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Review

Forest pests in 21st century Britain: a review of impacts and management

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Abstract

Threats to trees and forests from insect pests are increasing as a result of the globalization of trade and climate change. Impacts are greatest when insects attack hosts lacking evolutionary resistance. Preventing the establishment of new, non-native forest pests—defined here as insect species posing economic or ecological risks to trees—and reducing damage from existing ones is essential for sustaining forest ecosystem services, including timber production, carbon sequestration, and biodiversity. This study provides a comprehensive assessment of forest pests in Britain, identifying 56 pest species of concern. Fifteen are native, while the remainder originate from mainland Europe (27), Asia (10), North America (9), and Australia (1). A structured scoring system showed pest pressure continues to rise through increasing detections, but more recently detected pests are not necessarily more damaging than those detected earlier. Key drivers of pest establishment and impact included trade, climate, and tree stress. Forest management acted as both a driver of pest problems and a mitigator of damage. Pine, spruce, and oak experienced the greatest pest pressures. Two beetles—the native large pine weevil and the non-native great spruce bark beetle—were classified as having very high impact. Ten additional pests were rated high impact affecting both conifer and broadleaf hosts under varied management regimes. Most species (44) were scored as low to medium impact under current conditions, although several have caused substantial damage historically, in other regions, or under different environmental or management conditions. Native and non-native species occurred across all impact categories. Only 4 pests were intensively managed, and 7 routinely managed; the remaining 45 species received minimal or no management effort. Five species were identified as potentially under-managed relative to their impacts, highlighting opportunities to better align management effort. Overall, forest pest management in Britain only partially aligned with Integrated Pest Management (IPM) and Sustainable Forest Management principles, relying heavily instead on natural regulation. This emphasizes the need to embed core IPM practices to prevent further pest establishment, reduce damage, and strengthen long-term forest resilience under future environmental changes.

Keywords Integrated Pest Management, Tree Health, Climate Change, Sustainable Forest Management, Global trade, Great Britain

Introduction

Insects that feed on the roots, bark, or foliage of trees perform essential ecosystem functions, contributing to nutrient cycling and forming a key trophic level within forest food webs (Scudder 2017). Under certain conditions, however, herbivorous insects can cause extensive tree damage or mortality. Such events may be triggered by environmental change, forest management practices, or the introduction of insect species into new regions where host trees lack evolved defences and natural enemies are absent or ineffective (Whitehill et al. 2023). This paper is concerned specifically with insect species that pose economic or ecological risks to trees—hereafter referred to as forest pests.

Globally, the threat from forest pests is increasing. The globalization of trade has provided entry routes for invasive organisms, via the importation of infested wood products, wood packaging material, as well as seeds and plants (Roy et al. 2014a, 2014b). Britain is particularly vulnerable to new pest incursions due to its long-standing reliance on imported planting material and forest products. Although restrictions on plant imports have tightened in recent years, the UK remains the second-largest net importer globally of forest products (including sawn wood, wood panels, and wood packaging) and has imported over 40 million cubic meters of wood raw material equivalent (WRME) annually since the 1980's (Forest Research 2024a).

In addition to globalization, climate change further exacerbates forest pest threats. Rising temperatures can shorten insect generation times, increase fecundity and survival, and extend flight periods, thereby promoting population growth and spread, although negative effects, such as lethal high temperature events, may also occur (Pureswaran et al. 2018). Indirect climate change impacts include shifts in host tree distributions, changes in host resilience, and

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disrupted synchronicity between forest pests and their hosts (Ramsfield et al. 2016), all of which can alter pest pressure and outbreak dynamics. Climate change also affects the abundance and effectiveness of natural enemies, with both positive and negative consequences (Jactel et al. 2019). Forest management practices can similarly influence pest dynamics. The establishment of large monocultures, clear-fell and restock regimes, and the retention of deadwood can all provide abundant breeding material, facilitating population increases (e.g. Leather et al. 1999).

As pest pressures intensify, so too do their impacts on the ecosystem services provided by forests. British forests contribute to climate mitigation (carbon storage), timber and wood fuel supply, biodiversity, water quality, recreation, soil protection, and flood regulation (Sing et al. 2018). These services are valued at £382 billion, with timber and wood fuel contributing £14.8 billion (Office for National Statistics 2024a).

Despite the importance of forestry, woodland cover in the UK remains low at 14% of land area, compared with an European average of 46% (Forest Research 2024b), although it has increased from a low of 5% after the First World War aided by the planting of large, predominantly non-native conifer plantations (Forestry Commission 2019). Today, 52% of UK woodland is broadleaf, dominated by birch (*Betula* spp.), oak (*Quercus* spp.), European ash (*Fraxinus excelsior* L.), sycamore (*Acer pseudoplatanus* L.), and European beech (*Fagus sylvatica* L.) (Forest Research 2024b). The remaining 48% is conifer, with Sitka spruce [*Picea sitchensis* (Bong.) Carr.] representing the most widespread species (54% of conifer area) (Forest Research 2024b). Other conifer species include native Scots pine (*Pinus sylvestris* L.), and non-native larches (*Larix* sp.), lodgepole pine (*Pinus contorta* Dougl.), Norway spruce [*Picea abies* (L.) H. Karst.], and Douglas-fir [*Pseudotsuga menziesii* (Mirb.) Franco] (Forest Research 2024b).

There is substantial pressure to increase tree planting as part of the UK's climate mitigation strategy (Defra 2021a, Climate Change Committee 2023). However, forest pest pressures—alongside diseases, nursery stock shortages, land-use competition, workforce limitations, and complex grant schemes—have contributed to the UK Government's failure to meet its target of planting 30 000 ha per year by 2025 (House of Commons Environmental Audit Committee 2023). Planting rates averaged only 14 800 ha per year between 2019 and 2024 (Forest Research 2024b). In parallel, the UK Government has reaffirmed its commitment to sustainable forest management through the UK Forestry Standard (Forest Research 2023a) and through international agreements such as the Bonn Ministerial Declaration (Forest Europe 2024), which emphasizes the need to enhance forest resilience and reduce vulnerability to invasive insect pests. Public and political awareness of tree health threats in the UK has also grown since the arrival of ash dieback (Chalara disease) in 2012 (Fellenor et al. 2019).

Despite these developments, a comprehensive, up-to-date assessment of the forest pests affecting British trees is lacking. Evans (1997) provided the last major review, updating Munro's (1927) earlier work and documenting forest pests that emerged during the 20th century. Since then, forest pest incursions into the UK have increased markedly (Freer-Smith and Webber 2017, UK Government 2023). Although improved surveillance may partly explain this rise (Poland and Rassati 2019), the scale of the threat is underscored by the ∼300 insect species on the UK Plant Health Risk Register that potentially pose direct or indirect risks to trees if populations establish in the UK (Defra 2025).

This study aims to identify the insect pests that currently threaten British trees and forests, assess how these pests have changed over time, and evaluate factors driving these changes. It also reviews current approaches to pest mitigation and management. By synthesizing available evidence, this study seeks to highlight key knowledge gaps and inform future research and policy. Specifically, it examines patterns in the origins, drivers, and management of forest pests in Britain, and evaluates how these reflect the principles of sustainable forest management. We hypothesize that both the number of forest pests present in Britain and overall pest pressure have increased, driven by global trade, climate change, and heightened tree stress.

Materials and methods

Although broader contextual information relevant to the UK is presented elsewhere in the manuscript, the pest dataset and subsequent analyses were restricted to Great Britain. Great Britain constitutes a geographically coherent landmass with connected forest ecosystems and invasion pathways, making it an appropriate unit for assessing forest pest occurrence and establishment. This approach is also consistent with previous reviews of forest entomology that focused explicitly on Great Britain (Munro 1927, Evans 1997). Throughout this study, 'Britain' refers to Great Britain (England, Scotland, and Wales) unless stated otherwise.

This study comprised four main stages: (i) compilation of a list of forest pests present in Great Britain, (ii) review and synthesis of the relevant literature for each species, (iii) development of an impact-scoring framework, and (iv) analysis of forest pest origins, impact drivers, and current management approaches.

Forest pest species compilation

A list of insect species that are classified as forest pests and are native to or have become established in Britain was compiled via an extensive literature review. An initial list of 22 forest pests found in Britain prior to 1997 was extracted from 2 review papers published 70 years apart (Munro 1927, Evans 1997). An additional four species were added to this list from cross-checking against 'Part Two: Principal Forest Pests' in Bevan (1987). Further forest pests that have arrived in Britain since 1997 were added to this list as follows. The UK Plant Health Risk Register (Defra 2025) was downloaded on 20 March 2025 and filtered for 'insects' classified as 'forest tree pests' with a UK status of either 'present' (limited, unknown distribution, or widespread) or 'unknown', the latter applied to two species. This filtering returned 45 species. Although it was not possible to exclude Northern Ireland from the search, subsequent checks confirmed that all retained pests are present in Great Britain. Twelve species associated with trees other than those in forests and woodlands (e.g. orchards, shrubs) were removed. Seven records were duplicates of those already listed, leaving 25 species to be added. Lastly, five more species were extracted from internal annual reports produced by Forest Research's Tree Health, Diagnostic and Advisory Service between 2015 and 2023, see source list in Table 1. Pests listed as groups (e.g. Ambrosia beetles) were excluded from analysis but were revisited in the discussion. This process produced a final list of 56 forest pest species for analysis, which are ordered by impact score and then by year of detection (Table 2 and Supplementary_material_1_ForestPests.xlsx).

Literature search

A literature search was conducted to identify scientific publications relating to forest pests, particularly those identified in step one, and their management in Britain since the review by Evans (1997). Three broad search themes were defined: 'insect pest', 'management', and

Table 1 Number of British forest pest species identified from five key sources. Columns report the total forest pest species mentioned in each source and number of unique species added from each to the British forest pest list in this study.

Source	Total number of principal forest pests mentioned	Number of new species added to forest pest list in this study
Munro 1927	11	11
Bevan 1987	15	4
Evans 1997	29	11
Defra 2025	32	25
Forest Research 2023b	83	5
Total	170	56

'forest'. For each theme, associated search terms were compiled (Table 3) and combined into a full search string used in Scopus (Supplementary_material_2_Full_SCOPUS_search_string).

The search was restricted to peer-reviewed articles and reports published in English between 1997 and 2025 and containing evidence directly relevant to Britain. Titles and key words were screened to remove papers unrelated to forest pests or forest management. Where no recent research existed for particular forest pests, older publications were retained. Additional species-specific searches were conducted in Google Scholar to identify literature not indexed in Scopus, for example several key accounts of recently detected forest pests were located in specialist journals, including *The Entomologist's Record and Journal of Variation* and *The British Journal of Entomology and Natural History*.

Papers identified as relevant were reviewed in full, whereas partially relevant papers—typically those providing comparable information from other forest systems—were revisited to support contextual comparisons in the discussion. Information relating to forest pests, including their impact, status, and management in Britain, was extracted from the selected papers and collated in an Excel table under 22 headed columns, see list of column headings and summary of the information captured under each heading in Table 4. A full detailed version of this results table is available as Electronic Supplementary Material (Supplementary_material_1_ForestPests.xlsx), whereas a reduced version is presented in the results (Table 2). Data were then imported into R 4.4.2 using RStudio to be summarized and analysed, as detailed below.

Impact score method

A simple scoring system was developed to compare the impact of forest pests listed in Table 2, focusing on their current threat to British trees and forests, rather than past or potential future impacts. As quantitative data varied widely across species, three factors were assessed using indicative scores: distribution in Britain (0 = not present, 1 = present—restricted, 2 = present—localized, 3 = present—widespread), pest management effort (0 = none, 1 = minimal, 2 = routine, 3 = intensive), and damage severity (0 = negligible, 1 = occasional, 2 = regular, 3 = severe), as defined in more detail in Table 4. Distribution was weighted equally with damage and management because the spatial extent of a pest strongly influences its overall impact; widespread pests can impose substantial cumulative effects even when per-tree damage is moderate. Management effort was included because it provides an indicator of the operational consequences of pest presence. These scores reflected the overall level of resources and operational activity directed towards a pest, including surveillance, control and eradication measures where applicable, but did not include passive regulation through biotic resistance. In contrast, management categories (see 'Distribution of management effort') describe the type of management activity employed and were analysed separately. The three scores were summed to produce an overall impact score from 0 (lowest) to 9 (highest) for each forest pest. Two additional metrics were calculated by multiplying the distribution score with the management and damage scores to identify pests where management effort or damage severity is disproportionate to their current distribution. The scoring system was intended as a transparent comparative framework rather than a formal risk assessment and necessarily involved expert judgement where quantitative evidence was limited.

