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Review

Using Drones for Dendrometric Estimations in Forests: A Bibliometric Analysis

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Abstract: Traditional field inventories have been the standard method for collecting detailed forest attribute data. However, these methods are often time-consuming, labor-intensive, and costly, especially for large areas. In contrast, remote sensing technologies, such as unmanned aerial vehicles (UAVs), have become viable alternatives for collecting forest structure data, providing high-resolution images, precision, and the ability to use various sensors. To explore this trend, a bibliometric review was conducted using the Scopus database to examine the evolution of scientific publications and assess the current state of research on using UAVs to estimate dendrometric variables in forest ecosystems. A total of 454 studies were identified, with 199 meeting the established inclusion criteria for further analysis. The findings indicated that China and the United States are the leading contributors to this research domain, with a notable increase in journal publications over the past five years. The predominant focus has been on planted forests, particularly utilizing RGB sensors attached to UAVs for variable estimation. The primary variables assessed using UAV technology include total tree height, DBH, above-ground biomass, and canopy area. Consequently, this review has highlighted the most influential studies in the field, establishing a foundation for future research directions.

Keywords: bibliometric analysis; remote sensing; forest inventory; unmanned aerial vehicle; Scopus; keyword search

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1. Introduction

The concept of sustainable forest management is closely linked to the sustainable development of specific forest regions, aiming to balance the use of forest resources with the preservation of environmental integrity, ultimately promoting optimal environmental outcomes [1]. Comprehensive data collection regarding forest characteristics is conducted via forest inventory, aimed at tracking forest regeneration and quantitatively assessing the structure and dynamics of the forest at the individual tree level. This includes metrics such as tree count, crown base height, diameter at breast height (DBH), and tree height [2,3], in addition to the estimation of wood volume and biomass [4,5].

Traditional field research is known for its ability to collect comprehensive data regarding forest characteristics; however, the process of gathering data in forested areas and conducting structural measurements of individual trees can be economically unfeasible, labor-intensive, and physically demanding for field teams [4,6]. This challenge is particularly pronounced in extensive regions characterized by trees of diverse shapes and sizes [7].

To enhance both cost-effectiveness and precision, remote sensing technology has emerged as a viable method for acquiring information about the structure, dynamics, and distribution of forest resources [8]. Applications such as tree counting and forest condition reconstruction, integrating remote sensing and geographic information systems [9], as well as the potential to estimate tree-level forest biomass using LiDAR data [10], demonstrate the significant advancements in remote sensing techniques and technologies from the mid-20th century to the present. Among the various remote sensing technologies, satellites, manned aircraft, and unmanned aerial vehicles (UAVs) are the most widely utilized [11]. UAVs offer distinct advantages over traditional remote sensing platforms, including higher spatial resolution, better positioning accuracy, increased safety, and lower costs [12]. The deployment of UAVs can lead to substantial reductions in both capital and labor expenditures, as well as a decrease in the time required for data collection [11,13].

UAVs possess the significant advantage of accommodating a diverse array of sensors. The primary sensors used with UAVs include thermal, infrared, and multispectral cameras, as well as LiDAR technology [14,15], along with conventional digital cameras, such as RGB sensors. Cameras operating in the visible spectrum are widely used for vegetation monitoring [16]. The application of Structure from Motion (SfM) algorithms has become a promising and cost-effective approach in forestry research, enabling the collection of data on canopy structures [17], the identification of individual trees [18], and various other applications relevant to forest inventory data collection [2,19–22]. Additionally, LiDAR sensors integrated into mobile devices, such as the iPhone and iPad, are increasingly being employed to obtain forest inventory data [23,24].

Alternative sensor technologies can also be used to derive dendrometric variables related to forest structure in a more accurate and economic way. LiDAR and airborne laser scanning (ALS) are increasingly applied to estimate parameters, such as tree height, diameter at breast height (DBH), individual tree identification, canopy delineation, as well as volume and biomass assessments [4,7,25–28]. Nonetheless, many studies are still focused on temperate forest ecosystems or areas with open vegetation. As a result, using UAV imagery for the rapid estimation of dendrometric data is considered a more cost-effective alternative to traditional field data collection methods, improving the efficiency of forest inventory updates [7,27].

The growing use and potential of unmanned aerial vehicles (UAVs) in forest management require a thorough review of the existing scientific literature on this topic. Such an analysis seeks to identify the most significant contributions to the field and highlight knowledge gaps that could guide future research and practical applications. As the volume of academic output in a scientific discipline increases, it is essential for researchers to employ quantitative review methods to clarify the knowledge base of that domain [29].

Consequently, this bibliometric review seeks to delineate the developmental trends of scientific publications and evaluate the current state of UAV applications for estimating dendrometric variables in forest ecosystems. Specifically, the objectives are to (i) quantitatively analyze the annual growth of publications in this area, (ii) identify the leading authors and journals in this area, (iii) examine trends in international collaboration and the most prevalent keywords in the literature, (iv) ascertain the primary indexing categories relevant to the field, and (v) determine the types of vegetation, dendrometric variables, and sensor technologies most frequently employed in this research area.

