A feasibility study on the performance of a harwarder in the thinning of small scale forests in Ireland

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Abstract

Private forest plantations in Ireland, if properly managed, have the potential to generate significant amounts of harvestable timber over the coming decades. However, the average size of private plantations is just 9 ha, therefore the identification of compatible, economic harvesting systems requires careful consideration.

A feasibility study was carried out to compare the machine operation and movement costs for a harvester-forwarder system and a harwarder system (an integrated harvester and forwarder on a single machine base) for projected harvesting over the period 2020-2025 in a selection of privately-managed forests in Co Wexford. Sensitivity analysis was carried out to determine the combination of factors that could make the harwarder system more cost-effective than the harvester-forwarder system.

The results showed that if the harwarder and the harvester-forwarder systems are used on all sites, and if stands with attributes that favour the harwarder system are not pre-selected, the harvester-forwarder system was more cost-effective. However, the harwarder was more cost-effective on sites with small harvesting volumes (<100 m^3). With a reduction of 10% in the operating cost of the harwarder system (representing the expected rapid technological and operational development of this new concept), both systems broke even, while, if only those sites with smaller harvest volumes were considered, the harwarder system would outperform the harvester-forwarder system. Management of the forests to establish tight harvesting clusters, by changing the thinning year of some of the stands, produced a marginal cost advantage for the harvester-forwarder system.

Keywords:

Harvesting, thinning, harwarder, small scale forestry

Introduction

The forest cover of the Republic of Ireland is approximately 700,000 ha or 10% of the land area (Forest Service 2007). Coillte (The Irish Forestry Board), the largest forest landowner in Ireland, owns 440,000 ha (Nieuwenhuis and Nugent 2000, O'Carroll 2004), with owned by companies, institutions and private landowners account for the remainder.

The public sector (Coillte and the Northern Ireland Forest Service) currently accounts for 95% of the annual harvest volume, with the private sector supplying the remainder (Bacon et al. 2003). However, it is anticipated that this situation will change over the next 15 years, with the private sector contribution set to increase to almost 25% (Phillips 2004a). A significant proportion of this increase will come from thinning of small sized private forests (Gallagher and O'Carroll 2001).

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Thinning is the most effective process that the grower possesses for manipulating the development of forest plantations and the quality and log size of the final crop (Savill et al. 1997). Thinning operations can be either mechanised or motor manual. In mechanised short-wood thinning, a harvester fells, delimbs and crosscuts the stem into product assortments, e.g. pulpwood, pallet wood, stake wood and sawlog (usually based on the top diameter, length, and quality of the log). The material is then extracted to roadside by a forwarder. This is the most common system used in Ireland and accounts for approximately 95% of mechanised thinning operations undertaken (Phillips 2004b). However, high harvesting cost and low value output are typical of first thinning. Current silvicultural practice in Ireland entails frequent light thinning operations (resulting in low harvesting volumes), which compounds the challenge of prescribing cost-effective thinning methods (Lilleberg 1997). Small stem size, low volume removal per hectare, the high number of remaining trees, the often dense non-marketable undergrowth, and the frequent movement of machines between harvesting sites, results in low machine productivity and low value production (Hurley et al. 2002).

The location, size and quality of privately-owned forests will significantly determine the economics of the small-scale private forestry sector (Redmond et al. 2003). Timber sale size and location in relation to other contracted harvesting operations, is seen as a major factor influencing the efficiency and cost of the operations. Sale volumes are often small and isolated, and distributed among many timber procurers employing different harvesting and haulage contractors. In addition, many privately-owned forests are located in relatively inaccessible areas with poor infrastructure, while the average size of private forests is just 9 ha (Farrelly 2007), which is significantly smaller than the Coillte average. This has the potential to reduce the profitability margin for privately-owned forests during all forestry operations, including harvesting.

A number of factors contribute to roundwood harvesting and extraction costs. These include the size of the plantation, ease of access, type of machinery used, and the competence of the machine operator (Phillips 2004b). Higher harvesting costs are incurred (Kellogg and Bettinger 1994) where:

1. harvested volumes and tree size are small,
2. access is poor,
3. areas are isolated and
4. site conditions are difficult.

