

PRODUCTIVITY AND COST ANALYSIS OF LOGGING ARCH USED WITH FARM TRACTOR IN MEDITERRANEAN FOREST SKIDDING OPERATIONS

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SUMMARY

The development and use of a simulator of wooding production for stands *Pinus radiata* D. Don in the Basque Country.

The logging arch is a skidding implement studied to reduce log friction by lifting the forward log end above the ground. The tractor-arch combination reached its golden age between 1945 and 1965, and was then replaced by the skidder. The authors believe that it still has a large potential for small scale forestry, because of its versatility and low cost.

This paper reports 10 case studies, concerning the use of 6 tractor-arch combinations in different conditions.

The use of logging arches proved profitable in all cases, with the exception of stands whose residual density exceeds 600 trees per hectare. Farm tractors equipped with logging arches can skid heavy turn loads at comparatively high speed. Moreover, delays in incidence and soil damage are substantially reduced as a result of logging arch use.

KEY WORDS: Logging Arch

Italy

Mediterranean Basin

Coppice

High Forest

Forest Operations

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BACKGROUND

Industrial forestry is characterized by large forest organizations investing big capitals and getting high yearly outputs. This kind of forestry, which involves the use of advanced mechanization in forest operations, is practicable only when some conditions occur. If these conditions are missing, one has to find different solutions, all classed in the general term «small scale forestry».

Small scale forestry results from the incapability of investing enough money to start an industrial forestry system. This incapability is most often caused by one of the following conditions:

- strong currency is not available, therefore the investment cost is too high when compared to its benefits: that is the very case of Developing Countries.
- the wood to be harvested is not available in sufficient amounts for a reasonably sure time span. That is caused by fragmentation of forest holding, lack of associationism among forest owners and poor forest planning. It is the case of Italy and other Mediterranean Countries, as well as a minor reality in Scandinavian Countries.

Whatever the cause, the result is the same: small scale forestry. It associates the economic reality of forestry in the Developing Countries to the one of Italian forestry, even if they are very different in other aspects.

In small scale forestry, the mechanization of logging is based on the farm tractor, because it is reliable, versatile and cheap (Spinelli, Baldini, 1992 a). Moreover, it has an advantage over specialized forestry equipment: the fact of being lighter. That's why it causes less environmental damage, and is particularly appreciated by forest owners. Of course, farm tractors cannot be used in forestry in their standard configuration. They must be fitted with proper implements and efficient protective structures, in order to get high productivity and avoid machine breakdowns or operator injuries. This paper deals with one of these implements: the logging arch.

The logging arch is an implement devised to facilitate log skidding. It keeps the front end of the log off the ground, decreasing log resistance to movement (Samset, 1985); it may also be used to lift the whole log, for a conversion of dragging resistance into rolling resistance. In any case, friction and bumping against obstacles on the ground is greatly reduced, and so are cycle time, delays and breakdowns (Conway, 1976).

Similar devices were used when the only motive power was muscular power, and logging arches originate from these early logging tools (Burroughs, 1953; Wackerman, 1949). Logging arches have been specifically designed for use with tractors, and are easily recognized by a roller assembly used to deflect the tractor winch line: that is made to enable the tractor winch to lift the front end of the log under the arch framework. The diffusion of logging arches reached its apex between 1945 and 1965. By then, skidders had replaced the tractor and arch combination, which had originated the skidder itself ten years earlier. Of course, skidders are more productive than tractors and arch, but they are not suited to small scale forestry because they are too expensive. That's why we think that the use of logging arches is still interesting nowadays: a logging arch may substantially increase the skidding efficiency of a farm tractor by adding very little to its total cost.

A logging arch is composed of a sturdy steel framework, in the form of two A frames, laying on two perpendicular planes and connected to each other base-to-base. The A on the horizontal plane is fitted with an eye on its top and a wheel on each leg: It is like a trailer chassis, and the eye is used to hitch the whole device to the tractor drawbar.

A roller assembly, called fairlead, is mounted on top of the vertical A, and strong bracings reinforce the framework, connecting the A-frames. Of course, there are many variations of this structure, and often the vertical A-frame is rectangular rather than in the shape of a precise A. For safety, the arch structure must always fulfill two requirements: The fairlead height must not exceed the distance between the wheels, and the eye must be fitted to the horizontal A-frame by a swivel (Giordano, 1956). That is made in order to increase arch stability and to avoid that if the arch overturns, the tractor is involved.

