Eucalyptus replanting model representation for sustainable productivity: A review

Nurhayati Sembiring, Humala Lodewijk Napitupulu, Meilita Tryana Sembiring, Aulia Ishak Sipahutar, and Lydia Yesica

Department of Industrial Engineering, Faculty of Engineering, Universitas Sumatera Utara, Indonesia

Corresponding author email: nurhayatipandia68@usu.ac.id, humala@usu.ac.id, meilita@usu.ac.id, aulia.ishak@usu.ac.id, lydiaycs@gmail.com

Abstract. The stable natural resources will encourage the productivity of sustainable eucalyptus replanting for the benefit of human life. Replanting eucalyptus plants is one of the things that drive sustainable productivity in eucalyptus processing. Eucalyptus replanting planning requires supporting tool decisions to increase productivity, analyze variability, climate change, measure environmental impacts, and maximize profits. The paper aims to evaluate various models in representing the replanting of sustainable eucalyptus used for crop management. In this review, the discussion started from the history of eucalyptus, the approach to the compilation of literature reviews, the method for reviewing the literature, yields and discussions, and finally providing some significant recommendations. Reviews of physiological models based on 3PG (Physiological Principles in Predicting Growth) processes are considered capable of being optimal support tools in the management of sustainability strategies to evaluate the growth of eucalyptus plant. Its usefulness in providing simulations about the impacts of climate change, simulation of forest management practices, the impact of hydrology on forests, the attributes of location to standing growth, biomass dynamics and potential disruption to forest ecosystems make this model a supporting tool in forest management sustainability strategies. Review literature was obtained relevant literature for qualitative analysis from 2010 to 2021.

Keywords: eucalyptus replanting, decision support tools, qualitative analysis, simulation.

1. Introduction

Eucalyptus species is one of the most widely planted trees in the hardwood tree type. Its raw material in the wood industry is very well known and growing rapidly [1]. The variety of eucalyptus plants is more than 900 species. The average planting area is 6m² eucalyptus harvested every 4 to 5 years [2]. In particular, Eucalyptus globulus species are broadly used in the pulp industry, and the many benefits of eucalyptus have been well proven by studies such as extraction into the production of eucalyptus oil, aromatherapy ingredients, and others. These days, plants materials are one of the primary materials in timber, fuel, and pulp. Besides that, these plants are also used as environmental planting that has a function in control wind and water erosion [3, 4].

Optimal strategic management decision making requires tools in sustainable forest management. Assessment of the impact of climate change in eucalyptus plantation ecosystems is required in sustainable resource management. Good forest management results in higher quality species in their growth and provides predictive plant growth yields [5]. Accurate databases in integrated plantation
management are also required, such as growth models, data quality, or other planning tools. Many models can be used in sustainable forest management. In this regard, the authors also summarize each simulation in sustainable forest management such as GIS software, hybrid modeling, 3PG process-based modeling, etc. [6].

This research was conducted by collecting collections related to forest resource management in a simulation of eucalyptus growth to describe the growth development of eucalyptus plants. The description is taken from several published journals and is considered worthy of reference. The discussion is not only about the management of forest resources but also the simulation of eucalyptus growth. Materials from related journals are managed and analyzed to obtain information on the management of eucalyptus growth.

2. Literature review

2.1. Plant growth visualization

Proper management of eucalyptus plants to deal with critical resources due to climate change is needed among eucalyptus plant managers. The impact of climate change on eucalyptus replanting management can be studied more deeply with the process-based models. This based model process uses climate inputs in an ecosystem as a driver to estimate the need for sustainable crop processing [7]. Furthermore, modeling the growth of eucalyptus plants using the process-based models in various countries can be a practical and simple tool to model plant growth in recent years [8].

2.2. Benefits of using visualization in planting

Modeling or visualization is the process of formulating a system. The benefits of modeling or visualization is to provide predictions that are close to reality for analysis before applying modeling systems in the field. In 3GP process-based modeling or visualization of sustainable eucalyptus replanting is beneficial for; Estimating appropriate variables such as high-growth stands, providing simulations of forest management practices, hydrological impacts on forests, location attributes to stands growth, biomass dynamics and potential disruption of forest ecosystems [9].

