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Biomass Harvesting from Salvage Clearcuts on Young Eucalypt Stands and Post-Wildfire Pine Thinnings with Fixteri FX15a Feller-Bundler in Spain

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Abstract: We studied two *Eucalyptus globulus* salvage clearcuts—after a wildfire and a *Gonipterus* attack—and a strong thinning on a dense *Pinus pinaster* stand which was regenerated 20 years after a wildfire and also affected by a *Matsococcus* pest. Biomass harvesting was performed using the feller-bundler Fixteri FX-15a, which was time-studied during several weeks using GNSS combined with an automatic weight/time registration system (WNexus-2®). Detailed in situ time studies were applied during shorter periods as well. The productivity equations found as main explanative factors for the salvage clearcuts the unit weight per tree and the felling reason (wildfire vs. pest); for the thinning, besides the unit weight, the percentage of extracted basal area explained the productivity. Biomass collection did not allow an economic positive balance: in the *Gonipterus*-affected plantation the cost was reduced to 125 €·ha^{-1}, reaching a zero balance for unit weights greater than 33 kg (dry matter) per tree; the restoration cost in the pine stand was 265 €·ha^{-1}, much lower than the cost without biomass harvesting. In the burned eucalypt, the zero cost would be achieved for a dry unit weight much greater than the observed values. Although Fixteri performance and utilization were remarkable, recommendations about possible improvements of its design and operation were concluded from the detailed time studies.

Keywords: forest biomass; whole-tree system; forest mechanization; salvage logging; Mediterranean plantations; post-wildfire restoration; *Eucalyptus globulus*; *Pinus pinaster*

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1. Introduction

Natural biotic or abiotic disasters affecting young forest plantations are often costly to the forest owners, while the products' value is small. Blue gum (*Eucalyptus globulus* L.) and maritime pine (*Pinus pinaster* Ait.) are the main planted species in Northern Spain, besides radiata pine. One of the main pests affecting eucalypt in Northwest Spain is *Gonipterus platensis* [1]. On the other hand, forest fires have been a major forest threat to forests in Spain that is becoming increasingly dangerous, mainly due to abandonment of the land use and climate change [2]. One of the main uses of small trees from salvage harvesting after those disasters is biomass for energy.

Technologies combining whole-tree felling and bundling, such as Fixteri FX15a, are an alternative to these operations. Following [3], the first small whole-tree feller-bundler prototype manufactured by Fixteri OY was assessed in Finland in 2007 [4]. This first study showed that bundling productivity was limited because felling and bundling work phases were performed simultaneously only between 8 and 18% of effective worktime. They concluded that that development was not competitive at that time with the conventional machines and harvesting systems, but the concept had a great future potential.

A second prototype was studied in 2009 [5,6]. The productivity had increased by between 38 and 77% compared with the former one, thanks to the greater felling and accumulating capacity of the head and the hydraulic improvements in the bundling unit, which increased the potential of simultaneous felling and bundling.

A third version, FX15a, was launched in 2013, and its efficiency in terms of time per bundle increased between 90 and 160% when compared with the former prototypes [7].

This technology is considered as preferable to the alternative ones in Nordic countries for tree DBHs between 7 and 14 cm [8] or volumes between 30 and 85 dm^3 [9,10], one of its advantages being the savings in forwarding cost [5,10,11] and in long-distance transportation cost [12], besides the high productivity of chipping bundles, between 1.5 and 3.2 times greater than loose-slash chipping [13].

The feasibility of introducing an innovative technology in a region is linked to the existence of sufficient appropriate workload for it. This study has addressed real and frequent situations in Spain and other European countries. This study is focused on silvicultural treatments that currently have a negative economic balance for the ownership and are not often carried out because the medium-term profitability is uncertain.

The tried technology was the whole-tree bundling unit Fixteri FX15a with a felling-bunching head Nisula 280E+ (Nisula Forest OY) mounted on a 125 kW base machine Logman 811 FC with a telescopic boom Logmer C140-11, allowing the felling of several trees without moving the base machine.

The bundles were extracted by a six-drive-wheel 125 kW forwarder Valmet 840.3—empty weight 13.9 t and loading capacity 12.0 t—in the Galician forests, and with a 115 kW eight-drive-wheel Spanish forwarder Dingo AD8-18 with loading capacity of 8.0 t in the Catalonian case.

The research's main aim is the assessment of Fixteri FX15a technology applied to these salvage and fire prevention treatments by means of time and productivity study techniques. As a result, productivity and cost equations are fitted as a function of the stand or individual tree parameters identified as the most influential. Also, through the more detailed time-study methods, it is the intention of this research to identify inefficiencies or potential improvements in the machine design or work system.