2. Materials and Methods

A bibliometric analysis was performed to investigate the application of UAVs in the assessment of dendrometric variables within forest ecosystems. This type of analysis quantitatively evaluates research publications over a designated timeframe in a particular discipline, allowing for an examination of scientific progress over the years. It also facilitates the identification of key authors, influential journals, geographic study areas, and prominent academic institutions relevant to the field [30,31].

For this study, the database used was the Scopus platform, a widely recognized, multidisciplinary scientific database commonly used in bibliometric analyses and for assessing the current state of specific research areas [32,33].

To enhance the volume of documents pertaining to the application of UAVs in the assessment of dendrometric variables, a selection of pertinent keywords in both Portuguese and English was made to create a more extensive information repository on the subject. The search methodology employed was as follows: (TITLE-ABS-KEY (“vant” OR “veículo aéreo não tripulado” OR “drone” OR “uav” OR “unmanned aerial vehicle” OR “arp” OR “aeronave remotamente pilotada”) AND TITLE-ABS-KEY (“variáveis dendrométricas” OR “diâmetro à altura do peito” OR “dap” OR “altura total” OR “área de copa” OR “dendrometric variables” OR “total height” OR “diameter at breast height” OR “dbh” OR “crown area” OR “detection of individual trees” OR volume OR biomass OR “biomassa”) AND TITLE-ABS-KEY (“forest” OR “dry forests” OR “floresta” OR “floresta tropical seca” OR “dry tropical forest”)) AND PUBYEAR > 1986 AND PUBYEAR < 2023 AND (LIMIT-TO (DOCTYPE, “ar”)). This search was executed in August 2023, with an additional limitation on the publication timeframe, focusing on works published up to the conclusion of 2022.

Following the data collection phase, the identified documents were reviewed and subjected to an analysis based on inclusion criteria. This analysis focused on research articles, studies conducted solely within forest environments, those that examined at least one dendrometric variable, and investigations utilizing UAVs. Consequently, review articles, case studies, book chapters, and research not directly pertinent to forests and dendrometric variables were excluded from this study’s parameters.

Upon completing the article screening, data were extracted for a comprehensive analysis of the current state of research on the topic, specifically addressing (i) the types of vegetation investigated, (ii) the dendrometric variables measured, and (iii) the types of sensors employed. For the bibliometric analysis, information was gathered regarding the authors’ nationalities, their institutional affiliations, collaborative efforts among leading research nations, annual publication counts, highly cited works, the most prolific countries, and the frequently utilized keywords for indexing purposes.

The data collected that met the inclusion criteria were organized and subjected to descriptive statistical analysis to assess the current state of the art. Bibliometric analyses and world maps were generated using the *biblioshiny* function from the *bibliometrix* package [34] within the R software (version 4.1.1) environment [35]. The interaction network for the most frequently used keywords in the documents was constructed using the specified bibliometric analysis program, *VOSviewer* version 1.6.15 [36].

3. Results

A comprehensive analysis was conducted on a total of 454 articles, out of which 43.6% met the established selection criteria, resulting in the inclusion of 198 articles in this research. The remaining 56.4% comprised review articles, case studies, and research focused on agronomic crops, which did not align with the parameters set for this study. The findings revealed that Asia led in the number of publications within the field of study, totaling 98, followed closely by Europe with 95 publications. North America contributed 61 publications, while South America had 20, Oceania 16, and Africa 7. A total of 52 countries engaged in research related to this topic, with China leading the way with the highest number of studies ($n = 60$). This was followed by the United States ($n = 41$), Japan ($n = 17$), Brazil ($n = 14$), Australia ($n = 14$), Finland ($n = 13$), Canada ($n = 13$), Belgium ($n = 12$), Spain ($n = 10$), and Norway ($n = 9$), identifying them as the top ten contributors to research in this area.

The network of interactions among countries that have investigated the application of UAVs for the acquisition of dendrometric variables is illustrated in Figure 1. The thickness of the lines connecting these nations reflects the volume of collaborative publications produced. Notably, the most significant collaboration occurred between the United States and Brazil, which engaged in 10 joint research initiatives. This was closely followed by the partnership between China and the United States ($n = 9$), as well as collaborations between Australia and Belgium ($n = 5$) and between the United States and Spain ($n = 5$). These findings highlight a robust level of international cooperation, which is advantageous for enhancing the body of literature and understanding regarding the utilization of UAVs in forestry.

