

Article

Skidders Fuel Consumption in Two Different Working Regions and Types of Forest Management

Hrvoje Koseak, Marijan Šušnjar, Marin Bačić, Mario Šporčić and Zdravko Pandur *

Faculty of Forestry and Wood Technology, University of Zagreb, Svetošimunska Cesta 25, 10000 Zagreb, Croatia; hkopseak@sumfak.unizg.hr (H.K.); msusnjar@sumfak.unizg.hr (M.Š.); mbacic1@sumfak.unizg.hr (M.B.); msporcic@sumfak.unizg.hr (M.Š.)

* Correspondence: zpandur@sumfak.unizg.hr

Abstract: For the needs of fuel consumption analysis, a database for a period of 2 years was created for three types of skidders operating in two different management methods—even-aged and selective forests. A total of 436 skidders were processed in the database, of which 255 skidders worked in even-aged forests and 181 skidders worked in selective forests. The average consumption of skidders in even-aged forests ranged from 1.38 to 1.65 L/m³ or from 7.81 to 9.34 L/PMH, while in selective forests, the average consumption ranged from 1.06 to 1.34 L/m³ or from 6.49 to 7.10 L/PMH. The obtained results indicate higher fuel consumption for all three types of skidders in regular forest management. There is no statistically significant difference in fuel consumption between the studied skidders. Comparing fuel consumption in L/PMH, we notice that there was an increase in fuel consumption in relation to the age of the skidder.

Keywords: skidder; fuel consumption; selective forests; even-aged forests; Croatia



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1. Introduction

Fuel consumption in logging is a major cost component of timber harvesting. Baker [1] states that fuel has been found to make up 22.8% of the in-woods logging cost, while Jovanović [2] determined that as much as 43% of the total energy consumed during the timber harvesting is spent on logging. Depending on the type of fuel and the amount of time a tractor or machine is used, fuel and lubricant costs will usually represent at least 16% to more than 45% of the total machine costs [3].

With an expected increase in the level of timber harvesting, coupled with greater levels of mechanization, we can expect higher levels of total fuel used in future harvesting operations. The ability to predict tractor fuel consumption is very useful for budgeting and management. Fuel prices are influenced by market forces beyond the control of logging contractors and stakeholders in the industry. This variability makes it difficult to forecast the impact of change on the logging industry [4].

Several recent studies deal with fuel consumption rates of different timber harvesting systems, including all forest machines in the production process [5–7].

Studies have shown that fuel consumption of applied timber harvesting methods is affected by many factors, including operator experience, stand, and terrain variables, as well as machine specifics [8–10]. Fuel consumption rates for a single forest machine in a timber harvesting system are affected by the engine size, load factor, condition of the equipment, operator's driving skill, and environmental conditions, as well as the design of the machine [11]. According to Halilović et al. [12], the following factors affect fuel consumption: external factors (climatic, field, and stand), machine factors (engine, working, and transmission part factors), technological factors (working method and work operations), and organizational factors (machine maintenance and operator education).

Comparison of fuel consumption rates among studies is sometimes difficult because data is often published in different units: liters per unit of extracted timber (L/m³), liters

per productive machine hours (L/PMH) or scheduled machine hours (L/SMH), liters per unit of power (L/kWh), liters per unit weight of the machine (L/ton).

FP Innovations in Canada have produced a guide with suggestions for reducing fuel consumption rates, which could be applied for any forest operation and include use of diesel engines at maximum torque, avoiding thermostatic and hydraulically driven fans operating at full speed under all working conditions, use of the work lights only when required, minimizing idling, keeping the radiator and oil cooler clean, choosing appropriate tires to minimize sinking and loss of traction, and preferring downhill skidding and forwarding [13].

In most countries of southern Europe, the use of skidders and agricultural tractors equipped with forest winches are the most common technique for timber extraction [14]. In the forests of the hilly and mountainous areas of Croatia, skidders with winches weighing up to 10 tons are primarily used for timber extraction from regular felling of broadleaves and selective felling of coniferous species [15]. According to Tomašić et al. [16], about 55% of the total timber assortments are extracted by skidders with a winch.

There are not many studies available on the fuel consumption of skidders commonly used in the middle, south, and south-east Europe despite environmental and economic concerns on the fuel consumption, emissions, and increasing fuel costs.

Sabo and Poršinsky [17] detected skidder average fuel consumption per operating hour in the range between 6.7 L/h and 7.0 L/h.

Jovanović [2] investigated the dependence of skidder fuel consumption on operating time and found that fuel consumption and the duration of unloaded driving are in correlation. Each increase of unloaded driving time by 1 min causes an increase in fuel consumption of approximately 0.25 L.

