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ORIGINAL PAPER

Prediction of costs of selected silvicultural treatments by linear approximation and the Holt-Winters model

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ABSTRACT

The article examines the possibility of predicting the cost of the most important silvicultural treatment activities. The study used information on the executed unit cost of agrotechnical land reclamation, artificial restoration, soil management, early treatment and late treatment for the period 2010-2022. The actual cost performance data was used to forecast costs for 2021 and 2022 and compare the results with the actual (empirical) costs incurred in those years. Two forecasting methods were adopted to conduct the analysis. Linear approximation (AL) and the Holt-Winters (HW) model. The effectiveness of the predictions was estimated by calculating MAE (Mean Absolute Error) and MAPE (Mean Absolute Percentage Error). Based on the study, it was shown that the quality of forecasts obtained by both methods decreased over the period for which it was made. The cost forecasts obtained by the AL and HW methods deviated from the actual costs for AL from PLN –1.76 to PLN –448.59, and for HW from – PLN 24.68 to – PLN 458.90, respectively. The effectiveness of the forecasts ranged from –0.2% to –17.72% for AL, and from –0.62% to –17.5% for HW. The costs of the phenomena studied showed a strong upward trend in both the direction and wide amplitude of changes. The projections obtained were, in most cases, lower than the actual costs incurred in carrying out silvicultural treatments. Both methods can be used to make silviculture cost forecasts, especially when the economic situation is stable. Projections for 2021 were significantly better than those for 2022. The reasons for this phenomenon should be sought in changes in the economic and political situation (COVID 19, the war in Ukraine). The experimental research on the prediction of silviculture costs using various mathematical models should be continued. The results of the research based on heterogeneous models will provide the knowledge to begin work to create a homogeneous model for the prediction of silviculture costs in the future.

KEY WORDS

forestry economics, prediction, prediction methods, silviculture

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Introduction

In Poland, the pattern of multifunctional forestry has been adopted for implementation. Sustainable development of forest management based on this principle requires the interaction and mutual cooperation of many economic, ecological and social areas (Płotkowski, 2004; Adamowicz, 2020; Pater and Sroka, 2023). The strategic tasks of forestry are to ensure the sustainability of forests, accessibility to society, and contribution to development of the economy (Strategy, 2013). State Treasury forests are managed by the State Forests National Forest Holding (PGL LP), which operates based on the principle of financial independence (revenues cover costs) (Adamowicz, 2010; Paschalis-Jakubowicz, 2011). The ability to plan properly is one of the key elements of modern management. The balance of revenues received and costs incurred is the basis for the financial self-reliance of the State Forests (Molińska-Glura and Glura, 2021). Decisions made in forest management should be in accordance with natural laws, as well as economic principles (Buraczewski and Grygier, 2011). With this in mind, it is important that the cost of forest management, including the cost of silvicultural treatments, be at an acceptable level and managed effectively. Cost information is very important in business management (Warowny, 2016). The problems of analyzing the cost of forest management in general, as well as the cost of silvicultural treatments, were addressed, among others by: Glura *et al.* (2012), Adamowicz (2020), Sadowska (2021, 2022, 2023). From reading these studies, it is clear that the level of costs incurred depends on many natural and market factors. Unit costs, on the other hand, can be related primarily to the market situation in a given period and the trends of changes occurring in the forestry services market. With this in mind, it was decided to test the prediction methods in order to identify their effectiveness in predicting the costs that will be incurred in the future. Scientific prediction of costs is the basis for formulating a business plan, which helps companies set target costs and control operating costs (Zhai *et al.*, 2013). Cost level forecasts help administrators effectively plan workloads and achieve optimal resource allocation strategies (Guo and Xu, 2021). Predicting costs is now an essential process in management and is especially important for entities that carry out economic tasks in the field of the natural environment. This necessitates the search for cost prediction methods that take into account the problems of causal environmental management, differentiation of environmental indicators, and difficulty of collecting environmental data (Wang *et al.*, 2020).