2.3. Eucalyptus plant content

The extraction of eucalyptus globulus through previous research, by chromatographic analysis found hydroxybenzoic, coumaric, syringic, gallic, and vanilla acids. The activity of allelopathy in eucalyptus species is also high, which makes it phytotoxic and inhibits the growth of other plants [10], [11].

2.4. Strategies used for eucalyptus growth model

The 3PG (Physiological Principles in Predicting Growth) is a model that requires practical data input in its use. These 3PG models were later described as hybrid, process-based models, mechanistic, and semi-empirical. The ease of a 3PG model that can be used to optimally validate climate change is considered the optimal model in sustainable crop processing [12].

In various types of previous research, methods were also collected that discussed the development of eucalyptus plant growth used in sustainable crop management. The collected methods will be compared with the 3PG model. The collection and selection of scientific literature is made using reliable sources such as Elsevier, Research Gate, IOP Conference, Springer, etc. After the reading frame of mind is mapped into several conclusions, then they are presented in Table 1.
### Table 1. Resume category of paper review results on eucalyptus growth representation.

| Published in | Author | Purposes | Factors | Modeling Methods | Object | Place |
|--------------|--------|----------|---------|------------------|--------|-------|
| 2011         | C. P. Cruzado et al. | Investigate the connection among the impactful parameters and eucalyptus growth [13]. | ● Foliage biomass  
● Wood biomass  
● Height, diameter  
● Age | The 3-PG Process-Based Model and The Empirical Model | Eucalyptus nitens | Spain |
| 2011         | A. Mateus et al. | Simulate the diameter distribution of Eucalyptus to expect and estimate eucalyptus' general stand volume [14]. | ● No of tree per ha  
● Diameter  
● Age | Probability Density Function | Eucalyptus Globulus | Portugal |
| 2013         | R. Vinícius et al. | Develop individual eucalyptus trees by explaining the impact of the distribution of variable factors monitored against modeling [15]. | ● DBH (Diameter at Breast Height)  
● Basal Area  
● Volume  
● Density  
● Age | STATISTICA 8.0 software | Eucalyptus urophylla and Eucalyptus Grandis | Brazil |
| 2013         | C. Marsden et al. | Recognizing spatial variability in tropical soils by simulating eucalyptus growth [16]. | ● Net primary production (leaf, branch, stem, coarse root, fine root)  
● Height, Depth, Age | G'DAY process-based model | Eucalyptus Grandis | France |
| 2013         | R. I. C. Lumbers et al. | Using six nonlinear models for DBH high growth modeling [17]. | ● DBH (Diameter at Breast Height)  
● Height | DBH-height modeling and validation | Eucalyptus pellita | Philip pines |
| 2016         | A. Satana de Oliveira et al. | Modeling the growth of E. plantation seedlings with thermal sum explanation as a parameter [18]. | ● Fresh biomass  
● Temperature  
● Dry biomass | Sigmoidal Model | Eucalyptus Grandis and Eucalyptus urophylla | Brazil |
| 2017         | P Nyman. | Compared four research models using 10 forest locations to simulate radiation [19]. | ● Geographical location  
● Path length  
● Skyview factor | PAINC, PAIMS LPI and PL model | Eucalyptus Forest’s Canopy | Australia |
| 2018         | Siti Latifah et al. | Assess nonlinear models to estimate eucalyptus growth and yield requirements [20]. | ● Depth of top Soil  
● Total height  
● Stand Age  
● Basal Area  
● Site index  
● Stand Density | Spatial analysis in a regression model | Mixed Eucalyptus; E. Grandis, E. Hybrid, E.Pellita, Eucalyptusurophylla | Indonesia |
| 2019         | H.F. Scolforo, et al. | Knowing the level of compatibility stands for clonal Eucalypt stands, development of individual tree growth and yield systems in Brazil [21]. | ● Upright Structure  
● Diameter  
● Age | Tolerance of Eucalyptus Clones to Eucalyptus Hydric, Thermal and Biotic Stresses | Clonal Eucalyptus | Brazil |
