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Construction of Urban Tree Risk Assessment and Management System Based on Knowledge Graph Analysis

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Abstract:

Taking the Web of Science core database literature in the field of tree risk research as the research object, using the CiteSpace knowledge map software to analyze the important tree risk research literature over the past 30 years which shows the international tree risk research discipline and journal distribution characteristics, research and practice hotspots and trends. The results show that the international tree risk research has formed a relatively complete research network system and is still expanding rapidly, but has not yet established a cross-regional and interdisciplinary collaborative research mechanism and platform; the research hotspots of tree risk are mainly concentrated in the two fields of risk assessment and detection, and have formed a research paradigm combining quantitative and qualitative research; Urban tree risk research is a key research area in the past 10 years, based on accurate detection urban tree risk research has been a key research area in the last decade, and urban tree risk assessment and management based on accurate detection technology is the latest research trend, providing a greater contribution to the refined management of urban trees. Based on the above research and analysis, the risk management of urban trees in China, especially the risk management about urban street trees, old and valuable trees and so on, should make comprehensive reference to theories of tree mechanics, near-Earth meteorology and other disciplines, and use non-destructive detection means such as downward ground-penetrating radar and ground-based laser scanning technology to carry out stability and risk research of tree risks, and to further improve the risk assessment and management system for urban trees. At the same time, we should make full use of the advantages of modern information technology and big data to build a systematic "whole life cycle" risk management system for urban trees.

Key words: *Tree risk, CiteSpace, Risk detection, Risk assessment, Big data.*

I. INTRODUCTION

As an important part of urban greening, trees represent the green base and high-quality ecology in ecological civilization construction, which are also an important part of urban refined management and safety management [1-4]. Due to the particularity of urban habitats, urban trees are prone to problems such as weak growth, damaged root systems, dead branches, broken branches, and tree tilting [5-7]. In case of typhoon, rainstorm and other bad weather, tress will easily collapse and break, posing a threat to the safety of people

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and construction facilities [8-10]. In the 1960s, the international academic community first put forward the articles and theories of "tree risk management" [11]. Thereafter, urban management or forestry departments in European and American countries begin to carry out extensive inventory of tree stocks, and research on tree risks in street environments, community green spaces, forest recreation areas, parks and other environments has gradually started [2]. The tree risk assessment and management concept gradually matured, and there is growing related research on systematic models and methods for quantitative and qualitative assessment of tree safety traits [12]. There are extensive scientific literatures on biomechanics, effects of strong winds, soils, wood decay, and topics related to tree risk assessment [13]. However, little research is recorded from the perspective of literature statistical analysis. It is thus necessary to systematically review relevant literature on tree risk research, which will also bring new enlightenment to urban tree risk assessment and management in China.

In recent years, related research has exhibited a trend of rapid increase and update, and the disciplines and theoretical foundations involved are constantly expanding. It is therefore necessary to further analyze the latest progress and development trend of tree risk research, clarify research hotspots, and explore the direction for future urban tree risk management. Based on the scientific knowledge graph analysis tool CiteSpace, this paper conducts a visual analysis of the relevant literature on tree risk research, visually presents and systematically summarizes and explores the representative literature, scholars, research institutions, research hotspots, achievements, and trends of international tree risk research in 1987-2021, with a view to providing reference for the domestic research on urban tree risk.

II. RESEARCH METHODS AND DATA SOURCES

With the development of data and information visualization, CiteSpace has become one of the most popular and representative knowledge graph drawing tools [14-15]. It is mainly presented in the form of nodes and connections. The node size reflects the frequency of the relevant cited data. The thickness of the connection between nodes reflects the strength of the connection between the cited data, and the color represents the time interval in which the cited data appears [16]. Using CiteSpace knowledge graph software, we selected the core collection database in Web of Science as the data source. The time period was set from 1987 to 2021. The research covers 14,637 related documents in research direction of "tree risk assessment", "tree risk management", "dangerous trees", "tree risk perception", "tree failure" and "non-destructive testing". We evaluated by title, deleted duplicates and eliminated invalid literature such as newsletters, conferences, newspapers, and literature irrelevant with the research topic, conducted preliminary screening of about 3,208 articles, read the abstract of each article, and eliminated articles outside the scope of review, thus screening a total of 1026 valid literature samples.

High-frequency keywords can reflect the hot content of the research field, and the co-frequency refers to the number of times the word pair appears in the title, keyword or literature abstract. Using the principle of co-word analysis, we plotted a co-occurrence map of keywords in the field of tree risk research. Through keyword clustering analysis, the relationship between various research topics in this field can be learned to analyze the hotspots and evolution of international tree risk research, summarize and prospect the development trend.

