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INTENSIFYING THE MANAGEMENT OF PROTECTION FORESTS IN THE ALPS

In the Alps, forests are generally multi-functional, and they are classed according to their primary role as production, protection or recreation forests. The dominance of one of these roles does not exclude all the others, although it shapes management, which must reflect the primary role of each forest. That is also the case of protection forests, which must be managed for their secondary production and recreation roles as well. What is more, management is a vital requirement because it supports forest health, and therefore periodic harvesting remains a necessity. However, the physical conditions that characterize a protection forest (e.g. extremely steep terrain, sensitive soil, remote location etc.) and the prescriptions of a specifically designed silviculture tend to constrain harvesting and make it especially difficult. Special harvesting equipment and novel approaches to harvesting are required in order to achieve environmental, social and financial sustainability. This study reports about cable yarding in a protection forest, under conditions that are representative of the challenges encountered when negotiating this forest type. The productivity of the yarding operation was 6.1 m^3_{ub} SMH^{-1} for the yarding distance of 135 m, an average load of 0.88 m^3 and a lateral distance of 20 m. Of the remaining trees, 27.1% were damaged during forest operations due to felling, log contact or falling rocks. Falling rocks have a great influence on log quality and value. Consequently, 73% of conifers and 90% of broadleaves are C class logs or other lower grade wood, making a large impact on the economy of the operation.

Keywords: forestry, forest harvesting, cable crane, protection forest, forest operations, stand damages, timber value

Introduction

The protective function of forests is one of the most important forest functions and is becoming even more important over time [Motta and Haudemand 2000]. It is important to differentiate between general and specific protective functions,

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as all forests have a general protective role, therefore contributing to surface soil conservation, watershed management, and air quality. However, only some forests have a specifically human-related role, and so they are also protecting people and infrastructure from natural hazards such as avalanches, rock falls, landslides, erosion, and floods. Such forests have a direct protective function [Schönenberger 1998], and this function is so important that it has been one of the first forest functions to be explicitly acknowledged by humans, as far back as the 13th century [Gerbore 1997]. This direct protective role needs to be efficient and continuously effective. In such forests, it is important to prevent destructive logging while making sure that they are not abandoned to their natural course of evolution, as such stands are highly susceptible to destructive events during their natural development. Disturbances like windfall, insect outbreaks, snow break, and fire (though natural in occurrence) have the potential to impair effective protection by killing trees [Wasser and Frehner 1996]. Forests with a direct protective function should, therefore, be a high priority for silvicultural intervention and should definitely not be abandoned [Motta and Haudemand 2000].

Unfortunately, in the Alps, there are many protective forests that cannot perform their protective role to the best of their abilities. For centuries the only prescribed silvicultural measure in these forests was a logging ban. This has led to a lack of regeneration, a scarcity of medium-aged trees, insufficient stability, and an increasing vulnerability to natural disturbances [Motta and Haudemand 2000]. In order to improve the direct protective role of forests, targeted silvicultural measures need to be carried out. They consist of cutting parts of the stand to create a diversified structure. With these measures, stand regeneration is promoted in the short term and in the medium term, more stable stands with an abundance of medium-aged trees will develop. Gaps should be from 30 to 50 metres wide in the direction parallel to the maximum slope, and up to 100 metres parallel to the contour line. This would prevent avalanche release on slopes with a gradient below 70% [Brang 2001].

These measures go hand in hand with public perceptions and expectations. It has been determined that visitors perceive mountain forests differently from foresters. Research shows that the general public is sensitive to intensive forest operations [Hemström et al. 2014] and that in mountain areas visitors expect untouched natural conditions [Paletto et al. 2013]. The perceptions of the general public have raised concerns with the forest managers and cutting in gaps was seen as a viable option. On the other hand, opting for the more radical solution offered by diffused selection thinning would have caused an unacceptable increase in harvesting costs, with dubious results on rapid regeneration [Mercurio and Spinelli 2012] and increased stand damages [Siren et al. 2015].

Tree damage is another important issue when dealing with uneven-aged forest management, and especially on steep rocky sites. In that instance, tree damage can be differentiated into damage from natural and from human agents.

