood harvesting and extraction on soft soil conditions

1.5. Role of Cable Systems in Sustainable Forest Management (SFM) on Sensitive Sites

1.6. Current trends in the utilisation of cable systems for wood extraction in Europe

### 2. Description of Cable Extraction Systems

2.1. Cable yarder

2.2. Rope configurations for Cable Systems

2.2.1. High lead system

2.2.2. Skyline systems

2.2.3. Motorised carriages

2.2.4. Yarding patterns

2.3. Anchorage Systems

### 3. Operations in Cable Extraction Systems

3.1. Operations Planning

3.1.1. Spatial location

3.1.2. Layout design

3.2. Road Construction

3.3. Selection of appropriate cable system

3.3.1. Yarder specifications

3.3.2. Cable configuration

3.3.3. System power requirements

3.3.4. Cable tension during load transport

3.3.5. Economic considerations

3.4. Wood harvesting

3.5. Yarders

3.5.1. Tower yarding

3.5.2. Sledge yarding

3.5.3. Motorised yarding

3.6. Tree processing

### 4. Productivity and Cost of Wood Extraction with Cable Systems

4.1. Factors affecting the productivity of cable systems

4.2. Cable systems and small-dimensioned timber

4.3. Maintenance costs for cable systems

4.4. Cost of wood extraction using cable systems

### 5. Adaptation of Cable Systems for Cost-effective Wood Harvesting on Sensitive Sites

5.1. Trends in the Use of Cable Systems

5.1.1. Increased use of contract labour

5.1.2. Increased productivity of cable yarders

5.1.3. Integrated machine processes

5.1.4. Use of steep terrain harvesters

5.1.5. Use of excavator based cable yarders

5.2. Management of human resources

5.2.1. Ergonomic concerns

5.2.2. Safety considerations

5.2.3. Effective training

5.2.4. Motivation

5.2.5. Future development of cable extraction systems

### 6. Recommended Practice for Use of Cable Systems on Sensitive Forest Sites

### References

### Annexes
## LIST OF ABBREVIATIONS

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Full Form</th>
</tr>
</thead>
<tbody>
<tr>
<td>ATS</td>
<td>Austrian Schilling</td>
</tr>
<tr>
<td>AYD</td>
<td>Average Yarding Distance</td>
</tr>
<tr>
<td>CTL</td>
<td>Cut-to-Length harvesting system</td>
</tr>
<tr>
<td>DBH</td>
<td>Tree Diameter at Breast Height</td>
</tr>
<tr>
<td>DEM</td>
<td>Digital Elevation Model</td>
</tr>
<tr>
<td>DSS</td>
<td>Decision Support System</td>
</tr>
<tr>
<td>DTM</td>
<td>Digital Terrain Model</td>
</tr>
<tr>
<td>EU</td>
<td>European Union</td>
</tr>
<tr>
<td>FAO</td>
<td>Food and Agricultural Organisation of the United Nations</td>
</tr>
<tr>
<td>FOPS</td>
<td>Falling Object Protective Structures</td>
</tr>
<tr>
<td>GIS</td>
<td>Geographic Information System</td>
</tr>
<tr>
<td>GPS</td>
<td>Global Positioning System</td>
</tr>
<tr>
<td>ILO</td>
<td>International Labour Organisation</td>
</tr>
<tr>
<td>OP</td>
<td>Operations Protocol</td>
</tr>
<tr>
<td>PH</td>
<td>Productive Hours</td>
</tr>
<tr>
<td>PMH</td>
<td>Productive Machine Hour</td>
</tr>
<tr>
<td>pmh</td>
<td>Productive Man Hour</td>
</tr>
<tr>
<td>PTO</td>
<td>Power-take-off</td>
</tr>
<tr>
<td>PSH₀</td>
<td>Productivity per standard hour with delays greater than 0 minutes excluded</td>
</tr>
<tr>
<td>PSH₁₅</td>
<td>Productivity per standard hour with delays greater than 15 minutes excluded</td>
</tr>
<tr>
<td>SFM</td>
<td>Sustainable Forest Management</td>
</tr>
<tr>
<td>SDSS</td>
<td>Spatial Decision Support System</td>
</tr>
</tbody>
</table>
LIST OF TABLES

Table 1. General terrain classification scoring for Ireland (Forest Service, 2000) ................................. 3
Table 2. Machines operations most suited to respective terrain classes (Adapted from Forest Service, 2000) ...................................................................................................................... 3
Table 3. Examples of steep terrain harvesters ............................................................................................... 4
Table 4. Comparison of the intensity of soil erosion resulting from skidding operations between tractor, horse and cable systems (Lukáč, 2001) ......................................................... 6
Table 5. Estimated number of cable systems in operation and the percentage annual cut that is extracted by cable systems in Europe in the period 1999-2000 ........................................ 7
Table 6. Proportion of wood extracted by cable and wheeled skidder systems in the Ukraine region for the period 1950-1995 .................................................................................. 8
Table 7. Sample of commercially available cable yarders ........................................................................... 10
Table 8. Road densities as a function of yarding distances for various harvest plans in western Washington (Schiess, 2001) ......................................................................................... 16
Table 9. Summary of results from a scheduling and network analysis for two (5-year) management plans for a 36 square mile planning area in Eastern Washington, USA. (Schiess, 2001). ......................................................................................................................... 16
Table 10. Optimal line lengths for a Syncrofalke cable crane in Slovenian conditions (Košir, 2001). ............................................................................................................................................... 18
Table 11. Purchase prices for a range of cable systems in the market (FBVA, 1999). ................................. 22
Table 12. Examples of the working combinations available for the operation of cable systems ......... 26
Table 13. Estimated productivity of cable systems .................................................................................... 28
Table 14. A 12-year productivity (1986-1998) and cost breakdown for a Koller K300-yarder operating in Austria.................................................................................................................. 30
Table 15. Examples of production costs for cable systems in France and Italy ........................................... 31
Table 16. Productivity and tree damage results between conventional and mechanised harvesting on steep slopes (Oswald and Frutig, 2001) ........................................................................ 36
LIST OF FIGURES

Figure 1. Valmet™ 911 steep terrain harvester, and the Shift/Tilt mechanism of Timberjack 608L/762C harvester that is designed for operation on slopes of up to 27º (51%).... 4
Figure 2. Challenges to forwarding operations on sensitive forest sites................................................. 5
Figure 3. Site disturbance and increased potential erodibility due to wood harvesting and extraction on soft soil sites............................................................... 6
Figure 4. Example of skyline with fully suspended log (adapted from Sist et al., 1998)................. 9
Figure 5. Illustration of a highlead layout (Conway, 1986)............................................................ 11
Figure 6. Illustration of common cable rope configurations (Owren, 1997)........................................ 11
Figure 7. Illustration of fan shaped and parallel yarding pattern, the latter showing extraction lines from areas lateral to roadlines................................................................. 12
Figure 8. Types of cable anchors in use (Samset, 1985)................................................................. 13
Figure 9. Planning map with terrain classification codes (Mellgren, 1980).................................... 14
Figure 10. Variation of setup and skidding costs with line length for a Syncrofalke™ cable crane in Slovenian conditions (Košir, 2001). ................................................................. 17
Figure 11. Situations that may cause shock loading of a cable system (Visser, 1999)........................ 21
Figure 12. Tension in the skyline caused by concentrated load (Q) and the weight of skyline (q). 21
Figure 13. A sledge yarder and set-up for extraction. Set-up courtesy of Greifenberg snc, Trento, Italy......................................................................................................................... 23
Figure 14. Woodliner™ motorised carriage and setup (Konrad Forsttechnik, 2001)..................... 24
Figure 15. A continuous roadside-processing rig composed of the cable yarder and processing unit with combined processing head and grapple (inset right) and an independently rotating cab (inset left). ............................................................................................................................................ 24
Figure 16. Mode of uphill operation with a continuous processing system (Konrad Forsttechnik, 2001). ............................................................................................................................................. 25
Figure 17. The relationship between tree size and harvesting and transportation costs for a cable system (Sirois, 1981). .................................................................................................................. 29
Figure 18. The effect of average load size on productivity for a Koller K 300 cable yarder extracting uphill over a 200m extraction distance (Tunay, 2001). ................................................................. 29
Figure 19. A 12-year maintenance cost breakdown for a Koller K300-yarder operating in Austria.. 30
Figure 20. Effect of pmh on the costs of operating a Koller 300-yarder in Austria for period of 12 years (Rieger, 2001). ............................................................................................................ 30
Figure 21. Trend of cable extraction costs in Austria (Loschek, 2001). ............................................. 32
Figure 22. Trends in contract labour in the forestry sector in Austria. Source (Fladl et. al, 2001).. 33
Figure 23. Trend in mechanisation and contract labour as experienced by MM Forestry Enterprises, Austria (Loschek, 2001). ............................................................................................................. 34
Figure 24. Variation of productivity with DBH for mechanised and conventional (chainsaw) harvesting on steep slopes (Oswald and Frutig, 2001). ................................................................. 34
Figure 25. Valmet™ steep terrain harvester and Timberjack walking harvester. ......................... 35
Figure 26. Typical variation of productivity (PSH15) of a tracked harvester with tree volume (without bark) at 25 and 50% terrain slope (Stampfer, 1999). ...................................................... 35
Figure 27. End and side views of an excavator based cable extraction system in working position. .............................................................................................................................................. 37
Figure 28. Excavator based yarder that allows for slew of base-machine for simultaneous yarding and processing. Inset is detail of the processor-head .............................................. 38
Figure 29. Illustration of a cable systems mounted on light wheeled carriage (Unimog). Details show the winch drums and the guylines spools ............................................................................. 39
Figure 30. Details of a combined yarder/processor (Konrad Forsttechnik, 2001) ......................... 41
EXECUTIVE SUMMARY

A sensitive forest site is where alterations to the normal mechanised harvesting practices are required in order to avoid adverse effects on ecological, economic and social functions of the forest and its surroundings. Harvesting of such sites presents considerable limitations to the use of ground-based forest harvesting machines, as significant damage to forest ecosystems may be incurred from:

- soil disturbance and compaction — may impede the growth of residual trees in thinning operations, and also increase the potential for soil erosion and windthrow;

- physical damage to residual trees and other vegetation — may lead to timber value and volume loss in subsequent harvests, and;

- direct and indirect damage to streams (including the damage to drainage and soil stabilisation features) — for example, skidding/forwarding of timber across streams and steep road embankments without proper temporary bridging structures, and; introduction of spilled fuel and lubricants into streams.

In order to minimise the potential damage to the forest ecosystem (e.g. soil compaction, damage to residual stand, accelerated soil erosion, and siltation of watercourses adjacent to harvesting sites), there is increasing demand for envirogentle harvesting and extraction of wood on sensitive forest sites. Cable extraction or cable logging systems involve the transportation of material within the forest by means of steel cables, the load being partially or wholly lifted off the ground. It is different from the ground-based wood extraction systems (forwarders and skidders) in that soil-machine interaction is minimal or eliminated altogether, hence, it offers possible means of minimising the site disturbance and damage that may result from wood harvesting and extraction. For example, soil losses of between 0.16–0.51 m$^3$ per m$^3$ of extracted material have been recorded for skidding operations with a crawler-tractor under the unfavourable condition of low soil bearing capacity. In contrast, the expected soil erosion resulting from the use of cable system and by skidding with horses are both less that 0.14 m$^3$ per m$^3$ of extracted material.

Although wood extraction with cable systems is environmentally friendly, hence may contribute to Sustainable Forest Management (SFM) on sensitive sites, it is also recognised that it is more complex and expensive than current alternative option such as ground skidding. Generally, there has been a decline in the use of cable systems in Europe due mainly to the cheaper cost (less that 50% of the production costs for cable extraction), and increased capability of harvester and forwarder combinations to operate on steep terrain. Currently, less than 3% of the annual timber harvested in the European Union (EU) countries is by cable systems. The relatively lower productivity of cable systems (1–10 m$^3$ per Productive Machine Hour), when compared to ground-based systems (5–25 m$^3$ per Productive Machine Hour) significantly reduce profit margins. In addition, the high manual workload and skill demands for operating the systems, and comparatively low wages, impede the recruitment and retention of personnel.

While wood extraction with cable systems may be more complex and expensive than ground-based systems, it is a viable complement to the adaptation of ground-based machines for SFM on sensitive sites. New trends in wood harvesting with cable systems are therefore geared to the development of: integrated machine processes (to maximise on productive time) and enhancement of mobility of harvesters used with cable extraction systems on difficult terrain (bearing capacity < 40 kPa, and gradient > 20% or 12°); improvement of related operational planning/logistics, and; ergonomic consideration (viz. minimisation of workload, and improvement of tools and accessories), in order to enhance the cost-effectiveness. Advances in these areas, and the need for ecoefficient wood harvesting and extraction suggest that cable systems will continue to play a significant role in Sustainable Forest Management on sensitive forest sites.
1. **INTRODUCTION**

1.1. **Background on the ECOWOOD Project**

Wood harvesting conditions vary considerably across Europe, ranging from the wet peat-based soils of Ireland and Scotland, to the alpine conditions of the continent (Italy, France, Austria), and the seasonally frozen soils of Fennoscandia. Many of the sites may be classified as "sensitive", i.e., alterations to the normal mechanised forest harvesting practices are required in order to avoid adverse effects on ecological, economic and social functions of the forests and their surroundings (ECOWOOD, 2001). In addition, the shortage of labour in the forestry industry has necessitated an increased use of machinery on sensitive sites, and unless properly selected and utilised there is a danger of causing considerable environmental damage. A need therefore exists for development of ecoefficient and cost-effective mechanisation systems for wood harvesting and extraction on such sites.

The most significant damage to forest ecosystems during wood harvesting and extraction, include:

- **soil disturbance and compaction**— which may impede the growth of residual trees in thinning operations, and also increase the potential for soil erosion and windthrow;
- **physical damage to residual trees and other vegetation**— which may lead to timber value and volume loss in subsequent harvest, and;
- **direct and indirect damage to streams, and drainage and soil stabilisation features**— for example, skidding/forwarding of timber across streams and steep road embankments without proper temporary bridging structures; or the introduction of spilled fuel and lubricants into streams.

The ECOWOOD project is developing an *Operations Protocol (OP)* for ecoefficient wood harvesting on sensitive sites. The OP will integrate the systems in wood harvesting, extraction and transportation, by matching the functional requirements of the forest machines with the environmental and socio-economics concerns in order to achieve cost-effective and sustainable operations. It will also optimise product qualities, minimise site disturbance and/or damage, maximise industrial socio-economic benefits, and provide ergonomically sound wood harvesting and extraction operations. The multidisciplinary approach in the ECOWOOD Project encompasses studies on performance of harvesting and extraction machines, telemetrics, computer based systems optimisation, environmental impact and socio-economic effects (see The ECOWOOD project at URL: [www.ucd.ie/~foresteng](http://www.ucd.ie/~foresteng)). By selecting and using forestry machinery in an integrated manner, the negative environmental consequences of wood harvesting and extraction/delivery processes can be minimised.

1.2. **Terrain Classification for Ecoefficient Wood Extraction**

Extraction is the process of moving trees or logs from a felling site to a landing or roadside where they are subsequently processed as full poles, log-lengths, or wood-chips, or are consolidated into larger loads for secondary transportation to mills and other wood conversion facilities. Wood extraction systems that are best suited to a specific harvesting site are assigned on the basis of general terrain classes in Table 1 and Table 2 (an international classification system is presented in Annex 1). In order to minimise damage to the sites (and the residual stands in the case of thinning operation) including safety consideration for the harvesting machines and the operators, the integration of machine suitability to respective harvesting site conditions is crucial when dealing with 'sensitive sites'.

Cut-to-length (CTL) forest-harvesting technique is predominantly used in wood harvesting in Europe. It involves the use of CTL harvesters, or chainsaw felling and bucking (motor-manual tree harvesting), with both options employing various configurations of purpose built forwarders or tractor trailer systems for moving timber within the forest. The need for environmentally sensitive forest management has a direct bearing on the efficiency and cost of CTL machine operations. For example, the forwarder is considered a higher environmental risk than the harvester, since it moves over a wider area (Taartila, 1994). While its speed and payload determine its productivity, higher values of these parameters increases the environmental risks incurred by the machine. Optimisation of such a system requires a systematic match of machine tractive and flotation gear (tyres or tracks, including their contact phenomena with the terrain, e.g., speed, attitude and contact pressures), and physical characteristics of the floor that are modified to affect productivity of forest stands, or accelerate soil degradation (surface rutting, accelerated erosion, compaction and layer inversion). Forest harvesting in alpine areas and sites with soft soils (shaded terrain classes in Table 2) present considerable challenges and limitations to ecoefficient use of ground-based machines for wood extraction.
### Table 1. General terrain classification scoring for Ireland (Forest Service, 2000)

<table>
<thead>
<tr>
<th>Ground condition</th>
<th>Ground roughness</th>
<th>Slope</th>
</tr>
</thead>
<tbody>
<tr>
<td>Good (1)</td>
<td>Even (1)</td>
<td>Gentle, &lt; 8° (1)</td>
</tr>
<tr>
<td>Average (2)</td>
<td>Uneven (2)</td>
<td>Intermediate, 8° – 14° (2)</td>
</tr>
<tr>
<td>Poor (3)</td>
<td>Rough (3)</td>
<td>Steep, &gt; 14° (3)</td>
</tr>
<tr>
<td>Very poor (4)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Table 2. Machines operations most suited to respective terrain classes (Adapted from Forest Service, 2000)

<table>
<thead>
<tr>
<th>Terrain class</th>
<th>Machines</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1.1</td>
<td>Forwarder, Skidder, Horse</td>
</tr>
<tr>
<td>1.1.2</td>
<td>Forwarder, Skidder, Horse, Tracked Forwarder, Cable</td>
</tr>
<tr>
<td>1.1.3</td>
<td>Forwarder, Skidder, Horse</td>
</tr>
<tr>
<td>1.2.1</td>
<td>Forwarder, Skidder, Horse, Tracked Forwarder, Cable</td>
</tr>
<tr>
<td>1.2.2</td>
<td>Forwarder, Horse, Tracked Forwarder, Cable</td>
</tr>
<tr>
<td>1.2.3</td>
<td>Chained Forwarder, Cable</td>
</tr>
<tr>
<td>1.3.1</td>
<td>Forwarder, Cable</td>
</tr>
<tr>
<td>1.3.2</td>
<td>Forwarder, Tracked Forwarder, Cable</td>
</tr>
<tr>
<td>1.3.3</td>
<td></td>
</tr>
</tbody>
</table>

**Example of application:**

Terrain class 1.2.3 in Table 2 denotes 'Good' ground condition (1), 'Uneven' ground roughness (2), and 'Steep' slope (3).
1.3. Challenges to wood harvesting and extraction under alpine conditions and other steep terrain

The use of harvester and forwarder combinations in CTL harvesting of wood is a well-developed concept for flat terrain. However, the associated logging costs and the decline in the number of skilled forest workers have forced development of mechanisation solutions for steep terrain, sometimes involving the use of excavator-based harvesters with wheels/legs, or tracks that have been developed for steep terrain (Torgersen, 2001). The use of ground-based harvesters was traditionally not possible on steep terrain with slopes in excess of 35%. Until recently, such sites were seen as the sole preserve of chainsaw harvesting because the conventional harvesting and extraction machines such as purpose-built harvesters, and skidders and forwarders could not operate safely on the steep slopes. However, developments in the late 1990’s have seen the production of steep terrain harvesters that are capable of operating safely on slopes between 35 – 55%. Specially designed tracked platform (Figure 1) provides a solution for mechanised harvesting of forests on steep terrain (Stampfer, 1999).

The steep terrain harvesters (Table 3) are more productive, cost-effective and safer means of felling timber on steep terrain, when compared to harvesting with chainsaws, and are popular in countries where there is a shortage of forest workers. Since their introduction, the harvesters have proven to be a cost-effective alternatives to chainsaw operators, particularly when processing larger diameter trees (Oswald and Frutig, 2001). Integration of tilting operator cabins on tracked machine chassis has increased the operational capability of harvesters on steep terrain (Schöttle et al, 1997; Weixler, et. al. 1997; Weixler et al., 1999).

Table 3. Examples of steep terrain harvesters.

