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## ARTIFICIAL NEURAL NETWORKS APPLIED IN FOREST BIOMETRICS AND MODELING: STATE OF THE ART (JANUARY/2007 TO JULY/2018)

CHIARELLO, F.; STEINER, M. T. A.; OLIVEIRA, E. B.; ARCE, J. E.; FERREIRA, J. C. Artificial Neural Networks Applied in Forest Biometrics and Modeling: State of the Art (January/2007 to July/2018). **CERNE**, v. 25, n. 2, p.140-155, 2019.

### HIGHLIGHTS

Artificial Intelligence and Artificial Neural Networks in Forest Engineering.

Systematic and Bibliometric Review: Science Direct, Scopus and Web of Science.

32% of the analyzed papers predict the final total marketable volume.

63% of the analyzed articles were from Brazilian researchers.

78% making use of Multilayer Perceptron Networks (MLP).

28% using Statistica software.

### ABSTRACT

Artificial Intelligence has been an important support tool in different spheres of activity, enabling knowledge aggregation, process optimization and the application of methodologies capable of solving complex real problems. Despite focusing on a wide range of successful metrics, the Artificial Neural Network (ANN) approach, a technique similar to the central nervous system, has gained notoriety and relevance with regard to the classification of standards, intrinsic parameter estimates, remote sense, data mining and other possibilities. This article aims to conduct a systematic review, involving some bibliometric aspects, to detect the application of ANNs in the field of Forest Engineering, particularly in the prognosis of the essential parameters for forest inventory, analyzing the construction of the scopes, implementation of networks (type – classification), the software used and complementary techniques. Of the 1,140 articles collected from three research databases (Science Direct, Scopus and Web of Science), 43 articles underwent these analyses. The results show that the number of works within this scope has increased continuously, with 32% of the analyzed articles predicting the final total marketable volume, 78% making use of Multilayer Perceptron Networks (MLP, Multilayer Perceptron) and 63% from Brazilian researchers.

#### Keywords:

Artificial Intelligence  
Systematic Review  
Bibliometric Review  
Multilayer Perceptron,  
Forest Engineering Problems

#### Historic:

Received 23/01/2019  
Accepted 29/05/2019

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## INTRODUCTION

The human brain has attributes that would be desirable in any artificial system. Its skills in dealing not only with probabilistic and/or inconsistent information in different situations, but also its flexibility to adapt to poorly defined situations, has attracted the attention of many scholars, who intensified their research in the field of artificial intelligence (AI) in the 1980s with the use of intensive computing.

The dissemination of the methodologies found in this field has achieved interesting results in different areas of knowledge. In forestry, the Artificial Neural Network (ANNs) technique is considered a promising and very efficient alternative for defining the best management of forest resources (Menziés et al., 2007; Bhering et al., 2015; Miguel et al., 2015; Ribeiro et al., 2016 and Çatal & Saplıoğlu, 2018).

Studies guarantee that in different scenarios ANNs have contributed to high performance compared with classical regression models. Their purely massive structure, distributed (in layers) and ability to learn and generalize situations, tolerance of flaws and noises, and their flexibility in modeling categorical (qualitative) and numerical variables provide the methodology with a favorable context regarding the capacity to solve problems of any size (Binoti et al., (2013).

The wide range of spectra allows the evaluation of different network configurations based on alterations to the input data, number of neurons in the hidden layer, the output feedback (as input signals for the next iteration) or weight adjustments. Consequently, ANNs allow the finding of feasible solutions in the search space, even with small, but well balanced, population samples.

The need to develop studies and analyses for the parameterization and adaptation to different scenarios, such as final volume prediction, basal area, dominant height or growth and production of forest plantations (Binoti, 2014), has attributed a high potential to ANNs, particularly with regard to the variables and phenomena modeling, which are considered complex. Studies in this line of research, such as those conducted by Diamantopoulou et al. (2009); Özçelik et al. (2010); Soares et al. (2011) and Binoti et al. (2017), have been considered relevant to the applications that occur in forestry science.

The significant increase in scientific content, not only in the field of forestry, but also in several others, has shown that the development of syntheses that facilitate access to this information (forecasting of intrinsic variables) is urgently needed. In other words, its idealization has enabled the formation of conclusions

based on a combination of results from numerous sources. Thus, we can define a systematic review as a process that compiles and clusters a series of works (or studies) related to one or more topics based on the focused, well-defined investigative approach, which defines criteria on the identification, selection, assessment and synthesis of relevant information for conducting research.

Researchers have recently shown a strong tendency to conduct systematic and/or bibliometric literature reviews. Studies of this kind, although secondary, not only allow the expansion of knowledge but also address different relevant prisms and perspectives of themes of the same nature.

Considering these premises, unlike analogous works (with the same semantic), this article prioritizes the construction of a holistic view behind articles related to the application of ANNs in the field of forest sciences based on a detailed systematic review plan involving some bibliometric aspects. In other words, it seeks to clarify very important points on which to base the knowledge and directives that can support or not support the notion that the methodology can be viewed as promising. For this purpose, a survey of scientific articles was conducted by analyzing the construction of their respective scopes, verifying the form of implementation of ANNs (type (classification), architecture, configurations, computational language), data stratification, sample size, complementary techniques and findings.

The study is structured into five sections, including introduction. Section 2 presents the concept of ANNs, their applications and some relevant aspects regarding systematic and bibliometric literature reviews. The methodological procedure used in the study is outlined in Section 3. The results are presented and discussed in Section 4. The conclusions of the study are given in Section 5.

## THEORETICAL FOUNDATION

The theoretical foundation is based on two approaches. First, the study briefly discusses the concept of Bibliometric and Systematic Literature Reviews. This is followed by the contextualization and a detailed description of what constitutes an ANN. The functioning of an artificial neuron is explained, and the main implementation algorithm for network learning/training, backpropagation, is presented.

### Systematic Literature Review

Galvão and Pereira (2015) claimed that systematic reviews should be made available so that other researchers can repeat the applied methodological procedure and that their search criteria need to be comprehensive and free of bias.

Normally, the development of this type of review establishes a relatively solid pattern in the search for works and ends up being modified according to the researcher's needs or the field under study. Although a sequence of steps should be followed, there is, in fact, no single rule for the definition of the search criteria or the way in which the search will be directed.

As pointed out by Medeiros et al. (2015), the Bibliometric Literature Review can be understood as a purely investigative action that focuses on issues that are similar to the one being addressed. For this reason, it is considered one of the initial steps of the scientific method (applied to avoid any possibility of duplication in studies).

As a contribution, Gil (2002) emphasized that this classic approach to analyzing (or assessing) a review is intended to allow researchers much greater coverage/measurement of the indexes oriented to the production and dissemination of relevant subjects than pragmatic, i.e., direct research.

### Artificial Neural Networks

The first study of neurocomputation dates back to 1943, when the physiologist McCulloch and the mathematician Pitts developed a pioneer work, which consisted of assimilating the behavior of biological neurons as a binary circuit for the creation of a corresponding mathematical model. Despite its ability to separate two Boolean inputs, this model was not able to perform the learning process, since it did not have free parameters (Aguar, 2010).

Years later, more precisely in 1949, the neuropsychologist Donald Hebb made his great contribution to the McCulloch and Pitts' model. In brief, Hebb's projects had as a guideline the creation of a specific learning law for the synapse of neurons, demonstrating that the competence of ANNs is the result of altered synaptic efficiency (ALMEIDA, 2001).

Despite the considerable reductions in related research, ANNs reached their peak in 1980. With the advent of computers with greater calculation processing capacity, Rumelhart, Hinton and Williams formalized the development of the back-propagation algorithm. (Rumelhart et al., 1986). This new approach provided the training of Multilayer Perceptron (MLP) networks with great generalization power, opening up new areas of implementation, which until then were only idealized (Freiman, 2004).