Analysis

Biogeographic origins and introduction patterns

Forest pest origins

Forest pest origins were assigned to seven biogeographic regions: native (Great Britain), mainland Europe, Asia, Africa, North America, South America, and Australia. Region-level pie charts showing the proportional representation of insect orders were plotted on a world map using *rnaturalearth* and *sf*, with pie size scaled to species richness. UK goods import volumes (2018–2023; Office for National Statistics 2024b) were summarized using *dplyr* and *countrycode* and visualized as arrows proportional to import volume. Africa and South America were retained as import origins despite no forest pests being identified from these regions.

Temporal trends in pest introductions

Annual forest pest detections were grouped by non-native origin region (North America, Asia, Australia, mainland Europe). Cumulative counts were calculated across years to visualize long-term introduction trends.

Impact scoring and distribution of pest severity

Distribution, management, and damage scores

Forest pest counts were plotted by impact scores (0–3) across three categories: distribution, pest management effort, and damage severity.

Overall impact scores

Overall impact scores were grouped into four categories: Low (0–2), Medium (3–5), High (6–7), and Very High (8–9). Forest pest counts within each category were then summarized by insect order and visualized using a stacked bar chart to compare how impact severity is distributed across major taxonomic groups.

Impact scores per origin

Impact scores were compared across origins using a Kruskal–Wallis rank sum test (Australia excluded due to $n < 3$). Where the overall Kruskal–Wallis test was significant, pairwise comparisons were conducted using Dunn's tests with Bonferroni correction. Distributional patterns were visualized using boxplots.

Impact scores over time

Annual detection rates were calculated by aggregating first-record dates for all non-native forest pests into calendar-year totals. Impact scores were plotted against year of detection, to assess temporal

Table 2 Established forest pests in Britain, including taxonomic details, origin, year of detection, host type, overall impact score, and key drivers and management strategies (abbreviated), ordered by impact score and then by year of detection.

Common name	Scientific name	Insect order	Origin	Detection year	Tree type	Overall impact score	Drivers	Management
Large pine weevil	*Hylobius abietis*	Coleoptera	Native	Native	Both	9	FM	M, P, B, A
Great spruce bark beetle	*Dendroctonus micans*	Coleoptera	Mainland Europe; Asia	1982	Conifer	8	T, FM, C, TS	M, P, B, A
Elm bark beetles	*principally Scolytus scolytus and S. multistriatus*	Coleoptera	Native (pathogen: Asia)	1930	Broadleaf	7	T, C	M, P, A
Eight-toothed spruce bark beetle	*Ips typographus*	Coleoptera	Mainland Europe	2018	Conifer	7	T, FM, C, TS	M, P, A
Furniture beetle	*Anobium punctatum*	Coleoptera	Native	Native	Both	6		M, P, A
Oak pinhole borer	*Platypus cylindrus*	Coleoptera	Native	Native	Broadleaf	6	FM, C, TS	M, P
Pine shoot beetle	*Tomicus piniperda*	Coleoptera	Native	Native	Conifer	6	FM, C, TS	M, P
Green spruce aphid	*Elatobium abietinum*	Hemiptera	Mainland Europe	1900	Conifer	6	T, FM, C	P, B
Silver fir adelges	*Dreyfusia nordmannianae*	Hemiptera	Mainland Europe	1900	Conifer	6	T, FM	P
Large larch bark beetle	*Ips cembrae*	Coleoptera	Mainland Europe	1955	Conifer	6	T, FM, C, TS	M, P
Oak processionary moth	*Thaumetopoea processionea*	Lepidoptera	Mainland Europe	2006	Broadleaf	6	T, C	M, P, B, A
Box tree moth	*Cydalima perspectalis*	Lepidoptera	Asia	2007	Broadleaf	6	T, C	P, B
Conifer ambrosia beetle	*Trypodendron lineatum*	Coleoptera	Native	Native	Conifer	5	FM, C, TS	M
Oak leaf roller moth	*Tortrix viridana*	Lepidoptera	Native	Native	Broadleaf	5		B
Douglas-fir seed wasp	*Megastigmus spermotrophus*	Hymenoptera	North America	1906	Conifer	5	T, FM	P, B
Winter moth	*Operophtera brumata*	Lepidoptera	Native	1981	Both	5	FM	B
Two-spotted oak buprestid beetle	*Agrilus biguttatus*	Coleoptera	Native	1982	Broadleaf	5	C, TS	M, P, B
Horse chestnut leaf miner	*Cameraria ohridella*	Lepidoptera	Mainland Europe	2002	Broadleaf	5	C	M, P, B
Pine shoot moth	*Rhyacionia buoliana*	Lepidoptera	Native	Native	Conifer	4	FM	P, B
Powder post beetle	*Lyctus brunneus*	Coleoptera	Origin disputed (Native; North America)	1900	Both	4		NM
Douglas-fir woolly aphid	*Adelges cooleyi*	Hemiptera	North America	1913	Conifer	4	T, FM	B
Pine looper moth	*Bupalus piniaria*	Lepidoptera	Native	1953	Conifer	4	FM	P, B
Knopper gall wasp	*Andricus quercuscalicis*	Hymenoptera	Mainland Europe	1961	Both	4	T, FM	P, B
Fox-coloured sawfly	*Neodiprion sertifer*	Hymenoptera	Native	Native	Conifer	3	FM	B
Six-toothed bark beetle	*Ips sexdentatus*	Coleoptera	Mainland Europe	1900	Conifer	3	T, C, TS	M
Pine beauty moth	*Panolis flammea*	Lepidoptera	Native	1970	Conifer	3	FM, C	P, B
Spongy moth	*Lymantria dispar*	Lepidoptera	Current population: Mainland Europe	1995	Broadleaf	3	T, C	M, B
Pale Japanese elm aphid	*Tinocallis nevskyi*	Hemiptera	Mainland Europe	1995	Broadleaf	3	T	NM
Plane lace bug	*Corythucha ciliata*	Hemiptera	North America	2006	Broadleaf	3	T, FM	M, P
Pine-tree lappet moth	*Dendrolimus pini*	Lepidoptera	Origin disputed (Native; Mainland Europe)	2008	Conifer	3	FM, C	M, P
Oriental chestnut gall wasp	*Dryocosmus kuriphilus*	Hymenoptera	Asia	2015	Broadleaf	3	T	P, B
Elm zigzag sawfly	*Aproceros leucopoda*	Hymenoptera	Asia	2018	Broadleaf	3	T, C	M, P
	Dryomyia lichtensteinii	Diptera	Mainland Europe	2021	Broadleaf	3	T, FM	M
Oak scale insect	*Nidularia pulvinata*	Hemiptera	Mainland Europe	2024	Broadleaf	3	T, FM	M
Large larch sawfly	*Pristiphora erichsonii*	Hymenoptera	Mainland Europe	1906	Conifer	2	T, FM	B
Larch tortrix	*Zeiraphera griseana*	Lepidoptera	Mainland Europe	1950	Conifer	2	T, FM	B
Web-spinning larch sawfly	*Cephalcia lariciphila*	Hymenoptera	Mainland Europe	1953	Conifer	2	T, FM	B

(continued)

Table 2 Continued.

Common name	Scientific name	Insect order	Origin	Detection year	Tree type	Overall impact score	Drivers	Management
Horse chestnut scale	*Pulvinaria regalis*	Hemiptera	Asia	1964	Broadleaf	2	T	NM
Cypress twig borer	*Argyresthia cupressella*	Lepidoptera	North America	1997	Conifer	2	T	NM
Balsam fir aphid	*Cinara curvipes*	Hemiptera	North America	1999	Conifer	2	T	M
Brown spruce longhorn beetle	*Tetropium fuscum*	Coleoptera	Mainland Europe; Asia	2014	Conifer	2	T, FM, C, TS	NM
Eucalyptus leaf beetle	*Paropsisterna selmani*	Coleoptera	Australia	2015	Broadleaf	2	T, FM	NM
	Agrilus ater	Coleoptera	Mainland Europe	2017	Broadleaf	2	TS	M
	Agrilus convexicollis	Coleoptera	Mainland Europe	2023	Broadleaf	2	TS	M
White pine scale	*Leucaspis pusilla*	Hemiptera	Mainland Europe	2023	Conifer	2	T, TS	P, B
European spruce sawfly	*Gilpinia hercyniae*	Hymenoptera	Mainland Europe	1906	Conifer	1	T, FM	B
Nassonov's mealybug	*Planococcus vovae*	Hemiptera	Mainland Europe; Asia	1982	Conifer	1	T	NM
Asian elm aphid	*Tinocallis takachihoensis*	Hemiptera	Asia	2007	Broadleaf	1	T	NM
Monterey pine aphid	*Essigella californica*	Hemiptera	North America	2010	Conifer	1	T, FM, C, TS	NM
Fletcher scale	*Parthenolecanium fletcheri*	Hemiptera	North America	2011	Conifer	1	T	B
Ash mirid plant bug	*Tropidosteptes pacificus*	Hemiptera	North America	2012	Broadleaf	1	T	NM
Asian longhorn beetle	*Anoplophora glabripennis*	Coleoptera	Asia	2012	Broadleaf	1	T, C	M, P
Royal midget	*Phyllonorycter pastorella*	Lepidoptera	Mainland Europe	2014	Broadleaf	1		B
	Simo hirticornis	Coleoptera	Mainland Europe	2014	Both	1	T	NM
	Oxycarenus modestus	Hemiptera	Mainland Europe	2017	Broadleaf	1	T	NM
Sacred pine spinner	*Acantholyda heiroglyphica*	Hymenoptera	Mainland Europe	2024	Conifer	1	T	NM

Abbreviations: Drivers — T = Trade, FM = Forest management, C = Climate, TS = Tree stress. Management — NM = No management, M = Monitoring, P = Preventative measures, B = Biotic resistance (i.e. natural enemies), A = Active control measures.

patterns in severity. A colour gradient visualisation was generated by summarizing their annual detections and associated impact scores, allowing comparison of impact distributions over time.

Forest and host context

Forest management and host tree categories

Impact scores were compared across three forest categories: Productive (managed primarily for timber production), Amenity (managed for recreational, cultural, or environmental benefits), Native woodland (dominated by tree species naturally occurring in the UK and managed to maintain or restore their ecological character), and three host tree categories (Conifer, Broadleaf, Both). One-way ANOVA tested for differences in mean impact scores, with assumptions checked prior to analysis; Kruskal–Wallis tests were used when assumptions were violated. Significant ANOVA results were followed by Tukey's HSD *post-hoc* tests, and pairwise Wilcoxon tests were applied for non-parametric comparisons.

Tree species

The scientific names of tree genera or species were extracted from the results table and standardized for consistency. Pests were then classified according to overall impact score into low (0–2), medium (3–5), or high (6–9) threat levels and plotted per tree genera or species.

Drivers of pest establishment and impact

Drivers of pest arrival, abundance, or damage were grouped into four themes—trade, climate, forest management, and tree stress—based on evidence reported in the literature for each species. For each factor, the frequency of its identification as a driver of forest pests in Britain was recorded, and supporting evidence was summarized.

Management approaches and mismatches

Distribution of management effort

Management activities for forest pests were assigned to five categories aligned with FAO-based integrated pest management principles (FAO n.d.). 'No management' referred to cases where no actions were taken to detect, suppress, or mitigate pest impacts. 'Monitoring' involved surveillance of pest presence or damage without direct intervention. 'Preventative measures' included actions implemented to reduce risk, such as phytosanitary measures and silvicultural practices. 'Biotic resistance' captured the role of resident biotic communities in limiting pest success through competition, predation, or parasitism (Núñez-Mir et al. 2017, Horrocks et al. 2020). 'Active control' comprised direct suppression measures, including eradication, mechanical removal, trapping, biological control releases, and chemical treatments. Text data were cleaned and standardized to assign each pest to these groups. Overall impact scores (0–9) were compared across strategies using pairwise Wilcoxon tests with P-value adjustment. Data processing and visualization were done in R using 'dplyr', 'stringr', 'ggplot2', and 'ggpubr' packages.

