Integrating Animal and Mechanical Operations in Protected Areas

Natascia Magagnotti, Raffaele Spinelli

Abstract – Nacrtak

The authors tested two alternative treatments for small wood extraction in protected conservation areas, respectively based on direct skidding by small crawler tractors and integrated horse bunching and crawler tractor skidding. The integration of horse bunching with tractor skidding proved cheaper than direct tractor skidding, and allowed extending the distance range of horse skidding. Integration also offers many additional benefits, as it can improve work safety and system sustainability. The performance of the integrated system can be optimized by paying special attention to team balance and by manipulating extraction distance. In industrialized countries, the number of horse loggers is so small that they may not contribute large wood volumes to the markets: however, the integration of animal and mechanical power may allow making the most efficient use of the few remaining horse logging operations, and increase their contribution to low-impact, cost-effective wood extraction in protected conservation areas. A similar and converse effect could be obtained in developing countries, where integration would allow making the most efficient use of the few available tractors. Efficient use of draught horses may also help increasing horse logger revenues, thus providing a further motivation to stay in business, and contributing to environmentally compatible economic development.

Keywords: logging, protected areas, draught animals, economics

1. Introduction – *Uvod*

In most industrialized countries, the use of draught animals in forest operations represents a curiosity, rather than a technical necessity. The rapid mechanization of all rural activities has brought animal power to the brink of extinction, despite the staunch resistance of its few loyal supporters. Every now and then, the concurrent publication of some works seems to signal a revival of animal power, but the tide cannot be turned. Until now, development pairs with mechanization, and in our modern economies animal power cannot aspire to much more than a small niche. But at least, that will prevent the loss of a huge cultural heritage, which includes genetic resources as well as specific know-how. If the horse was first domesticated in the Bronze Age (Mallory 1997), we are looking at over 5000 years of R&D, an effort that will dwarf the most ambitious of our current research programs. It would be a huge waste to lose this knowledge, if there was some sensible use for it. Many modern authors believe that there are still several reasons for resorting to animal power, and in particular to draught horses. Special opportunities could be offered by the current interest in mobilizing non-industrial private forestry (NIPF) resources. These are often too small for cost-effective mechanized harvesting, whose overall cost-efficiency is heavily affected by the fixed cost of moving the operation to the worksite (Väätäinen et al. 2006). That calls for appropriate system design and equipment selection, but the development of dedicated light-weight, low-cost and fully-mechanized operations (Becker et al. 2006) cannot solve all problems, especially when negotiating rough terrain (De Lasaux et al. 2009). Here draught horses are still somewhat popular, even in such an industrialized country as the United States (Toms et al. 1998). Furthermore, animal power can be deployed with much benefit in protected areas (Magagnotti and Spinelli 2011), where it configures as a low-impact alternative to conventional operations (Bahls 1991). Horses can skid through tight spaces in partial cuts with very little damage to residual trees (Thompson and Sturos 1984). Comparative studies have found that the percent of damaged trees drops to half (Dietz 1981, Schotz 1985) and damage severity to one third (Fickling et al. 1997) when animals are used instead of tractors. Similar considerations are true for soil impacts (Wang 1997, De Paul and Bailly 2005, Shresta et al. 2008), and the lower soil compaction caused by animal logging is indicated by Fries (1977) as the reason why trees growing near animal skid trails show significantly higher yields, compared to similar trees growing near machine skid trails. For these reasons, animal logging is becoming relatively popular in protected areas (Herold et al. 2009) and in the urban fringe (Egan 1998), to the point that some National parks in Italy routinely prescribe animal logging as the sole log extraction method allowed in their most sensitive zones (Proto, personal communication 2010). However, the design of such operations can be improved, with the purpose of maximizing profits, thus providing a solid financial justification for the deployment of draught animals. Draught horses are particularly effective in those bunching tasks that represent the weak spot of most tractor operations (DePaul et al. 2006), and this consideration was the starting point for this study, whose goals are: 1) to determine the performance and the cost of horse bunching in rough terrain; 2) to relate bunching productivity and cost to the main work conditions, such as distance, log volume and crew size; 3) to measure the productivity and cost benefits gained by tractor skidding as a result of pre-bunching; 4) to gauge the potential for improvement of both animal bunching and tractor skidding, and provide guidelines to optimized joint implementation.