We can observe an ANN as a complex system of massively distributed data processing that aims to simulate the functions of the neurons in the human brain based on mathematical values or equations (Diamantopoulou

et al., 2009). This traditional computational tool is capable of obtaining excellent results in different areas and applications, as described in the work of Oliveira et al. (2015) and Steiner et al. (2006), regarding bank lending through clients' classification (defaulters or paying customers). Other works in this respect are those of Valente et al. (2014), concerning solving problems involving adulteration in the milk manufacturing process, and Gonçalves et al. (2016) on the classification of forest strata, based on remote sense data. These are just some of the practical examples that could be mentioned.

According to Haykin (2001), the ANN structure assumes a classical behavior of systems based on interconnected neurons, responsible for the basic processing of information/knowledge acquired by the network. This process occurs mainly due to the learning procedures and the connecting forces between the neurons, called synaptic weights, as shown in Figure 1.

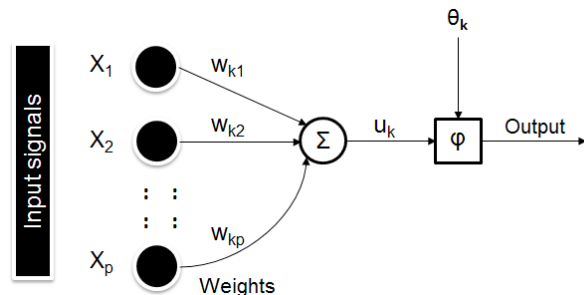


FIGURE 1 Description of the k-th neuron.

In Figure 1,  $x_1, x_2, \dots, x_p$  corresponds to the process inputs, usually associated with the previous neuron output. The synaptic weights,  $w_{k1}, w_{k2}, \dots, w_{kp}$  represent, in synthesis, the network memory, from the experience acquired through the presentations of the patterns. The sum symbolizes the linear combination process. In other words, it is responsible for producing an activation potential based on the sum of the input signals, weighted with their respective synaptic weights. The activation function  $\phi$  is observed as an output saturator from the neurons ( $u_k$ ), restricting their amplitude to a finite value  $y_k$ , usually normalized in the closed interval of  $[0,1]$ . Finally, the parameter  $\theta$ , or limit value (threshold), has the characteristic to help the ANN to adjust to the knowledge provided.

In general, ANN models are defined by the network topology, the node features, training type, and learning rules which, in addition to specifying an initial set of weights, indicate how these weights (or parameters) must be adapted, so that the performance of the networks is the best possible. According to Diamantopoulou et al.

(2009), the design procedures and the training algorithm definitions are widely discussed and, therefore, they add value to many researches' development.

Although there are numerous learning algorithms, the most well-known and commonly used algorithm is the back-propagation algorithm, a method with a supervised paradigm that operates in two consecutive stages, feeding the network (forward propagation) and back-propagating the error (backward propagation) (Rumelhart et al. 1986; Fausett 1994 and Silva 2009).

As a contribution, Silva (2009) guarantees that this algorithm pragmatic character is directed to make the application of a set of inputs able to produce the desired or, at least, consistent, outputs. In theory, this is due to the gradual convergence of the network weights, so that the application of the input vectors can produce the necessary outputs.

## MATERIAL AND METHODS

In order to formalize all the important conditions for a successful review, the present study adopted, a priori, the interpretation of the subjects that are considered relevant and that could serve as a basis for the development of the following research question: what advances were made in the field of forestry regarding the use of the ANN methodology for the prediction, prognosis or estimation of variables for its management?

In order to answer this question, a pilot study was conducted with different terms, followed by a logical AND or OR operator to find out which search format would be the most convenient in the following search bases: Science Direct, Scopus and Web of Science. The preliminary analysis showed that most of the authors reject the manipulation of derivations or very specific terminologies in the field of forestry, particularly with regard to the titles, abstracts or keywords, since the research space and, consequently, the index of the articles found, were relatively low.

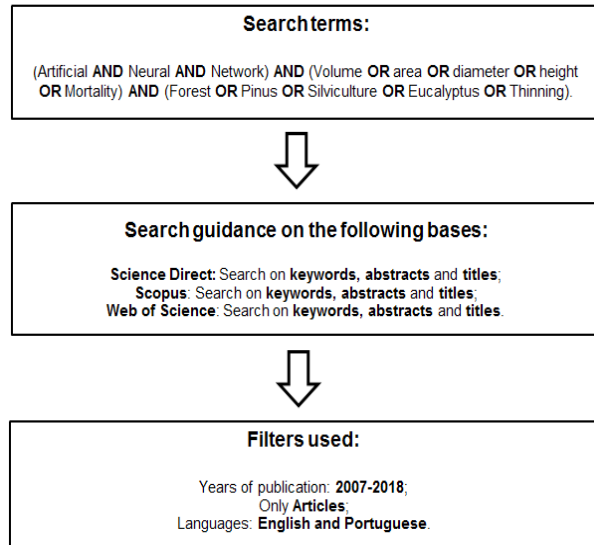
The search filters were adjusted to refine the search, especially regarding the date of submission, document type and language (to check the progress in the field in national and international scenarios).

Thus, the prerogatives obtained by the several experiments were described by identifying the best configuration in the search terms, which delimits the selection of articles to the maximum, as shown in Figure 2.

Figure 2 shows that the preliminary search surveyed 1,140 articles in the three databases, of which 465 were from Scopus, 557 from the Web of Science and 118 from Science Direct up to the end of July 2018. However, the subsequent step was directed towards preparing an activity that could offer a solution to separating the articles based on their relevance. To do

this, we conducted a survey of these works by applying a selection criterion processed in steps 1 and 2 (defined below) and in the exclusion of duplicate articles.

Theoretically, although different steps are considered, their natures encompass the same objective, i.e., they are responsible for weighing — by title (Step 1) or abstract (Step 2, analyzed when only the title does not allow us to decide whether the subject is of interest) — the works of interest (or not) to the research in question.



**FIGURE 2** Methodology applied to Systematic and Bibliometric Reviews.

Despite these assumptions, it is important to emphasize that, on various occasions, the reading of the abstracts (step 2) was unnecessary, since the paper title did not present any kind of analogy or relation to the study's subject, such as forensic context, population growth, landslides in urban areas, electrocardiograms, X-ray examinations, limb fractures, innovations in the clean energy sector, climate changes, density patterns, possibility of radiation, bleeding problems, and hurricane forecasting.

Theoretically, with the execution of the first step, 636 articles guided the survey and, with the exclusion of duplicate articles (using Excel 2010) the final set contained 438 articles for a more detailed analysis (step 2) to identify those that could actually contribute to the study. With these definitions, 43 works were filtered up to July 2018, serving as a basis for conducting the surveys of the main themes in each article: definition of their scope, the software used, classification of ANNs, activation functions, validation methods, authors by country, complementary techniques (applied cases), filiations, main journals and findings. Some of these alignments can be viewed in Figure 3.

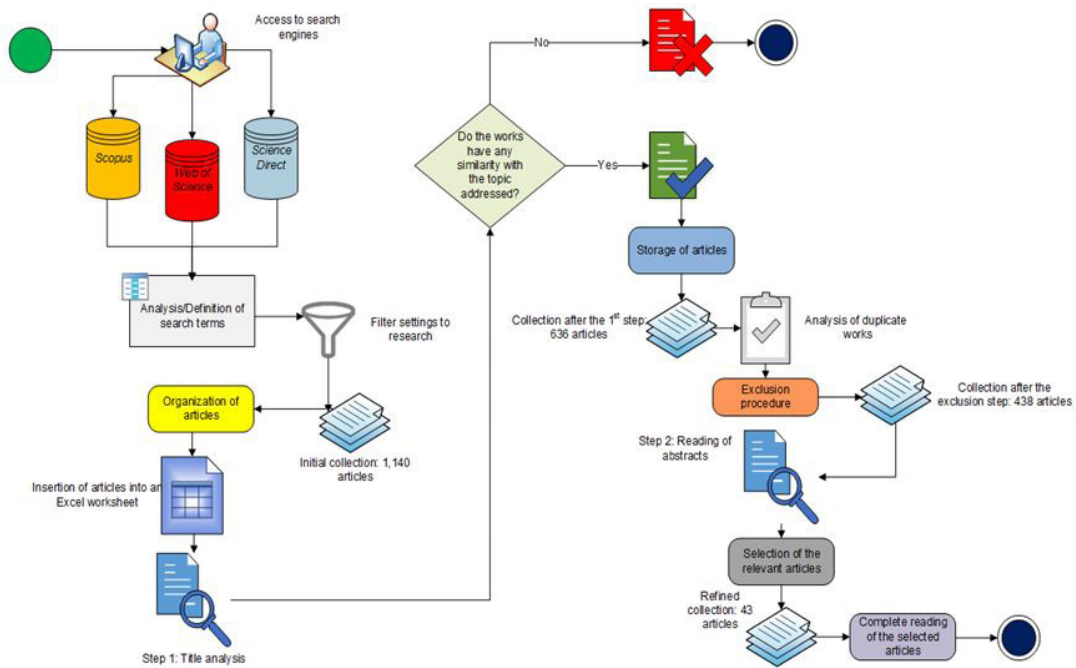


FIGURE 3 Criteria for filtering the 43 related articles.