Holzleitner [18] analyzed the efficiency of forest machines based on long-term data of forest machines of the Austrian Federal Forests in the period from 2004 to 2008 and obtained an average fuel consumption per operating hour of the skidder of about 7.3 L/PMH. Janeček and Adamovský [19] concluded that a TERRI 2040 clambunk skidder, when skidding 1 m³ of timber over a skidding distance of 154–731 m, consumed 0.52–1.30 L of diesel fuel. Kenney [20] states that the average fuel consumption of skidders is 23.61 L/PS and 0.93 L/m³. Compared to forwarders, skidders consume on average 3.31 L more per productive machine hour and 0.12 L more per m³. Enache et al. [21] determined fuel consumption for skidders at 12.5 L/PMH.

Borz et al. [22] investigated differences between fuel consumption of skidders by considering logging distance and species group (resinous or broadleaved) when working in different stand conditions. Fuel consumption of skidders is always higher during timber extraction in broadleaved stands. At the logging distance of 1000 m, the fuel consumption of a skidder is 0.62 L/m³ in coniferous stands, while it reaches 1.00 L/m³ during extraction in broadleaved stands.

The aim of this research is to analyze collected data of skidders owned by the state company “Croatian forests” Ltd., Zagreb the Republic of Croatia. The data of total wood extraction, fuel consumption, working hours, and years of use of three different types of skidders in two different working regions and types of forest management are involved in the calculation, comparison, and statistical analysis.

2. Materials and Methods

For this research, for a period of 2 years, data on skidder productivity records from the state company “Croatian forests” Ltd. Zagreb the Republic of Croatia was used. A database was made from productive parameters of skidders working in different working regions and types of forest management for the period of 2 years.

The analysis was performed for three types of skidders of the same performance category, weighing more than 5 tons: Ecotrac 120 V, Ecotrac 140 V, and Timberjack 240 C. The technical characteristics of the researched skidders are shown in Table 1.

Table 1. Technical characteristics of researched skidders.

	Ecotrac 120 V	Ecotrac 140 V	Timberjack 240 C
Engine type	Deutz, D914L6, diesel, 6-cylinder, air cooling	Cummins Inc., QSB4.5, diesel, 4-cylinder, water cooling	Cummins 4BTA diesel, 4-cylinder, water cooling
Power (kW/HP)	86.5/116	104/140	75/100
Maximum torque (Nm)	375	624	483
Specific fuel consumption (g/kWh)	220	221	203
Emission standard	EU Stage IIIA	EU Stage IIIB	EU Stage IIIA
Weight (kg)	7660	8060	8409
Tire size	16.9-R30	16.9-R30	18.4-34
Winch	2-drums, hydraulically driven, nominal pulling force 2 × 80 kN	2-drums, hydraulically driven, nominal pulling force 2 × 100 kN	2-drums, hydraulically driven, nominal pulling force 2 × 80 kN

Fuel consumption (L), volume of extracted wood (m³), productive machine hours (PMH), and years in use (year) are the parameters that are collected for every total 436 skidders. From the selected parameters, the average fuel consumption of the skidder was calculated per unit of extracted timber (L/m³) and per productive machine hour (L/PMH). The skidders were divided into two different groups depending on the working area— even-aged forests were located in the hilly relief area and selective forests were located in the mountainous relief area. In the even-aged forests, 255 skidders worked, and in selective forests, 181 skidders worked. The difference was due to an assumption that the stands in the selective forest, which are located in mountainous areas, consist mostly of fir and spruce and that where logs and skidder piles are bigger, therefore skidders consume less fuel during wood extraction.

The establishment of a database and basic calculations were done in MS Excel software. For statistical analysis (descriptive statistics, ANOVA) STATISTICA 13.5 software was used.

3. Research Results

During the 2-year data collection period (2018 and 2019), 436 skidders performed a total of 379,964 productive machine hours (PMH), extracting 2,144,330 m³ of wood assortments and consuming 2,824,966 L of diesel fuel.

In even-aged forests, a total of 1,247,224 m³ of wood assortments was extracted, or 58.16% of total volume. Skidders performed 233,055 PMH (61.34%), and 1,893,134 L of fuel (67.12%) was consumed. The average fuel consumption was 1.59 L/m³ or 8.70 L/PMH, while the highest was 3.00 L/m³ or 36.21 L/PMH and the lowest 0.66 L/m³ or 2.05 L/PMH.

In selective forests, a total of 897,106 m³ of wood assortments, or 41.84% of total volume, was extracted. Skidders performed 164,909 PMH (38.66%), and 928,832 L of fuel (32.88%) was consumed. Average fuel consumption was 1.13 L/m³ or 6.67 L/PMH, while the highest was 2.52 L/m³ or 17.90 L/PMH and the lowest was 0.50 L/m³ or 1.78 L/PMH. Table 2. shows the average, minimum and maximum consumption values for all three types of skidders in both methods.

Table 2. Descriptive statistics of skidders fuel consumption in selective and even-aged forest stands.