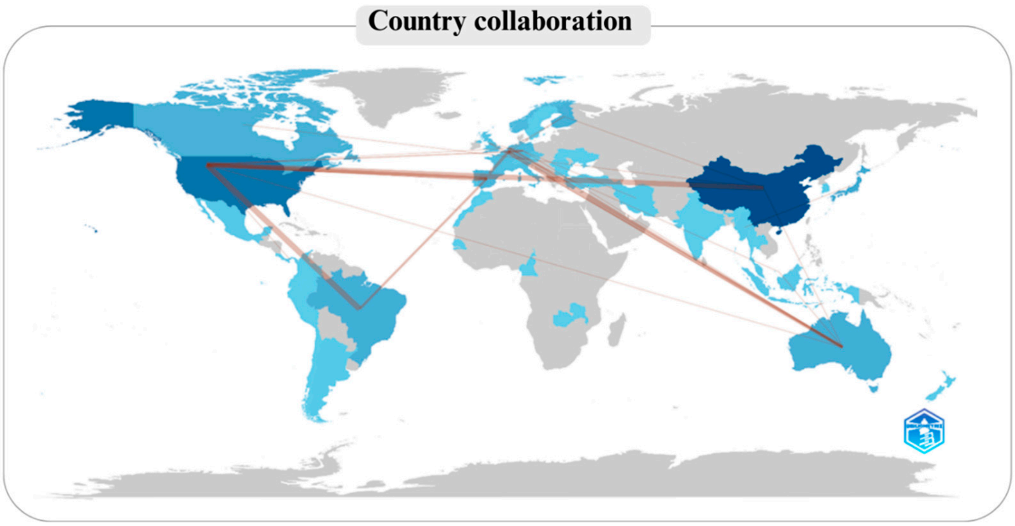

Figure 1. Collaboration network between countries in publishing scientific articles on the topic. The color intensity represents the number of publications per country, with darker shades indicating higher publication outputs. The lines show the connections between countries, with thicker lines reflecting stronger collaboration.

The institutions that produced the highest volume of research utilizing UAVs for the acquisition of dendrometric variables included Nanjing Forestry University, the Chinese Academy of Sciences, and the Ministry of Education of the People's Republic of China, with respective publication counts of 13, 10, and 9. These universities are all situated in China, underscoring the nation's prominent role in the research area explored in this study.

Collaboration between countries and institutions has significantly influenced advancements in UAV technology for forestry. The collaboration among European countries under the ICP Forest program has provided a standardized framework for forest assessment and monitoring, facilitating the exchange of methodologies and data, and enabling the development of more robust and versatile UAV applications in the forestry sector [37]. Despite this, the notable dominance of countries such as China and the United States in UAV technology for forestry can be attributed to substantial investments in research and development, advanced technological infrastructure, and strong academic–industry partnerships [38]. In China, for example, contributions to UAV technology are supported by extensive public funding and a rapidly growing tech industry [39]. Similarly, the United States benefits from its well-established research institutions and collaborations with private sector companies, driving innovation in UAV applications [40]. Over time, UAV applications in forestry initially focused on basic aerial photography and mapping, later migrating to forest inventories and health monitoring. Recent advancements have led to the integration of sophisticated sensors, such as LiDAR and multispectral cameras, improving the precision and efficiency of dendrometric estimations and the scope of data collection [37]. Recent studies continue to expand their potential applications, including forest fire management, biodiversity assessment, and carbon stock estimation [41,42]. This shift reflects the growing recognition of UAVs as versatile tools for addressing a wide range of forestry management issues.

In recent years, the application of remote sensing methodologies for the evaluation of forest resources has seen a significant increase, both in direct and indirect assessments [43,44]. This trend is supported by the data presented in Figure 2, which illustrate a notable rise in the number of scholarly articles addressing this subject, particularly following 2017. These studies primarily highlight the advantages of using drones to significantly reduce costs for data collection, analysis, and continuous monitoring of tree height, canopy openness, forest disturbances, and other forest parameters in both short-term and long-term monitoring [45]. Additionally, technological advancements have enhanced practical applications by increasing drone autonomy and obtaining high-resolution images that provide precise information about forest ecosystems, aiding in decision-making [46]. Furthermore, it is important to highlight that research concerning the utilization of UAVs for the acquisition of dendrometric variables commenced only in 2013, suggesting that this approach is relatively novel and continues to evolve within the scientific community.

