Sanitation Felling and Helicopter Harvesting of Bark Beetle–Infested Trees in Alpine Forests: An Assessment of the Economic Costs

Massimo Faccoli
Valerio Finozzi
Paola Gatto

Abstract

Since 2004, an outbreak of *Ips acuminatus* killed thousands of Scots pines (*Pinus sylvestris* L.) in the southeast Alps. In autumn 2007, all infested trees were cut and the timber was harvested by helicopter. The aims of this article are to provide detailed information on total stump-to-truck costs and to analyze the single components of those costs. The felling of 4,519 trees, about 970 m^3, needed about 2,417 working hours. The overall cost for tree felling amounted to €35,100, which included €24,600 for labor, €8,300 for coordination and management, and €1,800 for machinery, with a mean cost of about €7.8 per tree. Timber harvesting by helicopter required 73 hours, with an hourly production rate of 13.3 m^3. Timber harvesting cost about €56,000, with a mean of €58/m^3. The total cost for tree felling and timber harvesting amounted to about €91,000, with a mean cost of €20.1 per tree, i.e., €94/m^3. The main results are discussed by comparing our data with those published in similar studies or with costs of alternative harvesting techniques. We argue the environmental aspects may justify the use of helicopter harvesting in alpine forests.

The high summer temperatures in 2003, the warmest European summer in the last 500 years (Luterbacher et al. 2004), stressed several thousands Scots pines, *Pinus sylvestris* L., growing in the Dolomites, on the eastern Italian Alps. In the same area, heavy infestations of the pine bark beetle, *Ips acuminatus* (Gyllenhal) (Coleoptera: Curculionidae, Scolytinae), began in 2004 and progressively expanded over the years, killing thousands of trees (Faccoli et al. 2007, Colombari et al. 2011). *I. acuminatus* is a Palearctic bark beetle infesting the upper part of trunks and main branches of Scots pines suffering from drought or other biotic or abiotic factors (Chararas 1962, Mattson and Haack 1987). *I. acuminatus* has been included among the 10 most damaging European bark beetles (Grégoire and Evans 2004), with strong outbreaks recently reported in many alpine forests (Lozzia and Rigamonti 2002, Faccoli et al. 2007, Wermelinger et al. 2008, Colombari et al. 2011).

A series of control practices to contain bark beetle outbreaks are available. These include sanitation thinning or clear-cutting, pheromone traps and trap-trees, and insecticide treatments (Faccoli and Stergulc 2008). However, there is a great deal of discussion about the type of control measures that should be applied, especially in relation to both operative problems and forest value (Grégoire and Evans 2004). Removal of breeding material through sanitation felling or cutting of infested trees is among the most technically feasible measures. Harvesting the felled trees, nevertheless, can be difficult to implement in alpine areas with steep slopes and a scarcity of forest roads. In these orographic conditions, timber extraction by helicopter often represents the best, or the sole, technical solution. However, the extent to which this solution is also economically efficient remains an open question.

In 2007, the Regional Forest Service decided to apply a control program starting with the infestation and population monitoring and ending with the sanitation felling of all the

The authors are, respectively, Researcher in Forest Entomology, Univ. of Padova, Dept. of Agronomy, Food, Natural Resources, Animals and Environment (DAFNAE), Legnaro, Italy (massimo.faccoli@unipd.it [corresponding author]); Forest Consultant, Regional Forest Serv., Veneto Region, Belluno, Italy (valerio.finozzi@regione.veneto.it); and Associate Professor of Forest Economy, Dept. of Land, Environment, Agric. and Forestry, Univ. of Padova, Legnaro, Italy (paola.gatto@unipd.it). This paper was received for publication in November 2011. Article no. 11-00130.