2. Materials and Methods

2.1. Study Area

The studied felling and bundling operations took place in three forest stands, two located in Galicia and the third one in Catalonia:

1. One of the Galician forests was a *E. globulus* young plantation severely affected by *Gonipterus platensis*, a eucalypt defoliator weevil. The trees were clearcut in order to change the eucalypt species to *E. nitens*, a priori less vulnerable to this pest.
2. The second Galician eucalypt plantation had been damaged by a wildfire 18 months before the salvage clearcut. The stand had already been partially harvested for pulpwood. This meant that the remaining trees, which had to be felled to favor the new sprout growth, were small or located in steep slopes.
3. The Catalonian forest had been affected by a wildfire twenty years ago. It was a mixture of Mediterranean hardwoods dominated by cork oak (*Quercus suber*) with maritime pine (*Pinus pinaster*) post-wildfire regeneration from burned former plantations located in the less steep zones. Sparse residual eucalypt individuals from old plantations, severely damaged or dead, were present as well. The dense pine stands were severely affected by *Matsucoccus sp.*, the maritime pine bast scale. The treatment was the clearcut of the eucalypts and the most affected pines, reducing the pine stand density and favoring cork oak as the main species, in addition to preventing new wildfires and easing the firefighting works in case they occur.

Regarding the latter treatment, the promotion of hardwood species, particularly fire-resistant and -resilient species such as cork oak [14,15], and the stand density control by mulching and thinnings, as well as the biomass collection to manage forest fuel, have been recommended as treatments to prevent wildfires or mitigate their consequences [16–19].

2.2. Forest Inventory

A previous forest inventory was performed on each of the forests. In the first Galician eucalypt plantation, 70 plots with a 4 m radius were measured; in the second Galician stand, 71 plots with an 8 m radius were inventoried; while in the Catalonian forest, 45 plots (8 m radius) were assessed. The plot size in the first Galician site was smaller as it was a denser and more homogeneous stand than the other two.

For the biomass weight per tree and per hectare estimation, the weight curves for Galician *E. globulus* based on data from [20], referred to in [21], were applied to the DBH distribution obtained from the inventory results. From the total estimated aerial biomass, some fractions—leaves, small branches—lost because of defoliation or wildfire were subtracted. In the case of the Catalonian forest, the biomass weight equations [22] were applied to eucalypts and pines in the inventoried DBH distribution before and after the treatment, as the treated plots were measured again after thinning. The remaining dead biomass was collected and weighed, and the damages to soil and remaining stand were assessed in smaller subplots (4 m radius) following the methodologies proposed by [23] and [24].

To express the inventory and treatment characterization results in terms of oven-dried weight, a sample was collected in every plot and its moisture content was determined following the gravimetric method according to the standard ISO 18134-3:2015.

2.3. Time Study

The machine work was followed using three different complementary methodologies, two of them continuous—all the machine scheduled time through—and the other one intensive and in shorter intervals during the worktime:

1. Machine movements were followed through a Garmin Etrex GPS to control the daily work areas (allowing the association of the productivity those days with the dasometric parameters measured in the correspondent plots to each zone). The machine movements and production were controlled during 23 days in the Galician forests and 14 days in the Catalonian one.
2. Automatic production and time recording was performed with the software WNexus-2®, which uploaded to the cloud the weight of each bundle and the exact time of the measurement. During a few days, this procedure produced some mistakes in Galicia, so the daily production was recorded directly by the machine driver from the onboard computer. In any case, as the machine automatically recorded the number of cuts per day, this gave an estimation of the number of felled trees—and of the average unit weight—as they were plantations, so no trees were clumped together.
3. The detailed time study was performed for 18.4 h in the Galician plantations (11.9 h in the pest-affected stand and 6.5 h in the burned plantation) and 12 h in Catalonia, using the time–frequency sampling or discontinuous method [25]. The feller-bundler was considered as three different work units working simultaneously:
   - Felling unit (telescopic boom + felling head).
   - Feeding unit (feeding tray and rolls + guillotine).
   - Bundling unit (bundling function, weighing the bundles and releasing them).

The aim of the division is identifying whether the work capability of each unit is aligned with the others or not and if there exists any bottleneck. Another object of this method is evaluating the distribution of the worktime among elemental phases, trying to identify time-costing tasks. Finally, this more detailed analysis allows for determining if the differences between the stands are significant and exploring the reasons for those differences.

2.4. Productivity Equations

To develop empiric equations to predict daily productivity, in the three stands were tried several explanative variables: stand density (number of trees per hectare, basal area), felling intensity (oven-dried tonnes per hectare, odt·ha^{-1}), average DBH and average height—estimated by the inventory—and average weight per tree—for this variable, two options were used, the unit weight estimated by the inventory and the quotient between the recorded daily weight and the number of recorded cuts. In the Galician case, it was observed a significant difference of productivity between the pest-affected stand and the fire-affected one, which led to fit different productivity curves for each of the sites.