In alpine forests, most stand damage occurs because of natural causes. The most frequent cause of natural tree damage is rock fall. While most of the literature is focused on dendrogeomorphic methods for tree damage determination as caused by a number of different natural agents such as rock fall [Trappmann and Stoffel 2013], forest engineers are interested in injuries caused by forest operations, and in determining the number of damaged trees in the forest prior to and after the logging operation. Stand damages have a detrimental effect on round wood quality and on the economy of the operation, as the price of damaged round wood is lower.

The goal of this study was to determine a productivity benchmark for cable yarding operations in protection forests, generally representative for this forest type as defined in the European Alps. With some caution, such a benchmark could be extended to protection forests in other mountain regions of Europe, until more specific alternative benchmarks have been made available.

Materials and methods

Site and technology

Slovenia is an Alpine country, and forests with a direct protection function are common all over the Slovenian territory. The forest on the study site was chosen carefully, because of its important protective role. This was a beech-spruce mixed forest located directly above a busy mountain pass, protecting a major road and its border crossing facilities from the danger of mud flow, erosion and avalanche. Local forest managers decided that measures had to be taken in order for the forest to continue performing its strategic protective role. The protection efficiency of the forest was being weakened by aging, which resulted in the dominance of mature even-sized stands and the absence of young and middle--class trees. A more diversified structure had to be created. Since the forest also has a strong tourist function, hiking and sledding were performed on the road, which required careful planning of the operation to avoid interference with recreation activities. The site was considered representative of the conditions commonly encountered by forest operations in protection forests under Alpine conditions. The characteristics of the work site are shown in table 1. Cutting in small gaps, rather than diffused thinning was chosen as the silvicultural measure, with the aim of promoting rejuvenation and diversification, which were expected to guarantee the protection of facilities down-slope. Another major concern for the forest managers was to carry out the intervention in an inconspicuous way and to avoid impacts on the aesthetic function of the forest. Gap cutting fulfilled this goal, as well.

The right choice of technology was essential for achieving good results. The construction of skid trails was not possible for obvious ecological and economic

Table 1. Description of the site

Height above sea level	M	1350 to 1550
Latitude (WGS84)		46° 43' 42"
Longitude (WGS84)		14° 26' 24"
Species		Spruce, beech, maple, larch
Average inclination	%	79
Forest type		Rhodothamno-Rhododendretum hirsute
Rock outcrops	%	45
Soil type		Rendzic leptosol
Bedrock type		Limestone and dolomite

reasons, so ground-based technologies were not contemplated [Spinelli et al. 2010]. The forest was accessed through an unpaved road, located at its lower border. These conditions called for down-hill cable yarder extraction. A modern, multi-winch tower yarder was chosen, which offered better crew safety and efficiency, compared with a simpler machine.

This was a Syncrofalke U3t mounted on a truck base. The machine was a standard model and was 2 years old. The truck engine (410 kW) also powered the winches, through a hydraulic power take-off. The yarder was fitted with a 3--ton capacity all-terrain Sherpa carriage: table 2.

Table 2. Main cable crane characteristics

Truck manufacturer	Iveco
Truck model	Trakker
Truck engine power	410 kW at 1800 RPM
Cable crane manufacturer	MM Forsttechnik GmbH
Cable crane model	Syncrofalke 3t
Carriage	MM-Sherpa U3
Carriage weight	400 kg
Telescope mast height	11.5 m
Weight (crane+truck)	24500 kg
Length	9.5 m
Width	2.55 m
Height (transport position)	4.0 m
Crane	LIV L25.94 N
Crane reach	6.5 m
Crane lifting power	240 kNm
Processor manufacturer	Conrad GmbH
Processor type	Woody 60
Processor maximum delimbing diameter	0.08-0.60 m
Processor weight	1350 kg
Sky line diameter	20 mm
Main line diameter	11 mm
Haulback line diameter	9 mm

Note: Data provided by the manufacturer and contractor.

Felling took place in two phases. In the first phase, the workers felled the trees located on the line and all trees that could compromise the skyline at a later time. All other trees were felled during yarding. All felling was performed motor-manually with chainsaws. Some cross-cutting and delimbing were also carried out in the forest, but only if the tree exceeded the payload capacity of the yarder carriage. Most of the tree processing was performed at the yarder pad using a Woody processor mounted on the integral loader that equipped the yarder.