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infested trees. This operation was paid for with public funds. The aims were to reduce the pest population density, mitigate the risk of fire posed by the large amount of dead wood in the forest, and maintain the general landscape quality of the valley (Shepard 1994, Jones et al. 2000, Aust and Blinn 2004, Christian and Brackley 2007, Pröbstl 2007), which is a famous tourist area. Moreover, all dead trees needed to be removed to leave space for the forest's natural regeneration (Jones et al. 2000). This choice was further supported by the consideration that forest value does not depend only on the timber quality and market, but may also have other economic relevance, such as soil protection and biodiversity conservation (Shepard 1994, Pröbstl 2007). The *I. acuminatus* outbreaks were not concentrated in a few large areas but were scattered along the valley over hundreds of hectares in many typical small infestation spots (Colombari et al. 2011; Fig. 1). The size of these spots ranged between a few trees in the smallest up to a few dozen trees in the largest. Owing to the difficult environmental conditions (steep slopes) and the lack of infrastructure (especially forest roads), most of the spots could be reached only by hours of walking, without any motorized support for the transport of persons and equipment or for timber harvesting. The only technically feasible solution in this context was manual tree cutting using chainsaws and tree harvesting by helicopter.

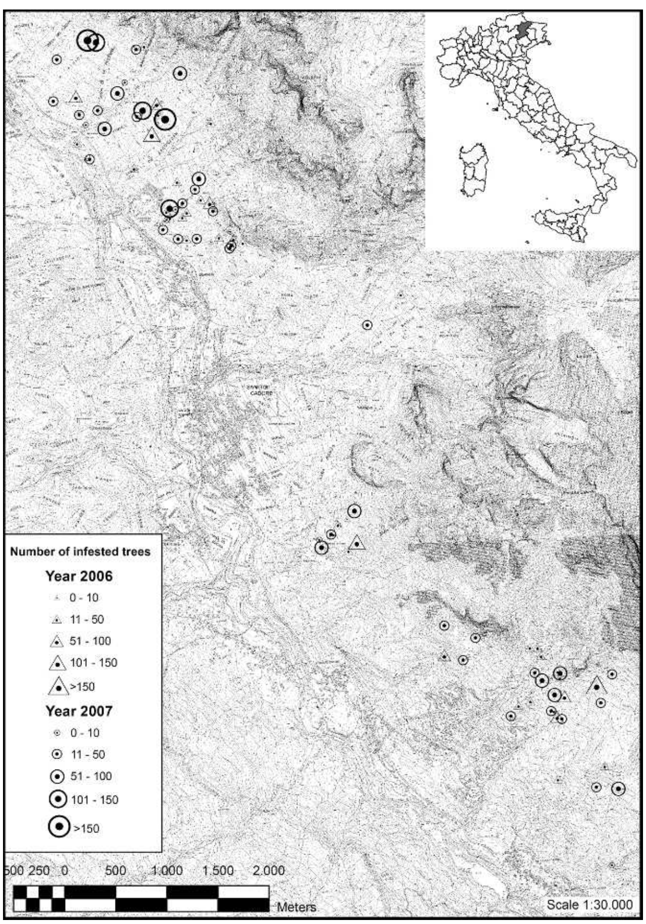

Figure 1.—An example of the infestation spots scattered in the Cadore Valley, recorded in 2006 (triangles) and 2007 (circles) in the investigated stands of the Belluno Province (shaded gray on the inset map), southeast Italian Alps.

Experiences on helicopter use reported in the literature refer mainly to removals of logs from timbered areas for final productive felling rather than to precommercial or sanitation practices. In the vast productive North American forests, timber extraction by helicopter was considered as early as the late 1950s (Walbridge 1960). Helicopter-based techniques are now widely used for timber harvesting and tree pruning (Keegan et al. 1995, Han et al. 2004, Wang et al. 2005) because they are deemed faster and less expensive than traditional techniques (Rowan et al. 2003). Nevertheless, no European country uses harvesting by helicopter as a common technique, since it is considered too expensive when compared with timber value, i.e., quantity or quality too low for a cost-effective extraction. The few available data refer only to some preliminary studies conducted in England (Shaw 1959), Norway (Samset 1964), Austria (Bauer 1965, Grindling and Stampfer 2000, Stampfer et al. 2002), and Slovakia (Messingerova and Tajbos 2006).

Knowledge on the costs of harvesting by helicopter in Italy is almost nonexistent. Estimations were published by Baldini (1977), but these data are obsolete and, above all, they do not refer to sanitation felling. However, the literature has highlighted how such information would be crucial to decide on appropriate and efficient pest management strategies, providing valuable input for decision makers (Messingerova and Tajbos 2006, Christian and Brackley 2007). The same data would be useful to incorporate additional ecological/social values to economic costs and benefits (Gatto et al. 2009, Slaney et al. 2010). In order to fill this gap, we report an economic analysis of a sanitation felling program followed by timber extraction via helicopter in a valuable alpine context. The aim of the article is to provide novel and detailed information on total costs attributed to sanitation felling and helicopter harvesting in the southeastern Italian Alps and to analyze the single components of such costs.