Under- and over-managed pests, outlier analysis

To assess the relationship between forest pest distribution, management effort, and damage, the distribution impact scores were

Table 3 Complete list of search terms used in Scopus literature search, organized under three thematic categories: 'insect pest', 'management', and 'forest'.

Insect pest	Management	Forest
'Insect pest' OR lepidoptera OR tineidae OR geometridae OR hymenoptera OR sawflies OR coleoptera OR 'Ambrosia beetles' OR scolytinae OR platypodinae OR 'Bark beetles' OR longhorns OR cerambycidae OR weevils OR curculionidae OR jewel AND beetle OR buprestidae OR hemiptera OR aphid OR 'Green spruce aphid' OR 'Elatobium abietinum' OR 'Horse chestnut scale' OR 'Pulvinaria regalis' OR 'Douglas-fir woolly aphid' OR 'Adelges cooleyi' OR 'Silver fir adelges' OR 'Dreyfusia nordmannianae' OR 'Furniture beetle' OR '*Anobium punctatum*' OR 'Powder post beetle' OR '*Lyctus brunneus*' OR 'Large pine weevil' OR 'Hylobius abietis' OR 'Pine weevils' OR pissodes OR 'Elm bark beetles' OR '*Scolytus scolytus*' OR '*Scolytus multistriatus*' OR 'Great spruce bark beetle' OR '*Dendroctonus micans*' OR 'Large larch bark beetle' OR 'Ips cembrae' OR 'Six-toothed bark beetle' OR 'Ips sexdentatus' OR 'Pine shoot beetle' OR '*Tomicus piniperda*' OR 'Conifer ambrosia beetle' OR '*Trypodendron lineatum*' OR 'Web-spinning larch sawfly' OR 'Cephalcia lariciphila' OR 'European spruce sawfly' OR '*Gilpinia hercyniae*' OR 'Large larch sawfly' OR '*Pristiphora erichsonii*' OR 'Fox-coloured sawfly' OR '*Neodiprion sertifer*' OR 'Douglas-fir seed wasp' OR 'Megastigmus spermotrophus' OR 'Knopper gall wasp' OR 'Andricus quercuscalicis' OR 'Pine looper moth' OR 'Bupalus piniaria' OR 'Winter moth' OR '*Operophtera brumata*' OR 'Spongy moth' OR '*Lymantria dispar*' OR 'Pine beauty moth' OR 'Panolis flammea' OR 'Pine shoot moth' OR 'Rhyacionia buoliana' OR 'Larch tortrix' OR 'Zeiraphera griseana' OR 'Oak leaf roller moth' OR 'Tortrix viridana' OR tineids OR 'Asian longhorn beetle' OR '*Anoplophora glabripennis*' OR 'Citrus longhorn beetle' OR 'Anoplophora chinensis' OR 'Brown spruce longhorn beetle' OR 'Tetropium fuscum' OR 'Larger eight-toothed European spruce bark beetle' OR 'Ips typographus' OR 'Two-spotted oak buprestid beetle' OR 'Agrilus biguttatus' OR 'Elm zigzag sawfly' OR 'Aproceros leucopoda' OR 'Oriental chestnut gall wasp' OR '*Dryocosmus kuriphilus*' OR 'Horse chestnut leaf miner' OR 'Cameraria ohridella' OR 'Pine-tree lappet moth' OR 'Dendrolimus pini' OR 'Oak processionary moth' OR 'Thaumetopoea processionea' OR 'Box tree moth' OR 'Cydalima perspectalis' OR 'Agrilus ater' OR 'Agrilus convexicollis' OR 'Plane lace bug' OR '*Corythucha ciliata*' OR 'Oxycarenus modestus' OR 'Eucalyptus leaf beetle' OR 'Paropsisterna selmani' OR 'Royal Midget' OR 'Phyllonorycter pastorella' OR 'Oak pinhole borer' OR 'Platypus cylindrus' OR 'Pale Japanese elm aphid' OR 'Tinocallis nevskyi' OR 'Tinocallis takachihoensis' OR 'Ash mirid plant bug' OR 'Tropidosteptes pacificus' OR 'Simo hirticornis' OR 'Cypress twig borer' OR 'Argyresthia cupressella' OR 'Balsam fir aphid' OR 'Cinara curvipes' OR 'Monterey Pine Aphid' OR 'Essigella californica' OR 'Small pine scale' OR 'Leucaspis pusilla' OR 'Fletcher scale' OR 'Parthenolecanium fletcheri' OR 'Nassonov's mealybug' OR 'Planococcus vovae' OR 'oak scale insect' OR 'Nidularia pulvinata' OR 'Holm oak gall' OR 'Dryomyia lichtensteinii' OR 'Sacred Pine Spinner' OR 'Acantholyda heiroglyphica'	manag* OR mitigate* OR control OR prevent* OR resist* OR resilience OR 'biological control' OR 'chemical control' OR 'physical control' OR 'integrated pest management' OR ipm OR 'Integrated forest management' OR strategy OR insecticide OR pesticide OR 'natural enemies' OR 'entomopathogenic fungi' OR 'entomopathogenic nematodes' OR predator OR parasitoid OR monitoring OR surveillance OR interception OR trap OR pheromone OR 'risk assessment' OR damage OR treatment OR evaluation OR assessment	forest OR forestry OR 'forest industry' OR restock OR nursery OR afforestation OR 'seed orchard' OR woodland OR tree OR conifer OR broadleaf OR pine OR fir OR spruce OR larch OR pinus OR picea OR larix OR abies OR beech OR birch OR oak OR ash OR aspen OR alder OR 'Sweet chestnut' OR fagus OR betula OR quercus OR fraxinus OR populus OR castanea OR alnus

multiplied by the management effort and damage impact scores. The relationship between two disturbance impact metrics (I.S_Dist_Man and I.S_Dist_Dam) was examined across forest pests. A linear regression model was fitted to assess the general trend and 95% confidence interval bands were visualized. Outliers were identified as points with residuals exceeding two standard deviations from the regression fit and were labelled with scientific name abbreviations.

Narrative synthesis

Additional information on surveillance systems, pest management approaches, and ecological impacts was synthesized qualitatively from the reviewed literature to provide contextual interpretation of the quantitative findings. Firstly, the surveillance and detection activities identified in the study, including current monitoring approaches,

Table 4 List of 22 column headings presented in results table and summary of the information captured under each heading.

Column heading	Information captured (*indicates only included in full version of table)
Common name	Common name of forest pest species (if given)
Scientific name	Scientific name of forest pest species
Family*	Taxonomic family of forest pest species
Insect Order	Taxonomic order of forest pest species
Origin	Region of origin: Native; Mainland Europe; Asia; North America; Australia
Detection year	Year species found breeding in Britain or that first outbreak occurred (native species) (those with 1900 = possibly earlier, exact date not known)
Tree type	Broadleaf; Conifer; Both
Associated tree species*	Main host tree species
Forest type*	Productive (managed primarily for timber production); Amenity (managed for recreational, cultural, or environmental benefits); Native (dominated by tree species naturally occurring in the UK and managed to maintain or restore their ecological character)
Risk Register (RR) score*	Mitigated Score extracted from the Defra Risk Register (Defra 2025) if listed
Status in 1927*	Information extracted from Munro 1927
Status in 1997*	Information extracted from Evans 1997
Impact score—distribution*	0 = Not present (species not recorded); 1 = Present—restricted (occurs at very few sites or at very low frequency, often isolated or incidental); 2 = Present—localized (occurs in several discrete areas, forming small clusters but not broadly distributed); 3 = Present—widespread (occurs across much of the region, broadly distributed)
Impact score—pest management intensity*	0 = None (no management required or undertaken; species poses no operational concern); 1 = Minimal (occasional or low-effort interventions, typically small-scale or opportunistic; management not routinely necessary); 2 = Routine (regular, planned management actions are required to limit impacts or spread; species is an ongoing operational consideration); 3 = Intensive (high-effort, resource-demanding management needed; often involves coordinated or repeated interventions across multiple sites)
Impact score—damage severity*	0 = Negligible (no observable damage or effects on hosts or ecosystems); 1 = Occasional (minor or infrequent damage; impacts are limited in extent or severity); 2 = Regular (damage occurs consistently or predictably, affecting host health, productivity, or ecosystem function); 3 = Severe (substantial or widespread damage, often leading to significant host decline, mortality, or major ecological or economic impacts)
Impact score—overall	Sum of presence, management and damage scores
Impact score—Dist*Man*	Distribution score multiplied by management score
Impact score—Dist*Dam*	Distribution score multiplied by damage score
Drivers	Drivers of pest arrival, abundance or damage grouped into four themes—trade, climate, forest management, and tree stress—based on evidence reported in the literature for each species
Information on Pest Status and Management*	Summary text of pest impact and management
Management	Management activities identified for forest pest grouped into five main themes: No management; Monitoring; Preventative measures; Biotic resistance (i.e. natural enemies); Active control measures
References*	References of source material

diagnostic tools, and reporting pathways were summarised. Secondly, the pest management activities undertaken in Britain for each of the 56 forest pests identified in this study were assessed against broad Integrated Pest Management (IPM) and Sustainable Forest Management (SFM) principles. These include monitoring (plus modelling and decision-support tools), preventative measures, biotic resistance, and active control (classical biocontrol, sanitation felling, other non-chemical methods, and chemical methods). The ecological impacts of these management activities on ecosystems and biodiversity were also evaluated.

Results

Evidence base

A Scopus search conducted on 10 April 2025 returned 514 records. Screening of titles and keywords removed 182 papers unrelated to forest pests or their management. Of the remaining papers, 201 papers were classified as fully relevant and reviewed in full, while an additional 121 partially relevant papers were revisited for contextual comparison in the Discussion. In total, 228 papers were used to compile the information on established forest pests in Britain, as presented in Table 2 and Supplementary_material_1_ForestPests.xlsx. A complete list of references is provided in the 'Full references' tab of the supplementary file. The number of papers identified for each forest pest varied considerably (Table 5).

Analysis

Overview of forest pest species

A total of 56 insect species were identified as forest pests which are native to, or established in, Britain (Table 2 and Supplementary_material_1_ForestPests.xlsx). Five insect orders were represented, with Coleoptera (18 species) being the most prevalent, followed by Hemiptera (15), Lepidoptera (13), and Hymenoptera (9). Only one species of Diptera was recorded (Fig. 1).

Biogeographic origins and introduction patterns

Forest pest origins

Fifteen forest pest species are native to Great Britain. Among non-native forest pests, the greatest number originated from mainland Europe (27 species), followed by Asia (10), North America (9), and Australia (1). Hemiptera dominated among species of American origin, whereas Coleoptera were most common among Asian introductions.

Table 5 Number of publications identified for the forest pests included in this study.

Forest pest	Number of papers
Large pine weevil (*Hylobius abietis* L.)	43
Horse chestnut leaf miner (*Cameraria ohridella* Deschka and Dimić)	12
Great spruce bark beetle (*Dendroctonus micans* (Kugelann))	11
Pine beauty moth (*Panolis flammea* (Denis and Schiffermüller))	11
Winter moth (*Operophtera brumata* L.)	11
Asian longhorn beetle (*Anoplophora glabripennis* (Motschulsky))	10
Eight-toothed spruce bark beetle (*Ips typographus* L.)	10
Oak processionary moth (*Thaumetopoea processionea* L.)	9
Green spruce aphid (*Elatobium abietinum* (Walker))	7
Pine-tree lappet moth (*Dendrolimus pini* (L.))	7
Oriental chestnut gall wasp (*Dryocosmus kuriphilus* Yasumatsu)	7
Box tree moth (*Cydalima perspectalis* (Walker))	6
Large larch bark beetle (*Ips cembrae* (Heer))	6
Two-spotted oak buprestid beetle (*Agrilus biguttatus* (Fabricius))	6
25 species	3–5
17 species	1-2
Other species not identified on forest pest list compiled for this study	44

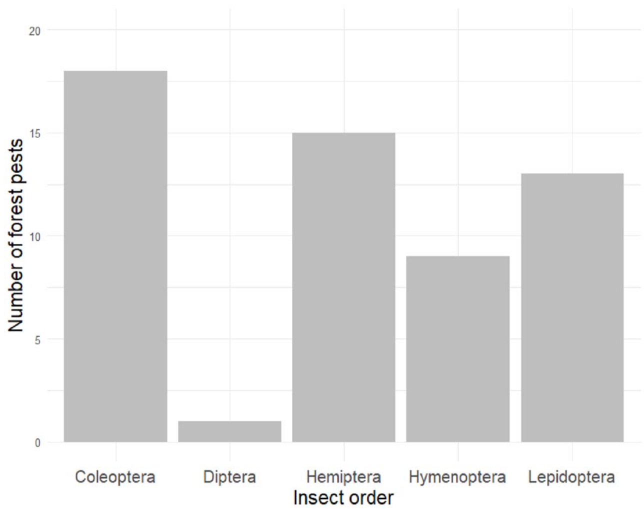

Figure 1 Distribution of forest pests by taxonomic order.

