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REVIEW

Management of invasive alien plants in forests: A global perspective

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Abstract

1. Forests are critical to the provision of goods and services. They experience many threats including the presence of invasive alien plants (IAPs) which can impact native biodiversity and ecosystem functioning. However, there is a lack of synthesis around outcomes and costs of managing IAPs in forests.
2. We conducted a systematic review to identify (i) where IAP management is reported globally, (ii) which IAP species are being managed, (iii) which methods are being used and (iv) which are the most effective, relative to a control or baseline condition, at managing IAPs in forests.
3. Studies assessing outcomes of IAP management in forests were conducted in 26 countries. The United States dominated the evidence base, accounting for 61% of included studies, covering the widest range of IAP species. This likely reflects a combination of extensive forest cover, high IAP prevalence, and research infrastructure and investment.
4. Across 192 studies, 623 combinations of species and management treatments were studied. Chemical application was most popular (41% of methods) and generally had a high success rate. Most methods had mixed outcomes, with the use of animals for grazing being the most varied. Low replication across treatments made it difficult to draw firm conclusions about management effectiveness.
5. Only 15% of included studies evaluated the effect of seasonal timing on management outcomes, despite evidence from these studies that seasonality can influence success. Furthermore, only 6% of studies reported management costs, and reporting was inconsistent among those that did.
6. *Synthesis and applications*. This review exposes urgent and critical knowledge gaps in forest IAP management, which need addressing to meet global targets for biodiversity and forest health. These gaps include highly uneven global research effort, narrow species focus, limited method replication, overlooked seasonal effects, and inconsistent cost reporting. A strong legacy of using chemical methods may also be deterring efforts to develop non-chemical approaches. Immediate action

is needed to develop standardised methodologies and reporting channels to close these gaps and thus aid informed choice of management options by practitioners.

KEYWORDS
biocontrol, chemical control, evidence synthesis, herbicide, non-indigenous, non-native, weed management, woodland

1 | INTRODUCTION

Invasive alien species (IAS) are one of the top five drivers of biodiversity decline and the second most common cause of species extinctions with 1 in 10 species on the IUCN Red List threatened by IAS (IPBES, 2023; IUCN, 2018). Globalisation and environmental change can facilitate the spread, establishment and impact of IAS (IUCN, 2021; Spence, 2020), thereby increasing the threats posed by IAS (Seebens et al., 2020). The Thematic Assessment Report on Invasive Alien Species and their Control of the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES, 2023) reported that invasive alien plants (IAPs) were responsible for almost half (45%) of the reported negative impacts on nature in the terrestrial realm (IPBES, 2023). Economically, the global cost of IAPs is an estimated US$8.9 billion (Diagne et al., 2021), although this is a gross underestimate (Novoa et al., 2021; Soto et al., 2025). Forests are important habitats worldwide given their extensive provision of goods and services such as carbon storage and sequestration (Gamfeldt et al., 2013; Thomas & Packham, 2007). They also harbour most of the Earth's terrestrial biodiversity with, for example, 60% of all vascular plants found in tropical forests (FAO and UNEP, 2020). While the rate of forest loss has slowed globally since 2000 (IPBES, 2019), current rates are still alarming with a global forest area net loss of 4.7 million ha a year between 2010 and 2020 (Betts et al., 2017; FAO, 2020). Forest creation and tree planting have been proposed as a cost-effective nature-based solution to mitigate climate change and global biodiversity loss (FAO, 2024). Promoting forest restoration by reducing deforestation and anthropogenic degradation has been highlighted as a key strategy to achieve this (Chazdon & Brancalion, 2019; Crouzeilles et al., 2016; FAO, 2024).

However, multiple stressors on forest habitats, including invasion by IAPs threaten progress towards restoration targets and halting degradation (Trumbore et al., 2015; Weidlich et al., 2020). IAPs have been reported to negatively impact the diversity of native flora (Halarewicz & Rowieniec, 2009) and invertebrates (Landsman et al., 2021), alter soil fungal and bacterial communities (Gaggini et al., 2018), affect stand structure including the regeneration of native tree species (Basnet et al., 2016; Langmaier & Lapin, 2020), and impede the movement of animals (Mungi et al., 2020). IAPs can also reduce forest productivity and regeneration which carries economic impacts through a resultant timber value decrease (Jones & Grenz, 2023). Given the impact of IAPs on forest habitats, several studies (Basnet et al., 2016), NGOs (Wildlife and Countryside Link, 2024), policy initiatives (e.g. IPBES, 2023) and the public have called for improved IAP management in forests (Genazzi et al., 2022).

Multiple anthropogenic and geographic factors facilitate the spread of IAPs into forests. Pathways include the deposition of garden waste (Šipek & Šajna, 2020), road construction and traffic (Joly et al., 2011; Son et al., 2024), the presence of adjacent water courses (Čuda et al., 2020), forest machinery (Čuda et al., 2020), land conversion to agriculture (Hardy et al., 2024) and natural disturbances such as storms and flooding (Lake & Leishman, 2004). The rate of spread of IAPs into forests has been increasing over the last century (Golivets et al., 2019).

Effective management of IAPs in general can reduce their spread, and biological and economic impacts (Hanley & Roberts, 2019; IPBES, 2023; Weidlich et al., 2020). The feasibility and efficacy of management methods is dependent on the characteristics of the species (e.g. dispersal mechanisms, ability to form persistent soil seedbanks Gioria & Pyšek, 2016; or reproduce vegetatively Lorenzo & Morais, 2023), the stage and size of invasion, and the local habitat characteristics such as site accessibility (Verbrugge et al., 2019). Therefore, identifying and implementing successful management actions is extremely difficult and costly, especially over large, invaded areas (Verbrugge et al., 2019). A wide range of management approaches have been used for IAPs which can be classified into the broad categories of Biological (e.g. biological control), Chemical (e.g. use of herbicides), Physical (e.g. hand pulling) or a combination of these (Guo et al., 2018; Lorenzo & Morais, 2023). However, managing IAPs in forest habitats is complex, and there is no consensus on the most effective methods or their success.

Dyer et al. (2018) and McConnachie et al. (2016) highlighted the need to carry out management feasibility studies that allow comparison of methods to determine their efficacy and cost-effectiveness before undertaking larger scale management campaigns. This would aid cost-effective allocation and prioritisation of funding for IAP management. Yet, there is limited information on cost-effectiveness of methods, little understanding of method efficacy or which species are being managed in forests globally (Kettenring & Adams, 2011). Additionally, the IPBES report (IPBES, 2023) highlighted the need to proactively consider alternative non-chemical IAP management options, develop better technologies to control widespread IAPs and quantify the cost-effectiveness of various management strategies.

Owing to the increase of IAP invasions and the difficulty associated with their successful management in forests, coupled with the importance of these habitats for combating climate change, an assessment of IAP management in forests is timely. Here we conducted a systematic literature review to summarise (1) the global distribution of reported IAP management in the published literature, (2) which IAP species are being managed, (3) which methods are being used and (4) which methods are most effective, relative to a control or baseline condition, at managing IAPs in forest habitats globally.

2 | METHODS

To evaluate the reported effectiveness of different management methods at reducing IAPs in forests, based on outcome metrics relative to the control or baseline conditions, we reviewed peer-reviewed and grey literature following a systematic review protocol conforming to the Collaboration for Environmental Evidence Guidelines (Pullin et al., 2022). A fully detailed systematic review protocol can be found in Appendix S1 and PRISMA reporting in Figure 1.

2.1 | Search strategy

To guide the Scoping Phase of this systematic review, our research question was identified according to the PICO principles (Pullin et al., 2022). The PICO principles consisted of four statements:

Population. Woodland and forest ecosystems. Woodlands and forests were used as terminology in the search criteria but owing to these terms being used interchangeably, throughout this review, we only refer to forests.

Intervention. Any management/control method with the aim to reduce the target IAP species using the measure of outcome metric relative to the control or starting point.

Comparator. A comparison between a location or time over which a management intervention has been carried out with one where no management intervention has been undertaken; comparison between a baseline assessment that has been conducted prior to management being implemented; or a comparison between management methods.

Outcome. Effectiveness of the management/control method in reducing the IAP using the measure of outcome metric relative to the control or starting point.

