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A REVIEW ON THE ECOLOGY AND RESEARCH EFFORTS OF THE INVASIVE ALIEN *POPULUS ALBA* L. (WHITE POPLAR) IN SOUTH AFRICA

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Abstract

Invasive alien plant species cause biodiversity loss globally and in South Africa. *Populus alba* is one of the introduced alien tree species that has become invasive in South Africa. It is native to Europe, Asia, and North Africa and was introduced to South Africa as an ornamental plant. Information on the ecology of *P. alba* was collated using peer-reviewed published literature using Web of Science, Google Scholar, and Science Direct. The study revealed 2767 records with 168 relevant publications included for retrieval. The review discussed nine parameters ranging from different taxonomic levels, distributions, environmental conditions, and threats. Most publications focus significantly on habitat conditions (45.09%), followed by its distribution (12.95%). Most of these publications originated from Europe (65%) and Asia (11%). Africa constitutes 9% of the datasets, with South Africa leading in relevant publications. In South Africa, most studies were conducted at national level (38%), followed by Limpopo Province (31%). The study revealed minimal research efforts with gaps in many provinces, which might be attributed to the potential underestimation of the *P. alba* presence or impact. This review is a critical appraisal to understand the ecological traits and drivers of the distribution of *P. alba* for future management strategies. In conclusion, this review highlights the level of research efforts on *P. alba* over the years and identifies the knowledge gaps for future studies.

Key words: Invasive; Biodiversity; Peer-reviewed; Datasets; Management strategies

Introduction

Invasive alien species are regarded amongst key drivers of biodiversity loss, globally (Anon., 2019; Roy *et al.*, 2024). Many alien species are transported from their native habitats and introduced intentionally or unintentionally, by humans and their activities. They however have to overcome many kinds of barriers on their journey from native habitats to new areas through many pathways that facilitate their transportation, introduction, spread and invasion (Richardson *et al.*, 2011; Faulkner *et al.*, 2020).

Woody alien plants have been intentionally introduced in many parts of the world for horticulture or agroforestry and have eventually become established (Richardson & Rejmánek, 2011) and some become invasive (Le Maitre *et al.*, 2000). The invasion of woody alien species has negative impacts on native species diversity, genetic flow through hybridization, ecosystem structure, and habitat alteration (Downey & Richardson, 2016).

Populus alba L. (White poplar), a member of the Salicaceae family, is amongst the intentionally introduced woody alien species in South Africa. It originates from southern and central Europe, Northern Africa, western and central Asia (Dickmann, 2001a) and widely introduced to other parts of the world for ornamental purposes (Dickmann & Stuart, 1983). Its invasiveness has been reported in many parts of the world, including Argentina (Alberio & Comparatore, 2014), Serbia (Nikolić *et al.*, 2010), Canada, United States (Anon., 2024), New Zealand and South Africa (Caudullo & De Rigo, 2016; Van Wilgen & Wilson, 2018). *Populus alba* is a riparian tree, closely associated with disturbed floodplains, early successional dune communities (Gucker, 2010), plantations, and prairie communities (Henderson, 2001; Mararakanye *et al.*, 2017). It can also be found in abandoned homesteads and open sunny habitats including meadows, roadsides, and pastures (Henderson, 2001). *Populus alba* is reported to grow in a variety of climatic conditions including drylands, Mediterranean and subtropical areas (Randall, 2017). It also grows well on rich alluvial or sandy soils (Palancean, 2018) with excess water (Constandache *et al.*, 2020).

Populus alba is an important commercial tree, particularly in its native range as it is used in agroforestry (Pezhhanfar *et al.*, 2021), short rotation forestry (Klašnja *et al.*, 2008), silviculture (Soares *et al.*, 2011), *In vitro* propagation and reclamation afforestation (Vysotska *et al.*, 2021), including its role in pollution mitigation, improved structure, and microclimate regulation (Tognetti *et al.*, 2013). The uses of *P. alba* outside its native range include the usage of its leaves as cattle feed (Gucker, 2010), biofuel production (Mushtaq *et al.*, 2018), timber, dune stabilization, land reclamation, and windbreaks (Moyo *et al.*, 2017). However, the negative impact of *P. alba* on natural ecosystems remains a problem. This necessitates the need to weigh the benefits and associated impacts for successful management strategies.

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However, *Populus alba* has escaped cultivation in many parts of the world (Little, 1961) including South Africa, posing threats to biodiversity and ecosystem services (Gucker, 2010). It forms dense monospecific stands that suppress and outcompete existing vegetation (Gucker, 2010). Invasions by *Populus* species in the Grasslands of South Africa have reduced the biome's structure and functioning (Le Maitre *et al.*, 2016). The stands of *P. alba* become brittle as they age and may damage nearby vegetation (Mbedzi *et al.*, 2019) and infrastructure. *Populus alba* is considered a high water-consumer invader (Versfeld *et al.*, 1998), leading to a reduction of soil moisture (Mbedzi *et al.*, 2019). The root system of *P. alba* clogs drains, sewers, and water channels (Gucker, 2010). *Populus alba* is known to hybridize readily with other poplar species (Gucker, 2010). The extensive root system of *P. alba* has been reported to damage buildings and roads in nearby houses and suburbs in Limpopo province, South Africa (Mbedzi *et al.*, 2019). *Populus alba* is associated with *Cryptosphaera* species, a canker pathogen for grapevines (Moyo *et al.*, 2017).

Understanding the ecological traits, habitat and environmental preferences, and impacts of *P. alba* is required to assess its ideal distribution and spread for better planning and management. This study reviews the ecology, habitat, and environmental determinants of *P. alba* in both its native and invaded habitats. It further assesses the level of research efforts on *P. alba* over the years and highlights the gaps in understanding of the species and management in South Africa.

Materials and Methods

Methodology: A review of relevant peer reviewed and published literature related to this study was conducted using the Preferred Reporting Items for the Systematic Reviews and Meta- Analyses (PRISMA) guidelines as described by Moher *et al.*, (2009) in Fig. 1. Literature was sourced using online bibliographic databases such as Google Scholar, Science Direct, and Web of Science using the keywords "White Poplar Ecology," "Ecology of *Populus alba*", and "The ecology of *Populus alba* (white poplar)". Other sources included (Henderson, 2001; Randall, 2017; Henderson, 2020) and dissertations (Mbedzi, 2020; Matukana, 2021).