In the case of the Catalonian forest, as it was a selective felling, some treatment parameters were also considered, such as the number and percentage of extracted trees per hectare, the value and percentage of extracted basal area, and the value and percentage of dry weight extracted.

The regression equations were fitted using techniques of simple and multiple linear regression. When logarithmic transformations showed better results, nonlinear regression techniques were applied in order to obtain more significant results and statistics. The software StatGraphics v18 was used.

The collection efficiency could only be assessed in the wildfire-affected Galician forest and in the Catalonian one. In the pest-affected stand, the managers had mulched the slash, and it was not possible to measure the biomass left on the terrain after the treatment.

The forwarding productivity was not registered in situ but was estimated using a general productivity equation developed after a meta-analysis by [26], for a maximum forwarding distance of 400 m.

2.5. Cost Estimation

The estimated costs of the treatments were based on the productivity equation combined with the estimated hourly costs, expressed in euros per effective work hour (€·EWH^{-1}). In Galicia, as the machines were hired, the hourly costs were the actual ones. In Catalonia, they were estimated as 120 €·EWH^{-1} for the Fixteri FX15a [27] and 50 €·EWH^{-1} for the forwarder [28].

The quotient between hourly cost and hourly productivity—based on effective work hours—allowed for the estimation of unit costs and conversion of productivity equations in unit cost equations—and economic balance equations, in which the biomass selling incomes and the rest of the costs were taken into account.

The knowledge of the extracted biomass weight per hectare permitted the development of cost balance on surface basis (€·ha^{-1}) curves. This allowed for the assessment of the limits of self-financing for these salvage and wildfire preventive treatments. Those costs were compared with the Spanish references for this kind of treatment [29].

Regarding the cost analysis, the basic data about hourly costs were the following:

- Hourly cost of Fixteri FX15a feller-bundler: 120 €·EWH^{-1}.
- Hourly cost of Valmet 840.3 6 × 6 forwarder: 55 €·EWH^{-1} (of the Dingo 8 × 8 Forwarder: 50 €·EWH^{-1}).
- Average forwarding productivity in Galicia, estimated by a productivity equation for coppices [25]: 5.19 odt·EWH^{-1}. Forwarding productivity in Catalonia, estimated by the same equation: 5.24 odt·EWH^{-1}.
- Fixed and indirect costs (% of direct harvesting costs): 10%.
- Bundle short-distance (<50 km) transportation cost: 10.9 €·odt^{-1}.
- Industrial profit of the supplying company: 12.5% of total costs.
- Chipping cost of bundles at the plant—fixed electrical chipper—4.3 €·odt^{-1}.
- Chips price at 30% moisture (humid basis): 68.6 €·odt^{-1}.

3. Results

The dasometric conditions of the three forests are reflected in Table 1, as well as the biomass productions and productivities.

Table 1. Summarized dasometric conditions, productions and productivities of the studied sites.

Site	Treated Surface, ha	Aver DBH, cm	Nr of Extracted Trees·ha^{-1}	Extracted Weight, odt·ha^{-1}	Unit Fresh Weight, kg·tree^{-1}	Biomass Moisture, % Humid Basis	Unit Weight, odkg·tree^{-1}	Extracted Weight, Fresh Tonnes	Average Productivity, Fresh Tonnes/odt·EWH^{-1}
Galician 1, pest affected	17.50	10.7	1043	18.2	36.4	52.0	17.5	664	6.90/3.10
Galician 2, wildfire affected	17.75	12.4	775	9.9	19.3	33.8	12.8	265	3.63/2.40
Catalonian, post-wildfire thinning	6.10	9.0	4200 (69%)	45.4	18.6	45.0	10.2	477	4.49/2.47

Productivity differences between the two eucalypt plantations—lower values for the wildfire-affected one—were caused by the more difficult handling and bundling of the dry burned material, combined with a lower collection efficiency. Moreover, the fire-affected forest was less dense and more heterogeneous and had been partially harvested in the areas with available pulpwood. Additionally, there were zones with steep slopes and stoniness which prevented access by the Fixtery and forced it to do longer displacements. In the case of the strong thinning of the Catalonian stand, the greater productivity was due to the much greater density in terms of extracted trees and biomass weight per hectare.

The most conditioning variables influencing the productivity identified in the analysis of the salvage clearcuts were the type of damage (wildfire vs. pest) and the unit weight per tree (using more the recorded values by the machine than the inventory estimations).

The productivity equations fitted by nonlinear regression of logarithmic models were the following.

For the eucalypt plantation affected by *Gonipterus*:

$$\text{Productivity (odt}\cdot\text{EWH}^{-1}) = -0.711 + 1.328 \times \log\text{ (Unit dry weight, odkg}\cdot\text{tree}^{-1}) \quad (1)$$

where odt = oven dried tonne, EWH = effective work hour, odkg = oven dried kg and log in the function is "natural logarithm".