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III. RESULTS AND ANALYSIS

3.1 Literature Statistical Analysis

3.1.1 Number of published papers and distribution in disciplines

Analysis of the number of annually published papers can reflect the development speed, evolution trend and degree of attention of tree risk assessment research. According to the number of published papers (Figure 1), the development of tree risk research can be divided into four stages: 1987-2001 is the initial research stage, in which there are few scholars engaged in research of this field, and the number of published papers is small; 2002-2011 is the research wave point growth period, in which many scholars begin to pay attention to this field, but no continuous research is formed, so the number of papers published in this stage fluctuates greatly; 2011-2019 is the stage when the number of published papers begins to increase year by year and enters a steady growth period. At this stage, a large number of documents appear and continually grow; from 2019 to now, the number of published papers experiences a short-term downward trend.

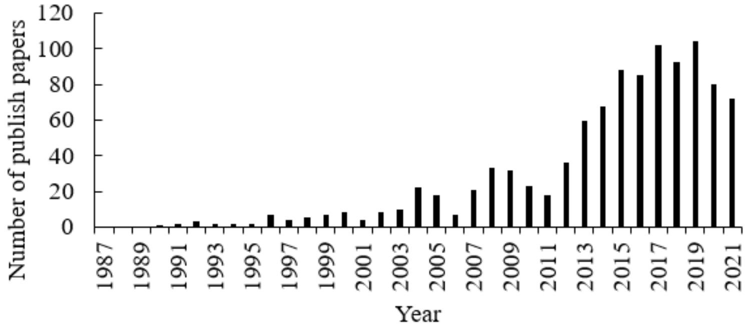

Fig 1: Annual distribution of tree risk assessment research literature (1987-2021)

CiteSpace is used to draw the knowledge graph regarding the discipline distribution structure of the literature. It can be seen from Figure 2 that Forestry, Environmental Sciences & Ecology, and Plant Sciences are the three disciplines with the most literature, followed by Environmental Studies, Urban Studies, Ecology, Materials Sciences, etc., indicating that tree risk assessment has been widely studied in the above disciplines. The betweenness centrality of environmental science and ecology, ecology, engineering and other disciplines are all greater than 0.1, indicating that such disciplines are more extensively connected with other disciplines during the expansion of the research fields in tree risk assessment, which play a pivotal role in strengthening multidisciplinary connections.

3.1.2 Publishing countries and research structure analysis

The distribution of literature sources by country or region reflects the international distribution of research in this field to a certain extent, and the distribution analysis of research institutions can help us understand the degree of support and recognition of the subject in the academic community. The darker the color of the area in Figures 3 and 4, the more papers the country or research institution publishes, and darker carea represents the main concentration area and institution of the current research. From Table I, it can be seen that the United States has the largest number of published papers, with a total of 148 papers, accounting for 14.42% of the total number of papers, followed by China, with a total of 97 papers, accounting for 9.45% of the total number of papers, and then Germany (48 papers, 4.68%)), the United Kingdom (44 articles,

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4.29%), Italy (41 articles, 4.00%), Spain (34 articles, accounting for 3.31%), Canada (33 articles, accounting for 3.22%), Australia (30 articles, accounting for 2.92%). The number in the rest of the countries and regions are all below 30. The United States and China are currently the two countries with the most research on tree risk, contributing nearly one-fifth of the number of published papers. In terms of its betweenness centrality, the United States has the largest betweenness centrality in tree risk research, laying a foundation for research in this field and playing a key role in research, thus exerting the greatest impact on tree risk research. Although China publishes a large number of papers, its betweenness centrality value is very small, indicating insufficient originality and influence of the published papers.

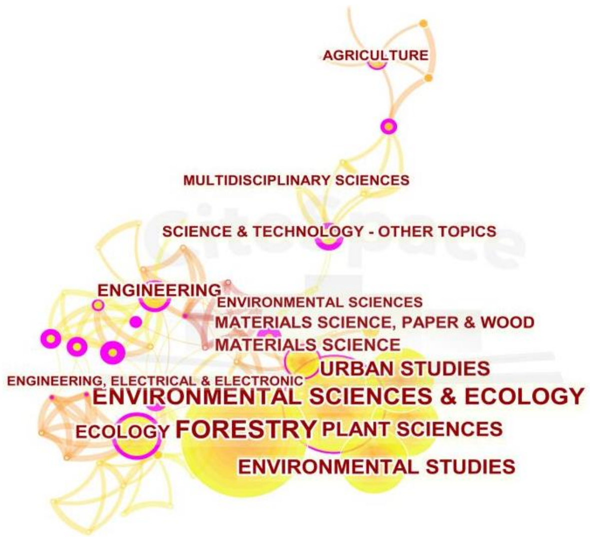

Fig 2: Discipline analysis of research literature

Fig 3: Source country analysis of research literature

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Fig 4: Institutional source analysis of research literature