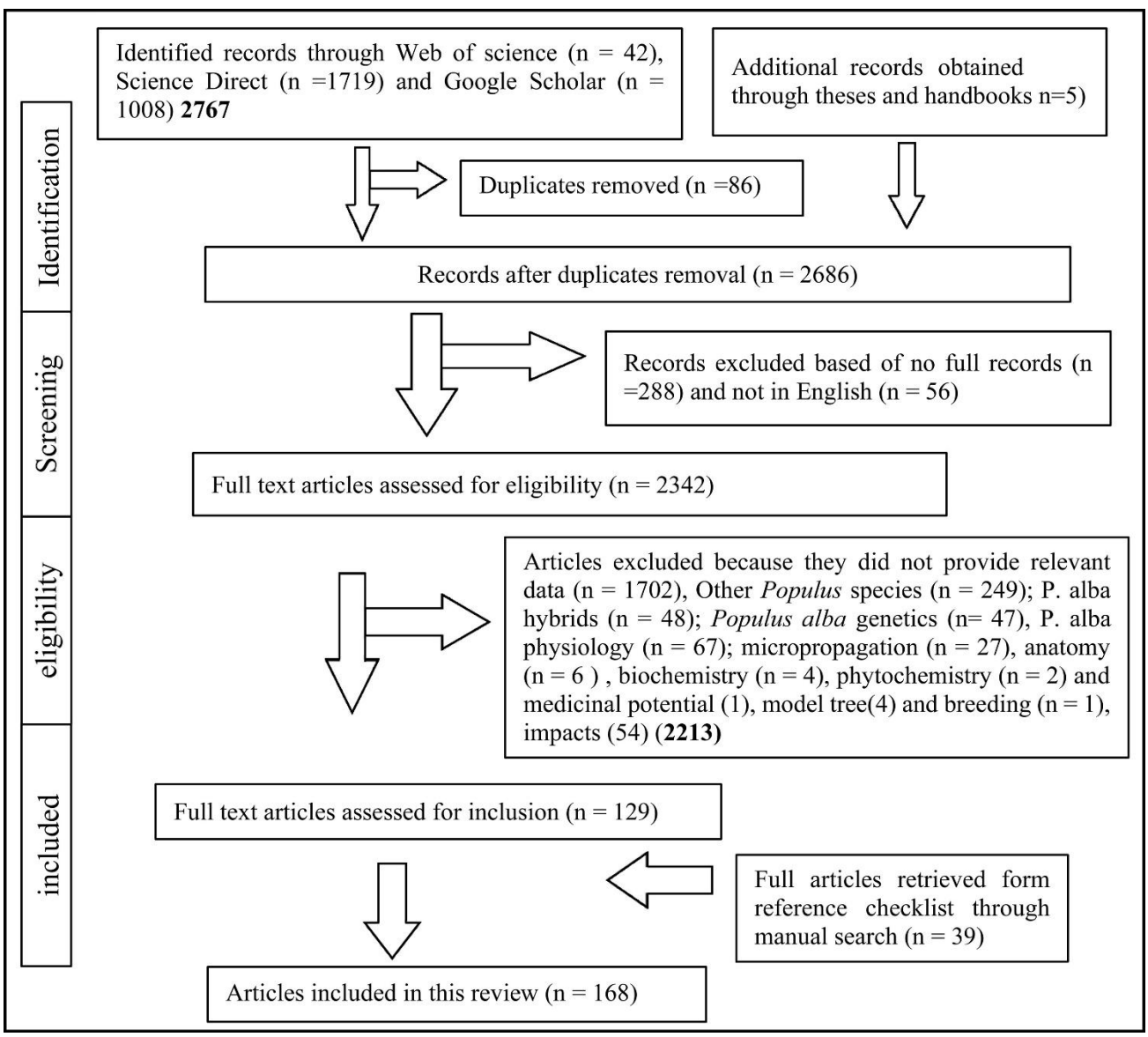

Fig. 1. PRISMA flow diagram used for the search and retrieval of the study.

Table 1. The ecological and conservation attributes of *Populus alba.*

Aspect	Description	References
Taxonomy	Taxonomy of *P. alba*	(Berry, 1917; Eckenwalder, 1996; Anon., 2000; Dickmann, 2001b; Cervera *et al.*, 2005)
Description	Description	(Hubbard, 1926; Rehder, 1927; Little, 1961; Gilman E.F and Watson, 1994; Dickmann, 2001a; Henderson, 2001; Bueno *et al.*, 2003; Jordaan, 2005; Tsarev, 2005; Wyckoff & Zasada, 2005; Dickmann & Kuzovkina, 2014; Đukić *et al.*, 2014; Isebrands & Richardson, 2014; Caudullo & De Rigo, 2016; Leuschner & Meier, 2018; Henderson, 2020; Matukana, 2021)
Distribution	Native distribution	(Hubbard, 1926; Rehder, 1927; Dickmann, 2001b; Henderson, 2001; Jakucs, 2002; Bueno *et al.*, 2003; Roiron *et al.*, 2004; Wyckoff & Zasada, 2005; Manzanera & Martínez-Chacón, 2007; Rédei & Keserű, 2008; Rédei *et al.*, 2012; Saccone *et al.*, 2013; Kuczman, 2014; Richardson *et al.*, 2014; Tsaralunga *et al.*, 2016; Guarino *et al.*, 2019; Henderson, 2020; Bayón *et al.*, 2021; Matukana, 2021; Ho *et al.*, 2023; Anon., 2024)
	Alien distribution	(Hubbard, 1926; Spies & Barnes, 1982; Dickmann, 2001b; Khuroo *et al.*, 2011; Müllerová *et al.*, 2015; Sizemskaya & Sapanov, 2023)
Habitat preferences	Riparian forests	(Roiron *et al.*, 2004; Kondolf *et al.*, 2007; Schnitzler *et al.*, 2007; Domínguez *et al.*, 2008; Kakouros, 2008; Costa *et al.*, 2011; Saccone *et al.*, 2013; Dyderski *et al.*, 2015; Quadt *et al.*, 2016; Palancean, 2018; Przepióra & Ciach, 2022; Camarero *et al.*, 2023a; Camarero *et al.*, 2023b)
	Forests	(Vukelić & Rauš, 2001; Martín-Queller & Saura, 2013; Erdős *et al.*, 2014; Simmons *et al.*, 2016; Randall, 2017; Šabić *et al.*, 2018; Ho *et al.*, 2023; Anon., 2024)
	Floodplains	(Siebel, 1998; Karrenberg *et al.*, 2002; Sánchez-Pérez *et al.*, 2008; Schneider-Binder, 2009; González *et al.*, 2010b; González *et al.*, 2010c; Moga *et al.*, 2010; Blujdea *et al.*, 2012; Milner, 2012; Drescher *et al.*, 2014; Biurrun *et al.*, 2016; Schneider-Binder, 2016; Sivolapov *et al.*, 2019; Frymark-Szymkowiak & Kieliszewska-Rokicka, 2023; Galina, 2023)
	Riverine tree	(Henderson, 2001; Jakucs, 2002; Rédei, 2002; Bueno *et al.*, 2003; Fossati *et al.*, 2004; Linstädter & Zielhofer, 2010; Rédei *et al.*, 2010; Moreira *et al.* 2013; Đukić *et al.*, 2014; Lapteacru & Georgescu, 2014; Richardson *et al.*, 2014; Onete *et al.*, 2016; de las Heras *et al.*, 2020; Henderson, 2020; Malik *et al.*, 2021; Milović *et al.*, 2021)
	Streams	(Henderson & Musil, 1984; Henderson, 2001, 2020; Schneider-Binder, 2020)
	Dongas	(Henderson, 2001, 2020)
	Wetlands	(Henderson, 2007; Lioma, 2010; Moreira *et al.* 2013*;* Schneider-Binder, 2016; Anon., 2024)
	Pond edges	(Sizemskaya & Sapanov, 2023)
	Open woodlands plantations	(Csecserits *et al.*, 2016; Randall, 2017)
	Cotton	(Randall, 2017)
	Orchards	(Randall, 2017)
	Disturbed habitats	(Spies & Barnes, 1982; Hill, 1996; Manzanera & Martínez-Chacón, 2007; Ahmad *et al.*, 2023)
	Full sun areas	(Gilman and Watson, 1994; Anon., 2024)
	Pastures	(Henderson, 2001)
	Meadows	(Henderson, 2001)
	Fields	(Anon., 2024)
	Islands	(Adam *et al.*, 2008)
	Grasslands	(Henderson, 2007; Alberio & Comparatore, 2014; Lorenc-Plucińska *et al.*, 2017; Mbedzi *et al.*, 2019; Mbedzi, 2020)
	Salinity	(Toth, 1981; Fossati *et al.*, 2004; Sixto *et al.*, 2005; Dickmann & Kuzovkina, 2014; Isebrands & Richardson, 2014; Richardson *et al.*, 2014; Palancean, 2018)
	Fluvisol soils	(de las Heras *et al.*, 2020)
	Neutral-alkaline soils	(Caudullo & De Rigo, 2016; Mbedzi *et al.*, 2019; Mbedzi, 2020; Ahmad *et al.*, 2023)
	Nutrient-rich soils	(Caudullo & De Rigo, 2016; Mbedzi *et al.*, 2019; Mbedzi, 2020)
	Alluvial soils	(Jakucs, 2002; Costa *et al.*, 2011; Schneider-Binder, 2016; Mamai, 2017; Cojoacă & Niculescu, 2018; Palancean, 2018; Constandache *et al.*, 2020; Przepióra & Ciach, 2022)
	Bottomland soils	(Dickmann, 2001a)
	Sandy soils	(Rédei *et al.*, 2010; Rédei *et al.*, 2012; Palancean, 2018; Camarero *et al.*, 2023b; Frymark-Szymkowiak *et al.*, 2024)