R^2 = 84%

Mean absolute error = 0.18 odt·EWH^{-1}

For the wildfire-affected stand:

$$\text{Productivity (odt}\cdot\text{EWH}^{-1}) = -1.573 + 1.218 \times \log\text{ (Unit dry weight, odkg}\cdot\text{tree}^{-1}) \quad (2)$$

R^2 = 27%

Mean absolute error = 0.26 odt·EWH^{-1}

Those curves are depicted in Figure 1.

In the case of the Catalonian thinning, the number of points—daily productivities over zones represented by two or more plots—was 10, with the dependent variable that best explained the productivity being odt per scheduled machine hour (SMH). Two main explanative factors were identified: dry unit weight and percentage of extracted basal area. The original multiple linear regression, with logarithmic transformation, was fitted again as a nonlinear regression in order to estimate in a direct way the exponents and to obtain the statistics referred to the original variables. The resultant equation and its statistics are the following.

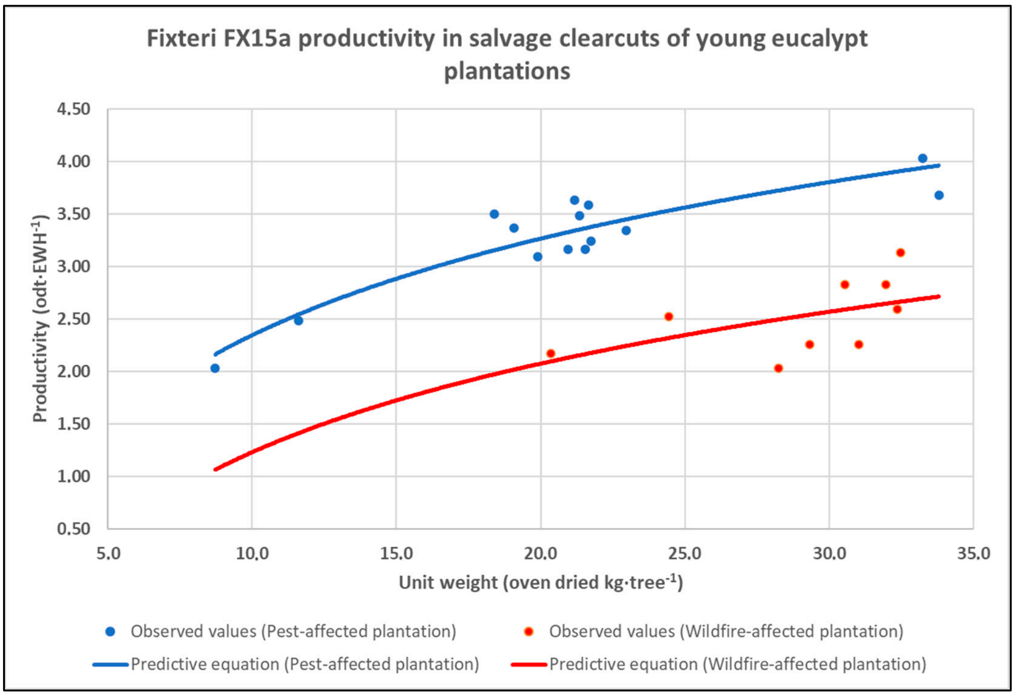

Figure 1. Logarithmic productivity models (1) and (2) for felling and bundling with Fixteri FX15a in salvage clearcuts in eucalypt young plantations as a function of unit dry weight per tree.

The fitted equation for the thinning in the Catalonian case and its main statistics were the following:

$$\text{Productivity (odt·SMH}^{-1}) = -11.77 + 2.73 \times \text{Ext BA\%}^{0.233} + 4.93 \times (\text{Unit Dry Weight, odkg·tree}^{-1})^{0.124} \quad (3)$$

where ExtBA = extracted basal area (percentage of initial basal area which was felled)

R^2 = 73%

R^2 (adjusted by d.f.) = 52%

Mean absolute error = 0.16 odt·SMH^{-1}

The predictive equations fitted for the Catalonian thinning are represented in Figure 2, where the different curves correspond with different values of the percentage of extracted basal area (ExtBA, %).