MATERIALS AND METHODS

The authors have selected a sample of six tractor and arch combinations from a larger sample made available by a previous study (Spinelli, Baldini, 1992 b). The sub-sample included very different tractor models, all equipped with winches and arches very similar to each other in dimensions and structure. Indeed, whatever their size, farm tractors generally use small, rubbertyred arches, which are often called «sulkies» (Simmons, 1949).

These six machines were used in a range of different working conditions, generating a total number of ten cases. All ten cases were real logging operations. The operators had at least five years of experience in tractor skidding, and were all very skilled.

TABLE 1
COPPICE: SITE DESCRIPTION

Monte bajo: descripción de las estaciones forestales

Site n.º		1	2	3	4
Case study n.º		1	2&3	4	5&6
Location		Valentano (VT)	Onano (VT)	Capranica (VT)	S.Martino(VT)
Height	m a.s.l.	547	586	385	605
Average slope gradient	%	14	23	46	23
Average striproad gradient	%	6	8	10	13
Terrain unevenness	class	1	1	2	1
Forest road density	m/ha	50	40	21	18
Species		Turkey oak	Turkey oak	Chestnut	Chestnut
Operation		Clearcut	Clearcut	Clearcut	Clearcut
Rotation	years	14	15	18	17
Age of standards	years	42-70	31-61	36	34
Average d.b.h.	cm	10.9	9.2	11.5	14.6
Average stem height	m	8.7	7.3	8.7	9.5
Average stem volume	m³	0.072	0.046	0.071	0.128
Stool density	stools/ha	530	730	400	800
Residual stand density	trees/ha	140	120	40	36
Harvested stems	tress/ha	1671	1987	1300	1350
Harvested volume	m³/ha	121.1	91.7	92.3	172.8
Fresh density (% weight)	kg/m³	1028	951	939	895

Estación n.º; Caso n.º; Localización; Altitud; Pendiente media del terreno; Pendiente media de pista; Irregularidad del terreno; Densidad de pistas forestales; Especie; Operación; Turnos; Edad; Diámetro normal medio; Altura media; Volumen medio; Densidad masa; Densidad residual; Troncos extraídos; Volumen extraído; Densidad de la madera en verde (%).

In each case, the authors performed a standard time-study, by measuring cycle time elements, extraction distances and load size. Extraction cost have been calculated by the Miyata method (Miyata, 1980) but lubricant and fuel consumptions have been measured directly. This cost is valid for the Italian economic conditions, and should be recalculated when the results have to be extended to different economic conditions.

The authors have assumed annual usage levels of 1000 hours for the farm tractor and 720 hours for both winch and arch: that is consistent with the part-time usage of logging implements, which is characteristic of small scale forestry.

TABLE 2
HIGH FOREST: SITE DESCRIPTION
Monte alto: descripción de las estaciones forestales estudiadas

Site n.º		5	6	7
Case study n.º		7	8	9&10
Location		Vetralla (VT)	Casteldelpiano (GR)	S. Fiora (FR)
Height	m.a.s.l.	470	1229	1195
Average slope gradient	%	12	21	29
Average striproad gradient	%	5	14	14
Terrain unevenness	class	1	2	2
Forest road density	m/ha	6	7	25
Species		Turkey oak	Beech	Silver fir
Operation		Removal of	Second thinning	Sanitary thinning
Stand age at operation		seed trees		
	years	80-130	88	55
Average d.b.h.	cm	59.8	30.3	22.5
Average stem height	m	22.5	18.7	18.3
Average stem volume	m ³	4.465	0.524	0.428
Residual stand density	trees/ha	612	414	788
Harvested stems	trees/ha	10	117	278
Harvested volume	m ³ /ha	46.4	61.3	119.0
Fresh density (% weight)	Kg/m ³	1068	1052	950

Estación; Caso n.º; Localización; Altitud; Pendiente media del terreno; Pendiente media de pista; Irregularidad del terreno; Densidad de pistas forestales; Especie; Operación; Edad en la operación; Diámetro normal medio; Altura media; Volumen medio; Densidad residual; Troncos extraídos; Volumen extraído; Densidad de la madera en verde (%).