2. Materials and methods – *Materijal i metode*

The study was conducted in the Castelli Romani Regional Park, a protected conservation area of strategic importance for its immediate vicinity to the city of Rome, in Italy. The park includes 9000 ha of forests and agricultural crops, and is richly endowed with cultural and historical heritage (www.parcocastelli-romani.it). Sweet chestnut (*Castanea sativa* L.) is the main forest species in the area, favored by the fertile volcanic substrate. Chestnut stands are normally coppiced every 15 – 20 years, with the purpose of producing poles and fencing assortments, particularly appreciated by the many local vine-growers. In its management plan, the Park maintains traditional economic exploitation, but requires that such activities be conducted with the utmost respect for the natural environment. Hence the need for conducting all logging operations with low-impact harvesting techniques, which explains the survival of animal logging and the interest in optimizing rather than replacing it. The study site is described in Table 1, and is representative for the area and for many chestnut stands, which generally grow on the slopes of extinct volcanoes, colonizing rather steep sites. Trees were felled, delimbed and topped by two-man crews, with a main operator felling and topping with a chainsaw, and a helper directing the fall with a pole and delimbing with an axe. Delimbed stems were then pulled downhill with draught horses, which dropped them along the main tractor trails, forming bunches of 5 – 10 pieces. Given the very steep slope, horse teams would use any pre-existing old tracks for climbing uphill to the loading site. If needed, new narrow tracks could be prepared within a very short time, using a pick and a shovel. Loads were dragged downhill, and the animals were trained to move fast and to step aside whenever stopping, so that the load would not hit their rear legs. As the slope gradient increased, choker chains were left longer, to avoid lifting the log ends, thus increasing friction and mitigating the risk of the load slipping downhill and towards the horse. For this very reason, stems would be dragged from the small end (Fig. 1). That would also minimize the need for any new tracks, as trees could be felled towards the old pre-existing mule paths, placed 20 to 40 m apart. In any case, full length stems were more stable than short logs, and had a limited tendency to slip or roll sideways. Two different horse teams were used for the study, each represented by one horse and its driver, because the rough terrain demanded agility and prevented the use of horse pairs. Both animals belonged to the Italian AITPR breed, which offers both strength and speed, since it was specifically selected in the XIX century for pulling coaches (www.caitpr.it). AITPR horses have similar traits to other heavy breeds normally used for logging, such as the Belgian and the Percheron (Pynn 1991), with which they share part of their gene pool. Both specimens selected for the study were stallions, aged between 7 and 10 years, and weighing about 700 kg. Three drivers were tested, all comparatively young (25 – 35 years of age) but very experienced with horse logging, which they had practiced for at least 5 years. No attempt was made to normalize individual performances by means of productivity ratings, recognizing that normalization or corrections can introduce new sources of errors and uncontrolled variation in the data material (Gullberg 1995). The study also included the tractor that collected bunched trees and dragged them to the main landing. This was a very simple operation, consisting of a small 44 kW crawler tractor, weighing about 4 tons. The crawler was manned by one operator, also young and expert. This operation was studied under two

Fig. 1 Delimbed stems were hooked by the small ends and dragged downhill

Slika 1. *Okresana su debla vezana u tovar tanjim krajem odignutim od tla i vučena nizbrdo*

Table 1 Description of the test site

Tablica 1. *Opis mjesta istraživanja*

Municipality – *Općina*	Velletri
Province – *Pokrajina*	Rome
Altitude – *Nadmorska visina*	650 m
Slope gradient – *Nagib terena*	61 %
Trail gradient – *Nagib vlake*	15 %
Road density – *Otvorenost šuma*	32 m^3/ha
Species – *Vrsta drveća*	*Castanea sativa* L.
Management – *Uzgojni oblik*	Coppice – *Šikara*
Treatment – *Vrsta sječe*	Clearcut – *Čista sječa*
Age – *Dob*	18 years – *18 godina*
Removal – *Sječna gustoća*	112 m^3/ha
	925 trees/ha – 925 stabala/ha
Residual density – *Preostala stabla*	85 trees/ha – 85 stabala/ha
Tree DBH – *Prsni promjer stabla*	0.13 m
Stem Height – *Visina debla*	9.2 m
Stem volume – *Obujam debla*	0.121 m^3

work modes, and namely: skidding with and without horse bunching. In the latter mode, the tractor driver was assisted by a choker man, and reached the loads in the forest, using existing small tracks or natural pathways. The effect of an assistant was also included in the horse bunching study, where observations were divided in two batches, depending on whether the horse team was or was not assisted by a second operator at the hooking site, who prepared the loads and cleared obstacles (Fig. 2). Since the eventual assistant would serve two horse teams at a

Fig. 2 A second operator assisting the horse driver at the loading site

Slika 2. *Pomoć drugoga radnika vodiču konja pri slaganju tovara u sječini*

Table 2 Costing: assumptions, cost centers and total cost
Tablica 2. *Troškovi: pretpostavke, mjesta troška i ukupni trošak*

Unit – *Sredstvo za rad*		Horse – *Konj*	Horse – *Konj*	Tractor – *Traktor*	Tractor – *Traktor*
Mode – *Način rada*		No helper *Bez pomoćnoga radnika*	Helper *S pomoćnim radnikom*	No helper *Bez pomoćnoga radnika*	Helper *S pomoćnim radnikom*
Investment – *Investicija*	Euro	3500	3500	45000	45000
Resale – *Preprodaja*	Euro	700	700	13500	13500
Service life – *Razdoblje održavanja*	Years – *Godina*	10	10	10	10
Utilization – *Iskorištenost*	h/year *h/god.*	1000	1000	1000	1000
Interest rate – *Kamatna stopa*	%	4	4	4	4
Depreciation – *Pad vrijednosti*	Euro/year *Euro/god.*	280	280	3150	3150
Interests – *Kamate*	Euro/year *Euro/god.*	90	89.6	1233	1233
Insurance – *Osiguranje*	Euro/year *Euro/god.*	179	179.2	1233	1233
Fodder – *Krmno bilje*	Euro/year *Euro/god.*	3000	3000	-	-
Vet – *Veterinar*	Euro/year *Euro/god.*	400	400	-	-
Shoeing – *Potkivanje*	Euro/year *Euro/god.*	500	500	-	-
Daily care – *Dnevna njega*	Euro/year *Euro/god.*	2738	2738	-	-
Diesel – *Dizelsko gorivo*	Euro/year *Euro/god.*	-	-	6600	6600
Lube – *Motorno ulje*	Euro/year *Euro/god.*	-	-	2442	2442
Repairs – *Popravci*	Euro/year *Euro/god.*	-	-	2520	2520
Total – *Ukupno*	Euro/h	7.2	7.2	17.2	17.2
Crew – *Broj radnika*	n	1	1.5	1	2
Labor – *Trošak radnika*	Euro/h	15	15	15	15
Labor – *Trošak rada*	Euro/h	15	22.5	15	30
Overheads – *Opći troškovi*	Euro/h	4.4	5.9	6.4	9.4
Total rate – *Ukupna cijena*	Euro/h	26.6	35.6	38.6	56.6

Cost in Euro (€) as on April 30, 2010. – *Troškovi izraženi u eurima prema tečaju 30. travnja 2010.* (1 € = 1.33 US$)

time, only half of its cost was added to the cost of the single horse team when working in the »assisted« mode.