The scoping phase was carried out in English and 12 peer-reviewed articles which fit the PICO principles were selected as benchmark articles to guide the Scoping Phase, SI 1. Keywords used in the initial scoping search strings were extracted from the benchmark articles. 'Eradication' was not included in the search string as this was considered an outcome of management via control and/or removal (Prior et al., 2018; Ramsey et al., 2023). Each search string was developed and tested in Web of Science

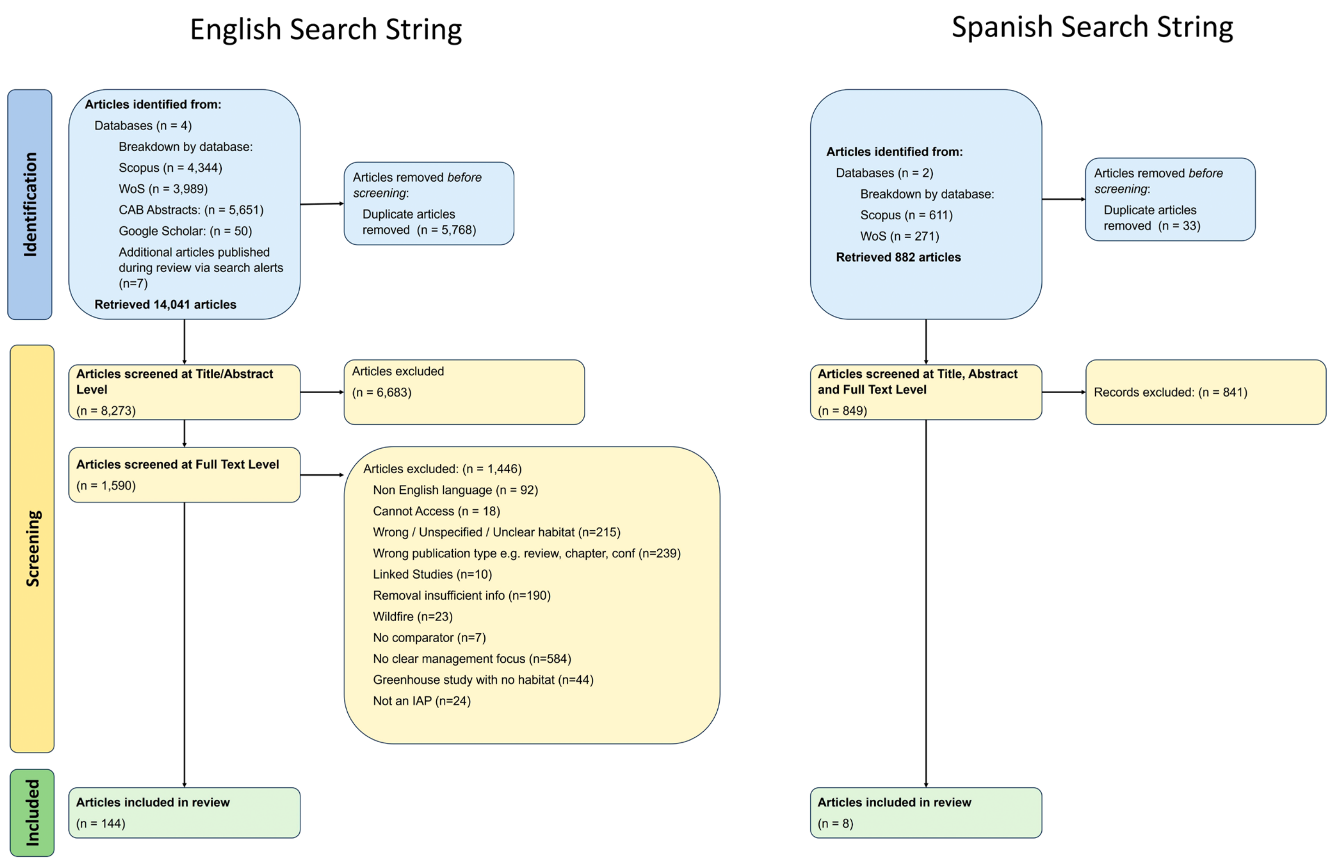

FIGURE 1 PRISMA diagram for the review process, showing the number of articles (represented by *n*) and decisions at each stage for the English and Spanish language search.

and started off broad to maximise the retrieval of relevant results. The search string was made more precise by the addition of words reflecting the range of terminology used to describe IAPs (Golebie et al., 2022). For example, we identified conflicting use of terminology whereby some IAS were only referred to as '*invasive species*' despite being IAS (e.g. Bieberich et al. (2020)). During the development of the search string, the comprehensiveness of each search string was tested through its ability to return the benchmarked articles (Foo et al., 2021). The final search string returned 100% of the benchmarked articles and consisted of four substrings which were combined using the Boolean AND operator. The search consisted of any publications up until 31/12/2022. The search was performed in Spanish and English, using identical methods. The search string and criteria was directly translated into Spanish. However, due to some differences in nomenclature, broader search terms were used. The full search string (formatted for Web of Science), run in 2024, was therefore:

English: (invasive AND (non-native OR nonnative OR "non native" OR alien OR exotic OR introduced OR species OR nuisance OR non-indigenous OR nonindigenous OR "non indigenous")) (Topic) AND (plant* OR flora OR vegetation OR shrub OR tree) (Topic) AND (woodland* OR forest* OR "riparian wood*" OR "riparian forest*") (Topic) AND (control* OR manag* OR remov*) (Topic) Refined by: and 2023 (Exclude – Publication Years).

Spanish: TS=("invas*") AND TS=("no nativ*" OR "exotic*" OR "exótic*" OR "especie*" OR "biol*" OR "introducid*" OR "alien*") AND TS=("planta*" OR "vegeta*" OR "flor*" OR "hierb*" OR "arb*" OR "suculen*" OR "cactus" OR enredadera*) AND TS=("control" OR "gesti*" OR "manej*" OR "erradica*").

2.2 | Databases

Scopus and Web of Science Core Collection were searched for published peer-reviewed articles using the subscriptions of Newcastle University. In addition, CAB Abstracts was accessed via EBSCO to search for specialist articles using the subscriptions of Newcastle University for the English search only. Google Scholar was used to identify grey literature by searching the titles with the simplified search string (owing to a character limit) of: (invasive AND (non-native OR nonnative OR "non native" OR alien OR exotic OR introduced OR species OR nuisance OR non-indigenous OR nonindigenous OR "non indigenous")) AND (woodland* OR forest*) AND (control* OR manag* OR remov*) for the English search only. The results were filtered by relevance and the first 50 articles were exported.

2.3 | Article screening and eligibility criteria

All results from each of the above databases were exported with their Title, Abstract, and Keywords. All results for the English search ($n=14{,}034$) were then imported into EPPI Reviewer (Thomas et al., 2010) where duplicates were removed. The threshold for automatic removal of duplicates was set at 0.9, whereby any articles with a 0.9 similarity score or above were automatically removed and any potential duplicates identified with a score less than 0.9 were manually checked and removed if confirmed. A score of 0.9 has previously been used in reviews, with the application creators advising that above a similarity threshold of 0.8 duplicates are unlikely to be incorrectly identified (Ridley et al., 2022). We are therefore confident that no articles were accidentally removed. After duplicate removal the results were exported into Rayyan (Ouzzani et al., 2016) for screening. All results for the Spanish search ($n=882$) were manually screened for duplicate removal and exported into MS Excel for screening. A total of 8273 articles were screened at Title Abstract level in English and 849 articles in Spanish.

2.3.1 | Screening process

A two-stage screening process was undertaken for the English search; Title and Abstract and Full-text. A one-stage screening process was undertaken for the Spanish search, carrying out Full-text screening immediately for any articles which were included at the Title and Abstract stage. At each stage, all articles were compared against the eligibility criteria for inclusion or exclusion. Two separate criteria were used, one for Title/Abstract and one for Full text. The criteria were identical except that the Full-text screening was more detailed regarding the Comparators to avoid any ambiguity.