In recent years, the issue of prediction has been addressed by many researchers. Contreras *et al.* (2003), Garcia *et al.* (2005), Poplawski (2006), Menniti *et al.* (2012), Wu *et al.* (2013) and Ejdys *et al.* (2015), presented electricity price forecasts. Stock market share price forecasts were created by Mondal *et al.* (2014) and Du (2018), research on future bitcoin prices was done by McNally *et al.* (2018) and Chen (2023), oil price forecasts were made by Kowalik and Herczakowska (2010) as well as Cao *et al.* (2015). The prediction of timber and biomass prices was prepared by Adamowicz and Górna (2020), as well as Górna *et al.* (2022). Research results comparing different prediction models in terms of their capacity for predicting price trends were presented by Chou and Ngo (2016), Omar *et al.* (2016) as well as Shao and Dai (2018).

Seiringer *et al.* (2013) believe that cost prediction is one of the most important aspect that has not received the required attention. In Polish forestry, the issue of economic analysis in planning was addressed by Wysocka-Fijorek (2018, 2019a, b), who noted the importance of the forest business plan in the system of management of modern forestry. Kocel (2010, 2012) presented the methodological basis for financial and economic forecasting for the State Forests and noted in his studies, among others, the importance of cost forecasting. In the context of the issues raised, particular valuable information was provided by Wysocka-Fijorek (2020) who, using the Brown exponential smoothing model and the Winters model, presented the results of forecasting such costs as: administrative costs, costs of primary activities, of timber sales, and of incidental activities. These costs were analyzed collectively. With this in mind, it was decided to extend the research with detailed analyses and test the effectiveness of predicting the cost of selected silvicultural treatments using the least squares error method (linear approximation AL) and the Holt-Winters (HW) model. The decision to use the AL method in the forecasting process was based on the fact that it is one of the most important and oldest computational methods in statistics. The HW method was chosen for testing due to the fact that it is among the most widely used adaptive (exponential equalization) models in forecasting variables with seasonal fluctuations on the basis of complete time series, especially when the dynamic status quo principle is not satisfied (Szmuksta-Zawadzka and Zawadzki, 2009). In addition, studies related to the prediction of the price of forest biomass showed the highest efficiency of this method in terms of the effectiveness of price predictions (Górna *et al.*, 2023). The purpose of the study was to identify the effectiveness of the obtained forecasts while identifying the possibility of applying the results of the forecasts as part of supporting the process of making decisions with regard to planning.

Materials and methods

In order to achieve the purpose of the study, the economic activities associated with silviculture were identified. The research was conducted using the passive experiment method and was of recording and observational nature. The necessary data was obtained without interfering with forestry work. Five treatments were selected for analysis: agrotechnical reclamation (ATI), artificial restoration (AR), soil management (SM), early treatment (ET) and late treatment (LT).

Source data for the analyzed unit costs was obtained from the financial records of 26 forest districts of the Regional Directorate of State Forests in Krosno. The data was from 2010-2022 and was taken from the National Forest Information System database.

The data obtained was compiled into a time series system. A time series including financial data from 2010 to 2020 provided data for building the forecast models. Bearing in mind that the basic planning period in forestry is 10 years, forecasts relative to 2021 were made based on a time series covering the period 2011-2020, while cost volume forecasts for 2022 were made based on the 2012-2021 time series. The identified costs from 2021 and 2022 were the values that provided a benchmark for the accuracy of the forecasts. The study was performed using Excel 2019.