A time-motion study was carried out to evaluate team productivity and to identify the variables that are most likely to affect it, such as extraction distance and payload size (Bergstrand 1991). Each cycle was stop watched individually, separating productive time from delay time (Bjorheden et al. 1995). Extraction distances were determined with a measuring tape. No correction was made for slope gradient, so that these distances represent the actual paths covered by extraction units. Load size was estimated by measuring the diameter at breast height (DBH) of all trees in each cycle. DBH records were converted into stem wood volume using a single-entry tariff table specifically calculated for the purpose, on the basis of 100 sample trees, distributed along all diameter classes. Sample trees were scaled by measuring DBH, total length and diameter at mid-length. Data from individual cycle observations were analyzed with regression techniques in order to calculate meaningful relationships between productive time consumption and work conditions, such as extraction distance and load size. Indicator variables were used to mark differences between treatments (Olsen et al. 1998).

The tractor rate was calculated with the method described by Miyata (1980), on an estimated annual utilization of 1000 scheduled machine hours (SMH) and a depreciation period of 10 years. The costs of fuel, insurance, repair and service were obtained directly from the operator. The cost of the animals was calculated along similar lines, after making some adjustments to account for the difference between machines and living creatures (Akay 2005). The cost of the horse also includes the labor needed for daily animal care, estimated to 0.5 hours per day. In all cases, labor cost was set to 15 € SMH^{-1} inclusive of indirect salary costs. The calculated operational cost of all teams was increased by 20% to account for overhead costs (Hartsough 2003). Further detail on cost calculation is shown in Table 2, where all costs are first presented as annual costs and then converted into hourly costs, to facilitate comparison. These figures are comparable to those recently presented by Blumenstein (2008) and Schroll (2008), after accounting for the lower labor rates of Italy compared to Germany.

The study material consisted of 185 horse turns and 40 tractor turns, necessary for extracting 436 and 263 stems, respectively (70 and 42 m^3). Overall, the time study sessions lasted about 50 hours. The experiment was divided in two parts: one for horse bunching and the other for tractor extraction. In both cases, one complete turn would represent a replicate. Replicates were distributed randomly over the full work area, trying to cover the largest range of bunching and extraction distances.

However, readers must note that data were collected from actual commercial operations, which made it very difficult to obtain the balance of factors normally obtained under more artificial conditions. Despite randomization and extensive replication, our results are only representative of the specific case described here, and should not be extrapolated or generalized without much caution. However, these results well represent the actual world, where different systems are seldom used under identical conditions.

3. Results and discussion – *Rezultati s diskusijom*

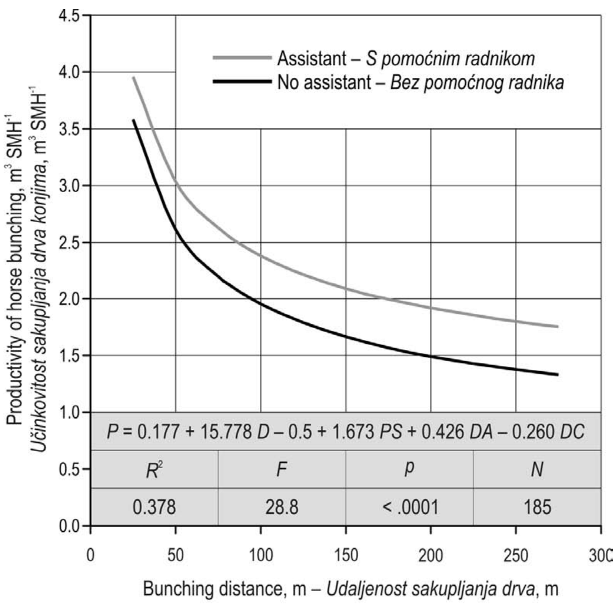
Table 3 shows the main results obtained from the test. The average net productivity of horse bunching varied between 1.7 and 2.6 m^3 SMH^{-1}, depending extraction distance and the presence of a loading assistant at the stump site. Horse bunching did tractor productivity, which jumped from 2.3 to 5.3 m^3 SMH^{-1}, despite the longer extraction distance. The system based on horse bunching allowed a 10% reduction of extraction cost, and a potential for reducing skid trail density to one third of the original value.

However, the data shown in Table 3 represent average values recorded under different extraction distances, and a better comparison can be made only after recalculating productivity as a function of distance, using regression analysis. The results are shown in Fig. 3 for horse bunching and in Fig. 4 for tractor skidding. Both regressions are highly significant, but explain only 35 to 55% of the overall variability. That is the effect of delays time, typically erratic and capable of introducing a significant degree of variability in any regression. Better results could be obtained by excluding delay time from the observations, or by spreading it evenly (Spinelli et al. 2009). However, the authors thought that the inclusion of the original delay time records may better

Table 3 Extraction productivity and cost: summary table
Tablica 3. *Učinkovitost i troškovi privlačenja – zbirna tablica*

Unit – *Sredstvo za rad*		Horse – *Konj*	Horse – *Konj*	Tractor – *Traktor*	Tractor – *Traktor*
Mode – *Način rada*		No helper *Bez pomoćnoga radnika*	Helper *S pomoćnim radnikom*	Horse bunching *Sakupljanje drva konjima*	Direct skidding *Neposredno privlačenje*
Distance – *Udaljenost*	m	173	99	445	206
Stem size – *Obujam debla*	m^3	0.15	0.20	0.10	0.19
Load size – *Veličina tovara*	Pieces – *Komada*	2.5	2.2	8.5	4.6
Load size – *Obujam tovara*	m^3	0.33	0.39	1.30	0.82
Total time – *Ukupno vrijeme*	min	13.7	10.3	17.4	24.4
Delay – *Prekidi*	%	26.8	33.5	7.6	24.7
Productivity – *Učinak*	m^3 SMH^{-1}	1.73	2.60	5.31	2.27
Cost – *Trošak*	Euro/m^3	15.4	13.7	7.27	24.94