Machine relocation costs can also add significantly to unit costs (€ m^{-3}), particularly for harvesting small volumes. The economic viability of the harvester-forwarder system is highly dependent on machine utilisation levels and productivity rates (Eliasson et al. 1999). However, where the harvest volume per site is small, the utilisation rates will be low, since frequent relocation of machines to new sites will be required. Figure 1 illustrates how the machine relocation component cost varies with the level of harvest per site, and demonstrates the need to develop harvesting systems to cope with sites with low harvestable volumes.

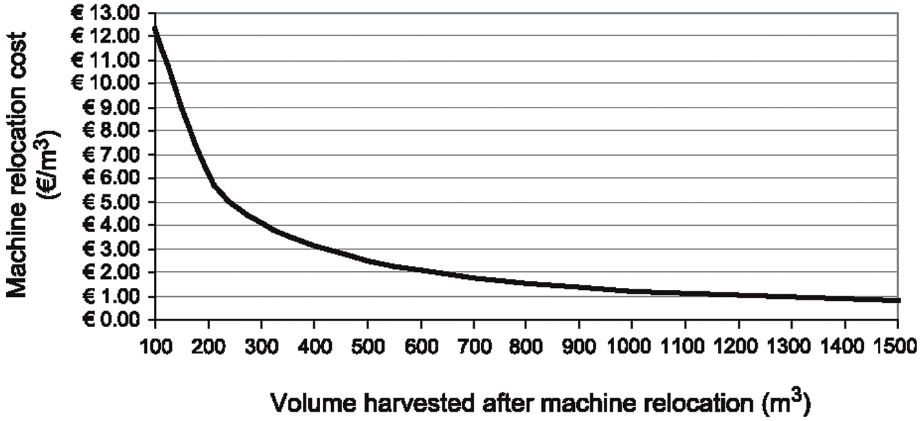

Figure 1: Variation of the machine relocation component of unit harvesting cost with harvested volume for a harvester-forwarder system (adapted from Kellogg and Bettinger 1994).

An example of such a harvesting system is the harwarder, which combines harvester and forwarder functions on the same base machine. Harwarders have not been used in Irish forestry to date.

The harwarder is seen as a way to reduce harvesting costs (Hallonborg and Norden 2000). A rapid development of the harwarder concept is taking place in Sweden and Finland (Siren and Aaltio 2001, Andersson and Eliasson 2004). In 2000, a new prototype equipped with a rotatable and tiltable load carrier was built in order to enhance the possibilities for processing logs directly into the load carrier (Wester and Eliasson 2003, Bergkvist 2008). It can be argued that complexity in harvesting is reduced by hardwarder use, as harvesting and forwarding is integrated on the same unit and therefore only one machine needs to be relocated. Furthermore, roundwood is presented at roadside soon after the commencement of felling, thereby minimising supply lead-in times. A further advantage is that one machine captures, processes and transmits all production data (Gellerstedt and Dahlin 1999).

The objective of this study was to compare the harvesting operation and machine movement costs for a harvester-forwarder system with a harwarder system, for a specific Irish harvesting programme in privately-owned, small sized forests in Co Wexford, Ireland. Sensitivity analysis was carried out to determine which combination of factors (thinning volume, tree size, machine cost, movement cost and movement distance) could make the harwarder system more cost-effective than the harvester-forwarder system.

Materials and methods

Forest harvesting sites were located in Co Wexford, in the south-east of Ireland. All were managed by Green Belt Ltd. The projected thinning programme for the selected forests scheduled for the period 2020-2025 was used to determine the harvesting locations and stand characteristics for the study. The study procedure was as follows:

1. locate forest sites managed by Green Belt Ltd. in Co Wexford (planted between 1999 and 2004) and determine their national grid coordinates,
2. determine the year of first thinning and forecast total thinning volumes and the average stem sizes to be removed from the forests over the period 2020-2025,
3. determine cost functions for the harwarder and the harvester-forwarder systems from literature,
4. determine machinery movement or relocation costs for both systems, based on the proximity of the sites to each other,
5. calculate total production costs for all thinning years together for the forwarder and harvester-forwarder systems,
6. evaluate unit costs (per m^3) for the harwarder and harvester-forwarder systems,
7. determine the point where the cost of the two systems was the same, and the more cost-effective system, under default variable settings,
8. conduct sensitivity analysis to determine the impact of the input variables (harvest volume, machine cost and thin year) on where the cost of the two systems became the same.

Methods were developed using literature, through personal communication with contractors and from Green Belt's GIS and databases, and tree species certification maps. Thirty four forests were included, comprised of 79 sub-compartments, and an overall total area of 265 ha.