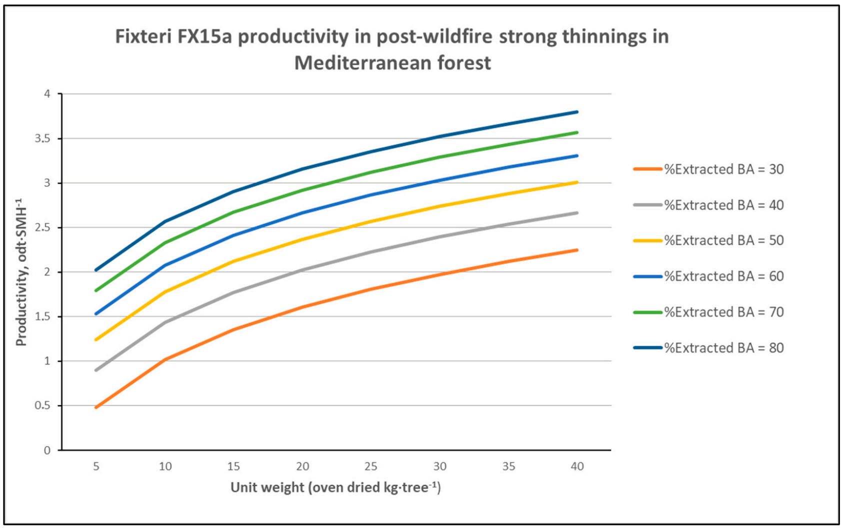

Figure 2. Predictive Equation (3) for Fixteri FX15a productivity in felling and bundling whole trees from strong thinnings in a Mediterranean forest affected by a wildfire and damaged by pests.

The zones covered daily by the Fixteri's work, in distinct colors or frames for each day, are depicted in Figure 3, as obtained from the GPS data. The work pattern seems not to be systematic, with frequent movements over areas previously treated. This reflected changes of criteria by the private forest owner, forcing the machine driver to come back to some stands already thinned, and the traditional method of mechanized thinning in the region, working from already existent temporary roads and avoiding opening a parallel net of strip roads. These factors obliged the machine driver to come back through the same temporary roads to continue work where he had finished the day before.