Materials and Methods

Study area and stand characteristics

The forest area considered in the study covers about 2,200 hectares located in the Cadore Valley (46°40′N, 12°20′E), southeastern Italian Alps (Fig. 1). The investigated Scots pine forest grows on south-southwest–facing slopes on dolomite and limestone bedrock, with natural regeneration and no active silvicultural management. This is a rather common occurrence in the Alps, where low timber values and high extraction costs are the root cause of forest unprofitability. The stands are more than 100 years old, with a mean density of about 300 trees per ha and a very low growth (on average about 0.2 to 0.3 m^3 per mature tree) because of limited nutrients and water (Colombari et al. 2011). The closest carriage road runs along the bottom of the valley at about 1,000 m above sea level (a.s.l.), whereas the pine forests—and the infestation spots—cover the whole valley slopes until about 1,800 m a.s.l. (Fig. 1). Although there is no silvicultural management, the investigated pine stands have a very important role in protection against soil erosion and avalanches. Moreover, they are an essential component of the local Dolomite alpine landscape, in an economy largely based on tourism (Volin and Buongiorno 1996).

Population monitoring by pheromone traps

The population of *I. acuminatus* occurring in the investigated stands was monitored by pheromone traps. In early spring 2007, 70 pheromone multifunnel traps (Witasek, Austria) were set up in 29 infestation spots chosen among the largest in the valley. Traps were baited with a species-specific pheromone lure (Acuwit, Witasek, Austria) and checked twice a month from April to September by two employees of the Regional Forest Service and a student of the University of Padova (Faccoli et al., in press). All pheromone dispensers were replaced once in June, 2 months after the beginning of the trial. Because of the difficult orographic conditions of the slopes and the distances between the monitored spots, each periodical checking of all traps took 2 days. All insects caught were identified and counted. The aim of the population monitoring was to collect information about occurrence and distribution of sites characterized by a high bark beetle population level and a high risk of infestation. At the same time the population monitoring carried out by pheromone traps gave biological information about insect phenology and voltinism, which was useful for deciding the best period in which to perform the sanitation felling (Faccoli et al., in press).

Infestation monitoring

The infestation monitoring aimed to check number, size, and geographic position of the spots of attached trees occurring in the infested forest. This operation provided detailed information used to plan and manage the next steps, i.e., tree felling and timber harvesting, according to the local site conditions, such as accessibility, road availability, and slope gradient.

From June to August 2007 the whole pine forest was monitored and the infestation spots identified as soon as the infested trees turned red. Each spot was located using a global positioning system (GPS), and the number and volume of the infested trees were recorded (Colombari et al. 2011). Data were collected from old infestation spots made by trees that had died in previous years (2005 to 2006). In many cases, some healthy uninfested trees were growing inside the infestation spot. Monitoring was performed by a team of foresters working for the Regional Forest Service, in collaboration with entomologists of the University of Padova.

Tree felling and timber harvesting

Tree felling and harvesting lasted from October 2 to November 14, 2007. The work was performed by two teams of six laborers of various specialization levels, coordinated by two group leaders under the supervision of a manager responsible for the whole project (Table 1). The teams worked on average 7 to 8 h/d and 5 d/wk. During the sanitation program, all infested trees were cut. Small branches and limbs with diameters over 3 to 4 cm broken from the trees during tree felling were collected manually and piled in heaps not larger than 2.5 m^3 each. Branches with smaller diameters, i.e., not susceptible to and not containing *I. acuminatus,* were scattered on the litter. Both branch piles and trunk bundles were stacked in clear-cuts until harvesting. The helicopter used for the timber harvesting was the model Ecureuil AS 350, with a maximum carrying capacity of 1.2 tonnes. The helicopter was already available to the Forest Service and was usually employed by the Fire Service. The limited capacity of such a small model was, however, enough to harvest small-diameter trees, with loads of about 1.0 to 1.1 tonnes per flight. The helicopter began the harvesting when all trees were felled and the branches piled. The trees, whole and undebranched, were harvested in bundles of 2 to 8 trunks each, according to their size and the helicopter capacity. Large trunks were harvested singly. The base of the trees was bounded directly to the helicopter winch. After the tree yarding, branches were harvested by a 3 by 3-m net closed to form a bag of about 2.5-m^3 capacity. Harvested timber was initially stocked in four landing points arranged along the forest road running in the bottom of the valley and was finally moved by trucks to a biomass power station to be used as fuel wood.