Skidder Type	Even-Aged Forests						Selective Forests					
	L/m ³			L/PMH			L/m ³			L/PMH		
	Min	Average	Max	Min	Average	Max	Min	Average	Max	Min	Average	Max
Ecotrac 120 V	0.66	1.61	3.00	3.10	8.69	36.21	0.58	1.06	2.08	2.16	6.49	15.05
Ecotrac 140 V	0.92	1.38	2.33	2.05	7.81	16.80	0.74	1.34	2.27	4.28	6.58	17.90
Timberjack 240	1.23	1.65	2.44	4.76	9.34	15.70	0.50	1.13	2.52	1.78	7.10	15.58

In order to compare the fuel consumption (L/m^3) of the skidder between the two methods, a two-factor analysis of variance was performed (Figure 1). The printout of the two-factor analysis of consumption variance per m^3 from the STATISTICA program is shown in Table 3. Results of the analysis of variance ($F = 143.718$; $p = 0.0000$) show that the average fuel consumption, expressed in L/m^3 , in different operating conditions differed significantly at a 95% confidence level. In selective forest management, the consumption of L/m^3 was lower compared to regular forest management. The difference in consumption is expressed in the Ecotrac 120 V and Timberjack 240 C, while in the Ecotrac 140 V, there was no significant difference in fuel consumption with regard to the method of forest management. Comparing the skidders with each other within the same method, there was no statistically significant difference in fuel consumption ($F = 0.628$; $p = 0.5341$).

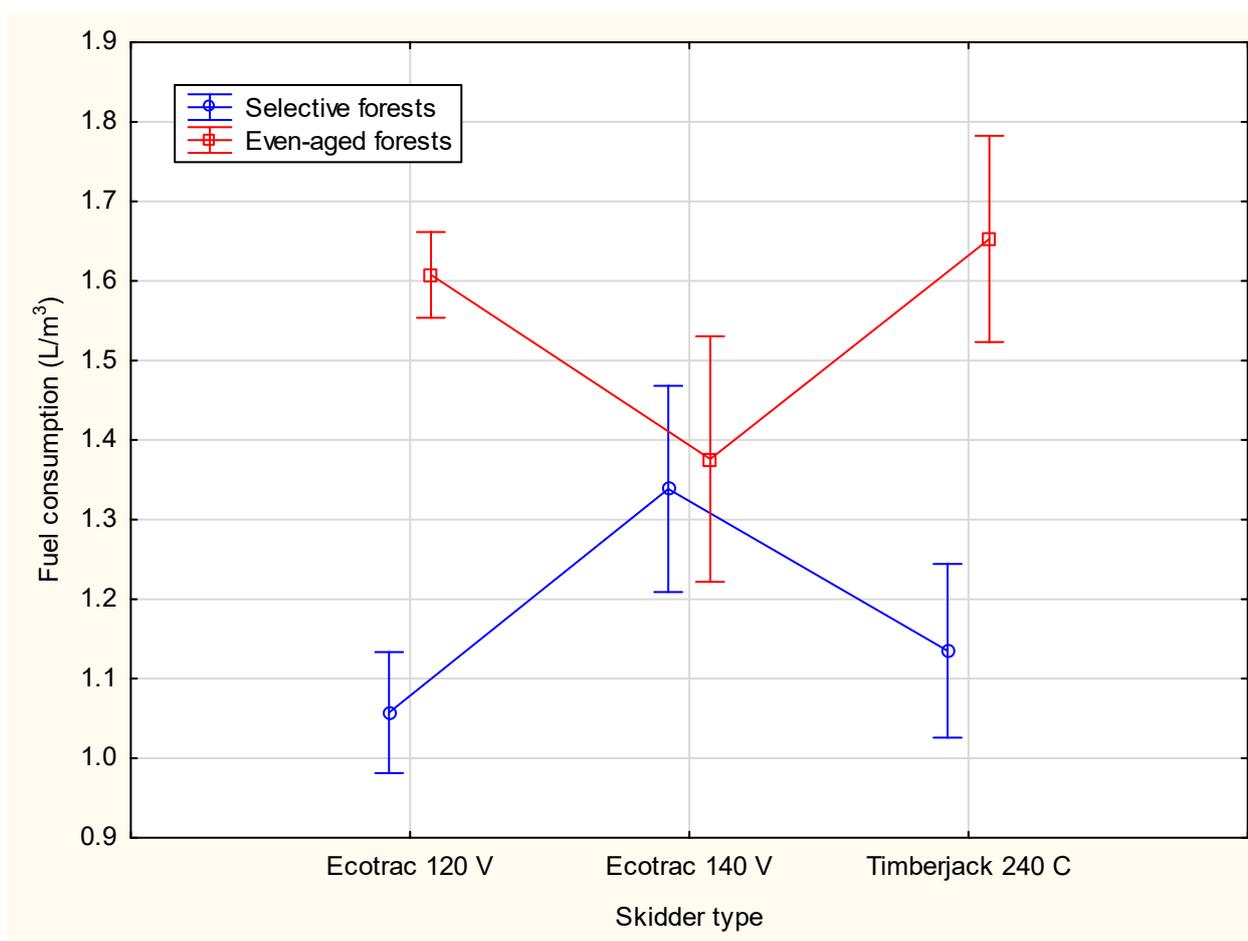


Figure 1. Fuel consumption expressed in L/m^3 .