RESULTS AND DISCUSSION

Tables 3 to 5 show the results obtained. As a first step, the 10 case studies have been subdivided in two classes, according to the forest typology of the working site. Two broad forest typologies have been considered: Coppice and high forest. Coppice stands are very common in the Mediterranean Countries, and should be taken into account as a source of renewable energy for the Developing Countries.

The case studies included in each forest typology class differ in other parameters, such as tractor size, machine crew, working system, slope gradient, tree size. Of course, this research does not deal with all the possible working conditions: most cases involve operation in easy terrain and final harvests. The study is based on real operations by logging contractors, who are generally unwilling to accept difficult jobs. Moreover, the farm tractor

is not suitable for operations in uneven terrain, unless a good forest road network has been built: that is not the case of Italy, where the lack of forest roads is one of the major constraints to the mechanization of logging.

Coppice

Six cases are included in this forest typology class. Again, we can operate a further subdivision between oak coppice and chestnut coppice, with three cases each.

TABLE 3

**BUNCHING AND SKIDDING STANDARDS IN OAK BY FARA TRACTORS
EQUIPPED WITH WINCH AND LOGGING ARCH: PRODUCTIVITY AND COST**

Atado y arrastre de resalvos de roble en monte bajo mediante tractores agrícolas equipados con cabrestante y arco de saca: Productividad y costes

Case n.º		1	2	3
Site n.º		1	2	2
Assortments extracted		Stemlengths	Assortments	Assortments
Tractor brand and type		FIAT, 4 WD	LANDINI, 4 WD	LANDINI, 4 WD
Engine power	kW	118	44	44
Av. skidding distance	m	362	95	458
Av. winching distance	m	7	20	16
Travel time		8'55"	4'28"	12'50"
Stationary time		11'12"	14'21"	11'46"
Delays		1'03"	2'53"	3'15"
Total cycle time		21'10"	21'42"	27'51"
Pieces per load		3.1	3.0	2.8
Volume per load	m ³	3.040	1.052	0.583
Crew		2	2	2
Productivity	m ³ /p.m.h.	8.622	2.914	1.256
Hourly cost	USD/p.m.h.	71.14	51.02	50.30
Unit cost	USD/m ³	8.25	17.51	40.05
Notes		—	—	Without arch

Caso n.º; Estación n.º; Tipo de piezas extraídas; Marca y tipo del tractor; Potencia del tractor; Distancia promedio de saca; Distancia promedio de enganche; Tiempo de viaje; Tiempo estacionario; Retrasos; Tiempo total; Piezas por carga; Tripulación; Productividad; Coste horario; Coste unitario; Notas.

Oak coppices produce fuelwood and a minor amount of timber from the old standards. The fuelwood is processed at the stump site and forwarded by farm tractor and trailer, while the standards are delimbed and skidded by farm tractor with winch and arch. Therefore, tractors operating in the oak coppice skid standards only.

Chestnut coppices produce a variety of assortments, which are often too long to be loaded onto a trailer. In most cases, both sprouts and standards are delimbed and skidded by farm tractors, but in level terrain farm tractors with trailer are used to forward the short assortments only, processed at the stump site: In any case, skidding by farm tractors plays a major role in the harvesting of chestnut coppices.

TABLA 4

ATADO Y ARRASTRE DE FUSTES DE CASTAÑO EN MONTE BAJO MEDIANTE TRACTORES AGRICOLAS EQUIPADOS CON CABRESTANTE Y ARCO DE SACA: PRODUCTIVIDAD Y COSTES

Atado y arrastre de fustes de castaño en monte bajo mediante tractores agrícolas equipados con cabestrante y arco de saca: productividad y costes.