Cost assessment

Costs for each of the three phases of the sanitation program—population monitoring, infestation monitoring, felling and harvesting—have been assessed by analytically accounting time and materials spent on the three most important cost components: labor, machinery, and consumables (i.e., products usable only once). The hourly labor costs (Table 1) were provided by the work administrative office of the Regional Forest Service.

Results

Population monitoring by pheromone traps

The purchase of 70 pheromone traps and 140 pheromone dispensers cost €1,150 and €2,240, respectively. Including 2 days to set up and dismantle the traps, the population monitoring by pheromone traps lasted 19 working days, for a total of 297 working hours corresponding to about €3,300 paid to two employees of the Regional Forest Service. The labor provided by the student of the University of Padova was unpaid graduate work that counted toward the completion of his degree program. The whole population monitoring carried out in 2007 cost about €6,690, i.e., about €95 per trap.

Infestation monitoring

The checking of the infested stands was carried out by two employees of the Regional Forest Service, who, in 11 working days, recorded and measured 4,519 infested trees (about 970 m^3) distributed in 51 spots, the smallest having two and the largest having 346 trees, with a mean of about 88 trees per spot. The infestation was spread over three municipalities of the Cadore Valley (Borca, San Vito, and Cortina) covering about 2,200 hectares of pine forest. The monitoring of the whole area took 154 working hours for a total cost of €1,710.

Tree felling and timber harvesting

Tree felling and harvesting lasted 29 working days, for a total of 2,417.3 hours, on 47 infestation spots that covered a total area of about 15 hectares. Forty-five spots were harvested by helicopter and two spots that were close to a forest road were harvested by tractors; four spots were left in the forest because they were inaccessible to the work teams. In total, the cost for tree felling was €35,177, which includes €24,671 for labor, €8,389 for coordination and management, and €1,800 for machinery (Table 2). The

Table 1.—Labor cost of felling and harvesting used in the assessment, per category of employee.[a]

Employment category	Total no. of working days	No. of hours/day[b]	Total hours	Hourly cost (€)	Total cost (€)
Laborer	60	7.8	468.0	11.12	5,204
Qualified laborer	18	7.8	140.4	13.15	1,846
Specialized laborer	99	7.8	770.6	13.72	10,573
Ultraspecialized laborer	65	7.8	505.4	14.57	7,364
Group coordinator[c]	60	7.8	468.0	15.78	7,385
Manager	9	7.2	64.8	15.50	1,004
Total	311	46.2	2,417.2	—	33,377

[a] The data were provided by the work administrative office of the Regional Forest Service. The reported labor rates include all employer costs.
[b] Laborers worked 39 h/wk, whereas managers worked 36 h/wk (5 d/wk).
[c] Specialized laborers, coordinating the work team only for the duration of the project, were paid 15 percent more than their usual salary as compensation for extra responsibility.

mean costs for felling were about €7.8 per tree and about €36.3/m^3.