Two forecasting methods were adopted for conducting the analysis. The least squares method (AL – linear approximation) and the Holt-Winters (HW) model. Linear approximation uses the equation of a linear function within itself. Its form is as follows:

$$y_t = a_t + b \tag{1}$$

where:

a – directional coefficient of the straight line,

b – free expression.

$$\begin{gathered} \sum_{t=1}^{n} y_t = n \cdot b + a \cdot \sum_{t=1}^{n} t \\ \sum_{t=1}^{n} y_t \cdot t = b \cdot \sum_{t=1}^{n} t + a \cdot \sum_{t=1}^{n} t^2 \end{gathered} \tag{2}$$

where:

y_t – the cost of the selected silvicultural treatment in period t,

t – the period,

n – the number of observations,
a – the coefficient of the cost change trend,
b – the free expression of the cost change trend (theoretical cost in period t=0).

First, using the formula above, the value of the trend coefficient (a) was estimated:

$$a = \frac{\overline{y \cdot t} - \bar{y} \cdot \bar{t}}{\overline{t^2} - (\bar{t})^2} \tag{3}$$

Based on the coefficient a, the average increase or decrease in costs between periods (t) was determined. The amount of the free parameter of the analyzed function (b) was estimated using information on the value of the trend coefficient of the analyzed price (a), the arithmetic average of the number of periods taken for simulation ($\bar{t}$) and the arithmetic average of costs ($\bar{y}_t$):

$$b = \bar{y}_t - a \cdot \bar{t} \tag{4}$$

The effectiveness of matching the trend function of the analyzed costs to real costs was carried out by determining the parameters of the stochastic structure, *i.e.*: the standard deviation of the residual component, the coefficient of variation of the residual, the coefficient of convergence, the coefficient of determination and the standard errors of the structural parameters of the trend equation.

A comparison was made with the multiplicative HW model. The HW model is one of the forecasting methods using exponential smoothing. Exponential smoothing involves the creation of a weighted moving average, the weights of which are determined according to the scheme that the older the data on the studied phenomenon, the smaller the value they present for a given forecast. Specific assumptions and formulas were used to build a model for silviculture costs:

$$F_t = a \cdot y_t + (1 - \alpha) \cdot (F_{t-1} + S_{t-1}) \tag{5}$$

The formula for trend estimation:

$$S_t = \beta \cdot (F_t + F_{t-1}) + (1 - \beta) \cdot S_{t-1} \tag{6}$$

where:

α and β are model parameters with values between 0 and 1.

During model development, expired forecasts were calculated:

$$y_{t*} = F_{t-1} - S_{t-1} \tag{7}$$

and actual forecasts:

$$y_{t*} = F_n + (T - n) \cdot S_n \tag{8}$$

where:

$T = n+1, n+2\ldots$

The following assumption was made: $F_1=y_1$ and $S_1=0$ or $S_1=y_2-y_1$.

Kocel (2010) indicates that forecasts should be monitored. Their accuracy should be checked. With this in mind, the next step in the analysis was to determine the validity of the resulting forecasts. In order to verify the accuracy of the forecasts of the costs of silvicultural treatments, the theoretical quantities obtained, based on the adopted time series, were compared with the actual quantities. The effectiveness of the predictions was estimated by calculating MAE (Mean

Absolute Error) and MAPE (Mean Absolute Percentage Error):

$$\text{MAE: } \Delta x = x - x_0 \tag{9}$$

$$\text{MAPE: } \delta = \frac{x - x_0}{x} \cdot 100\% \tag{10}$$

where:

x – real value of costs,

x_0 – projected value of costs.

In econometric practice, many methods are used to evaluate models, including assessing the acceptability of a forecast. In practice, it is accepted that a model is considered good when the error is less than 10% (Wysocka-Fijorek, 2020). Such a classification was adopted to evaluate the obtained forecasts in the presented research.