The operation was a hot deck operation, meaning that log transportation occurred immediately after the yarder had filled the landing site. Trucks had to back up to the pile and transport the logs to an intermediate landing. The logistics of round wood transportation were extremely strained, as the road was steep and narrow with several switchbacks. The route from the main road to the cable yarder was 550 m long, with no place for trucks to turn.

Work technique

In order to reduce the risk of rock fall, the line was set at an angle to the slope and trees were felled parallel to the slope in order to facilitate extraction and to minimise the risk of them sliding downhill, uncontrolled.

Tree fall was directed in such a way as to minimise residual stand damage. Removal trees placed on the downhill side of the cable corridor were left uncut to act as bumper trees and were eventually cut at the end, before dismantling the yarder, starting from the uppermost tree and ending with the lowermost tree, nearest to the tower. These measures were crucial to safety, because the full tree method was employed, and the length of loads often exceeded 35 metres.

Small gaps were opened on both sides of the line corridor, alternating with uncut areas that would be harvested in the next rotation, using the same corridor.

Productivity

A typical time study [Magagnotti and Spinelli 2012] was performed using a handheld computer, running the dedicated Laubrass UMT Plus time study software. The snap-back timing method was used. All tests were conducted between October and early December 2011. There was no snow during the trial, but long periods of heavy rainfall hindered the operation.

Timing sessions lasted for the entire workday, with the purpose of obtaining a good representation of the structure of a typical workday, subdivided between different productive and non-productive activities. Yarding was understood as transporting the wood from the stump to the roadside, with processing and other necessary work included into productive time. Productive time was separated from delay time. All delays were included in the study, and not only those delays that were below a set duration threshold, because such exclusions could provide the wrong estimate of downtime, especially on comparatively long observation periods. Delays caused by the study itself were separated and excluded from the data set. The felling of one tree and the extraction of one load were considered as one work cycle for felling and extraction, respectively. Cycle time was divided into defined time elements, in accordance with the most recent harmonized European guidelines: table 3. A tree feller and a choker setter were stationed at the loading site, helping each other if necessary, while the yarder and the processor were operated by the yarder operator. Together, these three men represented an experienced crew that had been working on this specific task for a long period of time. The time study was aimed at determining the productivity benchmark for the cable yarder and felling productivity with the change from classical felling to a full tree method.

Output was measured with a caliper, and corrections were applied in order to calculate the underbark volume (m^3_{ub}) which is the unit used throughout the article. The length of roundwood was 4 m, but if there was any exception to this standard length, log length was determined with a tape metre. Only commercial round wood was accounted for, while residues have not been included as a product.

Table 3. Time study summary

Full work days of felling	n°	5
Total felling study time	h	32.5
Productive time of felling	H	9.9
Trees felled	n°	90
Roundwood volume felled	m^3_{ub}	151 (34 Conifers, 117 Broadleaves)
Tree DBH (min / max / average)	Cm	12 / 83 / 31
Full work days of yarding	n°	6
Total cable yarder study time	H	32.9
Productive time of yarder	H	23.0
Set-up time of the yarder	H	4.7
Loads produced	n°	171
Roundwood volume yarded	m^3_{ub}	135
Average load	m^3_{ub}	0.88 ±0.63
Average distance of lateral yarding	M	20
Site organization		Yarding downhill, full tree method, limited space at the pad

The tower was located on the road at 1150 a.s.l., while the tail anchor was installed higher up, 1336 m above sea level. The horizontal length of the line was 260 m, and no intermediate supports were needed. The line was planned and trees were marked for felling before the actual work began. Overall, 316 m^3_{ub} were marked for cutting, of which 152 m^3_{ub} were broadleaves, and 164 m^3_{ub} conifers. However, the study was conducted on alternate days, and therefore it recorded only the time to fell 151 m^3_{ub} and to yard 135 m^3_{ub}. Yarding distance varied between 15 and 223 m, with a mean yarding distance of 135 m. The mean load volume was 0.88 ±0.63 m^3_{ub}, after bucking (i.e. excluding top and branches).

Tree damage assessment

Damage to residual trees was conducted on border trees on the gap edges. All trees within a 10 m wide buffer were visually inspected for damage, recording their species, diameter at breast height (DBH) and location (above or below the line). If damages were found, then the following additional parameters were determined:

- what was damaged (crown, branches, bole, root collar, roots),
- surface area of damage (10-29; 30-49; 50-99; 100-199; ≥ 200 cm^2),
- age of damage (old, new, old and new).