SMH = Scheduled Machine Time, i.e. worksite time including all delays – *Vrijeme stroja na radnome mjestu koje uključuje sve prekide rada*



P = Productivity of horse bunching, m^3 SMH^{-1}
Učinkovitost sakupljanja drva konjima, m^3 SMH^{-1}
D = Bunching distance, m – *Udaljenost sakupljanja drva*, m
PS = Piece size, m^3 – *Obujam komada*, m^3
DA = Dummy assistant: 0 if no assistant, 1 if an assistant is detached
Koeficijent pomoćnika: 0 bez pomoćnog radnika, 1 s pomoćnim radnikom
DC = Dummy crew: 0 if crew A, 1 if crew B
Koeficijent skupine: 0 za skupinu A, 1 za skupinu B
Note: the curves in the graph were calculated for crew A, 0.26 m^3 SMH^{-1} more productive than crew B
Opaska*: skupina A je 0.26* m^3 SMH^{-1} *produktivnija od skupine B*

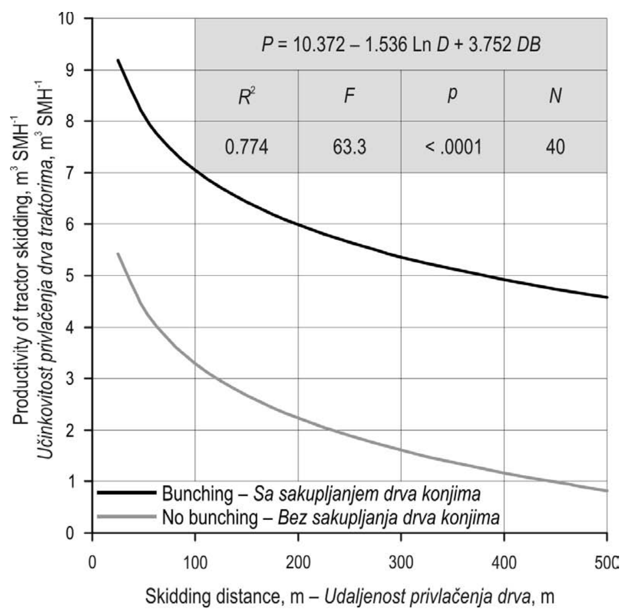
Fig. 3 Horse bunching productivity as a function of distance and crew size

Slika 3. *Učinkovitost sakupljanja drva konjima u ovisnosti o udaljenosti i broju radnika*

represent the inherent variability of the process, and would not invalidate the equations, which do retain a high statistical significance. At any rate, Table 4 reports the time consumption regressions calculated for each time element: readers can use these equations to check the relationship between time consumption for a specific task and the main influencing factors. The authors calculated bunching and extraction productivity both by using the overall productivity equations shown in Fig. 3 and 4, and by using the time consumption equations in Table 4. The results were very near, and the authors decided to stick with the original all-inclusive productivity equations, which are simpler to use and guarantee a better representation of the observed cycles. It is worth noticing that the bunching productivity increase offered by detaching an assistant to help with loading can barely repay the additional cost of the assistant: therefore, it is best if the horse driver attaches the loads on his own, without additional help.

Fig. 5 reports the result of a three-way comparison including: a) tractor skidding without horse bunching, b) tractor skidding after horse bunching, over an average bunching distance of 75 m (which is deducted from skidding distance), c) horse extraction up to the maximum recorded distance of 275 m. Overall cost was calculated after estimating bunching and skidding productivities with the equations in Fig. 3 and 4. The integration of horse bunching and tractor skidding allows significant economies over direct tractor skidding, with savings ranging between 18 and 65%. Among other things, horse bunching allows accumulating larger tractor loads (1.3 vs. 0.8 m^3), which limits the effect of extraction distance: therefore, the savings obtained with horse bunching increase with total extraction distance. If the total extraction distance is shorter than 200 m, then horse skidding is the cheapest alternative.

Notes: the curves were calculated based on the equations attached to Fig. 1 and 2; for the integrated horse + tractor treatment it was assumed that the horse would bunch over the first 75 m and the tractor would skid over the remaining distance; maximum horse extraction distance corresponds to the maximum observed in the study.



P = Productivity of tractor skidding, m^3 SMH^{-1}
Učinkovitost privlačenja drva traktorima, m^3 SMH^{-1}
D = Bunching distance, m – *Udaljenost sakupljanja drva*, m
DB = dummy bunch: 0 if no horse bunching, 1 if horse bunching
Koeficijent sakupljanja: 0 bez sakupljanja drva konjima, 1 sa sakupljanjem drva konjima

Fig. 4 Tractor skidding productivity as a function of distance and bunching

Slika 4. *Učinkovitost privlačenja drva traktorima u ovisnosti o udaljenosti i sakupljanju drva*

Table 4 Basic relationships for the analytical calculation of productivity
Tablica 4. *Osnovni odnosi za analitičko izračunavanje učinkovitosti*