Results

According to the adopted methodology, unit costs of basic silvicultural activities were identified. In order to verify the effectiveness of the prediction of the analyzed silviculture costs, a forecast of these costs was made for 2021 and 2022. The obtained forecast results were referred to the actual values. Based on the tests performed, it was found that in most cases the projected values were lower than the actual ones. In the case of AL, forecasts were lower than the actual cost level in 8 cases, including in 2022 all forecasts were lower than the actual costs incurred. Using this forecasting method, the forecasted values were higher than the actual ones only 2 times (2021 – SM and LT). In the case of forecasting using the HW method, a similar phenomenon was observed. In most cases (7 times), the projected costs were lower than actual ones. Higher projections relative to actual volumes were recorded 2 times in 2021 (ATI and LT) and once in 2022 (ATI) (Table 1). The magnitude of absolute forecast errors ranged from PLN 1.76 (ET forecast in 2021 made using the AL method) to PLN 458.90 (AR forecast in 2022 made using the HW method). Considering the averaged result for all the analyzed cost categories, it was found that,

Table 1.

The amount of the actual costs

Year	Results		ATI	AR	SM	ET	LT
2021	real value		1 677.10	8 330.40	1 156.42	878.98	951.63
	prediction	AL	1 560.00	8 307.40	1 262.86	877.22	1 021.59
		HW	1 843.22	8 278.15	1 107.69	854.30	988.05
	MAE	AL	–117.10	–23.00	106.44	–1.76	69.96
		HW	166.12	–52.25	–48.73	–24.68	36.42
	MAPE [%]	AL	–6.98*	–0.28*	9.20	–0.20*	7.35
		HW	9.91	–0.63	–4.21*	–2.81	3.83*
2022	real value		1 999.49	9 050.59	1 419.15	1 070.78	1 196.78
	prediction	AL	1 645.04	8 602.00	1 298.29	914.58	1 067.73
		HW	2 102.73	8 591.69	1 170.78	869.58	1 001.25
	MAE	AL	–354.45	–448.59	–120.86	–156.20	–129.05
		HW	103.24	–458.90	–248.37	–201.20	–195.53
	MAPE [%]	AL	–17.73	–4.96*	–8.52*	–14.59*	–10.78*
		HW	5.16*	–5.07	–17.50	–18.79	–16.34

agrotechnical reclamation (ATI), artificial restoration (AR), soil management (SM), early treatment (ET), late treatment (LT) and their forecasts obtained using the least squares method (AL) and the Holt-Winters (HW) method, as well as the mean absolute error (MAE) and mean absolute percentage error (MAPE) of the forecasts for 2021 and 2022 regardless of the prediction method used, the accuracy of forecasts was better in 2021 than in 2022.

The key information for making inferences in the case at hand were the results of the analyses by which the MAPE was determined. Using a comparative analysis of forecasts, it was proven that better forecasts were obtained using the AL method relative to those developed using the HW method. Out of the 10 forecasts analyzed, 7 forecasts built using AL showed less error than the actual figures and only 3 times (2021 – SM and LT and 2022 – ATI) the forecasts made using the HW method were more accurate (Table 1). Noteworthy is the fact that in 2021, MAPEs for forecasts made with AL ranged from 0.20% (ET) to 7.35 (LT). For the forecasts obtained with HW, the identified relative differences between the forecasts and the actual values ranged from 2.81% (ET) to 9.91% (ATI). All the forecasts were therefore below the accepted difference threshold of 10%. In 2022, the quality of the forecasts obtained was worse. For AL, only 2 forecasts (AR – 4.96% and SM – 8.52%) were within the acceptable MAPE level. In the case of forecasts obtained using the HW model, 2 forecasts could also be considered good (ATI – 5.16% and AR – 5.07%). The remaining forecasts were characterized by MAPEs above 10%.