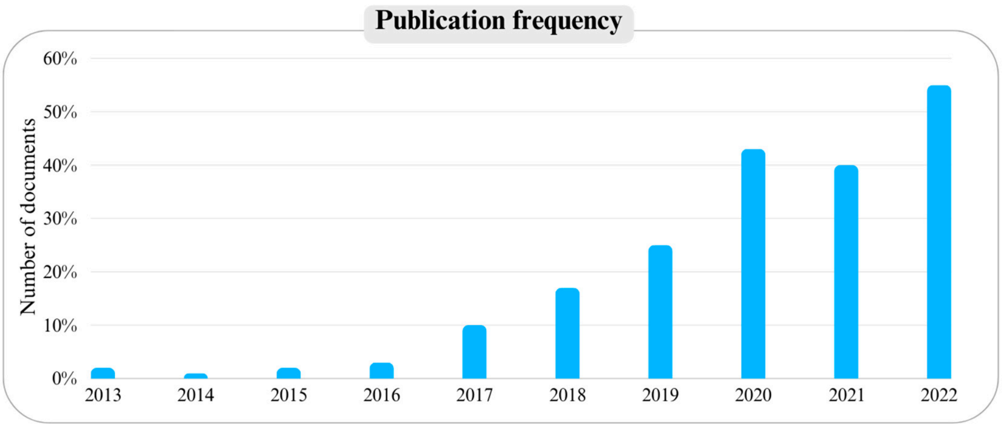

Figure 2. Publication frequency per year of studies addressing the use of UAVs for obtaining dendrometric variables in forests.

Table 1 presents the ten most frequently cited articles related to this subject, along with their essential details. The research illustrates a variety of methodologies and dendrometric variables that can be acquired through the use of unmanned aerial vehicles (UAVs). Notably, a considerable proportion of the cited works employed RGB sensors, which are typically integrated cameras on UAVs. This preference is likely attributable to the advantages of the lower material and operational costs, as well as the flexibility and repeatability they offer in data collection [6,47]. However, excellent results have also been obtained with RGB sensors' data, with studies showing that the digital aerial photogrammetry approach using UAVs is equivalent to or surpasses airborne LiDAR in measuring forest structure, not to mention cases in which the multi-angle approach of UAV digital aerial photogrammetry enhances the spatial accuracy of forest canopy height measurements [48]. In contrast, the studies conducted in [25,49] utilized UAV/LiDAR sensors, which can deliver more comprehensive three-dimensional insights into forest structures compared to conventional remote sensing methods. Furthermore, the digital terrain model (DTM) using LiDAR is much more accurate than the DTM generated from a point cloud by digital aerial photogrammetry [48], which brings comparative advantages, especially in dense forests or non-flat terrain. Nonetheless, the high costs associated with obtaining airborne LiDAR data pose a significant barrier to its widespread application [50–52], but it is also important to mention that the rapid pace of technological advancement could bridge these gaps, both by enhancing the technological capabilities of RGB sensors and by making LiDAR sensors more cost-effective. In relation to the dendrometric variable examined, height emerged as predominant across nearly all articles listed in the table, with the exception of [53], who investigated the volume of standing timber in forest growth by integrating data from UAVs, Sentinel-2 satellite imagery, and field measurements.

We should not fail to mention that one of the main challenges in this area is the high volume of data generated by UAVs, especially when using high-resolution sensors;

in that sense, scalable data processing frameworks that can handle the influx of large datasets are required, so that it is possible to develop efficient data pipelines that can process and analyze large volumes of UAV data in a timely manner [54]. Efficient data storage solutions are also necessary and crucial. Options such as cloud computing facilitate collaborative research and provide access to large volumes of data and real-time analysis. This approach not only addresses storage issues but also enhances data accessibility and sharing among researchers [37]. Additionally, processing LiDAR and photogrammetric data involves complex algorithms and significant computational resources. The application of deep learning techniques, along with the use of open-source software and standardized workflows [55], will help mitigate complexity and ensure consistency in processing large volumes of data obtained with UAVs.

A total of sixty-two journals were recognized for their publication of articles related to the subject matter. Notably, Remote Sensing (n = 60), Forests (n = 23), Remote Sensing of Environment (n = 9), and the International Journal of Applied Earth Observation and Geoinformation (n = 9) emerged as the primary contributors to the advancement of research concerning the application of UAVs in the acquisition of dendrometric variables within forest ecosystems.

The analysis of the gathered data revealed that the published articles were organized and classified into 16 distinct thematic categories. Among these, 32.4% pertained to Earth and Planetary Sciences (n = 103), while Agricultural and Biological Sciences accounted for 25.5% of the articles (n = 81). Additionally, 14.8% of the articles were classified under Environmental Science (n = 47; Figure 3). It is noteworthy that multiple categories may have been assigned to individual articles, underscoring the interdisciplinary character of the research conducted across various academic domains [32].