Stage one: Title Abstract

Criteria for Title/Abstract screening for the English search was as follows:

Populations. We were interested in multiple habitats in this systematic review. This included any forest habitat (e.g. woodland, semi-natural ancient woodland, ancient woodland, broadleaf woodland, riparian woodland). Any studies which focused on non-woodland/non-forest habitats (e.g. grasslands or aquatic habitats) or any studies which do not mention the habitat type studied were excluded. Any studies that covered the restoration of a habitat had to be restoring the habitat back to forest (e.g. studies which focus on restoring a grassland which has been converted into a forest back into grassland were excluded).

Interventions. We were interested in any study focusing on the effectiveness of any management method for any IAP species following its invasion/presence. Any non-plant IAS were excluded and the IAP had to be invasive AND non-native. Databases, information organisations and governmental websites such as the GRIIS (https://griis.org) and Centre for Agriculture and Bioscience International (CABI) Invasive Species Compendium (https://www.cabi.org/ISC/) were used to establish that a species was both invasive and non-native.

Comparators.We included any study which compared an area or time in which a management intervention had been carried out

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with one where no management intervention had been undertaken. Any study which compared a management method with an alternative method (e.g. hand pulling vs. grazing) was included. Moreover, any studies which investigated different intensities of the same management method (e.g. grazing intensity) were included. Any study carried out in the natural habitat or under greenhouse or laboratory conditions whereby the sample had been taken from the populations specified above was included. Any studies without a baseline assessment prior to management implementation, no comparison with an alternative management method or no comparison with an area where no management had been undertaken were excluded.

Outcomes.We included any studies which compared the efficiency of the management method by comparing the outcomes in relation to IAP density/abundance prior and post-IAP management implementation. Any study which did not study either the efficiency of a management method as defined above was excluded.

Screening was carried out by one person. To ensure consistency in screening decisions, a random 10% of articles were selected for second review at Title Abstract stage. Any disagreements were discussed. After Title/Abstract screening was completed, seven additional articles that were published during the screening process were identified through search alerts and were also screened at the Title/Abstract level, resulting in a total of 8273 articles being screened at the Title/Abstract stage for the English language search. No articles were identified through search alerts for the Spanish language search.

Stage two: Full Text

A total of 1590 articles were manually screened at the Full-Text stage by one person for the English texts and one person for the Spanish texts. Full texts were obtained by manual searching and inter-library loans. The criteria were identical to the Title/Abstract criteria except the Comparators were more detailed for Full text to avoid ambiguity:

Comparators. The study required a clear management focus, for example the title, abstract or aims explicitly state it will investigate the clearance/management/control/removal of an IAP. Management could be in the form of managing the seed bank to reduce above-ground biomass or the direct management of the above-ground biomass. If environmental variables were studied (e.g. canopy alternation) the study had to explicitly state that the aim was to manipulate these to manage IAPs. Articles concerning restoration were included only if they stated they were managing IAPs as part of the restoration. Articles modelling IAP removal were included but they had to use experimental field data. Wildfires, as opposed to prescribed burns, were not included as prescribed burns are typically carried out with the purpose of managing an IAP. If a study looked at factors that may promote invasion/cause spread (e.g. fire) it was excluded unless there was a clear management focus whereby the factor was reported as being a management method. Studies looking at the impacts of invasion (e.g. on fire regime) or establishment/drivers behind encroachment of IAPs were excluded.

2.3.2 | Data coding and extraction

A data extraction template was developed, SI 2, to extract key information for each article included at full-text screening. The key information that was extracted can be broken into the following categories; (i) bibliographic, (ii) study, (iii) stakeholder, (iv) geographical and species and (v) management. Individual articles could report one or multiple management studies. Where an article assessed management of several IAP species or conducted multiple independent experiments on the same species, each was treated as a separate study. Therefore, one article could contain multiple independent studies. Each study could involve multiple management methods or the same method but applied (a) in the same way to a different IAP species or (b) in a different way (e.g. different dose or duration) to the same IAP species. Each time a method was applied to a different IAP species or in a different way, it was recorded as a separate treatment. Consequently, a single article could contribute multiple studies, each comprising one or more treatments using single or multiple management methods.

To assist with data interpretation, each treatment was grouped by management method type and an overarching Category; Physical, Biological, Chemical or Mixed (a combination of two or more of these categories) as used by Guo et al. (2018) and IPBES (2023), SI 2. Management outcomes were categorised relative to the control, comparator or start point as (1) positive—management significantly reduced the IAP based on the outcome metric; (2) negative— management significantly increased the IAP based on the outcome metric; (3) neutral—management had no significant impact on the IAP based on the outcome metric; (4) mixed—when sites had significant conflicting outcomes, such as one site reported a positive outcome but another site reported a negative outcome; (5) insufficient information—when an outcome for a particular method was not reported at the end-point but was reported at other time points ($n=2$, 0.3% of all studies) or more commonly, when an outcome was ranked in success relative to other methods and therefore the outcome could not be quantified objectively.

A reference list of included articles can be seen in Appendix S2. Graphics and analysis were run in R version 4.5.0 (R Core Team, 2023).

3 | RESULTS

In total, 152 articles met the inclusion criteria for this review, comprising 192 individual studies. These studies spanned 26 countries, investigated 99 IAP species, and applied 623 treatments, encompassing 33 management methods grouped into four overarching management Categories.

3.1 | Geographic spread of studies

Most studies were carried out in the USA (*n* = 120), Australia (*n* = 11) and New Zealand (*n* = 8, Figure 2a). Similarly, the USA managed the greatest number of different IAP species (*n* = 50), followed by Australia (*n* = 10, Figure 2b). However, most countries had only published literature on the management of one or two IAP species (Table S1). The Spanish search string yielded three additional countries: Uruguay, Argentina, and Chile.

3.2 | Management methods and outcomes

The majority of the 623 management treatments reported were categorised as Chemical (41%, *n* = 258), followed by Mixed (26%, *n* = 165), Physical (24%, *n* = 147) with less than 10% being Biological (9%, *n* = 53, Table 1). Within each Category the most popular methods were the application of a Single chemical (*n* = 201, Chemical), Mechanical + Chemical (*n* = 62, Mixed), Mechanical (*n* = 110, Physical), replanting invaded sites with native species (*n* = 19, Biological) and grazing animals (*n* = 19, Biological). Many management methods had mixed outcomes, with the use of Animals/grazing having the most varied success (Table 1). The use of Biocontrol, Chemical(s) + Bioherbicide, Single chemical, and Multiple chemicals were the most effective management methods, achieving a high percentage of reported positive outcomes (80%, 95%, 73% and 79%, respectively, Table 1). Interestingly, for the Chemical category, more studies used single rather than Multiple chemicals. Of all 258 chemical treatments, only one negative outcome was reported. Three active ingredients dominated the chemicals being applied: Glyphosate (26%, *n* = 134), Triclopyr (24%, *n* = 124) and Imazapyr (14%, *n* = 73, Table S2). Most studies did not report the chemical application method.

Mechanical methods provided mixed results, with 50% of treatments having a positive outcome. However, although Mechanical methods were the second most popular treatment applied, many studies reported their effectiveness only as rankings relative to other methods, limiting quantitative assessment. Overall, many management methods were only represented by one or two studies making it difficult to draw conclusions on outcomes (Table 1).

3.3 | Invasive alien plant species studied

Just 17 IAP species (17% of those reported upon) had three or more studies on their management, while the majority of IAPs (71 species, 72%) were only studied once, leading to difficulties in drawing conclusions on effective management strategies. Few studies (18%) featured an IAP species being managed using more than five treatments, with the median number of treatments (excluding controls) trialled per study being three (Figure S1 and Table S3). The five most studied IAP species were *Alliaria petiolata* (*n* = 16), *Lonicera maackii* (*n* = 14), *Microstegium vimineum* (*n* = 13), *Ailanthus altissima* (*n* = 8) and *Cytisus scoparius* (*n* = 8, see Section 3.2–3.6 below). Twenty-four IAPs (24%) were managed using one treatment, while only 18 (18%) IAP species had 10 or more treatments tested (Figure 3), predominantly in the USA.

3.3.1 | Growth form

IAP species studied represented a variety of growth forms (Figure S2). When studies were split by continent, North America managed the most varied growth forms (*n* = 9 unique categories), followed by Oceania (*n* = 6) with other continents managing four or less (Figure S2). Africa and Europe mainly managed arboreal IAPs. When assessing plant life history classification, 79% of studies focused on perennials (*n* = 152, Figure S3).