## RESULTS AND DISCUSSION

Initially, the analysis focused on the production of published articles, with emphasis on the application of ANNs in the forest context. As can be seen in Figure 4, there was a slight rise in the first years (up to 2012), with some stationary periods (2009, 2011 and 2012, with only two publications), and more significant production in the last 6 years, with emphasis on the eight publications in 2015 and five new works up to July of 2018, when this research was conducted. This growth is associated with interest in the field, the availability of databases, new software and updated packages, with different functional techniques, often distributed free of charge.

Considering the interpretation of the objectives proposed by each author, some authors chose to deepen their studies with more than one aim, often due to the

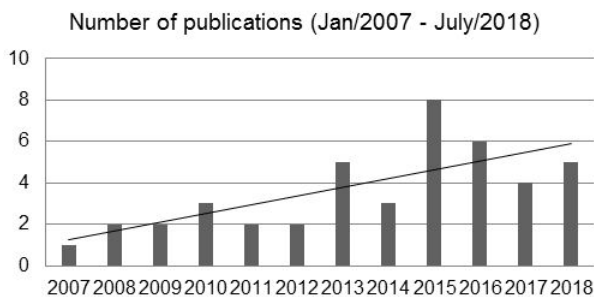


FIGURE 4 The 43 forestry publications analyzed and their publication years.

possibility of finding an alternative tool to the traditional techniques or models that are frequently used in the forest scenario. Of these, we can mention Castro et al. (2013), whose objectives addressed the issue of Mortality, DBH (Diameter at Breast Height) and Total Height. Others include Ashraf et al. (2015) and Binoti et al. (2015), who worked with the Volume Increase and Basal Area, and Miguel et al. (2015), who worked with Volume and Final Height. Nunes and Gorgens (2016) conducted a study on Volume and Diameter, and Vieira et al. (2018) dealt with Growth and Future Height.

In the same circumstances, we can highlight that the most addressed scope of the whole sample was the prediction (prognosis) of the total final volume of marketable wood (32% of the works). Figure 5 presents the integration of all the information into a relationship format (Author-Objectives).

Despite the orientation towards ANNs, 31 articles included the application of a complementary technique, be it of Linear Regression (37%), Cellular Automata (7%) or Kalman filter (13%) (procedure incorporated to networks), as shown in Figure 6. Other approaches, such as Volumetric Equations, Random Forest, the Support Vector Machine (SVM), Least Squares, Individual-tree Models and the Image Segmentation technique, were also applied, but only once. Therefore, they are aggregated as “other techniques”, accounting for 43% of the total.

Another premise of this study involved identifying the most frequently applied types of ANN to solve the



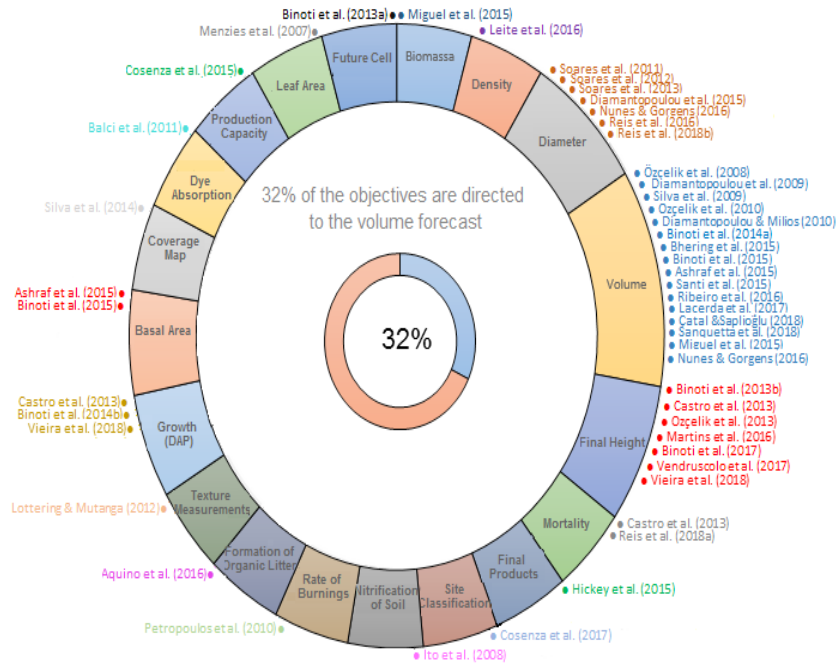


FIGURE 5 Relationships (Author-Objectives) of the 43 articles selected.

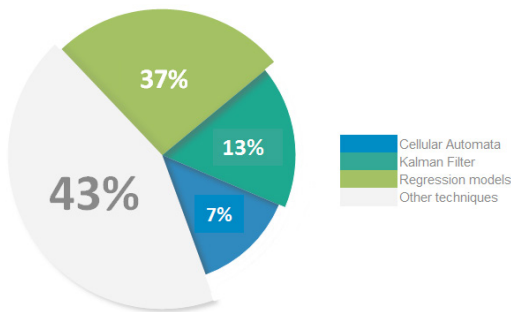


FIGURE 6 Complementary techniques addressed by the 31 (out of 43) articles that used more than one technique.

problems. With five different classifications at the end of the research, the authors' preference (Figure 7) was restricted to the classical Multilayer Perceptron (MLP) model with 78% of the total, followed by the Radial Basis Functions (RBF) with 13%, the Cascade Correlation Artificial Neural Network (CCANN) — a model considered promising for achieving satisfactory results in the total volume prognosis, according to Diamantopoulou & Milios (2010) — with 7%, and fuzzy logic networks and the Single Layer Perceptron, with 1% each.

In addition to the panorama that was identified, another item of information was extracted regarding the use of ANNs, namely the type of activation function employed in their respective input and output layers. Although there are different types (or mathematical components), most authors (15 in total) chose to use the Hyperbolic Tangent, followed

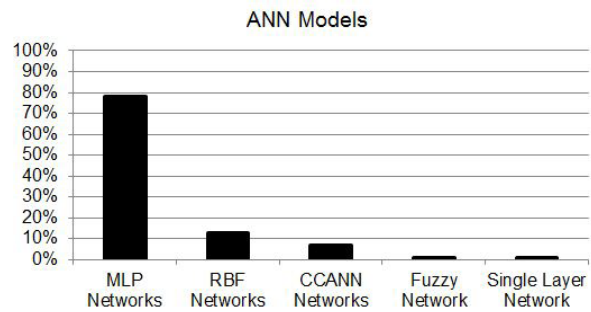


FIGURE 7 CANN models most used in the 43 studies.

by the Sigmoid or Sigmoidal function (11), Logistics (10), Linear and Exponential (5), Sigmoidal Tangent (4), Sine and Identity (3), Softmax and Log (2), others (1). There were 13 unspecified (uninformed) works, as shown in Figure 8.