The notional area of plantations was reduced by 15% to account for unplanted areas such as roads, ridelines, landings etc. As dynamic yield models for Ireland were not available for all the species included in the study, standard Forestry Commission (FC) yield models (Edwards and Christie 1975) were used to forecast stand development. The conifer stands in the study were planted at 2 x 2 m spacing and managed using an intermediate thinning intensity. The closest approximating yield models were applied depending on tree species. For example, the models for 1.8 m spacing for Japanese larch and hybrid larch, and 1.7 m spacing for European larch, both for intermediate thinning, and the model for 1.7 m spacing and crown thinning for Douglas fir were used. For the alder and oak sites, the combined sycamore, ash, beech (SAB) yield model was used.

Year of planting, site number, sub-compartment number, species, area, and yield class for all 79 sub-compartments were tabulated in an Excel spreadsheet. Additional data were extracted from the FC yield models: year of first thinning, the volume to be thinned (m^3 ha^{-1}) and the average stem size of the thinned material (m^3).

Determination of machinery relocation/movement costs

The cost of moving machines depended on the distance between sites and the number of machines to be transported. National grid coordinates for each site were obtained from the OSI Discovery Series map (1:50000). Using the coordinates, the distance between any pair of sites could be calculated. Data were sorted in order of the expected year of thinning and within each year, and the shortest path between forests was determined (using an Excel macro). Movement cost from one site to the next could then be calculated for the harwarder system and the harvester-forwarder system, using the costs in Table 1.

Table 1: Machine movement costs associated with the distance between sites (from Browne 2005).

Distance km	*Harwarder*	*Harvester-forwarder*
	Cost €	
<20	75	150
20-40	85	170
40-60	100	190

Development of machine operating cost functions

As there were no harwarder productivity or cost models available for Ireland, models developed for Finland were used (Talbot et al. 2003). The tree sizes in the study were similar to those used in the development of the Finnish models. As the Finnish study provided only contained graphs, these were transformed to tabular data, and the production cost (€ m^{-3}) was regressed on average stem size for each stand, for both systems.

The equation obtained for the harwarder system was:

$$Y = 14.62 - 0.03337x + 168.32 \left(\frac{1}{x}\right)$$ and

for the harvester-forwarder system:

$$Y = 8.86 - 0.01192x + 294.44 \left(\frac{1}{x}\right)$$

where y is the production cost (€ m^{-3}) and x is the average stem size of the stand (dm^3).

Determination of machine operation costs

The volume to be thinned (m^3) in each stand was determined from the yield models (Hamilton 1975) and site data. Using thinning volume (m^3) and harvesting cost (€ m^{-3}) the total production cost for the systems was calculated. Total thinning programme cost was determined as the sum of the total production cost and the total movement cost, summed over all the stands under consideration. Unit costs (€ m^{-3}) were calculated for both systems by dividing the total thinning volume, over all years, into the total thinning programme cost of each system. As the thinning programme time period was relatively short (6 years), undiscounted costs were used.

Analysis of harvesting scenarios

The costing procedure was applied to 13 scenarios (Table 2). These were selected based on variation in the harvesting volumes per site and in the harwarder cost. The variation in volumes was used to identify the scale of operations at which the two systems were most economic, while the variation in the harwarder cost was used to simulate the further technological and operational developments in harwarder design and manufacturing, as the system is still in a developmental stage. The final scenario was used to investigate the benefit of allowing stands to be thinned earlier or later than the prescribed thinning year.

Table 2: Harvesting scenarios analysed.

Scenario	*Harvest volume m³*	*Harwarder cost*	*Flexibility in thin year?*	*Sites thinned per year 2020 – 2025*
1	no restriction	standard	no	8, 18, 17, 12, 11, 13
2	<150	standard	no	5, 16, 12, 9, 8, 7
3	<100	standard	no	3, 13, 7, 9, 8, 6
4	<50	standard	no	2, 9, 2, 8, 5, 2
5	no restriction	- 10%	no	8, 18, 17, 12, 11, 13
6	no restriction	- 20%	no	8, 18, 17, 12, 11, 13
7	<150	- 10%	no	5, 16, 12, 9, 8, 7
8	<100	- 10%	no	3, 13, 7, 9, 8, 6
9	<50	- 10%	no	2, 9, 2, 8, 5, 2
10	<150	- 20%	no	5, 16, 12, 9, 8, 7
11	<100	- 20%	no	3, 13, 7, 9, 8, 6
12	<50	- 20%	no	2, 9, 2, 8, 5, 2
13	no restriction	standard	± 1 year	10, 17, 15, 12, 9, 16

Results

Scenario 1

Summing the total production cost and the total transport cost, a total programme cost was calculated for both systems (Table 3). The resulting unit cost of the harwarder was €1.77/m³ higher than that of the harvester-forwarder system.