Management outcomes varied by plant growth form. Chemical methods showed positive outcomes across all growth forms, whereas Biological methods exhibited more variable effectiveness, with higher success for vine/climbers than for shrubs (Figure S4). Chemical and mixed management methods were most frequently applied to shrubs, which were the most extensively studied growth form overall.

3.3.2 | *Lygodium japonicum*

Two articles studied *L. japonicum* (vine/climber) management in one country (USA), implementing 30 treatments; all chemical-based management methods. These included applications of Single (*n* = 19 treatments) or Multiple chemicals (*n* = 11), both resulting in a high positive outcome (68% and 100% respectively). For Single chemicals, 26% of outcomes varied between positive and neutral.

3.3.3 | *Lonicera maackii*

Thirteen articles studied *L. maackii* (shrub) management in one country (USA). Some management methods had a low sample size, so lack of replication constrains conclusions. *Lonicera maackii* was mainly managed with Mixed methods (*n* = 28) which included the use of Mechanical + Chemical (*n* = 14) and Chemical(s) + Bioherbicide (*n* = 14). Chemical(s) + Bioherbicide had a 100% positive outcome, whereas Mechanical + Chemical had a 43% positive outcome. However, this was due to outcomes being ranked and therefore not quantifiable. Thereafter, treatments in Chemical and Physical categories were used (Table S3), but low replication (*n* = <4) of treatments for remaining management methods prevents robust conclusions on outcomes.

3.3.4 | *Cytisus scoparius*

Six articles studied *C. scoparius* (shrub) management across Australia, Canada, New Zealand, and USA, together implementing 38 treatments. Some proved highly effective, while others had neutral

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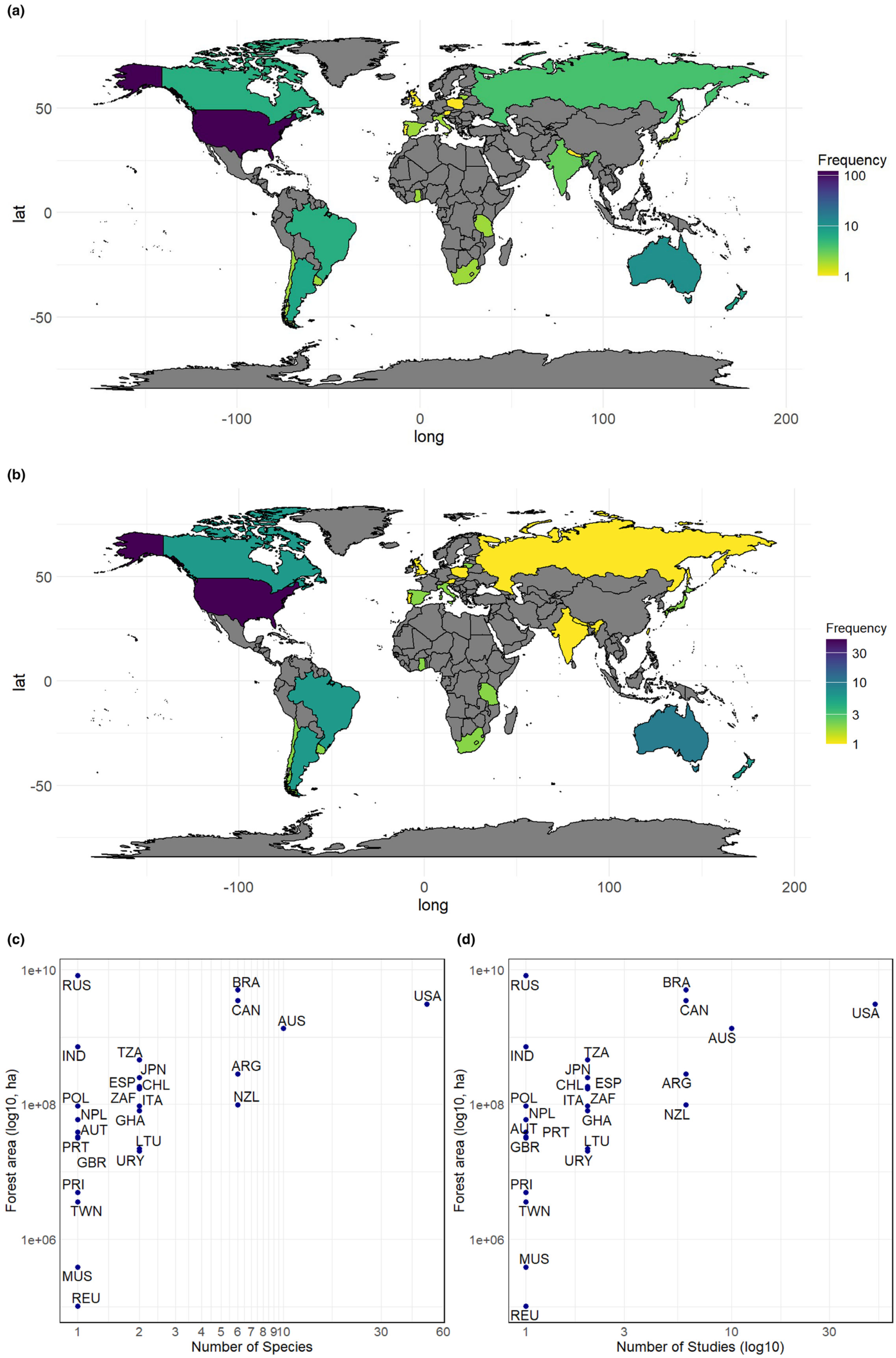

FIGURE 2 Global maps of (a) The log number of studies per country. (b) The log number of unique invasive alien plant (IAP) species studied per country. Scatterplots showing number of (c) IAP species studied compared with forest area (log 10, ha) and (d) Studies compared with forest area (log 10, ha) of each country. Forest area data are from Food and Agriculture Organisation of the United Nations (2020).

TABLE 1 The end-point outcome of each treatment per Management method for each Category where the outcome is expressed as a percentage of treatments per method.

		% of treatments per management method for each category				
Category	Management method	Management effective [positive outcome]	Management increased invasion [negative outcome]	No measurable outcome [neutral outcome]	Mixed effectiveness [mixed outcome]	Ranked/not reporting outcome on IAP abundance/cover [insufficient information]
Biological ($n=53$)	Planting native species ($n=19$)	42.1	0.0	57.9	0.0	0.0
	Animals/Grazing ($n=19$)	31.6	36.8	31.6	0.0	0.0
	Biocontrol ($n=15$)	80.0	0.0	20.0	0.0	0.0
Physical ($n=147$)	Mechanical ($n=110$)	50.0	8.2	18.2	2.7	20.9
	Fire ($n=29$)	41.1	17.2	34.5	0.0	6.9
	Mulching ($n=6$)	16.7	16.7	0.0	0.0	66.7
	Shading ($n=2$)	0.0	0.0	100.0	0.0	0.0
Chemical ($n=258$)	Single chemical ($n=201$)	73.1	0.5	12.4	1.5	12.5
	Multiple chemicals ($n=42$)	78.6	0.0	19.0	0.0	2.4
	Bioherbicide ($n=15$)	60.0	0.0	33.3	0.0	6.7
Mixed ($n=165$)	Mechanical + Chemical ($n=62$)	48.4	1.6	11.3	1.6	37.1
	Chemical(s) + Bioherbicide ($n=44$)	95.4	0.0	2.3	0.0	2.3
	Planting + Chemical ($n=15$)	80.0	0.0	20.0	0.0	0.0
	Mechanical + Planting ($n=7$)	85.7	0.0	14.3	0.0	0.0
	Bioherbicide + Mechanical ($n=4$)	0.0	0.0	0.0	0.0	100.0
	Fire + Chemical ($n=4$)	50.0	25.0	0.0	0.0	25.0
	Fire + Mechanical ($n=4$)	100.0	0.0	0.0	0.0	0.0
	Fire + Nutrients ($n=4$)	50.0	0.0	50.0	0.0	0.0
	Fire + Planting ($n=3$)	66.7	0.0	33.3	0.0	0.0
	Mulching + Mechanical ($n=3$)	66.7	0.0	0.0	0.0	33.3
	Animal + Planting ($n=2$)	0.0	0.0	100.0	0.0	0.0
	Mechanical + Biocontrol ($n=2$)	0.0	0.0	0.0	0.0	100.0
	Mechanical + Shading ($n=2$)	50.0	0.0	0.0	0.0	50.0
	Animal + Chemical ($n=1$)	0.0	0.0	100.0	0.0	0.0
	Chemical(s) + Bioherbicide+Fire ($n=1$)	0.0	0.0	0.0	0.0	100.0
	Chemical + Mechanical + Planting ($n=1$)	100.0	0.0	0.0	0.0	0.0
	Fire + Litter ($n=1$)	0.0	0.0	100.0	0.0	0.0
	Fire + Mechanical + Chemical ($n=1$)	0.0	0.0	0.0	0.0	100.0
	Fire + Mechanical + Planting ($n=1$)	0.0	0.0	0.0	0.0	100.0