Element – *Element*	Relationship – *Odnos*	r^2	*F*	*p*
	Horse bunching – *Sakupljanje drva konjima*			
Empty trip – *Hod nenatovarenih konja*	$T = 0.243 + 0.016\ D + 0.003\ DC * D$	0.916	989.5	<.0001
Load – *Utovar*	$T = 1.445 + 0.800\ NP - 0.834\ DA$	0.340	46.9	<.0001
Loaded trip – *Hod natovarenih konja*	$T = -0.051 + 0.009\ D + 0.001\ DC * D$	0.799	361.1	<.0001
Unload – *Istovar*	$T = 0.450 + 0.303\ NP$	0.243	58.6	<.0001
Delay Factor – *Koeficijent prekida*	0.47 if no assistant, 0.68 if assistant *0,47 bez pomoćnoga radnika, 0,68 s pomoćnim radnikom*	Unpaired *t*-test *Neparni t-test*		0.049
Load size – *Obujam tovara*	0.33 m^3 if no assistant, 0.39 m^3 if assistant *0,33 m^3 bez pomoćnoga radnika, 0,39 m^3 s pomoćnim radnikom*	Unpaired *t*-test *Neparni t-test*		0.007
	Tractor skidding – *Privlačenje drva traktorom*			
Empty trip – *Vožnja praznoga traktora*	$T = 0.135 + 0.010\ D - 0.002\ DB * D$	0.966	524.7	<.0001
Load – *Utovar*	$T = -4.551 + 18.898\ V - 12.413\ DB * m^3$	0.416	13.2	<.0001
Loaded trip – *Vožnja natovarenoga traktora*	$T = 0.335 + 0.009\ D + 0.833\ V - 0.834\ DB$	0.954	250.3	<.0001
Unload – *Istovar*	$T = 1.663 + 1.745\ V - 1.134\ DB$	0.324	8.9	<.0001
Delay Factor – *Koeficijent prekida*	0.39 if no horse bunching, 0.12 if horse bunching *0,39 bez sakupljanja drva konjima, 0,12 sa sakupljanjem drva konjima*	Unpaired t-test *Neparni t-test*		0.002
Load size – *Obujam tovara*	0.82 m^3 if no horse bunching, 1.30 m^3 if horse bunching *0,82 m^3 bez sakupljanja drva konjima, 1,30 m^3 sa sakupljanjem drva konjima*	Unpaired t-test *Neparni t-test*		0.001

T = time consumption per turn, min×turn^{-1} – *Utrošak vremena po turnusu*, min × turn^{-1}
D = bunching or extraction distance, m – *Udaljenost sakupljanja ili privačenja drva*, m
NP = number of pieces in the load – *Broj komada u tovaru*
V = load volume size, m^3 – *Obujam tovara*, m^3
DA = dummy assistant: 0 if no assistant, 1 if an assistant is detached – *Koeficijent pomoćnika: 0 bez pomoćnoga radnika, 1 s pomoćnim radnikom*
DB = dummy bunch: 0 if no horse bunching, 1 if horse bunching – *Koeficijent sakupljanja: 0 bez sakupljanja drva konjima, 1 sa sakupljanjem drva konjima*
DC = dummy crew: 0 if crew A, 1 if crew B – *Koeficijent skupine: 0 za skupinu A, 1 za skupinu B*
Delay Factor = Delay time/Net work time – *Koeficijent prekida = vrijeme prekida/efektivno vrijeme* (Spinelli i Visser 2009)

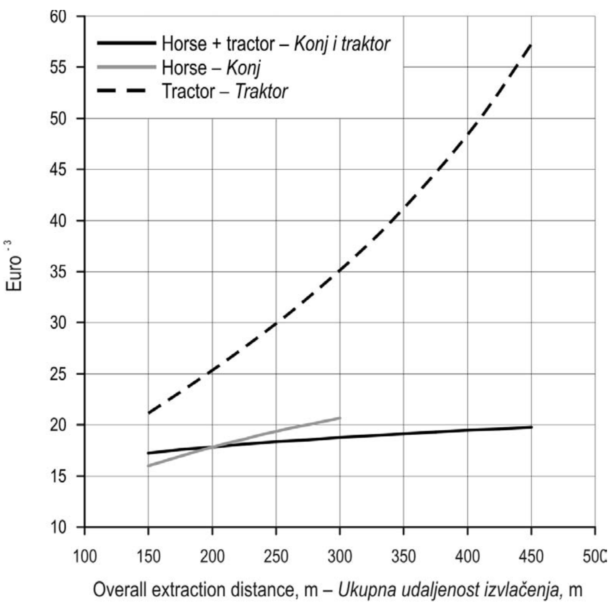


Fig. 5 Total extraction cost as a function of distance and treatment
Slika 5. *Ukupni troškovi u ovisnosti o udaljenosti privlačenja i sredstvima rada*

4. Discussion – *Rasprava*

Skidders work best with pre-assembled loads, which explains the enduring success of traditional operations that integrate feller-bunchers and grapple-skidders. However, steep terrain harvesting does not offer favorable conditions to traditional operations, especially when dealing with small trees. Opening a dense trail network may result unprofitable, and will certainly clash with the environmental restrictions imposed on protected areas. On these sites, managers try to contain both the density and the width of extraction trails, which also explains the choice of a small agricultural tractor rather than a rubber-tired skidder. Here, the mechanical alternatives to horse bunching are winches and mini-skidders. Other authors have already compared horse bunching with winching, demonstrating that horses offer a cheaper alternative to tractor-mounted winches (Harstela and Tervo 1981, Hedman 1988) and independent radio controlled winches (Leek 1976, Leinert 1979). As to mini-skidders, most models cannot negotiate rough terrain, and even in flat terrain horses offer a cheaper service than mini-skidders (Dekking 1984).

Apparently, draught horses are still the best option for tree bunching on steep terrain. In fact, when the extraction distance does not exceed 200 m, draught horses can perform the whole job at a lower cost than crawler tractors, as already reported by Host and Schlieter (1978) some 30 years ago. The fact that these basic relationships have not changed in 30 years is not surprising, because mechanization has replaced animal power in big wood and easy terrain, but is still struggling to find a viable solution to small wood harvesting in steep terrain, especially when environmental performance is a crucial issue. In industrialized countries, the number of horse loggers is so small that they may not offer this solution on any significant scale, even if they had it: however, the integration of animal and mechanical power may allow making the most efficient use of the few remaining operations. A similar and converse effect could be obtained in developing countries, where integration would allow making the most efficient use of the few available tractors. Efficient use of draught horses may also help increasing horse logger revenues, thus providing a further motivation to stay in business. That may add a further social and historical dimension to conservation, by fostering a work technique which roots deep into local history and culture.