Scenarios 2, 3 and 4

Scenarios 2, 3 and 4 included only sites that could be thinned between 2020 and 2025 and that had a thinning volume per site less than 150 m³, 100 m³ and 50 m³, respectively. The total costs of movement for the harwarder and harvester-forwarder systems in scenarios 2, 3 and 4 are presented in Table 3. The cost (€ m^{-3}) of the harwarder system was lower than that of the harvester-forwarder system when the systems were used on sites with a harvest volume of 100 m³ or 50 m³ (Scenarios 3 and 4), while in scenario 2 the two system costs were only marginally different.

Scenarios 5 and 6

Scenarios 5 and 6 included all sites that could be thinned between 2020 and 2025. In these scenarios the cost of the harwarder system was decreased by 10% and 20% respectively, to simulate the rapid development of the technology. The cost (€ m^{-3}) of the harwarder system was lower than that of the harvester-forwarder system if the cost of the harwarder was decreased by 20%. When the cost of the harwarder system was decreased by 10%, the two systems had the same cost (Table 3).

Scenarios 7, 8 and 9

Scenarios 7, 8 and 9 were a combination of scenarios 2 and 5, 3 and 5 and 4 and 5, respectively. These scenarios included all sites that could be thinned between 2020 and 2025 that had thinning volume less than 150 m^3, 100 m^3 and 50 m^3 respectively, and the cost of the harwarder was decreased by 10%. The cost (€ m^{-3}) of the harwarder system proved to be lower than that of the harvester-forwarder system for all 3 scenarios analysed (Table 3).

Scenarios 10, 11 and 12

Scenarios 10, 11 and 12 were a combination of scenarios 2 and 6, 3 and 6, and 4 and 6, respectively. These scenarios included all sites that could be thinned between 2020 and 2025 that had thinning volumes less than 150 m^3, 100 m^3 and 50 m^3 respectively, while the cost of the harwarder was decreased by 20%. In contrast to scenario 1, but similar to scenarios 7, 8 and 9, the harwarder system proved to be more cost-effective than the harvester-forwarder system in all three scenarios (Table 3).

Scenario 13

Scenario 13 involved moving the thin year of stands forwards or backwards by one year, to create tight clusters of stands in each year. When the thinning ages of various stands were changed by one year, the difference in cost (€ m^{-3}) between the harwarder and harvester-forwarder systems did not change greatly from scenario 1 (Table 3).

Table 3: Results of the analysis for thirteen harvesting scenarios.

Scenario	*Harwarder cost*	*Max. harvest volume per site*	*Total volume harvested*	*Harwarder*		*Harvester-forwarder*		*Difference in unit cost*
				Total cost	*Cost per m^3*	*Total cost*	*Cost per m^3*	
	%	*m^3*	*m^3*	*€*		*€*		*€ m^{-3}*
1	100	no restriction	14,008	230,637	16.46	205,823	14.69	1.77
2	100	150	3,471	65,254	18.80	63,770	18.37	0.43
3	100	100	2,088	42,083	20.15	42,953	20.57	-0.42
4	100	50	785	17,423	22.20	18,622	23.72	-1.53
5	90	no restriction	14,008	207,945	14.84	205,823	14.69	0.15
6	80	no restriction	14,008	185,153	13.22	205,823	14.69	-1.48
7	90	150	3,471	58,983	16.99	63,770	18.37	-1.38
8	90	100	2,088	38,101	18.25	42,953	20.57	-2.32
9	90	50	785	15,775	20.10	18,622	23.72	-3.63
10	80	150	3,471	52,688	15.18	63,770	18.37	-3.19
11	80	100	2,088	34,103	16.33	42,953	20.57	-4.24
12	80	50	785	14,122	17.99	18,622	23.72	-5.73
13	100	no restriction	14,008	225,107	16.07	200,094	14.28	1.79

Discussion and conclusions

When the harwarder and the harvester-forwarder systems were compared based on all sites, the harvester-forwarder system was more cost-effective. However, the harwarder was as, or more cost-effective on sites with small harvesting volumes, having the same cost as the harvester-forwarder system where harvesting volumes were between 150 m^3 and 100 m^3, and being cheaper where volumes were 50 m^3 or less.