Table 3. Results of the univariate test of significance for fuel consumption with the method and skidder type as independent variables.

Effect	Univariate Tests of Significance for L/m^3 Sigma-Restricted Parameterization Effective Hypothesis Decomposition				
	SS	Degr. of Freedom	MS	F	p
Intercept	519.8434	1	519.8434	3364.262	0.000000
Forest management type	22.2071	1	22.2071	143.718	0.000000
Skidder type	0.1941	2	0.0970	0.628	0.534148
Error	66.7523	432	0.1545		

Figure 2 shows the analysis of fuel consumption per hour of the skidder. The results of the analysis of variance ($F = 44.950$; $p = 0.0000$) show that there was a statistically significant difference in fuel consumption per operating hour between different methods. In selective forest management, the consumption of L/PMH was also lower compared to the regular forest management. Comparing the consumption of L/PMH per skidder, the Ecotrac 120 V and Timberjack 240 C in regular forest management had higher consumption compared to the skidder in selective forest management. There was no statistically significant difference with the Ecotrac 140 V skidder, but this type of skidder had equal consumption in both working methods.

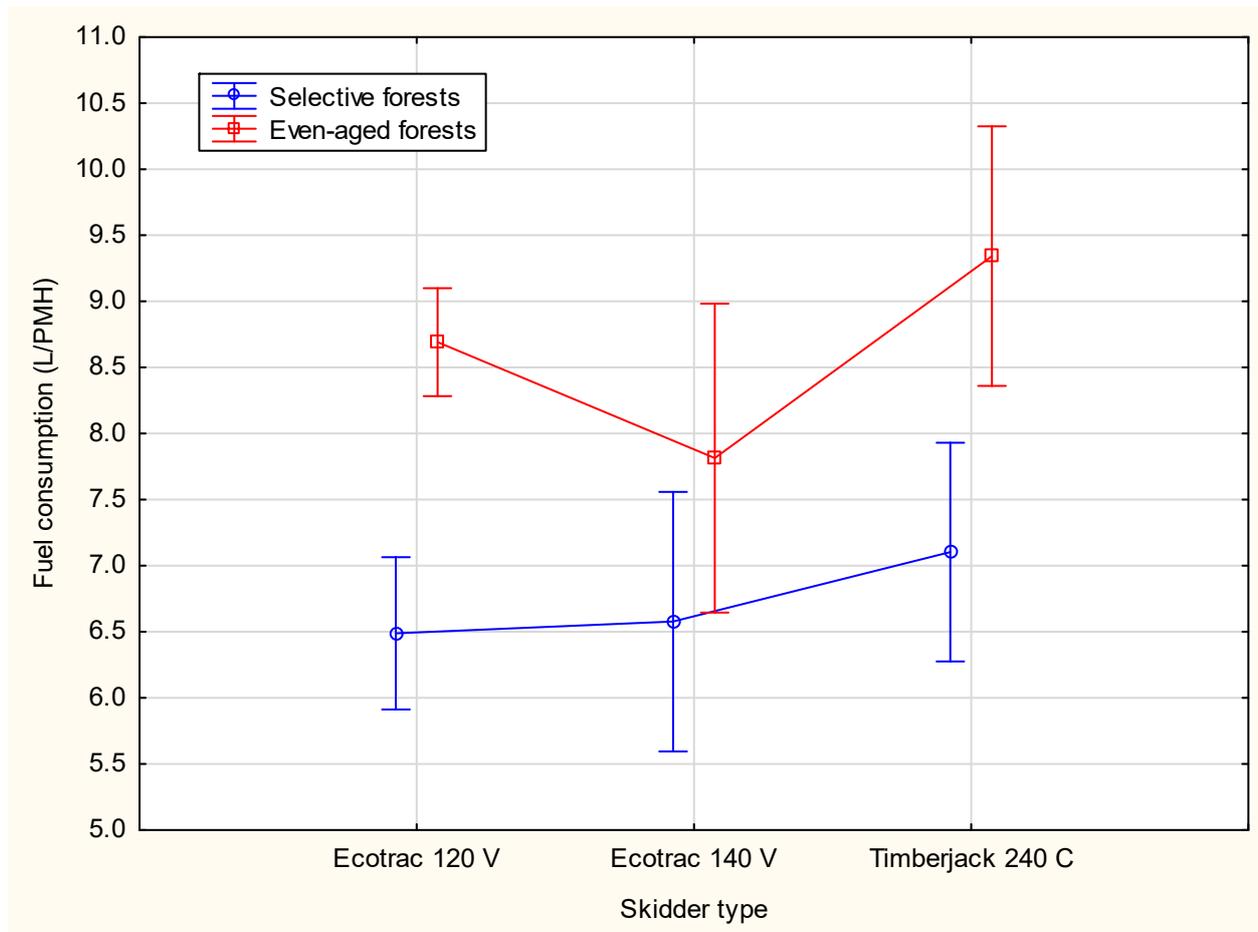
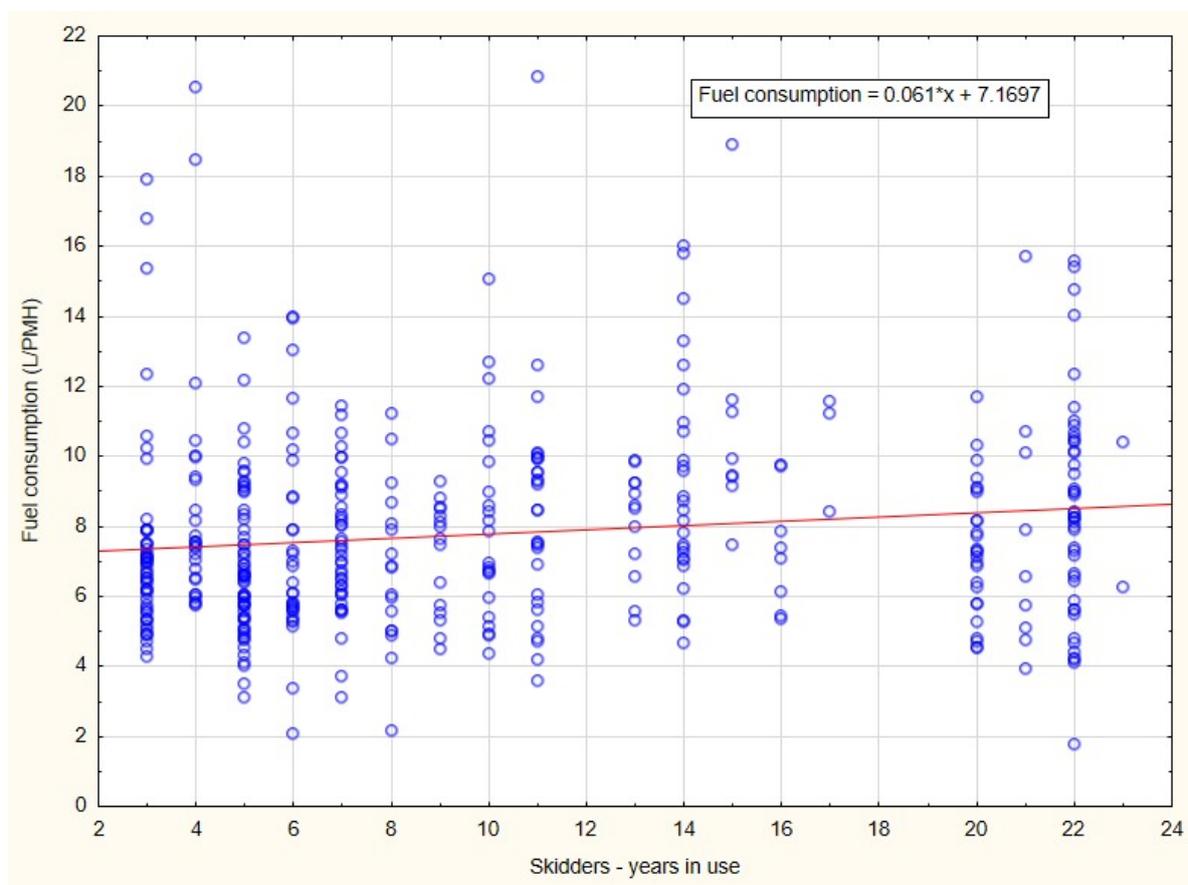


Figure 2. Fuel consumption expressed in L/PMH.

By performing the analysis of influencing factors on fuel consumption per operating hour, in addition to the parameters of the operating method and the type of skidder, the age of the skidder was also included. As shown in Table 4, it can be seen that there was no statistically significant influence of the age of the skidder on fuel consumption ($F = 1.733$, $p = 0.141615$), while, according to the diagram in Figure 3, the growth trend of fuel consumption with the age of the skidder was visible.

Table 4. Results of univariate test of significance for fuel consumption with the method, skidder type, and skidder age as independent variables

Effect	Univariate Tests of Significance for L/PMH Sigma-Restricted Parameterization Effective Hypothesis Decomposition				
	SS	Degr. of Freedom	MS	F	<i>p</i>
Intercept	13,557.98	1	13,557.98	2027.590	0.000000
Forest management type	300.57	1	300.57	44.950	0.000000
Skidder type	0.86	2	0.43	0.064	0.938045
Skidder age	46.36	4	11.59	1.733	0.141615
Error	2,855.24	427	6.69		