A careful analysis of the bunching sequence may address the question of improvement potential. Any attempts at increasing horse bunching productivity may not follow the same principles normally applied to mechanized operations. The living machine works on muscle power, which gets depleted very quickly and needs frequent rest stops for energy recovery. It is unlikely that one may increase travel speed and/or decrease loading and unloading time, without experiencing a proportional increase in the frequency and duration of rest stops. This was demonstrated by the study, where detaching an assistant to the loading site resulted in a decrease of loading time from 11.9 to 6.6 min per m^3, which was followed by an increase of the delay factor (e.g. the ratio between delay time and net work time, see Spinelli and Visser 2009) from 0.65 to 0.76. Both these differences resulted significant to ANOVA testing, with p-values of 0.001 and 0.031, respectively for loading time and delay factors. Apparently, the best strategy to increase horse bunching productivity is the reduction of animal fatigue, by avoiding unnecessary effort. In flat terrain, this would involve the adoption of suitable devices to reduce drag friction, such as sleds, cones or skidding pans (Hedman 1987). These devices may not suit steep terrain operations, where friction is required for load control. Here, unnecessary effort can be avoided by reducing extraction distance to the bare minimum, since rest time per turn is significantly correlated (R^2 0.55, F 20.8, $p < 0.001$) to both bunching distance and load size, according to the following equation: T (min turn^{-1}) = 0.486 + 0.028 * distance (m) + 11.540 load (m^3). While reducing load size would also reduce productivity, reducing bunching distance will decrease rest time and increase productivity. In turn, the reduction of bunching distance is obtained by integrating animal and mechanical power, which is the very subject of this paper. A further strategy to increase bunching productivity may consist in using more animals per driver, since draught horses can do most of the work independently, without direct human intervention. This technique is already very common with pack mules, where it certainly offers good results (Ghaffariyan et al. 2009). Its effect with horse skidding could be checked by further studies, which should also determine if the productivity increase is large enough to justify the cost of the additional horse, which represents a 33% increase over the cost of a single horse team. Finally, it must be stressed that any integrated system involves team interaction and the risk for interaction delays: therefore, optimization must also address the crucial questions of organization and team balance, which may be the reason for the low utilization already observed in some integrated animal-machine operations (Shresta et al. 2005).

5. Conclusions – *Zaključci*

The integration of horse bunching with tractor skidding offers a cost-effective solution to small wood extraction in steep terrain and in protected conservation areas. This solution proves cheaper than direct tractor skidding, and allows extending the distance range of horse extraction. The result is a reduction of harvesting cost and skid trail density, both particularly desirable. Integration also offers many additional benefits, as it can improve work safety and system sustainability. Horse bunching is potentially safer than tractor extraction, as drivers can control their horses with voice commands, keeping at a safe distance whenever required (Snoek 2000). Furthermore, horse logging systems are based on renewable resources for 60% of their inputs, whereas tractor systems rely on renewable resources only for 9% of their inputs (Rydberg and Jansén 2002). The performance of the integrated system can be optimized by paying special attention to team balance and by manipulating extraction distance, so that horse bunching may occur over reasonably short stretches. This will allow achieving a higher productivity, while making the most efficient use of the few animal crews still available.

6. References – *Literatura*

Akay, A., 2005: Determining cost and productivity of using animals in forest harvesting operations. J. Appl. Scie. Res. 1(2): 190–195.

Bahls, J., 1991: Horsepower logging. Am. For. 97(1/2): 49–59.

Becker, P., Jensen, J., Meinert, D., 2006: Conventional and Mechanized Logging Compared for Ozark Hardwood Forest Thinning: Productivity, Economics, and Environmental Impact. Nort. J. App. For. 23(4): 264–272.

Bergstrand, K.G., 1991: Planning and analysis of forestry operation studies. Skogsarbeten Bulletin 17, 63 p.

Blumenstein, B., 2008: Arbeitswirtschaftliche ehrebungen beim arbeitspferdeeinsatz als kalkulationsgrundlage der produktionsplanung. Thesis, Faculty of Agricultural Ecology and Economy, University of Kassel, Germany.

Björheden, R., Apel, K., Shiba, M., Thompson, M., 1995: IUFRO Forest work study nomenclature. Swedish University of Agricultural Science, Dept. of Operational Efficiency, Garpenberg, 16 p.

Dekking, J., 1984: Goliat, a small tractor with tracks. IEA/FE/CPC7 Report, 17 p.

De Lasaux, M., Hartsough, B., Spinelli, R., Magagnotti, N., 2009: Small parcel fuel reduction with a low-investment, high-mobility operation. West. J. Appl. For. 24(4): 205–213.

De Paul, M., Bailly, M., 2005: À propos de la pression exercée par les pneus, chenilles et sabots. Forêt Wallonne 78: 21–33.

De Paul, M., Lombaerde, F., Jourez, B., 2006: Approche économique du cheval en forêt. Forêt Wallonne 81: 15–25.

Ficklin, R., Dwyer, J., Cutter, B., Draper, T., 1997: Residual tree damage during selection cuts using two skidding systems in the Missouri Ozarks. Proceedings of the 11th Central Hardwood For. Conf. USDA Forest Service Gen Tech Rep NC-188: 36–46.

Dietz, P., 1981: Vermeidung und behandlung von rückenschaden. Allgemeine Forstzeitschrift 12: 263–265.

Egan, A., 1998: Clashing values at the urban fringe: is there a niche for horse logging. North Log Timber Process 32: 16–17.