<table>
<thead>
<tr>
<th>Harvester</th>
<th>Tractive device</th>
<th>Mass, kg</th>
<th>Boom reach, m</th>
<th>Working* slope, [degrees [%]]</th>
<th>Max. swing speed, rpm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Valmet 911</td>
<td>Tracks</td>
<td>16900</td>
<td>9.5</td>
<td>39[80]</td>
<td>-</td>
</tr>
<tr>
<td>Timberjack 608L/762C</td>
<td>Tracks</td>
<td>25,700</td>
<td>9.5</td>
<td>27[51]</td>
<td>6</td>
</tr>
<tr>
<td>Neuson 9002 HV</td>
<td>Tracks</td>
<td>11,000</td>
<td>9.0</td>
<td>30[58]</td>
<td>9</td>
</tr>
<tr>
<td>Neuson 11002 HV</td>
<td>Tracks</td>
<td>11,600</td>
<td>9.0</td>
<td>30[58]</td>
<td>9</td>
</tr>
<tr>
<td>Robin 2.29 SN</td>
<td>Tracks</td>
<td>8,700</td>
<td>9.2</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Timbco 445-c</td>
<td>Tracks</td>
<td>27,500</td>
<td>15</td>
<td>27[51]</td>
<td>9</td>
</tr>
<tr>
<td>Neuson 1100 HV</td>
<td>Tracks</td>
<td>11,600</td>
<td>9.1</td>
<td>30[58]</td>
<td>11</td>
</tr>
<tr>
<td>MHT Robin</td>
<td>Tracks</td>
<td>9,000</td>
<td>9.0</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Menzi Muck A71</td>
<td>Wheels/legs</td>
<td>8,700</td>
<td>8.5</td>
<td>17[30]</td>
<td>-</td>
</tr>
<tr>
<td>Kaiser S2 Bergbiber</td>
<td>Wheels/legs</td>
<td>12,700</td>
<td>11.5</td>
<td>45[100]</td>
<td>12</td>
</tr>
</tbody>
</table>

*Maximum values for different possible machine orientations with respect to the terrain slope.
1.4. Challenges to wood harvesting and extraction on soft soil conditions
Wood harvesting on soft soil conditions such as in forests planted on deep peat soils is commonly clear felling, and quite often premature felling, i.e., harvesting of forest before the normal age and tree size is reached in order to forestall losses and costly salvage harvesting of wind-felled trees (Buswell, 1992). Currently, the approach applied to the harvesting of such sites in Western Europe, is to lay a brashmat ahead of harvesting machinery traffic. However, machine mobility is still a major constraint and CTL harvester and forwarders must be fitted with wide tyres or dual wheels, and band-tracks or specially adapted moccasins (Daly, 1998) to complement the use of a brashmat in order to avoid excessive rutting and machine sinkage (Figure 2). Reduction of forwarder payload with a multiple load-handling regime may also be considered.

Excessive machine sinkage has direct bearing to the cost of machine operations, and may lead to excessive site disturbance and soil damage (Figure 3). The latter may have significant effects on soil structure and runoff characteristics, with potential negative affects on the yield of the residual stands for thinning operations, and increased potential soil erodibility.

Tree root structures are known to stabilise soil and enhance the load bearing capacity and shear resistance of the forest floor. Wästerland (1989) estimated such incremental soil-reinforcement due to the presence of tree roots to be in the range of 50 to 70%. In areas with peat soils, this reinforcement factor (from the inherent vegetation layer as well as tree roots) is the determinant of mobility of the forest machines, as the soils deform easily to develop deep ruts with poor support for machine traction. It also determines the potential damage to the residual stands, during the primary and/or subsequent thinning operations, hence, may dictate the need for alternative wood extraction systems such as the cable.

Figure 2. Challenges to forwarding operations on sensitive forest sites
Machine mobility on forest sites with soft soils may be a limiting factor when tree growth in such areas has low yield of branches (e.g., in prematurely felled areas) that could be used as brashmat to enhance trafficabilty during timber harvesting and forwarding (Daly, 1998). The soil reinforcement by root networks may therefore influence the selection and operation of mechanical harvesting and extraction systems for ecoefficient wood harvesting of such ‘sensitive’ sites. However, soil reinforcement by root networks also diminishes with increasing number of vehicle passes (Cofie et al., 2000). On peat and other soft soils where such reinforcement is the only supporting medium, the brashmat on the extraction racks may degrade rapidly with machine successive passes to stall the timber extraction process altogether (Figure 3).

1.5. Role of Cable Systems in Sustainable Forest Management (SFM) on Sensitive Sites
Current trends in wood harvesting on sensitive forest sites is towards full mechanisation of the harvesting process, hence, such sites are getting exposed to increased machine traffic. However, due to the growing environmental concerns for Sustainable Forest Management, there is need to reassess the suitability (technical and economic) of cable extraction systems as a means of minimising soil disturbance which may generate secondary environmental concerns, i.e., soil compaction, erosion and siltation of watercourses. Cable extraction or cable logging is the system of wood extraction involving the transportation within forest along and/or by means of steel cables, the load being partially or wholly lifted off the ground (Nieuwehuis, 2000). Cable extraction is different from other ground-based wood extraction systems (forwarders and skidders) in that soil-machine interaction is minimal or eliminated.
altogether. Movement of the base winching machine is confined to translocation between adjacent landing areas and harvesting sites. During operation, the winching machine is fixed, hence, the system can be used in steep terrain and on wet soil sites. If the cable system permits full suspension of the load (skyline), the soil disturbance associated with wood extraction is eliminated (see Chapter 2).

![Figure 3. Site disturbance and increased potential erodibility due to wood harvesting and extraction on soft soil sites.](image)

From an environmental point of view, cable systems are considered to be low-impact systems that generally fall into the category of skyline systems, also called cable-cranes (FAO, 1998). It is therefore arguable that cable systems have an increased role in the sustainable management of sensitive forest sites. Such forests typically require a multifunctional management approach to satisfy the socio-economic (mainly sustainable production) and environmental protection (ecology, landscape, and heritage). Due to its minimal requirement for extraction tracks and less roading on steep hillsides, negative impacts to soils and water catchments, and the visual impact on sensitive sites, are less.

Selection of wood harvesting and extraction systems for SFM on sensitive sites require limitation of soil damage, and the impacts on residual trees in thinning operations. In this regard cable systems offer the most eco-friendly method of wood extraction when compared to ground-based systems. However cable systems are more complex and expensive than alternative systems (see Chapter 4), hence, other simpler and less expensive technologies such as skidding are used.

The use of ground-based systems such as skidding can have negative impacts on forest soils. For example, skidding with a crawler-tractor under the unfavourable condition of low soil bearing capacity (Table 4), can result in soil loss of between 0.16 – 0.51 m³ per unit volume of extracted material depending on the soil type. The corresponding eroded soil by cable system and by skidding with horses was 0.025 and 0.14 m³ per unit volume of extracted material, respectively (Table 4).

**Table 4. Comparison of the intensity of soil erosion resulting from skidding operations between tractor, horse and cable systems (Lukáč, 2001).**

<table>
<thead>
<tr>
<th>Geological complex</th>
<th>Kind of soil</th>
<th>Bearing capacity</th>
<th>Means of extraction</th>
<th>Skidded volume of timber, m³·ha⁻¹</th>
<th>Mean slope, %</th>
<th>Density of lines, m·ha⁻¹</th>
<th>Intensity of soil erosion* m³·ha⁻¹</th>
<th>V</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flysh (slate)</td>
<td>Sandy soil</td>
<td>B Tractor</td>
<td>386</td>
<td>30</td>
<td>280</td>
<td>62</td>
<td>0.16</td>
<td></td>
</tr>
<tr>
<td>Crystalline</td>
<td>Loamy soil</td>
<td>A Tractor</td>
<td>469</td>
<td>31</td>
<td>274</td>
<td>131</td>
<td>0.28</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>B Tractor</td>
<td>380</td>
<td>27</td>
<td>405</td>
<td>195</td>
<td>0.51</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>B Horse</td>
<td>469</td>
<td>33</td>
<td>471</td>
<td>66</td>
<td>0.14</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>B Cable</td>
<td>427</td>
<td>41</td>
<td>110</td>
<td>11</td>
<td>0.03</td>
<td></td>
</tr>
<tr>
<td>Carbonates</td>
<td>Loamy soil</td>
<td>B Cable</td>
<td>573</td>
<td>47</td>
<td>74</td>
<td>11</td>
<td>0.02</td>
<td></td>
</tr>
</tbody>
</table>

A = soils with good bearing capacity; B = soils with low bearing capacity; \*V = volume of eroded soil per unit volume of extracted timber.
With regards to the need for limitation of the visual impacts of harvesting operations, cable systems integrate well with silvicultural practices that require a continuous cover (e.g. shelterwood systems) and discrete harvesting requirements, e.g. strip-felling. Cable systems have a dominant advantage in prevention of natural risks (floods, avalanches, landslide and soil erosion), and; limit the impacts of forest harvesting on the landscape.

Cable systems will have an increasingly more important role to play in the sustainable management of forests on sensitive sites. Forests established on such sites require a multifunctional management approach that satisfies both socio-economical factors (production and protection) for sustainable production, and the control of environmental degradation (ecology, visual/landscape, and heritage).

Productivity of cable systems working on steep slopes is typically higher than that for flat wet sites. The difference is mainly be attributed to:

1. **difficulty in the rigging of cableways** — rigging or setup of cableways may be more time consuming and less reliable on wet sites than on steep slopes due to the need for intermediate supports to provide adequate lift on the skyline, and the lack of well rooted trees for anchoring the guylines and tailholds, respectively (see Chapter 2). Trees in perpetually wet forest soils tend to have shallow rooting, which makes them prone to uprooting when used as intermediate supports and anchors for guylines and tailholds;

2. **tree size** — trees on wet forest sites, e.g. the peat soils of Ireland and Scotland are usually much smaller (Buswell, 1992; Daly 1998), and therefore making it necessary to choke several trees or logs per turn to get economic loads, and;

3. **the inherent higher transport cycle times associated with low gradient sites** — transport of the carriage to the stump area is slower with the winch drum than when it descends by gravity.

Cable operations in wet and flat harvesting sites should therefore consider the use of excavators (Fraser and Robinson, 1998a) or adapted agricultural tractors (Fraser and Robinson, 1998b) as mobile tail anchors (also see Section 5.1.5). Thompson et al. (1998) have suggested that the necessary extraction corridors may be initially set by autonomous crews, since the associated increased yarding cost could be invariably offset by enhanced yarder productivity when it is operated without the loss of Productive Machine Hours to rigging operations.

### 1.6. Current trends in the utilisation of cable systems for wood extraction in Europe

Generally, there has been a decline in the use of cable systems in Europe (Table 5) mainly due to the cheaper operation cost and increased capability of harvester and forwarder combinations for operation on steep terrain. Less than 3% of the annual timber harvested is extracted by cable systems (Table 4). The notable exception is Austria where 17% of the annual cut utilises cable systems for extraction, and is estimated to have doubled over the last ten years (Fladl et. al, 2001). The extensive use of cable systems in Austria can be directly attributed to the inherent terrain where 25% of the forest cover is on slopes with average grade in excess of 60% (31°).

<table>
<thead>
<tr>
<th>Country</th>
<th>Austria</th>
<th>Croatia</th>
<th>Czech Republic</th>
<th>Finland</th>
<th>Ireland</th>
<th>Italy</th>
<th>Slovakia</th>
<th>Spain</th>
<th>UK</th>
<th>Ukraine</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of cable systems in operation</td>
<td>-</td>
<td>-</td>
<td>90</td>
<td>0</td>
<td>6</td>
<td>-</td>
<td>60</td>
<td>2</td>
<td>38</td>
<td>10</td>
</tr>
<tr>
<td>Related annual extraction, %*</td>
<td>17.0</td>
<td>&lt; 3.0</td>
<td>2.0</td>
<td>&lt; 1</td>
<td>4.5</td>
<td>1.5</td>
<td>&lt; 1</td>
<td>&lt; 2.5</td>
<td>3.0</td>
<td></td>
</tr>
</tbody>
</table>

*Percentage of annual cut

<table>
<thead>
<tr>
<th>Country</th>
<th>Austria</th>
<th>Croatia</th>
<th>Czech Republic</th>
<th>Finland</th>
<th>Ireland</th>
<th>Italy</th>
<th>Slovakia</th>
<th>Spain</th>
<th>UK</th>
<th>Ukraine</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of cable systems in operation</td>
<td>-</td>
<td>-</td>
<td>90</td>
<td>0</td>
<td>6</td>
<td>-</td>
<td>60</td>
<td>2</td>
<td>38</td>
<td>10</td>
</tr>
<tr>
<td>Related annual extraction, %*</td>
<td>17.0</td>
<td>&lt; 3.0</td>
<td>2.0</td>
<td>&lt; 1</td>
<td>4.5</td>
<td>1.5</td>
<td>&lt; 1</td>
<td>&lt; 2.5</td>
<td>3.0</td>
<td></td>
</tr>
</tbody>
</table>

Percentage of annual cut

*There are approximately 50-70 cable winch systems used with farm tractors

Source of data: Fladl et al. (2001); Saunders (2001); Lukáč (2001); Sabadyr and Zibtsev (2001); Owende et al. (2001), and; Krpan et al. (2001).

In developing countries, the decline in use of cable systems is primarily attributed to the predominant use of cost-effective alternatives such as skidding with crawler tractors. For example, Table 6 illustrates that the number of cable systems in use in the Ukraine declined in the period 1960-1995, while the use proportion of timber extracted by using wheeled skeders increased four-fold from 21% to 87%. In addition, the unfavourable foreign exchange rates in most of the countries make the cost of importation of cable systems prohibitive. Relatively lower productivity of cable systems, when
compared to ground-based wood extraction systems, significantly reduce profit margins and in some instances the continued operation of cable systems may require subsidies.

Table 6. Proportion of wood extracted by cable and wheeled skidder systems in the Ukraine region for the period 1950-1995.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Cable systems</td>
<td>20</td>
<td>48</td>
<td>40</td>
<td>27</td>
<td>17</td>
<td>3</td>
</tr>
<tr>
<td>Wheeled skidders</td>
<td>10</td>
<td>21</td>
<td>45</td>
<td>63</td>
<td>73</td>
<td>87</td>
</tr>
</tbody>
</table>

Adapted from Sabadyr and Zibtsez (2001).

In the more developed countries, cable systems also find it difficult to compete with more cost-effective alternatives offered by the recent increased ability of ground-based machines to operate on steep terrain. In addition, the high manual workload requirement of operating cable systems and comparatively low wages is presenting a problem in attracting and holding onto the skilled personnel required for operating the cable systems.

The key reasons for the observed decline in the use of cable systems for wood extraction in Europe when compared to the ground-based extraction systems are due to technical and operational challenges, including:

- Cable system operation is labour intensive, requires specialist training, and there is difficulty in engaging and retaining suitably trained staff;
- Load carrying capacity of a skyline system is limited, especially if the load must be fully suspended (determined by the ground condition and tolerable surface disturbance) which results in low productivity;
- Well-rooted and stable support and anchor trees must be carefully selected, hence, there are practical difficulties in harvesting sites with shallow rootplating;
- Problems of crew movement especially on wet sites with high ground roughness reduces the productivity in wood extraction;
- Setting up is time consuming and more portable equipment may be desirable, and this has necessitated the use of mobile plant in some cases, which may incur additional operational costs, and;
- Difficulties in obtaining adequate insurance cover.

New trends in wood harvesting with cable systems include, the improvement in technology, logistics, working operations and ergonomics (see Annex 1). These advances, together with the need for an ecoefficient system, should ensure that cable systems will continue to play an important role in specialised environmentally friendly forest operations in the future, particularly on sensitive sites. This report provides an overview of the current and contemporary use of cable systems in Sustainable Forest Management in Europe, with specific reference to their relevance for wood extraction on sensitive forest sites.
2. DESCRIPTION OF CABLE EXTRACTION SYSTEMS

A cable system for wood extraction consists of a tower (head-spar), set of winch drums, power source or prime-mover that is capable of winching logs, whole trees and tree parts uphill or downhill in a partially or fully elevated state (Figure 4). The type of yarder used in combination with a particular rope configuration defines the type of cable system.

The cables are operated by the winching machine (yarder), which may be installed either at the landing or at the tail end of the cableway, often on a ridgetop. In thinning operations, a narrow corridor is cleared as a pathway for the operating cables, which are suspended above the ground with the ‘head-spar’ located near the winching machine. The spar can be either standing trees or a steel tower. To obtain additional ground clearance, the cables may be suspended on a tail-spar located at the end of a cableway. Additional intermediate supports (multi-span system) may be provided at intervals between the head and tail spars when the extraction distance or nature of the terrain demands extra elevation. Differences among cable systems include variations in the configuration of the cable as well as in the methods for conveying trees or logs to the landing, and for returning the empty chokers to the felling site.

The wheeled carriage carrying the load rides on the skyline cable, and the load is attached to the carriage by a skidding line. A separate mechanism (payout cable) is usually provided on the carriage for increasing the length of the haul/skidding line, so that it can be used to winch loads laterally onto the cableway by spooling it onto a drum. After the load reaches the cableway, it is conveyed to the landing by:

1. winching the carriage using the mainline in uphill extraction from the felling site;
2. unspooling the mainline to allow the loaded carriage to move by gravity in downhill extraction from the felling site.

Ground-based machines are used only at the landing (location of yarder in Figure 4), unless a mechanised feller is used (see Section 5.1.4). Such felling machines are usually tracked excavator-type machines with low ground pressure, which minimise site disturbance and soil damage. They also have better stability on steep and uneven surface, and better flotation soft ground.

2.1. Cable yarder

The type of yarder used, in combination with a particular rope configuration define the type of a cable system. There is a wide range of yarders available in different levels of sophistication and size ranging from the smaller trailer mounted units to the larger 4-axle truck mounted yarders (Table 7). Not all cable yarders require a tower to operate. Such systems such as sledge systems rely on steep slopes...
The ECOWOOD Project (Cable Systems)  

DESCRIPTION OF CABLE EXTRACTION SYSTEMS

Cable systems can be broadly classified into three groups based on the rope configuration, including:

- **High lead system**;
- **Skyline systems** (viz. running skyline-uphill/downhill, standing skyline, gravity system), and;
- **Motorised carriages**.

### 2.2.1. High lead system

The high lead system has only two ropes (a main line and a haulback line) and requires only two winch drums (Figure 5). One drum acts as a haul in line and the other drum acts as a haul back line. The rope passes through a pulley block attached to a spar tree at the end of the haul. Both lines form an endless cable that can move both clockwise and anticlockwise. This movement allows the chokers to be moved to the logs (clockwise) and returned to the landing (anticlockwise). Suspension of the trees is determined by the height of the tower, the height of the spar tree and by the load block connected to the haul back line. Both drums have a clutch and a brake, and by applying the brake on the haul back line when hauling, the cable tightens and the load can be suspended. This system is best suited to uphill logging. Highlead systems do not suspend their load above soil, hence, do not have long spans (FAO, 1998).

### 2.2.2. Skyline systems

These systems (Figure 6) have at least three lines (viz. a skyline, a haulback line and a main line). The carriage travels along a pre-tensioned static tensioned cable line known as the skyline. The carriage has both a haul in and haul back line attached to it. It is similar to the gravity system except that the haulback line is used to haul the carriage and chokers to the log, giving this system the ability to log downhill. The skyline is attached to the base machine at one end and to a spar tree at the other end. The base machine of the skyline requires stabilisation using securing cables to prevent movement...
during yarding operations. The mainline pulls the carriage and logs uphill or downhill to the landing. This system requires considerable set-up times due to the number of pulley blocks required. Three winch drums are required to operate the skyline, haulback line and mainline. Skylines also have a smaller straw line drum, which holds a lighter cable (usually polypropylene rope) for the riggers to lay out before the heavier steel cables are pulled into position (Hibberd, 1991).

Figure 5. Illustration of a highlead layout (Conway, 1986).

Figure 6. Illustration of common cable rope configurations (Owren, 1997)
A running skyline system has two lines, a haulback line and a main line, i.e., there is no fixed line. It provides lift for up or downhill logging without using a pre-set skyline. Instead the haulback line acts as a skyline but provides lift only when it is in tension. To create this tension a brake is applied to the haulback line while the mainline is hauling the carriage and the load to the landing. The mainline can be a single or a double rope so this system requires two or three winch drums. The main advantage of this system is the reduced set-up times due mainly to the use of a single pulley block.

In gravity systems (Figure 6), the carriage travels along the skyline rope by gravity to the chokerman. Once the logs are attached, the carriage is brought to the landing by winching in the haulback line. This system uses only two ropes and two winch drums.

2.2.3. Motorised carriages
With a motorised carriages, the load is choked on the pulley systems of a carriage that runs on a skyline (details are presented in section 3.5.3). The tractive effort is provided by an autonomous engine on the carriage, while a winch is used to tension the main cable to provide the required lift.

2.2.4. Yarding patterns
With any cable system, the area over which the skyline or mainline runs, and from which trees/logs are removed is called the roadline (Figure 7). As each roadline is completed, i.e., by the removal of all merchantable tree/logs, the lines are moved through the remaining forest area that is to be extracted.

A fan-shaped extraction pattern results, in the case where the yander or spar remains stationery and several roadlines radiate from it in approximately circular direction before it is relocated to the next point. When a single roadline is used for each location of the yander (parallel pattern), then lateral yarding is from the same lateral distance throughout the extraction corridors (Figure 7). Careful corridor layout and choker setting can minimise the damage to residual trees (Thompson et al., 1998).