**Figure 3.** Skidder fuel consumption depending on years in use.

4. Discussion

The obtained results show higher fuel consumption in even-aged forests in both ways of displaying fuel consumption (L/m^3 , L/PMH) and in all investigated skidders. A statistically significant difference in fuel consumption, with regard to the method of forest management, was observed in the Ecotrac 120 V and Timberjack 240 C skidders when expressing fuel consumption in L/m^3 , as well as in fuel consumption expressed in L/PMH . Comparing the fuel consumption between the skidders expressed in L/m^3 , a significant deviation was visible in the Ecotrac 140 V skidder in both forest management methods. It is interesting to note that in even-aged forests, the Ecotrac 140 V skidder had the lowest fuel consumption, and in selective forests, it had the highest (Figure 1). A similar phenomenon was observed when expressing fuel consumption in L/PMH , for which the Ecotrac 140 V skidder had the lowest fuel consumption in even-aged forests

and which was statistically different from the other two types of skidder, while in selective forests, the mentioned skidder had approximately the same fuel consumption, which was not statistically different from the fuel consumption of the other two types of skidder (Figure 2). Ecotrac 140 V is a new model of skidder that has been on the market for only a few years, so we can assume that workers have not yet realized its capabilities and that it works below the nominal extraction capacity in selective forests, which can be seen in Figure 4. The Ecotrac 140 V, compared to the other two types of skidders, has the lowest productivity in selective forests, while in even-aged forests, its productivity is the highest. Another assumption is that the mentioned skidder consumes more fuel because it has a more powerful engine installed. As shown in Figure 5, the Ecotrac 140 V has a higher total fuel consumption than the Ecotrac 120 V, but lower total fuel consumption compared to the Timberjack 240 C. At the same time, the Ecotrac 140 V has the highest production hours (Figure 6.), which is to be expected, because the mentioned type of skidder has been on the market for only a few years and consequently has the fewest breakdowns. Comparing the fuel consumption between the Ecotrac 120 V and Timberjack 240 C, a slightly higher fuel consumption (but not statistically significant) is observed in the Timberjack 240 C in both forest management modes and in both ways of expressing consumption (Figures 1 and 2). As shown in Figure 6, it can be seen that the Timberjack 240 C skidder also consumes the largest total amount of fuel. This can be explained by the fact that the average age of the Timberjack 240 C skidder is over 20 years, while the average age of the remaining two skidders is younger, especially the Ecotrac 140 V skidder. According to the diagram in Figure 3, the growth trend is visible for skidder fuel consumption with regard to their age.

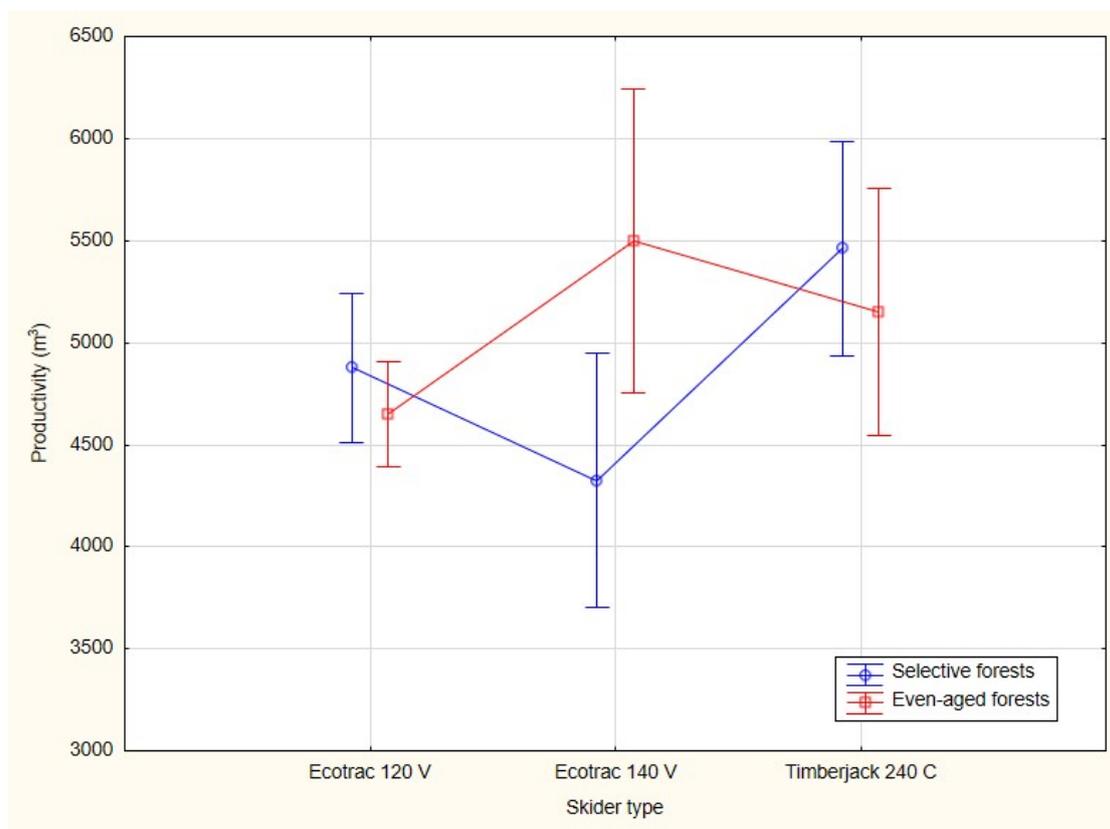


Figure 4. Total average productivity of skidders.