| 2019         | R. Gupta, L. Sharma | Review the overview, structure, application, and efficacy of process-based 3PG models for forest management [8]. | ● - | Model 3-PG/3-PGS | Physiological India  
Principles in Predicting growth | India |
| Year | Authors | Title | Methods | Acronyms | Location |
|------|---------|-------|---------|----------|----------|
| 2021 | H. Deng, L. Shen, J. Yang, et al. | Evaluate the differences in no spatial structure and stability of pure and mixed Eucalyptus forest stands, knowing the best-mixed patterns of Eucalyptus forests with the highest stability in hurricane-prone areas [22]. | ● Preservation rate, ● Upright Density, ● Height, ● Diameter, ● Trunk Shape, ● Degree of the slope of the trunk, ● Composition of the tree, ● Age Structure. | Nonspatial analysis using measurement data and the maintenance of statistical data. | Mixed Eucalyptus (E. grandis W. Hill x E. urophylla S. T. Blake) Zhanjiang, Guangdong, China. |
| 2021 | P. Wirabuana, S. Alam, J. Matatula, et al. | Testing the early performance of eucalyptus s knowing the best species developed in Jepara [23]. | ● Survival Parameters, ● Biomass Accumulation, ● Crown Projection Area, ● Individual Leaf Area, ● Leaf Area Index. | ANOVA, followed by HSD Tukey | E. Alba, E. Pelitta, and E. Indone Urophylla, Jepara, Indonesia. |
| 2021 | A Brito, G. Vidaurre, J. Oliveira, et al. | Evaluation of the influence of distance differences when planted on the properties of wood three clones Eucalyptus age four years. | ● Basic Density, ● Dry Mass, ● Anatomy, Structural Chemical Composition, ● Ash Content And Higher Calorific Value. | Using Cochran And Shapiro-Wilk Tests, then Conducted Linear Regression Analysis. | Eucalyptus Grandis×Eucalyptus Urophylla Parana panema, São Paulo state, Brazil. |
| 2021 | A. Hassan, P. Balachandean, K. Khamis, et al. | To relate the root growth of two different types of E. pellita seedlings and learn the effect of different nitrogen levels on the reproduction of two dissimilar types of E. pellita [24]. | ● Shoot Biomass, ● Root Intensity (RI), ● Total Root Intensity (TRI), ● Root Biomass, Root Length Density (RLD), and ● Specific Root Length (SRL) | Method and Tracer Technique by Thorup-Kristensen. | Eucalyptus Pelitta Sabah, Malaysia. |
| 2021 | K. Murata, M. Nakano, K. Miyazaki, et al. | Check the effect of alternate lamination of soft poplar veneer and hard eucalyptus veneer. Preliminary assessments are made by using physiological models to assess the long-term growth of eucalyptus under the forecast of climate change [25]. | ● Soft Poplar Veneers, ● Hard Eucalyptus Veneers | The compression Test Uses Digital Image Correlation Method. | The hybrid of Jiangs E. grandis x u, E. urophylla China. and Eucalyptus urophylla |
| 2021 | J. HN Palma, R. Hakamada, G. Moreira, et al. | Evaluate eucalyptus standing growth under climate change predictions by conducting preliminary assessments with physiological models [7]. | ● Sustainable Harvest Volume, ● Net Value, ● Changes In Forest Productivity, ● Climate Change. | 3PG Process-Based Physiological Models. | Planting Southe eucalyptus m with clay soil,Brazil. 10 m depth, and sandy soil, 3 m depth. |
| 2021 | J. Silva, M. Nereu, S. | Tested two methods for controlling the population by studying the demographics and development of the wild population of Eucalyptus globulus, which formed one year after the fire [26]. | ● Mechanical Cutting, ● Spraying of Herbicides, ● No Interference (Control Tiles). | using the R package PMCMR | E. Globulus, Santa Comba dão, Pinus Pinaster, the exotic Acacia, Centa Dealbata, and Quercus spp. Portugal. |
3. Methods
Through this research, the literature review method is used to develop a framework of thinking that follows the findings, theories, and results of previous research to formulate the problem at the beginning of the study. The sequence of procedures of the literature review method is also described in Figure 1.