Discussion

Forecasting is the scientific and rational prediction of future events. It is the selection of a probable path for the development of an event or phenomenon in the coming period of time, within the limits of a given system. The basis for selection is the past course of the phenomenon and the current state of the system (Żurowska, 2005). Forecasting socio economic phenomena is becoming increasingly important. The ability to make forecasts in the process of managing economic phenomena, with the help of available tools, is a desirable skill for modern managers (Górna and Adamowicz, 2020). Forecasting leads to the elimination of losses in various economic areas, as well as reducing uncertainty and increasing the accuracy of decisions (Sobczyk, 2008). In modern forestry, one of the priorities of modern management is proper planning, in particular planning the costs of carrying out economic tasks. Zastocki and Kaliszewski (2021) showed that silviculture costs are a large financial burden on forest holdings (9.4% of all costs incurred by the State Forests National Forest Holding in 2020) and are much higher than forest protection costs. With this in mind, an attempt was made to test the possibility of predicting the costs of selected silvicultural treatments. The paper presents the results of a study conducted using the AL and HW methods. The obtained forecasts in most cases indicated a volume lower than the volume of actual costs. Based on the results, one has to agree with the opinion of Zelias (1997), Dittmann (1999) and Kocel (2010) that we rarely have virtually error-free forecasts. Wysocka-Fijorek (2020), on the basis of her own research in the field of cost prediction, found that the values of the index of admissibility of forecasts of various costs vary so much that the use of the obtained forecast results is fraught with risk. The forecasts obtained in the research process were also subject to some errors. This does not mean that scientific solutions should not be sought to support the management system and especially the primary function of management, which is planning.

An interesting observation is the variation in the accuracy of the predictions made using selected predictive models in different aspects of forest management. Górna *et al.* (2023) claim that the HW method yields better results when forecasting the price of the timber in Poland, *i.e.* the post-production biomass, compared to the ARIMA method. In the case of the analysis of the issue of the cost of silvicultural activities, HW did not give as good results as in the case of the forecast of the price of the timber in Poland. A number of analyses prepared in the field of timber prices indicate an adequate match of the prediction model with the characteristics of the analyzed data (Adamowicz and Górna 2020; Górna and Adamowicz, 2020, 2021; Górna *et al.*, 2022, 2023).

The results of the study show good verifiability of AL and HW forecasts in 2021 and definitely worse ones in 2022. It should be noted that between these years, an increase in the cost of the analyzed silvicultural treatments was observed. The increase was largely due to the change in economic conditions after the COVID-19 pandemic. The approach of the State Forests National Forest Holding to the silvicultural activities performed has also changed recently. Description of the Technology Standard for Forestry Work Execution was introduced in 2021 and the Catalog of Time Standards for Work in Forest Management was revised. In addition, in 2022 there appeared major changes in the prices of energy carriers. The increase in fuel prices, in particular, had a cost-creating effect on forestry task execution. We should agree with Złoty (2023) that the prices of fuels in Poland in 2022 were significantly influenced by changes in the price of WTI crude oil and natural gas, the business cycle (recession during the COVID-19 pandemic), geopolitical events (the outbreak of the war in Ukraine), the USD/PLN exchange rate, changes in the VAT on fuel, excise taxes, fuel and emission fees, and the margins of oil companies. The increase in fuel prices in Poland at the end of the period under review was influenced by depreciation of the zloty and an increase in the margins of oil companies. Fuel prices in Poland respond much more quickly to increases in the price of oil and natural gas than to decreases in the price of these commodities (Erias and Iglesias, 2022). The results obtained from the study of the prediction of selected cost categories, in particular the MAPE discrepancies between the 2021 and 2022 forecasts, suggest that in a situation of stabilized economic processes, the analyzed methods can be used for supporting the process of business planning in forestry. It should be noted that in 2021 the relative forecast errors obtained, regardless of the prediction method analyzed, were within the error limit (MAPE<10%). The effectiveness of the forecasts deteriorated significantly in the following year, which may have been due to changes in the energy carrier market. The problem was also highlighted, among others, by: Kilian and Zhou (2022), Hashmi *et al.* (2022) or Wang *et al.* (2022) who point out that fluctuations in global oil prices affect domestic oil prices in developed and developing countries. Rising oil prices are driving up product costs, leading to sharp fluctuations in the price of goods and services. With this in mind, it should be suspected that such a situation occurred in 2022, which consequently affected the effectiveness of forecasts built on the basis of a time series covering a period of relative economic stability.