No single order dominated among European introductions. Several species were associated with multiple geographic origins, while none were recorded as originating from Africa or South America. Overall, the pattern of pest incursions broadly reflects recent total trade volumes (Office for National Statistics 2024b), with Europe accounting for the largest share of UK imports (Fig. 2), reinforcing the link between trade pathways and invasion pressure.

Temporal trends in pest introductions

Cumulative detections reveal distinct temporal patterns among origins (Fig. 3). Introductions from mainland Europe and North America increased early in the 20th century, followed by several decades with few new detections. From the latter half of the 20th century onward, detections from these regions—and increasingly from Asia—rose steadily, with the most rapid increases occurring after 2000. The only detection of an established species from Australia occurred in 2015.

Impact scoring and distribution of pest severity

Distribution, management effort, and damage components

All but one of the 56 forest pests identified are currently present in Britain, with the exception being Asian longhorn beetle [*Anoplophora glabripennis* (Motschulsky)], an outbreak of which was declared eradicated in 2018 (Eyre and Barbrook 2021). Across the distribution component, 19 forest pests were classified as restricted (score = 1, few sites/very low frequency), 21 as localized (score = 2, several discrete areas/small clusters), and 15 as widespread (score = 3, broadly distributed across the region).

Pest management effort was generally low: only four forest pests—eight-toothed spruce bark beetle (*Ips typographus* L.), great spruce bark beetle [*Dendroctonus micans* (Kugelann)], large pine weevil (*Hylobius abietis* L.), and oak processionary moth (*Thaumetopoea processionea* L.)—were classified as receiving intensive management effort (score = 3, high-effort, repeated management), with eradication the stated objective for the eight-toothed spruce bark beetle. Seven pests were subject to routine management effort (score = 2, regular planned management), 23 received minimal management (score = 1, occasional low-effort intervention), and 22 received no management effort (score = 0). This final category included some species for which biotic resistance was identified.

Damage severity was similarly skewed toward the lower categories. Only one pest (large pine weevil) was classified as causing severe damage (score = 3, substantial damage or major impacts), while 10 caused regular damage (score = 2, consistent damage or effects). Seventeen pests were assessed as causing occasional damage (score = 1, minor or infrequent damage) and a further 28 caused negligible damage (score = 0, no observable impact) (Fig. 4).

Overall impact scores

More than half of the assessed forest pests were classified as having a low to medium overall impact, with 22 species scoring in the low range (scores 0–2) and a further 22 in the medium range (scores 3–5) (Fig. 5). Ten species spanning multiple insect orders (Coleoptera, Lepidoptera, and Hemiptera) were assigned high impact scores (6–7). This group included pests such as elm bark beetles (principally *Scolytus scolytus* (Fabricius) and *Scolytus multistriatus* (Marsham)) and green spruce aphid [*Elatobium abietinum* (Walker)]. Only two species—large pine weevil and great spruce bark beetle, both Coleopteran pests of productive conifers—were categorized as having a very high impact (scores 8–9).

Impact scores per origin

Forest pest impact scores varied significantly among origin regions (Kruskal–Wallis test, χ^2 = 10.91, df = 3, p = 0.0123). Dunn's *post hoc* comparisons with Bonferroni adjustment indicated that the native (Great Britain) group had significantly higher impact scores than pests originating from both North America (p = 0.0307) and Mainland Europe (p = 0.0283) (Fig. 6). Although forest pests originating from Asia tended to have lower impact scores than native pests, this difference was not significant (p = 0.189). No significant impact differences were found among pests originating from North America, mainland

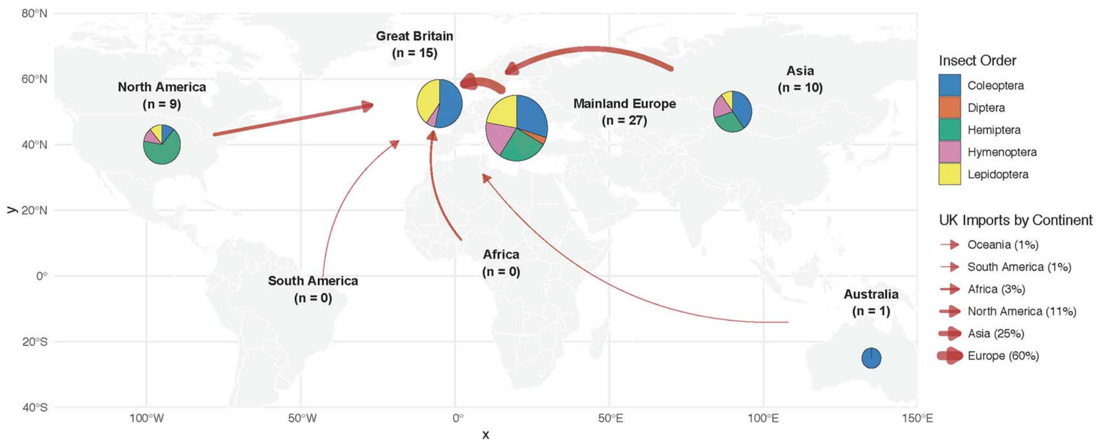

Figure 2 Biogeographic origins and taxonomic diversity of forest pests detected in Britain. Region-specific pie charts show the proportional representation of insect orders (colours), with pie size scaled to total species richness (n). Fifteen native forest pests were identified for Great Britain. Several species were associated with multiple geographic origins, whereas none were recorded from Africa or South America. Arrows indicate major UK import routes, with arrow thickness proportional to recent (2018–2023) trade volume (e.g. Europe 60%), calculated from import data provided by the Office for National Statistics (2024b).

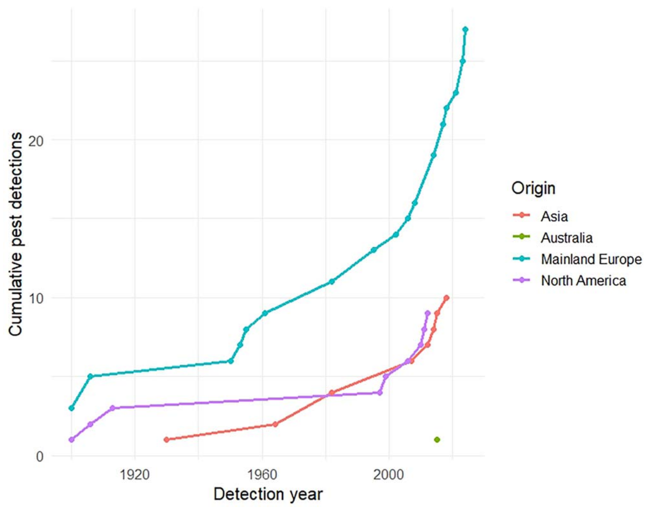

Figure 3 Cumulative number of non-native forest pests detected in Britain by geographic region of origin. Points show annual detections (years with zero detections omitted for clarity). Coloured lines show the cumulative increase in detected species from each region, illustrating contrasting introduction trajectories among origins.

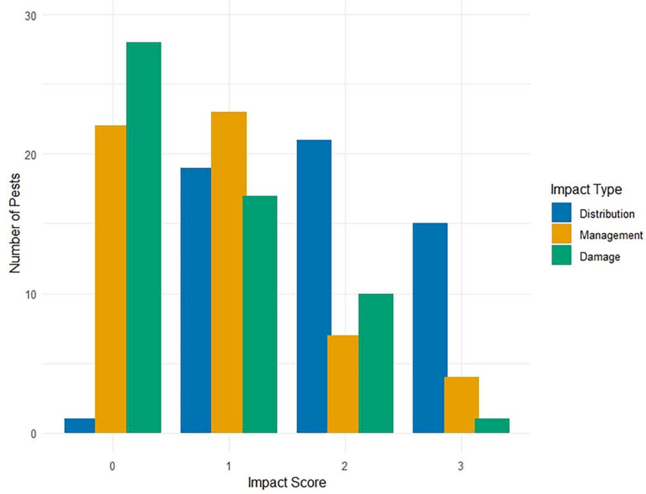

Figure 4 Number of forest pests assigned to each impact score across three impact components. Distribution scores reflect presence in Britain (0 = not present, 1 = present—restricted, 2 = present—localized, 3 = present—widespread). Pest management effort scores indicate the level of intervention (surveillance, control and eradication) directed towards a pest (0 = none, 1 = minimal, 2 = routine, 3 = intensive). Damage scores represent the severity of tree impacts (0 = negligible, 1 = occasional, 2 = regular, 3 = severe). The figure summarizes pest impact profiles across these key categories.

Europe, and Asia (all adjusted p = 1.00). Australia was excluded from the analysis due to its small sample size.

Impact scores over time

The frequency of non-native forest pest detections in Britain has increased since the early 2000's (Figs 3 and 7). Impact scores showed no consistent long-term trend and instead fluctuated irregularly over time. Recent detections are dominated by lower impact species, although high-impact pests occur sporadically across the full temporal range (Fig. 7).

Forest and host context

Forest management categories

Forests managed for productive purposes were associated with more pests (38 species) than those managed for amenity (31) or native woodland objectives (25). Many pests impacted more than one management category. Despite differences in the number of associated pests, overall impact scores did not differ between management categories (p > 0.05).

Tree groups and species

More forest pests were associated with conifer hosts (27) than broadleaf hosts (23), with 6 species linked linked to both tree groups. Overall impact scores did not, however, differ between tree types (p > 0.05). At the genus level, pine *(Pinus)* hosted the highest number of associated forest pests (12), followed by spruce (*Picea*) and oak (*Quercus*), each with 8 species. All other genera or individual tree species were associated with fewer than four pests (Fig. 8).

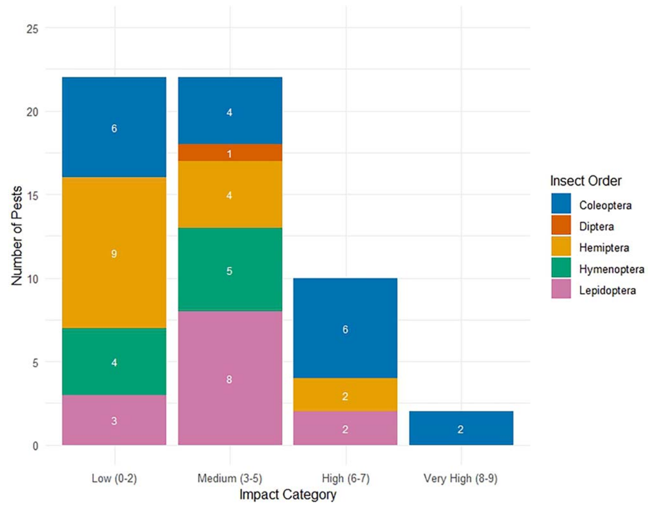

Figure 5 Number of forest pests from each taxonomic insect order grouped by overall impact level, ranging from low to very high. The figure illustrates how impact severity is distributed across major insect orders.