2.3. Anchorage Systems
Anchorage systems are used for the head and tail spars, and for intermediate supports in a multi-span skyline system. A cable extraction system therefore relies to a great extent on availability of suitable anchors for the spars and intermediate supports. Site conditions may dictate the use of stump or log anchor, earth or ‘deadman’ anchor, rock bolt anchor, expansion bolt anchor (Figure 8), and mobile plant. Earth anchors are used where no suitable stump or trees are available, and the soil is firm to support the loading. Expediency in the relocation of anchors for wood extraction from successive roadlines (area on which the cable way runs and from which logs are removed), is key to enhanced productivity. The use of mobile plant to anchor the systems can reduce the set-up/movement time by up to 20% (Owende et al., 2001).
Figure 8. Types of cable anchors in use (Samset, 1985)
3. OPERATIONS IN CABLE EXTRACTION SYSTEMS

3.1. Operations Planning

The high cost of cable operations and the relatively low production, when compared to ground-based wood extraction systems, make the planning for operation of cable systems all the more important. Current trends include the use of computer based Decision Support Systems (DSS) to enhance the planning process. DSS in this context refers to the use of computers to support rather than replace managerial judgement in the structuring of cable systems, and to improve the effectiveness of decision making rather than its efficiency (Keen and Morton, 1978). These computer models are abstractions of realistic situations and, as such, may not capture all possible variations that could be encountered in practice. Where the DSS is extended to the spatial domain using Geographical Information Systems (GIS) and Digital Terrain Models (DTM), the DSS is then a Spatial Decision Support System (SDSS) (Yuam, 1993). In general, there are three principle areas where planning for cable systems is required, namely: spatial location; layout design, and; skyline design.

3.1.1. Spatial location

Spatial location refers to the position and location of terrain or site that can be harvested using cable systems. Planning at this stage involves dividing the forest into terrain units based on location and terrain classes as illustrated in Figure 9. Traditionally the location of cable terrain units was done manually but this planning stage can now be vastly improved with the use of computer mapping technology.

Developments aimed to improve planning at this stage involve the use of computer mapping technologies such as GIS and DTM or Digital elevation model (DEM). These are used to identify and locate the terrain units for cable logging. The GIS and the DTM can also be used to supply information on the most suitable type of cable extraction (uphill or downhill) for each terrain unit. The systems are highly specialised and require expert knowledge and large databases for accurate analyses. The information they can provide is crucial for the enhancement of the spatial planning for harvesting with cable systems.

Figure 9. Planning map with terrain classification codes (Mellgren, 1980)

Recent developments have sought to improve the area of layout design by adopting the combined use of mathematical programming with “Digital terrain models” (DTM). Mathematical programming involves the use of mathematical models to solve managerial decision making problems (Wardle, 1971). Due to the complexity and large scale involved in modelling for large forest units, heuristic mathematical modelling is favoured as a means of optimising the layout design. One such approach developed by Chung et al. (2001), to improve road layout design, was the use of heuristic network analysis in conjunction with a DTM. The model connects the cable system with individual terrain units in the DTM. Demand from the mills is identified and using the DTM the transportation costs for each terrain unit can be quantified. Using network analysis, the optimum landing profile and the associated terrain units can be determined. The model is used to determine the optimum position of new roads for cable extraction.

3.1.2. Layout design

The layout design concerns site planning for location and set-up of the cable system. It includes such factors as location of roads and landing areas, determination of the optimal length of the cable line, positioning of extraction cable, and the type of cable extraction (uphill or downhill).
In the layout design, the positioning of links in the road network for cable systems is crucial for environmentally sound road construction (Robek and Medved, 2001). The main deficiency of mountain forest harvest planning may be the absence of detailed topographical mapping and inventory data for felling sites (Sabadyr and Zibtsev, 2001). Contemporary cable systems require a dense road network and therefore minimisation of site-disturbance can be achieved using vertical alignment optimisations, adjustments in plan view and adaptations in cross-sectional profile using sets of templates for predefined cable systems (Robek and Medved, 2001). The inclusion of these strategies into environmentally sound road construction may be undertaken at any of the three stages for road planning in layout design, namely: strategic planning; tactical planning, and; operational planning.

3.1.2.1. Strategic planning
Strategic plans refer to the infrastructure development strategy for road making, with the associated directives for land use, environmental protection, harvesting technology, and access development. Efficient use of cable systems requires effective strategic plans for infrastructure development. The absence of such plans may favour the use of ground systems (ground skidding and skid trials), which have more adverse site impacts.

Strategic plans need to be up-to-date and capable of projecting the future trends. Such plans need to be compatible with management objectives and based on the available forest information. Planning at this stage affects the extent and type of construction works as well as the extent and type of cable systems that may be used.

3.1.2.2. Tactical planning
Tactical plans are those that are intended to achieve minimal impacts to the site, residual stand, and biological diversity, while simultaneously minimising the associated direct and indirect costs. Tactical planning produces site-specific construction/reconstruction guidelines and the preliminary locations of new roads and skid trials. For cable systems, tactical planning should include:

- A review of the boundaries for cable logging;
- Adaptations of existing roads for cable systems;
- Utilisation of old/abandoned infrastructure for positioning of tower yarders, and;
- The location of the preliminary roads with the associated cable corridor layout.

These plans provide comprehensive and site determined solutions regarding access development. The aim is to harmonise the required access development and available harvesting technology. Such plans are based on an integral access development strategy for both cable and ground-based harvesting systems, and include aspects such as the existing infrastructure, reconstruction works and preliminary locations of new roads. Opening up plans for small areas are simple and may not require elaborate DSS. However, for larger areas the use of GIS/GPS enhance the process. For example, these can speed up the analysis of road and cable line design. The GIS allows the planner to see the existing road network and/or skid trial corridors, and it is possible to model alternatives routes for road layout with the map overlay feature.

3.1.2.3. Operational planning
Operational planning involves matching the tactical plans with on-site reconnaissance in a manner that matches the terrain with optimal use of the selected cable system. The operational planning should aim to minimise site disturbance by providing for vertical alignment optimisations, adjustments in plan view and adaptations in cross-section profile. Suitable computer software for road design may be used, to which the log landings (location of the yarder), slope, and bedrock conditions may be added. The horizontal and vertical road alignments may be optimised, and the extent of the earth works required calculated.

Road management in forest areas can impact related stream habitats in a number of ways (WFPA, 1997), including:

- *Land sliding* — can result in coarse sediments filling stream pools habitats necessary for summer rearing;
- *Surface erosion* — can deliver fine sediments that fill and destroy the gravel beds necessary for incubating fish eggs;
- *Changing runoff patterns* — result in flash flooding and scouring of streamside edges. Streamside roads can also remove trees that provide both shading for streams and the logs required for forming pools and other structures necessary for a healthy stream habitat.
Impacts on water resources are influenced by activities in any one of the six general phases of road development: (i) harvest setting planning; (ii) road design; (iii) construction; (iv) use, (v) maintenance, and (vi) decommissioning. (Everest, et al. 1987). The harvest setting planning may involve a trade-off of yarding distance with road density. In evaluating the true cost of the road network, it is essential to consider the aspects of sediment generation and delivery to the stream network.

Average yarding distance (AYD) determines the necessary road density, which varies with forest site. The AYD that is used to determine most road densities is between 100 and 300 meters (Table 8).

### Table 8. Road densities as a function of yarding distances for various harvest plans in western Washington (Schiess, 2001).

<table>
<thead>
<tr>
<th>Site</th>
<th>Planning area, ha</th>
<th>Setting size, ha</th>
<th>Average yarding distance, m *</th>
<th>Road density, km/km²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beaver Creek East</td>
<td>246</td>
<td>14</td>
<td>135</td>
<td>3.41</td>
</tr>
<tr>
<td>Beaver Creek South</td>
<td>405</td>
<td>7</td>
<td>109</td>
<td>2.46</td>
</tr>
<tr>
<td>Heckle Creek</td>
<td>1175</td>
<td>12</td>
<td>162</td>
<td>2.21</td>
</tr>
<tr>
<td>Siouxon 88</td>
<td>1122</td>
<td>16</td>
<td>187</td>
<td>2.83</td>
</tr>
<tr>
<td>Siouxon F</td>
<td>603</td>
<td>8</td>
<td>183</td>
<td>2.66</td>
</tr>
<tr>
<td>Elochoman B</td>
<td>736</td>
<td>8</td>
<td>164</td>
<td>3.81</td>
</tr>
<tr>
<td>Washougal</td>
<td>5118</td>
<td>14</td>
<td>264</td>
<td>2.59</td>
</tr>
</tbody>
</table>

* Average yarding distance based on fan-shaped settings.

With modern cable systems, the increased line lengths and average yarding distances can potentially allow for a reduction in road densities. The impact of reducing the roading density in this way was compared to the existing system using economic and load sediment deliveries indicators (Schiess, 2001). The results (Table 9) indicated that short-span management plan was more cost-effective despite the fact that it constructed an additional 19.6km of new roads. The short-span plan utilised 119km of existing road compared to 83.2km used by the long-span plan.

### Table 9. Summary of results from a scheduling and network analysis for two (5-year) management plans for a 36 square mile planning area in Eastern Washington, USA. (Schiess, 2001).

<table>
<thead>
<tr>
<th>Description of regime</th>
<th>Volume harvested, m³</th>
<th>Existing roads used, km</th>
<th>New roads used, km</th>
<th>Yarding Costs ($/m³)</th>
<th>Haul Costs ($/m³)</th>
<th>Construction Costs ($/m³)</th>
<th>Total Costs ($/m³)</th>
<th>Revenue Costs ($/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional Short-span</td>
<td>1909</td>
<td>119</td>
<td>18.5</td>
<td>20</td>
<td>8</td>
<td>7</td>
<td>35</td>
<td>47</td>
</tr>
<tr>
<td>Alternative Long-span</td>
<td>1646</td>
<td>83.2</td>
<td>0</td>
<td>36</td>
<td>8</td>
<td>0</td>
<td>44</td>
<td>44</td>
</tr>
</tbody>
</table>

Sediment delivery, for both the “short-span” and “long-span” plans were simulated. The results on sediment delivery (Table 9), contrary to expectations, indicated that the “long-span” plan with no new roads produced more total sediments than the “short-span” plan with 18.5 km of new roads. The no-new-roads plan produced less sediment from cut-and-fill slopes (because no new roads were made), but this reduction was diminished by haul related erosion. Analysis indicated that the long-span plan routed more timber along roads in close proximity to the stream network, which suggests that with respect to sedimentation, the usage of roads may be far more significant than road density. The results suggest that reduction of road density should be considered together with the management of traffic patterns within the forest. For example, sedimentation may be minimised by using ridge-based road-network whereby the roads are located along ridges and as far away as possible from the stream network (and crossing the streams only rarely). This is expected to deliver little or no sediment compared to a riparian-based network (Schiess, 2001).

The set-up and dismantling of cable systems is a time consuming and costly process, therefore, it is important to maximise production and minimise costs for each setup. In addition, the optimal line length used will determine the roading density, with longer line lengths having a smaller roading density and shorter line lengths having a larger roading density requirement. The determination of the optimal line length concerns the most cost-effective mainline length to operate a cable system, so that...
the total wood extraction cost of the operation can be minimised. Optimal line length is dependent upon the skyline patterns (parallel or fan-shaped), skidding direction (uphill or downhill), average size of the payloads, and the wood concentration (bunching).

Line length is a key factor affecting wood extraction costs, but skyline patterns (parallel or fan-shaped), bunching distance, average log size and wood concentration per metre of line length also have significant effects. The line length of the cable system contributes to the overall set-up and dismantling times. In general, the longer the line length the longer the set-up and dismantling times. Approximately 73-75% of the total time is due to setup and only 25-27% of the total time is for dismantling (Košir, 2001).

3.1.2.4. Costs considerations for establishment of optimal line length
To evaluate the optimal line length, it is necessary to calculate the total costs of the wood extraction method, including the cost related to the setting up and dismantling of the system, and the related tree/log skidding costs. Košir (2001) indicated that set-up costs and dismantling costs are dependent on line characteristics (line length, layout pattern). Skidding costs are influenced almost entirely by bunching, skidding direction, skidding and bunching distances and the size of the timber. He recorded variations of up to 4% in the setting costs between uphill and downhill skidding directions, with downhill set-up costs being higher, but the related costs of skidding were equal. The setting costs also differed with the skidding method used. For the same skidding direction, the fan-shaped method was approximately 20% cheaper than the parallel method. Analysis indicated that the skidding costs were mainly influenced the most by the log size (69-86%), and by the bunching distance (23-24%).

Setting costs (setup and dismantling costs) contribute strongly to the total cost for short line lengths, but decreases at the longer line lengths (> 300m). Skidding costs tend to increase for the longer line lengths and there is an optimal line-length corresponding to minimum total cost. The economic range of line-lengths may be quite wide. For example, Figure 10 shows that for operating line lengths in 160 – 420 m range, the total cost only varies by approximately 5% from optimum.

![Figure 10. Variation of setup and skidding costs with line length for a Syncrofalke™ cable crane in Slovenian conditions (Košir, 2001).](image)

The main factors affecting the range of optimal line length (Table 10), include:
- **Wood concentration (bunching)** — wood concentration is inversely proportional to the optimal line length;
- **Size of timber** — optimal line length increases with the size of harvested wood;
- **Extraction method** (parallel or fan) — parallel settings increased the optimal line lengths when compared to fan-shaped settings;
- **Timber sizes** — increasing the timber sizes increased the optimal line length (also see Section 4.2: Cable systems and small dimensional timber);
- **Skidding direction** — optimal line lengths are longer for uphill extraction.
Table 10. Optimal line lengths for a Syncrofalke cable crane in Slovenian conditions (Košir, 2001).

<table>
<thead>
<tr>
<th>Cable extraction layout</th>
<th>Bunching distance, m</th>
<th>Size of log (t)</th>
<th>Wood concentration, tonnes/m</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1 1.1</td>
<td></td>
</tr>
<tr>
<td>Uphill Parallel</td>
<td>10</td>
<td>0.1 340 300 260 240 220 220 200 200 180 180</td>
<td></td>
</tr>
<tr>
<td>Uphill Parallel</td>
<td>10</td>
<td>1.0 440 400 360 340 300 300 280 280 260 240</td>
<td></td>
</tr>
<tr>
<td>Uphill Parallel</td>
<td>20</td>
<td>0.1 340 300 260 240 220 220 200 200 180 180</td>
<td></td>
</tr>
<tr>
<td>Uphill Parallel</td>
<td>20</td>
<td>1.0 440 400 360 340 320 300 280 280 260 240</td>
<td></td>
</tr>
<tr>
<td>Uphill Fan-shaped</td>
<td>10</td>
<td>0.1 260 220 200 180 160 160 140 140 140 120</td>
<td></td>
</tr>
<tr>
<td>Uphill Fan-shaped</td>
<td>10</td>
<td>1.0 320 280 260 240 240 220 200 200 200 180</td>
<td></td>
</tr>
<tr>
<td>Uphill Fan-shaped</td>
<td>20</td>
<td>0.1 260 220 200 180 160 160 140 140 140 120</td>
<td></td>
</tr>
<tr>
<td>Downhill Parallel</td>
<td>20</td>
<td>1.0 320 280 260 240 240 220 200 200 200 180</td>
<td></td>
</tr>
<tr>
<td>Downhill Parallel</td>
<td>10</td>
<td>0.1 360 320 280 260 240 220 200 200 180 180</td>
<td></td>
</tr>
<tr>
<td>Downhill Parallel</td>
<td>10</td>
<td>1.0 460 420 380 340 320 300 300 280 260 260</td>
<td></td>
</tr>
<tr>
<td>Downhill Parallel</td>
<td>20</td>
<td>0.1 360 320 280 260 240 220 200 200 180 180</td>
<td></td>
</tr>
<tr>
<td>Downhill Parallel</td>
<td>20</td>
<td>1.0 460 420 380 340 320 300 300 280 260 260</td>
<td></td>
</tr>
<tr>
<td>Downhill Parallel</td>
<td>10</td>
<td>0.01 260 220 200 180 180 160 160 140 140 140</td>
<td></td>
</tr>
<tr>
<td>Downhill Fan-shaped</td>
<td>10</td>
<td>1.0 340 300 280 260 240 220 220 200 200 200</td>
<td></td>
</tr>
<tr>
<td>Downhill Fan-shaped</td>
<td>20</td>
<td>0.1 260 220 200 180 180 160 160 140 140 140</td>
<td></td>
</tr>
<tr>
<td>Downhill Fan-shaped</td>
<td>20</td>
<td>1.0 340 300 280 260 240 220 220 200 200 200</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Maximum</td>
<td>460 420 380 340 320 300 300 280 260 260</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Minimum</td>
<td>260 220 200 180 160 160 140 140 140 120</td>
<td></td>
</tr>
</tbody>
</table>
3.2. Road Construction

In SFM the technical specification for the road network must be in accordance with the natural conditions and land uses (Abegg and Hunderwadel, 1983), and the expected logging operations and landscape aesthetics (FAO, 1998). Due to the favourable economic and ecological balance, cable logging and a suitable road network are recommended in mountainous terrain (Dykstra and Heinrich, 1995). The building of a forest road network in steep terrain is demanding and very expensive, so planning and designing those routes that will give the highest profit at the lowest investment and minimum damage to the forest ecosystem, have to be chosen (Pičman et al, 2001).

Forest road construction activities are the most damaging agents to the environment and in particular with relation to soil erosion and sedimentation within forest operations (Dykstra and Heinrich, 1996). Skidders will not work on extremely steep terrain where they have low efficacy, high costs and result in unacceptable damages to the soil in the form of rutting and compaction. Therefore, cable systems represent an ecologically acceptable alternative due to their minimal impact on the forest environment, particularly the forest soil. (Pičman et al, 2001). The planning of forest roads needs to take into consideration the harvesting method used for timber extraction so that a long-term efficient road network can be established. Once planned the construction of the actual road itself should use ecologically acceptable machines and tools.

Environmentally sound forest road construction should minimise damage to the forest, soil and terrain. Using the grade line surveying method the forest engineer will require 5-7 working hours in easy terrain and 8-12 working hours in difficult terrain per km forest road location (Sedlak, 1985). Traditionally bulldozers were used in the construction of forest roads but recent trends and the demand for eco-friendly road construction has seen the introduction of more excavators for forest road construction. In mountainous areas the use of bulldozers in forest road construction often caused considerable soil damages caused by side casting of the soil material. Due to environmental concerns, the introduction of more environmental sound construction methods using excavators and advanced blasting techniques have occurred (Heinrich, 2001).

The different work sequences involved in environmental sound construction methods using excavators, include (Winkler, 1998):
(i) removal of felled trees along the road corridor;
(ii) removal of the organic layer from the construction area;
(iii) excavation of a base for the fill foundation;
(iv) construction of the fill slope, and;
(v) preparation of the cut slope, formation of the road and placement of the organic matter on the side slopes.

Using an excavator, felled logs can be moved out of the area of construction by attaching them to a chain on the bucket of the excavator. The logs can be stored in designated storage places. Removal of the organic layer can be utilised to minimise the erosion impacts of the excavated soil material by placing the wood residues and organic soil along and below the base of the fill slope. A base for a fill slope should be built on solid ground of approximately 1m wide. Using appropriate coarse material the fill should be built to a depth of 0.5m to 1.5m. This method when compared to bulldozers, involves moving 25-35% less soil material (FAO, 1989). The excavator bucket spreads the appropriate coarse road material in layers of 30-50cm and this material should be compacted by repeated passes with the excavator. If possible a sub-grade (if available) can be applied. Once the road surface is finished the drainage ditch and the cut slope should be shaped and organic material should be placed on the exposed side slopes to reduce erosion and sedimentation. As with most newly constructed roads, a period of time (approximately one year) should be allowed to pass to allow the road to settle.

When compared to excavators, production figures for bulldozers in road construction appear somewhat higher (13.6 versus 5.6 m/PMH) with lower operational costs (6.07 versus 9.28 $/m). However, a direct comparison is not possible as excavators also do additional work, such as finishing the road and putting in culverts and drainage ditches. In addition, the quality of the road construction is higher for the excavator with possible reductions in future maintenance work compensating for the higher initial costs. Other advantages of the excavators include the reduced impact on the environment, less restricted road widths, good drainage facilities, road protection structures and vegetation cover of cut and fill slopes. Other research suggests that there is most likely no economic advantage of using bulldozers in forest road construction on slopes over 50-60% (FAO, 1989: Gorton, 1985).
Advantages of using excavators for forest road construction include:

- Precise excavations i.e. digging and depositing of material done by the bucket;
- Can reduce cut and fill slopes;
- Versatile as different attachments can be used for different tasks, e.g., compacting, loading, ditching, ripping, rock breaking and drilling;
- Rock hammering and drilling can be done reducing the need for drilling machines and blasting;
- Excavators can be used for other work such as putting in culverts, surfacing, constructing drainage structures, placing organic material on the cut and fill slopes etc.

3.3. Selection of appropriate cable system

Due to the diversity in configuration of cable systems (see Section 2.2) and the high capital costs of investment, the selection of an appropriate cable system is crucial. The main factors to consider when selecting a cable system for forest operations are the tower yarder specifications; rope configuration; load capacity and horsepower requirements; rope strength requirements and purchase price.

3.3.1. Yarder specifications

Due to the variability of terrain conditions, yarder specification will determine the optimal cable configuration. A yarder with one or two winch drums may limit operations to the highlead system, gravity system (and running skyline system if the mainline is a single rope). A three drum tower yarder provides a greater flexibility as it allows the operation of all four cabling methods. The necessary elevation also has a bearing on the lifting capacity, with the higher tower yarders having a greater lift capacity.