![Figure 1. Methods used in research.](image)

Level 1, The first level is selecting papers related to the theme discussed in this research. This study examines eucalyptus growth modeling for forest resource management. The chosen article aims to see developments in eucalyptus growth modeling to develop forest resources in optimizing replanting in various countries.

Level 2, The second level of this research is the accumulation, of related research. Each appropriate paper has been collected from various types of trusted publishers. Related papers are collected or accumulated for later review one by one. The accumulated papers must have a topic that follows the purpose of this research.

Level 3, The third level in this research method is to take the essence contained in the accumulated papers. To take the essence of the review, the researcher needs to read each paper that has been selected in the second stage based on the theme that has been determined. The essence of the review that is of concern in this paper is the year of publication, the author, the researcher’s purpose, the factors in the research, the method used, the object studied, and the place of publication of the scientific work. Taking the gist is done to get important information on the research discussion. Thus, we can find papers that match the subject of this research from various countries.

Level 4, The fourth level in this research is to present the results of the selected papers. Each paper is selected and analyzed to extract the results that are the core of the presentation in this paper review. Each paper that has been described will be analyzed starting from the background, research objectives, methods, discussion, and conclusions to know the contents of the discussion of the selected paper.

4. Results and discussion
Papers that have been rigorously selected, can be classified by country of publication. The country that publishes the most papers on related topics shows interest and broad coverage of Eucalyptus Growth Modeling for Forest Resource Management. The country of publication of the study can be seen in Figure 2.
Through the graph shown in Figure 2, the location of the published research shows research related to the representation of eucalyptus replanting in dominance by Brazil. As the country that contributed the most papers, in this case Brazil contributed 29% of the seventeen papers summarized. In a paper published in Brazil discussing the benefits of expanding tree species, a model for monitoring eucalyptus replanting performance with its parameters.

Eucalyptus replanting evaluates factors such as; upright growth, survival rate, height, diameter, and accumulation of biomass (stems, branches, leaves, and total air parts), crown radius, crown length, crown ratio, crown projection area, dry weight of single leaf, single leaf area, leaf mass area, specific leaf area, and leaf area index.

This paper discusses some of the methods used to find the best sustainable eucalyptus replanting model. In the study, which came from an Australian promo process-based model hybridized with the NITGRO model for growth projections, it was unclear when it was 6 to 10 years of growth due to a lack of data. In studies originating in Portugal, methods of control with chemical or physical control show that long-term application can cause chemical disorders. In methods originating from Spain, the area control method itself can trigger environmental changes and even habitat decline in forest areas. The Brazilian-derived model use of 3GP process-based methods addresses providing simulations on climate change, providing simulations of forest management practices, hydrological impacts on forests, location attributes to stands growth, biomass dynamics and potential disruptions to forest ecosystems, estimating appropriate variables, practical research applications, outstanding predictive capabilities for forest management and sustainable productivity for replanting eucalyptus.

5. Conclusion
The expansion of fast-growing tree species can be a beneficial result in achieving the goal of sustainable eucalyptus re-sustaining representation. However conducting risk assessments, measuring silviculture regimes effect on productivity, and profitability on sustainable forest growth representations required an accurate assessment. Furthermore, changing climate conditions are considered a threat in the continued replanting of eucalyptus. Thus, climate change can be evaluated with process-based 3PG models.
The process-based 3PG model for forest management performs well in estimating precise variables, practical research applications, outstanding predictive capabilities for forest management. Besides being useful in providing simulations about the effects of climate change, this 3GP process-based model also provides simulations of forest management practices, hydrological impacts on forests, attributes of the location to stands growth, biomass dynamics and potential disruptions to forest ecosystems that make this model as a supporting tool in forest management sustainability strategies.