Results

Productivity benchmarks

Since felling and yarding proceeded together, felling time included a large proportion of waiting time that occurred when the tree was hooked and extracted. Furthermore, whole tree extraction implied that the feller only had to fell the trees, without spending time on delimbing, measuring and crosscutting – except for the occasional oversize trees. The study included 23.3 h of scheduled feller work (i.e. worksite time), out of which only 6.8 h represented productive work time. As a result, chainsaw utilization was 29.5%, although mechanical availability reached 98%. The total delay factor of 238% was determined [Spinelli and Visser 2008]. The main productive time (notch-cutting, wedging, back-cutting, delimbing, bucking and cross-cutting, butt trimming) represented 6% of the total worksite time (fig. 2). Depending on whether delays were excluded or not, productivity was estimated at 25.1 m^3_{ub} per Productive Machine Hour (PMH) or 10.5 m^3_{ub} per Scheduled Machine Hour (SMH).

The study also covered 29.5 h of scheduled yarder work, including machine set up that accounted for 4.7 h. The productive time represented 23.0 h, for a total utilization of 93%. Delays represented 5.5% of total worksite time and were due to a major malfunction in the machine electronics and to the need interaction between yarding and felling, which resulted in some waiting time. Nevertheless, mechanical availability was very high and reached 96%. The total delay factor was 7.0%, calculated as a ratio between delays and PMH. Productivity was calculated at 6.86 m^3_{ub} PMH^{-1} or 6.41 m^3_{ub} SMH^{-1} for an average tree of 31 cm DBH.

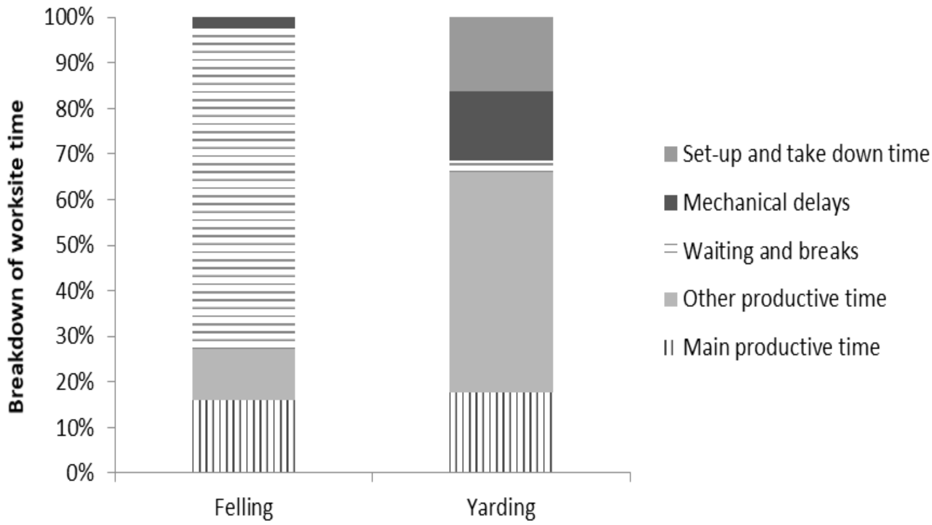

Fig. 1. Breakdown of worksite time

Productivity model for chainsaw felling

The number of valid observations collected during the tests was large enough to develop reliable models for predicting cycle time. Regression analysis showed that main productive time for felling was strongly correlated to tree DBH. The relationship can be described by the equation:

$$\text{Felling (s tree}^{-1}) = 0.192 \text{ DBH (cm)}^2 - 4.998 \text{ DBH (cm)} + 94.692 \qquad r^2 = 0.734$$

and the relationship between DBH volume of felled trees can be expressed as:

$$\text{Volume}_{ub} \text{ (m3)} = 0.0009 \times (\text{DBH (cm)})\text{^}2.4434 \qquad r^2 = 0.912$$

Once the main productive time has been estimated, then delays can be calculated using the felling delay factor. The sum of productive time and delay time will represent actual scheduled time, which can be used to calculate a productivity benchmark as a function of tree size.