3.3.2. Cable configuration

The rope configuration determines the cable system used, and the choice is based on the inherent topography and other site related factors such as terrain roughness. If there is no need to lift the logs off the ground, the high lead system can be used for both uphill and downhill extraction. However, if the logs must be fully suspended then the running skyline system could be used. If all the logging is to be uphill than the gravity system can be used.

3.3.3. System power requirements

The power requirement to pull loads up or downhill is a function of the load, the ground resistance acting on that load and the line speed. The size of loads to be yarded can be estimated whereas, the required line speed will depend on the required daily production. In general, the bigger the load at a constant horsepower the lower the haul in speed. This will provide a minimum horsepower requirement needed to effectively haul loads. In most cable systems there are peaks of demand for available horsepower that are determined by the terrain and the felling and bucking factors (Figure 11), and orientation of haulage. For example, in the case of the running skyline (with mechanical drives) that needs 75 kW to yard a load, while the mainline is being pulled in, the haulback line may be braked to provide lift, resulting in a higher power demand of 134 kW. The extra 60 kW is lost as heat through the braking mechanism.

Cable yarders with hydrostatic breaking mechanisms transfer the braking horsepower that would otherwise be lost as heat, back into the mainline drum. Such yarders are therefore more efficient in their use of horsepower than mechanical drive yarders, and more importantly they brake by reducing the horsepower input to the particular drum rather than dissipating it as heat energy. The net result is that the cable yarder with hydrostatic drive can handle the same load as mechanical drive yarders but with lower horsepower input. In addition, hydrostatic drive cable yarders have a reduced running cost and provide improved control over the load due to improved braking capabilities (Ward, J., Selecting a cable thinning system, Queensland Department of Forestry).
3.3.4. **Cable tension during load transport**

The loads exerted on the ropes is a function of line tension, deflection, weight of the rope per unit length, span and the distance out to the load (Figure 12). The absolute cable tension \( T \) is expressed as:

\[
T = \frac{qL^2}{8y_m} + \frac{QL}{4y_m}
\]

Where:
- \( T \) is the absolute cable tension (N)
- \( q \) is the unit weight of cable (N/m)
- \( Q \) is the total point load (N)
- \( L \) is the horizontal distance between two suspension points of the cable (m)
- \( y_m \) is the deflection in the cable at the midspan (m).

As illustrated in Section 3.3.3, the forces on the cable can increase dramatically during operations and peaks in these forces can significantly exceed the force applied by the weight of the load. Factor of safety (ratio of the maximum anticipated cable tension to the breaking load) of 2.5–3, and 4–5 are recommended for fixed/live skylines and running skylines, respectively (Samset, 1985). The rope specifications must be examined closely to ensure safe operation of the cable system. In addition, all operators should have an appreciation for the effect of work practices on the forces generated in the
ropes. Specifically, they should be aware that excessive tightening of the skyline, jerking of the loads, overloading, and inadequate schedule of rope inspection and maintenance can compromise safety.

3.3.5. Economic considerations
The purchase prices of cable systems are high for all levels of sophistication (Table 11). In addition, the running costs such as wages and downtime also contribute to the high extraction costs per cubic meter for viable systems. These factors have resulted in a marked decline in the use of cable systems in Europe (see Table 5). The high purchase prices may be discounted against their minimal negative environmental impacts, and the fact that they may be the only viable and sustainable extraction method for management of sensitive sites.

<table>
<thead>
<tr>
<th>Table 11. Purchase prices for a range of cable systems in the market (FBVA, 1999).</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Type of cable system</strong></td>
</tr>
<tr>
<td><strong>Small sized cable systems</strong></td>
</tr>
<tr>
<td>TST 400</td>
</tr>
<tr>
<td>Koller K300</td>
</tr>
<tr>
<td><strong>Medium sized cable systems</strong></td>
</tr>
<tr>
<td>Wanderfalke</td>
</tr>
<tr>
<td>Koller K303</td>
</tr>
<tr>
<td>Koller K501-2</td>
</tr>
<tr>
<td>Adler DSK 25</td>
</tr>
<tr>
<td>Adler MS 500 UNI</td>
</tr>
<tr>
<td>Koller K501-4</td>
</tr>
<tr>
<td><strong>Combined yarder/processor</strong></td>
</tr>
<tr>
<td>Mounty 4000</td>
</tr>
<tr>
<td>Koller K 500</td>
</tr>
<tr>
<td>Koller K301-4</td>
</tr>
<tr>
<td>Koller K301-2</td>
</tr>
<tr>
<td>Koller K500</td>
</tr>
<tr>
<td><strong>Motorised carriage</strong></td>
</tr>
<tr>
<td>Woodliner 1000</td>
</tr>
<tr>
<td>Woodliner 2000</td>
</tr>
<tr>
<td><strong>Sledge system</strong></td>
</tr>
<tr>
<td>Gantner HSW 50 NB</td>
</tr>
<tr>
<td>Gantner HSW 80 NBF</td>
</tr>
<tr>
<td>Gantner HSW 80 D 1000</td>
</tr>
</tbody>
</table>

3.4. Wood harvesting
Cable systems can be used in the Cut-to-length (CTL) or assortment, and full tree harvesting systems. The CTL system involves felling, delimbing and cutting stems into assortments in the forest using chainsaws or mechanical harvesters. Using a chainsaw and directional felling techniques with cable systems, the timber is bunched under or near the skyline for extraction, with the butt end of the logs nearest the skyline. With mechanical harvesters, timber is concentrated within the reach of the harvester with all assortments bunched together in lines. Full tree harvesting involves felling of whole trees in the wood where stems may or may not be delimbed. This method uses mainly chainsaws, in conjunction with directional felling techniques, to present the butt end of logs for cable extraction. The whole trees are processed at the landing.

3.5. Yarders
There are three options in yarders that are currently used with cable systems, including: tower yarder; sledge yarder, and; motorised yarding carriages;

3.5.1. Tower yarding
A tower yarder (Figure 4) consists of winches, cable lines and cable towers to extract timber. The type of cable yarding systems varies depending on the rope configuration adopted to operate the cable system (see Section 2.2: Types of rope configurations).
3.5.2. Sledge yarding
Sledge yarders are simple winch-gravity systems used mainly for long distance uphill extraction (Figure 13). The motorised winch or sledge has no tower, but is positioned at a harvesting site to use a gravity-fed rope configuration. Tree anchors are used with elaborate pulley mechanisms (see automatic tackle clamps in Figure 13) to create the tension to provide cable elevation. The sledge cable system has greater pulling power than a tractor winch and uses its own winch (self-dragging) for translocation at the site and through inaccessible areas.

3.5.3. Motorised yarding
Motorised yarding involves the use of a motorised carriage, cable lines and cable towers to extract timber. A radio controlled petrol engine moves the carriage. Motorised carriages are a new innovation that eliminates the need for a haul back line (Figure 14), which reduces the setup times significantly. The need for winch drums for the cables is replaced with a motorised carriage. A small winch is required to tension the main cable. The motorised carriages can extract both uphill and downhill, but the carriage is more suited to downhill extraction as a very large engine is required to haul loads uphill. Motorised carriages weigh approximately 300 kgs and load capacities are approximately 1.5 to 2.5 tonnes (Greifenberg, 2001). The main advantage of this system is the reduced set-up times as it uses only one cable, and the reduction in the number of personnel required to operate the system.

3.6. Tree processing
Mechanised roadside processing has integrated into the current cable extraction systems. The increasing labour costs and the shortage of skilled workforce required to operate cable systems have enhanced the extent to which it is used with cable systems. Related systems include continuous processing, and delayed processing.
The continuous processing systems consist of a cable yarder and processing units mounted on the same platform (Figure 15). Typically the cable system is mounted on a truck chassis and the processor unit (including the operators cab) is positioned around the base of the tower. The processing unit can rotate independently of the tower (see inset in Figure 15), and may possess either a processing head or grapple, or a combination of a processing head and grapple. Typically this system extracts whole trees to the roadside where they are either processed and stacked (whole trees) or stacked (assortments). Lorries with rear mounted cranes are required to reverse to the stack to load (Figure 16).
In the delayed processing systems, the yarder and processing units are mounted on separate platforms. The processing unit may possess a processing head, a grapple or a combined processing head and grapple unit. As in continuous processing, this system extracts whole trees and/or assortments separately to the roadside where they are either stacked (in CTL or assortment), or processed and stacked (whole trees).
Table 12. Examples of the working combinations available for the operation of cable systems

<table>
<thead>
<tr>
<th>Example</th>
<th>Harvesting system</th>
<th>Tree felling method</th>
<th>Yarding</th>
<th>Road processing</th>
<th>Orientation of extraction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cut-to-length</td>
<td>Whole tree</td>
<td>Chainsaw</td>
<td>Steep terrain</td>
<td>Cable system</td>
</tr>
<tr>
<td>Small sized cable system</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
</tr>
<tr>
<td>Small sized cable system</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
</tr>
<tr>
<td>Small sized cable system</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
</tr>
<tr>
<td>Medium sized cable system</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
</tr>
<tr>
<td>Medium sized cable system</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
</tr>
<tr>
<td>Medium sized cable system</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
</tr>
<tr>
<td>Medium sized cable system</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
</tr>
<tr>
<td>Medium sized cable system</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
</tr>
<tr>
<td>Combined yarder/processor</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
</tr>
<tr>
<td>Combined yarder/processor</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
</tr>
<tr>
<td>Combined yarder/processor</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
</tr>
<tr>
<td>Combined yarder/processor</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
</tr>
<tr>
<td>Motorised carriage</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
</tr>
<tr>
<td>Motorised carriage</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
</tr>
<tr>
<td>Motorised carriage</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
</tr>
<tr>
<td>Motorised carriage</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
</tr>
<tr>
<td>Sledge system</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
</tr>
<tr>
<td>Sledge system</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
</tr>
<tr>
<td>Sledge system</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
</tr>
<tr>
<td>Sledge system</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
</tr>
<tr>
<td>Sledge system</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
</tr>
</tbody>
</table>
4. **PRODUCTIVITY AND COST OF WOOD EXTRACTION WITH CABLE SYSTEMS**

4.1. **Factors affecting the productivity of cable systems**

The key factors that influence the productivity and cost of wood extraction with cable systems, include:

- **Stand density** — Density of the forest stand determines the volume that can be extracted per meter of line length. Higher volume can be extracted at the larger stand densities, making the operation more productive. Influence of stand density is more critical in thinning operations.

- **Volume per set-up** — The total volume extracted for each yarder set-up is critical to productivity. Due to the high set-up times care should be taken to maximise the volume for each set-up. This volume per set-up could be enhanced through efficient planning and location of the cableway, and lateral bunching (see Chapter 3).

- **Harvesting method** — Whole tree extraction is more productive than cut-to-length systems.

- **Log sizes** — Cable systems are more productive for the larger sized logs (see Section 4.2).

- **Slope** — In most cases steeper slopes increase productivity by providing more clearance. However, this is offset somewhat with increased difficulties in setting up.

- **Yarding distance** — There are many factors determining the optimum yarding distance to use to maximise production (see section 3.2 on optimal line lengths). Cable systems operating outside their optimum yarding distance experienced depressed productivity.

- **Storage space at the landing** — Productivity of cable systems can be reduced if there is not enough space for stacking logs at the roadside. Many modern cable methods employ hot logging techniques, i.e., once extracted the logs are piled away from the yarder at the landing. Timely organisation of transport trucks may minimise the effect of limited space at landing.

- **Lateral bunching** — Lateral bunching can increase productivity when small lateral bunching distances are used (<10 m). However, the process becomes less efficient at larger lateral bunching distances.

- **Felling direction** — Felling should present the butt ends of the trees for easy choking.

- **Use of chokers** — Multiple chokers together with automatic release (manual or radio-controlled) can help increase productivity.

  - **The working crew.** The experience, motivation and level of training of working crews are central to the productivity of the cable system (see section 5.2: management of human resources). Cable systems require a high physical input and in order to secure and retain productive staff adequate payments that reward workers for the high intensity manual labour are required.

- **Weather** — Cable systems have less impact on the soil and surface vegetation than ground-based harvesting systems. However, where felling and processing is by chainsaws, efficient operation is more affected by poor weather conditions (rainfall, lightening and snowfall) than ground-based harvesting systems.

- **Communication** — Systems with good means of communication (*viz.* two-way radios, intercoms, or horns with the number of blows that are cored for different actions) between the choker setters and landing are more efficient.

Studies on productivity of cable systems are widely available (Table 13). However, due to the differences in time-study methods and tree characteristics involved, direct comparisons are inappropriate. In general, productivity of the outlined cable systems are predominantly in the range of 1 – 10 m³/PMH. The cable systems with the higher productivity values tend to be the large sized cable systems operating in mature stands (tree volume greater than 1m³) over yarding distances of less than 500 m. For the same yarding distance, yarder productivity is expected to reduce when extracting smaller sized timber.
Table 13. Estimated productivity of cable systems

<table>
<thead>
<tr>
<th>Description of system</th>
<th>Productivity (m³/PMH)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gantner skyline, 1200m extraction</td>
<td>4.03</td>
<td>Acar et al., 2001</td>
</tr>
<tr>
<td>Gantner skyline, 800m extraction</td>
<td>6.98</td>
<td>Acar et al., 2001</td>
</tr>
<tr>
<td>Long distance winch skylines</td>
<td>5.10</td>
<td>Acar and Erdaş, 1992</td>
</tr>
<tr>
<td>Gantner long distance skyline</td>
<td>5.01</td>
<td>Acar, 1995</td>
</tr>
<tr>
<td>Gantner skyline, 700m extraction</td>
<td>4.96</td>
<td>Acar and Gümüş, 2000</td>
</tr>
<tr>
<td>Cable car skylines, 400 – 750m extraction</td>
<td>8 – 10</td>
<td>Baldini and Pollini, 1998</td>
</tr>
<tr>
<td>Cable car skylines, 750 – 1200m extraction</td>
<td>5 – 8</td>
<td>Baldini and Pollini, 1998</td>
</tr>
<tr>
<td>Long distance cable crane in clearfell</td>
<td>3.88</td>
<td>Winkler, 1999</td>
</tr>
<tr>
<td>Long distance cable crane in group selection</td>
<td>5.01</td>
<td>Winkler, 1999</td>
</tr>
<tr>
<td>Tyler yarding system, 100m extraction</td>
<td>9.5</td>
<td>FAO, 1977</td>
</tr>
<tr>
<td>Tyler yarding system, 500m extraction</td>
<td>6.1</td>
<td>FAO, 1977</td>
</tr>
<tr>
<td>Tyler yarding system, 1000m extraction</td>
<td>4.2</td>
<td>FAO, 1977</td>
</tr>
<tr>
<td>Short distance extraction, Koller K300</td>
<td>6.41</td>
<td>Tunay et al., 2001</td>
</tr>
<tr>
<td>Extra light cable extraction in coppice</td>
<td>1.2 - 2.2</td>
<td>Baldini et al., 2001</td>
</tr>
<tr>
<td>Koller K300, uphill extraction</td>
<td>6.0</td>
<td>Rieger, 2001</td>
</tr>
<tr>
<td>Koller K300, uphill extraction</td>
<td>5.67</td>
<td>Aykut et al., 2001</td>
</tr>
<tr>
<td>Timbermaster yarding system</td>
<td>3.0</td>
<td>Owende et al., 2001</td>
</tr>
<tr>
<td>KSK 16 yarder*</td>
<td>9.6</td>
<td>Krpan et al., 2001</td>
</tr>
</tbody>
</table>

*Combined yarder and processor units

4.2. Cable systems and small-dimensioned timber

Cable systems are recognized to be expensive options for wood extraction in forest harvesting. The efficiency of their use is very much influenced by the dimension of wood, especially in young stands, shelterwood systems (areas requiring continuous forest cover) and selective cuttings. Therefore, in practice harvesting of small-sized timber with cable systems present economic problems (Efthymiou, 2001). Piegaï (1984) estimated that for economic operation of cable systems, the extraction volume per meter of field length of cable crane line should be between 0.5 and 1 m³.

The problem of handling small dimensioned wood lies in the increased time and cost per m³ as the dimension of wood decreases as it becomes necessary to choke several trees or logs per turn to get economic loads. Sirois (1981) showed the generic relationship between the cost of harvesting and transportation of wood chips with the dimension of wood in form of exponential decay function illustrated in Figure 17. The cost of wood chips from a 25 mm DBH was estimated at 122 euro/tonne (107 $/tonne) compared to 9 euro/tonne (8 $/tonne) at a DBH of 380 mm.
Generally, productivity of cable systems increase with the load size as depicted in Figure 18. To counteract the reducing effects on productivity of cable systems presented by harvesting smaller dimensioned timber, it becomes imperative that the operation of all aspects of cable systems are streamlined so that the negative impacts of reducing productivities can be minimised. This can only be achieved by improving the productivity and cost-effectiveness of cable operations.

### 4.3. Maintenance costs for cable systems

While cable systems are generally regarded as complex wood extraction systems, their maintenance is often straightforward and cost effective. Rieger (2001) provided a breakdown of the costs in a standard cable system (Table 14). The data relate to performance of a Koller K300-yarder (trailer version), operating in Austria, over a 12-year period (1986-1998). The cable system consisted of one yarder, one tractor and a crew of three members.

Maintenance costs represented 35% of the total cost of the operation of the Koller K300-yarder over the 12-year observation period. The breakdown of the costs (Figure 19) showed maintenance costs were related to the wire ropes (32%) and winches (25%). The remaining 43% of costs were related to the engine, gears and tower (17%), the carriage (14%), and miscellaneous items (12%).
4.4. Cost of wood extraction using cable systems

Wood extraction costs are generally higher with cable systems when compared to ground-based operations, and is the main reasons for decline in the use of cable systems in Europe (see Section 1.6). For example, it is not unusual for the production costs for cable extraction to be twice to three times the values of ground-based systems (Krpan et al., 2001). Production costs vary from country to country and from site to site (Table 15), and are due mainly to the key issues affecting productivity (see Section 4.1), including: stand and site characteristics, cable system configuration and crew-related factors.
Table 15. Examples of production costs for cable systems in France and Italy

<table>
<thead>
<tr>
<th>Site</th>
<th>Area, ha</th>
<th>Logged surface, ha*</th>
<th>No. of stems</th>
<th>Marked volume, m³</th>
<th>Logged volume, m³</th>
<th>Felling time, min/m³</th>
<th>Yarding time, min/m³</th>
<th>Felling cost, euro/m³</th>
<th>Yarding cost, euro/m³</th>
<th>Total logging cost, Euro/m³</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>France</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Boutat</td>
<td>30</td>
<td>14</td>
<td>1523</td>
<td>819</td>
<td>395</td>
<td>36.5</td>
<td>40.3</td>
<td>15</td>
<td>49</td>
<td>64</td>
</tr>
<tr>
<td>Pralognan</td>
<td>13</td>
<td>13</td>
<td>439</td>
<td>820</td>
<td>743</td>
<td>24.9</td>
<td>13.3</td>
<td>10</td>
<td>28</td>
<td>38</td>
</tr>
<tr>
<td>Contamines</td>
<td>25</td>
<td>25</td>
<td>615</td>
<td>1397</td>
<td>1397</td>
<td>(26.7)**</td>
<td>9.5</td>
<td>(11)**</td>
<td>32</td>
<td>43</td>
</tr>
<tr>
<td><strong>Italy</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cadino</td>
<td>26</td>
<td>9</td>
<td>159</td>
<td>343</td>
<td>343</td>
<td>18</td>
<td>14.2</td>
<td>7.3</td>
<td>22</td>
<td>29</td>
</tr>
<tr>
<td>Sadole</td>
<td>51</td>
<td>2.5</td>
<td>383</td>
<td>1070</td>
<td>1070</td>
<td>26</td>
<td>9.1</td>
<td>11</td>
<td>18</td>
<td>29</td>
</tr>
<tr>
<td>Lavaze</td>
<td>31</td>
<td>0.7</td>
<td>162</td>
<td>278</td>
<td>278</td>
<td>11.3</td>
<td>7.8</td>
<td>4.6</td>
<td>5.8</td>
<td>10</td>
</tr>
</tbody>
</table>

Source: LIFE programme (No.94/F/A15/EU/00173)

* Surface of the lanes actually opened in Italy

** Global estimate
5. **ADAPTATION OF CABLE SYSTEMS FOR COST-EFFECTIVE WOOD HARVESTING ON SENSITIVE SITES**

5.1. **Trends in the Use of Cable Systems**
Despite the general decline in the use of cable systems in Europe (see Section 1.6), the requirements of SFM has lead to an increased demand to harvest forests in a manner that is environmentally sensitive and sustainable. Consequently, it is envisaged that there may be a reversal of the current declining trends in the use of cable systems and their role will become increasingly more important, especially on steep and sensitive terrain.

Loschek (2001) has exemplified that introduction of various rationalisation measures may regulate the production costs (Figure 21). Such measures include:

- Increased use of contract labour;
- Increased productivity of cable yarders;
- Integrated machine processes;
- Use of steep terrain harvesters and excavator based cable units (other mobile plant may also be appropriate, see Section 5.1.5), and;
- Enhanced management of human resources (cable-crews).