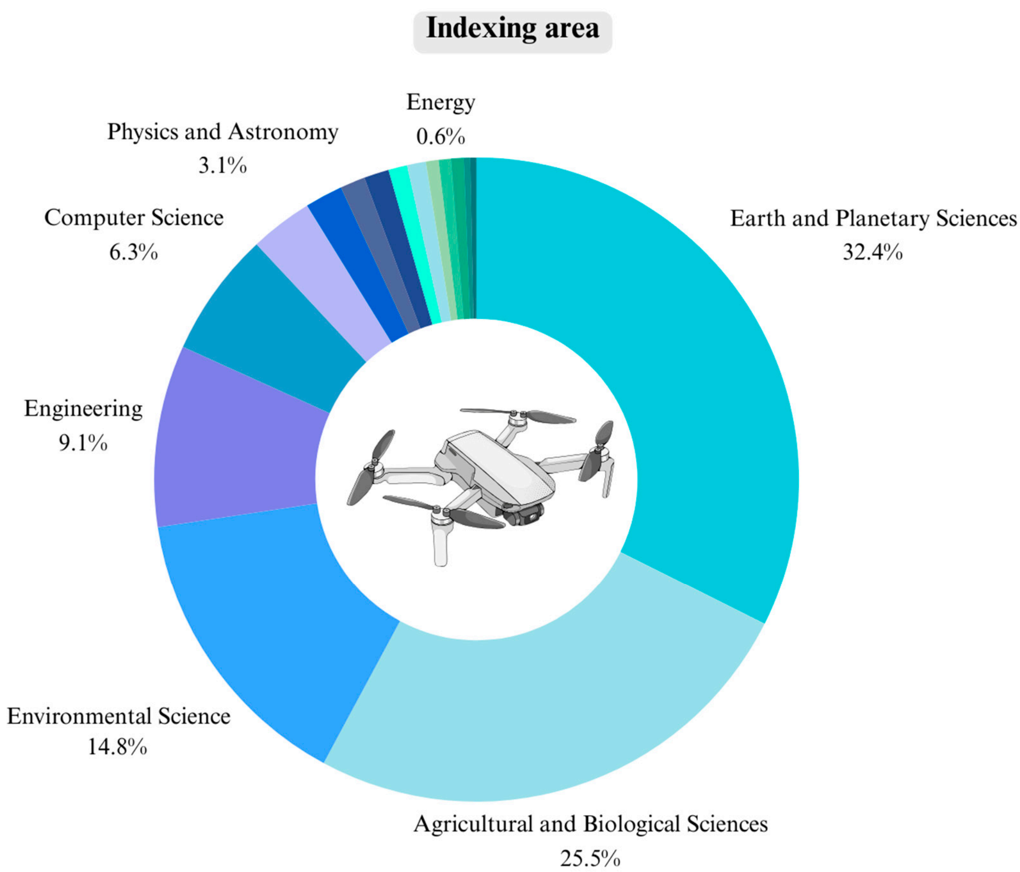

Figure 3. Areas included in the indexing of articles in journals.

The authors identified a total of 609 keywords in the articles published until the conclusion of 2022 (see Figure 4). These keywords play a crucial role in shaping the representation and dissemination of the articles within scientific communities, as they highlight the primary research themes [56,57]. The most frequently encountered terms in the studies included UAV (*n* = 38), forest inventory (*n* = 33), drone (*n* = 23), Structure from Motion (*n* = 19), and photogrammetry (*n* = 14). In terms of article indexing, a total of 1321 distinct terms were recorded, with notable examples being forestry (*n* = 133), unmanned aerial vehicles (UAVs; *n* = 124), antennas (*n* = 103), remote sensing (*n* = 63), and unmanned vehicle (*n* = 62).