Forest management is associated with constant decision-making that affects the income from the business conducted. Multifunctional forestry combines economic needs, timber production and maintenance of the natural character of the forest (Gostołek *et al.*, 2018). Knowledge of changes in costs of silvicultural treatments supports the forestry planning and decision-making processes. Further research can help better identify the need to improve the current cost and revenue planning system with the specifics of forest management.

Conclusions

The article presents a pilot study in the field of predicting the cost of silvicultural treatments. It was found that:

- The costs of the phenomena studied showed a strong upward trend in both the direction and wide amplitude of changes. The projections obtained were, in most cases, lower than the actual costs incurred in carrying out silvicultural treatments.
- Both methods can be used to make silviculture cost forecasts, especially when the economic situation is stable. Projections for 2021 were significantly better than those for 2022. The rea-

sons for this phenomenon should be sought in changes in the economic and political situation (COVID 19, the war in Ukraine).

- Forecasts built using the least squares method were better suited to reality, even in 2022, which was the year of the economic turmoil. On this basis, it was concluded that the least squares method should be the reference method for further work aimed at the search for an appropriate model that will be best suited to predicting the cost of silvicultural treatments.
- The experimental research on the prediction of silviculture costs using various mathematical models should be continued. The results of the research based on heterogeneous models will provide the knowledge to begin work to create a homogeneous model for the prediction of silviculture costs in the future.

Authors' contributions

Conceptualization – K.A. and A.G.; methodology – K.A., and A.G.; validation – M.C.; investigation – M.C. and A.G.; data curation – M.C; writing-original draft preparation – A.G and P.S.; supervision – K.A.; funding acquisition – K.A.

Conflicts of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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STRESZCZENIE

Predykcja kosztów wybranych zabiegów hodowli lasu metodą najmniejszych kwadratów błędów i modelem Holta-Wintersa

W Polsce realizowany jest wzorzec leśnictwa wielofunkcyjnego. Zrównoważony rozwój gospodarki leśnej opartej na tej zasadzie wymaga interakcji i wzajemnej kooperacji wielu obszarów gospodarczych, ekologicznych i społecznych. Lasami Skarbu Państwa zarządza Państwowe Gospodarstwo Leśne Lasy Państwowe (PGL LP), które działa na zasadzie samodzielności finansowej (przychody pokrywają koszty). Decyzje podejmowane w gospodarstwie leśnym powinny być zgodne z prawami przyrodniczymi, a także zasadami ekonomicznymi. Istotne jest zatem, aby koszty prowadzenia gospodarki leśnej, w tym koszty zabiegów hodowli lasu, znajdowały się na akceptowalnym poziomie i zarządzano nimi w sposób skuteczny. Mając na uwadze zależność kosztów hodowlanych od sytuacji rynkowej, postanowiono przetestować metody predykcji w celu zidentyfikowania ich skuteczności.

Postanowiono szczegółowo przeanalizować oraz przetestować skuteczność predykcji kosztów wybranych zabiegów hodowli lasu z wykorzystaniem metody najmniejszych kwadratów błędów (aproksymacja liniowa AL) oraz modelu Holta-Wintersa (HW). Decyzję o zastosowaniu w procesie prognostycznym metody AL podjęto, ponieważ jest ona jedną z najważniejszych i najstarszych metod w statystyce. Metoda HW została wybrana do testowania z uwagi na fakt, że należy ona do najczęściej wykorzystywanych modeli adaptacyjnych (wyrównywania wykładniczego) w prognozowaniu danych z wahaniami sezonowymi na podstawie kompletnych szeregów czasowych.