Net productivity (excluding delays) was high, because the feller's task only included felling, with no or only minimal delimbing and cross-cutting. That, combined with the large tree size was used to determine a net productivity of 25.1 m^3_{ub} h^{-1}, excluding delays. However, supportive time and non-productive time (delays) decreased scheduled productivity and brought it down to match the productivity of the yarder.

Productivity model for yarding

The model resolution was increased by splitting the cycle time into three main tasks: outhaul, with an empty carriage; inhaul, with a loaded carriage; all other tasks, which could also be defined as terminal tasks. Outhaul and inhaul time was closely correlated with distance. Yet, this was the only strong correlation that was found through regression analysis: contrary to expectation, no correlation was found between load size and the duration of any tasks. That is probably due to a relatively small load size, which averaged 0.88 m^3_{ub} and varied a great deal (SD = 0.63). Such a small load was well below the rated capacity of the 3t carriage used for the study and may be the reason why load size was not found to have any significant effect on the cycle time. Regression analysis showed that cycle time could be predicted by the following equations:

Outhaul (s $turn^{-1}$) = 0.252 Dist (m) + 45.360 $r^2 = 0.604$

Inhaul (s $turn^{-1}$) = 0.318 Dist (m) + 58.560 $r^2 = 0.658$

Terminal time (s $turn^{-1}$) = 281

Terminal time includes loading, unloading and other stationary tasks. This model reflects productive time only and does not include delay time, which can be estimated from productive time using the 7.0% delay factor mentioned above. Using these equations, one could estimate productivity as a function of the extraction distance (fig. 2), for the average load (0.88 m^3_{ub}) and lateral yarding distance (20 m).

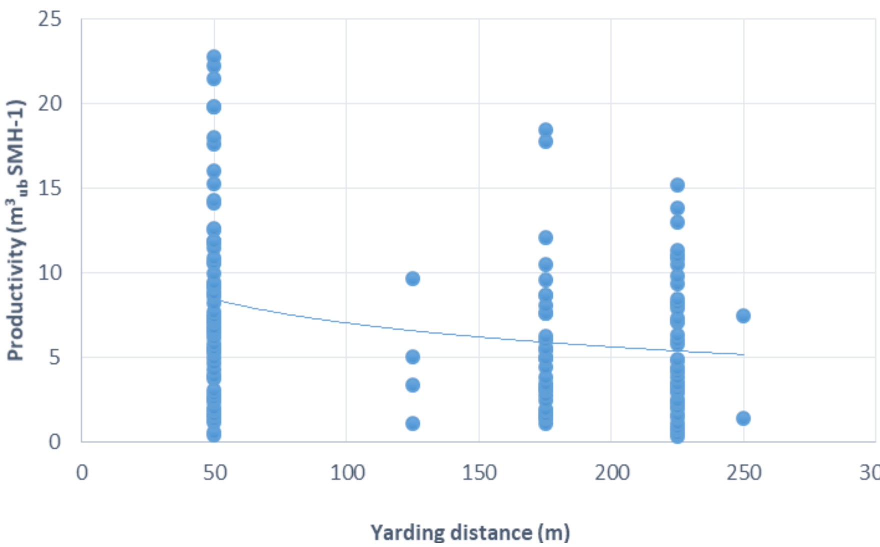

Fig. 2. Yarder productivity (m^3_{ub} SMH^{-1}) as a function of yarding distance

Stand damage

Overall, 218 trees were inspected for damage. Of these, 176 were damaged in some way, which represented an appalling 80%. In fact, the stand was denser on the lower border of the gaps than it was on the upper border so that the inspected trees were distributed unevenly and 126 were located on the lower buffer zone, while only 92 were located on the upper buffer zone. Damaged trees were 73 and 103, respectively. Therefore, the incidence of damage was 79% and 82% respectively for the forest above and below the gaps: table 4. However, a Chi-Square analysis showed that these differences had no statistical significance ($p = 0.496$) and therefore, one cannot state that damage was heavier on the lower portion of the forest.

In fact, much of the damage found in the survey was old. New damage caused by the logging operation represented 27% of the total.