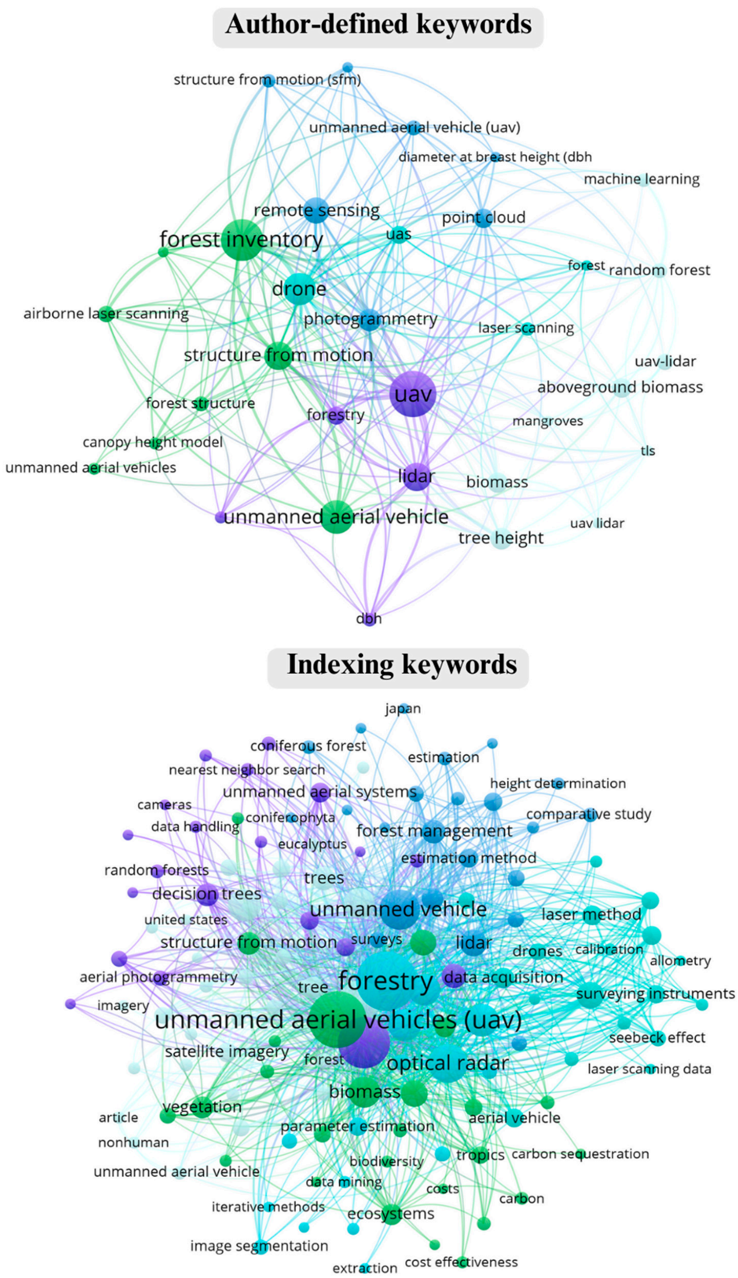

Figure 4. Interaction network between keywords used by authors in articles and those used in indexing. The network is weighted by the frequency of each keyword, represented by the size of the circle areas. Terms positioned closer together indicate a higher frequency of co-occurrence. The links (lines) reflect the interaction between terms, with thicker links representing more frequent connections. Clusters, distinguished by different colors on the map, group items with higher affinity.

The authors identified a variety of terminologies associated with unmanned aerial vehicles, which were among the most defined keywords. These terms included UAV (n = 38), drone (n = 23), UAS (n = 10), and unmanned aerial vehicle (n = 24).

Figure 5 presents an overview of the various vegetation types, dendrometric variables, and sensor types predominantly employed in studies utilizing UAV technology to gather dendrometric data in forested environments. The analysis revealed that planted forests were the most frequently examined vegetation type, appearing in 57 articles and accounting for 29% of the total vegetation types analyzed. Native forests followed, represented in 41 articles and comprising 21% of the vegetation types discussed. Although Pinus is classified as a coniferous species, the studies differentiated between Pinus forests (n = 24) and general coniferous forests (n = 13) due to the presence of other species within the latter category. Consequently, Pinus forests constituted 12% of the studies, while coniferous forests made up 7%. Additionally, mangroves were noted as a significant vegetation type, appearing in 9 articles and representing 5% of the total studies reviewed.

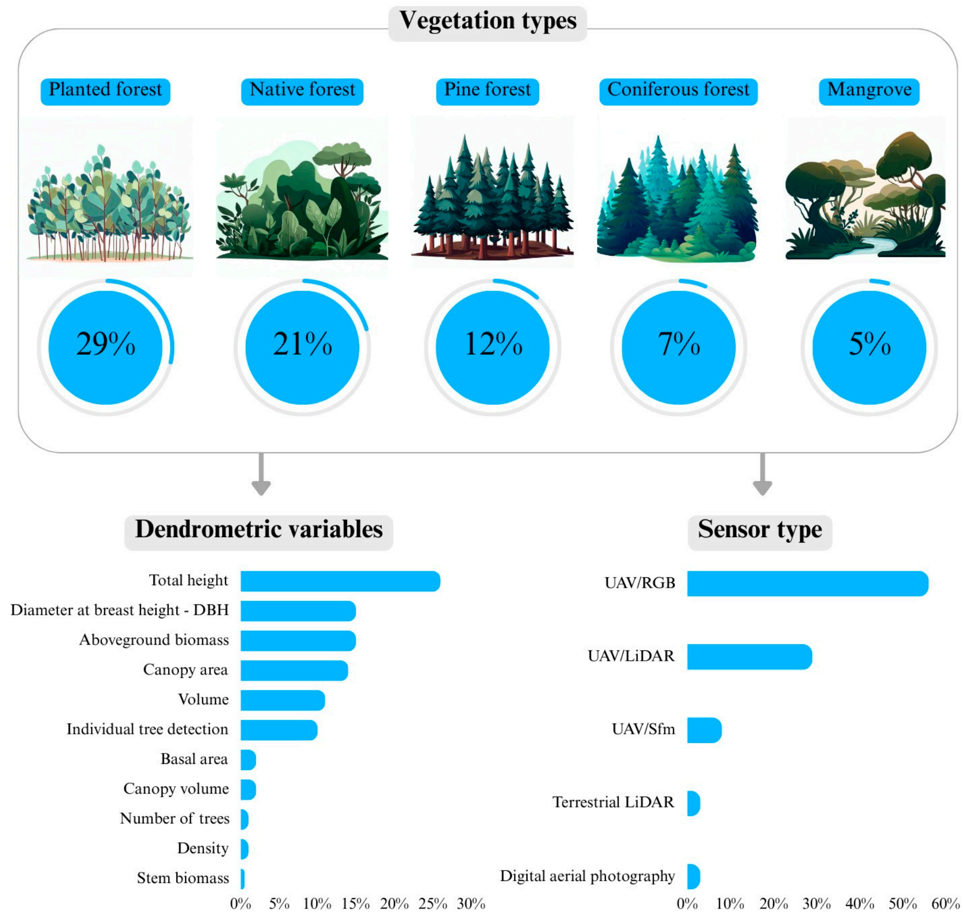

Figure 5. Types of vegetation, dendrometric variables, and types of sensor most used in UAV research to obtain dendrometric variables.