Fries, J., 1977: Sänker skogstractoren tillväten? Skogen 6: 222–224.

Ghaffaryian, M., Durston, T., Sobhani, H., Mohadjer, M., 2008: Mule logging in northern forests of Iran: a study of productivity, cost and damage to soil and seedlings. Croat. J. For. Eng. 29(1): 67–75.

Gullberg, T., 1995: Evaluating operator-machine interactions in comparative time studies. Int. J. For. Eng. 7(1): 51–61.

Harstela, P., Tervo, L., 1981: Bunching of timber by winches and horse. Folia Forestalia 466, 20 p.

Hartsough, B., 2003: Economics of harvesting to maintain high structural diversity and resulting damage to residual trees. West. J. Appl. For. 18(2): 133–142.

Hedman, L., 1987: Tools and equipment for horse logging. Small Scale For. 1: 10–17.

Hedman, L., 1988: Skidding with horse to strip road. Small Scale For. 2: 15–19.

Herold, P., Jutta, J., Scharnhölz, R., 2009: Arbeitspferde im Naturschutz. BfN-Skripten 256. Bonn, Germany, 139 p.

Host, J., Schlieter, J., 1978: Low-cost harvesting systems for intensive utilization in small-stem lodgepole pine stands. USDA Forest Service Research Paper no. INT-201. 20 p.

Leek, N., 1976: Bunching with Radiotir 740 in thinnings. Nederlands Bosbouw Tijdschrift 48: 151–157.

Leinert, S., 1979: Einsatz veraltungseingener pferde beim vorrücken von schwachholz. Forsttechnische Informationen 1: 4–6.

Magagnotti, N., Spinelli, R., 2011: Financial and energy cost of low-impact wood extraction in environmentally sensitive areas. Ecological Engineering 37(4): 601–606.

Mallory, J., 1997: Encyclopedia of Indo-European Culture. Ed. Fitzroy Dearborn, London. ISBN 9781884964985

Miyata, E., 1980: Determining fixed and operating costs of logging equipment. General Technical Report NC-55. Forest Service North Central Forest Experiment Station, St. Paul, MN. 14 p.

Olsen, E., Hossain, M., Miller, M., 1998: Statistical Comparison of Methods Used in Harvesting Work Studies. Oregon State University, Forest Research Laboratory, Corvallis, Oregon. Research Contribution n 23. 31 p.

Pynn, L., 1991: Logging with horse power. Can. Geogr. 3: 31–35.

Rickenbach, M., Steele, T., 2006: Logging firms, nonindustrial private forests, and forest parcelization: evidence of firm specialization and its impact on sustainable timber supply. Can. J. For. Res. 36(1): 186–194.

Rydberg, T., Jansén, J., 2002: Comparison of horse and tractor traction using emergy analysis. Ecol. Eng. 19(1): 13–28.

Shresta, S., Rummer, R., Dubois, M., 2005: Utilization and cost of log production from animal logging operations. Int. J. For. Eng. 16: 167–180.

Schotz, J., 1985: Bestandesschäden bei der holzernte: forderungen und wünsche des waldbauhaus. Der Forst und Holzwirt, 14: 375–379.

Schroll, E., 2008: Holzrücken mit pferden – Handbuch für die waldarbeit mit pferden. Starke Pferde Verlag, Lemgo, Germany.

Shresta, S., Lanford, B., Rummer, R., Dubois, M., 2008: Soil disturbances from horse/mule logging operations coupled with machines in the Southern United States. Int. J. For. Eng. 19(1): 17–23.

Snoeck, B., 2000: Ces chevaux »qui traînent au bois«. Forêt Wallonne 46: 12–23.

Spinelli, R., Visser, R., 2009: Analyzing and estimating delays in wood chipping operations. Biomass Bioenergy 33(3): 429–433.

Spinelli, R., Magagnotti, N., Picchi, G., 2009: Complete tree harvesting as an alternative to mulching in early thinnings. Forest Products Journal 59(6): 79–84.

Toms, C., Wilhoit, J., Dubois, M., Bliss, J., Rummer, B., 1998: Animal logging fills important timber harvesting niche in Alabama. Alabama Agricultural Experiment Station. Highlights of Agricultural Research 45(1): 7–8.

Väätäinen, K., Asikainen, A., Sikanen, L., Ala-Fossi, A., 2006: The cost effect of forest machine relocations on logging costs in Finland. For. Studies 45: 135–141.

Wang, L., 1997: Assessment of animal skidding and ground machine skidding under mountain conditions. J. For. Eng. 8(2): 57–64.

Sažetak

Povezivanje animalnoga i strojnoga rada u zaštićenim područjima

U većini je razvijenih zemalja upotreba animalne snage pri izvođenju šumskih radova vrlo rijedak slučaj. Tek se povremeno pojavi pojedini znanstveni članak koji zagovara ponovnu upotrebu životinja u šumskom radu. Istraživanje upotrebe životinja pri izvođenju šumskih radova u kombinaciji sa šumskom mehanizacijom počiva na pretpostavci da vučni konji ostvaruju veći učinak pri sakupljanju drva nego rad skidera (DePaul i dr. 2006).

Ciljevi su istraživanja: 1) odrediti učinak i troškove sakupljanja drva na teškom terenu; 2) povezati učinak sakupljanja drva s utjecajnim čimbenicima, kao što su udaljenost privlačenja, obujam tovara, brojnost grupe; 3) odrediti proizvodnost i smanjenje troškova traktora koji privlači sakupljena drva; 4) odrediti mjere za optimiziranje zajedničke proizvodnosti životinjskoga sakupljanja drva i privlačenja drva traktorima.