![Figure 21. Trend of cable extraction costs in Austria (Loschek, 2001).](image)

The future success and commercial viability of cable system operation will rely on the implementation of these and other rationalisation strategies that will have the desired effect of making the operation of cable systems more cost-effective. Although the implementation of these strategies may make cable systems more cost-effective, they are unlikely to surpass ground-based extraction, but they should be instrumental in their economic operation to enhance their use on sensitive forest sites.

5.1.1. **Increased use of contract labour**
One rationalisation strategy adopted in the 1990’s throughout Europe, to improve the cost-effectiveness of conventional ground-based harvesting methods and cable systems, was the increased use of contract labour. This rationalisation measure was adopted by most state and private companies in Europe, as a cost-effective means of dealing with the large capital and running costs of forest machinery, rising manpower costs and the shortage of forest workers. In cable systems the use of contractors varies from motor manual contractors to fully mechanised cable contractors. In Austria, where there is the largest use of cable systems in Europe, the implementation of this strategy resulted in an increase in the percentage of the annual cut harvested by contractors from 6% in 1981 to 17.0% in 1999 (Figure 22).

5.1.2. **Increased productivity of cable yarders**
In parts of Europe, (e.g., Austrian and Swiss Alps) the operational concepts of cable systems that are designed for the transport of materials and passengers have been widely developed in countries where vast forest resources located on steep terrain are linked by economic demands for processing and utilisation of local wood, (Pestal, 1961; Hafner, 1964; Trzesniowski, 1985; Heinimann and Schmidt, 1990; Aggeler, 1992). Developments in cable systems in these areas over the years have resulted in improvements in productivity of cable yarders.
In the early 1960's the first cable yarders, such as the “Gösser Seilkran” were introduced for uphill logging only in the Austrian and Swiss Alps. Shortly after their introduction the carriage was modified to facilitate downhill logging also. In the 1970's and 1980's the development occurred of large and small mobile yarders equipped with hydraulic power transmission. An example of the smaller mobile yarders was the “Turmfalke” which was introduced in 1985 (loading capacity of approximately 2.5 t) with capstan-winches replacing the conventional winch drums. An example of the larger mobile yarders was the “Hydrokran” (loading capacity of 5-6 t) which was introduced in 1972.

In the 1980's remote control locking carriages were introduced. This new device for the first time allowed the chokerman to operate the yarder by radio control. Today these are used extensively and they are very effective for both up and downhill extraction. When the carriage comes within a pre-set distance of the tower (generally 20 m) control is taken over by the driver, who then guides the load to the landing site. Once the load is unchokered the carriage is returned to the wood. Once the carriage passes the pre-set distance from the tower, control of the carriage passes to the chokerman. The distance from the landing to the chokerman can be measured using the length of haul cable removed from the drum. If the chokerman fails to take control of the carriage once it passes the pre-set distance from the tower the carriage will automatically return to position of the previous run. The main advantage of this system is that it allows both the chokerman and the operator to work while the carriage is travelling in and out. These carriages are generally quite heavy (approximately 100 kg) but they are extremely effective when handling full poles or whole trees. Most modern carriages have the facility to release up to 50 m of feed haul cable, to facilitate a 1 man choking system at longer distances.

Currently, cable yarders are highly advanced with the introduction of continuous processing and delayed processing techniques (see section 3.6). Consequently, most modern cableway systems (except for the lighter ones) have approximately equal productivities (Lukáč, 2001).

### 5.1.3. Integrated machine processes

In the last two decades integration of machine processes has helped to moderate the costs for cable extraction (Dürrstein, 2001). Mechanisation for cable systems began in the 70's with the introduction of roadside processors. These machines were used mainly for whole tree extraction systems and were used for bucking and deliming trees (otherwise known as delayed processing). Currently, such operations can also occur usually with a roadside tractor or forwarder, which is used for moving and piling the timber at roadside. The more efficient delayed processing systems have just one roadside processor to process and stack the timber at roadside. These processors have a specialised combination head that has both a processor and a grapple for stacking and handling the processed logs. Introduction of continuous processing, where the cable yarder and processor are mounted on the same unit, increased the productivity and effectiveness of cable systems significantly.

The use of integrated machine processes with cable systems coincided with the transfer of labour from company or state organisations to contract labour (Figure 23). While such innovations have enhanced machine productivity, prohibitive capital investment costs coupled with labour shortages resulted in the rise of mechanised contract labour.
5.1.4. Use of steep terrain harvesters

While the harvester and forwarder combination is a well-developed concept for flat terrain, logging costs and lack of workers have forced development of a mechanised solution for steep terrain. It is mainly the excavator-based harvesters with wheels/legs, or tracks that have been developed for steep terrain (Torgersen, 2001). The innovations in tiltable cabins on tracked chassis has enhanced the operational capability of harvesters to operate on steep terrain (Schöttle, et. al 1997; Weixler, et. al 1999). A concept walking machine is also on its test phase (Timberjack, 2001), and these should enhance machine capability on sensitive sites with soft soils. Lately, specially designed tracked platforms have increased the potential for use of ground-based machines on steep terrain (Stampfer, 1999).

The use of ground-based harvesters was traditionally not possible on steep terrain with slopes over 35%. Up to recently these areas were seen as the sole preserve of chainsaw harvesting because other harvesting machinery such as skidders and purpose-built harvesters and forwarders could not operate safely on these steep slopes. However, developments in the late 1990’s have seen the production of steep terrain harvesters that are capable of operating safely on slopes between 35–55%. This new development is a more productive (particularly when processing larger diameter trees), cost-effective and safer means of felling timber on steep terrain, when compared to motor manual harvesting (Figure 24), and they are popular in countries where there is a shortage of forest workers.

![Figure 23. Trend in mechanisation and contract labour as experienced by MM Forestry Enterprises, Austria (Loschek, 2001).](image)

![Figure 24. Variation of productivity with DBH for mechanised and conventional (chainsaw) harvesting on steep slopes (Oswald and Frutig, 2001).](image)
Recent trends in Central Europe have seen the replacement of chainsaw operators, especially in thinning operations, with steep terrain harvesters. These harvesters (Figure 25) can be tracked or wheeled/walking harvesters (the walking harvester is still a concept machine). Cable systems with steep terrain harvester are used in CTL harvesting systems with the bunching done along the skyline corridor. While the bunching reduces the time required for choking the extent of such a reduction may be downgraded by poor log presentation for choking. In terms of productivity, the increase in time required for choking of logs becomes more of a problem when handling smaller sized assortments (Figure 26).

The combination of steep terrain harvesters with cable crane extraction has resulted in large increases in productivity (Schöttle, et al. 1998; Heinimann et al. 1998; Stampfer, 1999). The productivity of the steep terrain harvester is 12 to 15 times higher than the productivity of chainsaws and this difference increases with increasing tree size dimensions (Figure 26).

Research has shown that the steep terrain harvester with cable extraction of 4 m assortments is more productive than chainsaw felling with cable extraction of whole trees. Current experiences in Austria indicate that the economic viability of steep terrain harvesters with cable extraction only becomes viable for tree sizes with a DBH over 20 cm. A productivity model developed for a Königstiger steep terrain harvester by Stampfer (1999) indicates the effect of tree size and slope on the productivity of the harvester (Figure 25). Increases in tree size increase the harvester productivity, whereas increases in slope have a reducing effect on overall harvester productivity.

![Figure 25. Valmet™ steep terrain harvester and Timberjack walking harvester.](image)

![Figure 26. Typical variation of productivity (PSH_{15}) of a tracked harvester with tree volume (without bark) at 25 and 50% terrain slope (Stampfer, 1999).](image)
While the use of steep terrain harvesters may substantially increase the productivity when compared to the conventional chainsaw system, the improvement in the productivity of subsequent cable yarder extraction may be marginal (Table 16). Damage to the soil and residual stand is still higher with steep terrain machines, and these relate to the inherent soil conditions (Oswald and Frutig, 2001).

<table>
<thead>
<tr>
<th>Tree size and harvesting method</th>
<th>Productivity, m³/h</th>
<th>Mean extraction volume, m³</th>
<th>Proportion of tree damage, %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Harvesting</td>
<td>Extraction</td>
<td></td>
</tr>
<tr>
<td><strong>DBH 24 cm</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chain saw</td>
<td>2.1</td>
<td>6.1</td>
<td>0.79</td>
</tr>
<tr>
<td>Mechanised</td>
<td>25.3</td>
<td>7.7</td>
<td>1.26</td>
</tr>
<tr>
<td><strong>DBH 36 cm</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chain saw</td>
<td>2.7</td>
<td>10.5</td>
<td>1.31</td>
</tr>
<tr>
<td>Mechanised</td>
<td>41.1</td>
<td>11.8</td>
<td>1.69</td>
</tr>
</tbody>
</table>

### 5.1.5. Use of excavator based cable yarders

Excavator based cable yarders are considered to be cost-effective alternatives to the conventional (purpose-built) yarders. These excavator based cable units are converted into cable systems by adding winches to the excavator and modifying the boom to act as a tower. This option is proving to be more cost-effective than purchasing a purpose-built cable system, mainly because it utilises existing excavator base machines that were redundant (fully depreciated) or in danger of becoming redundant (almost fully depreciated). For example, in the UK the first prototype was built in 1998 and to date there are 7 such units in operation (Forestry Commission, 1999). The main advantages of excavator based cable yarders are:

- the fast set-up times (no requirement for tower anchors);
- multipurpose machine;
- ease of operation, and;
- good off road ability.

The necessary modifications depend on whether the hi-lead or skyline rope configuration is to be used (see Section 2.2). The modifications for highlead system include:

- Guarding the undercarriage;
- Installation of Falling Object Protective Structures (FOPS), i.e., guard on front window; operator protection frame, and; steel mesh on operator protection frame guarding the front window;
- Work lights;
- Detachable skyline tower on dipper (secondary boom);
- Winch mounting chassis;
- Double drum winch;
- Two 200mm pulleys (attached to tower);
- Strawline drum;
- Hydraulic motors and control system;
- Automatic release choking system.

Required modifications for a skyline are similar to the highlead, but also include a skyline drum and a locking skyline carriage.

In excavator based cable units the winch drums are powered by hydraulic pumps via the existing excavator pumps. Valve blocks and electric switch over units are added to allow the functions of existing excavator control levers to be alternated between operation of the cable system and the excavator. The pioneering versions of the excavator based cable yarders did not posses an integral processor (Figure 27), therefore, piling of logs on the landing was avoided either by releasing the
skyline tension and the base machine moving away from the logs or, the boom of the excavator was used to push the pile of logs to one side.

Figure 27. End and side views of an excavator based cable extraction system in working position.

Later versions of the excavator based cable yarders have integral processors attached to the boom for roadside processing. In this case, the unit may act as both a cable system and a roadside processor in steep terrain, and as a conventional harvester in moderately steep terrain. The main disadvantage of this system is in the decreased tension of the cable lines during processing. Such systems use a quick hitch system on the end of the boom so that the processing head and excavator bucket could be interchanged when required. The main advantages of this system include:

- The ability to operate as a conventional harvester and cable system;
- The additional roadside processing capacity;
- Digger bucket attachment allows road building/landing construction.

Current excavator based cable extraction plants can process timber at the roadside, without decreasing the tension in the cable lines (Nitteberg, 2001). The advantage of this system is that the excavator can rotate and process without decreasing tension in the lines (Figure 28), hence, allowing simultaneous yarding and processing (when lines are operated using automatic or remote control). During winching the boom may be used to enhance stability. During set-up there is no need to secure the guylines, which makes it possible for the machine to move freely along the road. Rigging of the cableway may be done by means of a chainsaw-powered winch. The principal advantage of this new development is the need for only one machine (one excavator) which can do all operations from yarding logs to processing and sorting of the logs at the roadside. When harvesting small and dispersed forests, in cable spans of < 300 m, light cable systems that are mounted on trucks (Figure 29) are ideal as the set-up times are minimal and high road speeds are possible thereby allowing for speed transfer between sites (MacDonncadha, 1997).

5.2. Management of human resources

Sustainable forest management is not possible without the sustainable use and development of human resources, especially for forestry workers (Apud, 1995). While the capital costs of cable logging equipment have received a great deal of attention, it may be that the human resource basis for improving productivity is far more important. Changes in human resource management should adhere to the active health and safety codes (ILO, 1997), whose objectives are to protect forest workers through operational safety procedures, eliminate health hazards in forestry work and prevent or reduce the incidence of illness or injury caused by forestry work.

The pace of work in cable systems may be only 50% of the machine’s potential, with 40 – 50% of the productive cycle times controlled by the input of the human-controlled work pace. Improvements in productivity of up to 30% resulting from training are not uncommon (Garland, 2001). The human element is also central to the effective decision-making process particularly during planning, set-up, operations and post-harvest operations. Human input into operation with cable systems is central to their efficient and effective operation. Therefore improvement in productivity would potentially result from increasing the effectiveness of the human resource-input, specifically, the ergonomic concerns (viz., reducing the workload, improving tools and accessories), safety considerations, effective planning and training, motivation and advancement in career (Garland, 2001).
Figure 28. Excavator based yarder that allows for slew of base-machine for simultaneous yarding and processing. Inset is a close-up showing features on the processor-head.
Figure 29. Illustration of a cable system mounted on light wheeled carriage (Unimog). Inset details the winch drums and the guyline spools.
5.2.1. Ergonomic concerns

5.2.1.1. Minimisation of workload

The workload in the operation of cable systems is unfavourable because the nature of the work is heavy and dangerous, with poor working postures, and exposure to noise and vibration (Gandaseca et al., 2001). Strategies that can improve the work environment include:

- **Development of motorised slack-pulling carriages** — These propel the line through the carriage to assist the chokerman. In the motorised slack-pulling carriages, the line is propelled by either a hydraulic system or an electric motor in the carriage (Acme Manufacturing, 2001);
- **Job rotation between chokersetting jobs and operating the yarder** (Kellogg and Olsen, 1984) — This may reduce the workload by preventing workers from spending the entire shift doing the heavy work since such work is shared among the working crew;
- **Rest pauses** — Resting from all activity for a small period of time. During operations, work pauses can be created by the chokerman by sending a large load to the landing for processing. The extra material can cause a delay long enough to provide the chokerman with a rest.

5.2.1.2. Improvement of tools and accessories

Tools and accessories may be designed to make the cable extraction operation less demanding in related manual tasks, and safer. For example, **pre-set chokers** can be used effectively by the chokerman to hook up logs while the carriage is waiting to return to the landing. This would reduce the time pressure and also increase productivity by reducing delays in return of the carriage to the landing. Automating the release of chokers at the landing can also minimise the workload, hence, making the operation safer and more productive. **Automatic release chokers** that unhook when the logs are placed on the ground at the landing should be used. Radio controlled chokers (i.e., actuated by a radio signal from the operator at the landing) may also be used (Acme Manufacturing, 2001).

5.2.2. Safety considerations

The setting up and safe operation of a productive cable system requires a well-trained working crew that is capable of recognising conditions that could potentially lead to failure, such as weak stump anchors, unusual line stresses etc. Technical guidance to avoid cable system failures is often available in the form of operating manuals. However, their application often depends on the knowledge and the skill of each individual crew.

Cable systems involve high-tensioned cables and heavy loads (including peak loads) which can produce excessive strains on the equipment, trees, and anchors. Failures in such operations can be catastrophic and even fatal. Central to failure avoidance in cable systems is correct/safe tensioning of the mainline. To ensure the maintenance of a safe tension value in the main cable line, specialised **tension monitoring equipment** should be used. Such equipment is attached to the main cable line, with direct display or remote monitor of tension status.

5.2.3. Effective training

Training is essential to allow crews to efficiently operate cable systems (Garland, 2001). Focused training such as **crew productivity training** for entire crews, with emphasis on how the actions of individual crew-members may influence the productivity of the entire team. Key areas that may be addressed include identification and correction of bottlenecks, and avoidance of breakdown and their correction.

**Integrated job-sequence** could be adopted as a means of developing and sharing knowledge and skills among cable crews. This system operates by breaking the working operations into a hierarchy of job progressions. Each crew-member occupying a job learns how to do the next higher job in the hierarchy from his fellow crew-member. This facilitates crew-members to share their working experience and knowledge with each other, while simultaneously allowing individuals to work up through the hierarchy, gaining experience at each job sequence.

The heavy nature of the work demanded from cable crews could be alleviated with the adoption of **job-sharing**. Such a system may pair-off older members of cable crews with younger members to share a work task. The experience of the older crew-member compensates for the loss of physical abilities when performing lifting, carrying, and climbing or other physically demanding tasks.

5.2.4. Motivation

Motivation of cable crews is central to a productive cable operation. The productivity differences between unmotivated and motivated crews can be as much as 50%, with more mistakes made from the crews that are improperly motivated (Garland, 2001). The principal motivational factor is **financial motivation**. Financial rewards for crews with high productivity are motivating. An example of such a
system would be a piece rate system where one rate is paid per log up to a set production level and a higher rate per log is paid after that level. Another approach uses a cost level target set as a parity price for a contractor, when company crews are more productive then cost savings are split between workers and the company (Olsen, 1988).

Difficulties in recruitment of forest workers for operation of cable systems are usually compounded by high worker turnover. In order to retain existing crew-members it is important that their ambitions and expectations can be satisfied by definitive career paths. For some crew-members this may involve promotional prospects, for others it may simply require an assessment of one’s potential. Assisting crew-members with their personal advancement is a motivational factor that helps retain and develop existing workers.

5.2.5. Future development of cable extraction systems

Combined yarder/processor units that are mounted on truck platforms have allowed extraction and processing of wood to be done from one base unit (see Figure 15). These systems extract, process and stack the timber at roadside. The design allows for the use of a minimum of 2 operators. These systems are increasing in popularity in Central Europe and they are used mainly with whole tree extraction of large trees (> 1 m³).

Typically the cable system is mounted on a truck chassis and the processor (including cab) is positioned around the base of the tower and can rotate independently. An extended platform is provided with a serrated edge onto which trees are landed. Stabilisation of the unit provided by weight of the unit and the guylines are complemented with hydraulic stabilisers on the truck (Figure 30). Once the trees reach the landing they are unhooked by the first operator and the carriage is returned into the wood. The second operator takes control of the carriage in the wood and positions it where required. Meanwhile at the landing the first operator can process the logs and stack the material for subsequent transport. Once the trees are processed they are generally stacked behind the unit and/or across the road, so lorries with rear mounted cranes can reverse to the timber stack to load (see Figure 16). This innovation not only led to the rationalisation of the operation and hence an increase in capacity (Table 13), but moreover, it led to a considerable reduction in machine costs when compared to other cable systems.

![Figure 30. Details of a combined yarder/processor (Konrad Forsttechnik, 2001)](image)

The combined yarder/processor is a versatile cable logging systems that is designed to handle large tree sizes. Smaller units that are typically mounted on 2 or 3-axle trucks are used for small tree sizes (such as in thinning operations), and have been specifically developed to satisfy the demand for cost efficient cable logging for smaller dimensioned timber.
An essential feature of the combined yarder/processor unit is the integrated radio-controlled carriage. Two operators share the control of the carriage thus ensuring that the process is both efficient and safe. The first operator controls the processor and the cable yarder from the truck, whereas the second operator fells the trees and operates the carriage by remote control. A safety feature is built into the radio-controlled carriage to ensure that the returning carriage stops at a point just short of the landing. This is the buffer zone where transfer of control of the carriage is made between the carriage and processor operators. This safety feature ensures that if the first operator is still processing the yarded load will stop a safe distance from the landing. In addition, the first operator cannot control the carriage after it passes the buffer zone ensuring that safe movement of the carriage in the felling area.
6. **RECOMMENDED PRACTICE FOR USE OF CABLE SYSTEMS ON SENSITIVE FOREST SITES**

A sensitive forest site is where alterations to the normal mechanised harvesting practices are required in order to avoid adverse effects on ecological, economic and social functions of the forest and its surroundings (ECOWOOD, 2001). Eco-efficient and cost-effective wood extraction system for such sites should:

1. minimise or eliminate the associated soil disturbance (viz. terrain surface rutting, soil compaction, layer inversion, erodibility) that ordinarily may be incurred by an extraction operation;
2. minimise the damage to residual tree crop and seedlings, in thinning operations and natural regenerating stands, respectively;
3. minimise or eliminate the damage to natural waterways, and artificial drainage and soil protection structures within or adjacent to the harvested areas;
4. optimise the productivity of the extraction operation, i.e., deliver the trees/logs to landings at economic rates and with minimal loss of volume and/or quality, and;
5. ensure the safety of the extraction crews and other personnel involved in the related harvesting processes, by ensuring that only skilled operators are engaged for planning and execution of the extraction work.