Case n.º		4	5	6
Site n.º		3	4	4
Assortments extracted		Stemlengths	Stemlengths	Stemlengths
Tractor brand and tupe		LANDINI, 4 WD	LANDINI, 4 WD	CARRARO, 4 WD
Engine power	kW	55	62	72
Av. skidding distance	m	471	493	420
Av. winching distance	m	17	12	9
Travel time		11'04"	12'33"	10'30"
Stationary time		36'15"	16'19"	17'40"
Delays		10'31"	1'44"	4'25"
Total cycle time		57'50	30'36"	32'35"
Pieces per load		23.0	17.0	14.3
Volume per load	m³	1.604	2.163	1.860
Crew		2	2	1
Productivity	m³/p.m.h.	1.663	4.243	3.484
Hourly cost	USD/p.m.h.	54.04	56.52	41.82
Unit cost	USD/m³	32.50	13.32	12.00
Notes		—	—	—

Caso n.º; Estación n.º; Tipo de piezas extraídas; Marca y tipo del tractor; Potencia del tractor; Distancia promedio de saca; Distancia promedio de enganche; Tiempo de viaje; Tiempo estacionario; Retrasos; Tiempo total; Piezas por carga; Tripulación; Productividad; Coste horario; Coste unitario; Notas.

Thinnings are scheduled in the case of chestnut coppices only, but they are unprofitable and are seldom performed: therefore, all the operations reported are clearcuts. Cases 1 to 3 are illustrated in Table 2, and cases 4 to 6 in Table 3.

In the first case, a powerful 118 kW farm tractor skids oak standards in easy terrain (site n.º 1, Table 1). The tractor is 4 WD, and is equipped with forest winch and arch: A 2 men crew operates this machine. Thanks to its size, the tractor can drag full length standards, averaging a 3 cubic metre load size. Pieces are winched one by one, and their front ends are dropped on the chain swinging from the arch framework. As soon as a whole load has been assembled, the winch roped is wrapped around the whole bunch and used to lift it: then the return trip begins. At landing the whole bunch is dropped again on the chain, the winch line unhooked and the chain lock disengaged to drop the load on the ground: that is the standard loading-unloading routine used with all the logging arches observed in this study.

The productivity of this machine is very high, because of large tractor size, suitable implements, favourable terrain and large piece size: as a consequence of high productivity and machine versatility, extraction cost is very low.

In case n.º 2, a two men crew operates a much smaller 44 kW farm tractor, skidding oak standards in difficult terrain (site n.º 2, Table 1). The tractor is 4 WD, and is equipped with salvaged winch and arch. Very large standards are crosscut into 2.6-5.2 metre assortments. Even so, some pieces are difficult to winch and the tractor slips in many

occasions. To avoid slipping, the operator often leans the arch against the standards before starting the winching routine; that causes substantial damages to the trees and should always be avoided. Tractor lightness highlights one of the arch defects: the lack of anchoring devices to stabilize the tractor when winching. At any rate, load size is unusually high for such a small tractor, and so its productivity.

Case n.° 3 involves the same tractor, crew and site of case n.° 2; only, in this case the arch is not used, and loads are dragged directly on the ground. As a result, load size drops by 40 p. 100 and delays increase by 60 p. 100. Machine productivity is reduced to 43 p. 100 of the original productivity, and extraction cost is more than doubled.

Cases n.° 4, 5 and 6 concern three farm tractors used in chestnut coppices: the tractors are 55, 62 and 72 kW respectively.

The first tractor skids full length stems from a steep site (site n.° 3, Table 1), and is operated by a two men crew. The other two tractors are used in a second site (site n.° 4, Table 1), where slope gradient is lower and stem size larger. One of these tractors is operated by a two men crew, while the second and larger one has one operator only. In all cases, load size is large and productivity is high. When slope gradient exceeds 40 p. 100 and stem size is below 0.1 cubic metre, productivity drops: in case n.° 4 it is half as much as in case n.° 5, where terrain is favourable and stem size larger.

In favourable terrain, the one man crew is more cost-efficient than the two men crew, which is probably most suited to steeper terrain and long distance winching.

The studies in coppice stands show that the logging arch may substantially increase load size, travel speed and, thus, productivity.

Tractor size shouldn't drop below 55 kW, while performance is not very different for tractors in the range between 55 and 72 kW. Larger tractors are useful only when very large trees must be extracted, but a smaller machine can do the same job, provided that the trees are crosscut into lighter pieces.

Salvaged winches are inefficient and must be replaced with professional forestry winches; the choker system should be used to increase bunching productivity, especially when small stems are harvested.

Stem size and terrain conditions have a strong influence on logging productivity, that will decrease dramatically when slope gradient is higher than 40 p. 100.