Fig 5: Cited journals analysis of research literature

Among the research institutions in the field of tree risk assessment and management (Table I), the top 5 institutions in terms of number of published papers are the Chinese Academy of Sciences, the Forest Service of the US Department of Forestry, the University of Munich, the City University of Hong Kong, and the University of Massachusetts. 2 scientific research institutions of China enter the top 10 of WOS, namely the Chinese Academy of Sciences and the City University of Hong Kong. These 2 research institutions have published a total of 38 WOS papers in this field, accounting for 25.16% of the number of WOS documents in the top 10 research institutions and accounting for 3.70% of the number of WOS documents in research institutions in this field. Only the Chinese Academy of Sciences, the Forest Service of the US Department of Forestry have published more than 20 papers, and the rest of the institutions publish less than 20 papers. Seen from betweenness centrality, the betweenness centrality of all research structures is below 0.1,

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indicating that no core research institution with sufficient scale has formed in this field. Foreign research is mainly carried out by the Forest Service of the US Department of Forestry and the University of Munich, as well as academic institutions such as the University of Massachusetts, the French Academy of Agricultural Sciences, and Michigan State University. At the same time, there are also academic exchanges between the University of Gothenburg, Chalmers University of Technology, and the Austrian Forest Training Center. Domestic institutional cooperation is mainly undertaken by the Chinese Academy of Sciences, Beijing Forestry University and City University of Hong Kong, including Jiangnan University, National Taiwan University and Taiwan Forestry Research Institute. The cooperation of research institutions in this field is mostly limited by geographical scope, and no cross-regional and interdisciplinary collaborative research mechanism and platform has formed.

TABLE I. The top counties and institutions of tree risk research

County/regions	**Count**	**centrality**	**%**	**Research institutions**	**Count**	**centrality**	**%**
USA	148	0.7	14.42%	Chinese Acad Sci	24	0.04	2.32%
CHINA	97	0.06	9.45%	US Forest Serv	21	0.05	2.05%
GENMAY	48	0.16	4.68%	Tech Univ Munich	18	0.04	1.77%
ENGLAND	44	0.08	4.29%	City Univ Hong Kong)	14	0	1.36%
ITALY	41	0.06	4.00%	Univ Massachusetts)	13	0.01	1.23%
SPAIN	34	0.08	3.31%	INRA	11	0.08	1.09%
CANADA	33	0.02	3.22%	CIEMAT	11	0.05	1.09%
AUSTRALIA	30	0.07	2.92%	Tech Univ Denmark	11	0	1.09%
FRANCE	28	0.06	2.73%	Michigan State Univ	10	0	0.96%
IRAN	28	0.02	2.73%	Univ Florida	10	0.01	0.96%

3.1.3 Citation analysis

By analyzing the references cited in the published papers, the co-citation network map was plotted. From Figure 5, it can be seen that the journal with the highest number of citations in the past 25 years is ARBORICULTURE & URBAN FORESTRY, with a total of 154 cited papers. FOREST ECOL MANAG, JOURNAL OF ARBORICULTURE, CAN J FOREST RES also have more than 145 cited papers. ARBORICULTURE & URBAN FORESTRY and FOREST ECOL MANAG have much bigger number of published papers than other publications and high betweenness centrality, reflecting the main object and research scope of international tree risk research to a certain extent.

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3.2 Analysis of Research Hotspots