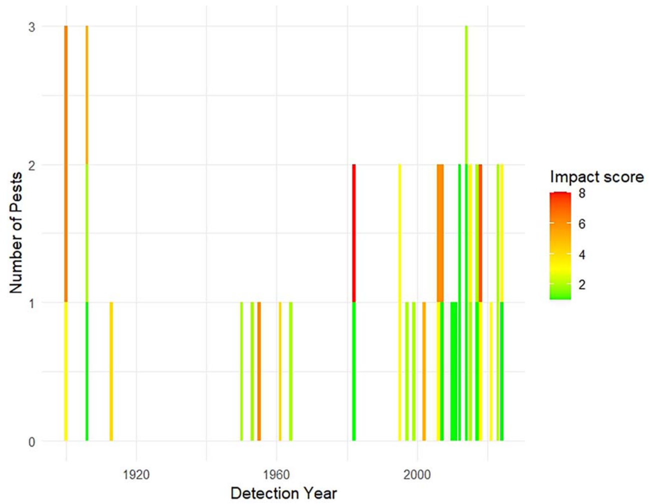

Figure 7 Trends in non-native forest pest detections in Britain over time, showing annual counts and associated impact scores. Bars represent the number of newly detected species per year with colour gradient indicating impact severity from low (green) to high (red), with intermediate scores shown in yellow and orange.

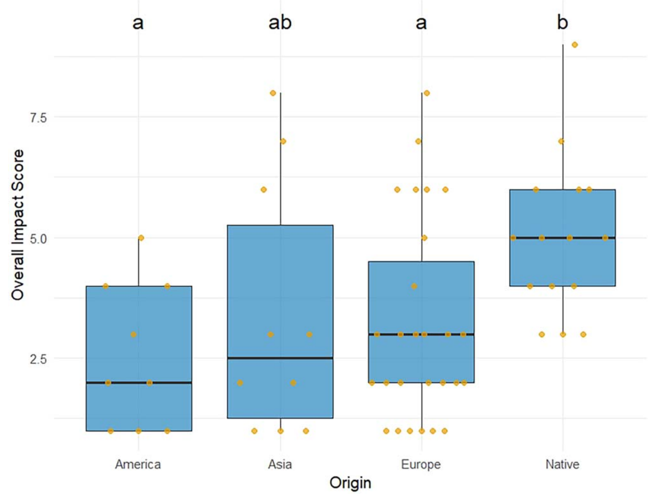

Figure 6 Boxplots of overall forest pest impact scores by origin region (native=—Great Britain, Europe = Mainland Europe). Boxes represent interquartile ranges (IQR), horizontal lines indicate medians, and whiskers extend to 1.5 × IQR. Different letters above boxes indicate significant differences among origin regions based on Dunn's *post hoc* tests with Bonferroni-adjusted *p* values ($p < 0.05$). Australia was excluded from the analysis due to its small sample size.

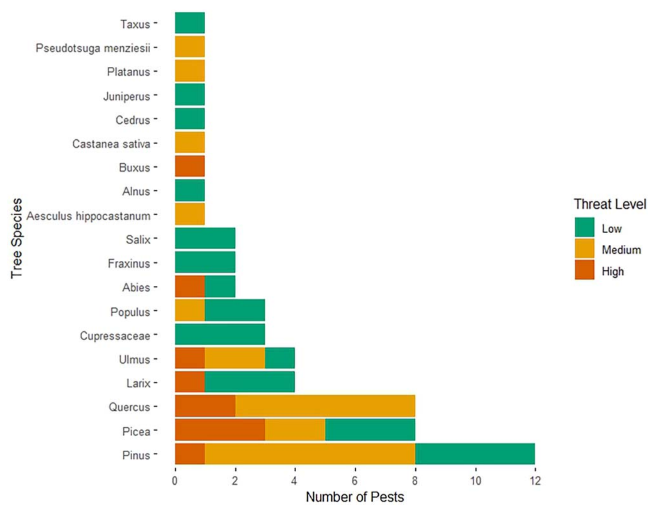

Figure 8 Number of forest pests associated with different tree genera or species, categorized by threat level based on overall impact scores [low (0–2), medium (3–5), and high (6–9)]. Bars represent the total number of associated forest pests per host taxon, with colours indicating the severity of threat posed by each pest. Pine (*Pinus*), spruce (*Picea*) and oak (*Quercus*) hosted the greatest numbers of associated pests.

When pest species were categorized by threat level—low (0–2), medium (3–5), and high (6–9)—based on their overall impact scores, differences in threat composition were evident among host taxa (Fig. 8). Although some tree species, such as box (*Buxus*) and fir (*Abies*) hosted relatively few pests, these were predominantly high-threat species. In contrast, other hosts such as yew (*Taxus*) and willow (*Salix*) were associated primarily with low-threat pests. Across all hosts, pine, spruce, and oak were associated with the greatest numbers of pests and the highest cumulative threat levels.

Drivers of pest establishment and impact

Trade was the most prevalent driver, influencing the arrival, abundance and associated damage of 38 out of 56 forest pests. The remaining species are either native or are thought to have arrived here naturally through primary immigration [e.g. Royal midget (*Phyllonorycter pastorella* (Zeller))] (Freed 2015). Forest management practices were identified as a driver for 28 pests, including the planting of non-native tree species, the retention of windblown or felled timber, and clear-fell restocking. Climate, primarily in the form of warmer temperatures, storm events, and drought, was identified as a driver for 20 pests, while tree stress (e.g. poor growing conditions or physiological decline) was linked to 13 pests.

Global trade

Of the 56 forest pests identified as present in Britain, ~75% are non-native, highlighting the risks associated with global trade. Most originated from mainland Europe, with additional species from Asia, North America, and Australia. However, interception data indicate a broader pool of potential introductions: UK plant health inspectors have recorded more than 100 intercepted insect species, with China the most frequently reported country of origin (Blake pers. obs.). Longhorn beetles (Cerambycidae) are the most commonly intercepted taxonomic group (Eyre et al. 2018).

Forest management

Forest management practices in Britain, including tree species selection, silvicultural systems and operational practices, strongly influence the distribution abundance and impact of forest pests. Although British forests are generally smaller (c. 10–100 ha), more diverse, and less intensively managed than those in many other temperate regions [e.g. mainland Europe, New Zealand (Leslie et al. 2024, Scherpenhuijzen et al. 2025)], they remain vulnerable to pest damage.

Pests affected multiple stages of the forest lifecycle. Seed and nursery production were affected by pests such as Douglas fir seed wasp (*Megastigmus spermotrophus* (Wachtl)) and knopper gall wasp (*Andricus quercuscalicis* (Burgsdorf)). Whereas Britain's predominant clear fell and restock system has promoted damaging populations of large pine weevil, with annual management costs estimated at £7–40 million (Willoughby and Moore 2020).

Planted monocultures—particularly of non-native species such as Sitka spruce and lodgepole pine—were associated with increased pest occurrence. Several native insects listed in this study only became significant pests following the introduction of non-native hosts. For example, pine beauty moth [*Panolis flammea* (Denis and Schiffermüller)] shifted from low-impact populations on Scots pine to damaging outbreaks on lodgepole pine after its widespread planting (Watt and Leather 1988, Hicks et al. 2008). Lodgepole pine's susceptibility to pests, alongside foliar diseases such as *Dothistroma* needle blight, has contributed to its large-scale removal from the British landscape (Brown and Webber 2008, Edwards 2017).

The productivity of non-native spruce trees, particularly Britain's dominant commercial tree—Sitka spruce, is challenged by both native and non-native pests, including great spruce bark beetle, green spruce aphid, European spruce sawfly [*Gilpinia hercyniae* (Hartig)], and winter moth (*Operophtera brumata* L.) (Evans and Fielding 1994, Day et al. 1998, Raymond et al. 2002, Williams et al. 2003). Several fir (*Abies*) species are highly vulnerable to silver fir adelges (*Dreyfusia nordmannianae* Eckst.), limiting their suitability for planting despite their productive potential (Savill 2019).

Operational forestry practices also influenced pest dynamics. Slow clearance and poor storage of blown or felled timber were associated with outbreaks of bark and ambrosia beetles, including eight toothed spruce bark beetle, pine shoot beetle (*Tomicus piniperda* (L.)), conifer ambrosia beetle (*Trypodendron lineatum* (Olivier)), brown spruce longhorn beetle (*Tetropium fuscum* (Fabricius)), and oak pinhole borer (*Platypus cylindrus* (Fabricius)), all of which breed in dead or dying material.

While these examples relate primarily to productive forestry, pest impacts were not confined to commercial forests. Beyond forests managed for timber production, this study identified numerous conifer and broadleaf species planted for amenity and native conservation purposes that are threatened by forest pests in Britain. Box tree moth [*Cydalima perspectalis* (Walker)] is a major threat to native common box (*Buxus sempervirens* L.), which is locally restricted in the wild but is widely planted in amenity settings (Plant et al. 2019, Bird et al. 2020). Other examples include plane lace bug [*Corythucha ciliata* (Say)], horse chestnut leaf miner (*Cameraria ohridella* Deschka and Dimić), Eucalyptus leaf beetle (*Paropsisterna selmani* Reid and De Little) on their associated hosts, as well as *Nidularia pulvinata* Pagenstecher and *Dryomyia lichtensteinii* (Löw) on Holm oak (Straw and Tilbury 2006, Whitham, Bowdrey and Blake 2022, Defra 2024, Facey et al. 2025, Platoni, Facey and Malumphy 2025).

Climate

Climate change is associated with shifts in the arrival, survival, abundance, and spread of several forest pests in Britain. Warmer temperatures have facilitated the expansion or increased activity of species such as elm bark beetles, green spruce aphid, and two-spotted oak buprestid beetle [*Agrilus biguttatus* (Fabricius)]. Across mainland Europe, recent large-scale outbreaks of eight-toothed spruce bark beetle have coincided with heat and drought events (Netherer and Hammerbacher 2022), although its long-term spread is linked to the historical expansion of Norway spruce across Europe (Grégoire et al. 2024). Since 2018, multiple incursions of the eight-toothed spruce bark beetle into southern England—via cross-Channel dispersal from mainland Europe—have been linked to recent climate warming events coinciding with population peaks on the continent (Inward et al. 2024).

Tree stress

Tree stress was identified as a distinct factor associated with increased vulnerability to forest pests. Stress arising from storms, flooding, drought, and other environmental pressures reduced tree defence capacity and resource availability, increasing susceptibility to pests such as *Agrilus convexicollis* (Obenberger) and white pine scale (*Leucaspis pusilla* Löw) (Fish and Malumphy 2023, Williams 2024, internal report).

Forest management practices also contributed to stress. Poor cultivation, planting, or thinning operations were linked to heightened vulnerability to pests including great spruce bark beetle and pine shoot beetle (Evans and Fielding 1994, de Becquevort et al. 2024).

These findings indicate that tree stress interacts with other drivers—climate, management practices, and pest pressure—to influence outbreak likelihood and forest resilience.

Management patterns and mismatches

Distribution of management effort

Active control measures were identified for only six forest pests. Five species with overall impact scores of 6 to 9 were subject to suppression measures such as felling, trapping, biological control, or chemical treatments: large pine weevil (impact score 9), great spruce bark beetle (8), elm bark beetles (7), furniture beetle [*Anobium punctatum* (De Geer)] (6), and oak processionary moth (6). An additional species—the eight-toothed spruce bark beetle (7)—was under active eradication management. Asian longhorn beetle (1) was previously managed but has since been eradicated, while previous active control of other species, including Oriental chestnut gall wasp (*Dryocosmus kuriphilus* Yasumatsu) (3), has been reduced or discontinued following reassessment of management needs.

Monitoring and preventative measures were more common: 23 pests were monitored and 25 were subject to preventative measures. These groups spanned nearly the full impact score range (1–9), with mean scores of 4.52 (± 2.17 SD) and 4.96 (± 1.93 SD), respectively.

Biotic resistance from natural enemies such as parasitoids, predators, or entomopathogenic fungi, was recorded for 25 forest pests (mean impact score 3.96 ± 2.09 SD, range 1–9).

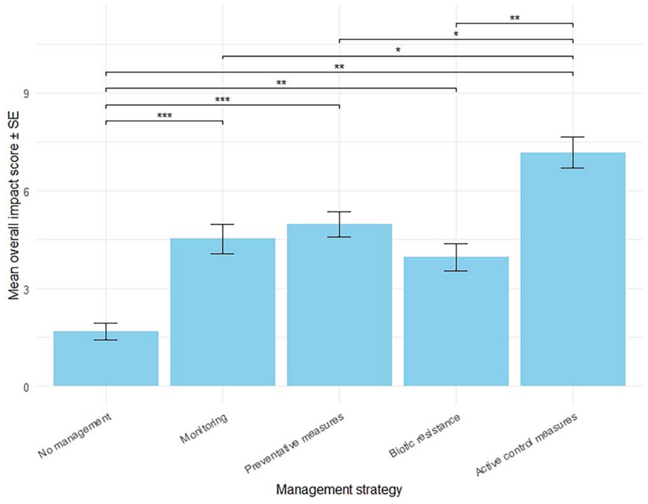

Figure 9 Mean overall impact scores (±SE) of forest pests across management categories. Pests subject to active control had the highest impact scores, whereas unmanaged pests had the lowest. No significant differences were detected among monitoring, preventative measures and biotic resistance. Management categories were not mutually exclusive. Asterisks indicate significant pairwise differences from post hoc tests ($^{*}P < .05$, $^{**}P < .01$, $^{***}P < .001$).