Cable systems are uniquely suited to harvesting timber on sensitive sites (viz. steep slopes, and soft and wet soils), and access to such sites is more feasible throughout the year with cable than with ground-based wood extraction systems. Operating conventional ground-based equipment in such sites is often unproductive, costly, and results in undesirable negative impacts (see Sections 1.1, 1.4, and 1.5). Increasing environmental concerns have generated interest in the use of cable systems for extraction of timber from wet and low gradient sensitive sites where they could help to ensure compliance with Codes of Best Forest Practice to enhance SFM initiatives (Thompson *et al.*, 1998). With the use of cable extraction systems on sensitive forest sites, it is recommended that:

1. the capacity of the yarders and cable cranes selected should be commensurate with the size of material to be handled (trees or logs), and the limitations imposed by the nature of the terrain of operation;
2. skyline systems should be preferred over highlead systems as they ensure adequate suspension of the loads above the ground to minimise site disturbance or eliminate it altogether, and they also allow for longer extraction distance in multi-span systems;
3. proper planning, adequate crew training, and operation control should be implemented in order to meet the environmental and economic objectives outlined above, e.g., temporary ramps, culverts, and other hydraulic structures should be installed where plant must cross over drainage and erosion control structures;
4. where significant soil disturbance or exposure has been incurred despite the operational control precautions that were in place prior to a harvesting/extraction operation, control structures should be installed to control material flow into waterways;
5. well rooted and stable support and anchor trees must be carefully selected, hence, on low gradient soft soil sites with shallow root-plating (e.g., peat based soils of western Europe), available mobile plant may be used but with caution as these may incur additional operational costs, and;
6. where practical, the road networks should be located along ridges, and as far away from stream networks (and crossing the stream only rarely, or ‘safe passages’, e.g., temporary bridges are provided), in order to minimise sedimentation.


Trends in Wood Harvesting with Cable Systems for Sustainable Forest Management in the Mountains, 18-24 June 2001, Ossiach, Austria.


FAO. 1977. Planning forest roads and harvesting systems, FAO forestry papers-2, Rome, Italy.


Greifenberg. 2001. VF 1800 Freeman slide winches. Greifenberg snc, Trento, Italy.


Hudson, R.J and J. B. Hudson. 2000. Reliability and harvesting productivity when using excavators as base machines in forest operations. Forestry Contracting Association, Dalfling, Inverurie, Aberdeenshire, AB51 5LA.


Keen, P.G. and M. S. Scott Morton. 1978. Addison-Wesley series on decision support. Addison-Wesley publishing company.


Krpan, A.P.B., T. Poršinsky and A. Sabo. 1999. Wood extraction using choker skidders LKT 80 and 81 in selection forests in mountain conditions. Abstracts “emerging harvesting issues in technology transition at the end of century” IUFRO division 3, RGs: 3.04.00 Operational planning and control; work study, 3.06.00 Forest operations under mountainous conditions, 3.07.00 Ergonomics, Opatija 27.9.-1.10.1999, Faculty of Zagreb university, 121-122.


Harvesting with Cable Systems for Sustainable Forest Management in the Mountains, 18-24 June 2001, Ossiach, Austria.


REFERENCES

Cable Systems for Sustainable Forest Management in the Mountains, 18-24 June 2001, Ossiach, Austria.


Washington (State) Department of Natural Resources. 1997. Final habitat conservation plan. Olympia, WA.


ANNEXES
Terrain classification provides simple, uniform and practical description of trafficability. In mechanised forest operations, such classifications are primarily intended for applications in:
(1) planning of wood harvesting, extraction and silvicultural operations;
(2) operations control;
(3) machine evaluation and comparisons;
(4) machine development and marketing plan, and;
(5) harvesting contract negotiations.

The system used in European countries (Ireland, Great Britain, and the Scandinavia) and Canada, are based on researched site description methods, and concentrate on the three main factors that affect off-road machine mobility and performance, namely:
(1) Ground strength;
(2) Ground roughness, and;
(3) Slope or grade.

The Canadian classification system from Mellgren (1980) is presented in this annex, as it is a good generalised International system of terrain classification for mechanised forest operations.
<table>
<thead>
<tr>
<th>CLASS</th>
<th>1-VERY GOOD</th>
<th>2- GOOD</th>
<th>3'-MODERATE</th>
<th>4''-POOR</th>
<th>4''-POOR</th>
<th>5'-VERY POOR</th>
<th>5'-VERY POOR</th>
</tr>
</thead>
<tbody>
<tr>
<td>M A I N</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FACTORS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NORMAL</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SUMMER</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MOISTURE</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>REGIME</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VERY</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FREELY</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DRAINED</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FREELY</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GRAVEL</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BEDROCK</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SAND</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SANDY</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LOAMS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MEDIUM</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>COURSE</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SAND</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FINE</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SANDS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SILT</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CLAY</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LOAM</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Silty</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sandy</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clay</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Organic</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>soil,</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>less</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>than</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FEET</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SOIL</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TEXTURE</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>COARSE</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SAND</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GRAVEL</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BEDROCK</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SANDY</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LOAMS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MEDIUM</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>COURSE</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SAND</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SEDIMENTS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>STRATIFIED</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GLACIO-LACRUSTINE</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SEDIMENTS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GLACIAL TILL</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FLUVIAL-LACRUSTINE</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SEDIMENTS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DUNE AND</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CLASTOFLUVIAL</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Deposits</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(PRECAMBRIAN)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GLACIAL TILL</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FLUVIAL-LACRUSTINE</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SEDIMENTS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TYPICAL</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FOREST</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>COVER</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>JACK PINE</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BLACK SPRUCE</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(WHITE BITCH)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(ASPEN)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BALSAM FIR</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>WHITE SPRUCE</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ASPEN</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>WHITE BIRCH</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>WHITE PINE</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BALSAM FIR</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BLACK SPRUCE</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ASPEN</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>JACK PINE</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BLACK SPRUCE</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ASPEN</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Poplar</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>White spruce</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Black spruce</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tamarrack</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Eastern white cedar</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Treed muskog</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Black spruce</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tamarack</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Willow</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DUNE AND</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CLASTOFLUVIAL</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Deposits</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(PRECAMBRIAN)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GLACIAL TILL</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FLUVIAL-LACRUSTINE</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SEDIMENTS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TYPICAL</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GROUND</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VEGETATION</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LICHEN</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BEARBERRY</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GRASS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FEATHER MOSS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GRASS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HERBS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FEATHER MOSS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FEATHER MOSS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HERBS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FEATHER MOSS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HERBS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ALDER</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SPHAGNUM MOSS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LABRADOR TEA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>KALMIA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SPHAGNUM</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MOSS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LABRADOR TEA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>KALMIA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LEATHER LEAF</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SPHAGNUM</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MOSS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LABRADOR TEA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>KALMIA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LEATHER LEAF</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SPHAGNUM</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MOSS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LABRADOR TEA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>KALMIA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LEATHER LEAF</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SPHAGNUM</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MOSS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LABRADOR TEA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>KALMIA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LEATHER LEAF</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SPHAGNUM</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MOSS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LABRADOR TEA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>KALMIA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LEATHER LEAF</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SPHAGNUM</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MOSS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LABRADOR TEA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>KALMIA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LEATHER LEAF</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SPHAGNUM</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MOSS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LABRADOR TEA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>KALMIA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LEATHER LEAF</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SPHAGNUM</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MOSS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LABRADOR TEA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>KALMIA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LEATHER LEAF</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SPHAGNUM</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MOSS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LABRADOR TEA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>KALMIA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LEATHER LEAF</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SPHAGNUM</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MOSS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LABRADOR TEA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>KALMIA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LEATHER LEAF</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SPHAGNUM</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MOSS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LABRADOR TEA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>KALMIA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LEATHER LEAF</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SPHAGNUM</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MOSS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LABRADOR TEA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>KALMIA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LEATHER LEAF</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SPHAGNUM</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MOSS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LABRADOR TEA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>KALMIA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LEATHER LEAF</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SPHAGNUM</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MOSS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LABRADOR TEA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>KALMIA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LEATHER LEAF</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SPHAGNUM</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MOSS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LABRADOR TEA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>KALMIA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LEATHER LEAF</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SPHAGNUM</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MOSS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LABRADOR TEA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>KALMIA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LEATHER LEAF</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SPHAGNUM</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MOSS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LABRADOR TEA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>KALMIA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LEATHER LEAF</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SPHAGNUM</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MOSS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LABRADOR TEA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>KALMIA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LEATHER LEAF</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SPHAGNUM</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MOSS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LABRADOR TEA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>KALMIA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LEATHER LEAF</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SPHAGNUM</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MOSS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LABRADOR TEA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>KALMIA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LEATHER LEAF</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SPHAGNUM</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MOSS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LABRADOR TEA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>KALMIA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LEATHER LEAF</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SPHAGNUM</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MOSS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LABRADOR TEA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>KALMIA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LEATHER LEAF</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SPHAGNUM</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MOSS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LABRADOR TEA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>KALMIA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LEATHER LEAF</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SPHAGNUM</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MOSS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LABRADOR TEA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>KALMIA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LEATHER LEAF</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SPHAGNUM</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MOSS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LABRADOR TEA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>KALMIA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LEATHER LEAF</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SPHAGNUM</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MOSS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LABRADOR TEA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>KALMIA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LEATHER LEAF</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SPHAGNUM</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MOSS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

x- Can be class 1 or 2 if the clay loam or clay is dry
y- Can be class 3 if underlain by a hard pan 30-60 cm below the soft surface
### ROUGHNESS CLASS ASSESSMENT

<table>
<thead>
<tr>
<th>PLOT EXAMPLE 100 m²</th>
<th>OBSTACLE HEIGHT (OR DEPTH)</th>
<th>NUMBER OF OBSTACLES PER 100 m²</th>
<th>ROUGHNESS CLASS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10-30 cm</td>
<td>0 - 4</td>
<td>1 VERY EVEN</td>
</tr>
<tr>
<td></td>
<td>10-30 cm</td>
<td>&gt; 4</td>
<td>2 SLIGHTLY UNEVEN</td>
</tr>
<tr>
<td></td>
<td>30-50</td>
<td>1 - 4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>10-30 cm</td>
<td>&gt; 4</td>
<td>3UNEVEN</td>
</tr>
<tr>
<td></td>
<td>30-50</td>
<td>5 - 40</td>
<td></td>
</tr>
<tr>
<td></td>
<td>50-70</td>
<td>1 - 4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>10-30 cm</td>
<td>&gt; 4</td>
<td>4 ROUGH</td>
</tr>
<tr>
<td></td>
<td>30-50</td>
<td>5 - 40</td>
<td></td>
</tr>
<tr>
<td></td>
<td>50-70</td>
<td>1 - 4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>70-90</td>
<td>1 - 4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>ALL COMBINATIONS MORE SEVERE THAN CLASS 4</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**NOTE:** The frequency of the obstacle of maximum size class found on any site is to be considered the limiting factor when assessing ground roughness class.

Isolated large boulders are not considered to create an obstacle to the passage of logging equipment.

### SLOPE OR GRADE

Slope to be measured between points min 25 m (75 ft) apart horizontally, i.e.: a = 25 m
REPORT ON SHORT-TERM MISSION TO THE
WORKSHOP ON NEW TRENDS IN WOOD HARVESTING WITH CABLE
SYSTEMS FOR SUSTAINABLE FOREST MANAGEMENT IN THE
MOUNTAINS

Summary
The ECOWOOD project is developing a protocol for ecoefficient wood harvesting on "sensitive" sites, that matches wood harvesting machines to forest sites, and integrates the stages in the wood chain from tree-felling to the extraction from the forest. Work-package 1 of the project deals with optimisation of wood harvesting/extraction, and includes a review of Cable Systems. The project outputs include Deliverable D2 on soil/machine interaction model, which will provide guidelines for harvester/forwarder/cable selection and operation.

A short-term mission was undertaken to the Workshop on New Trends in Wood Harvesting with cable Systems for Sustainable Forest Management in the Mountains, that was organised by the Joint FAO/ECE/ILO committee on Forest Technology, management and Training. The workshop was held in July 18-24, 2001, at the Forestry Training Centre in Ossiach, Austria. Objectives of attending the workshop were, to:

- acquire information on state-of-the-art equipment and trends in cable systems that are adaptable for sensitive wood harvesting sites, to enable a thorough technical review of the Cable Systems element of Operations Protocol, which will be the final Deliverable of the ECOWOOD Project (see the proceeding workshop agenda);
- present an overview of the technical challenges to wood extraction with forwarders on soft soil sites in Ireland, and to outline the potential role of cable systems in wood extraction on such sites (see Annex 2);
- exchange research findings with respect to productivity, economics, and environmental aspects of cable systems, with researchers from Europe and elsewhere (see proceeding list of workshop participants and Draft Workshop Report).
INTRODUCTION (Agenda Item 1)

1. The Workshop on “New Trends in Wood Harvesting with Cable Systems for Sustainable Forest Management in the Mountains” was held from 18 to 24 June 2001 at the Forestry Training Centre in Ossiach, Austria, at the invitation of the Government of Austria and under the auspices of the Joint FAO/ECE/ILO Committee on Forest Technology, Management and Training. There were 87 registered participants from the following 26 countries: Austria, Bolivia, China, Croatia, Czech Republic, Equatorial Guinea, France, Germany, Greece, Ireland, Italy, Japan, Kenya, Republic of Korea, Morocco, Netherlands, Peru, Russia, Slovakia, Slovenia, Sri Lanka, Switzerland, Turkey, UK, Ukraine and USA.

2. The participants were welcomed on behalf of the Joint FAO/ECE/ILO Committee by the past Chairman, Mr Paul N. Efthymiou, who opened the Workshop, on behalf of FAO by Mr Joachim Lorbach, on behalf of IUFRO by Mr Hans Rudolf Heinimann, on behalf of the Forestry Training Centre, Ossiach, by Mr Johann Zöscher, and on behalf of the Government of Austria by Mr Gerhard Mannsberger, Director General, Forestry Department.

ADOPTION OF THE AGENDA (Agenda Item 2)

3. The Provisional Agenda was adopted.

ELECTION OF OFFICERS (Agenda Item 3)

4. The following Chairpersons were elected:

- Paul N. Efthymiou (Greece) - Items 1, 2 and 3
- Rudolf Heinrich (Austria) - Item 4
- John Garland (USA) - Item 5
- Philip Owende (Ireland) - Item 5
- Peter Schiess (USA) - Item 6
- Rien Visser (USA) - Item 6
- Hans Rudolf Heinimann (Switzerland) - Items 7 and 8
- Joachim Lorbach (FAO) - Items 9 to 11

INTRODUCTION TO AUSTRIAN FORESTRY (Agenda Item 4)

5. Rudolf Heinrich opened Agenda Item 4. The following topics were presented:

Sustainable Forest Management as a Basis for a Steady Supply of High Quality Wood and Lumber presented by Gerhard Mannsberger

Forestry in Carinthia presented by the President of the Forest Association of Carinthia, Christoph Habsburg-Lothringen

Activities and Programmes of the Austrian Chambers of Agriculture and Forestry for Forestry in Austria presented by Thomas Stemberger
NEW DEVELOPMENTS IN CABLE SYSTEMS (Agenda Item 5): Planning and organization of work; application of systems; productivity and costs of cable crane operations; evaluation of environmental impacts using cable systems, and post harvesting assessment.

6. John Garland opened Agenda Item 5. The following presentations were made:
   - IUFRO Programme on Global Forest Information by Heinrich Schmutzenhofer
   - Skyline Logging Systems presented by Othmar David
   - Forest Cableways in Shelterwood System presented by Premysl Horek

7. A guided tour of the forest equipment exhibits was made with Rudolf Heinrich. The following equipment was on display on the Training Centre grounds:
   - Wolf Systems
   - Maxwald
   - Heinz Stuefer
   - SEIK Zona Artigialale S. Lugano
   - Husqvarna-Ges.m.b.H Nfg. KG
   - Koller GmbH
   - Reinhold Hinteregger
   - Gantner
   - Franz MAYR-MELNHOF-SAURAU
   - Greifenberg s.n.c.
   - Tröstl
   - Konrad Forsttechnik GmbH
   - MZLU, SKOLNI LESNI PODNIK

8. Günter Sonnleitner provided a guided tour of the Forest Training Centre facilities.

9. An excursion was made to Ossiacher Tauern to see a demonstration of forest cable equipment. (See Annex 1.)

10. Philip Owende continued with Agenda Item 5 and the following papers were presented:
    - Aspects of Mechanical Engineering for Cable Systems presented by Walter Huettnear
    - Multi Criteria Evaluation of Thinning Operations in Steep Terrain presented by Karl Stampfer
    - Optimal Line Lengths when Skidding Wood with the Syncrofalke Cable Crane in Slovenian Conditions presented by Boštjan Košir
    - Skyline Yarding Distance Modelling for Logging in Mountains presented by Jan Tucek
    - Time Analyses on Koller K300 Mobile Skylines in Artvin Region presented by Tolga Öztürk
    - Structure of Cost and Performance of a Koller K300 Yarder presented by Gerhard Rieger
    - Work Performance of Koller K300 Cable System on Difficult Terrain in Turkey presented by Metin Tunay
    - Gantner Skyline for Timber Extraction in Turkish Forestry presented by Mehmet Eker
    - Cable Logging Opportunities in the Eastern USA presented by Rien Visser
    - Helicopter logging in the Slovak Republic by Valeria Messingerova
    - Forest Machine CD-Rom presented by Wilfried Pröll
    - Winch Uses in Work with Extra Light Cable System in Centre South of Italy presented by Paolo Calvani
    - Timber Extraction Technologies in Croatian Mountainous Selection Forests presented by Marijan Susnjak
Timber Production Is Changing - Demands and Chances in Austria presented by Hubert Dürrstein

Efficiency Problems in Harvesting Small-Dimensional Wood presented by Paul N. Efthymiou

USE OF CABLE SYSTEMS FOR SUSTAINABLE FOREST MANAGEMENT (Agenda Item 6): Requirements of roads for the use of cable systems; use of cable systems in combination with other extraction machines, and cable systems in combination with wood processors.

11. Peter Schiess opened Agenda Item 6. The following papers were presented:

Production of Fuel Chips from Logging Residue at Cable Landings by Raffaele Spinelli

Relation between Forest Roads and Extraction Machines in Sustainable Forest Management presented by Tibor Pentek

Cable Crane Utilisation in the Close-to-Nature Silviculture in the Upper Piave River Valley (Belluno Province, Northern Italy) presented by Raffaele Cavalli

Implementation of the Cable Logging Requirements in Environmentally Sound Road Construction presented by Robert Robek

Characteristics of the Cable Yarding System Application in the Ukrainian Carpathians presented by Sergiy Zibtsev

12. Rien Vissser continued with Agenda Item 6 and the following papers were presented:

Current Trends in Cableway System in the UK presented by Colin J. Saunders

Is There a Role for Cable Extraction on Low Gradient Sensitive Sites? presented by Philip M. Owende

Road Management Strategies to Reduce Habitat Impacts - A Case for Engineered Cable Yarding Operations and Harvest Schedules presented by Peter Schiess

Approaches to the Design of Forest Cable Systems by Hans Rudolf Heinimann

Optimization of Cable Harvesting Equipment Placement and Road Locations Using Digital Terrain Models presented by Woodam Chung

New Algorithms for Solving Large Scale Harvesting and Transportation Problems Including Environmental Constraints presented by Woodam Chung for John Sessions

Wood Harvesting and Sustainable Forest Management in Morocco presented by Mohammed Ellatifi

Communal Forest Management in Chiquiacá-Bolivia presented by Gabriela Gutiérrez Pérez

Forestry Operations in Cajamarca, Peru presented by Luis A. Novoa Robles

Presentation of the Austrian Federal Forests Joint Stock Company and the Millstatt Enterprise by Günther Tragatschnig

13. An excursion was made to the Austrian Federal Forests Enterprise, Millstatt, with Günther Tragatschnig to see a demonstration of cable machinery developed and produced by the Enterprise. (See Annex 2.)

USE OF CABLE SYSTEMS AND NORMS FOR WORK SAFETY (Agenda Item 7): Safety and health in cable crane operations; accident prevention, training and extension in cable crane operations.

14. Hans Rudolf Heinimann introduced Agenda Item 7. The following papers were presented:
The Use of Cable Cranes in South Tyrol in the Light of Recent Legislation presented by Claudio Pollini

Productivity Improvement in Cable Harvesting from Human Resources presented by John Garland

Occupational Safety and Health of Forestry Workers of Cable Harvesting in Turkey presented by Seca Gandaseca

USE OF CONTRACTORS IN CABLE CRANE OPERATIONS (Agenda Item 8): Business contracts; work organization; work control and post harvesting assessment

15. Hans Rudolf Heinimann introduced Agenda Item 8. The following papers were presented:

Employment of Contractors in Cable Crane Operations in Austria presented by Hubertus Fladl

Development of Mechanised Logging presented by Johannes Loschek

View of the Contractor for Forest Companies presented by Anton Streif

Natural Forest Protection Programme and Timber Supply and Demand in China by Shouxin Xie

OTHER MATTERS (Agenda Item 9)

16. No other matters

CONCLUSIONS AND RECOMMENDATIONS (Agenda Item 10)

Conclusions

a) The Workshop agreed that cable systems in combination with a suitable road network are an environmentally friendly technology supporting sustainable forest management in mountainous terrain. Cable systems are key to extraction of wood from steep sites and other sensitive areas that are unsuitable for ground-based systems.

b) The meeting concluded that there are a broad variety of cable harvesting technologies and systems suitable for both developed and developing countries.

c) It was considered important that appropriate technologies and related training in cable systems should be offered to developing countries.

d) It is important that the reported performance of cable harvesting systems is comparable. Some standardized data items are desirable.

e) While cable harvesting may be more complex and expensive than some other harvesting systems, it is a viable solution to harvesting steep and difficult terrain as a means of sustainable forest management and social development.

f) There is a need for more studies on newly developed cable systems in mountainous terrain. The factors to consider in these studies include: costs, productivity, soil and water, occupational health and safety.

g) This Workshop was found interesting and useful and there should be further meetings organized on the use of cable and other harvesting and transport systems on difficult terrain conditions and low bearing capacity sites.
Recommendations

To the Joint Committee

a) There is a continuous need for technical developments and the associated information exchange/training in the area of cable harvesting. Cooperation among scientists, managers, practitioners, contractors and workers is especially necessary for cable harvesting. There is a need to also consider low-tech extraction systems for future workshops.

b) Support regional demonstration workshops on cable logging to introduce it to countries in transition and to developing countries. Create private-public partnerships between donor countries, suppliers of machinery and users in countries of need.

c) More work should be done within the framework of the Joint Committee towards improvements in wood harvesting operationally combined with new developments and interactions in technology, information, employment needs, sustainability, multiple use, certification, biodiversity and land use conflicts.