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TABLE 1 (Continued)

Category	Management method	% of treatments per management method for each category: Management effective [positive outcome]	Management increased invasion [negative outcome]	No measurable outcome [neutral outcome]	Mixed effectiveness [mixed outcome]	Ranked/not reporting outcome on IAP abundance/cover [insufficient information]
	Fire + Mechanical + Planting + Chemical (n = 1)	0.0	0.0	0.0	0.0	100.0
	Fire + Shading (n = 1)	0.0	0.0	100.0	0.0	0.0
	Mechanical + Chemical + Nutrients (n = 1)	0.0	100.0	0.0	0.0	0.0
	Shading + Chemical (n = 1)	100.0	0.0	0.0	0.0	0.0

Note: Management methods are grouped into one of four Categories: Biological, Physical, Chemical, and Mixed. Single chemical refers to the application of a Single chemical compound (e.g. glyphosate alone) whereas Multiple chemicals refer to the use of two or more chemical compounds (e.g. glyphosate and metsulfuron-methyl). Mechanical refers to physical removal such as hand pulling. Details of outcomes by invasive alien plant species can be found in Table S3. Colour shading is utilized to provide a visual grouping of data by category.

outcomes. *Cytisus scoparius* was mainly managed by Chemicals (n = 28) which included the use of Single (n = 20) and Multiple chemicals (n = 8). Single chemicals resulted in more positive outcomes (95%) compared with Multiple chemicals (63%). Thereafter Physical management, specifically Mechanical (n = 6 treatments), resulted in 50% positive outcomes.

3.3.5 | *Alliaria petiolata*

Sixteen articles studied *A. petiolata* (herb) management, implementing 40 treatments, but were confined to the USA and Canada. *Alliaria petiolata* was mainly managed using Biological methods (n = 15 treatments) which included the use of Planting native species (n = 11) and Animals (n = 4), and Physical methods (n = 15) which included Mechanical (n = 9) and Fire (n = 6). Mechanical methods, Fire, and Planting native species were generally effective, having 78%, 50%, and 64% positive outcomes respectively. However, the use of animals for grazing resulted in a 75% negative outcome. Thereafter Chemicals (Single chemical n = 6) had 83% positive outcomes.

3.3.6 | *Micostegium vimineum*

Thirteen articles studied *M. vimineum* (grass) management in one country (USA), implementing 44 treatments. *Micostegium vimineum* was mainly managed using Chemical methods (n = 17) which included the use of a Single chemical (n = 13), Bioherbicide (n = 3) and Multiple chemicals (n = 1), resulting in 92%, 67% and 100% positive outcomes respectively. Thereafter, Biological (n = 8) was used, which included the use of Animals/grazing (n = 4) and Planting native species (n = 4). Mostly positive outcomes occurred for Animals/grazing (75%), but 25% of studies had a negative outcome. Planting native species resulted in 100% neutral outcomes. Physical (n = 14), which included the use of Mechanical (n = 10) and Fire (n = 4), resulted in 80% and 74% positive outcomes, respectively.

3.4 | Seasonal management

Of the 192 studies, only 15% (n = 29) assessed the influence of seasonal timing on management outcomes. Of these studies, 38% (n = 11) reported that timing of method application was important, as there were significant differences in management outcomes between seasons. Additionally, 7% (n = 2) of studies reported that seasonal timing of management method application was dependent on the management method used, while 10% (n = 3) stated that the importance of seasonal management was site dependent. Across the 29 studies addressing seasonality, 16 IAP species were studied, with most only studied once. However, *A. petiolata* (n = 6), *M. vimieum* (n = 4), *Ligustrum sinense* (n = 2), *C. scoparius* (n = 3) all had multiple studies. For each species, optimal timing of management varied across studies, with conflicting results arising from site-specific

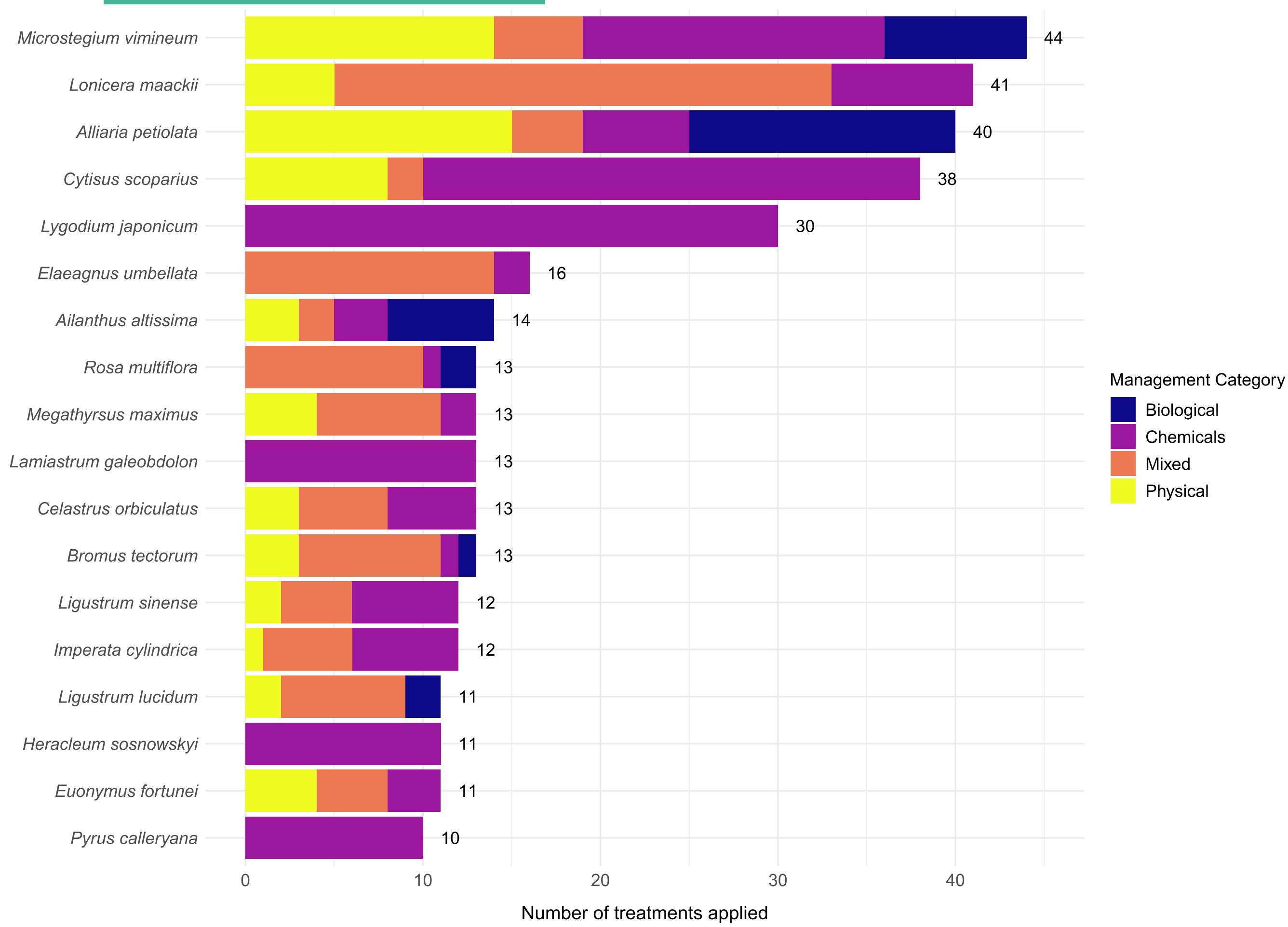

FIGURE 3 Invasive alien plant species found in forest habitats that have been managed by more than 10 treatments across the four management Categories (see Results Section 3.2–3.6 and Table 1).

differences. In some cases, seasonality influenced outcomes at one site but not another or, was important for only one of the management methods applied.