Table 1. (Cont'd.).

Aspect	Description	References
Climate variables	Drought	(Fossati *et al.*, 2004; Dickmann & Kuzovkina, 2014; Isebrands & Richardson, 2014; Richardson *et al.*, 2014; Constandache *et al.*, 2022)
	Rainfall	(Vospernik, 2021)
	Floods	(Milner, 2012; Mamai, 2017; Malik *et al.*, 2021; Milović *et al.*, 2021; Frymark-Szymkowiak *et al.*, 2024)
	Wind	(Bueno *et al.*, 2003; Fossati *et al.*, 2004; Dickmann & Kuzovkina, 2014; Isebrands & Richardson, 2014; Richardson *et al.*, 2014)
	Temperature	(Bueno *et al.*, 2003; Fossati *et al.*, 2004; Schnitzler *et al.*, 2007; Richardson *et al.*, 2014; Vospernik, 2021)
	Mediterranean	(Moreira *et al.* 2013; Rosso *et al.*, 2013; Randall, 2017)
	Humid areas	(Milović *et al.*, 2021)
	Dry climates	(Randall, 2017; Oliveira *et al.*, 2018)
	Tropical and subtropical climates	(Randall, 2017)
Reproduction	Root suckers	(Hubbard, 1926; Gilman E.F and Watson, 1994; Siebel, 1998; Dickmann, 2001a; Deiller *et al.*, 2003; Jordaan, 2005; Moreira *et al.* 2013; Dickmann & Kuzovkina, 2014; Isebrands & Richardson, 2014; Palancean, 2018; Mbedzi *et al.*, 2019; Mbedzi, 2020; Matukana, 2021; Anon., 2024)
	Seeds	(Siegel & Brock, 1990; Van Splunder *et al.*, 1995; Strauss, 1999; Dickmann, 2001a; Karrenberg & Suter, 2003; González *et al.*, 2010a; González *et al.*, 2010c; Richardson *et al.*, 2014; Palancean, 2018; Vysotska *et al.*, 2021)
	Coppice	(Henderson, 2007)
Dispersal pathways	Contaminant	(Randall, 2017)
	Humans (ornamental, forestry, crop)	(Randall, 2017)
	Wind	(Dickmann & Kuzovkina, 2014; Isebrands & Richardson, 2014; Randall, 2017; Anon., 2024)
	Animals	(Randall, 2017)
	Escapee	(Randall, 2017)
Host species	host of *Paenibacillus populi*	(Han *et al.*, 2015)
	host of lichens	(Cera *et al.*, 2020)
	host of fungi	(Cicatelli *et al.*, 2010; Trouillas *et al.*, 2015)
	Host of *Cytospora* species	(Fotouhifar *et al.*, 2010; Wang *et al.*, 2015)
	host of *Pheosia albivertex*	(Hussain *et al.*, 2024)
	host of ectomycorrhiza	(Katanić *et al.* 2015; Maremmani *et al.*, 2003; Jakucs *et al.*, 2005; Kovács & Jakucs, 2006; Tyburska *et al.*, 2013; Szuba, 2015; Milović *et al.*, 2021)
	Host of arbuscular mycorrhiza	(Maremmani *et al.*, 2003)
	host of bugs	(Mustafa *et al.*, 2020)
	host of *Ogataea populialbae*	(Péter *et al.*, 2009)
	host of *Chaitophorus populeti*	(Poljakovic-Pajnik *et al.*, 2020)
	host of *Pleurotus calyptratus*	(Prylutskyi *et al.*, 2022)
	host of mosses	(Rybak *et al.*, 2018)
	host of bats (*Ipistrellus pygmaeus*)	(Vidal-Cordero *et al.*, 2024)
	host of myxomycetes	(Vlasenko *et al.*, 2023)
Threats and diseases	*Taphrina rhizophora*	(Chira *et al.*, 2022)
	Aelosthes sarta	(Ahmad *et al.*, 1977; Anon., 2006; Hayat, 2022; Hayat *et al.*, 2023)
	Cryptosphaeria multicontinentalis	(Trouillas *et al.*, 2015; Moyo *et al.*, 2017)
	Bacterial diseases	(Danilewicz, 1980; Kalinichenko *et al.*, 2017; Goychuk *et al.*, 2023)
	Melanophila picta	(Khabir & Sadeghi, 2012)
	Septotis populiperda	(Cun-ti & Hong, 2000)
	Poplar leaf miner	(Đức *et al.*, 2021)
	Urbanisation	(Shuaib *et al.*, 2018)
Conservation species	Protected tree	(Durlak *et al.*, 2022)
	Threatened species	(Schulzke, 2000; Juhász *et al.*, 2020; Panici *et al.*, 2022; Ho *et al.*, 2023)