The systems had the same cost if there was a decrease of 10% in the production cost of the harwarder system over the full range of tree sizes and harvest volumes. If the production cost decreased by 20%, the harwarder system became more economical, being more than €1.50 m^{-3} cheaper. As outlined previously, these cost reductions simulated the rapid technical development of the harwarder system currently underway.

Scenario 12 resulted in the greatest cost difference between the two systems - the harwarder system was €5.70 m^{-3} cheaper (maximum harvest volume was 50 m^3 and the harwarder production cost was reduced by 20% (Table 3)).

Reduced relocation times are a primary advantage of the harwarder systems. This makes them suitable in forest operations involving lower object-volumes (small areas with light or early thinnings), or more frequent and longer relocations. The importance of relocation cost is illustrated in scenario 3, before transport costs were taken into account the harvester-forwarder system was more cost effective, however after these costs were accounted for, the harwarder system became more attractive.

In carrying out this study, a number of factors were excluded from the analysis. Fixed costs such as overheads (insurance, taxes, etc.) and depreciation were not charged while machines were being moved. To calculate such costs, the total distance travelled under each scenario would have to be determined and expressed as total travel time, depending on route and truck classification. A cost per hour could then be allocated to travel time between sites. Fixed costs during travel time for the harvester-forwarder system, involving two machines, will be higher than the harwarder; and if included would favour the harwarder system over the two machine combination.

The integration of many functions on one base machine often impairs its utilisation and cost efficiency (Silversides and Sundberg 1989). A multi-function machine can become more expensive than a combination of several single-purpose machines. High hourly costs are assigned to work cycles (such as forwarding in case of harwarders) that can be done by a simpler and less expensive machine. In addition, a multi-function machine resembles a system of machines, where waiting and blocking times between the machine elements reduce overall productivity of the system (Silversides and Sundberg 1989). These disadvantages must be compensated by other parts of the work sequence, such as in the relocation of machinery and in the overheads needed for the management of operations. If work sequences can overlap and several operations can be conducted simultaneously, the efficiency of the machine improves in the actual operation at the site. This is evident with the harwarder, as discussed in Tarleton and Phillips (2003), where the ability of the integrated machine to process logs directly onto the bunk provides it with an advantage that more than compensates for its reduced harvesting efficiency. In addition, as indicated, relocation of machinery is cheaper when only one machine unit has to be moved.

The productivity equations for the harvesting systems were derived from a Finnish study (Talbot et al. 2003) and may not be directly applicable to Irish conditions. As no Irish data existed for harwarder productivity, the use of equations from the literature was the only way to approach the study. However, the scenario analyses are of relevance to the development of the Irish harvesting infrastructure.

As noted by Russell and Mortimer (2005), if roundwood is sold at roadside, a timber purchaser would usually buy a minimum of 35 m^3 (one truck load). One of the scenarios was based on sites with a thinning volume less than 50 m^3. In this scenario the harwarder system was cheaper to use than the harvester-forwarder system. However, there were sites included with less than 35 m^3 roundwood, which most likely would not be purchased and the cost advantage of the harwarder in this scenario is theoretical.

The combinations of variables that made the harwarder system more cost effective than the harvester-forwarder system were small tree sizes and small thinning volumes in small areas, with long transport distances. The reason longer transport distances favour the harwarder system is evident from Table 1, while a similar trend was observed by Hallonborg and Norden (2000).

The current sustained research and development work by major manufacturers, focusing on integrated machines, is evidence of a general recognition of the potential that these machines hold for future harvesting operations. Based on the results obtained in this study and expected further development in technology, the hardwarder has the potential to be more cost-effective than the harvester-forwarder system where tree size is small and site volumes are low, requiring frequent movement of the machine(s) from site to site.

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References

Andersson, J. and Eliasson, L. 2004. Effects of tree harvesting work methods on harwarder productivity in final felling. *Silva Fennica* 38(2): 195-202.

Bacon, P. and Associates (Economic Consultants). 2003. Forestry: A growth industry in Ireland. Ballyrane House, Killinick, Co. Wexford.