Acknowledgments
The author gives very high appreciative of the support from TALENTA USU 2021.

References
[1] “Genetic improvement of eucalypts,” in Eucalyptus, 2021.
[2] N. Sembiring, H. L. Napitupulu, A. I. Sipahutar, and M. T. Sembiring, “A review of sustainable replanting eucalyptus: Higher sustainable productivity,” IOP Conf. Ser. Mater. Sci. Eng., vol. 935, no. 1, 2020, doi: 10.1088/1757-899X/935/1/012068.
[3] M. G. Vecchio, C. Loganes, and C. Minto, “Beneficial and Healthy Properties of Eucalyptus Plants: A Great Potential Use,” Open Agric. J., vol. 10, no. 1, pp. 52–57, 2016, doi: 10.2174/1874331501610010052.
[4] M. Bertomeu, D. B. Luis, and J. C. Giménez, “Forest management optimization in Eucalyptus plantations: A goal programming approach,” Can. J. For. Res., vol. 39, no. 2, pp. 356–366, 2009, doi: 10.1139/X08-083.
[5] N. Sembiring and H. L. Napitupulu, “Simulation for replanting eucalyptus: A review,” IOP Conf. Ser. Mater. Sci. Eng., vol. 1122, no. 1, p. 012051, 2021, doi: 10.1088/1757-899X/1122/1/012051.
[6] M. Battaglia, P. J. Sands, and S. G. Candy, “Hybrid growth model to predict height and volume growth in young Eucalyptus globulus plantations,” 1999, doi: 10.1016/S0378-1127(98)00548-9.
[7] J. essay topics HN Palma, R. Hakamada, G. G. Moreira, S. Nobre, and L. C. E. Rodriguez, “Using 3PG to assess climate change impacts on management plan optimization of Eucalyptus plantations. A case study in Southern Brazil,” Sci. Rep., vol. 11, no. 1, pp. 1–8, 2021, doi: 10.1038/s41598-021-00161-z.
[8] R. Gupta and L. K. Sharma, “The process-based forest growth model 3-PG for use in forest management: A review,” Ecol. Model., vol. 397, no. December 2018, pp. 55–73, 2019, doi: 10.1016/j.ecolmodel.2019.01.007.
[9] J. A. Rodríguez-Suárez, B. Soto, M. L. Iglesias, and F. Diaz-Fierros, “Application of the 3PG forest growth model to a Eucalyptus globulus plantation in Northwest Spain,” Eur. J. For. Res., vol. 129, no. 4, pp. 573–583, 2010, doi: 10.1007/s10342-010-0355-6.
[10] K. G. El-Rokiek, M. G. Dawood, M. S. Sadak, and M. E.-S. El-Awadi, “The effect of the natural extracts of garlic or Eucalyptus on the growth, yield and some chemical constituents in quinoa plants,” Bull. Natl. Res. Cent., vol. 43, no. 1, 2019, doi: 10.1186/s42269-019-0161-3.
[11] R. Rodríguez-Souleiro et al., “Exploring the factors affecting carbon and nutrient concentrations in tree biomass components in natural forests, forest plantations and short rotation forestry,” For. Ecosyst., vol. 5, no. 1, 2018, doi: 10.1186/s40663-018-0154-y.
[12] P. M. Feikema, J. D. Morris, C. R. Beverly, J. J. Collopy, T. G. Baker, and P. N. J. Lane, “Validation of plantation transpiration in south-eastern Australia estimated using the 3PG+ forest growth model,” For. Ecol. Manage., vol. 260, no. 5, pp. 663–678, 2010, doi: 10.1016/j.foreco.2010.05.022.
[13] C. Pérez-Cruzado, F. Muñoz-Sáez, F. Basurco, G. Riesco, and R. Rodríguez-Souleiro, “Combining empirical models and the process-based model 3-PG to predict eucalyptus nitens plantations growth in Spain,” For. Ecol. Manage., vol. 262, no. 6, pp. 1067–1077, 2011, doi: 10.1016/j.foreco.2011.05.045.
[14] A. Mateus and M. Tomé, “Modelling the diameter distribution of Eucalyptus plantations with Johnson’s S B probability density function: Parameters recovery from a compatible system of equations to predict stand variables,” *Ann. For. Sci.*, vol. 68, no. 2, pp. 325–335, 2011, doi: 10.1007/s13595-011-0037-7.