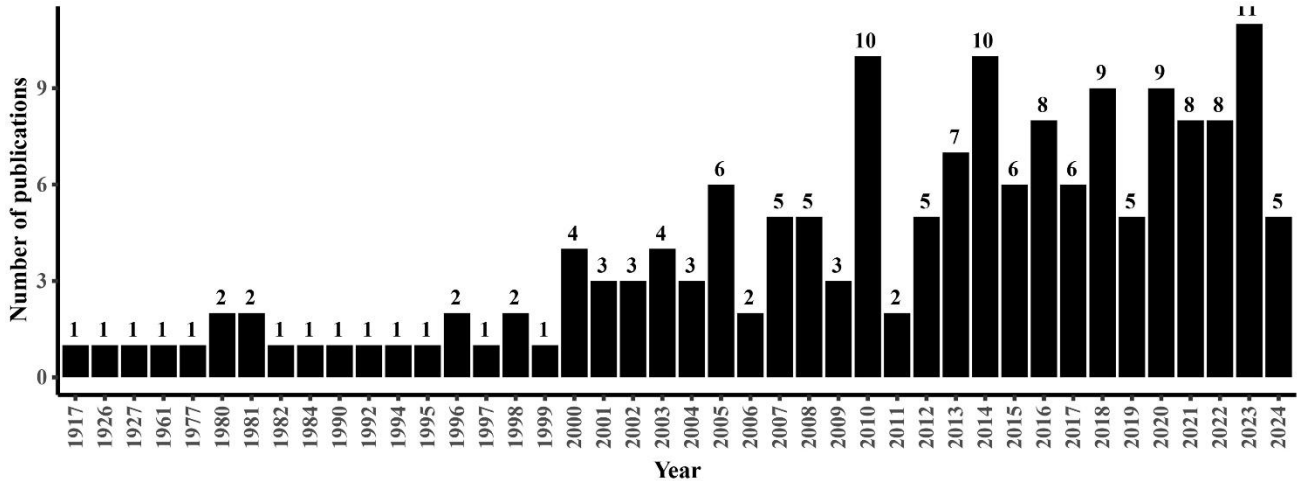

Fig. 2. Number of publications per year. There has been an increasing interest in the ecological knowledge of *P. alba* since 2000.

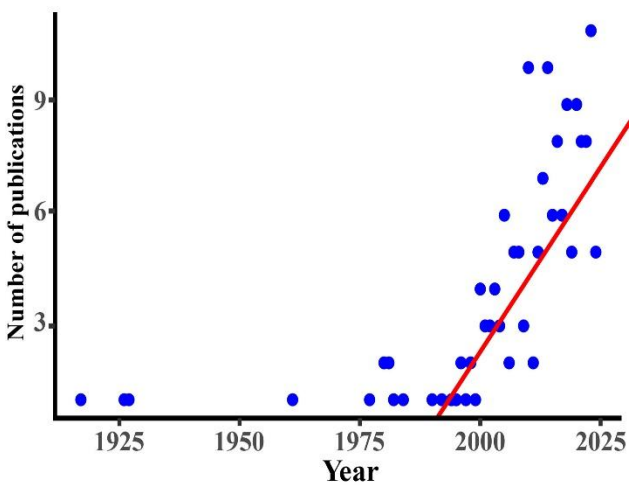

Fig. 3. The temporal trends in number of global publications over time retrieved from the dataset.

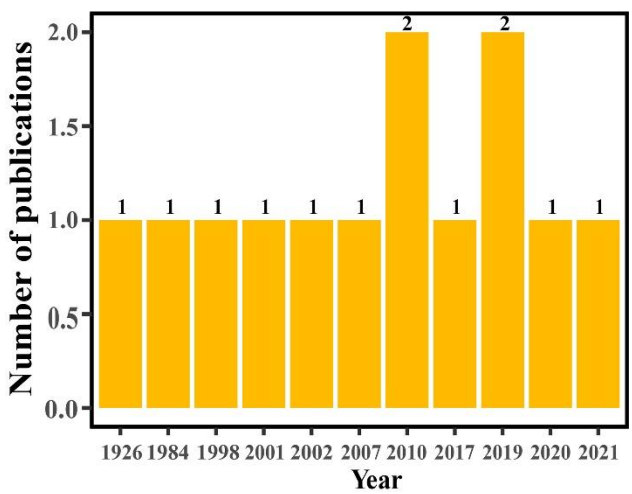

Fig. 4. Number of publications per year found in a review of publications for South Africa.

Inclusion and exclusion criteria: Only peer-reviewed published articles in English language were considered for this review, and papers containing only English abstract were excluded from the search. All full text articles, books, reports, and dissertations dated from 1917 to January 2024 were considered.

Data extraction and analysis: Full text articles that included the ecological aspects, uses, and impacts of *Populus alba* were extracted and captured using Microsoft Excel and visualized using R Studio. A master list containing all relevant information generated enlisting ecological parameters, descriptions, and references (Table 1). The collated data was analyzed using descriptive and inferential statistics. The temporal trends and the slope of the trends of publications per year were analyzed using the Mann-Kendall test (Pettitt, 1979) and Sen's estimator (Sen, 1968), respectively.

Relevant data denotes studies including information on *Populus alba* ecology: Distribution, habitat, climate, dispersal and reproduction modes, and associated host species and threats.

Results

Assessment of literature: The initial search yielded a total of 2767 publications. After removing duplicates and screening the publications according to the defined criteria, 168 publications were included in the study (Fig. 1). Several scientific publications were reviewed based on the ecology of *P. alba* and are presented in the sections below. Although the numbers could be higher, there is increasing knowledge on the ecology of *P. alba*, and these have been documented under the reference section.

Year of publication: The study indicated more relevant publications in 2023 with 11 publications, followed by 2014 with 10 publications (Fig. 2). Noticeably, some years before 1996 did not have relevant publications, and no gap year was identified since 1996. Most years have one publication, including 1917-1977, 1982-1994, and 1997-1999. However, the increasing number of publications on this aspect is worth noting, especially since 2000. A significant increasing trend with a p-value < 0.001 was observed using the Mann-Kendall test. The observed trend had a tau value of 0.707, indicating a strong upward monotonic trend in global publications over time. Sen's slope of the trend had a slope of 0.1923077 with a p-value of <0.001 (Fig. 3). These values indicate a significant increase in publications over time.