Table 4. Results of the tree damage survey

Results of tree damage survey	Above the line	Below the line	SUM
Number of trees			
Undamaged trees	19	23	42
Trees with only old damages	51	66	117
Trees with new damage, but previously undamaged	11	9	20
Trees with old and new damage	11	28	39
SUM of all surveyed trees	92	126	218
Shares in %			
Share of trees without damage %	20.7	18.3	19.3
Share of trees with only old damage %	55.4	52.4	53.7
Share of trees damaged for the first time by the operation %	12.0	7.1	9.2
Share of all trees damaged by the operation%	23.9	29.4	27.1

Only 5% of the damage occurrences were located in the tree crown, while most of them (73%) were located on the boles, root collar and roots. Logging damage is especially frequent in these regions [Marchi et al. 2014], but that is also true for wounds caused by rock fall, which are most frequent in the first 2 m from the ground [Stoffel 2005]. Therefore, neither the position nor the characteristics of the wounds point at a specific agent. However, the relatively old age of most wounds, and the absence of logging in the past 80 years is a powerful indicator that rock fall is the main cause of tree damage, and that logging only inflicted an insignificant amount of damage.

Class 5 damage (≥200 cm^2) was dominant and represented over 70% of the damage surveyed: table 5. In fact, severe damage was generally old, which can be associated with the likely damage agent (large rocks) and also with the fact that small-size old damage is likely to become invisible over time, as the tree heals. New damage was distributed more evenly among severity classes, without any of them being as dominant as old damage (fig 4). As for damage incidence, no significant differences were found for damage severity between the upper and lower buffers, therefore, the data were not reported separately for these two zones.

Table 5. Damage severity

Damage	Area (cm^2)	Old	New	New & Old	Total	%
Class 1	10-29	0	2	0	2	1.1
Class 2	30-49	3	6	1	10	5.7
Class 3	50-99	6	3	2	11	6.3
Class 4	100-199	23	2	2	27	15.3
Class 5	≥200	85	7	34	126	71.6

Extensive previous damage also explained the relatively low quality of the harvest, which was represented by a majority of low-grade assortments – especially pulpwood in conifers and wood for boards and packaging in broadleaves (56%), and also C grade sawlogs (28%), according to Slovenian national standards for state-owned forests [Official Gazette 2011]. A and B grade sawlogs only represented 16% of the harvest, with negative consequences on owner revenues, and in general on the financial success of the harvesting operation (fig 3).

Discussion

Many papers already offer detailed information about yarder performance under a variety of work conditions [Lindroos and Cavalli 2016] and yet this study is the first one that explicitly addresses forests with such a dominant protection role to be the main factor in the selection of silvicultural treatment, harvesting technology and harvesting technique. Despite its preliminary character, this study contributes to filling an important knowledge gap, which makes it especially valuable. In practical terms, the study offers a productivity benchmark for forest managers, increasing their ability to correctly schedule and cost maintenance operations in protection forests.