W ramach realizacji celu pracy zidentyfikowano czynności gospodarcze związane z hodowlą lasu. Do analizy wybrano 5 zabiegów: melioracji agrotechnicznej (ATI), odnowienia sztucznego (AR), pielęgnowania gleby (SM), czyszczenia wczesnego (ET) i czyszczenia późnego (LT). Dane źródłowe dotyczące analizowanych kosztów jednostkowych pozyskano z ewidencji finansowej 26 nadleśnictw Regionalnej Dyrekcji Lasów Państwowych w Krośnie. Dane pochodziły z lat 2010--2022 i zostały pobrane z bazy danych Systemu Informatycznego Lasów Państwowych. Ponieważ podstawowy okres planistyczny w leśnictwie to 10 lat, prognozy względem roku 2021 opracowano w oparciu o szereg czasowy obejmujący okres 2011-2020, natomiast prognozy wielkości kosztów dla 2022 r. sporządzono w oparciu o szereg czasowy 2012-2021. Zidentyfikowane koszty z lat 2021 i 2022 stanowiły wielkości stanowiące punkt odniesienia trafności prognoz.

Uzyskane wyniki prognoz odniesiono do wartości rzeczywistych. Kluczowymi informacjami pozwalającymi na wnioskowanie w przedmiotowej sprawie były wyniki analiz, przy pomocy których określono MAPE. Przy użyciu analizy porównawczej prognoz udowodniono, że metodą AL uzyskiwano lepsze prognozy względem budowanych metodą HW. Wielkość błędów prognoz w układzie bezwzględnym wahała się od 1,76 zł (prognoza ET w 2021 r. wykonana metodą AL) do 458,90 zł (prognoza AR w 2022 r. wykonana metodą HW). Na 10 analizowanych prognoz 7 zbudowanych z wykorzystaniem AL wykazywało mniejszy błąd od rzeczywistych wielkości, a tylko 3 razy prognozy sporządzone za pomocą metody HW były dokładniejsze (2021 r. – SM i LT oraz 2022 r. – ATI) (tab. 1). Na uwagę zasługuje fakt, że w 2021 r. MAPE dla prognoz wykonanych za pomocą AL mieściły się w przedziale od 0,20% (ET) do 7,35% (LT). W przypadku prognoz uzyskanych za pomocą HW zidentyfikowane względne różnice między prognozami a wysokościami rzeczywistymi mieściły się w przedziale od 2,81% (ET) do 9,91% (ATI). Wszystkie prognozy były

więc poniżej przyjętego progu różnicy wynoszącego 10%. W 2022 r. jakość uzyskiwanych prognoz była gorsza. W przypadku AL tylko 2 prognozy (AR – 4,96 % i SM – 8,52%) mieściły się w dopuszczalnym poziomie MAPE. W przypadku prognoz uzyskiwanych za pomocą HW również 2 prognozy można było uznać za dobre (ATI – 5,16% i AR – 5,07%). Pozostałe prognozy charakteryzowały się MAPE powyżej 10% (tab. 1).

Uzyskane rezultaty badań wskazują na dobrą sprawdzalność prognoz AL i HW w 2021 r. i zdecydowanie gorszą w 2022 r. Należy zwrócić uwagę, że między tymi latami zaobserwowano wzrost kosztów analizowanych zabiegów hodowli lasu. Wzrost ten wynikał w dużej mierze ze zmiany uwarunkowań gospodarczych po pandemii COVID-19. W 2021 r. wprowadzono też „Opis standardu technologii wykonawstwa prac leśnych" oraz zmieniono „Katalog norm czasu dla prac wykonywanych w zagospodarowaniu lasu". Dodatkowo w 2022 r. odnotowano duże zmiany cen paliw, co miało znaczenie dla realizacji zadań w leśnictwie. Te wydarzenia mogły mieć wpływ na precyzję sporządzonych prognoz.

Stwierdzono, że do wykonania prognoz kosztów hodowli lasu można używać obu metod, zwłaszcza w przypadku ustabilizowanej sytuacji gospodarczej. Prognozy na rok 2021 były lepsze od prognoz na rok 2022. Prognozami lepiej dopasowanymi do wartości rzeczywistych były te z wykorzystaniem metody najmniejszych kwadratów.