In South Africa, publications range was from 1926 to 2021. Amongst this, 2017 and 2019 had two publications each, while other years had one publication each (Fig. 4).

The Mann-Kendall test findings for South African publications were tau = 0.254, with a p-value of 0.4094. There was no significant trend in the number of publications over time, with a slope of 0.

Publications per geographic origin: This study revealed that most studies were conducted in Europe (65%), especially in Spain (18 publications) and Hungary (15 publications). The studies were conducted across 42 countries, excluding 7 global reviews (Fig. 5). Besides Spain (18), Hungary (15), a considerable number of studies were conducted in South Africa (13), and Poland (12) also. The global review dataset constituted 4% of the global review dataset, offering a broader perspective on the ecology of *P. alba.* Figure 6 illustrates an in-depth categorization of publications based on their geographic origin, ranging from global to South African perspectives. Africa constituted 9% of relevant publications, with more publications (13) published from South Africa. Noticeably, only two African countries (Morocco and South Africa) published relevant to this study**.** Hence the study points out the limited diversity in the African context.

Most studies in South Africa were conducted at national level (38%), followed by Limpopo Province (31%). Although national studies provide a broader understanding of the species distribution, they might overlook the variations present within specific regions. Two publications were conducted in Mpumalanga (13%) while Northwest, Gauteng, and Western Cape provinces had one study each (Fig. 6). No studies were documented from the Eastern Cape, Northern Cape, Kwazulu-Natal, and Free State provinces. However, some of these provinces were covered by national studies.

Distribution of *P. alba* in South Africa: *Populus alba* is amongst the recorded alien plant species mapped by the South African Invasive Plant Invaders (SAPIA) team. Based on SAPIA (accessed 2020), the first record was documented in a valley in 1925, Harrismith, Free State Province. However, coordinates for this record are not reported. The first geo-tagged record on the SAPIA database was found in 1979, in Gauteng Province. Furthermore, 14 specimen collections were reported from the Botanical Database of Southern Africa, with the first record in 1999 from Gauteng Province (SANBI, 2016). The increasing distribution of *P. alba* in South Africa is of great concern, however, there is no evidence to support its dispersal pathway across the country. Figure 5 illustrates the trend of new occurrence records over the years, ranging from 1968 to 2024. Most of the records were documented in 1979 (65), followed by 2008 (54) and 1998 (46). The current distribution of *P. alba* is shown in Fig. 7.

Ecological parameters: The publications were further categorized into different ecological parameters, as shown in Fig. 9-10. This ranges from its taxonomy, environmental conditions, and association with the environment. Most publications described the habitat conditions of *P. alba* (45,50%), followed by its distribution (12,16%). The species description was provided in 11 publications (4,95%), and its climate conditions were discussed in 17 publications (7,59%). The distribution of *P. alba* (12,16%) included its native and alien ranges, with 21 publications on the native range and 6 studies indicating its alien distribution. The preferred habitat conditions of *P. alba* covered the habitat type, soil type, and soil properties such as pH and salinity. *Populus alba* grows in various habitats, such as forests with 23 publications, and riparian areas (44 publications) including floodplains, rivers, streams, and wetlands. Taxonomy and conservation, accounting for 2,25% each, were the least published parameters on *P. alba.* A total of 18 publications (8,07%) discussed the reproduction and responsible pathways of dispersal. About 13 publications reported its vegetative reproduction through root suckers.

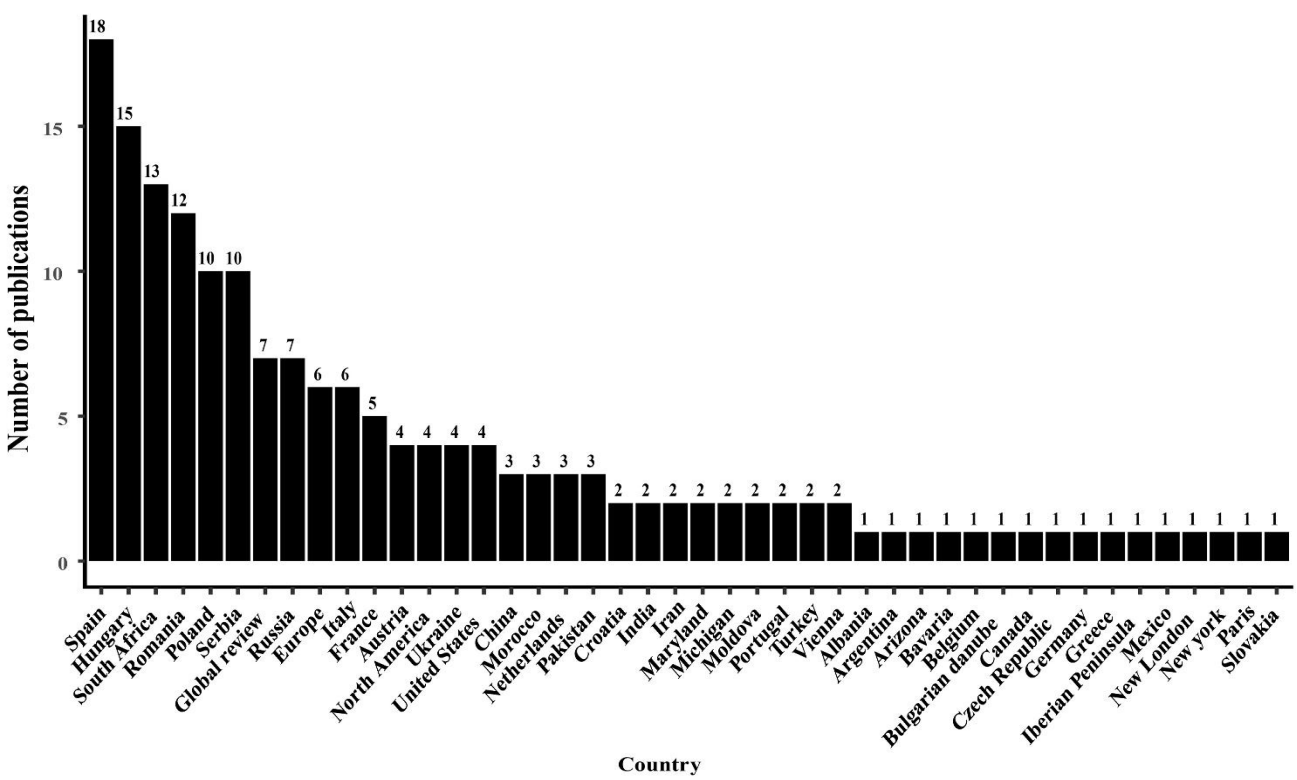

Fig. 5. Number of publications per country across the globe.