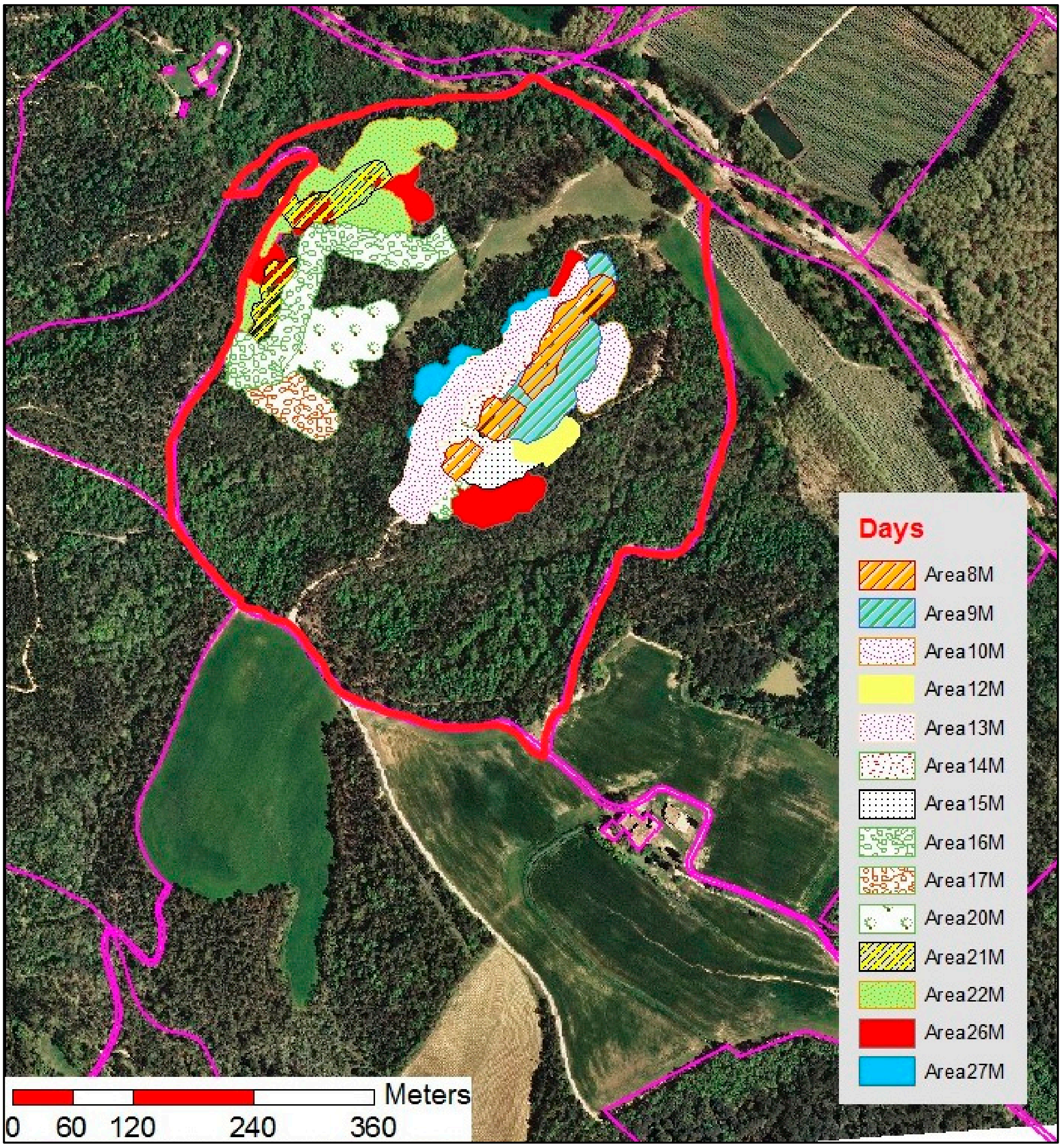

Figure 3. Daily treated areas. The codes in the legend correspond to the day and month (March).

The detailed work analysis by the time sampling method led to the following results:

1. In the Catalonian study, the utilization coefficients were 89% of productive time over work effective time and 75% of productive time over scheduled machine time.
2. The feeding unit acted as a bottleneck for the work of the felling boom. The waiting times of the felling head while feeding the bundling unit ranged from 15 to 34%, greater in the stand affected by the wildfire.

3. Bundling was much more complicated in the stand affected by the forest fire, particularly because the handling and bundling of the dry material was made difficult by the length of time since the wildfire occurrence. The activity time of the bundling unit was 51 and 49% of the worktime in the Galician 1 and Catalonian stands, respectively, while it reached 70% of the worktime in the Galician 2 burned stand.
4. The productive time per bundle was significantly greater in the forest affected by the wildfire (4.7 min·bundle^{-1}, in front of 3.1 min·bundle^{-1} in the *Gonipterus*-affected stand and 3.6 in the post-wildfire Catalonian treatment).
5. The fire-affected eucalypt plantation also presented other constraints, such as the heterogeneity and the existence of inaccessible or already harvested areas. These facts were reflected in non-productive time that doubled those of the other stands—4% in front of 2%. The delay in harvesting the plantation after the wildfire caused 14% of the biomass weight to be left uncollected.

Under the cost assumptions reflected in the Methodology chapter, curves predicting unit costs for felling and bundling were built, separately for the pest- and wildfire-affected eucalypt plantations. Those costs were added to the rest of harvesting, transport, chipping, and other costs, besides the supplying of company profit, and were compared with the income from the selling of the chips on a per-hectare basis. The results are shown in Figure 4. Using as an explanative variable the dry extracted weight per tree, the self-financing limit would reach 33 odkg·tree^{-1} (around 69 fresh kg·tree^{-1}) in the pest-affected plantation, but the wildfire-affected one would only achieve a unit weight of 80 odkg·tree^{-1}, far from the observed values.

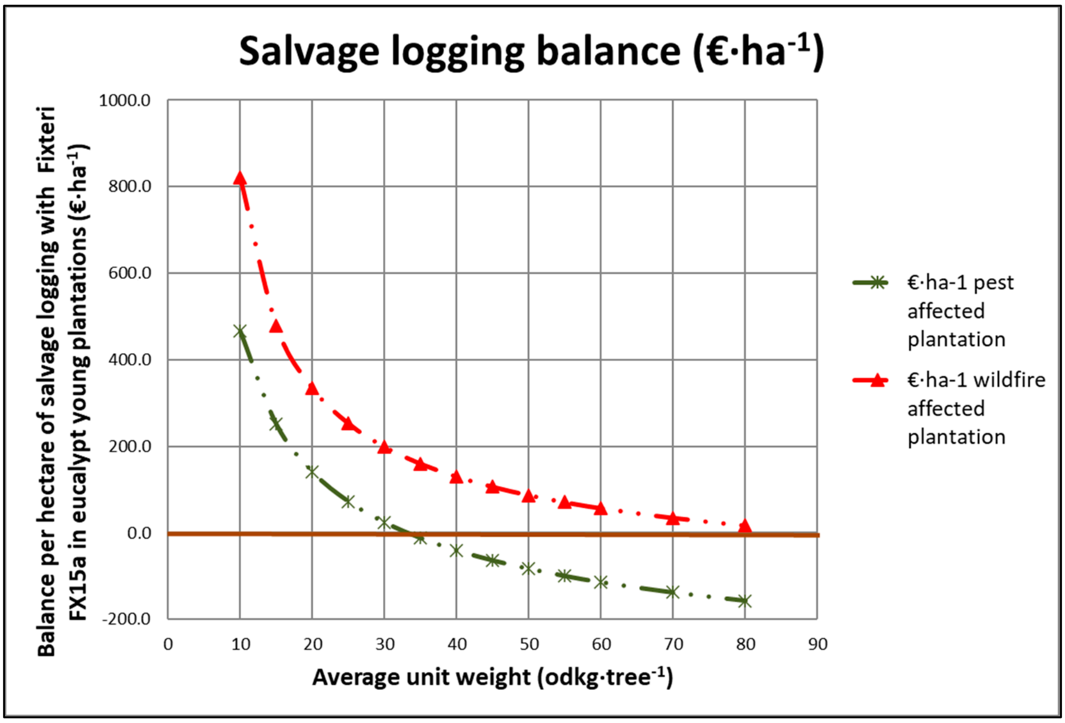

Figure 4. Cost balance (€·ha^{-1}) of salvage clearcut as a function of dry weight per tree (odkd·tree^{-1}).