[15] R. Vinícius Oliveira Castro, C. P. Boechat Soares, H. G. Leite, A. Lopes de Souza, G. Saraiva Nogueira, and F. Bolzan Martins, “Individual Growth Model for Eucalyptus Stands in Brazil Using Artificial Neural Network,” *ISRN For.*, 2013, doi: 10.1155/2013/196832.

[16] C. Marsden *et al.*, “Modifying the G’DAY process-based model to simulate the spatial variability of Eucalyptus plantation growth on deep tropical soils,” *For. Ecol. Manage.*, 2013, doi: 10.1016/j.foreco.2012.10.039.

[17] R. I. C. Lumbres, Y. Jin Lee, F. G. Calora, and M. R. Parao, “Model fitting and validation of six height-DBH equations for Pinus kesiya Royle ex Gordon in Benguet Province, Philippines,” *Forest Sci. Technol.*, vol. 9, no. 1, pp. 45–50, 2013, doi: 10.1080/21580103.2013.772542.

[18] A. S. de Oliveira, A. Ribeiro, C. R. A. Silva, A. Xavier, and A. F. de Freitas, “Modeling the Growth of Eucalyptus Plants Based on the Thermal Sum,” *Rev. Árvore*, vol. 41, no. 2, pp. 1–10, 2017, doi: 10.1590/1806-90822017000200012.

[19] P. Nyman *et al.*, “Evaluating models of shortwave radiation below Eucalyptus canopies in SE Australia,” *Agric. For. Meteorol.*, vol. 246, no. April, pp. 51–63, 2017, doi: 10.1016/j.agrformet.2017.05.025.

[20] S. Latifah, R. V. Teodoro, G. C. Myrna, C. B. Nathaniel, and M. F. Leonardo, “Predicted stand volume for Eucalyptus plantations by spatial analysis,” *IOP Conf. Ser. Earth Environ. Sci.*, vol. 126, no. 1, 2018, doi: 10.1088/1755-1315/126/1/012117.

[21] H. F. Scolforo *et al.*, “Modeling dominant height growth of eucalyptus plantations with parameters conditioned to climatic variations,” *For. Ecol. Manage.*, 2016, doi: 10.1016/j.foreco.2016.09.001.

[22] H. Deng, L. Shen, J. Yang, and X. Mo, “Stand stability of pure and mixed-eucalyptus forests of different tree species in a typhoon-prone area,” *Forests*, vol. 12, no. 4, 2021, doi: 10.3390/f12040458.

[23] P. Y. A. P. WIRABUANA *et al.*, “The growth, aboveground biomass, crown development, and leaf characteristics of three Eucalyptus species at initial stage of planting in Jepara, Indonesia,” *Biodiversitas J. Biol. Divers.*, vol. 22, no. 5, pp. 2859–2869, 2021, doi: 10.13057/biodiv/d220550.

[24] A. Hassan, P. Balachandran, and K. R. Khamis, “Early Root Development of Eucalyptus pellita F. . Muell . Seedlings from Seed and Stem Cutting Propagation Methods at Nursery Stage,” vol. 2021, 2021.

[25] K. Murata *et al.*, “Utilization of Chinese fast-growing trees and the effect of alternating lamination using mixed-species eucalyptus and poplar veneers,” *J. Wood Sci.*, vol. 67, no. 1, 2021, doi: 10.1186/s10086-020-01937-5.

[26] J. S. Silva, M. Nereu, S. Pinho, L. Queirós, C. Jesús, and E. Deus, “Post-fire demography, growth, and control of eucalyptus globulus wildlings,” *Forests*, vol. 12, no. 2, pp. 1–17, 2021, doi: 10.3390/f12020156.