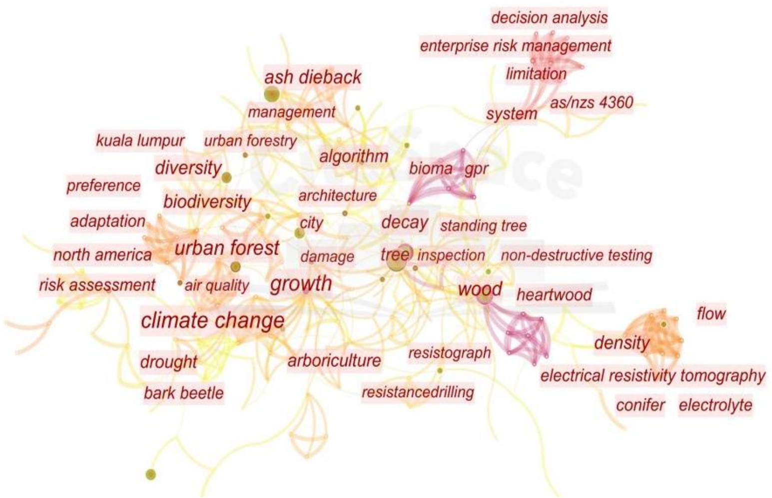

Fig 6: Knowledge graph based on keywords

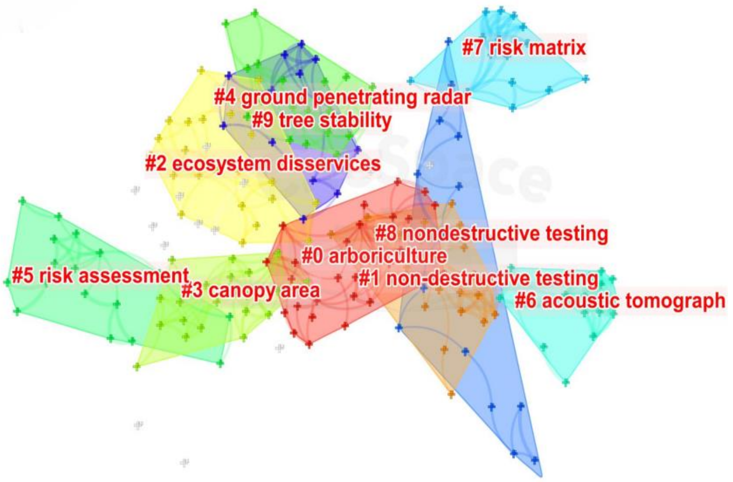

Fig 7: Knowledge graph based on research hotspots

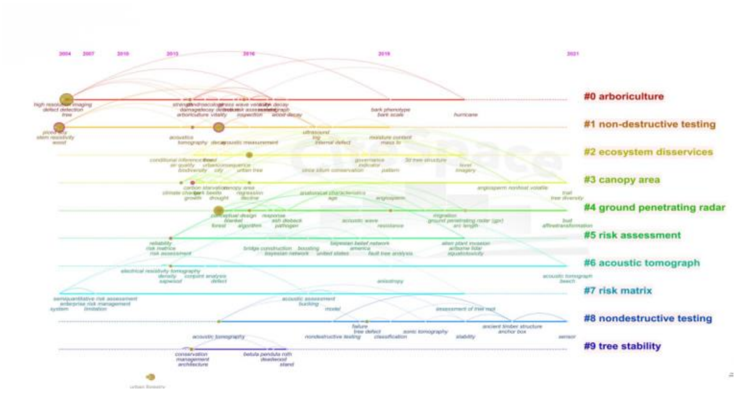

Fig 8: Knowledge graph based on research hotspots timeline

From the knowledge graph of keyword co-occurrence in Figure 6, it can be seen that tree risk research

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network has a high degree of dispersion, many research branches, and strong correlation between keywords. In addition to "risk assessment", the words with high frequency include: tree, decay, forest, wood, growth, climate change, biodiversity, urban forest and so on. To a certain extent, these keywords reflect the hot areas of tree risk research in this research period. In addition to tree risk assessment, tree defect diagnosis technology and internal wood decay detection technology have always been research hotspots. Non-destructive techniques such as ultrasound, stress wave technology and tomography provide important methods for tree risk assessment [17]. Increased climate variability may expose plants to environmental stress, which can lead to vulnerability and reduced stress resistance of trees [18]. Tree cave nesting, etc. increases urban biodiversity, but also increases the risk of tree holes, internal decay [19]. Management measures adopted to reduce tree risk also affect the richness and diversity of tree microhabitats, which in turn affects biodiversity [20]. Due to the special habitat characteristics of urban trees, there will be more conflicts between urban trees and the environment. Of course, there are many studies on the identification, assessment and mitigation of urban tree risks [21-22]. The above studies represent the research hotspots in this field for a period of time.

The cluster analysis on the co-occurrence of high-frequency keywords is shown in Figure 7, and the color blocks represent the clustered regions. The size of the module value Q is related to the density of nodes. The greater the Q value, the better the clustering effect. This can be used for scientific clustering analysis. The size of the average contour value S can be used to measure the homogeneity of the cluster. A greater value of S means higher homogeneity of the network, indicating higher credibility of the cluster. It can be seen from Figure 7 that Q=0.7715, indicating that the network structure has good clustering effect; S=0.9019, indicating that homogeneity is high, and the different clusters are well divided. The figure shows 10 major clusters, mainly headed by "arboriculture", "non-destructive testing" and "ecosystem disservices". Where, the largest cluster is "arboriculture", which contains 31 keywords. The main keywords include tree, damage, inspection, tree risk assessment, wood decay, etc. Other new keywords include "acoustic tomography", "stability", "tree defect", etc. The change and development of clustering has always revolved around tree risk detection and assessment.

It can be seen from Figure 8 that the first cluster "#0 arboriculture" has the highest cluster importance and the largest number of published papers. The related literature first appeared in 2004, and the research on this cluster is evenly distributed over 20 years. Additional clusters include eight themes including nondestructive testing, ecosystem disservices, canopy area, ground penetrating radar, risk assessment, acoustic tomography, risk matrix, and tree stability (Figure 8). Combining keyword co-occurrence map, cluster map and timeline map, we further screen and refine research hotspots, finding that for a long time in the past, international tree risk research mainly focuses on two aspects: tree risk detection and tree risk assessment.