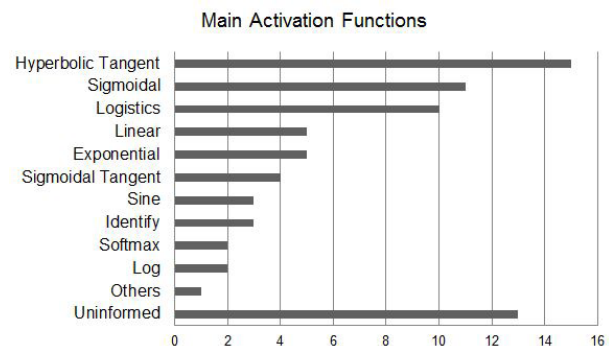


FIGURE 8 Main activation functions used in the 43 articles.

Regarding the application of the validation (or verification) methods of the ability of ANNs to predict the expected results successfully, Figure 9 shows that the correlation coefficient was the main criterion adopted by the authors (21 times), followed by Root Mean Square Error (RMSE) with 20, %RMSE (9), Bias (9), Mean Absolute Error (7), Histograms and Graphical Residue Analysis (6), Mean Error and Mean Square Error (5), Standard Error (4), Relative Error, Maximum Absolute Error and Coefficient of Determination (3), Statistical Test (L&O), Efficiency Models, Error Matrix, Akaike Information Criterion, Kappa Coefficient and the %Absolute Deviation totaled (2) and the “Other” class had only a single application.

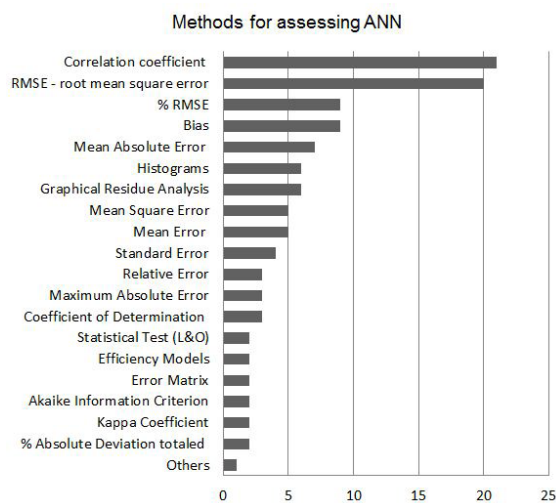


FIGURE 9 Methods used for assessing the ANNs in the 43 articles.

In addressing the researchers' nationality (Figure 10), Brazil was the main motivator in the development of articles in this line of research, responsible for 63% of the total. Brazil was followed by Turkey with 12%, Greece with 10% and, with 3%, South Africa, the USA, England, Ireland and Japan. The Federal University of Viçosa, Brazil, was the institution with the largest number of publications, a total of eight.

The analysis of the computational procedures for ANN implementation and execution showed that the most used interface was Statistica software, in 12 works, followed by Matlab (8), NeuroForest (7), R Software (2), WEKA - Waikato Environment for Knowledge Analysis - (1), ENVI - Environment for Visualizing Images - (1), JavaNNS - Java Neural Network Simulator - (1) and uninformed (11). However, it is worth noting that the different versions or derivations of the same package/program were not considered different operating systems, such as Statistica (7, 10 and 12) or Matlab (r2010a, r2013a and r2016b). These data are shown in figure 11.

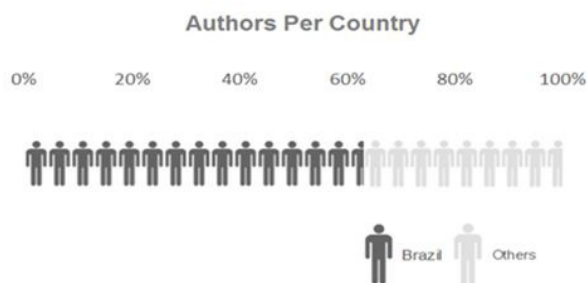


FIGURE 10 Geographical distribution of the 43 papers, involving several authors.

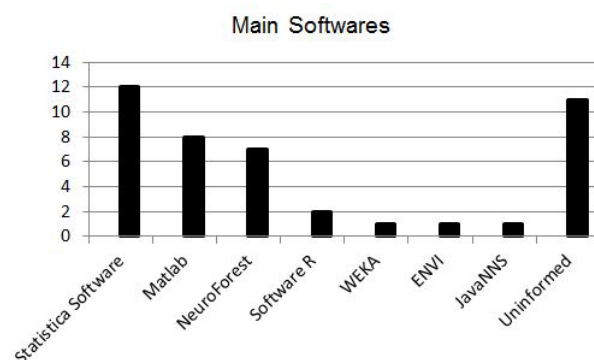


FIGURE 11 Software used to implement the language used in the 43 analyzed works.

In relation to the main journals, Table 1 shows that “Revista Árvore” and “Cerne” are considered the main journals, containing 6 and 5 published articles, respectively. On the other hand, the class designated as “Other” comprises a long list of journals with only one article, including Applied Ecology and Environmental Research, Applied Soft Computing Journal, Computers and Electronics in Agriculture, Comunicata Scientiae, Crop Breeding and Applied Biotechnology, Ecological Engineering, Ecological Modelling, European Journal of Remote Sensing, Expert Systems with Applications, Floresta, Forest Products Journal, Forest Science, GIScience & Remote Sensing, Journal of Environmental Management, Journal of Spatial Science, Nativa, Natural Resource Modeling, Neural Computing and Applications, Revista Brasileira de Ciências Agrárias, Science of the Total Environment, Sensors and Southern Forests.

TABLE 1 Descriptive statistics of the data groups.

Journals	Quantity
Revista Árvore	6
Cerne	5
Biosystems Engineering, Forest Ecology and Management, Pesquisa Agropecuária Brasileira, PlosOne and Scientia	2
Forestalis/Forest Sciences	
Other	1

To complement the information presented in Table 1, Table 2 shows, in perspective, the institutions that participated in the survey. In short, the Federal

University of Viçosa, located in the state of Minas Gerais, is the one that contributed the most, comprising 8 publications, followed by Süleyman Demirel University and the Federal University of Jequitinhonha and Mucuri Valleys, with 5 and 4 publications, respectively. The “Other” class consists of Arid Agriculture University, Cukurova University, Forestry and Forest Products Research Institute, Indiana University, Institute of Applied Physics, Federal University of Jequitinhonha and Mucuri, Federal University of Lavras, Federal University of Mato Grosso, Federal University of Espírito Santo, Federal University of Western Pará, Federal University of Paraná, University College Dublin, University of Bristol, University of Cambridge, University of KwaZulu-Natal and University of Lisbon.

Analyzing the conclusions of the studies, it can be said that all the information aided the development and execution of experiments to assess the capacity of ANNs in different contexts (scenarios and objectives). In general, all 43 studies showed that ANNs achieved satisfactory results (due to relatively low errors) and, therefore, can be considered a very efficient and accurate alternative in the prognosis of intrinsic variables in the forest inventory.

**TABLE 2** Main affiliations found in the sample of 43 articles.

Affiliation	Quantity
Federal University of Viçosa	8
Federal University of Jequitinhonha and Mucuri Valleys	5
Süleyman Demirel University	4
Aristotle University of Thessaloniki, University of Brasília and Federal University of Goiás	3
Mamirauá Sustainable Development Institute	2
Others	1

Detailed information on the Brazilian institutions, main researchers at these institutions, types of study and number of publications is shown in Table 3.