3.5 | Management cost

Only 6% ($n=12$) of the 192 studies reported any cost assessment associated with the management methods used. There were a variety of approaches towards cost reporting which fall into one of five categories: cost to manage a set area/per plant ($n=6$), direct comparisons of cost-effectiveness with other methods ($n=3$), amount of labour required to remove an IAP ($n=1$), total cost of the project ($n=1$) and the time taken to carry out management including a start-up cost ($n=1$). When area was standardised, the costs reported ranged from USD$0.01 to USD$1.20 per metre squared, with trees and shrubs generally being cheaper than grasses. Herbicide application was the most common method for which costs were assessed per given area. Herbicides were cheaper than other methods, such as ring barking, costing USD$0.07 and USD$0.12, respectively. Overall, Physical methods were more costly than Chemical methods (Table S4). The cost per individual plant (excluding grasses which were reported per area) ranged from USD$0.05 to USD$1.73 with trees being more costly to manage than shrubs. However, due to this disparity in measurement units (cost per plant vs. cost per area), direct comparisons across growth forms are not possible.

3.6 | Spatial and temporal scale of management

Twenty per cent ($n=38$) of studies did not provide details on the scale of management. Scale of management application varied across the remaining 154 studies. The most common ways of reporting scale were: number of individuals managed ($n=17$), total area managed ($n=38$), dimensions of the plot managed ($n=99$). The most frequently used experimental plot sizes were 1 m × 1 m ($n=15$) and 2 m × 2 m ($n=11$). Across all studies, 71 different sizes/areas were reported, ranging from 0.5 m × 0.5 m to 1.3 ha. The duration of monitoring for management outcomes also varied, ranging from 24 days to 13 years. Specifically, 8% of studies monitored outcomes for less than a year ($n=15$), 23% for 12–23 months ($n=44$), 26% for 24–35 months ($n=51$), 10% for 36–47 months and 17% for more

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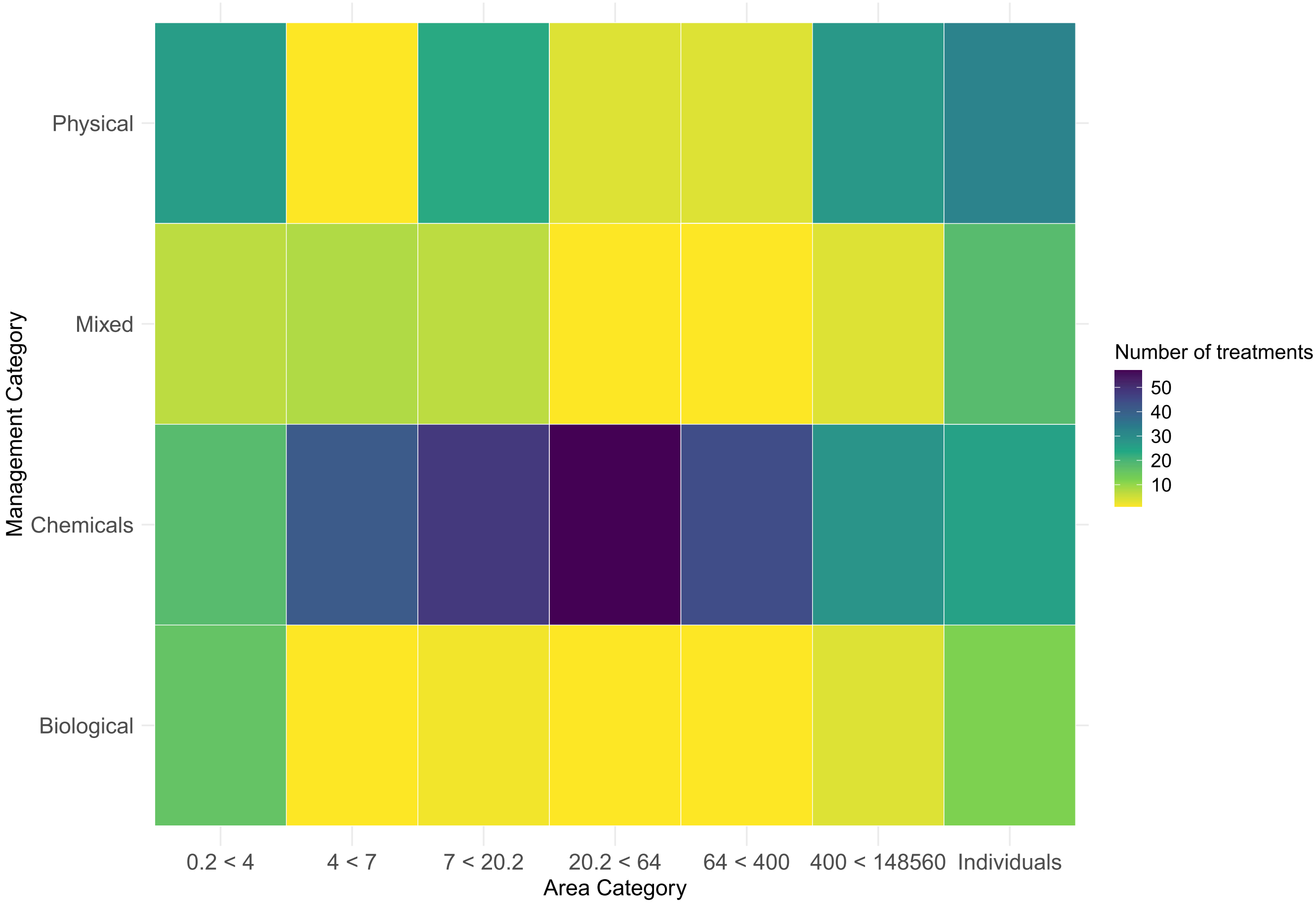

FIGURE 4 Heatmap showing the most frequently occurring management Category of treatments applied within each area (m^2) bin, with an additional column representing individual invasive alien plants, where outcomes were reported per plant rather than area.

than 48 months ($n=32$); 16% of studies did not report monitoring duration (Figure S5). Some treatments were applied at substantially larger spatial scales than others (Figure 4). For example, Physical management methods were generally implemented at smaller scales compared with chemical methods.

4 | DISCUSSION

Despite 192 studies undertaking IAP management in forests, there is no clear consensus on the best management methods for individual species. Chemical methods were most utilised and shown to be broadly effective. Management efforts were focused on a small subset of IAP species globally, with only 18% having 10 or more treatments applied and investigated for outcomes. There was a notable lack of consumable or labour cost reporting, despite numerous calls for this information (Kettenring & Adams, 2011). Furthermore, although seasonality influences plant growth, only 15% of studies evaluated management effectiveness in relation to seasonal timing. Those that did emphasised the importance of incorporating seasonal factors, underscoring the need to consider seasonality when designing context specific management programmes for IAPs in forest habitats.

4.1 | Geographic distribution of studies and species

Most IAP management studies were conducted in the USA. There are several reasons for this. The country has a long-standing commitment to scientific research and funding (Hather et al., 2010), English is the primary language and it has both extensive forest cover (310 million ha, Food and Agriculture Organisation of the United Nations, 2020) and high levels of plant invasions (Pagad et al., 2018, i.e. IAPs have been reported in up to 94% of randomly placed plots in forests across the United States USDA, 2014). In addition, the United States hosts one of the largest commercial forestry industries globally, further incentivising investment in research and management of invasive plant species within production forests (Butler & Sass, 2023). Similarly, countries with large forest areas and/or high IAP numbers, such as Brazil, Argentina, Canada, New Zealand, and Australia, were also among the most studied. In addition, these patterns are likely reflective of high-income countries publishing more research on management. However, some countries with high forest cover and IAP presence, like China, India, and Russia, had few or no studies. Language limitations in this review (English and Spanish) may have influenced these findings and we acknowledge that the inclusion of non-English sources can enhance data completeness and reduce apparent knowledge gaps (Angulo et al., 2021). Additionally, 215 articles (15% of total articles at full-text level) were excluded due to unclear habitat information, such as citing studies being carried out in a 'nature reserve'. Underrepresentation of certain countries, such as the Democratic Republic of the Congo and Peru (both with high forest cover) were expected owing to them having a low reported number of IAPs present and therefore a lower probability of IAP invasions in forests. Countries with both low IAP (Pagad et al., 2018) numbers and lower forest cover (FAO, 2020), like Liechtenstein, Tuvalu, and Oman, also had limited or no studies.