3.2.1 Tree risk detection

Risks arise when potentially problematic flowers, fruits, roots, branches, and leaves conflict with pavement, surrounding structures, and people after conflict between trees and social functions [23]. Tree risk detection is to detect trees with dangerous potential in the target area, and then propose correct tree management proposals before the public events of tree breakage and dumping, so that tree treatment actions can be taken [24-25]. There are broadly 3 categories of tree risk detection methods: 1) Visual detection:

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Visual detection of most trees is sufficient to determine tree defects and the likelihood of failure. Based on the observation of the appearance characteristics of tree damage, visual diagnosis is to observe whether the tree has damage, gaps, etc. [26], and then observe the crown, trunk and roots, etc., to quickly and conveniently determine the overall risk status, but it cannot accurately predict internal decay, degree of defects, etc. [10-11]; 2) Instrument detection. Some trees have serious internal lesions and defects, but no external symptoms, or tree roots are damaged due to engineering construction and cannot be visually detected, these trees need to be further examined using the appropriate detection equipment. The main diagnostic methods include percussion acoustic diagnosis method [27], growth cone sampling method [28], etc.; 3) Non-destructive testing. Acoustic wave instruments, resistance measuring instruments, radar detection devices, etc. can be used in field operations to provide internal decay information and images for tree risk detection. These detection devices can use electronic sensors, ray pulses, etc. to analyze the tree decay or cavities without damaging the trees, so that the decay location and size, shape, as well as distribution and damage of underground roots can be determined to form two-dimensional images about internal decay and root distribution [29]. With the advancement of science and technology, non-destructive testing techniques such as electrical conductivity method, tensile test method, γ-ray method, and X-ray method have also been continuously applied to tree detection.

3.2.2 Tree risk assessment

Tree risk assessment aims to assess the severity of tree defects, make recommendations and take corrective actions before trees pose a risk, thus keeping people and property safe in an economical and fast way. In recent years, the content of tree risk assessment has expanded from the assessment of economic value to the assessment of the healthy growth of trees, and then to the assessment of potential tree risks [30], including perception research of tree risks by the public and professionals [31-32], policy and practice of tree risk assessment [33], urban tree risk management [34-35], urban tree risk property loss calculation [36], and research on assessment results and mitigation recommendations [37]. There are three main tree risk assessment methods: 1) Tree stability assessment methods based on the laws of biomechanics [38-39], of which the most commonly used is the tree visual assessment method (VTA). It consists of two parts, "Appearance Evaluation" and "Precision Inspection" based on biomechanics, which belong to Nondestructive Evaluation (NDE) and are widely used in tree risk assessment at home and abroad; 2) Qualitative evaluation based on external symptoms and structural defects that lead to tree failure [32]. The most commonly used is the Tree Hazard Assessment Program of International Society of Arboriculture (ISA), which focuses primarily on photographic guidelines for hazard tree assessment in urban areas, and determines a hazard rating by identifying and evaluating structural defects in root caps, trunks, supports and branches [40]. It is designed to help locate and manage trees in urban areas. 3) Assessment methods [41-42] that focus on personal safety and property protection, which are popular in the United States. For instance, tree risk assessment method proposed by Forest Service Community of United States Department of Agriculture provides two different survey types, walkthroughs and drive-in inspection to identify defects in trees near the target, measure defect severity, and recommend remediation before failure [11]. Best management practice approach of ISA for tree risk assessment assesses tree risk and recommends mitigation measures based on relevant up-to-date scientific and technical information [43]. In recent years, researchers have also carried out quantitative research on tree risk assessment to reduce tree risk by quantifying risk,

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improving decision-making, defending recommendations, and quantifying remediation in some cases [44-45]. As time moves on, by using modern information technology, we can more accurately quantify the stability and fracture resistance of trees, better maintain valuable trees such as old trees and large trees in the city [46-47].

3.3 Implications of Research Fronts for Urban Tree Risk Practices

Keyword burst information (Table II) forecasts the development trend of tree risk research from three perspectives: burst strength, duration, and burst time. The results show that: from the perspective of burst duration, "conservation" has the longest burst duration (2014-2017), lasting 4 years; "benefit", "resistance", plant, classification, etc. also have long burst time, and these studies are still going on in the past decade, with relevant theoretical systems beginning to enter a fully mature stage. Where, the relevant literatures related to "conservation" mainly focus on the damage of pests and diseases to trees [48]. In particular, it studies risk of non-native tree species due to the damage of native insects [49], as well as tree lodging and breaking, etc. caused by bird nesting in caves and its mitigation measures [19], etc. Such papers are mostly published in journals about ecology and urban forestry.