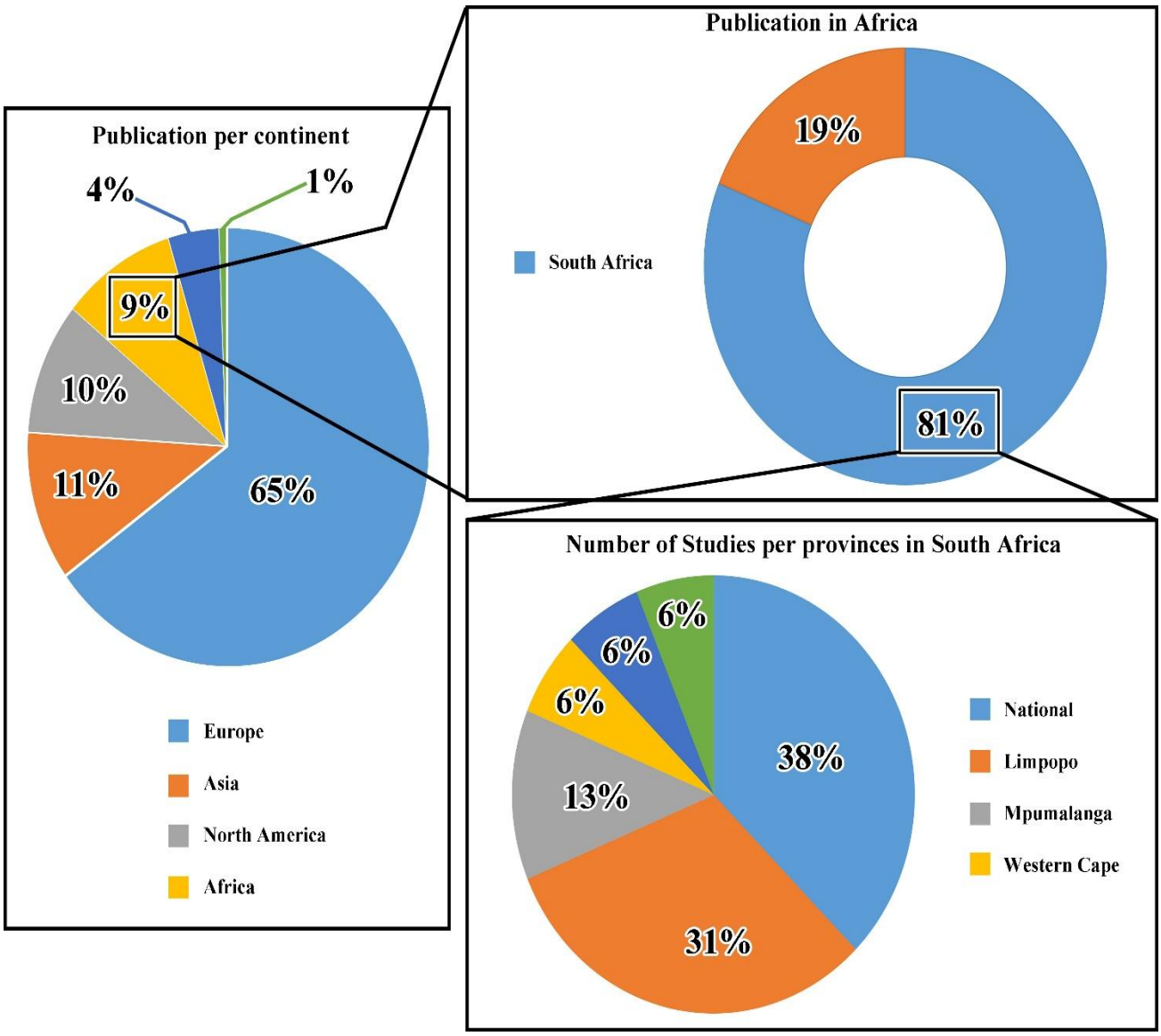

Fig. 6. Percentage of studies published globally, in Africa, and in South Africa.

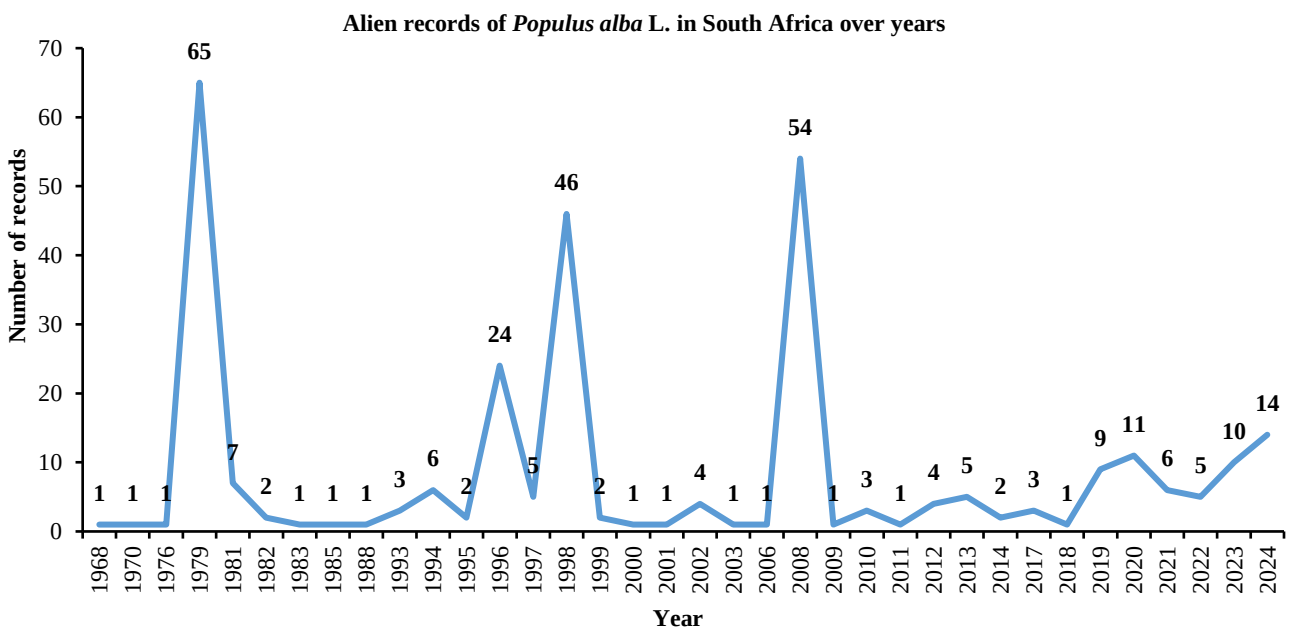

Fig. 7. New occurrence records of *Populus alba* in South over time.