4.2 | Management methods and outcomes

Chemical management was the most studied Category and among the most effective methods for reducing IAP abundance in forests, however, chemical application methods were rarely defined. Its prevalence in management may be self-reinforcing due to its high effectiveness. In contrast, the limited research on non-chemical methods, coupled with small sample sizes and varied approaches, creates uncertainty about their effectiveness, potentially discouraging further investigation. Stakeholders often favoured chemical methods over biocontrol and mechanical approaches, citing their practicality and reliability (Osunkoya et al., 2019), likely due to significant research investment. Despite the apparent effectiveness of chemical management there is controversy surrounding their usage. This includes potential non-target effects (Florencia et al., 2017), the partial ban or phasing out of chemicals such as glyphosate (USDA, 2021) and full bans of chemicals such as Paraquat in the European Union (European Court of Justice, 2007). The chemical active ingredients used within the included studies were split equally between broad-spectrum and selective herbicides, with two of the top three most used chemicals being broad-spectrum (glyphosate and Imazapyr). Stem injections, rather than foliar sprays, can minimise non-target impacts (e.g. human health, Ahmad et al., 2024; native biota Rani et al., 2021; and reduce costs Novoa et al., 2019) but are not always appropriate for non-woody species, such as *Impatiens glandulifera* (RAPID, 2018). When foliar sprays are the only options, weed wipers and spot treatments with a hand lance can improve accuracy of spraying and therefore increase the selectivity of non-selective herbicides (RAPID, 2018). However, continued use of chemicals may lead to some IAPs developing resistance to one or more herbicides (Hutchinson et al., 2007). Despite the effectiveness of chemical management, non-chemical methods are needed to prevent resistance and manage IAPs where stem injections and foliar spray are impractical.

Within the Biological management category, Biocontrol (the use of living organisms like insects or pathogens to manage IAS, as defined by CABI) had mostly positive outcomes (80%) in reducing IAP abundance in forests. Across seven countries, nine IAP species were managed by one host-specific biocontrol agent (Table S5). *Ailanthus altissima* was unusual in being managed by two different biocontrol agents. The high management success rate likely reflects rigorous pre-release testing to ensure effectiveness when released in situ. Despite management success, biocontrol was one of the least applied methods in our review. This may reflect high cost and country specific regulations (Barratt et al., 2018). For example, in New Zealand, regulatory approval to test and release a new agent is estimated at NZ$364,550 and NZ$138,300 for a repeat agent (Ehlers et al., 2020). Comprehensive pre-release testing, development restrictions and constrictive regulatory processes coupled with rigorous risk assessments can be time consuming (Barratt et al., 2018). In addition, the publicised cases of non-target effects of agent release, prior to the implementation of highly comprehensive pre-release testing, have driven negative perceptions of biological control, which may slow or prohibit the development of new biocontrol agents (Hinz et al., 2014). Bulk investment when developing a biocontrol is devoted to the screening and development of agents, with few resources being allocated to post-release monitoring (Havens et al., 2019). Furthermore, post-release studies to validate success or decisions to release an agent are rarely required by regulators and therefore valuable information on post-release impacts and effectiveness are lost (Barratt, 2011). More biocontrol studies may exist for IAP management in forests but are potentially not published due to the lack of mandatory post-release monitoring. All included studies involved field releases rather than laboratory studies, as laboratory studies did not report the source habitat of the IAP material (e.g. riverine vs. forest habitats).

Biological management of IAPs using grazing animals in forests yielded mixed outcomes. Coupled with logistical and animal welfare considerations, the practicality of grazing as a general management method requires further investigation. For example, an included article by Eschtruth and Battles (2009) assessed the impact of *Odocoileus virginianus* density on *M. vimineum* utilising three grazing intensities: low, medium, and high. They found positive outcomes at low and medium densities but negative outcomes at high density, suggesting that grazing intensity influences IAP management success and may explain outcome variability. The same methodology was applied to *A. petiolata* and *Berberis thunbergii*; however, all grazing densities had a negative outcome and were therefore not successful (Eschtruth & Battles, 2009). This suggests that grazing may be unsuitable for certain IAPs, and/or some IAPs and animals are incompatible owing to the combination of feeding preferences and plant traits. Goats, cattle, and deer were the primary grazers used, but limited replication prevents conclusions on whether grazer type influences outcomes. Our understanding surrounding the interaction between density, IAP and animal species is minimal, and further research into these interactions is required.

Mechanical management methods within the Physical category were most popular but showed varied outcomes, reflecting the variety of methods used such as hand pulling (Stinson et al., 2007) and girdling (Annighöfer et al., 2012). Hand pulling offers short-term efficiency and requires repeated implementation for sustained control to ensure all individuals are removed (Tu et al., 2001). The duration and frequency of hand pulling IAPs varied between studies, resulting in mixed outcomes. Outcomes were always positive when ring debarking, scything, and mowing were applied, whereas soil scarification, hand removal, felling, and girdling had more varied outcomes (Table S6).

The Mixed category included management studies which had generally high success rates, suggesting that combining methods enhances their effectiveness (Clements et al., 2021). A total of 23 treatment combinations were studied across included articles. Four combinations accounted for 78% of the management treatments, with the majority using chemicals with other techniques. Positive outcomes of over 80% were documented for three of these combinations: Chemical(s) + Bioherbicides (n = 44 treatments) 95%, Planting + Chemical (n = 15) 80%, and Mechanical + Planting (n = 7) 86%. Mechanical + Chemical (n = 62) had a lower positive outcome of 48%, which may be reflective of many treatment outcomes (37%) being only ranked relative to other methods, and therefore not being quantifiable. These findings suggest that some combinations of methods can enhance success, while others have antagonistic effects. Integrating assessment of method combinations into future management studies may prove valuable.

4.3 | Species managed

Data on IAP presence in forest habitats by country is limited, making it unclear whether management effort or success aligns with invasion risk or impact. Of the 99 unique IAP species studied, 71 were examined in only one study, with five IAPs accounting for 31% of studies. However, only one of these species is in the top 100 most widespread terrestrial invaders. By contrast, *Lantana camara* is recorded in 87 countries (Turbelin et al., 2017), recognised as one of the worst terrestrial invaders globally (Lowe et al., 2000) and readily invades forests (tropical dry forest, see Hardy et al. (2024)), threatening, for example, 44% of forests in India (Mungi et al., 2020). Yet, only four studies assessed management efficacy relative to a control or baseline condition (n methods = 6) of *L. camara* in forests across two countries (India n = 3, Australia n = 1). As a result of the criteria required for quantitative assessment, some relevant studies may have been excluded, potentially contributing to the apparent lack of evidence. However, this also highlights the need for future studies to include clear controls or baselines to enable quantitative comparisons. This trend is also observed for other widely distributed species that invade forests (Bakewell-Stone, 2023; Martins et al., 2011), such as *Leucaena leucocephala* (n = 66 countries) and *Ricinus communis* (n = 76 countries) (Turbelin et al., 2017), neither of which had studies included in this review. In contrast, *M. vimineum* was the most managed species, despite only being recorded as an IAP in three countries, whereas *A. altissima*, recorded as an IAP in at least 46 countries (Pagad et al., 2018), was the focus of only 14 studies.