High forest

From the logger's point of view, the operations included in this forest typology class are characterized by large size of the harvested tree and high density of the residual stand. All operation are selective removals: geometric thinnings are not included, neither are they usually performed.

Cases 7 to 10 are illustrated in Table 5.

In case n.° 7, two operators use a 95 kW tractor to skid old seed trees from a Turkey oak forest (site n.° 5, Table 4). Trees are exceptionally large and need to be converted into lighter logs at the stump site. Terrain conditions are favourable, but the poor density of the forest road network results in a very long extraction distance. Therefore, it is crucial that the tractor travel as fast as possible, and the load is completely lifted above the ground in order to avoid friction. Load suspension is achieved by leaning one end of the log on the chain fitted to the arch frame and lifting the other end by winch: the whole load is suspended this way, and the loaded tractor can travel as fast as 7.3 km/h. In addition,

manoeuvrability is improved by total suspension of the load, because the tractor can use the reverse gear, which is impossible to use when the load is dragged. Load size is very high and so is machine productivity, in spite of the long extraction distance.

TABLE 5

BUNCHING AND SKIDDING LOGS AND STEMS FROM HIGH FOREST BY FARM TRACTORS EQUIPPED WITH WINCH AND LOGGING ARCH: PRODUCTIVITY AND COST

Atado y arrastre de trozas y fustes en monte alto mediante tractores agrícolas equipados con cabestrante y arco de saca: productividad y costes

Case n.º		7	8	9	10
Site n.º		5	6	7	7
Species		Turkey oak	Beech	Silver fir	Silver fir
Assortments extracted		Logs	Logs	Stemlengths	Stemlengths
Tractor brand and type		SAME, 4 WD	CARRARO, 4 WD	CARRARO, 4 WD	CARRARO, 4 WD
Engine power	kW	95	72	72	72
Av. skidding distance	m	1119	221	136	73
Av. winching distance	m	7	10	14	12
Travel time		17'28"	6'37"	5'06"	3'18"
Stationary time		9'36"	8'02"	8'43"	7'59"
Delays		1'09"	3'23"	3'19"	4'32"
Total cycle time	28'13"	18'02"	17'08"	15'49"	
Pieces per load		4.3	3.5	3.4	2.8
Volume per load	m³	2.473	1.204	1.289	1.337
Crew		2	1	1	1
Productivity	m³/p.m.h.	5.236	4.011	4.509	5.080
Hourly cost	USD/p.m.h.	64.53	41.82	41.82	41.82
Unit cost	USD/m³	12.32	10.43	9.27	8.23
Notes		Total load suspension	Total load suspension	Uphill	Downhill

Caso n.º; Estación n.º; Especie; Tipo de piezas extraídas; Marca y tipo del tractor; Potencia del tractor; Distancia promedio de saca; Distancia promedio de enganche; Tiempo de viaje; Tiempo estacionario; Retrasos; Tiempo total; Piezas por carga; Tripulación; Productividad; Coste horario; Coste unitario; Notas.

Case n.º 8 deals with the second thinning of a beech forest (site n.º 6, Table 4). Tree size is medium, but the trees are converted at the stump site to enable total suspension of the load, as in case n.º 7. Extraction is performed by a 72 kW farm tractor, operated by one man only. Load size and machine productivity are very good. Productivity is reduced to 2/3 when soil trafficability is made poor by heavy rain. Residual stand density does not hinder tractor operation.

In cases n.º 9 and 10, silver fir stemlengths are skidded uphill and downhill respectively. The operator and the tractor are the same as in case n.º 8. The operation is sanitary thinning of a 55 year old stands, which has never been thinned: Therefore, the density of the residual stand is high, in spite of the heavy grade of thinning (site n.º 7, Table 4). As compared to case n.º 8, delays increase of 40 p. 100 and travel speed decreases by 21 p. 100 because of the negative effect of high density of residual stand on tractor manoeuvrability: the logging arch makes it worse, because the tractor-arch combination

is more clumsy than the tractor alone. nevertheless, productivity is good, thanks to the short extraction distance and the large load size. The main effect of reduced manoeuvrability is the high damage rate of the residual stand: 34 p. 100 of the residual trees show one or more wounds.