Considering that China has the largest area of planted forests in the world [58] and that a significant majority of research has been conducted within its borders (n = 60), it was anticipated that the literature on planted forests would be predominantly represented among the selected studies [59–61]. The authors of [49] conducted a study utilizing a UAV equipped with a LiDAR system to gather data on tree height, individual tree segmentation, and above-ground biomass. Their findings indicated that the variables could be effectively measured at the individual tree level rather than at the plot level, specifically in the context of planted forests.

Research conducted in planted forests has predominantly focused on the acquisition of dendrometric variables through the use of UAVs, particularly within plantations of various *Pinus* species [62–65] and *Eucalyptus* species [66–69]. Additionally, investigations have also been carried out on plantations of different *Quercus* species [17], *Picea* species [70–72], as well as *Ginkgo* plantations [49,73]. Furthermore, studies have explored planting areas that encompass a variety of species and genera [61,74].

Research on native forests is primarily conducted in countries with vegetation that differs significantly from that of Brazil. Among the fourteen studies identified within Brazil, only four were focused on native vegetation, specifically in the Amazon [75,76], Atlantic Forest [77], and Cerrado [42]. This underscores a notable gap in the literature regarding the application of UAVs for measuring dendrometric variables in other Brazilian vegetation types, such as the Dry Tropical Forest. This observation emphasizes the necessity for further investigations utilizing UAVs to assess dendrometric variables across various Brazilian ecosystems, thereby enhancing the scientific understanding in this field.

In the analysis of the most frequently examined dendrometric variables, tree height emerged as the most prominent, appearing in 104 studies, which accounts for approximately 28% of the total research. This was followed by diameter at breast height (DBH) with 60 studies, above-ground biomass with 59 studies, and canopy area with 56 studies, indicating that multiple variables were often investigated within individual articles. Most of these studies utilized point cloud data and the Canopy Height Model (CHM) to estimate tree height [78–80].

In research conducted in [81], the authors successfully acquired measurements of height, diameter at breast height (DBH), and canopy characteristics of a tropical forest in Australia through the utilization of point cloud data derived from UAV/Terrestrial Laser Scanning (TLS). Similarly, the authors of [5] employed UAV/LiDAR imagery to assess individual tree metrics, including DBH, height, canopy projection area, and above-ground biomass (AGB), within a planted forest in China. Additionally, the authors of [82] estimated the canopy volume of a pistachio plantation using UAV/RGB technology, providing an efficient and cost-effective solution.

We found that the RGB sensor integrated with UAVs was the most frequently utilized type of sensor in the reviewed studies (n = 118), followed by the LiDAR sensor (n = 62) and the Structure from Motion (SfM) technique (n = 18). This indicates a growing trend in research employing UAV-compatible sensors, while also revealing a notable gap in studies that utilize specific sensor types, such as multispectral sensors, for the acquisition of dendrometric variables.

The analysis of the studies incorporated in this review revealed several advantages and disadvantages associated with the most frequently utilized sensors. As illustrated in Figure 3, the RGB sensor emerged as the predominant choice among the studies, likely attributable to its affordability, high spatial resolution, ease of deployment, and adaptable flight planning [6,54,83]. Furthermore, it has demonstrated considerable efficacy in capturing forest dendrometric variables [51,82,84,85]. Nonetheless, UAV-based photography is constrained by its inability to provide terrain surface information in forested regions [54,86,87], and soil occlusion represents a significant limitation of the UAV/SfM technique in areas covered by forests [88,89].

Conversely, LiDAR sensors present the benefit of delivering superior resolution and rapidly providing highly accurate and spatially detailed data regarding forest characteristics across extensive landscapes [90]. These sensors possess the capability to penetrate the forest canopy, facilitating precise measurements of canopy structural parameters, such as tree height, canopy openness, and leaf density, thus enabling swift and reliable data acquisition concerning the forest structure [91,92]. However, the application of this method for extensive areas or large objects necessitates costly sensors, specialized team training, and advanced computational technology to ensure accuracy, resulting in substantial expenses [2,93]. Despite the financial implications, LiDAR technology is regarded as one of the most effective options for monitoring the forest structure, composition, and function, particularly in dense and irregular forest environments. In contrast, RGB or SfM sensors may be more suitable for uniform vegetation or when financial constraints are a consideration.