Bergkvist, I. 2008. *Harwarders in final felling.* Results No. 1 2008. Skogforsk, Uppsala.

Browne, P. 2005. Browne Plant Hire. Personal communication (May 1, 2006).

Coillte. 2005. Information for the Irish forestry and timber industry. *Forestry Focus Ireland* 1 Summer 2005.

Edwards, P. and Christie, S. 1975. *Yield models for forest management.* Forestry Commission Booklet No. 48. HMSO, London.

Eliasson, L., Bengtsson, J., Cedergren, J. and Lageson, H. 1999. Comparison of single-grip harvester productivity in clear- and shelterwood cutting. *International Journal of Forest Engineering* 10(1): 43-48.

Farrelly, N. 2007. The farm forest resource in Ireland: opportunities and challenges for rural development in Ireland. *Small-Scale Forestry* 6(1): 49-64.

Forest Service. 2007. *National Forest Inventory – Republic of Ireland – Results*. Forest Service, Johnstown Castle Estate, Co Wexford.

Gallagher, G. and O'Carroll, J. 2001. *Forecast of roundwood production from the forests of Ireland 2001-2015*. COFORD, Dublin.

Gellerstedt, S. and Dahlin, B. 1999. Cut-to-length: The next decade. *International Journal of Forest Engineering* 10(2): 17-25.

Hallonborg, U. and Norden, B. 2000. *Count on the harwarder for final felling*. Results No. 4 2000. Skogforsk, Uppsala.

Hamilton, G. 1975. *Forest mensuration handbook.* Forestry Commission Booklet No. 39. HMSO, London

Hurley, J., Dolan, G., Murphy, G., Hanrahan, P., Tarleton, M. and Philips, H. 2002. *OPTILOG. An efficiency analysis of the sale, purchase, harvesting and haulage of timber in the Irish forestry sector*. COFORD, Dublin.

Kellogg, L.D. and Bettinger, P. 1994. Thinning productivity and cost for a mechanized cut-to-length system in the northwest Pacific coast region of the USA. *International Journal of Forest Engineering* 5(2): 43-54

Lilleberg, R. 1997. *Harvester-forwarder for logging in first thinning stands*. Metsäteho, Helsingfors, Report 28.

Nieuwenhuis, M. and Nugent, C. 2000. The evaluation of a harvest scheduling system for Ireland – two case studies. *International Journal of Forest Engineering*. 11(2): 23-32.

O'Carroll, J. 2004. *Uses of home-grown Irish timber.* COFORD Connects Processing/Products No. 4. COFORD, Dublin.

Phillips, P. 2004a. *Thinning to improve stand quality.* COFORD Connects Silviculture/Management No. 10. COFORD, Dublin.

Phillips, P. 2004b. *Realising the potential of private plantations.* COFORD Connects Silviculture/Management No. 9. COFORD, Dublin.

Redmond, R., Ní Dhubháin, Á. and Gallagher, G. 2003. *A survey of Western Package afforestation scheme plantations in relation to thinning needs.* COFORD Connects Socio-Economic Aspects No. 2. COFORD, Dublin.

Russell, F. and Mortimer, D. 2005. *A review of small-scale harvesting systems in use worldwide and their potential application in Irish forestry.* COFORD, Dublin.

Savill, P., Evans, E., Auclair, D. and Falck, J. 1997. *Plantation silviculture in Europe.* Oxford University Press, Oxford.

Silversides, C. and Sundberg, U. 1989. *Operational efficiency in forestry*. *Volume 2: Practice*. Kluwer Academic Publishers, Dordrecht.

Siren, M and Aaltio, H. 2001. *Productivity and costs of thinning harvesters and harvester-forwarders*. Metla, Vantaa.

Talbot, B., Nordfjell, T. and Suadicani, K. 2003. Assessing the utility of two integrated harvester-forwarder machine concepts through stand–level simulation. *International Journal of Forest Engineering* 14(2): 31-43.

Tarleton, M. and Phillips, H. 2003. *OptiLog: an efficiency analysis of the sale, purchase, harvesting and haulage of timber in the Irish forestry sector.* COFORD, Dublin.

Wester, F. and Eliasson, L. 2003. Productivity in final felling and thinning for a combined harvester-forwarder (harwarder). *International Journal of Forest Engineering* 14(2): 45-50.