The helicopter operated from 8:30 a.m. to 12:30 p.m. and from 2:00 to 4:00 p.m. On average the helicopter flew about 4 h/d, and the rest of the time was accounted for by refueling, lunch breaks, and unfavorable weather conditions. The helicopter covered flight distances usually shorter than 2 minutes, from the infestation spots in the forest to the closest of the four landing points in the bottom of the valley. Tree harvesting by helicopter required 1,573 loaded flights for the transport of 1,208 trunk bundles, with a mean of about 3.5 (3.45 ± 0.23) trees per bundle; 365 single trunks were too large for cumulative transport. Branches were harvested only from 40 spots because the small number of branches in the smallest spots were scattered on the forest litter. The helicopter harvested 173 nets containing branches, with a mean of about 4.3 nets per spot (4.32 ± 0.44). In general, the helicopter transferred only one net per flight, rarely two small ones. The harvesting took 9.4 working days corresponding to 73 hours, with a harvesting rhythm of about 167 trunk packs and 18 nets per d and an hourly production rate of 13.3 m^3. The commercial cost of a helicopter of the same model we used is about €25/min. Nevertheless, by a commercial contract between the helicopter company and the Forest Service, which annually needs helicopters for the Fire Service, the applied price was only €12.8/min (including costs of pilot and copilot). Because the total number of minutes recorded was 4,380, the total cost for timber harvesting by helicopter was €56,064 (Table 2). The total cost for tree felling and timber harvesting, excluding the €1,710 for the infestation monitoring, therefore amounted to €90,924 (Table 2), with a mean cost of about €20.1 per tree and nearly €94/m^3. The mean cost paid for only the harvesting by helicopter was €58/m^3.

Wood sale

The 4,519 felled trees produced about 680 tonnes of wood. At the landing points there was only a Forest Service employee and a few power station employees in charge of unloading the helicopter and loading the trucks going to the power station. The cost of the Forest Service employee was included in the cost of the work team. The wood was sold to a biomass power station as roundwood, for a price of €12/tonne, with a total revenue of €8,160.

Over the whole sanitation program, each single cost component showed a different weight in determining the total cost. Labor, including coordination, covered about 38 percent of total costs, machinery more than 58 percent, and consumables only 3.5 percent (Table 2). Considering the costs were distributed among the different phases of the sanitation program, the single performed activities—although applied in an integrated way—contributed differently to generate the costs, with population and infestation monitoring covering, respectively, only 6.7 and 1.7 percent of the total cost and felling and harvesting operations covering nearly the totality of costs, i.e., as much as 91.5 percent.

Table 2.—Total costs of the applied sanitation program, by program phase and cost component.

Cost component	Population monitoring		Infestation monitoring		Felling and harvesting		Total cost	
	€	%	€	%	€	%	€	%
Coordination[a]					8,389	9.2	8,389	8.4
Labor	3,300	49.3	1,710	100.0	24,671	27.1	29,830	30.0
Machinery								
Helicopter					56,064	61.7	56,064	56.3
Chainsaw					1,800	2.0	1,800	1.8
Consumables								
Traps	1,150	17.2					1,167	1.2
Lures	2,240	33.5					2,273	2.3
Total cost (€)	6,690		1,710		90,924		99,524	100.0
Percentage of total cost	6.7		1.7		91.4		100.0	

[a] Coordination costs for population and infestation monitoring are included in the felling and harvesting costs.

Discussion

Cost analysis of the helicopter harvesting

The various components of the applied sanitation program contributed differently to the total cost. The felling and harvesting operations were very expensive, as a combined effect of both high labor and high helicopter costs (Table 2). High labor costs can be explained by the small size and the spatial distribution of the patches harvested, requiring longer times for yarding (Stampfer et al. 2002); the difficult mechanization conditions were linked to steep slopes and the lack of infrastructures such as forest roads (Cavalli and Grigolato 2010). A larger contributor to cost increases was the helicopter, which alone accounted for as much as 62 percent of the total stump-to-truck expenses. The use of the helicopter requires more coordination efforts because of the more risky and complicated harvesting procedure, whereas felling, limbing, and bucking labor costs would be similar independent of the applied harvesting system. Walbridge (1960) considered the possibility of timber transport by helicopter in the Tennessee Valley, concluding that helicopters were economically unfeasible at that time. A few years later, Samset (1964) suggested that the operation would have to be well organized to fully justify the use of such an expensive machine. Recent technologies largely reduced the mean cost of such operations, increasing their feasibility. In our study, the mean cost for tree felling and wood harvesting was about €36 and €58 per m^3, respectively. Keegan et al. (1995) reported similar values, indicating an average cost for harvesting activities, which included planning and administration, felling, limbing and bucking, and yarding and loading, of about €79/m^3. As in our study, Keegan et al. (1995) reported that operation planning and administration contributed least to total costs. In southwest Idaho, helicopter stump-to-truck logging and chipping cost about €70/m^3 (Han et al. 2004), whereas a more recent study from southeast Alaska reported a harvesting cost of about €108/m^3 (Christian and Brackley 2007). Cost variations found in the literature are often affected by tree size, with mean costs usually increasing with decreasing tree size (Stampfer et al. 2002, Han et al. 2004). For instance, Wang et al. (2005) reported a mean cost for felling and harvesting of only €52/m^3 for logs with an average volume of 0.45 m^3, a size double that of our logs (0.21 m^3). Also the carrying capacity of the helicopter is a determinant of costs, with productivity generally increasing with helicopter size. For example, in the present study, we used a small helicopter with a maximum carrying capacity of 1.2 tonnes, giving an hourly production rate of about 13.3 m^3, whereas Wang et al. (2005) used a Boeing Vertol 107, a medium lift helicopter with a payload size of about 3 tonnes, giving an hourly production rate of 23 m^3, almost double ours. However, the difficult operational conditions of the Alpine environment represent a limiting factor to the choice of large helicopter models, which are not justified even from the efficiency viewpoint, because of the difficulty of reaching optimal payloads (Püntener 2006), given the dispersion of the felled patches.