TABLE II. keyword mutation analysis of studies from 1987 to 2021

Keywords Burst type	Keywords	Burst strength	Duration
Duration of Burst	Conservation	2.44	2014-2017
	Benefit	1.77	2016-2019
	Resistance	1.97	2019-2021
	Plant	1.97	2019-2021
	Classification	1.66	2019-2021
(Strengths of Burst	Forest	3.5	2015-2015
	Risk assessment	2.89	2019-2019
	Conservation	2.44	2014-2017
	Street tree	2.34	2013-2014
	Inspection	2.03	2016-2017
the Beginning Year of Burst	Urban forest	1.63	2012-2014
	Street tree	2.34	2013-2014
	Conservation	2.44	2014-2017
	Forest	3.5	2015-2015
	Tree	1.72	2015-2015
	Inspection	2.03	2016-2017
	Stress wave velocity	1.85	2016-2016
	Benefit	1.77	2016-2019
	Modulus of elasticity	1.76	2017-2017
	Wood	1.79	2018-2019
	Internal defect	1.77	2018-2019

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	Algorithm	1.71	2018-2019
	Risk assessment	2.89	2019-2019
	Resistance	1.87	2019-2021
	Plant	1.97	2019-2021
	Classification	1.66	2019-2021
	Tree defect	1.65	2019-2019
	Damage	1.7	2020-2021
	Stability	1.69	2020-2021
	Ground penetrating radar	1.62	2020-2021

According to the burst strength of burst words, it can be seen that “forest” (Strength=3.5), “risk assessment” (Strength=2.89), “conservation” (Strength=2.44), and “street tree” (Strength=2.34) have very high burst strength, which constitutes the forefront of tree risk research, and involves risk assessment and management of urban trees, especially risk management of street trees. Where, the hot word "forest" emerged in 2015 and displays a downward trend since 2018. Despite some increase since then, it presents a downward trend as a whole. The research objects are mainly trees in urban areas, with research covering: composition evaluation of urban forest trees, information provision for management and policy [50], database construction for selection of urban forest trees [51], assessment of climate change impact on climate exposure of urban trees and its susceptibility, adaptive capacity [52], identification and assessment of public and private forest tree risk to goods and personnel [53], assessment of tree space in urban street space using data analysis [54], etc. Such papers are mostly published in journals about ecology, urban forestry, and urban planning.

Seen from time series of burst, mutation mainly appears in the past 10 years, and the research trend can be summarized into 3 different stages: 1)In 2012-2015, the three keywords "urban forest", "street tree" and "conservation" first appear. As the leading keywords in tree risk-related research, they have a wide coverage and rich connotation, which not only constitute a research focus, but also can trigger and radiate other keywords. Research during this time period focuses on the role of urban trees in mitigating the consequences of urban climate change and centers on studies of how to minimize disruption and risk [52]. It assesses the impact of urban tree composition and tree habitat on tree defects and disturbances and their correlation with tree damage levels [55]. In particular, it studies the diversity assessment of important trees such as street trees in urban greening, the identification of tree defects and risks, and the impact of strong winds on urban trees [56]. Cities in Europe and the United States have also carried out research on inventory of trees in street environments, parks, and other environments as well as the formulation of long-term management strategies [57], for instance, by mapping damaged trees to determine the most serious species and dimensions [58], conducting tree risk management and tree species diversity assessment[2] based on detection and risk analysis of pests and diseases, evaluating the possibility of urban tree wreck after hurricane [59]. Detailed field investigations of urban tree health or structural issues are carried out to address tree defect disorder symptoms. Risk probabilities are also mathematically modeled and predicted in order to reduce future harmful incidents to people or property due to tree instability or damage to tree components, so that we can take rapid mitigation measures to reduce potential tree hazard [60]. Urban trees play an irreplaceable role in