**TABLE 3** Brazilian affiliations and other information found in the sample of 43 articles.

Affiliation	Themes of the studies	Authors	Quantity
Federal University of Viçosa	Eucalyptus clone plantations (7); Managed forest in the Amazon (1).	Silva (2009); Binoti (2013a); Binoti (2013b); Bhering (2015); Cosenza (2015); Leite (2016); Reis (2016); Binoti (2017).	8
Federal University of Vales do Jequitinhonha and Mucuri	Eucalyptus plantations (hybrid or clone).	Binoti (2014a); Binoti (2014b); Binoti (2015); Martins (2016); Lacerda (2017).	5
Federal University of Goiás	Eucalyptus clone plantations.	Soares (2011); Soares (2012); Soares (2013).	3
University of Brasília	Disposal of Plant Litter (1); Commercial Eucalyptus Plantations (1); Biomass in the Cerrado region (1).	Miguel (2015); Castro (2013); Aquino (2016).	3
Mamirauá Sustainable Development Institute	Amazon Forest.	Reis (2018a); Reis (2018b).	2
Federal University of Mato Grosso	Tectona grandis trees.	Vendruscolo (2017).	1
Federal University of Lavras	Soil Coverage in Minas Gerais State.	Silva (2014).	1
Federal University of Paraná	Cryptomeria japonica.	Sanquetta (2018).	1
Federal University of Espírito Santo	Eucalyptus.	Vieira (2018).	1
Federal University of *Western Pará	Tapajós National Forest.	Ribeiro (2016).	1

Assuming that there are many other data and/or elementary information regarding the articles analyzed in this study, Table 4 provides a clear and organized summary of this content.

## CONCLUSION

Due to the great rise of Artificial Intelligence in the various fields of research and development, this study portrayed the construction and development of a systematic review, involving bibliometric aspects, orientated to identify the application of ANNs in different areas of the forest context, especially in forest biometry and modeling, more specifically, in the prediction of parameters considered important, from January 2007 to July 2018.

For this purpose, a methodological procedure was developed to scan articles in three research databases (Science Direct, Scopus and Web of Science), defining the main search terms (from a pilot study), filter selection and the exclusion of studies considered to be of no relevance and/or duplicated. Thus, at the end of the last step, 43 articles were selected, enabling the stratification of aggregating information for the study.

The variations in scope showed that advances were made in several respects, but the predominant one is estimating total marketable volume, making use of ANNs (especially the MLP network topology) and comparing them frequently with the traditional regression models. The results show that the number of works within this scope (volume) has increased continuously, with 32% of the analyzed articles predicting final total marketable volume (Figure 5), 78% making use of Multilayer Perceptron Networks (MLP; Figure 7), 28% using Statistica software (Figure 11) and 63% from Brazilian researchers (Tables 2 and 3).



**TABLE 4** Detailed description of relevant data/information regarding the survey of the 43 articles selected by the sample.

Publication	Intended Purpose(s)	Number of networks that authors have implemented	Identification of the Network Inputs and Outputs
Menzies et al. (2007)	The main idea of the paper was to predict environmental degradation by measuring the leaf area index (LAI) values using the Multiple Regression and ANN techniques, and then creating a comparative analysis to identify the best method.	4 MLP networks (1 for each assessed class).	"The network inputs considered distinct parameters for each developed class. Class 1: coverage types, urban land, pasture, cultivated fields, water and vegetation. Class 2: Initial and intermediate secondary succession. Class 3: Adult forests and advanced succession. Class 4: Adult forests. Output: Foliar area"
Ito et al (2008)	The proposal was to develop ANN models for the prediction of soil nitrification potential (with the lowest number of physicochemical properties as input data) and, later, to compare their results with the Multiple Linear Regression models.	The study tested different configurations in order to compare the model predictive performance. However, through a decision tree, it trained 5 different networks.	"Inputs: Carbon-nitrogen ratio, maximum water retention capacity and water saturation ratio. Output: Soil nitrification potential."
Özcelik et al. (2008)	This study's objective was to test the performance of a standard volume formula (using the Huber method and local volume tables), as well as several other techniques, including the modeling of the CCANN network, to predict the tree stem volume, from three species in the Mediterranean region of Turkey.	The final study included two CCANN networks for each of the three assessed species.	"Inputs: Stub diameter and the stem length for the CCANN I network, and the CCANN II network counted on the stub diameter, diameter at the top of the tree trunk and the stem length. Output: Volume."
Diamantopoulou et al. (2009)	This study's perspective work turned not only to the development of volume equations for the <i>Pinus brutia</i> stems, addressing the ANN techniques, but also to demonstrate the application of an alternative methodology in the field of reforestation project, responsible for allowing the estimate and optimization of the volume of dominant tree stems in reforestation (using factors easily measurable in the local and in the competition).	2 Networks: one MLP and one CCANN	"Inputs: Both the MLP network and the CCANN network were associated with four variables: density (correlated with competition) and the conditions related to the site factor (altitude, exposure and inclination/slope). Output: Volume."
Silva et al. (2009)	The first objective underwent the fitting assessment of Schumacher and Hall's volumetric model, using different algorithms. In addition, the study used the ANN methodology in the eucalyptus species, as a DBH function, for volume estimation.	18 Networks: 10 MLP and 8 RBF networks	"Inputs: 9 Networks considering DAP (4.5 to 28.3 centimeters) and Total Height (6.6 to 33.8 meters) and other 9 Networks with DAP (4.5 to 28.3 centimeters, Total Height (6.6 to 33.8 meters) and Clone. Output: Volume."
Diamantopoulou & Milios (2010)	The authors proposed to describe an ANN modeling to estimate the total volume of dominant <i>Pinus (Pinus brutia)</i> inside/outside the tree trunk in reforestation.	Selection of the two best networks, one for the volume inside the bark and another for the volume outside the bark	"Inputs: Mean diameter inside the bark (maximum and minimum, taken at two intervals [(0,3), (1,3), (3,3) and (5,3)], and the total height. On the other hand, network 2 (for the volume outside the bark) also had these variables; however, with changes in the diameter type (calculated outside the bark). Output: Total volume (inside and outside the bark)."
Özcelik et al. (2010)	This study's objective was the performance of different ANN models in the stem volume estimate of four tree species. To do so, it assessed the performance of two ANN types: 1) the multilayer perceptron architecture using the return propagation algorithm and 2) the CCANN architecture.	2 MLP networks and 2 CCANN for each species (total of 8 networks of each type).	"Inputs: Stub diameter, stem height and diameter at the stem top. Output: Stem volume."
Petropoulos et al. (2010)	The scope was to assess the ANN capacity and a Spectral Angle Mapper, both combined with the Landsat TM satellite imagery in a Mediterranean region, in the mapping of a burned area.	An MLP network for each of the 5 classes analyzed	"Inputs: Although not specified, we can assume that the inputs are related to the burning points indicated in the Landsat TM satellite images. Output: Total area burned. Each network has its predicted burning associated with a given class. Therefore, the sum of all burning areas, from all classes, will inform the total of burnings that occurred in the region."
Balci et al. (2011)	The achieved proposition aimed to apply Bohart and Adams' model to display the absorption process of textile dyes in glass pillars using <i>Eucalyptus</i> barks. In addition, the study chose to make use of ANN to determine the dye absorption capacity of the bed system.	Construction of two MLP networks (one for each dye absorption potential (BB41 and RB5)).	"Inputs: Volume of water, height of filtering material and concentration of dyes per liter of water. Outputs: Dye concentration of treated water."
Soares et al. (2011)	This study's scope aimed to present an approach for the diameter prediction for the <i>Eucalyptus</i> species with the ANN use.	Uninformed.	"Inputs: Measurements of diameters at three different heights, at each tree base (0.30m, 0.70m and 1.30m). Note: The next step considered the output of the first case as a new input, generating (0.7m, 1.3m and 2m). These steps are repeated at every 1m, along the stem, until reaching the total height of the tree. Thus, we can describe the inputs in a generalized way: $d = \text{diameter} (di-2, di-1 \text{ and } di)$ . Output: Future diameter following the time series $di + 1$ ."
Lottering & Mutanga (2012)	This study's objective was to determine the potential of integrated texture measurements with an ANN model and Multiple Linear Regression in the estimate of the edge effect of roads in adjacent forests of <i>Eucalyptus grandis</i> . Additionally, it investigated the use of texture measurements, calculated by multispectral and panchromatic SPOT-5 images, in DBH prediction, total height, basal area, volume and leaf area.	The study trained 5 MLP networks for the forest structural attributes and 5 MLP for texture measurement with the same architecture, differing only in the output type.	"Inputs: DBH, height of trees, basal area, volume and leaf area indexes. It is also worth mentioning that the study associated each variable with a texture measure: DBH: 3 measurements; volume: 2 measurements; height: 3 measurements; basal area: 3 measurements; foliar area index: 4 measurements. Outputs: Structural attributes of the forest and texture measurement (roadside effect)."
Soares et al. (2012)	The study outlined the modeling of two types of ANN, the MLPs and RBFs, for diameter prediction (applying only three actual measurements taken at the base of the tree). Unlike the other two works that the author (Soares et al. [2011 and 2013]) developed, this one introduced a new restriction: the study conducted the forecast, until the minimum marketable diameter had been reached, that is, the top with 4 cm off the bark. In addition, it made some comparisons between the two networks, debating on which presented the best results.	5 MLP networks and 5 RBF networks.	"Inputs: Measurements of diameters at three different heights at each tree base (0.30m, 0.70m and 1.30m). Note: The next step considered the output of the first case as a new input, generating (0.7m, 1.3m and 2m). These steps are repeated every 1m along the stem until reaching the total height of the tree. Thus, we can describe the inputs in a generalized way: $d = \text{diameter} (di-2, di-1 \text{ and } di)$ . Output: Future diameter following the time series $di + 1$ ."
Binoti et al. (2013a)	This study aimed at the construction and assessment of a cellular automata model, whose evolution rule was based on artificial neural networks, for the projection of diameters distribution in eucalyptus stands.	Initially, the study comprised the construction of 50 networks. However, the work selected the top 10, which were eventually used.	"Inputs: Current state of the cell, state of the cells in the extension of its neighborhood and the ages (current and future). Output: Future State of the Cell."