Over the same distance, downhill skidding is 36 p. 100 less productive than uphill skidding, because downhill skidding involves arch positioning by reversing the whole combination uphill: that is much more difficult than reversing downhill, because gravity causes the arch to slide sideways, and several attempts are needed to get an accurate positioning.

Again, cases n.° 7, 8, 9 and 10 show that the use of logging arches allow the extraction of large loads at good travel speeds: complete load suspension results in a smaller load size, but allows a much higher travel speed and is adviceable when extraction distance is long.

Logging of high forests requires rather large tractors, above 70 kw.

Density of the residual stand has a strong influence on productivity: a density of more than 700 trees/hectare may prevent the use of logging arches, unless a proper network of skidding paths has been prepared in advance.

Salvaged winches are inefficient and must be replaced with professional forestry winches: the choker system should be used to increase bunching productivity, when load suspension is not needed.

CONCLUSIONS

Literature often reports the increase in load size as a main benefit of logging arch usage (Giordano, 1956; De Megille, 1954; Pearce, Stenzel, 1972), and our study confirms this assumption: in all occasions, recorded load size exceeds 1 cubic metre, and is often around 2 cubic metre or more. When equipped with a logging arch, the 44 kW farm tractor can skid loads that are 80 p. 100 larger than those dragged without the arch, and it is achieved at an additional hourly cost that is about 1 p. 100 the cost of the whole machine, included operators.

The logging arch enables farm tractors to travel faster, especially when the arch is used for complete suspension of the load: increased travel speed is very useful when the extraction distance is long.

The use of logging arches results in smooth skidding: breakdowns and hangups are prevented, and in most occasions the incidence of delays drops below 7 p. 100.

The logging arch is regarded as an important safety device, because it prevents the tractor from rearing up when winching or skidding.

Soil damage is greatly reduced when logging arches are used, and in no case we have observed rutting, which is frequent when logs are dragged directly.

The tractor-arch combination is cumbersome as compared to the tractor only, and manoeuvre in close quarters may prove awkward: that's why a density of more than 600 trees/hectare may prevent the use of logging arches, unless a network of skidding paths has been prepared. To improve tractor-arch manoeuvrability, we report a minor modification (Vaughan, 1988): the arch shaft is hinged, and the whole arch is raised and hooked to the cab frame when the tractor is not loaded. That makes the arch similar to a bogie winch (e.g. Holzknicht, Agri-winch etc.), but the arch is lifted by the winch itself and is much cheaper.

A definite drawback of arches as compared to forestry winches is the lack of anchoring devices, such as legs or blades, that causes small tractors to slip back when winching large loads. Mounting manual brakes to both arch wheels may be helpful, and is worth a try: arch wheels come from discarded trucks, and the operator just needs to adapt the parking brakes already fitted to them. Another solution is the use of heavy tractors, from 60 kW on: it is a good choice when the tractor must work both in coppice and in high forest.

Finally, we can state that the logging arch is a very useful logging implement, offering many benefits at an extremely low price. Most blacksmiths may build a logging arch from T beams and discarded truck parts and in any case arch price never exceeds 1700 USD.

RESUMEN

Análisis de productividad y costes del arco de saca utilizado con tractores agrícolas en los montes mediterráneos

El arco de saca es un apero de arrastre ideado para reducir la fricción de las trozas de madera por medio de la elevación de su extremo delantero sobre el terreno. La combinación arco-tractor alcanzó su edad de oro entre 1945 y 1965, siendo entonces reemplazada por el tractor arrastrador o «skidder». Los autores creen que dicha combinación tiene un amplio potencial en la actual silvicultura de pequeña escala, dada su versatilidad y sus bajos costes.

En este artículo se analizan 10 casos de aprovechamientos correspondientes a 6 combinaciones arco-tractor bajo diferentes condiciones de estación forestal.

El uso del arco de saca resultó rentable en todos los casos, con excepción de aquellas masas cuya densidad residual excedía de los 600 pies por hectárea. Los tractores agrícola equipados con arcos de saca pueden arrastrar pesadas cargas a una velocidad relativamente alta. Además, los retrasos y los daños causados sobre el suelo se reducen considerablemente como resultado del uso de los arcos de saca en los aprovechamientos forestales.

PALABRAS CLAVE: Aprovechamientos forestales

Arcos de Saca

Monte bajo

Monte alto

Italia

Cuenca Mediterránea.

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