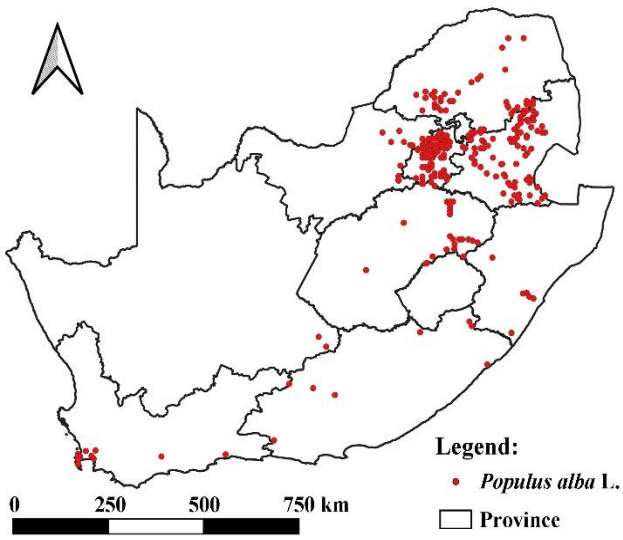

Fig. 8. A map showing the distribution of *Populus alba* L. in South Africa. Sources: Botanical Database of Southern Africa (BODATSA, Accessed: 17 January 2025) (SANBI 2016); South African Plant Invaders Atlas (SAPIA, unpublished) records (Accessed: 06 May 2020) and GBIF Occurrence Download (Anon., 2025) (Accessed: 17 January 2025).

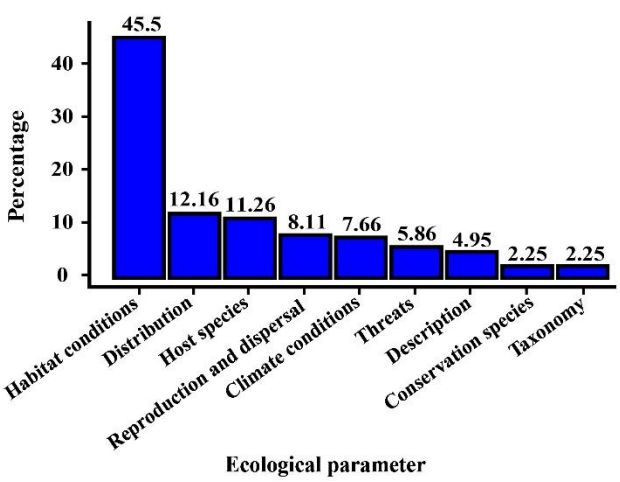

Fig. 9. Percentage of publications by ecological parameters found in the global review.

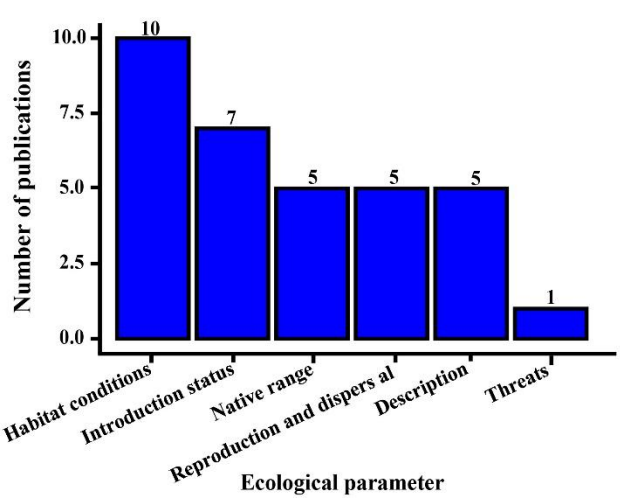

Fig. 10. Number of publications per ecological parameter found in a review of publications for South Africa.

In South Africa, 6 ecological parameters were documented as depicted in Figure 10. Similar to the global perspective, the majority of studies focused on the habitat type (10 publications). Other parameters included its introduction status (6 publications), reproduction and dispersal (5 publications), description (5 publications), native range (4 publications), and threats (1 publication). The detailed description of *P. alba* assists in the correct identification of the species. The native range was mostly mentioned to highlight that *P. alba* was not indigenous to South Africa.

Discussions

Publications per year: The study revealed a long history of publications on the ecology of *P. alba* from 1917 to 2024. The growth of interest in conducting studies was on *P. alba* informs its value, particularly in its native range. Outside its native range, *P. alba* appears to be invasive, and more efforts are required to understand the extent of its global alien range. Moreover, research efforts in South Africa have been reported since 1926, with several studies focusing only on its occurrence.

Publications per region: Most publications originated from its native range (Anon., 2024), suggesting a geographical correlation between the origin of the species and research interest. The distribution of publications across continents provides knowledge of the geographic focus of existing research and highlights potential areas for further investigation. Little or lack of publication within areas across its distribution range can be identified for further investigations.

In South Africa, the exploration and documentation of ecological studies across various provinces are crucial for understanding its distribution and impacts. There were no reported studies in the Free State, however, established (Hubbard, 1926) and naturalized (Jordaan, 2005) populations were recorded in the Free State Province. A book by Henderson (2020) further illustrated its distribution in Kwazulu-Natal. Therefore, the absence of relevant ecological studies on *P. alba* does not confirm its absence in other provinces. The minimal research efforts and gaps in some provinces might be attributed to the potential underestimation of the *P. alba* presence or impact. This necessitates the need for further research to fill the existing knowledge gaps. Without comprehensive data from all provinces, the understanding of *P. alba's* ecology, distribution, and potential impact remains incomplete. The first publication (Hubbard, 1926), indicated that *P. alba* was first observed in 1906. However, its year of introduction in the country remains unknown.

Ecological parameters: This study identified 9 ecological parameters of *P. alba* globally, with 6 of these parameters reported for South Africa. In both contexts, habitat conditions were the highest discussed parameter for *P. alba*. *Populus alba* is reported to grow best in full-sun habitats such as fields (Anon., 2024), abandoned homesteads (Henderson 2001), roadsides, meadows, pastures (Henderson, 2001) and grasslands (Henderson, 2007; Lorenc-Plucińska *et al.*, 2017; Mbedzi *et al.*, 2019). Other studies reported its occurrence in railways

(Mararakanye *et al.*, 2017) and plantations/woodlots (Jordaan, 2005). This shows that *P. alba* thrives in various habitats, making it a stronger competitor. South Africa appears to have suitable habitat conditions throughout the country, except for Northern Cape (Mapuru *et al.*, 2024).