Helicopter versus traditional methods

Helicopter logging is traditionally believed to be much more expensive than conventional ground-based methods (Wang et al. 2005). For instance, in Montana stump-to-truck harvesting by tractor costs from €29 to €41 per m^3, cable systems cost €44 and €55 per m^3 for a typical ground-lead system and a skyline system yarding downhill, respectively, and the helicopter costs €79/m^3 (Keegan et al. 1995). The factors affecting economic feasibility of timber harvesting by helicopter rather than traditional methods include road accessibility and condition, distance to manufacturing facilities, and market price of timber. In lowlands, with a good network of forest roads, the harvesting costs may be very low (about €14 to €16 per m^3), as reported for Norwegian spruce stands (Andreassen and Oyen 2002). In Italian alpine forests, harvesting by a cable system costs about €13 to €15 per m^3 according to slope and log size (Cavalli et al. 2008), whereas the stump-to-truck costs—including felling, limbing and bucking, and yarding—may reach about €60 to €65 per m^3. Comparing the efficiency of different harvesting methods, Wang et al. (2005) found that helicopter logging was about 1.5 to 2.8 times more productive but about 6 to 11 times more expensive than cable and grapple skidders. However, timber harvesting systems affect ecosystem functions and their ecological values (Shepard 1994), and some systems may have more negative effects on soil protection, site productivity, and forest conservation than others (Aust and Blinn 2004). In contexts where harvesting has to be carried out in fragile environments or inaccessible sites and environmental concerns are important decision-making elements, helicopter extraction could be competitive with the conventional ground-based methods of harvesting (Wang et al. 2005). It eliminates the need to build skid and forest roads and therefore strongly reduces the impacts on the logging site. Moreover, removal of logs by helicopter has been demonstrated to minimize soil damage and facilitate rapid revegetation (Jones et al. 2000).

Long-term perspectives and social benefits

If the standing timber has a low market value, e.g., because pest outbreaks occur in young forests or in areas with difficult accessibility, the sanitation costs are not compensated by the sale of the felled trees, and the outbreak control results in a financial loss. This was the case in the present study, where about €99,000 was spent on a wood product with a market value of only €8,100. From a financial point of view, in the short-term there is no financial incentive for forest owners to carry out bark beetle control. Moreover, a lack of knowledge of growth models with and without the effects of the pests, uncertainty about future timber markets, and owner attitudes (e.g., time preferences) often play an important role in the decision against sanitation programs. Nevertheless, pest control may be an input necessary to maintain the value of the capital asset and guarantee future forest outputs. In addition, in many cases the outbreak suppression could have different aims, like in this study, and be driven by a social demand for public goods, rather than by strictly financial considerations (Shepard 1994, Jones et al. 2000, Aust and Blinn 2004, Christian and Brackley 2007, Pröbstl 2007). On these grounds, helicopter harvesting can be justified by the need to reduce fire risk and pest spreading, but also to conserve the package of ecosystem services—soil protection against erosion, water regulation, landscape and amenity, tourist attractions and recreation, carbon sequestration, habitat conservation—traditionally produced by the alpine forests (Pröbstl 2007). Performing an economic evaluation that would also consider these public values would be a further step in the all-round assessment of sanitation programs for management of bark beetle outbreaks.

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