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promoting the material circulation and energy flow of the urban ecosystem and contributing to the coordinated development of the urban natural environment. Since the 19th National Congress of the Communist Party of China, China has placed the construction of ecological civilization in a prominent position, and the research on urban forestry will still be a hot issue in domestic urban research in the future. 2) In 2016-2019, the three keywords of "inspection", "stress wave velocity", "benefit" have become the main research directions. Wood detection enjoys a lasting research enthusiasm until now, which is also an important contextual node to promote the development of this research in the future. Advances in detection technology have also become the pursuit of tree risk researchers, and a rapid field-based non-destructive method for evaluating wood density and texture is being sought around the world. Where, resistance drilling [28] has smaller tree damage, faster operation speed and more sensitive measurement scale compared to traditional methods, which is widely used in the detection of tree trunks. Air-coupled ultrasound (ACU) is a non-contact ultrasonic measurement method that allows detailed treatment of wood properties (density, moisture content, strength, etc.) as well as wood defects (cracks, decay, insect pest, etc.) in trees [61]. Acoustic tomography for tree detection can be used to diagnose internal defects in urban trees by using stress wave velocity patterns and then improve the accuracy of 3D tomographic images in tree detection applications [62]. The progress of detection technology has greatly improved the accuracy in tree risk detection. In recent years, non-destructive testing technology has been widely used in urban tree risk detection, which can accurately collect the data of internal decay/cavity of the tree trunk and damage of the underground root system under the premise of minimizing damage to the tree, thus further improving the accuracy and speed of tree risk detection. 3) In 2019-2021, "risk assessment", "resistance", and "tree defect" have become research hotspots, and risk assessment and management of urban street trees and street trees attract widespread attention from researchers due to its representativeness and high research value, and the research enjoys enduring popularity [61-62]. Fatal tree fall accidents in urban areas have drawn widespread attention to tree hazards, which exacerbates the occurrence of tree felling and severe pruning [55]. A comprehensive assessment of risky trees with structural defects can help us identify candidate trees for timely treatment or removal. However, the lack of predictive models and prioritization of influencing factor have been the main drawbacks in the research, which are also being addressed in the current studies [63]. In Germany, the researchers adopt the concept of urban ecosystem services and natural disaster risk research to incorporate specific environmental vulnerability indexes as additional information into the risk assessment of street trees. The results showed that species selection is an important factor in urban tree risk. In selection of the same species, efforts should be made to reduce defects in rhizomes, trunks and numerical values [47]. Studies from Argentina also support this conclusion: tree species, crown grade, and number of single defects in rhizomes and branches create a significant impact on tree hazard status [64]. Iranian researchers also combined physical, biological and related tree

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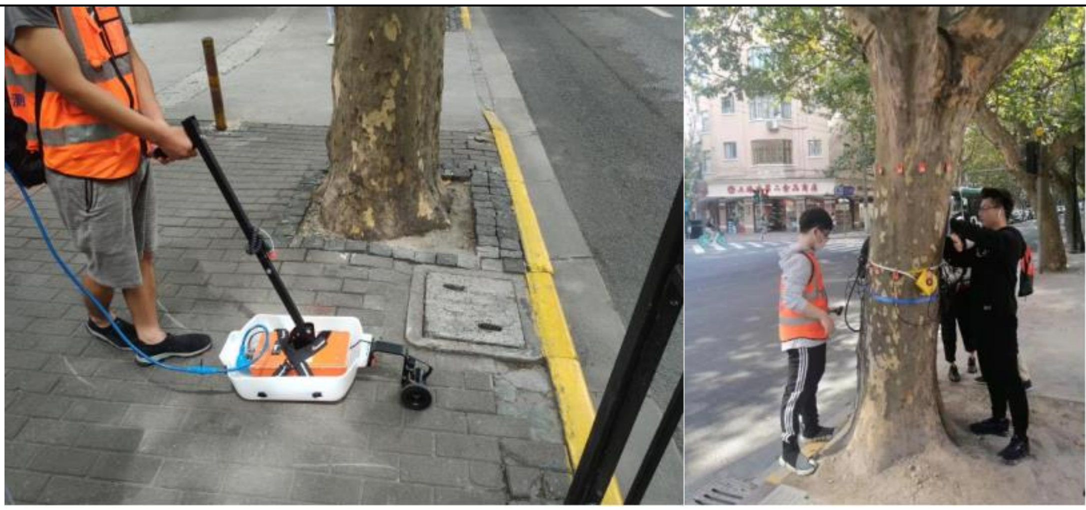

Fig 9: Quantitative method of urban tree risk detection (Left: Ground Penetrating Radar Technology; Right: electrical impedance tomography

Factors with the risk probability of sycamore, classified tree failure hazards using artificial neural network (ANN) modeling, constructed an environmental decision support system (EDSS) that can effectively reduce tree failure risk and proposed mitigation improvement measures [65]. For fallen urban trees in typical neighborhoods exposed to extreme strong winds, a comprehensive probabilistic approach was developed to simulate the performance of damaged infrastructure, and mitigation measures such as canopy sparseness were proposed [66]. In addition, "damage", "stability", and "ground penetrating radar" not only have high burst strength, but also have a short distance, which can be considered as the latest research hotspots. In recent years, it is a current research frontier to use ground penetrating radar and other technical means to carry out tree risk stabilization and resistance research. It is increasingly more popular to use tree roots for detection and analysis, because this method can provide information about root structure without damaging the tree, and it also allows long-term monitoring of tree root system without disturbing its development. With the further development of science and technology, optical technology is applied to quantitative methods such as 3D digital image technology of tensile test [67], electrical impedance tomography [68], ground laser scanning technology [69], etc. to provide a more advanced method for tree risk monitoring and assessment (Figure 9). In particular, the risk parameters of important green trees such as urban street trees and old trees will gain greater potential.