To continue..

**TABLE 4** Detailed description of relevant data/information regarding the survey of the 43 articles selected by the sample.

Publication	Intended Purpose(s)	Number of networks that authors have implemented	Identification of the Network Inputs and Outputs
Binoti et al. (2013b)	"This study's essence aimed at increasing the accuracy of tree height estimates and, at the same time, reducing the need for field height measurement, in order to decrease the forest inventory costs (from the construction and validation of a ANN model)."	4 MLP networks for scenario A (introduction of a new genetic material with no information regarding the hypsometric relation) and 15 MLP networks for scenario B (knowing the growth tendency in height of the stands implanted, based on the measurements of the CFI).	"Inputs: Quantitative variables: mean dominant height of the plot, diameter (with bark) at 1.30 m height (DBH) and age. Qualitative variables: only the soil. Output: Eucalyptus Final Height."
Castro et al. (2013)	"This article aimed at assessing and comparing two categories of growth and production models in commercial Eucalyptus plantations using simultaneous equations and ANN."	"Training of 500 networks for the estimate of mortality probability; 500 networks for total height prediction at future age; 500 networks for the DBH prognosis in the future age."	"Inputs: Each of the 15 networks suffered variations in the variables number and type, as follows: current and future age (I1 and I2), site index (S), DBH class (CLA), independent competition index of distance (IID1, IID2, IID3, IID4, IID5), the current age DBH (DBH1) and the total height at the current age (h1). Output: Each ANN had a possibility associated with its output: mortality probability, DBH at future age or total height at future age."
Özçelik et al. (2013)	"This study's purpose was to conduct a comparative work (among several methods) to obtain height predictions in sample plots of Crimerian juniper, located in the southern region of Turkey. For this, this work used several nonlinear growth functions, adjusted using nonlinear mixed-effect modeling techniques, as well as generalized models of the h-d type (height diameter measures) and ANN."	2 MLP networks.	"Inputs: Network I was fed with data of diameter at breast height (DBH) and Network II, with the same DBH, but taking into account the variation found for each plot analyzed. Output: Final height."
Soares et al. (2013)	"The work developed an approach for the use of MLP networks, for the recursive prediction of tree diameters, with the use of only three real measurements taken at the base of the tree, without prior knowledge of the total height. Then, the predicted diameters were used with the Smalian method, in order to calculate the volume of trees in a planted location."	Uninformed.	"Inputs: Measurements of diameters at three different heights at the base of each tree (0.30m, 0.70m and 1.30m). Note: The next step considered the first case output as a new input, generating (0.7m, 1.3m and 2m). These steps are repeated every 1m along the stem until reaching the total height of the tree. Thus, we can describe the inputs, in a generalized way: d = diameter (di-2, di-1 and di). Output: Future diameter following the time series di + 1."
Binoti et al. (2014a)	"Considering the high cost for tree cubing in forest companies, this study's objective was to propose a methodology with the ANN use, in order to reduce the number of trees to be scaled during the generation process of volumetric equations."	4 MLP networks.	"Inputs: DBH, height and diameters in positions 0,0; 0,5; 1,0; 1,5; 2,0; and 4,0m from the soil, besides the volumes obtained from 2 to 4m and the categorical variable defined as clone, which presents 15 subdivisions (C1 to C15). Output: Volume."
Binoti et al. (2014b)	"The work proposed the ANN development and assessment in the projection of Weibull distribution parameters and in the comparison of this method with some diametric distribution models commonly used in the forest area."	100 MLP networks developed. However, the study selected the top 16 networks.	"Inputs: Parameter $\beta$ of the Weibull function, initial age, future age, parameter $\gamma$ of the Weibull function, mean diameter, minimum height, dominant height, mean height, maximum height, minimum DBH, mean DBH, maximum DBH and number of trees planted. Output: The first four networks worked with the parameter $\beta$ of the Weibull function in the future age; Networks 5 to 8 predicted the parameter $\gamma$ of the Weibull function in the future age; Networks 9 to 12 completed the minimum DBH prognosis at future age and the last 4 networks estimated maximum DBH at future age."
Silva et al. (2014)	"This work aimed to model a methodology for the creation of a use and land coverage map in the northern region of the State of Minas Gerais. For this, it outlined three specific objectives: to test the use of image segmentation techniques for an object-based classification, contemplating spectral, spatial and temporal information; to test the use of high spatial resolution images (Rapideye) combined with time series Landsat-TM, aiming at capturing the seasonality effects; and the classification of the data through ANN."	Development of 10 MLP networks.	"Inputs: 4 NDVI values obtained through Landsat TM images, average reflectance of objects in each of the 5 bands, total brightness, contribution rate of a given band to the general brightness (bands 4 and 5), maximum difference between the mean intensities of each band, average difference between the pixel values of the objects (bands 4 and 5) and standard deviation (bands 4 and 5). Outputs: Each neuron represents a type of native class, as follows: Agricultural land (1), water (2), cerrado (3), deciduous forest (4), eucalyptus (5), others (6), pastures (7) and track (8)."
Ashraf et al. (2015)	"This study turned to the construction of a simple growth and yield model that has the capacity to predict the growth of individual trees under different climate change scenarios. These data come from the integration of historical records, ecological processes, JABOWA-3 (responsible for designing tree growth in different climate change scenarios) and ANN."	The study trained 12 MLP networks.	"Inputs: basal area, sum of total stands of softwood (SW) basal area in the PSP, total stands of basal area of finewoods or hardwoods (HW) in the PSP, basal area sum of SW-type large trees (based on the diameter) in a PSP, basal area sum of large HW trees (based on the diameter) in a PSP, dominant height, soil moisture, soil nutrients, species class identification, stock factor, days of increasing degree, solar radiation and climatic scenarios. Outputs: Volume increase and basal area."
Bhering et al. (2015)	"The main objective aimed at assessing the ANN methodology for the prediction of wood volume in eucalypt breeding programs and in the selection of families, comparing their results with those that the regression model found."	8 MLP networks segmented into 4 networks, for conditions at 3 years of age, and 4 networks for 6 years	"Inputs: Situation A: total diameter and height; Situation B: commercial diameter and height; Situation C: types of species, total diameter and height (both for total volume) and commercial diameter and height (used for commercial volume calculation). Output: Volume."