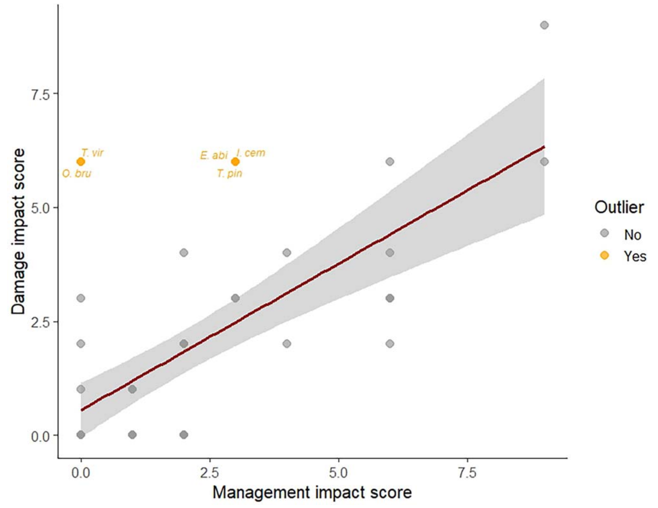

Figure 10 Scatterplot of impact scores for distribution multiplied by management effort (*I.S_Dist_Man*) versus impact scores for distribution multiplied by damage (*I.S_Dist_Dam*), with linear regression fit and 95% confidence interval ribbon. Positive outliers (standardised residual > 2) are highlighted in orange and labelled with abbreviated scientific names. Damage impact scores generally increased with management-effort scores, indicating greater management effort for pests associated with higher levels of damage. Five forest pests—winter moth (O. bru), oak leaf roller moth (T. vir), green spruce aphid (E. abi), large larch bark beetle (I. cem) and pine shoot beetle (T. pin)—exhibited higher damage impacts than expected given their associated management effort, suggesting potential under-management. No over-managed outliers were identified. Oak processionary moth had the largest negative residual, indicating a higher level of management relative to its damage impact than most other species, although it did not meet the threshold for classification as an outlier.

Thirteen pests were unmanaged, with no identified monitoring, preventative measures, active control or biotic resistance. These had the lowest impact scores (mean = 1.69 ± 0.95 SD; range 1-4), including ash mirid plant bug (*Tropidosteptes pacificus*) (1) and pale Japanese elm aphid (*Tinocallis nevskyi*) (3).

Impact scores differed among management categories (Fig. 9). Actively controlled pests had the highest mean impact score (7.17 ± 1.17 SD), whereas unmanaged pests had the lowest (1.69 ± 0.95 SD). Unmanaged pests had significantly lower impact scores than all other management categories (adjusted p < 0.01), while actively controlled pests had significantly higher impact scores than those associated with monitoring, preventative measures or biotic resistance (adjusted p = 0.014, 0.014 and 0.004, respectively). No significant differences were observed among monitoring, preventative measures and biotic resistance (all adjusted p > 0.05). As management categories were not mutually exclusive, these comparisons reflect differences in the mean impact scores associated with each category rather than distinct management strategies.

Under- and over-managed pests

Outlier analysis: impact scores for distribution multiplied by damage (I.S_Dist_Dam) generally increased in line with distribution multiplied by management (I.S_Dist_Man) scores. However, five forest pests were identified as positive outliers, exhibiting higher damage impacts than would be expected given their associated management effort (standardised residual > 2) (Fig. 10).

Under-managed forest pests

Five forest pests were identified as potentially ineffectively or under-managed relative to the damage they cause: green spruce aphid, large larch bark beetle (*Ips cembrae* (Heer)), oak leaf roller moth (*Tortrix viridana* L.), pine shoot beetle and winter moth. None of these pests were subject to active control measures. However, large larch bark beetle and pine shoot beetle were monitored, and preventative measures were in place for these species as well as green spruce aphid. Biotic resistance also contributed to the regulation of green spruce aphid, oak leaf roller moth and winter moth populations.

Over-managed forest pests

No forest pests were identified as being managed more intensively than would be expected based on the level of damage they cause. Oak processionary moth had the largest negative residual (standardised residual = −1.43), indicating a higher level of management relative to its damage impact than most other species, although it did not meet the threshold for classification as an outlier. This likely reflects the substantial risks posed by its urticating hairs to human and animal health, together with its occurrence in densely populated areas of London and southeast England, necessitating extensive surveillance, mapping, control, and public engagement activities (Tomlinson et al. 2015). Management and research relating to oak processionary moth are estimated to cost the public forestry sector ~£2 million annually (Haugh 2022).

Supporting evidence and context

Alignment of current practices with IPM and sustainable forest management

SFM and IPM prioritize preventative, low-environmental impact approaches, favouring biological, silvicultural, and physical methods before chemical interventions (Barzman et al. 2015, Forest Research 2023a). Preventative action is generally more effective and cost-efficient than post-arrival management (Otvos 2004, Epanchin-Niell

2017), although investment should remain proportionate to risk (Carrasco et al. 2010). This study identified management activities for 56 forest pests in Britain and grouped them into 4 categories aligned with IPM principles: monitoring, preventative measures, biotic resistance, and active control.

Monitoring

Monitoring is a cornerstone of IPM because it supports early detection, informed decision-making, and timely intervention. Recent decades have seen substantial improvements in forest pest surveillance in Britain, including biannual aerial surveys (UK Government 2023), the Observatree citizen science network (Crow 2017), the TreeAlert reporting platform (Forest Research 2024c), and Forest Research's Forest Trapping Network, which targets multiple quarantine and priority pests using lure-baited cross-vane traps (Walker et al. 2023). Advances in digital diagnostics, including high-resolution photography, smartphone applications, and rapid online reporting systems, are further improving the speed and accuracy of pest detection and verification (Roe et al. 2024).

Targeted monitoring activities were identified for 23 of the 56 forest pests assessed. Many species are surveyed using traps and lures, such as pheromone trapping to monitor the spread of oak processionary moth (Straw et al. 2019b). Monitoring also informs management decisions, for example through assessments of large pine weevil populations to determine protection requirements before restocking (Willoughby et al. 2020). The inclusion of ambrosia beetles within Britain's surveillance programmes reflects lessons learned from the discovery of *Xylosandrus germanus, Gnathotrichus materiarius*, and *Cyclorhipidion bodoanum* in 2013, which exposed shortcomings in surveillance and phytosanitary measures (Inward 2020).

Responses to newly established pests varied considerably. Elm zigzag sawfly (*Aproceros leucopoda* Takeuchi), for example, received intensive surveillance and publicity following its detection in south-east England because of reports of severe impacts elsewhere in Europe (Blank et al. 2015). Despite subsequently spreading across much of Britain, populations have remained relatively low, and significant damage has not been observed (Forest Research 2024d). Monitoring has therefore shifted towards *ad hoc* reporting through TreeAlert, as is also the case for balsam fir aphid (*Cinara curvipes* Patch), and surveillance through the Observatree citizen science network.

Despite these advances, significant gaps remain. Targeted monitoring was absent for 33 of the 56 pests examined. While some species are covered through incidental reporting systems, systematic surveillance data are lacking. This limits evidence-based decision-making and reduces the likelihood of detecting range expansions or new incursions at an early stage. This gap is concerning given climate-driven shifts in pest distributions and the increasing likelihood of new introductions through international trade. A recent pan-European assessment of forest damage surveillance programmes found that the UK performed well across most categories but identified opportunities to improve data quality and consistency (Hlásny et al. 2025).

Advances in monitoring, modelling, and decision-support tools offer opportunities to address these shortcomings. Spatial modelling platforms such as RangeShifter can improve understanding of pest dispersal and future outbreak risks under changing climatic conditions (Synes et al. 2016, Webb et al. 2025). Horizon-scanning approaches support identification of emerging threats, while decision-support systems such as ForestGALES can predict disturbances that increase pest susceptibility, including wind damage (Gardiner et al. 2008, Forest Research 2015). Enhanced surveillance has already contributed to increased detection rates of forest pests (Poland and Rassati 2019), although some additional species may already be established in Britain without having been detected.

Emerging technologies may further strengthen biosecurity. Molecular diagnostics, acoustic monitoring, remote sensing, and AI-based classification systems offer opportunities for earlier, broader, and more accurate pest detection than conventional methods alone. However, limitations remain, particularly in attributing canopy symptoms to specific pests and managing the operational costs associated with high-resolution monitoring (Luo et al. 2023). Machine-learning approaches may help overcome some of these constraints by improving automated host identification and pest damage attribution (Mahanta et al. 2024). To realize their full potential within IPM frameworks, however, these technologies must be integrated into routine operational practice rather than remaining largely research-led tools.

Preventative measures

Preventative measures were identified for 25 of the 56 pests included in this study, indicating uneven implementation. Such measures focused on reducing the introduction, establishment, and subsequent impacts of forest pests.

Phytosanitary actions included restrictions on the movement of trees, timber, and wood products, together with nursery hygiene measures designed to reduce introduction pathways. Silvicultural approaches sought to minimize host stress through appropriate species-site matching, provenance selection, and use of decision-support tools such as Ecological Site Classification (ESC) (Forest Research 2025). Avoiding harvesting damage was also identified as an important strategy, particularly for pests such as great spruce bark beetle (Evans and Fielding 1994).

Biosecurity measures, including cleaning tools, machinery, and equipment, reduce the risk of transporting cryptic life stages between sites. Sanitation felling was used both as a direct control and to slow the spread of pests such as elm bark beetles (Gibbs et al. 1994). Planting more resilient species also served as a preventative measure; for example, Norway spruce is less affected by green spruce aphid than Sitka spruce (Day et al. 1998). Breeding for genetic resistance was identified as a potential longer-term preventative strategy, illustrated by the development of Sitka spruce resistance to white pine weevil [*Pissodes strobi* (Peck)] in Canada (Tumas et al. 2021).

As climate change, international trade, and biological invasions continue to increase pest pressures, broader adoption of preventative measures is likely to become increasingly important.

Biotic resistance and biological control

Natural enemies regulated populations of nearly half of the forest pests assessed (25 of 56 species). Pest suppression occurred through biotic resistance, whereby resident communities limited pest success via competition, predation, parasitism, and disease. These natural enemies included native species, as well as specialist enemies that had been introduced—either intentionally as classical biological control agents (discussed below) or unintentionally alongside non-native pests.

Several pests are now considered minor due to effective natural enemy regulation. Douglas-fir woolly aphid [*Adelges cooleyi* (Gillette)] is suppressed by native lacewings, ladybirds, and predatory bugs (Varty 1956, Savill 2019), while green spruce aphid populations are regulated by a range of predators and the fungal pathogen *Neozygites* *fresenii* (Day et al. 2006). Similarly, European spruce sawfly populations collapsed in the 1970's following the bird-mediated spread of a naturally occurring nuclear polyhedrosis virus (Baculoviridae) and have never returned to previous outbreak levels (Bevan 1987, Williams et al. 2003). Generalist predators such as carabid beetles also prey on Lepidopteran forest pests (Jelaska et al. 2014).

These examples highlight the importance of conserving natural enemy communities. Conservation biological control is well-established in other systems, where natural enemy populations can be enhanced through habitat manipulation and nutritional resource provisioning (Nyffeler and Sunderland 2003, Tena et al. 2015). Although such approaches remain underdeveloped in forestry, some studies have shown promise: supplemental resources increased the longevity and fecundity of *Apanteles polychrosidis* (Ashmead), a native parasitoid attacking the introduced ash leaf-cone roller [*Caloptilia fraxinella* (Ely)] in urban tree landscapes in western Canada (McPike et al. 2022). Parasitoids also respond to tree-stress volatiles, and synthetic kairomones can enhance host-finding although some volatiles can mask these cues (Büchel et al. 2014).