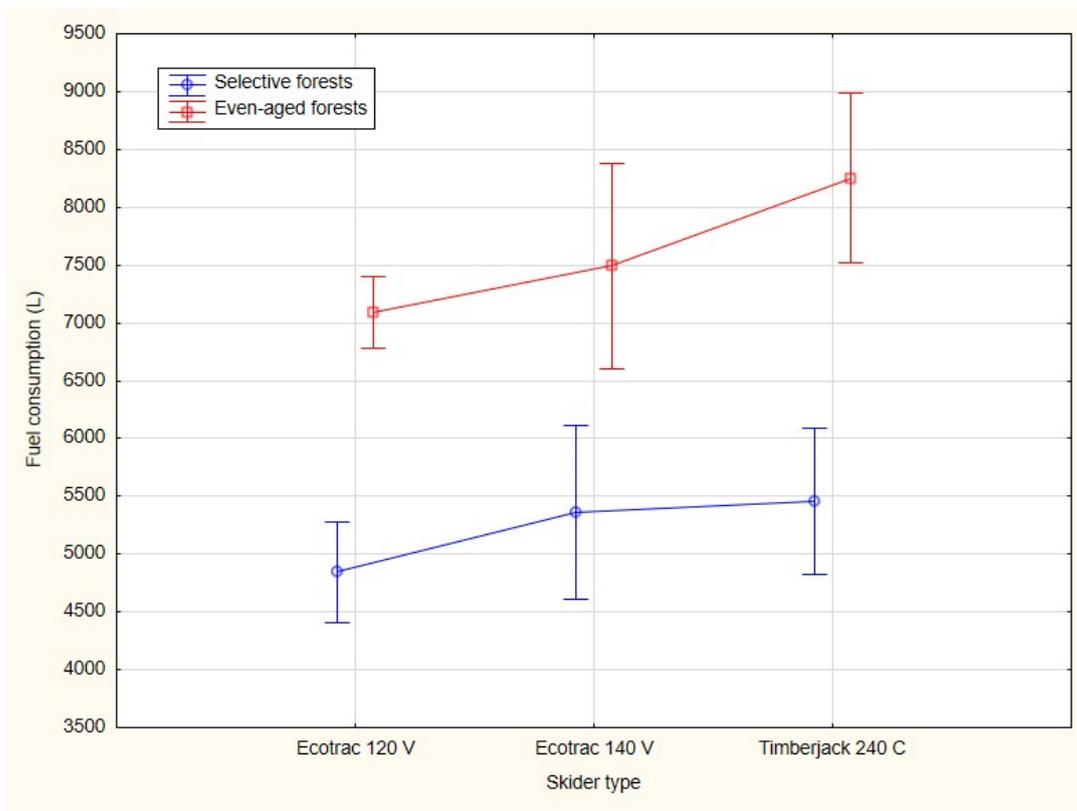


Figure 5. Total average fuel consumption of skidders.