For many IAPs it is difficult to draw conclusions about effective management methods due to the limited number of trials or replicates per method. However, where various treatments in different management categories were applied to a single species such as *A. petiolata*, results show that grazing was ineffective (Eschtruth & Battles, 2009; Martinez & Dornbush, 2013) and Single chemicals were effective (Frey et al., 2007; Shartell et al., 2012; Slaughter et al., 2007). For *C. scoparius*, Single chemicals had the most positive outcome (Haubensak et al., 2020; Oneto et al., 2010) but using more than one chemical type (Multiple chemicals) reduced efficacy and management success (Watt & Rolando, 2014). Conversely, both Single and Multiple chemicals for *M. vimineum* were highly effective (Flory, 2010; Johnson et al., 2015; Judge et al., 2005, 2008; Smith et al., 2022; Ward & Mervosh, 2012), with Mechnical methods also being generally successful (Cutway, 2017; Flory, 2010; Flory & Lewis, 2009; Judge et al., 2008; Tekiela & Barney, 2017; Ward & Mervosh, 2012). In addition, Physical methods were more successful for herbaceous IAP species than for trees. This may reflect the variety of Physical management methods, such as Hand Pulling (Herold et al., 2011; McAlpine et al., 2018), primarily used for herbs whereas trees were managed using a wider range of methods (Webb et al., 2001), leading to more variable outcomes. Nonetheless, Physical methods generally produced positive outcomes across both growth forms.

4.4 | Seasonal implementation of management

Our results showed that accounting for seasonality contributed to the success of IAP management in forests. IAPs may be more vulnerable to management during active growth periods (Graziano et al., 2022) particularly before seed set, when interventions can reduce further spread (RAPID, 2018). Seasonal weather conditions may also influence the effectiveness of management techniques (Mark, rtz, & Heim, 1996). Seasonal timing was shown to be important when managing *M. vimineum* by Flory and Lewis (2009) but unimportant by Judge et al. (2005) and Eschtruth and Battles (2009). Whereas Ward and Mervosh (2012) found seasonality affected the efficacy of some, but not all, management techniques for *M. vimineum*.

The outcomes of seasonal management were inconsistent, even when identical treatments were applied to the same IAP species. The use of fire to manage *M. vimineum* in Indiana, USA, was more successful in autumn compared with spring (Flory & Lewis, 2009). Whereas in Connecticut, USA, seasonality did not affect the efficacy of fire in managing *M. vimineum* invasions (Ward & Mervosh, 2012). This suggests that while the method applied is important, ecoregion may also moderate the influence of seasonality on management. This trend was seen across other IAP species whereby Herold et al. (2011) found that hand pulling *A. petiolata* in May (late Spring) was significantly more effective at reducing cover than in March (early Spring) in lowland woodland which was occasionally flooded. Whereas in well-drained upland woodland the timing of management (May compared with March) did not impact the management outcome. Local conditions are therefore likely to influence seasonal management efficacy and should be considered when designing management campaigns. Identifying the optimal season for IAP management depends on both the method and the species' growth form. However, with only 29 studies explicitly investigating seasonal effects, definitive recommendations cannot be made. Some patterns were evident: fire was generally more effective in autumn than in spring or summer, and grasses tended to be more successfully managed in autumn. Whereas trees required management in spring or summer, likely due to higher efficacy during active growth periods (Graziano et al., 2022).

4.5 | Management cost

Inclusion of broad cost estimates, as a minimum, is essential for decision-making and ensuring the effective allocation of resources for managing IAPs (Boyd et al., 2015). Yet, only 6% of studies included in this review reported management cost information. Generally, cost per individual plant was used for trees whereas cost to manage a set area was used for grasses, herbs, and shrubs. Studies reporting costs per area did so in various ways, for example, per metre^2 (Lowry et al., 2022), per 1 ha (Ramdu et al., 2020) and 1.5 ha (Malla et al., 2021). Other studies (see Hanula et al., 2009) reported either cost-effectiveness relative to other methods, without numerical data, or values featured only in the Supporting Information (Florido et al., 2022). This complicates cost comparisons between management methods due to inconsistent reporting and varying measurement units. Various studies have summarised management cost estimates of IAS more generally. For example, Fernandez et al. (2023) estimated the global cost of invasive alien tree management to be USD$1.2 billion and Soto et al. (2025) suggest a global estimate of >USD$50 billion to manage IAPs. However, these costs are not specific to IAP management in forest habitats and cost patterns are likely to be context dependent, varying with regional labour costs.

4.6 | Spatial and temporal scale of management

Variation in the size of managed areas complicates evaluation of management outcomes, limits feasibility assessments for scalability, and hinders comparisons between studies. For example, the median area managed for hand pulling was 4 m^2 whereas felling was carried out over at least 0.5 ha. Methods effective at smaller scales may not perform as well at larger scales, and some approaches, such as hand pulling (Meier et al., 2014), may not be feasible or scalable across all contexts. Hand pulling applied at small spatial scales (0.5 × 0.5 m; n = 16 treatments) resulted in 100% positive outcomes. In contrast, when applied at larger scales (≥2 × 2 m; n = 22 treatments), hand pulling achieved positive outcomes in 55% of cases and neutral outcomes in 45%, highlighting limitations in the scalability of this method. Temporally, over half of management studies monitored outcomes for less than 35 months post-management application, indicating limited long-term assessment of IAP management in forests. This may reflect the ongoing costs of monitoring, perceptions of management effectiveness reducing the need for further monitoring, or the discontinuation of ineffective approaches.

5 | CONCLUSION

Global IAP management in forests is fragmented, with diverse methods applied and only a few select species studied in any depth. This review highlights significant knowledge gaps and inconsistencies when managing IAPs. Some species received significant research attention that yielded varied outcomes based on method, season, and location. Many of these focal species are not listed as being among the worst global invaders while widespread problem species such as *L. camara* have been largely neglected. The USA dominates management literature included in this review, underscoring an urgent need for research in other invaded forested regions such as China, India, Russia, Tanzania, and Zambia. To maximise resources, studies must standardise cost reporting and methodology, including management area, seasonality, and provide treatment application details for chemicals. A simple unified reporting framework would improve data sharing, guide future management, and engage practitioners in reporting outcomes. While effective methods exist, they are predominantly chemical based. Future research should explore non-chemical alternatives, investigate barriers to IAP management, and ensure standardised reporting. Strengthening practitioner engagement and data harmonisation will enhance global IAP management efforts and their effectiveness.

AUTHOR CONTRIBUTIONS

Lizzie Keen, Zarah Pattison, and Nigel J. Willby conceived the research idea and designed the review protocol. Lizzie Keen and James Hardwick conducted the English data collection and article screening. Rocío Gómez and Ana Novoa conducted the Spanish literature search. Lizzie Keen carried out all analyses of results. Aileen C. Mill provided insight into the topic and offered guidance on the analyses. All authors contributed to finalising and interpreting results from analyses. The first draft of the manuscript was written by Lizzie Keen and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript and manuscript revisions.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

Data available via Zenodo https://doi.org/10.5281/zenodo.19741048 (Keen et al., 2026).

STATEMENT ON INCLUSION

Our study is a global review and was based on extracting information of secondary data as opposed to primary data collection. As a result, there was no local data collection. The authorship team contains members fluent in Spanish and English, which supported the inclusion of data from peer-reviewed studies published in both English and Spanish and ensured the appropriate interpretation of data and results in these languages.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

Figure S1. The number of unique management methods looked at in each study.

Figure S2. A summary of the growth form for each invasive alien plant in each study overall and per continent.

Figure S3. A summary of the life cycle classification for each invasive alien plant in each study overall and per continent.

Figure S4. Bubbleplot of the average outcome per management theme for each growth form type recorded. Growth forms were classified utilising CABI digital library and Kew Plants of the World Online.

Figure S5. The duration of study, and therefore, the duration of monitoring the management method outcome post-management application.

Table S1. A breakdown of the number of studies per country and the number of studies for each invasive alien plant studied per country.

Table S2. Table of the active ingredients of chemicals specified as being used across all chemical-based treatments (herbicides, mixture treatments, single chemical, and multiple chemical).

Table S3. A table summarising the methods used per each species and the outcome of each method.

Table S4. A summary of species whereby the cost to manage them was reported along with cost information.

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Table S5. A list of the IAP species that biocontrol was applied to including the biocontrol agent used, the country of release and the end-point outcome.

Table S6. summary of the outcomes for different mechanical methods when broken down.

Appendix S1. Systematic Review Protocol.

Appendix S2. Included Paper Reference list.

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