P. alba prefers mostly alluvial and sandy soils. Furthermore, *P. alba* can tolerate moderate to high salinity environments(Toth, 1981; Fossati *et al.*, 2004; Palancean, 2018). *P. alba* is reported to grow in a variety of climate conditions including drylands (Oliveira, 2018; Randall, 2017), Mediterranean (Moreira *et al.* 2013; Rosso *et al.*, 2013; Randall, 2017) and humid areas (Milović *et al.*, 2021). *P. alba* is resistant to periodic flooding, (Frymark-Szymkowiak & Kieliszewska-Rokicka, 2023) and intolerant to prolonged flooding (González *et al.*, 2010b). The establishment of invasive alien species is driven by the availability of suitable habitat and climate conditions. The wide range of identified habitats and climate conditions in this review suggests that *P. alba* can withstand various environmental conditions. This will result in an increased rate of invasions.

Populus alba reproduces through sexual and asexual reproduction modes. Sexual reproduction produces a thousand of highly viable, wind-dispersed seeds (Karrenberg & Suter, 2003). A previous study reported that Poplar's dispersal distance can reach up to 16 km (Fussi, 2010). However, the growth and survival of these seeds require favorable conditions, and these were discussed in several studies (Siegel & Brock, 1990; Van Splunder *et al.*, 1995; Strauss, 1999; Karrenberg & Suter, 2003; González *et al.*, 2010a; Alberio & Comparatore, 2014; Anon., 2024). Asexual reproduction appears to be a common reproduction mode for *P. alba*. In South Africa, *P. alba* was reported to reproduce vegetatively through root suckers (Hubbard, 1926; Jordaan, 2005; Mbedzi *et al.*, 2019; Mbedzi, 2020; Matukana, 2021) and coppice (Henderson, 2007). This is attributed to the presence of only female species in Southern Africa (Hubbard, 1926; Henderson, 2001; Jordaan, 2005; Henderson, 2020). It is therefore believed that long-distance dispersal *of P. alba* occurs through the water-dispersal pathway (Henderson, 2007).

Poplars tend to sprout vigorously from stumps after trees are cut or fall from natural causes (Strauss, 1999). This was also observed in a study conducted by (Mbedzi *et al.*, 2019; Mbedzi, 2020) in South Africa. In their experiment, suckers of *P. alba* were uprooted in 2016 and the species still emerged in larger numbers than before the eradication. Large number of suckers from a single tree can quickly develop into a dense colony (Gucker, 2010). Due to its aggressive behaviour, it is considered invasive in many alien ranges, including the United States, Canada, Australia, South Africa, and New Zealand (Caudullo & De Rigo, 2016). Another vegetative growth occurs through coppicing (Henderson, 2007). Apart from natural dispersal, humans also spread this species for benefits such as ornamental (Randall, 2017). The economic value of *P. alba* will further increase its spread worldwide.

The taxonomy of *P. alba* focused more on the generic level, particularly at the sections level of the genus. This highlighted the changes in the classification of *P. alba* from section *Leucoides* (Rehder, 1927) to section *Populus* (Stettler, 1996; Dickmann, 2001a). In terms of conservation, *P. alba* is a threatened species in Germany (Schulzke, 2000), Romania (Panici *et al.*, 2022) and Hungary (Juhász *et al.*, 2020; Ho *et al.*, 2023). Furthermore, *P. alba* is a protected tree in Poland (Durlak *et al.*, 2022).

The study revealed that *P. alba* hosts a range of pests and micro-organisms (11,26%), including fungi, ectomycorrhiza, and bugs. Moreover, *P. alba* is threatened by fungi (Cun-ti & Hong, 2000; Trouillas *et al.*, 2015; Moyo *et al.*, 2017; Chira *et al.*, 2022), bacteria diseases ((Danilewicz, 1980; Kalinichenko *et al.*, 2017; Goychuk *et al.*, 2023), beetles (Ahmad *et al.*, 1977; Khabir & Sadeghi, 2012; Hayat *et al.*, 2023) and moths (Đức *et al.*, 2021). This indicates its natural enemies and can aid in identifying potential biological control agents in its invasive alien range, including South Africa. In addition, urbanization resulted in decreased species richness of *P. alba* in Pakistan (Shuaib et al. 2018). These parameters inform the drivers and patterns of its distribution, which is critical for management strategies (Rouget *et al.*, 2015).

Invasion status of *Populus alba* in South Africa: South Africa is among the studies conducted in Africa, with 12 publications ranging from 1926 to 2024. Most of the occurrence records were documented in 1979, followed by 2008 and 1998. This trend is because the initiation of roadside surveys for mapping invasive alien plant species in South Africa began in 1979 in Gauteng Province (Henderson, 2011). The increasing interest in studies on its ecology is of great notice as *Populus alba* is among the widespread invasive alien species in the country (Nel *et al.*, 2004). This is supported by the expansion of occurrence records on studies conducted by (Henderson, 2001, 2020). In 2001, the distribution of *P. alba* was limited to Gauteng, Mpumalanga, and Free State provinces. Their findings in 2020 indicated its further distribution in Limpopo, KwaZulu-Natal, Western Cape, and Northwest provinces.

Based on introduction status, *P. alba* is reported invasive (Henderson & Musil, 1984; Versfeld *et al.*, 1998; Henderson, 2007; Lioma, 2010; Mararakanye *et al.*, 2017). Based on the national status report of biological invasions, *P. alba* is considered fully invasive, with individuals spreading, thriving, and reproducing in various locations across a wide range of habitats (Van Wilgen & Wilson, 2018). Other included introduction statuses transformer plant (Henderson, 2001) and naturalized (Jordaan, 2005).

Only one paper, conducted in Western Cape Province, focused on its threat (Moyo *et al.*, 2017). In their study, *P. alba* was associated with the fungus, *Cryptosphaera multicontinentalis*. However, the negative impact of these fungi on native species is not proven.

P. alba was initially regulated under category 2 of the Conservation of Agricultural Resources Act (CARA) (Act 43 of 1983). In 2004, the National Environment Management: Biodiversity Act (10 of 2004) was enacted, declaring *P. alba* under category 2 of the Alien and Invasive Species Regulations (2004), as amended in 2020. This means that competent authorities must grant a permit to own, cultivate, harvest, or trade *P. alba*. However, 18 permits have been issued for possession of *P. alba* in South Africa from 2017 to 2022 (SANBI, 2023). It has escaped cultivation and efforts towards its eradication have been reported (Marais *et al.*, 2004; Marais & Wannenburgh,

2008). This points to a significant gap in the research, underscoring the need for more studies to understand the potential impacts and values of *P. alba* on local ecosystems and biodiversity in regions where it is considered an invasive species.

Conclusions and Recommendations

In summary, *Populus alba* is distributed across all provinces in South Africa, with naturalized populations in Mpumalanga, Gauteng, and Free State provinces. The review indicated that *P. alba* is a problem in South Africa and other parts of its alien range. This review recognized the research efforts made in the country and identified all critical information that will assist in its detection for management purposes. Despite its vegetative reproduction, the distribution of *P. alba* is gradually increasing. This necessitates more research on its dispersal methods within the country and its impacts on the environment and livelihoods.

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