Classical biological control has also contributed to the management of several important pests. The specialist predator *Rhizophagus grandis* has been released against great spruce bark beetle since the 1980s (King and Fielding 1989, Steinke et al. 2024). More recently, the parasitoid *Torymus sinensis* Kamijo was released against Oriental chestnut gall wasp, reducing gall densities by ∼91%, after which management intensity declined substantially (Malumphy and Audsley 2019; Audsley pers. comm. 2024). Unintentional introductions of natural enemies were also recorded, such as *Olesicampe monticola* (Ashmead) arriving with web spinning larch sawfly [*Cephalcia lariciphila* (Wachtl)] and contributing to its suppression (Billany and Brown 1980, Billany et al. 1985).

Research is ongoing into parasitoids for oak processionary moth and green spruce aphid, and entomopathogenic fungi and other nematode species have shown promise against large pine weevil in laboratory trials (Ansari and Butt 2012, McNamara et al. 2018, Quinzo-Ortega et al. 2024) but remain difficult to deploy operationally (Willoughby et al. 2020).

Active management

Active control (including the classical biological control examples outlined above) was identified for only 6 of the 56 forest pests assessed, reflecting the practical and financial constraints associated with intervention in forest environments.

Chemical control remains available for a small number of forest pests but is increasingly constrained by environmental and regulatory considerations (Leather et al. 1999, Hicks et al. 2001, Palmer 2022, Dimmock et al. 2023). Current oak processionary moth management uses pheromone trapping, manual nest removal, and targeted spraying of biopesticides or insecticides (Defra 2021b). Aerial spraying, which is used in mainland Europe against pine tree lappet moth [*Dendrolimus pini* (L.)] (Skrzecz et al. 2020), is unlikely to be deployed in Britain except under exceptional circumstances. Examples include the successful, albeit contentious, deployment against oak processionary moth at Pangbourne (Blake pers. obs.) or a hypothetical incursion of a highly damaging North American budworm species into unpopulated upland plantation forests. Current policy and public expectations strongly favour lower-impact alternatives wherever possible, but non-chemical alternatives can be less reliable, require more specialist application techniques and increase management costs (Sweeney et al. 2023).

This trend is particularly evident in the management of large pine weevil, the only pest categorised as causing severe damage, where control remains heavily dependent on insecticides despite the development of an Integrated Pest Management strategy (Willoughby et al. 2022). This reliance creates vulnerability to future regulatory restrictions and highlights the need for a broader range of effective control options (Leather et al. 1999; Långström and Day 2004, Willoughby et al. 2022, Dimmock et al. 2023). Physical barriers have been developed to protect saplings from large pine weevil but their efficacy under British conditions has often been limited by high weevil pressure (Willoughby et al. 2020). Recent withdrawals of key insecticide approvals, including acetamiprid, have further constrained management options (Dimmock et al. 2023).

Sanitation felling remains one of the most important active control tools for cryptic bark- and wood-boring insects. It has been central to eradication and containment programmes targeting Asian longhorn beetle and eight-toothed spruce bark beetle (Straw et al. 2016, Blake et al. 2024). Brighton and Hove City Council (n.d.) also uses sanitation felling, alongside girdling and root trenching, to manage Dutch elm disease, which is vectored by elm bark beetles.

However, sanitation felling is not universally appropriate. Oriental chestnut gall wasp illustrates the need for adaptive management. Initial responses involved felling infested trees and on-site mulching, but these measures were discontinued once surveys demonstrated that the pest was widespread, caused limited damage and was increasingly regulated by biological control (Morath et al. 2015, Malumphy and Audsley 2019). Other non-chemical methods identified included mass trapping, lure-and-kill systems, and mating disruption techniques, all of which depend upon the availability of suitable attractants.

Taken together, these findings indicate that forest pest management in Britain is largely preventative rather than reactive. Of the 56 pests assessed, 33 (60%) received targeted management, although only 6 were actively controlled, with most management consisting of monitoring or preventative measures. While this aligns with the principles of IPM and SFM, it also reflects the limited availability of effective control options and the practical challenges of forest pest management, including difficulties in detection, accessibility of infested trees, and the resources and expertise required for intervention. For the remaining 23 pests, either no management activity was identified or regulation relied solely on biotic resistance. Although current approaches appear adequate for many forest pests that presently cause limited damage, increasing pest introductions, climate change and constraints on control measures may increase future demands on surveillance and management capacity.

Mismatch between pest impact and management effort

A key finding of this study was the mismatch between pest impact and management effort. Several pests associated with moderate or high levels of damage lacked active control measures, although some were subject to monitoring or preventative management. In some cases, populations were regulated by natural enemies, but reliance on biotic resistance alone may become increasingly uncertain under changing climatic and environmental conditions, which could disrupt existing regulatory mechanisms.

No forest pests were identified as statistically over-managed relative to their damage impacts. However, oak processionary moth showed the largest negative residual, indicating greater management effort relative to its damage score than most other species. This likely reflects concerns for human and animal health which influence management priorities beyond tree damage alone. Whereas, Oriental chestnut gall wasp demonstrates how management intensity can change over time with initial intensive intervention reduced once surveillance confirmed limited impacts and effective biological control. These examples illustrate the influence of social, economic, and political factors on management decisions.

These discrepancies highlight the challenges of translating pest risk into management action. While under-management may allow damaging pests to spread and increase in abundance, excessive intervention can result in unnecessary expenditure and unintended ecological consequences. The increasing number of recognised forest pests in Britain has not been matched by an expansion of active control options. Most species are managed through surveillance, preventative measures or natural enemy regulation, with relatively few requiring direct intervention. Although this may reflect the generally limited impacts of many recently recognised pests, climate-driven changes in pest abundance, increasing tree stress, and continued species introductions could alter future management needs. Continued investment in surveillance, improving early detection, contingency planning, forest resilience, and expanding sustainable management options will therefore be important to ensure that management capacity remains aligned with emerging risks.

Ecological considerations and biodiversity outcomes

The ecological impacts of pest management are difficult to quantify because biodiversity indicators such as abundance and species richness are influenced by multiple variables (Jukes et al. 2001). Pest management must be considered within broader forest ecological contexts. Early intervention can limit tree mortality and help protect associated invertebrate communities (Littlewood et al. 2015). Whereas delayed action can allow pests to reach damaging levels, yet overly intensive interventions can disrupt forest structure, reduce biodiversity, and impair ecosystem services (Simons et al. 2021). Ancient and semi natural forests require particular care due to their high biodiversity value and sensitivity to disturbance (Spake et al. 2015).

The biodiversity effects of forest management are highly context dependent. Conifer plantations supported substantial biodiversity, but species richness and abundance were generally higher in native broadleaf forests (Pedley et al. 2014). Increasing tree diversity and maintaining understory vegetation can enhance arthropod diversity and ecosystem resilience (Moffatt et al. 2008, Oxbrough et al. 2016), although mixed stands do not universally outperform monocultures (Humphrey et al. 1999, Barsoum et al. 2014). In contrast, more intensive management regimes have been associated with reduced invertebrate diversity, as demonstrated when thinning aimed at maximizing birch biomass and timber quality replaced low-intensity practices (Woodcock et al. 2003).

Effective forest pest management requires balancing biosecurity objectives with broader ecological considerations. Because many forest pests alter habitat structure and species interactions, management approaches that maintain biodiversity may also mitigate pest impacts by enhancing ecosystem resilience and supporting natural regulatory processes. Adaptive management, underpinned by monitoring and evidence-based decision-making, is therefore essential to minimize pest impacts while maintaining the biodiversity, resilience, and long-term functioning of forest ecosystems.

Overall, current forest pest management in Britain shows only partial alignment with IPM principles. Although substantial progress has been made in surveillance, prevention, and biological control, management effort is not always proportional to pest impact. Improving monitoring coverage, strengthening preventative measures, and expanding sustainable management options will be important for maintaining resilient forests under increasing pressures from climate change, biological invasions, and international trade.

Discussion

The number of insect species recognised as forest pests in Britain has increased markedly, from the 26 species recorded by Munro (1927), Bevan (1987) and Evans (1997) to the 56 species identified in this study. The implications of this increase, and the other principal findings of this study, are discussed below.

Drivers of pest arrival and impact

Globalization of trade

Patterns of non-native insect introductions continue to reflect global trade intensity. Two major historical peaks—one following the Industrial Revolution and another from the mid-20th century onwards—correspond with major shifts in transport efficiency and international trade volume (Bonnamour et al. 2021, Bertelsmeier et al. 2025).

Pathways are unresolved for some species, but clear associations exist for others, including introductions via plants for planting (e.g. oak processionary moth) and wood packaging material (e.g. Asian longhorn beetle) (Inward et al. 2024). Native species such as pine shoot beetle have also been supplemented by foreign introductions via natural dispersal or contaminated packaging (de Becquevort et al. 2024). Recent detections elsewhere, such as *Pseudips mexicanus* in Ireland—likely originating from Mexico via an unidentified route—demonstrate the continuing vulnerability within global supply chains (Department of Agriculture, Food and the Marine 2024).

Shifting trade patterns and future risk

Future pest threats will be shaped by evolving trade routes and supplier relationships. Declining sawn-wood imports from Canada and increasing imports from the Baltic states (Forest Research 2024a) have not yet produced detectable changes in pest arrival patterns, but the potential for future effects remains. Post-EU exit changes in trade relationships, import flows, and phytosanitary arrangements create additional uncertainty regarding future pest introduction pathways (Ward and Webb 2026).

Although ~75% of pests identified in this study are non-native, interpretation of impact patterns requires caution. This partly reflects classification bias: native insects are typically recognized as pests only after causing observable damage, whereas non-native species may be designated as pests based on perceived risk alone. This asymmetry inflates the apparent impact of native species, although several introduced pests from Europe and Asia were also scored as highly damaging.

Regulatory responses and mitigation

Recent phytosanitary reforms aimed to reduce uncertainty and improve traceability. Since 2019, all plants for planting imported from the EU require plant passports, and from 2024, phytosanitary certification and risk-based inspections have been extended to a broader range of plant and plant-product imports, including those entering via Northern Ireland (Defra 2024). In 2022, pine processionary moth nests were detected on imported ponderosa pine (*Pinus ponderosa* Doug. ex Lawson) from France, and trace-back investigations enabled targeted destruction of affected material (Blake, personal communication, 19 July 2022). Although regulation of wood packaging material cannot eliminate risk, it improves biosecurity practices and provides evidence on emerging threats (Eyre and Haack 2017).

Nevertheless, recent detections highlight persistent vulnerabilities. The 2013 detection of three invasive ambrosia beetles in Britain demonstrated that current European Union (EU) regulations for wood imports are insufficient for this group because bark removal does not reliably eliminate infestation. Although typically secondary pests, their prevalence may increase under climate-driven stressors such as drought and storm damage, alongside potential increases in voltinism (Inward 2020). Good silvicultural practice and prompt removal of cut or fallen timber remain important risk-reduction measures.

Future changes to the UK's plant health regime, including any move towards greater regulatory alignment with the EU, will require careful evaluation to ensure that biosecurity gains achieved through recent reforms (Defra 2024) are maintained.

Effectiveness and limitations of surveillance

Enhanced surveillance has likely contributed to rising forest pest detection rates and may partly explain the increasing number of forest pests recognized in Britain (Poland and Rassati 2019) and emerging technologies could further improve capability in coming decades. Molecular diagnostics (Lushai and Loxdale 2004, Hodgetts et al. 2016, Miller et al. 2016, Barsoum et al. 2018, Tedersoo et al. 2019, A'Hara et al. 2022, de Becquevort et al. 2023), acoustic monitoring (Görres and Chesmore 2019), and remote sensing and AI-based analytical tools (Tuominen et al. 2009, Lausch et al. 2017, Ecke et al. 2022, Fassnacht et al. 2024) can enable earlier, broader, and more accurate detection of pest populations than conventional methods alone. Although limitations remain, for example, remote sensing is constrained by sensor resolution, operational costs, and the difficulty of attributing canopy symptoms to specific pests (Luo et al. 2023). Emerging machine-learning and AI-based classification tools may help overcome some of these limitations by improving automated host recognition and pest damage attribution (Mahanta et al. 2024).