IV. CONCLUSION

By using CiteSpace software to analyze the knowledge graph of the literature on tree risk research in the past 3 decades, we objectively present the distribution of existing research disciplines and journals, the distribution of literature authors, research institutions and countries, as well as research hotspots and research trends in this field, which expands the existing understanding of tree risk research, with the main conclusions drawn as follows:

1) The field of tree risk research has formed a relatively complete research network system with diverse research perspectives, integrating forestry science, environmental science, ecology, plant science, engineering and other multidisciplinary fields. China and the United States are the main countries in tree

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risk research, the research institutions of the two countries are also the most important tree risk research centers, but no cross-regional and interdisciplinary collaborative research mechanism and platform has formed.

2) The tree risk research hotspots mainly focus on two aspects. "Tree risk assessment" is the main content of tree management. In particular, the urban tree risk assessment methods and policies are relatively mature. The practice of "tree risk detection" is in the stage of rapid development, forming combined quantitative and qualitative assessment method. Tree risk detection and assessment combined with modern information technology can allow more accurate assessment of the internal defects of tree trunks, root distribution and damage.

3) Urban tree risk research is a frontier issue in this field, involving risk assessment, street tree management, etc. In the past two years, urban tree risk assessment and tree defect repair based on accurate detection technology have become a new research trend. Ground penetrating radar and tomographic image diagnosis technology have greatly avoided the shortcomings of traditional detection due to inability to obtain accurate information and reliance on empirical judgment. In the future, quantitative methods such as terrestrial laser scanning technology will also provide greater potential for parameter acquisition in urban tree risk assessment.

After more than half a century of development, urban tree risk research has entered a stage of joint development in theoretical research and practice. Seen from the research area of urban tree risk, China has become an important area for tree risk research, and the problem of tree risk in the process of urbanization, especially in the development of large cities, has aroused widespread concern. Seen from research objects, tree risk research has gradually shifted from focusing on the defects of urban trees and cultivation techniques to the impact of climate change and biodiversity, but urban tree risk detection and assessment has always been a research hotspot. Seen from the cutting-edge trends of research, in the past decade, attention has gradually shifted from focusing on street tree management and detection technology progress to the risk assessment and management of street trees and park trees. In view of the above research results, the following systems should be built in the future risk management of urban trees in China:

First, it is necessary to carry out in-depth basic research work. In particular, for the related research on the occurrence mechanism of urban tree risk, we should carry out cross research based on plant science, engineering science and safety science. It is not only necessary to study the risk of individual and group urban trees, but also we should carry out multidisciplinary integration research in urban planning, building layout, municipal transportation, population distribution, etc. In particular, the wisdom of dendrology, ecological environment, landscape science, urban management and other disciplines should be integrated to reveal the occurrence mechanism of urban tree risk. At the same time, relevant scientific research institutions should strengthen the ability research and technology research and development of urban trees to defend against severe weather such as typhoons, rainstorms, and snowstorms.

Second, it is necessary to further improve the urban tree risk detection and assessment system, and establish a risk response system that integrates urban tree risk detection, risk discovery, risk assessment, risk exclusion, and risk management. In terms of tree detection, a risk detection system that combines rapid detection and accurate detection should be built, and tree risk investigation in key areas should be carried out to move forward urban tree risk management. The popularization in application of information technology and mathematical statistical methods has brought opportunities for tree risk detection. Digital

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three-dimensional technology and virtual reality technology have the advantages of big data processing volume, high efficiency, accurate measurement and modeling of complex shapes, which can greatly improve the speed and accuracy in tree detection. In tree risk assessment, we should fully learn from the methods and experiences of foreign countries, Hong Kong and Taiwan, optimize the relevant assessment system based on the current situation of urban development and management in China, carry out quantitative and qualitative risk assessment, and propose corrective measures before trees cause risks, so that the risk of urban trees is managed at an overall controllable level.

Finally, it is necessary to establish a long-term mechanism for urban tree risk management, and build an efficient management mechanism from system, concept and platform. (1) Starting from the safety management system of the entire city, it is necessary to incorporate urban tree risk management into the urban public safety management system, continuously improve the standards and regulations for urban tree risk management, refine emergency management plans after typhoons and other major disasters, and build a systematic urban tree risk management system running through the "full life cycle". (2) We need promote the construction of urban tree risk management platform system, embed application scenarios into great urban management platforms such as "integration network management system", gradually consolidate the hardware, software and data foundation, and build an urban tree risk management and emergency linkage disposal system. (3) Digitization and intelligence are an important manifestation of the modernization of the governance system and governance capacity in large cities in the future, which are also an important trend of urban tree risk management. First, we need use technologies like GIS to improve the intelligence level in urban tree risk prevention and control, establish ID cards for risky trees, pay close attention to them, and take corresponding preventive measures. Second, we need carry out data collection for key trees, use big data and network platforms to establish electronic files integrating pictures and texts for urban tree risk management, and monitor health and risk status of key trees throughout the process. Third, we need make good use of information technology and digital technology to promote the data sharing of risky trees in a coordinated manner, perfect the urban tree risk information management module, and enhance the city's risk perception and early warning capabilities.

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