In none of the Galician cases, taking into account the observed extracted weights (18.2 odt·ha^{-1} in the *Gonipterus*-affected plantation and 9.9 odt·ha^{-1} in the wildfire-affected one), was the balance positive. In the first case, the treatment balance was −125 €·ha^{-1}, while it was −255 €·ha^{-1} in the burned stand.

In the case of the Catalonian pine strong thinning after wildfire, even under these unfavorable conditions, the treatment would have been self-financed if a consumer close to the forest—transportation distance around 35 km—would have paid 49.5 €·t^{-1} for bundles at a 30% moisture content—humid basis. The studied operation would be close to the profitability of the present Spanish market situation. The used harvesting means—Fixteri FX15a + forwarding + bundles truck transport to the plant—even if they do not reach self-financing, do strongly reduce the wildfire preventive treatment costs. The estimated operational cost would be 265 €·ha^{-1}, in front of the cost of felling the trees and comminuting them on the terrain with a hammer mulcher, around 2400 €·ha^{-1} [29]. Under better conditions and using more appropriate work methods, the technology would have been profitable.

Regarding the environmental impacts in this latter case, the damages to the remaining stand were not severe, affecting 8.3% of the remaining trees, while the damages to the soil were isolated and barely noticeable. The treatment quality (selection efficiency, low stump height) was better in the less steep sloped zones, where the target species were more abundant and the shrubs were less dense. In any case, the stand health and wildfire risk conditions did improve in the thinned areas, where almost no slash was left on the terrain.

4. Discussion

Tree size (DBH, unit volume or weight) is the most common explanative variable in felling and bunching productivity equations [30–36].

In the Catalonian study, a significant relationship between productivity and felling intensity was found. Commonly, the related explanative variables are extracted weight per hectare or extracted basal area, as in other studies [30,37]. In the present work, extracted basal area has been significant, expressed as a percentage of the initial one.

The results of these Spanish experiences have been compared with two recent studies about the same machine in Sweden and Finland, both cases in selective thinnings in Scots pine (*Pinus sylvestris*) stands. In the Swedish case, this was a mixed stand with some proportion of birch [3], while in the Finnish study, the pine forest had an abundance of different shrubs [38]. The results are shown in Figure 5.

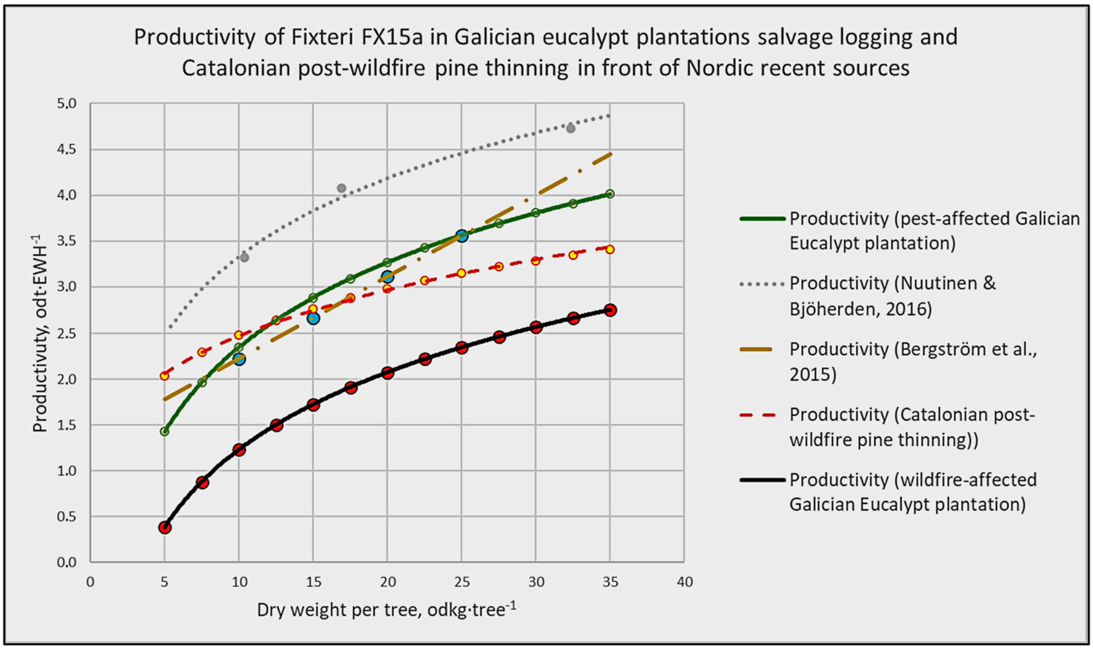

Figure 5. Comparison of the fitted productivity equations with other Fixteri FX15a studies [3,38].