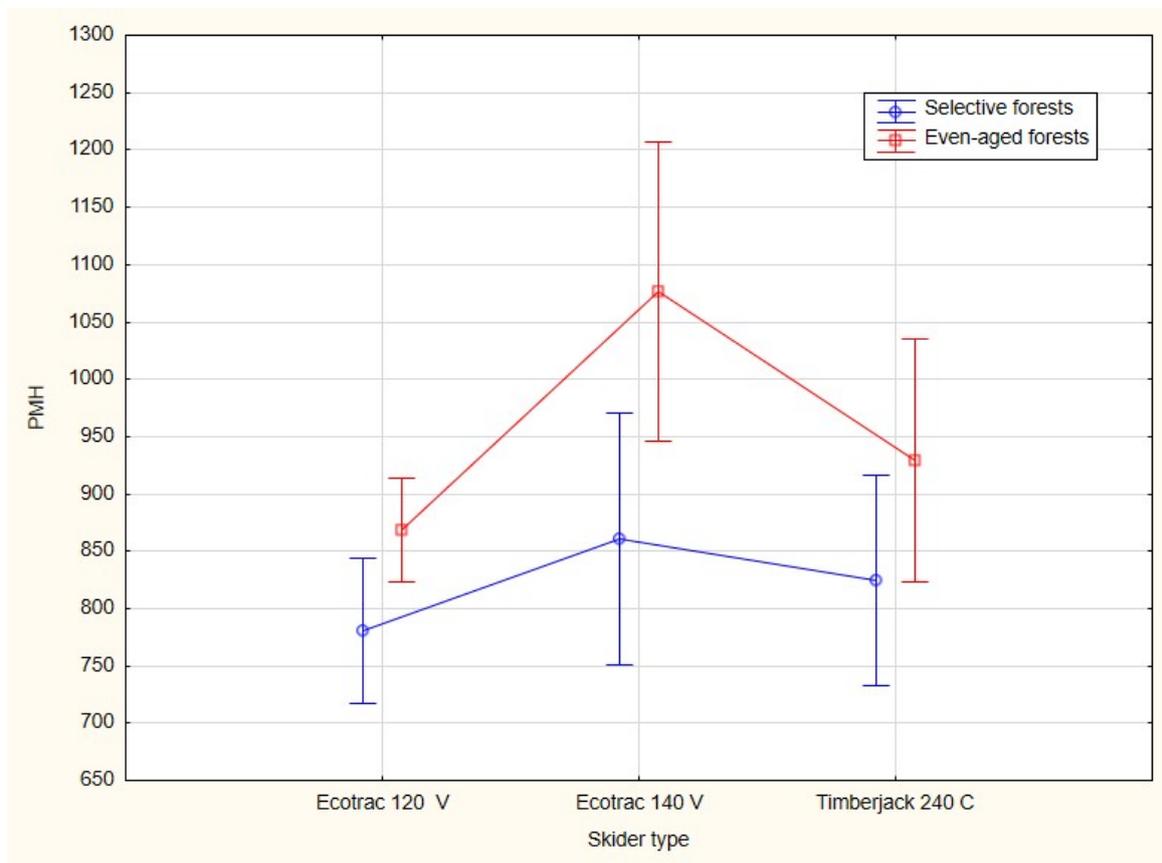


Figure 6. Total average PMH of skidders.

All diagrams showing fuel consumption (Figures 1, 2 and 6) show higher fuel consumption in even-aged forests. The same is true for the displayed production working hours (Figure 5), while, according to the diagram in Figure 4, it can be seen that there was no significant difference in total productivity between the studied skidders and between the methods of forest management.

This can be explained by the fact that, in selective forests, due to the method of work, skidders extracted larger logs but there was a smaller number of load pieces and, ultimately, a larger volume of wood was extracted per load compared to the regular forest management, where the assortment method was used, and in a single load, there was a larger number of smaller load pieces and the total volume of load was smaller. Due to the larger number of pieces of logs in one load, more time was spent on hooking the load and on the operation of the winch, and thus, the fuel consumption in even-aged forests was significantly higher than the consumption of skidders working in selective forests.

The obtained average fuel consumption in even-aged forests (1.38–1.65 L/m³) and selective forests (1.06–1.34 L/m³) was higher than the other studies conducted by Kenney [20]—0.93 L/m³ and Borz et al. [22]; 0.62 L/m³ in conifers or 1.00 L/m³ in deciduous trees. In this study, the average fuel consumption in even-aged forests ranged from 7.81 to 9.34 L/PMH and from 6.49 to 7.10 L/PMH in selective forests. The results obtained are similar to the results reported by Holzleitner et al. (2011) [18]—7.3 L/PMH—but significantly lower than the results reported by Enache et al. [21]: 12.5 L/PMH.

5. Conclusions

Fluctuation in fuel prices and the amount of skidder usage in wood extraction work make research on fuel consumption in different working conditions an important indicator in the organization of work and forecasting labor costs.

Based on the results, the assumptions about the influence of type of forest management, terrain conditions, vehicle age, engine type, and driver experience on the total fuel consumption are confirmed. It should be emphasized that skidders should primarily be used in the full tree and half tree method of wood assortment processing. The influence of drivers when operating new types of skidders can be primarily seen in the differences between fuel consumption expressed in L/PMH. Emphasis should be placed not only on working with new types of skidders, but also on the changes in the drive motors on existing types of skidders due to meeting the requirements of European emission standards for non-road diesel engines.

In order to reduce fuel consumption, it is necessary to install a Fleet Management System (FMS) on skidders and closely monitor fuel consumption data. It is possible to reduce fuel consumption by organizing the work of timber extraction better.

Additionally, research on the fuel consumption of skidders under different operating conditions is related to obtaining results on the total exhaust emissions of this type of working machine, as well as the total energy consumption during the operation of the skidders. This lays the foundations for the possibility of developing hybrid drive solutions in the construction of the skidder, especially regarding the required produced and/or stored electricity that can be used in the electric-hybrid solutions of the skidder drive.

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Data Availability Statement: The data that support the findings of this study are available from “Croatian forests” Ltd., Zagreb, the Republic of Croatia, but restrictions apply to the availability of

these data, which were used under license for the current study, and so are not publicly available. Data are however available from the authors upon reasonable request and with permission of “Croatian forests” Ltd., the Republic of Croatia, Zagreb.

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Conflicts of Interest: The authors declare no conflict of interest.

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