To continue...

**TABLE 4** Detailed description of relevant data/information regarding the survey of the 43 articles selected by the sample.

Publication	Intended Purpose(s)	Number of networks that authors have implemented	Identification of the Network Inputs and Outputs
Binoti et al. (2015)	The study's focus was to model not only the volumetric production of Eucalyptus clone stands in function of categorical and numerical variables, but also to evaluate the accuracy of ANN prognosis.	"The work trained 600 networks to prognose the basal area: 200 perceptrons, 200 MLPs and 200 RBFs. Analogously, the same applies to the volume forecast, that is, 600 networks divided into the three types of networks presented (200 each). However, the work considered the best 24 networks for the discussion of the results (12 as basal area and 12 as volume)."	"Inputs: Categorical (for basal area): design, soil type, relief, texture, clone and spacing. Numerical (for basal area): current age, future age and current basal area. Categorical (for volume): design, soil type, relief, texture, clone and spacing. Numerical (for volume): current age, future age, current basal area, initial volume and future basal area. Outputs: An output for the first set of networks: basal area. An output for the second set of networks: future volume. This happens because the future basal area is treated as input for the volume forecast."
Cosenza et al. (2015)	The objective was to compare the results obtained by the forest data processing, with the Support Vector Machine and ANN, aiming to classify the productive capacity of eucalyptus stands.	Preliminarily, the study considered the training of 400 networks with different configurations. After this process, it selected the 5 best networks, being 4 MLP and 1 RBF	"Inputs: The soil and preparation type before planting; the spacing used; the stand age; dominant height; basal area; volume with bark; diameter at 1,3m of height (DBH), minimum, average and maximum of the stand, and the number of individuals per hectare. Within these categorical variables, ten types of soils, two types of soil preparation and five types of spacing were described. Output: The value emitted by each of the three neurons of the output layer will represent the probability of a given field belonging to its respective class."
Diamantopoulou et al. (2015)	The article investigated the potential for improvement in the diameter distribution modeling, at a time when ANN models (with Levenberg-Marquardt learning) were used as an internal procedure to accurately estimate the parameters required in the Weibull distribution modeling of two parameters, using the Method of Moments (MOM) and the Maximum Likelihood Estimation (MLE).	3 LMANN networks (Neural Networks with Levenberg-Marquardt learning).	"Inputs: Tree age, mean square diameter and basal area. Output: Diameter distribution."
Hickey et al. (2015)	The proposal consisted of the construction of alternative forecast models for the proportion of planned final products that can be extracted from a forest compartment. For this, the study developed a Dirichlet regression model and an ANN to compare their respective results with a multivariate model of multiple regression benchmark.	Only one MLP network constructed with the aid of three heuristics, in order to obtain the best topology.	"Inputs: Mean diameter at breast height, first thinning harvest, second thinning harvest, SS/NS species and LP/LPS/OC species (both uninformed about what they mean) and elevation. Outputs: Sawlog ratio (size suitable for sawing wood, processed in sawmills); proportion of wood pallets; proportion of wood stakes; Proportion of wood pulp."
Miguel et al. (2015)	This study's objective was to assess the regression analysis effectiveness and ANN models in the prediction of the amount of wood and biomass above the soil, of the arboreal vegetation in an area composed of the cerrado biome, known as "cerradão".	The study counted on the development of 400 networks. However, from this added value, the authors configured 100 networks for each of the four selected outputs.	"Inputs: Basal area (G); Enhanced Vegetation Index Modified (EVI2); Normalized Difference Vegetation Index (NDVI); Soil Adjusted Vegetation Index (SAVI) and the simple ratio vegetation index (SR). Output: Total volume, stem volume, total biomass or stem biomass."
Santi et al. (2015)	The authors sought to investigate the potential of L-band SAR (ALOS/PALSAR) and C-band (ENVISAT/ASAR) images in the monitoring of forest biomass and, simultaneously, to develop a recovery algorithm based on ANN to estimate the wood volume the combined acquisitions of satellite images.	"Scenario for area A: 4 MLP networks considering the input data generated by: PALSAR 4 inches, PALSAR (HH, HV), PALSAR 2 inches + ASAR and PALSAR 4 inches + ASAR. Scenario for area B: 2 MLP networks considering all image data (ALOS/PALSAR and ENVISAT/ASAR)."	"Inputs: Acquisitions of available frequencies and polarizations intermediated by RAS, in addition to the incidence angles and an auxiliary database. Output: Volume."
Aquino et al. (2016)	The proposal considered the analysis of the environmental variables that act in the litter formation in a gallery forest through the application of the ANN methodology.	Initially, the work developed 500 MLP networks. However, it selected the best 3 ones to continue the experiment.	"Inputs: Elevation, spatial position (x and y coordinate in UTM), monthly accumulated rainfall data, number of rainy days, maximum and minimum temperatures, average temperature, average relative air humidity, average atmospheric pressure, average rainfall, average wind speed, number of individuals and species per plot, Shannon Weaver diversity index and number of individuals from the most representative families. Outputs: Leaf fractions; Branch fractions (branches and barks); reproductive structures and total litter in grams."
Leite et al. (2016)	The study involved the basic density modeling of wood for Eucalyptus clones as a function of numerical variables obtained by CFI with the ANN use under different training standpoints: Error backpropagation, resilient propagation, Manhattan update rule, scaled conjugate gradient, levenberg marquardt, quick propagation and the SA and GA metaheuristics.	Training of $4.16 \times 10^{12}$ and test of $4.16 \times 10^{10}$ MLP networks according to the various combinations of the number of neurons, training algorithms and activation functions.	"Inputs: Age (years); basal area (m <sup>2</sup> /ha); annual average increase (m <sup>3</sup> /ha/year) at the measurement age; total height (m); diameter at 1.3m from the soil surface (DBH); number of stems per hectare (n/ha) and the ratio between DBH and total height. Output: Density."

To continue...

**TABLE 4** Detailed description of relevant data/information regarding the survey of the 43 articles selected by the sample.