To Member Countries

a) Scarce resources and human expertise in the area of cable harvesting within individual countries make regional and international cooperation essential. Centres of excellence in cable harvesting should be identified and supported as national priorities and international agreements.

b) Review legal provisions for harvesting on steep slopes. Restrictions for steep slope extraction may be adjusted to enable low impact harvesting technologies.

c) Forestry administrations and services of the Member Countries should study the reform of the Austrian (ÖBF) Federal State Forests as an example of a modern, efficient and successful transformation of a state forestry administration.

d) Since site conditions are diverse and subject to varying levels of technical, economic and social constraints, each country/region needs to define suitable options in tree harvesting and extraction.

e) Issues of personal safety must be adequately addressed.

To Forest Research Institutes and IUFRO

a) There appears to be a need for improved methodologies in the statistical treatments within research projects and methodologies of analysing tensions and loads of cableways. Information exchange among scientists on these topics would be mutually beneficial for the field of cable harvesting.

b) Carry out research on cable logging for small-size timber in mountainous terrain.

c) Forest research institutions should strengthen their research activities in designing new harvesting systems with an integrated systems approach with a holistic study of the respective production chains from the stump to the final end-use products.

d) It is important to strengthen the networking of research groups in this area.

ADOPTION OF THE REPORT (Agenda Item 11)

17. The draft report, prepared by the Secretariat, and the conclusions and recommendations were adopted.

18. For the host country, Rudolf Heinrich thanked the participants for attending the Workshop, preparing papers and posters, for the lively discussions during the different sessions and for the conclusions and recommendations. Finally, Paul N. Efthymiou, on behalf of the Joint Committee, and Joachim Lorbach, on behalf of FAO, thanked the participants, the host country
and all support staff for their active contribution to the successful outcome of the seminar. Participants were presented with Certificates of Attendance.

19. An excursion was made to the Bistum Gurk Forest Enterprise with Joachim Gfreiner who made a presentation on the use of tracked harvester and cable systems. (See Annex 3.)

20. A final excursion was made to Klagenfurt and Hochosterwitz Castle.
### List of Participants

**Austria**

- **Mr Roman Andersag**  
  Gantner Seilbahnbau GmbH  
  Industriestraße 8  
  A-6832 Sülz  
  Tel. (39) 0650913788/Fax 0650918101  
  E-mail: roman.andersag@bmlf.gv.at

- **Mr Thomas Baschney**  
  Forest Engineer  
  Forestry Department, Min. of Forestry, Water Management and Environment  
  Marxergasse 2  
  A 1030 Vienna  
  Tel. (43)171100/Fax 171100  
  E-mail: thomas.baschney@bmlf.gv.at

- **Mr Othmar David**  
  Manager  
  KOLLER GmbH  
  Kollerareal 5  
  A 6330 Kufstein  
  Tel. (43)537263257/Fax (43)5372  639237  
  E-mail: koller.GmbH@aon.at

- **Mr Hubert Dürrstein**  
  Professor  
  University of Agricultural Sciences  
  Peter Jordan Str. 70/2  
  A 1190 Vienna  
  Tel. (43)147654-4301/Fax (43)47654-4342  
  E-mail: huderrst@edvl.boku.ac.at

- **Mr Hubertus Fladl**  
  Amt der Stmk. Landesregierung  
  Abt. Forstwesen  
  Brückenköpfgasse 6  
  8020 Graz  
  Tel./Fax (43) 316877-0/(43) 316877-4520  
  E-mail: post@faw.stmk.gv.at

- **Mr Hubert Konrad jun.**  
  Konrad Forsttechnik GmbH  
  A-9451 Preitenegg  
  Tel. (43) 43542432-0  
  Fax. (43) 43542354  
  E-mail: office@forsttechnik.at

- **Ms Margarethe Klammer**  
  Secretary  
  Forstliche Ausbildungsstätte Ossiach  
  A-9570 Ossiach, Kärnten, Austria  
  Tel. (04234) 2245-0, Fax (04234) 2245-55  
  E-mail: direktion@fastoss.bmlf.gv.at

- **Mr Mathias Hoesch**  
  Mechanical Engineer  
  Wolfsystembau GmbH  
  Fischerbuehel 1  
  A 4644 Scharnstein  
  Tel. (43) 7615300168/Fax 7615300310  
  E-mail: walter.huettner@wolfsystem.at

- **Mr Rudolf Heinrich**  
  Forestry Projects  
  Austrian Embassy  
  Via Gorgia di Leontini 260  
  10024 Rome  
  Italy  
  Tel. (39) 0650913788/Fax 0650918101  
  E-mail: rudolf.heinrich@tin.it

- **Mr Reinhold Hinteregger**  
  Skyline Logging Systems  
  Udinestrasse 13  
  9500 Villach  
  Tel. (39) 0650913788/Fax 0650918101  
  E-mail: rudolf.heinrich@tin.it

- **Mr Walter Huber**  
  FAST-Ossiach  
  A9570 Ossiach Nr. 21  
  Tel. (39) 0650913788/Fax 0650918101  
  E-mail: rudolf.heinrich@tin.it

- **Mr Richard Konrad jun.**  
  Konrad Forsttechnik GmbH  
  A-9451 Preitenegg  
  Tel. (43) 43542432-0  
  Fax. (43) 43542354  
  E-mail: office@forsttechnik.at

- **Mr Vitali Kondratenko**  
  Wolfsystembau GmbH  
  Fischerbuehel 1  
  A 4644 Scharnstein  
  Tel. (43) 7615300178/Fax 7615300311  
  E-mail: vitali.kondratenko@wolfsystem.at
Mr Adolf Kummer
FAST-Ossiach
A-9570 Ossiach Nr. 21

Mr Ernst Hans Lackinger
Bistum Gurk
Pöckstein 1
A-9330 Althofen

Mr Heinz Lenzhofer
ÖBF AG Forstbetrieb Millstatt
Stiftgasse 1
A-9872 Millstatt

Mr Johannes Loschek
Forstbetrieb Franz Mayr-Melnhof-Saurau
Mayr-Melnhof-Strasse 14
A 8130 Frohnleiten
Tel. (43)3126509015/Fax 3126509018
E-mail:j.loschek@mm-forst.at

Mr Gerhard Mannsberger
Director General
Forestry Department, Ministry of Forestry,
Water Management and Environment
Marxergasse 2
A 1030 Vienna
Tel. (43)171100-7301/Fax 171100-7399
E-mail: gerhard.mannsberger@bmlf.gv.at

Ms Elizabeth Maxwald
Maschinen GmbH & CoKG
Irresbergstrasse 2
A-4694 Olsdorfer
Tel. (43)7612 472190
Fax. (43)7612 472199
Homepage: www.maxwald.com

Mr Martin Noebauer
Forest Engineer
Amt der Noe Landesregierung Abt. LF4 -
Forstwirtschaft,
Landhausplatz 1, Haus 12
A 3109 St. Poelen
Tel. (43) 27429025-13102
Fax (43) 27429025-13620
E-mail: martin.noebauer@noel.gv.at

Mr Reinhard Pacher
Obf St. Johann
Fischerbuehel 1
A 4644 Scharnstein
Tel. (43)7615300168/Fax 7615 300310
E-mail: walter.huettner@wolfsystem.at

Mr Wilfried Proell
FBVA-Mariabrunn
Hauptstrasse 7
A-1140 Vienna
Tel. (43) 187838-2230/Fax 187838-2250
E-mail: wilfried.proell@FBVA.BMLF.gv.at

Mr Hermann Redl
Hernalser Gürtel 24/15
A 1090 Vienna
Tel. (43) 4081311

Mr Hermann Schmiderer
OBf AG
Marxergasse 2
A 1030 Vienna
Tel. (43) 6645451066
E-mail: h.schmiderer@oebf.at

Mr Heinrich Schmutzenhofer
Executive Secretary
IUFRO
IUFRO Secretariat
A 1131 Vienna
Tel. (43)18770151-12/Fax (43)18779355
E-mail: hschmutz@forvie.ac.at

Ms Carmen Seebacher
Secretary
Forstliche Ausbildungsstätte Ossiach
A-9570 Ossiach, Kärnten, Austria
Tel. (04234) 2245-0, Fax (04234) 2245-55
E-mail: direktion@fastoss.bmlf.gv.at

Mr. Günter Sonnleitner
Director
Forstliche Ausbildungsstätte Ossiach
A-9570 Ossiach, Kärnten, Austria
Tel. (04234) 2245-0, Fax (04234) 2245-55
E-mail: direktion@fastoss.bmlf.gv.at

Mr. Josef N. Stampfer
Förster, Fachlehrer
Forstliche Ausbildungsstätte Ossiach
A-9570 Ossiach, Kärnten, Austria
Tel. (04234) 2245-0, Fax (04234) 2245-55
E-mail: direktion@fastoss.bmlf.gv.at

Mr Karl Stampfer
Director
University of Agricultural Sciences
Peter Jorden Strasse 70/2
A 1190 Vienna
Tel. (43)147654-4342
E-mail: stampfer@mail.boku.ac.at

Mr Thomas Stemberger
Head of Department
Preseidentenkonferenz der
Landwirtschaftskammern
Österreichs, Löwelstraße 16
A 1014 Vienna
Tel.(43)153441-8591/Fax 153441-8529
E-mail: pkforst@pklwk.at

Mr Anton Streif
Forstunternehmung
A-4984 Weilbach 20
Tel. (43) 07757-6788/Fax (43)
E-mail: anton@streif.at
Mr Heinz Stuefer  
Maschinen-u. Forsttechnik GmbH  
Zellerstrasse 19  
A-6330 Kufstein  
Tel. (43) 537263682  
Fax. (43) 537262610

Mr Günter Tragatschnig  
DI Director  
Forstbetrieb Millstatt  
Stiftgasse 1  
9872 Millstatt  
Tel. (04766) 2014/Fax (04766) 2014-4  
e-mail: g.tragatschnig@oebf.at

Mr Johann Tröstl jun.  
Mobile Seilkran systeme  
A-3184 Fünritz  
Tel. (43) 2769

Mr Johann Zöscher  
DI, Fachlehrer  
Forstliche Ausbildungsstätte Ossiach  
A-9570 Ossiach, Kärnten, Austria  
Tel. (04234) 2245-0, Fax (04243) 2245-55  
E-mail: direktion@fastoss.bmlf.gv.at

Bolivia  
Ms Gabriela Gutiérrez Pérez  
Forest Manager  
PROMETA  
Tarija Alejandro del Carpio  
659 Tarija  
Tel. (591) 66 45865/Fax (591) 66 33873  
E-mail: freddy@olivo.tja.entelnet.bo

P.R. China  
Mr Shouxin Xie  
Deputy Division Director  
Department of Forest Resources  
State Forestry Administration  
No. 18, Dong Street  
Hepingli  
Beijing 100714  
Tel. (86) 1084238407/Fax.1084238495  
E-mail: xieshouxin@forestry.gov.cn

Croacia  
Mr Tibor Pentek  
University Assistant  
Forestry Faculty Zagreb  
Svetosimun ska 25  
10 000 Zagreb  
Tel. (385) 12352-417/Fax (385) 12352-517  
E-mail: pentek@hrast.sumfak.hr

Mr Tomislav Porsinsky  
University Assistant  
Forestry Faculty Zagreb  
Svetosimun ska 25  
10 000 Zagreb  
Tel. (385) 12352-417/Fax (385) 12352-517  
E-mail: tomislav.porsinsky@zg.hinet.hr

Czech Republic  
Mr Roman Hlousek  
Operator  
Krtiny Forest Training Enterprise  
Skolní lesní podnik, Masarykuv les  
679 05 Krtiny 175  
Tel. (420) 506439390/Fax 506439339  
E-mail: vyzkum@slpkrtiny.cz

Mr Premysl Horek  
Research Worker  
Krtiny Forest Training Enterprise  
Skolní lesní podnik, Masarykuv les  
679 05 Krtiny 175  
Tel. (420) 506439390/Fax 506439339  
E-mail: vyzkum@slpkrtiny.cz

Mr Pavel Mauer  
Krtiny Forest Training Enterprise  
Skolní lesní podnik, Masarykuv les  
679 05 Krtiny 175  
Tel. (420) 506439390/Fax 506439339  
E-mail: vyzkum@slpkrtiny.cz

Equatorial Guinea  
Mr André N. Ndong Angue  
Senior Forest Engineer  
Regional Service for Forestry, Fisheries and Environment  
Apdo. 207, BATA-Litoral  
Tel./Fax (240) 8 3338  
E-mail: inapat@intnet.gq

France  
Mr Jean-Luc Chagnon  
Forest Research Manager  
CTBA  
10, Avenue de St Maudé  
75012 Paris  
Tel. (33) 140194882/Fax (33) 144746521  
E-mail: didier.pischedda@ctba.fr

Germany  
Mr Gerhard Rieger  
Director of Forests  
KWF Forstamt Schopfheim  
Spremberger Str. 1, D-64823  
Gross-Umstadt  
Tel. (49) 607878513/Fax (49) 607878550  
E-mail: fb1@kwf-online.de
Mr Walter Warkotsch  
Professor  
Lehrstuhl für Forstliche Arbeitswissenschaft und Angewandte Informatik  
Am Hochanger 13  
85354 Freising  
Tel. (49) 8161714760/Fax(49) 81617147767  
E-mail: warkotsch@forst.tu

Greece  
Mr Paul N. Efthymiou  
Prof. Forest Utilization  
Aristotle University of Thessaloniki  
PO Box 227  
GR 54006 Thessaloniki  
Tel. (30) 31 998 873/Fax (30) 31 998 946  
E-mail: penefthy@for.auth.gr

Ireland  
Mr Dan O'Sullivan  
Production Manager  
Coillte Teo  
Government Buildings, Sullivans Quay  
Cork  
Tel. (353) 2242695/Fax (353) 2221336  
E-mail: donieosullivan@oceanfree.net

Mr Philip M. Owende  
Senior Research Fellow  
Forest Engineering Unit  
University College Dublin  
Earlsfort Terrace, Dublin 2  
Tel. (353) 17167346/Fax (353) 14752119  
E-mail: philip.owende@ucd.ie

Mr Dermot Tiernan  
Research Forest Manager  
ECOWOOD Project, Coillte Teoranta  
Davitt House, Castlebar, Co. Mayo  
Tel. (353) 9421255/Fax (353) 9421480  
E-mail: dermot.tiernan@coillte.ie

Italy  
Mr Sanzio Baldini  
Professor  
Università degli Studi della Tuscia  
Via San Camillo de Lellis  
01100 Viterbo  
Tel. (39) 761357403/Fax (39) 761357403  
E-mail: baldini@unitus.it

Mr Paolo Calvani  
Università degli Studi della Tuscia  
Via San Camillo de Lellis  
01100 Viterbo  
Tel. (39) 761357403/Fax (39) 761357403  
E-mail: baldini@unitus.it

Mr Raffaele Cavalli  
Professor  
Dip. Territorio e sistemi agro-forestali  
University of Padova, Agripolis  
35020 Legnaro PD

Tel. (39) 049 8272724/Fax 049 8272774  
E-mail: cavalli@ux1.unipd.it

Mr Piergiorgio Fabbri  
Researcher  
CNR-IRL  
Via Barazzuoli 23  
Florence  
Tel. (39) 055 661886/Fax (39) 055 670624  
E-mail: spinelli@irl.fri.cnr.it

Mr Michael Lantschner  
Seik KG  
Zona Artigionale S. Lugano  
I-39040 Trodena (BZ)  
Ms Carla Nati  
Researcher  
CNR-IRL  
Via Barazzuoli 23  
Florence  
Tel. (39) 055 661886/Fax (39) 055 670624  
E-mail: spinelli@irl.fri.cnr.it

Mr Rodolfo Picchio  
Universita degli Studi della Tuscia  
Via San Camillo de Lellis  
01100 Viterbo  
Tel. (39) 761357403/Fax (39) 761357403  
E-mail: baldini@unitus.it

Mr Claudio Pollini  
Researcher  
Wood Technology Institute  
Via Biasi 75, San Michele Adige  
38010 Trento  
Tel. (39) 0461 660206/Fax 0461 650045  
E-mail: pollini@tn.cnr.it

Mr Josef Schmiedhofer  
Director  
Autonome Provinz Bozen  
Landesbetrieb für Forst und Domaenverwaltung  
Bolzano  
Tel. (39) 0471 270835/Fax 0471 279089  
E-mail: Josef.Schmiedhofer@provinz.bz.it
Mr Raffaele Spinelli
Researcher
CNR-IRL
Via Barazzuoli 23, Florence
Tel. (39) 055 661886/Fax (39) 055 670624
E-mail: spinelli@mailbox.irl.fi.cnr.it

Japan
Mr Seca Gandaseca
Graduate School of Informatics
Kyoto University, Kyoto 606-8501
Tel. (81) 757533131/Fax (81) 757533132
E-mail: seca@bre.soc.i.kyoto-u.ac.jp

Morocco
Mr Dr. Mohammed Ellatifi
Senior Forestry Officer
Forestry Department
PO Box 20100 - Hay Salam
Casablanca
Tel. /Fax (212) 22 982428
E-mail: m.ellatif@mailto.city.com

Netherlands
Mr Frits Staudt
Director, Tropical Forestry
Wageningen University
POB 342, NL 6700 AH
Wageningen
Tel. (31) 317478015/Fax (31) 317478078
E-mail: frits.staudt@alg.bosb.wau.nl

Peru
Mr Luis I. Novoa Espinoza
ADEFOR
Carretera al Aeropuerto Km 3, Pundo Tartar
Cajamarca
Tel. (51) 044 821369/Fax (51) 044 823097
E-mail: ramaovi@ec-red.com

Russia
Mr Vladimir Firsov
Vice General Director
TsNIIME
21, Moscovskaya str., Khimki
Moscow 141400
Tel. (095) 5727517/Fax (095) 5727517

Mr Evgueni Mironov
Head Research Worker
TsNIIME
21, Moscovskaya str., Khimki, 141400
Moscow region
Tel. (095) 572 7517/Fax (095) 572 7517

Slovakia
Ms Valeria Messingerova
Professor
Technical University, Faculty of Forestry
T.G. Masaryka 24
960 53 Zvolen
Tel. (421) 8555206 308/Fax 8555332 654
E-mail: messin@vsld.tuzvo.sk

Slovenia
Mr Jurij Begus
Slovenia Forest Service
Vecna Pot 2 p.p. 71
Tel. (386) 41730177/Fax
E-mail: jurij.begus@gov.si

Mr Jan Tucek
Associate Professor
Technical University, Faculty of Forestry
T.G. Masaryka 24
960 53 Zvolen
Tel. (421) 8555206 308/Fax 8555332 654
E-mail: tucek@vsld.tuzvo.sk

Mr Samuel Zubo
Student
Technical University, Faculty of Forestry
T.G. Masaryka 24
960 53 Zvolen
Tel. (424) 8558206 279/Fax 8555206 699
E-mail: lukact@vsld.tuzvo.sk

Mr Valeri Soukhanov
Deputy Director General
State Scientific Centre of Timber Ind.
N. Syromjatnicheskaya Str., Bld. 5
Moscow 107120
Tel. (007) 095 917 1220/Fax (007) 095 917 1220
E-mail: gcvcnk@gnclpk.ru

Mr Dmitry Mojaev
Department Chief
TsNIIME
21, Moscovskaya str., Khimki, 141400
Moscow region
Tel. (095) 572 7517/Fax (095) 572 7517

Mr Raul Oblitas
ADEFOR
Carretera al Aeropuerto Km 3, Pundo Tartar
Cajamarca
Tel. (51) 044 821369/Fax (51) 044 823097
E-mail: ramaovi@ec-red.com

Mr Boštjan Košir
Docent
University of Ljubljana
Becca pot 83
1000 Lubljana
Tel. (386) 14232 161
E-mail: bostjan.kosir@uni-lj.si
Mr Robert Robek  
Project Leader  
Slovenian Forestry Institute  
Vecna pot 2  
1000 Ljubljana  
Tel. (386) 12007800/Fax (386) 12573589  
E-mail: robert.robek@gozdis.si