Regarding the algorithms available for these sensors, the most popular are based on detecting the maximum peaks in a Canopy Height Model (CHM), known as the local maximum, with variations in terms of window size, smoothing, and post-processing [7,37,94,95].

Finally, based on recent research and frequent innovations in unmanned aerial vehicle (UAV) technology, new trends for dendrometric estimates in forestry should undoubtedly emerge in the short to medium term. A key area for future research is the development of real-time data processing capabilities for UAVs, enabling immediate field analysis and decision-making, crucial for monitoring forest health and promptly detecting changes [96]. Additionally, integrating AI and machine learning with UAVs [97] and automating tree characteristic measurements can enhance the accuracy and efficiency in dendrometric estimations through advanced algorithms, such as convolutional neural networks (CNNs) [98]. Developing cloud-based platforms for UAV data, such as The Computree Platform (https://computree.onf.fr, accessed on 1 October 2024), or integrating data in Google Earth Engine will facilitate seamless integration with other remote sensing data and GIS, enabling comprehensive analyses and collaborative research [99]. In addition, advancements in sensor technology, including high-resolution cameras, multispectral and hyperspectral sensors, and improved LiDAR, will enhance UAV capabilities, providing detailed and accurate dendrometric data and capturing additional forest parameters. Also, future research should focus on the long-term monitoring of forest ecosystems [100]. This involves not only the continuous collection of data but also the integration of historical data to analyze trends and changes over time. Combining UAV data with other sources, such as satellite imagery and ground-based measurements, can provide a more holistic view of forest dynamics and support sustainable forest management practices.

Table 1. Articles with the highest citation counts as of the year 2022.

Authors	Location	Type of Vegetation	Sensor Type	Dendrometric Variables Obtained	Journal	Number of Citations
Puliti et al. (2015) [85]	Norway	Boreal forest	UAV/RGB	Height, stem volume, basal area	Remote Sensing	277
[2]	United States	Planted forest	UAV/SfM	Individual tree detection	Forests	271
[89]	Costa Rica	Restoration area	UAV/RGB	Height, crown size	Biological Conservation	211
[25]	Indonesia	Planted forest	UAV/LiDAR, terrestrial laser scanner, airborne laser scanning	DBH, height	Sensors	151
[51]	China	Native vegetation	UAV/RGB	Height, above-ground biomass, canopy cover	International Journal of Remote Sensing	124
[19]	Malaysia	Mangrove forest reserve	UAV/RGB	Height, above-ground biomass	Forest Ecology and Management	118
Brede et al. (2019) [101]	Netherlands	Native forest	UAV/RGB	Height, above-ground biomass	Remote Sensing of Environment	111
[53]	Norway	Planted forest	UAV, Sentinel-2	Volume	Remote Sensing of Environment	111
Krause et al. (2019) [102]	Germany	Native forest	UAV/RGB	Height	Remote Sensing	108
[49]	China	Planted forest	UAV/LiDAR	Height, individual trees, above-ground biomass	ISPRS Journal of Photogrammetry and Remote Sensing	105

4. Conclusions

This research included an analysis of the current literature concerning the application of UAVs for the measurement of dendrometric variables within forest ecosystems. Through a bibliometric assessment, the study identified and discussed prominent keywords in the existing body of work, the primary types of vegetation under investigation, and the scientific gaps that persist in this field. Furthermore, it emphasized the novelty of this research area and aimed to offer insights that will inform future inquiries related to UAV applications in forestry. It is essential to underscore several critical aspects and deficiencies to promote the scientific advancement of this subject:

(i) The subject has experienced a notable rise in the volume of publications over time; nevertheless, the overwhelming majority of investigations aimed at acquiring dendrometric variables through the use of unmanned aerial vehicles predominantly took place in cultivated forests or in vegetation exhibiting comparable traits. Exploring research across diverse types of vegetation represents a valuable avenue to enhance the applicability of the methodology in various geographic contexts.

(ii) In research pertaining to this subject, the sensors most frequently employed included RGB, LiDAR, and Structure from Motion (SfM), particularly for assessing variables such as total tree height, diameter at breast height (DBH), above-ground biomass, and canopy area. The LiDAR sensor appeared to be the most appropriate technology for acquiring dendrometric variables from forested areas, owing to its capability of utilizing a longer-range laser.

(iii) Research efforts that utilize multispectral sensors to derive dendrometric variables should be enhanced, while also evaluating their potential contributions to vegetation mapping and detection.

(iv) The identification of species through images of tree canopies has not yet been extensively explored in published studies, presenting a potential avenue for future research.

In conclusion, the bibliometric analysis offered fresh perspectives on the existing literature. The keywords employed in the research and their indexing highlighted the primary areas of focus regarding UAVs and the measurement of dendrometric variables. Furthermore, the compilation of the most frequently cited publications in the field aided in pinpointing the most significant studies conducted, thereby serving as a foundation for exploring potential avenues for future research.

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