Istraživanja su provedena u regionalnom parku Castelli Romani, koji je zaštićeno područje od strateške važnosti zbog neposredne blizine grada Rima. Park se prostire na 9000 ha šumskoga i poljoprivrednoga zemljišta, te je na području bogatoga kulturnoga i povijesnoga nasljeđa. Najproširenija je vrsta drveća pitomi kesten (Castanea sativa L.) koji se svakih 15 do 20 godina siječe čistom sječom zbog proizvodnje stupova i kolja za ograde za potrebe lokalnih vinara. Kako je to zaštićeno brdovito područje, potrebno je pri pridobivanju drva koristiti okolišno prihvatljive tehnologije te se stoga upotrebljavaju vučni konji pri izvođenju šumskih radova. Mjesto istraživanja objašnjeno je u tablici 1.

Prilikom istraživanja napravljena je studija rada i vremena kako bi se izračunala učinkovitost i odredili utjecajni čimbenici. Studijom rada i vremena snimane su po dvije inačice za privlačenje drva traktorom (s pomoćnim radnikom ili bez njega) te dvije inačice za sakupljanje drva (s pomoćnim radnikom ili bez njega). Pomoćni radnik kod traktora imao je ulogu kopčaša, a u radu s konjima zadatak mu je bio priprema tovara i uklanjanje zapreka s vlake. Sakupljanje i privlačenje drva konjima obavljalo se niz nagib, s tanjim krajem odignutim od tla zbog povećanja otpora izvlačenja čime se izbjegava udar tovara na konjske noge pri kretanju nizbrdo. U istraživanju je korišten gusjenični traktor, snage motora 44 kW i mase oko 4 tone. Mjernom je vrpcom mjerena stvarna udaljenost privlačenja. Obujam je tovara određivan pomoću jednoulaznih tablica, napravljenih samo za ovo istraživanje na 100 odabranih stabala ravnomjerno raspoređenih po prsnim promjerima. Prikupljeni su podaci dalje obrađeni statističkim metodama kako bi se utvrdili odnosi između efektivnoga vremena rada i radnih uvjeta, kao što su udaljenost privlačenja i obujam tovara.

Izračun je troškova prikazan u tablici 2. Troškovi su najprije određivani na godišnjoj razini, a zatim radi lakše usporedbe preračunavani su u troškove po satu. Ukupni se troškovi rada kreću od 26,6 €/h (konj bez pomoćnoga radnika) do 56,6 €/h (traktor s pomoćnim radnikom). Tijekom istraživanja snimljeno je 185 turnusa sakupljanja s konjima i 40 turnusa privlačenja drva traktorom.

Prosječna se proizvodnost sakupljanja drva konjima kretala od 1,7 m^3/h do 2,6 m^3/h, ovisno o udaljenosti privlačenja i prisutnosti pomoćnoga radnika (slika 3). Sakupljanje drva povećalo je proizvodnost traktora (slika 4) s 2,3 m^3/h na 5,3 m^3/h unatoč povećanju udaljenosti privlačenja (tablica 3).

Rezultati regresijske analize na slikama 3 i 4 pokazuju veliku značajnost, ali opisuju samo 35 % do 55 % varijabilnosti, jer je velik utjecaj vremena prekida rada na varijabilnost. Učinkovitost se sakupljanja i privlačenja drva izračunala temeljem jednadžbi dobivenim regresijskom analizom prikazanim na slikama 3 i 4 te također korištenjem jednadžbi utroška vremena iz tablice 4. Pri tome su dobivene podjednake vrijednosti, ali zbog velike varijabilnosti dobivene regresijskom analizom u daljnjem proračunu učinkovitosti korištene su samo jednadžbe utroška vremena.

Na slici 5 prikazani su rezultati usporedbe triju načina privlačenja drva: privlačenje drva traktorom bez prethodnoga sakupljanja drva konjima, privlačenje drva traktorom nakon prethodnoga sakupljanja drva konjima (srednja udaljenost sakupljanja 75 m) te izvlačenje drva konjima do udaljenosti izvlačenja od 275 m. Ukupni su troškovi određeni nakon izračuna učinka sakupljanja i privlačenja drva pomoću jednadžbi iz slika 3 i 4. Povezivanje sakupljanja i privlačenja drva omogućuje značajne uštede, između 18 % i 65 %, u usporedbi s neposrednim privlačenjem. Među ostalim, sakupljanje drva omogućuje povećanje tovara traktora (s 0,8 m^3 na 1,8 m^3), što ograničava učinak udaljenosti privlačenja, stoga se uštede napravljene sakupljanjem drva povećavaju s ukupnom udaljenošću privlačenja drva traktorom. Ako je udaljenost privlačenja manja od 200 m, tada je izvlačenje drva konjima jeftinija inačica.

Povezivanje sakupljanja i privlačenja drva isplativo je rješenje u pridobivanju drva maloga obujma na strmim terenima i u zaštićenim područjima. To se rješenje pokazalo isplativijim od neposrednoga privlačenja drva. Rezultat je toga smanjenje troškova pridobivanja drva, smanjenje gustoće traktorskih putova i vlaka i povećanje sigurnosti rada. Učinak objedinjenoga sustava može se poboljšati ako se obrati pozornost na broj radnika i na udaljenost privlačenja.

Ključne riječi: privlačenje drva, zaštićena područja, vučne životinje, ekonomika

Received (*Primljeno*): June 23, 2010
Accepted (*Prihvaćeno*): April 11, 2011

Authors address – Adresa autora:

Raffaele Spinelli, PhD.
e-mail: spinelli@ivalsa.cnr.it
CNR – Ivalsa
Via Madonna del Piano Pal. F
I-50019 Sesto Fiorentino
ITALY

Natascia Magagnotti, MSc.
e-mail: magagnotti@ivalsa.cnr.it
CNR – Ivalsa
Via Biasi 75
I-38010 San Michele all'Adige (TN)
ITALY