Sri Lanka  
Mr Bernhard Mohns  
Project Counterpart  
GTZ-Estate Forest and Water Resources Development Project  
POBox 98  
Kandy  
Tel. (94) 8228653/Fax (94) 8228652  
gefwrdp@sitnet.lk

Mr Upanada Vidanapathirana  
Director Planning  
Ministry of Plantation Industries  
55/75, Vauxhall Lane  
Colombo 2  
Tel.(94) 1304130/Fax (94) 1342010

Switzerland  
Mr Hans Rudolf Heinimann  
Professor, Forest Engineering  
ETH-Zentrum HG G 23  
CH-8092 Zurich  
Tel. (41) 1632 3235/Fax (41) 1632 1146  
E-mail: heinimann@fowi.ethz.ch

Turkey  
Mr Hulusi Acar  
Associate Professor  
Black Sea Technical University  
Faculty of Forest, Forest Engineering Dept.  
61080 Trabzon  
Tel. (90) 462377 2817/Fax 462325 7499  
E-mail: hlsacar@ktu.edu.tr

Mr Mehmet Eker  
Black Sea Technical University  
Faculty of Forestry  
Forest Engineering Department  
61080 Trabzon  
Tel. /Fax  
E-mail: meker@ktu.edu.tr

Mr Tolga Ozturk  
Istanbul University  
Faculty of Forestry, Forest Engineering Dept.  
80895 Istanbul  
Tel. 0.090.212.226 11 00 (10)  
Fax.0.090.212 226 11 13  
E-mail: tozturk@istanbul.edu.tr

Mr Metin Tunay  
Professor, Bartin Orman Fakultesi  
74100 Bartin  
Tel./Fax  
E-mail: mtunay74@ttt.net.tr

Mr Robert Robek  
Project Leader  
Slovenian Forestry Institute  
Vecna pot 2  
1000 Ljubljana  
Tel. (386) 12007800/Fax (386) 12573589  
E-mail: robert.robek@gozdis.si

Mr Robert Robek  
Project Leader  
Slovenian Forestry Institute  
Vecna pot 2  
1000 Ljubljana  
Tel. (386) 12007800/Fax (386) 12573589  
E-mail: robert.robek@gozdis.si

United Kingdom  
Mr Malcolm MacLean  
Training Officer  
Forest Operation Training Centre  
Ae Village, Parkgate  
Dumfries DG1 1QB  
Tel. (44) 1387 860271/Fax 1387 860366  
malcolm.maclean@forestry.gsi.gov.uk

Mr Colin J. Saunders  
Technical Development  
Forestry Commission  
AE Village, Parkgate  
Dumfries DG1 4HN  
Tel. (44) 1387 860264/Fax 1387 860386  
E-mail: colin.saunders@forestry.gsi.gov.uk

Ukraine  
Mr Anatoliy Sabadyr  
Head, Technical Politics  
Forestry Committee of Ukraine  
Kreshchatik 5, 252601  
Kiev 1  
Tel. (380) 44 2285998/Fax 44 2287794  
E-mail: yyy@mlg.kiev.ua

Mr Sergiy Zibtsev  
Senior Lecturer  
Ukraine National Agricultural University  
Dept. of Silviculture  
Geroiv Oborony str. 15  
Kiev 030  
Tel. (380) 44 553 72 48/Fax 44 553 72 48  
E-mail: zibtsev@info.kiev.ua

United States of America  
Mr Woodam Chung  
College of Forestry  
Oregon State University  
Corvallis  
OR 97331-5706  
Tel. (1) 541 737 4952/Fax 541 737 4316  
E-mail: Woodam.Chung@orst.edu

Mr John Garland  
Prof. Forest Engineering  
Oregon State University  
Corvallis  
OR 97331-5706  
Tel. (1) 541 737 3128/Fax 541 737 4316  
E-mail: John.Garland@orst.edu

Mr Peter Schiess  
McMc Resources  
University of Washington  
Box 352100  
Seattle, WA 98195-2100  
Tel. (1) 206 543 1583/Fax 206 685 3091  
E-mail: schiess@u.washington.edu
Mr Rien Visser  
Assistant Professor  
Virginia Tech Forestry Department  
228 Cheatham Hall, Blacksburg  
VA 24061  
Tel. (1) 540 231 6924/Fax 540 231 3330  
E-mail: rvisser@vt.edu

Mr Don Nearhood  
Consultant  
FAO Forestry Department  
Via delle Terme di Caracalla  
00100 Rome  
Italy  
Tel. (39) 06 57053642/Fax 06 57055137  
E-mail: don.nearhood@fao.org

Mr Joachim Lorbach  
Officer-in-Charge  
Forest Harvesting, Trade and Marketing Branch  
FAO Forestry Department  
Via delle Terme di Caracalla  
00100 Rome  
Italy  
Tel. (39) 06 57052596/Fax 06 57055137  
E-mail: joachim.lorbach@fao.org

Ms Gina Phillips  
Secretary  
FAO Forestry Department  
Via delle Terme di Caracalla  
00100 Rome  
Italy  
Tel. (39) 06 57052798/Fax 06 57055137  
E-mail: gina.phillips@fao.org
IS THERE A ROLE FOR CABLE EXTRACTION ON LOW GRADIENT SENSITIVE SITES?

Philip M. O. Owende†, Dermot Tiernan‡, Shane M. Ward† and John Lyons‡
†Forest Engineering Unit, Department of Agricultural and Food Engineering, University College Dublin, Earlsfort Terrace, Dublin 2, Ireland.
Tel.: (+353 1) 716 7346; Fax: (+353 1) 475 2119;
email: foresteng@ucd.ie; URL: www.ucd.ie/~foresteng
‡Irish Forestry Board (Coillte), Sullivan's Quay, Cork, Ireland.

Abstract
This paper discusses the challenges to extraction of wood on low gradient harvesting sites that are classified as ‘sensitive’ and therefore have limitations on the use of forwarders and skidders for ground-based wood extraction. Although the discussion is centred on plantation forests on peat soils in Ireland, the same may be generalised for forests on other soft soils that restrict the environmentally use of forwarders and skidders. Wood extraction by cable systems is important for sustainable harvesting operations on such sites.

Background
Ireland’s forest area comprises approximately 9% (626,000 ha) of the total land area (Forest Service 2000). The Irish Forestry Board (Coillte) manages 70% (450,000 ha) of the forest area, of which about 80% is under commercial timber crop. The main commercial tree species include Sitka spruce, Lodgepole pine, Norway Spruce, Larch, Scots pine and Douglas fir, and these are established on five major soil categories, with 44% on peat soils (Figure 1).

Cut-to-length (CTL) forest-harvesting technique is predominantly used in wood harvesting, and involves the use of CTL harvesters, and chainsaw felling and bucking (motor-manual tree harvesting), with both employing various configurations of purpose built forwarders and tractor trailer systems for moving timber within the forest. This paper gives an overview of the challenges that are encountered in the use of forwarders for wood extraction on forest sites that are located on soft soils. It is an initiative for assessment of the feasibility of cable systems, and for collation of technical information and experiences with new trends in wood harvesting with cable systems that could be adopted for extraction on soft peat soils in Ireland and elsewhere.

Figure 1. Total area by tree species in hectares (a) and principal soil types (b) in Coillte’s forest estate

Challenges to wood harvesting on sensitive forest sites

Terrain classification is based on three factors, namely (Table 1): the ground condition (principally soil bearing capacity); ground roughness (includes obstacles such as boulders and trenches), and; ground slope. Wood extraction operations that are best suited to a harvesting site are broadly assigned based on this classification (Table 2), in order to minimise damage to the sites (and the residual stands in case of thinning) including safety consideration for the harvesting machines and the operators. Integration of machine suitability to respective harvesting site conditions is crucial when dealing with ‘sensitive sites’. A sensitive forest site is where alterations to the normal mechanised harvesting practices are required in order to avoid adverse effects on ecological, economic and social functions of the forest and its surroundings (ECOWOOD, 2001).

Table 1. Typical terrain classification scoring

<table>
<thead>
<tr>
<th>Ground condition</th>
<th>Ground roughness</th>
<th>Slope</th>
</tr>
</thead>
<tbody>
<tr>
<td>Good (1)</td>
<td>Even (1)</td>
<td>Gentle, &lt; 8° (1)</td>
</tr>
<tr>
<td>Average (2)</td>
<td>Uneven (2)</td>
<td>Intermediate, 8° – 14° (2)</td>
</tr>
<tr>
<td>Poor (3)</td>
<td>Rough (3)</td>
<td>Steep, 14° &gt; (3)</td>
</tr>
<tr>
<td>Very poor (4)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 2 suggests that ground roughness and slopes are the dominant criteria for decision on employment of cable systems for wood extraction. For example, terrain classes 4.1.1 and 4.2.1 are in the worst ground condition, i.e., very poor, they are suggested as suitable for wood extraction by tracked forwarders. Classes 4.1.2, 4.2.2 and 4.3.1 suggest the potential use of both forwarders and cable systems.

Table 2. Machines operations most suited to each site

<table>
<thead>
<tr>
<th>1.1.1</th>
<th>2.1.1</th>
<th>3.1.1</th>
<th>4.1.1</th>
</tr>
</thead>
</table>
| Forwarder, Skidder, Horse | Forwarder, Skidder, Horse | Forwarder, Tracked Forwarder, Cable | Tracked Forwarder, Cable (?)
| 1.1.2 | 2.1.2 | 3.1.2 | 4.1.2 |
| Forwarder, Skidder, Horse | Forwarder, Tracked Forwarder, Cable | Forwarder, Tracked Forwarder, Cable | |
| 1.1.3 | 2.1.3 | 3.1.3 | 4.1.3 |
| Forwarder, Skidder, Horse | Forwarder, Tracked Forwarder, Cable | Tracked Forwarder, Cable | |
| 1.2.1 | 2.2.1 | 3.2.1 | 4.2.1 |
| Forwarder, Skidder, Horse | Forwarder, Skidder, Horse | Tracked Forwarder, Cable | Tracked Forwarder, Cable (?)
| 1.2.2 | 2.2.2 | 3.2.2 | 4.2.2 |
| Forwarder, Horse | Forwarder, Horse | Tracked Forwarder, Cable | |
| 1.2.3 | 2.2.3 | 3.2.3 | 4.2.3 |
| Forwarder, Tracked Forwarder | Forwarder, Tracked Forwarder, Cable | Tracked Forwarder, Cable | |
| 1.3.1 | 2.3.1 | 3.3.1 | 4.3.1 |
| Forwarder, Cable | Forwarder, Cable | Tracked Forwarder, Cable | |
| 1.3.2 | 2.3.2 | 3.3.2 | 4.3.2 |
| Forwarder, Cable | Forwarder, Tracked Forwarder, Cable | Tracked Forwarder, Cable | |
| 1.3.3 | 2.3.3 | 3.3.3 | 4.3.3 |
| Forwarder, Tracked Forwarder, Cable | Tracked Forwarder, Cable | |

Peatlands and other wood harvesting sites with soft soils present unique challenges to flotation and mobility of the CTL harvesters and forwarders; hence, the efficiency in their use. Wood harvesting in deep peat conditions is commonly clear felling, and quite often premature felling, i.e., harvesting of forest before the normal age and tree size is reached in order to forestall losses and costly salvage harvesting of wind-felled trees (Buswell, 1992). Currently, the approach applied to the harvesting of such sites in Ireland, is to lay a brashmat ahead of harvesting machinery traffic. However, machine mobility is still a major constraint and CTL
harvester and forwarders must be fitted with wide tyres, dual wheels, and band-tracks or specially adapted moccasins (Daly, 1998) to complement the use of a brashmat in order to avoid excessive machine sinkage (Figure 2). Reducing the payload on forwarders, with a multiple load-handling regime may also be considered. Excessive machine sinkage has direct bearing to the cost of machine operations, and may lead to excessive site disturbance and soil damage (Figure 3). The latter may have significant effects on soil structure and runoff characteristics, with potential negative affects on the yield of the residual stands for thinning operations, and increased potential soil erodibility (Figure 4). For these reasons, the harvesting areas on peat soils may be classified as ‘sensitive’.

Tree roots are known to stabilise soil and enhance the load bearing capacity and shear resistance of the forest floor. Wästerland (1989) estimated the incremental soil-reinforcement due to the presence of tree roots to be in the range of 50 to 70%. In areas with peat soils, this reinforcement factor (from the inherent vegetation layer as well as tree roots) is the determinant of mobility of the forestry machines, as the soils deform easily to develop deep ruts with poor support for machine traction. It also determines the potential damage to the residual stands, during the primary and/or subsequent thinning operations, and may dictate the need for alternative wood extraction systems such as the cable.

Machine mobility on forest sites with soft soils may be a limiting factor when tree growth in such areas has low yield of branches (e.g., in prematurely felled areas) that could be used as brashmat to enhance trafficability during timber harvesting and forwarding (Daly, 1989). The soil reinforcement by root networks may therefore influence the selection and operation of mechanical harvesting and extraction systems for ecoefficient wood harvesting of such ‘sensitive’ sites. However, soil reinforcement by root networks diminishes with increasing number of vehicle passes (Cofie et al., 2000). In deep peat and other soft soils where this reinforcement is the only supporting medium, the brashmat on the extraction racks may degrade rapidly with machine successive passes to stall the timber extraction process altogether (Figure 3). The trend in wood harvesting on sensitive sites is towards full mechanisation of the harvesting process due to reducing number of chainsaw operators, and such sensitive sites are getting exposed to increasing machinery traffic. However, due to the growing environmental concerns, there is need to reassess the site suitability (technical and economic) of cable extraction systems as a means of minimising soil disturbance which may generate secondary environmental concerns, i.e., soil compaction and erosion.

Figure 2. Illustration of typical challenges to harvester mobility and site impacts on soft soil harvesting sites.
Figure 3. Challenges to forwarding operation on sensitive forest sites.
Effective application of cable systems in wood harvesting on sensitive low gradient forest sites

Cable extraction system is less sensitive to ground condition and weather related machine productivity impedance factors that are depicted in Figure 2 through Figure 4. Due to its minimal requirement for extraction tracks and less roading on steep hillsides, negative impacts to soils and water catchments, and the visual impacts on sensitive sites are less. Cable extraction (Figure 5) is different from other ground-based wood extraction systems (forwarders and skidders) in that soil-machine interaction is minimal or eliminated altogether. Movement of the base winching machine is confined to translocation between adjacent landing areas and harvesting sites. During operation, the winching machine is fixed, hence, the system can be used in steep terrain and on wet sites soil. If the cable system permits full suspension of the load (skyline), the soil disturbance associated with wood extraction is eliminated.

Table 3 presents the age profile of cable systems that have been used in Ireland in the period 1970-1997. The systems had a combined capacity of about 120,000 m³ which was about 5% of the annual wood production (Forest Service, 1997). Currently, the number has reduced to about 6 units due to shortage of labour and unfavourable economics (Lyons, 2001), but the increasing need for compatibility of wood extraction methods with harvesting site conditions favours the increased use of cable systems.
Table 3. Age profile of cable systems in Ireland (1970-1997)

<table>
<thead>
<tr>
<th>Make</th>
<th>Year of manufacture</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Timbermaster</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Other</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Total</td>
<td>3</td>
<td>2</td>
</tr>
</tbody>
</table>

Cable systems can be employed for CTL, full pole/full tree extraction, and in both thinning and clearfell operations. The cable systems in Ireland have predominately been used for thinning, and a typical whole tree system requires a crew of 1 skyline operator, 2 chainsaw operators, 1 chockerman, and 1 forwarder/processor operator. For the trailer mounted and tractor powered ‘Timbermaster’ (Figure 5), maximum yarding distance is limited to 500 m. ‘Payout’ carriages allow for wood extraction from positions adjacent to the skyline corridors. Production rate is about 3 m³/hour (based on 40 productive man-hours per week). The use of mobile plant to anchor the systems can reduce the set-up/movement time by up to 20%. Greater use of cable extraction for clearfelling operations would require a change from the current systems to larger units.

Table 4. Wood harvesting and extraction prices in Ireland (IFCA, 2000)

<table>
<thead>
<tr>
<th>Average tree size category (m³)</th>
<th>System</th>
<th>Thinning</th>
<th>Clearfell</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>WF</td>
<td>S, LPL, BP, LPS</td>
<td></td>
</tr>
<tr>
<td>&lt; 0.055</td>
<td>21.70 – 23.15</td>
<td>20.26</td>
<td></td>
</tr>
<tr>
<td></td>
<td>24.60 – 26.05</td>
<td>21.70</td>
<td></td>
</tr>
<tr>
<td>0.056 – 0.075</td>
<td>20.98 – 22.43</td>
<td>19.53</td>
<td></td>
</tr>
<tr>
<td></td>
<td>23.88 – 25.32</td>
<td>20.98</td>
<td></td>
</tr>
<tr>
<td>0.076 – 0.090</td>
<td>20.29 – 21.70</td>
<td>18.08</td>
<td></td>
</tr>
<tr>
<td></td>
<td>23.15 – 24.60</td>
<td>19.53</td>
<td></td>
</tr>
<tr>
<td>0.091 – 0.105</td>
<td>19.53 – 20.98</td>
<td>17.36</td>
<td></td>
</tr>
<tr>
<td></td>
<td>22.43 – 23.88</td>
<td>18.81</td>
<td></td>
</tr>
<tr>
<td>0.106 – 0.125</td>
<td>18.81 – 20.29</td>
<td>16.64</td>
<td></td>
</tr>
<tr>
<td></td>
<td>21.70 – 23.15</td>
<td>18.08</td>
<td></td>
</tr>
<tr>
<td>0.126 – 0.145</td>
<td>18.08 – 19.53</td>
<td>15.19</td>
<td></td>
</tr>
<tr>
<td></td>
<td>20.98 – 22.43</td>
<td>16.64</td>
<td></td>
</tr>
<tr>
<td>0.146 – 0.200</td>
<td>17.36 – 18.81</td>
<td>13.74</td>
<td></td>
</tr>
<tr>
<td></td>
<td>20.26 – 21.70</td>
<td>15.19</td>
<td></td>
</tr>
<tr>
<td>0.210 – 0.300</td>
<td>16.64 – 18.08</td>
<td>13.02</td>
<td></td>
</tr>
<tr>
<td></td>
<td>18.81 – 20.26</td>
<td>14.47</td>
<td></td>
</tr>
<tr>
<td>0.310 – 0.450</td>
<td>15.19 – 16.64</td>
<td>11.57</td>
<td></td>
</tr>
<tr>
<td></td>
<td>18.81 – 20.26</td>
<td>13.02</td>
<td></td>
</tr>
<tr>
<td>0.460 – 0.600</td>
<td>13.02 – 14.47</td>
<td>10.86</td>
<td></td>
</tr>
<tr>
<td></td>
<td>18.81 – 20.26</td>
<td>12.29</td>
<td></td>
</tr>
<tr>
<td>0.610 – 0.800</td>
<td>10.13</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.800 – 1.000</td>
<td>9.40</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

WF – Wheeled Forwarder, TF – Tracked Forwarder
S – Spruce, LPL – Lodgepole pine, Lodgepole pine south coastal, BP – Branched pines

Cable systems in general are substantially more expensive to operate than other extraction systems such as forwarding and skidding (Table 4). It requires a high degree of
organisation, is labour intensive, and requires highly skilled operation and effective teamwork (Forest Service, 2000). The key concerns for economic operation on low gradient sensitive sites include: (i) economic yarding distance; (ii) size of payload per cycle; (iii) expected/tolerable deflection and sag in the main skyline (may further constrain the payload limits for sites with low gradient) including the type of rigging configuration, and; (iv) planned harvesting area or volume for extraction for each set-up.

The main technical and operational challenges in the use of cable systems in Ireland include:
- Load carrying capacity is limited for a skyline system if the load must be fully suspended (determined by the ground condition and tolerable surface disturbance);
- Well-rooted and stable support and anchor trees must be carefully selected, hence, there are practical difficulties in harvesting sites with shallow rootplating;
- Problems of crew movement especially on wet sites with high ground roughness reduces the productivity in wood extraction;
- Setting up is time consuming and more portable equipment may be desirable, and this has necessity the use of mobile plant in some cases, which may incur additional operational costs;
- Difficulties in obtaining adequate insurance cover, and;
- Difficulty in engaging and retaining suitably trained staff

CONCLUSION
There is an increasing demand for envirogentle extraction of wood on ‘sensitive’ forest sites to minimise soil compaction and damage to the roots of residual stands, and soils erosion and siltation of watercourses adjacent to the harvesting sites. The cable system offers possible methods for such limitation, but is currently under-utilised because of the low production rates, excessive set-up times, scarcity of labour for harvesting with chainsaws and on steep slopes, and difficulties in obtaining adequate insurance cover.

Acknowledgement
Compilation and presentation of this paper was supported by the ECOWOOD Project (URL: www.ucd.ie/~foresteng), which is funded by the European Commission under the Fifth Framework Programme (FP5) on Quality of Life and Management of Living Resources.

References