To make comparable the different biomass units used in those studies with the Spanish trials, a pine bundle density of 385 odkg per solid cubic meter of biomass, a ratio between productive and work time of 89.0% and a ratio between work time and schedule time of 83.7% [39] were assumed. In the case of the Catalonian thinning equation, a percentage of extracted basal area of 100% was assumed in order to compare the productivity with those of the Galician salvage clearcuts.

The productivity results in odt·EWH^{-1} in the pest-affected eucalypt stand are very close to those from [3]. Nonetheless, they are lower than those from [38], between 0.86 and 1.05 odt·EWH^{-1} less (see Figure 5).

The results of the Catalonian post-wildfire thinning, assuming the total extraction of basal area, are similar—or slightly lower for unit weights over 13 odkg·tree^{-1}—to the pest-affected Galician salvage logging, and the same is true if compared to [3]. So, they are clearly lower—much lower for the greater tree sizes—than the productivity recorded by [38], which probably reflects the stand heterogeneity and poorly planned work in the Catalonian case.

The productivity in the wildfire-affected Galician plantation was clearly lower than that of the pest-affected one and of the rest of the experiences. This is due to the condition of the burned stand—the fact that it was more than a year ago, its heterogeneity and the low extracted weight per hectare, as the pulpwood fraction had already been felled -. The result in this plantation is between 1.04 and 1.25 odt·EWH^{-1} less than the *Gonipterus*-affected eucalypt plantation and much inferior to the results of [38].

The simultaneous activity of the felling head and the feeding and bundling unit was deduced from the detailed time study as 35% of the work time, close to the maximum described in [6]. The time exclusively dedicated to bundling, described in [9] as the time when no other work element was being performed, was between 13% and 34%, significantly larger than [9]. The recorded waiting times of the feller-buncher unit due to the apparent lower speed of the bundling unit feeding system seem to contradict previous studies, emphasizing the greater capacity of the bundling unit when compared to the felling head [9,34,38]. These facts may be explained by the use of a crane Logmer C 140-11, with greater reach and speed than that used in these studies (Loglift FT 100 in [9], without specification in the other references). Additionally, the different machine drivers and especially the smaller tree sizes in the Nordic case studies may have conditioned these results.

Regarding this limitation of felling capacity, particularly for the smaller trees studied in the mentioned references, a possible improvement would come from the use of felling heads and work methods allowing for the accumulation of trees during continuous crane movements, such as the boom corridor method [40].

5. Conclusions

As a general conclusion, the use of the studied technology is convenient in homogeneous stands with small trees, such as the studied *Gonipterus*-affected eucalypt plantation. This reduces the costs of felling, accumulating and comminuting on site or disposing to waste the non-commercial trees. In such stands, a self-financing salvage clearcut could be achieved for a dry weight per tree of around 33 kg.

In the case of the Catalonian strong thinning on the pine plantations affected years ago by a wildfire, biomass collection using the Fixteri technology was also cost-saving if compared to the alternative of thinning and comminuting the whole small trees on site. Even under the constraining stand and work method conditions—heterogeneity, steep sloped areas, abundant shrubs, and inappropriate non-systematic work method—the average productivity was remarkably high, 5.33 fresh t·SMH^{-1} (4.49 fresh t·EWH^{-1}). The ratios between productive time vs. work time (89%) and productive time vs. scheduled time (75%) were also high for this kind of combined machine.

The studied salvage logging in the wildfire-affected eucalypt plantation was less significant because of the aforementioned diversely unfavorable circumstances. It is remarkable the convenience of harvesting in a shorter time after the wildfire, both to reduce the productive time per bundle and to increase the collection efficiency.

The analyzed technology presents relevant advantages, such as easy service and maintenance tasks because of the simple bundling technology, the automation of several functions and the high speed and accumulation capacity of the boom and felling head.

Nonetheless, the two main aspects that should be improved are (1) the low speed of the feeding and bundling system, which increases waiting times to the felling subsystem up to 34%, and (2) the height of the bundling unit, which makes the machine unstable, limiting its use in steep or uneven terrain. Both constraints are susceptible to improvements in the technology and/or work methods which should be analyzed by the machine manufacturer.

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