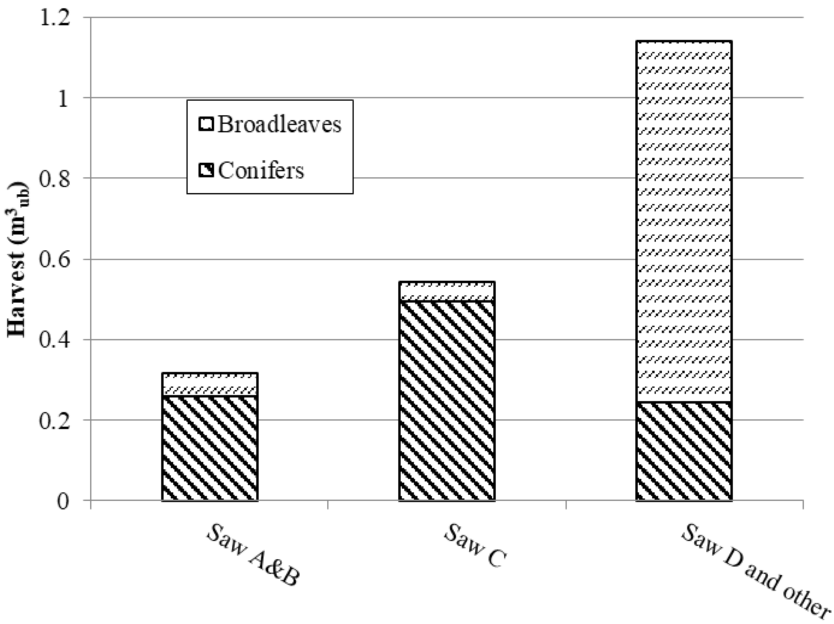

Fig. 3. Breakdown of total harvest by log quality class

Comparisons with the results of other yarding studies conducted in the European Alps indicate that the productivity recorded in this study is much lower than reported elsewhere. As a matter of fact, a recent study of whole tree yarding reports productivity figures between 20 and 26 m^3 PMH^{-1} [Spinelli et al. 2017]. A similar yarding study where the less efficient short-wood system was adopted also reports higher figures, varying from 12 to 17 m^3 PMH^{-1} [Spinelli et al. 2015]. In that regard, readers must notice that this comparison is intentionally presented in productive machine hours – not scheduled machine hours – in order to reduce the uncontrolled variability caused by the erratic occurrence of delays and by the differences in set-up and dismantle times due to specific terrain features, independent from the silvicultural treatment. Even so, yarder productivity as recorded in this study is 2 to 4 times lower than reported in other comparable studies conducted under similar conditions, but without the strong constraints imposed here by the dominant protection role of the forest being treated. That seems to reduce productivity to the levels reported for much smaller yarder types used in Mediterranean forests, such as the Turkish softwood stands [Açar et al. 2010; Senturk et al. 2007] or the Southern Italian coppice forests [Zimbalatti and Proto 2009].

That points to a marked loss of efficiency, which may be caused by the relatively small load size and/or the long cycle when compared with the other studies conducted under alpine conditions, mentioned above. These indicators are highly characteristic of difficult conditions and the special attention paid to avoiding soil disturbance, which has led to lower travel speed and payload size reduction. One could argue that short-wood extraction might have been a better option compared with whole-tree harvesting. By reducing the load length, one may have lifted it off the ground and prevented most of the soil disturbance, while increasing load size at the same time. Of course, short-wood extraction implies laborious stump site processing, but that might have had a limited effect on felling productivity, considering that under the whole-tree harvesting treatment the chainsaw operator was waiting idly most of the time, and therefore, much additional capacity was available.

Under standard conditions, short-wood harvesting is substantially less productive (and more expensive) than whole tree harvesting [Spinelli et al. 2008]. However, these were not standard work conditions and it is unlikely that turning to short-wood harvesting would have caused a further significant drop in productivity. In fact, removing the underutilized processor from the operation may have allowed for some savings, while sparing valuable landing space that had to be allocated to the piling of tops and branches.

Today short-wood harvesting can be completely mechanized even on steep terrain, with the introduction of cable-assist technology that enables ground-based machinery to negotiate steep terrain [Visser et al. 2014]. However, cable-assist technology is also quite expensive, and its main advantage is in increased worker safety rather than reduced harvesting cost [Visser and Stampfer 2015]. Furthermore, the specific conditions of protection forests may discourage use of cable-assist technology, especially if one of the main concerns is rock-fall. Obviously, driving heavy machines up and down the slope may turn into a major cause for rocks sliding down the hill and reaching the road down below, and the perpendicular offset of the line with high levels of lateral inclination is unfavourable for such machinery.

Regardless of the mechanization level, stump-site processing would allow the release of most of the nutrient on site, avoiding the risk of soil nutrient depletion, which might have been especially high on a rocky site such as the one covered by this study [Blanco 2012].

Conclusions

The main limitation of the study is in its preliminary and observational character. The study was performed under the conditions of a commercial operation and for this reason, it was impossible to organize a proper comparison between silvicultural treatments (e.g. small gaps vs. diffused selection harvest) or between alternative harvesting systems (e.g. whole-tree harvesting vs. short-wood harvesting). For the same reason, it was also impossible to test a wider and organized range of extraction distances and load sizes, among other things. Furthermore, the study covered one machine type and one crew, therefore, its results can only be generalized with much caution. Other similar studies have met with the same limitations, also explained by their observational character. In real practice, operators use specific techniques to deal with specific conditions, which makes it impossible to organize proper scientific experiments. Nevertheless, the information collected with this study is highly suggestive and may provide a solid starting platform for exploring the increasingly important issue of protection forest management, especially in the face of the effects of climate change [Seidl et al. 2011]. Further studies should address the harvesting of protection forests, and explore the full range of treatments, technologies and techniques.

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