Publication	Intended Purpose(s)	Number of networks that authors have implemented	Identification of the Network Inputs and Outputs
Martins et al. (2016)	The study's scope consisted in defining the appropriate ANN configurations to obtain the total height of eucalyptus trees, taking into account different training methods, among them: the Manhattan Update Rule, Scaled Conjugate Gradient, Levenberg Marquardt and two meta- heuristics, Genetic Algorithm and Simulated Annealing.	1.2 X 10 <sup>6</sup> MLP networks tested through a script containing all configurations.	"The inputs included the use of quantitative (diameter at breast height, dominant height and age) and categorical (project, clone, soil type, spacing and terrain, respectively, 4, 6, 15 and 6 classes) variables. Output: Total height of Eucalyptus trees."
Nunes & Gorgens (2016)	This study's alignment included the assessment of the abilities of ANN models and the RF technique in the prognosis of the tree diameter, at any height and accumulated volume, along the length of the stem (depending on the measurement of the tree concicity), in three different regions: the cerrado, a tropical forest and a semi-deciduous forest. At the end, the study compared these results with a specific model of taper equation.	1 network for the volume forecast and another for the diameter prognosis.	"Inputs: Diameter at breast height, total height and three categorical "dummy" variables that represent the forest type of each of the scenarios studied (cerrado, tropical forest and semideciduous). Outputs: Volume and diameter."
Reis et al. (2016)	The study's purpose was to model the projection of the future diameter of individual trees in a forest managed in the Amazon, using ANN as a source of subsidy for decision-making.	The study developed 1200 MLP networks, subdivided according to the competition index assessed. That is, 300 networks for each index (1, 2 and 3) and 300 networks that did not consider it.	"Inputs: Semi-independent distance competition index, diameter measured at 1.30m from the soil, forest class, growth group, trunk identification class, liana infestation intensity and crown illumination. Output: Annual periodical increment of diameter."
Ribeiro et al. (2016)	This study's guidelines aimed at the application and assessment of the regression methods, based on the expansion of the Schumacher model and on ANN for the estimate of stem volume and branches in the Tapajós National Forest.	The authors did not report the total number of networks.	"Inputs: The work unit, type of species, DBH, commercial height and a dummy variable (0 for the stem volume and 1 for the volume of branches). Output: Volume of stems and branches."
"Binoti et al. (2017)"	This study's objective was to assess the Neuroevolution of Augmenting Topologies (NEAT) method for adjusting the weights and the ANN topology, in the height estimate of clonal eucalypt stands, as well as to compare their predictions with the estimates found by a hypsometric regression model.	60 Neural Networks coded by the NEAT method.	"Inputs: Diameter adjusted to 1,3m high (DBH) and dominant height (Hd). Output: Total height."
Cosenza et al. (2017)	This study's objective was to evaluate the ANN for the classification of Eucalyptus plantation sites (based on silvicultural and environmental information), in order to answer two questions: to find the best network configuration for site classification and to know if the RNA approach, without stand feature as input, was more accurate than the guide-curve method.	Initially, the work created 200 MLP networks, but only one network for each classification type (the best one) was chosen for analysis, totaling 2 networks.	"Inputs: Genetic material, spacing, rotation, soil type and climatic information. According to the authors, they considered 17 soil types, 49 genotypes, 8 spacings and 11 different climate conditions. Outputs: The network with 3 classes presented 3 neurons at the output. For this case, the mapping classification of the area had amplitudes of 5.5m (32 - 37.5m, 26.5 - 31.9m and 21 - 26.4m). On the other hand, the network with 4 classes had 4 neurons in the output. Similar to the first case, the mapping classification of the area had amplitudes, however, with values equivalent to 4.0m: (33 - 37m, 29 - 32.9m, 25 - 28.9m and 21 - 24.9m). In other words, the output refers to the site classification based on the site index observed in the different classes with amplitude variation."
Lacerda et al. (2017)	This study's essence was to portray that the use of ANN can be seen as a highly feasible tool to estimate the volume of trees, considering different species of the Brazilian savanna. As a complement, it created comparisons between the estimates of the networks with some volumetric equations.	6 MLP Networks.	"Inputs: Situation A: total diameter and height; Situation B: commercial diameter and height; Situation C: types of species, commercial and total diameter, as well as total and commercial height. Outputs: Situation A: total volume; situation B: commercial volume and situation C: total volume (commercial + total)."
Vendruscolo et al. (2017)	This paper aimed at assessing and comparing the ANN modeling with the regression technique, regarding the total height estimate of <i>Tectona grandis</i> trees at different distances in the city of Cáceres, MT, Brazil.	5 MLP networks.	"Inputs: diameter at breast height (DBH), plus maximum diameter and spacing. Output: Total height."

To continue...

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Publication	Intended Purpose(s)	Number of networks that authors have implemented	Identification of the Network Inputs and Outputs
Catal & Saplioglu (2018)	The study analyzed which method could correctly determine the amount of bark in <i>Pinus brutia</i> ten., in a region of Turkey. The idea was to focus on the construction of ANN models and a NeuroFuzzy adaptive inference system, as an alternative to the nonlinear regression model.	One MLP network and one with Fuzzy logic	"Inputs: Diameter at breast height with bark, diameter at breast height without bark and volume of the tree with bark. Output: Bark volume." "
Reis et al. (2018a)	The purpose was to estimate the survival and mortality of individual trees in a selectively harvested forest, from the ANN use (as a source of subsidy) for silvicultural decisions on forest management in the Amazon.	1200 MLP networks stratified into 4 compositions each one containing 300 architectures.	"Inputs: Diameter at breast height, forest class, trunk identification class, competition index, growth groups, liana infestation intensity, crown illumination, lesions (or not) in trees and tree rot. Outputs: Mortality and Survival."
Reis et al. (2018b)	The work had the proposal of using the cellular automata, as a rule of evolution in ANN, to design the distribution of diameters in harvested forest, and could serve as a decision-making for sustainable Forest Management in the Brazilian Amazon.	Initially, the study counted on the creation of 300 networks; however, it selected only the 5 best ones.	"Inputs: Current density, future density and the measurement period (in years). Output: Diametric distribution."
Sanquetta et al. (2018)	The article sought to examine the performance of some Artificial Intelligence models (k-neighbors variant, one and three nearest neighbors and ANN) in estimating the tradable volume of <i>Cryptomeria japonica</i> logs in an experimental plantation in southern Brazil.	Training of 450 MLP-networks	"Inputs: Not informed. Output: Total volume."
Vieira et al. (2018)	Considering the Artificial Intelligence potential in forest measurement, this article proposed the application of ANN and a fuzzy inference system (ANFIS) to predict the growth in DBH and the Eucalyptus height.	Although 100 trained networks, the experiment had 8 MLP and 6 ANFIS.	"Inputs: Current diameter at 1.30 m (DBH), future age, current age, competition index (regardless of distance), genetic material, site index and current total height. One output per network, and can be directed to the future growth in DBH or future height."

Legend: ANN (Artificial Neural Networks); DBH (Diameter at Breast Height); LAI (Leaf Area Index); SAR (Synthetic Aperture Radar); ENVISAT (Environmental Satellite); ASAR (Advanced Synthetic Aperture Radar); ALOS (Advanced Land Observing Satellite); PALSAR (Phased Array type L-band Synthetic Aperture Radar); MLP (Multilayer Perceptron); RBF (Radial Basis Function); CFI (Continuous Forest Inventory); CCANN (Cascade Correlation Artificial Neural Network); SAR (Synthetic Aperture Radar); SA (Simulated Annealing); GA (Algorithm Genetic); RF (Random Forest); NVDI (Normalized Difference Vegetation Index); EVI (Enhanced Vegetation Index); SAVI (Soil-adjusted vegetation index); SRVI (Simple Ratio Vegetation Index); MOM (Method of Moments); MLE (Maximum Likelihood Estimation); LMANN (Levenberg - Marquardt Artificial Neural Network); NEAT (Neuroevolution of Augmenting Topologies); LM (Levenberg - Marquardt); SCG (Scaled Conjugate Gradient); MUR (Manhattan update rule); RP (Resilient Propagation); ANFIS (Adaptive Network based Fuzzy Inference Systems); RMSE (Root Mean Square Error); GC (Guide curve); AI (Artificial Intelligence); ITM (Individual Tree Models); SAM (Spectral Angle Mapper); Landsat (Land Remote Sensing Satellite); PSP (Permanent Sample Plots).

It should be highlighted that a justification for the MLP model being more widespread and used in the literature is that the architecture of this network is considered a "universal approximator". In other words, it is a general purpose model that can be applied on a large scale (ranging from linear to non-linear problems with high complexity). Other justifications are that it is easy to use (not requiring much knowledge of the functions that will be modeled) and has been proved efficient in many studies covering a wide range of areas of expertise. On the other hand, the majority of the authors opted to make comparisons of MLP with the traditional forecasting techniques most used by forest science researchers, as is the case of regression. The idea was generally to verify which of the approaches presents a better accuracy for the output variables (mainly volume).

The Brazilian researchers who stood out during the period in question were those from the Federal University of Viçosa (8 publications). The authors (cited here individually and in chronological order) were: Silva (2009);

Binoti (2013a); Binoti (2013b); Bhering (2015); Cosenza (2015); Leite (2016); Reis (2016) and Binoti (2017). The themes addressed in their studies were eucalyptus clone plantation sites (7 publications) and managed forests in the Amazon (1 publication), as shown in Table 3.

As a consequence of the information stratification, the synthesis of conclusions indicated that ANNs are capable of safely predicting the different parameters of the fields of biometrics and forest modeling (considering the low indexes found by the validation metrics) and, therefore, it can be considered a very promising alternative technique. Suggestions for future studies include applying ANN to other forest problems and using other types of ANN to maximize the accuracies involved in each problem.

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