Early detection is likely to improve management outcomes by reducing opportunities for pest spread and establishment; delayed discovery contributed to the widespread establishment of great spruce bark beetle in Britain (Fielding et al. 1991) and emerald ash borer (*Agrilus planipennis* Fairmaire) in North America (Herms and McCullough 2014). Gaps in existing surveillance mean that additional forest pest species may already be established in Britain but remain undetected.

Enhanced surveillance and monitoring data may also improve predictions of which established pests are most likely to become problematic by providing better evidence of their distribution, abundance, spread, and realized impacts. This could support more proportionate and adaptive management responses, helping to prioritize interventions for high-impact species while avoiding unnecessary expenditure on pests that pose relatively limited threats to forest health. Continued development of integrated, multi-method surveillance systems will be essential for improving early detection and reducing the likelihood of future incursions. Future work should also examine where pests are detected across urban and forest environments, as this spatial information is critical for optimizing surveillance strategies and targeting management interventions.

Despite increased detections, more recently detected pests did not generally have higher impact scores than earlier detections, indicating that many currently cause limited damage. This may reflect early-stage establishment, effective intervention, or the long lag times that often occur before impacts become apparent.

Forest management

Forest management both mitigates and drives pest impacts in Britain. Extensive planting of monocultures—particularly of non-native species—creates conditions that facilitate pest establishment and spread. The introduction of non-native hosts has also altered pest dynamics by enabling native insects to exploit novel, more susceptible hosts. As Britain considers introducing more climate-resilient tree species, including drought-tolerant taxa, new forest pest associations and potential forest pest arrivals are likely to emerge (Hurley et al. 2025), as illustrated by the establishment of Monterey pine aphid [*Essigella californica* (Essig)] following the planting of Monterey pine (Reid et al. 2015).

Native tree species can also become vulnerable to forest pests when planted in monocultures. Scots pine stands on sandy soils in Poland and Germany, for instance, experience severe defoliation during pine tree lappet moth outbreaks (Skrzecz et al. 2020). Although British populations remain low and localized, the species poses a potential future risk (Ray et al. 2016, Moore et al. 2017).

Britain's predominant clear-fell and restock silvicultural system also creates favourable conditions for large pine weevil, which has been a persistent and costly pest of conifer restock sites since the early development of British forestry (Munro 1928, 1929, Leather et al. 1999, Willoughby et al. 2022). Fresh conifer stumps provide abundant breeding material, supporting high weevil populations that can damage newly planted trees. The species therefore illustrates how forest management practices can inadvertently increase pest pressure and necessitate further management intervention (Leather et al. 1999, Willoughby et al. 2022).

Climate change

Climate change is expected to intensify forest pest pressures in Britain by increasing climatic suitability for both native and non-native species. Temperature thresholds influence potential arrival pathways. Cross-Channel dispersal of eight-toothed spruce bark beetle depends on minimum flight temperatures of 16°C combined with favourable winds, conditions projected to become more frequent under future climate scenarios (Inward et al. 2024). Warmer temperatures also increase voltinism, raising population densities and the beetle's capacity to overcome healthy host defences (Webb et al. 2025). However, climate change effects are not uniform. For example, milder winters are expected to increase green spruce aphid overwintering survival, whereas summer heat and drought may moderate population growth through heat stress and increased natural enemy activity (Straw et al. 2017, Straw et al. 2019a).

Climate interacts strongly with other drivers, including trade and host availability. Oak processionary moth abundance has been linked to warmer, drier conditions in the Netherlands (Van Oudenhoven et al. 2008), although its spread in Britain has been driven primarily by movement of infested plant material and habitat availability (Tomlinson et al. 2015, Godefroid et al. 2020). Northern Britain is currently climatically unsuitable, but future warming is projected to increase suitability (Godefroid et al. 2020).

Climate change may also increase the probability of establishment for regularly intercepted pests such as Citrus and Asian longhorn beetles (*Anoplophora* spp.), which are currently limited by Britain's cooler climate (van der Gaag et al. 2008, Straw et al. 2015, 2016). Climate-driven range expansions are already evident elsewhere in Europe, including the northward spread of pine processionary moth, driven by warmer winters and nights (Battisti et al. 2005, Roques 2015). The species now occurs in northern France and could survive in southern England if introduced (Defra 2022).

Forecasting future impacts remains challenging because pests, hosts, and natural enemies respond differently to changes in temperature and precipitation (Maunsell et al. 2015). Responses are unlikely to be linear, and generalists may be less affected than specialists (Gough et al. 2015). These interacting factors introduce substantial uncertainty into projections of future pest abundance and damage.

Tree stress

Tree stress is a major compounding driver of forest pest vulnerability. By weakening host defences, stress increases the likelihood that both native and non-native pests can establish, reproduce, and cause damage. Poor management practices can amplify these effects, contributing to heightened susceptibility to pests such as great spruce bark beetle and pine shoot beetle. Outbreaks of bark beetles in Europe and North America similarly follow widespread stress events, including storms and droughts (Hlásny et al. 2019, Kärvemo et al. 2023).

Some management interventions may unintentionally reduce resilience. Large-scale removal of pine forests during mountain pine beetle (*Dendroctonus ponderosae*) outbreaks in Canada demonstrates how reactive measures can diminish structural diversity and increase broader landscape risks (Adger et al. 2011).

Understanding how stress interacts with climate, management, and pest pressure is essential for designing effective management responses. These interactions influence pest establishment, spread, and the success of subsequent interventions, providing a critical foundation for evaluating current approaches to forest pest management in Britain.

Limitations of study

Biases in pest designation and impact interpretation

The designation of species as 'pests' is shaped by historical context, research focus, and impacts reported outside Britain. Although all 56 species included in this study are recognized as forest pests in the literature, several have caused little measurable damage domestically. Instead, their inclusion reflects historical outbreaks or higher impacts elsewhere—for example, elm zigzag sawfly has caused severe defoliation in mainland Europe (Blank et al. 2015) and brown spruce longhorn beetle has killed red spruce (*Picea rubens* Sarg.) in Canada (Sweeney and Smith 2002). These factors introduce uncertainty to pest lists and complicate impact assessments. The inclusion of furniture beetle was based on its presence in previous reviews; however, as a pest of timber products rather than living trees, it sits somewhat outside the scope of this study (Hutton 2019).

Uneven evidence base

A major limitation of this study is the uneven quality and quantity of information across species. Pests affecting commercially valuable conifers are well-studied, whereas other species appear only sporadically in the literature. Well-established pests with effective control methods often receive little new study (e.g. great spruce bark beetle), while new or difficult-to-manage pests (e.g. large pine weevil) attract disproportionate attention. The outbreak and successful eradication of Asian longhorn beetle in Kent, for example, generated multiple publications (Porth et al. 2015, Dandy et al. 2018).

This imbalance also reflects research and policy priorities, funding cycles, political and researcher interest, economic relevance, and historical presence. Consequently, the dataset captures not only ecological or economic importance but also the broader scientific and policy landscape that shapes which pests are studied, monitored, and managed.

Temporal bias and research lag

Temporal patterns also influence the dataset. Long-established pests naturally accumulate more publications, whereas recently detected species are under-represented. This time-lag bias means research volume does not necessarily correspond to current threat levels. Several forest pests lacked recent studies, although these are typically low-risk on non-priority hosts (e.g. *Oxycarenus modestus* Distant on alder; *Agrilus ater* L. on willows and poplars) or historically problematic but currently inactive [e.g. pine looper moth (*Bupalus piniaria* (L.))]. These gaps highlight opportunities to fill knowledge deficits and provide a baseline for tracking future changes in forest pest impact and research focus.

Comparison with earlier reviews (Munro (1927), Evans (1997), showed that several native species now recognized as pests—such as pine shoot beetle, two-spotted oak buprestid beetle, and oak pinhole borer—were absent from these pest lists, indicating that they were not considered significant forest pests at the time.

Additional pest species identified after analysis

Subsequent to the review and analysis carried out and reported here, several additional pests were identified as present in Britain but absent from the initial forest pest list. *Ips acuminatus* (Gyllenhal) has been recorded at low levels for over a century, but increasing damage on the continent suggests it warrants closer attention (Grégoire et al. 2024). Three invasive ambrosia beetles, *Xylosandrus germanus*, *Gnathotrichus materiarius* and *Cyclorhipidion bodoanum*, were also omitted from the original inventory despite their detection in Britain in 2013 (Inward 2020). Although they are currently regarded primarily as secondary pests, ambrosia beetles can exploit stressed or recently damaged trees and may become more problematic under future climate-driven increases in drought, storm damage and tree stress. Willow beetles [*Phratora vulgatissima* (L.) and *Phratora vitellinae* (L.)] are recognized pests of short-rotation willow coppice, where even minor defoliation reduces biomass productivity (Kendall and Wiltshire 1998). Effective management includes planting less-preferred *Salix* species and targeted insecticide use (Sage and Tucker 1998, Peacock et al. 1999, Sage et al. 1999, Batley et al. 2004). Alder leaf beetle (*Agelastica alni* L.) can also cause visually striking defoliation, but its long-term impact remains uncertain, particularly given its history of extinction and recolonization in Britain and the unknown extent of parasitoid recolonization (Stenhouse 2012).

Deathwatch beetle [*Xestobium rufovillosum* (De Geer)]—primarily a pest of building timbers—is attracted to volatiles from wood-decaying fungi (Belmain et al. 1998, 2002). Adult *Phyllobius pyri* (L.) weevils can damage some broadleaf species in newly planted woodlands, whereas other hosts, especially ash, show resistance (Billiald et al. 2010). Several invasive oak gall wasps inhibit acorn production but require Turkey oak (*Quercus cerris* L.) as an obligatory secondary host, restricting their distribution and providing a rationale for limiting future planting of this species (Schönrogge et al. 1998, Schönrogge et al. 2000).

Non-native forest pest threats

Although outside the scope of the current inventory, several non-native pests absent from Britain represent significant future threats and warrant consideration within preparedness and surveillance programmes.

Early detection tools have been developed for bronze birch borer (*Agrilus anxius* Gory and Laporte) and emerald ash borer. Bronze birch borer poses a major threat to British birch species, with optimum detection achieved using traps incorporating host kairomones (Silk et al. 2020), with green prism traps outperforming multi-funnel traps (Matula et al. 2023, Santoiemma et al. 2024). Similar traps exist for emerald ash borer, a potential threat to British ash trees, but they operate effectively only at short range (∼25 m) and predominantly capture males, limiting their use for mass trapping (Imrei et al. 2020, Parker et al. 2020). Potential management options include breeding or gene editing resistant ash (Kelly et al. 2020). A European preparedness framework emphasizes the need for coordinated prevention and response (Evans et al. 2020).

Pine wilt disease (PWD) and pine wilt nematode (PWN) are absent from Britain, but their vectors (*Monochamus* spp.) are regularly intercepted at borders (Back et al. 2024). Asymptomatic hosts complicate targeted management, as removal of infected trees is essential for eradication (Khan et al. 2020). Highly effective lures (Álvarez et al. 2015, Pajares et al. 2013, 2010) and risk models (Robinet et al. 2011) have been developed for *Monochamus* species (Pajares et al. 2017).

In Europe, bat predation contributes to regulating pine processionary moth [*Thaumetopoea pityocampa* (Denis and Schiffermüller)] populations (Bourlat et al. 2023, Tortosa et al. 2023). Were this forest pest to establish in Britain, additional control measures would be required.

Implications for forest health and biosecurity

The findings of this study underscore the multifaceted nature of pest threats to British forests. Increasing incursions facilitated by trade highlight the need to strengthen biosecurity measures targeting wood packaging, live plant imports, and other high-risk pathways. The generally higher impact scores of native pests relative to many non-native species emphasize that biosecurity must address both external introductions and internal drivers, including climate-induced stress and forest management practices that predispose stands to outbreaks.

The concentration of high-impact pests on pine, spruce, and oak indicates that these genera should remain priorities for monitoring, contingency planning, and resilience-focused management. The identification of mismatches between pest impact and management effort suggests that current control strategies may require reassessment. Opportunities for potentially under-managed, high-impact pests include expanding biological control, refining silvicultural practices, and improving early detection systems to ensure interventions are proportionate, effective, and ecologically sustainable.

Comparison with the UK Plant Health Risk Register shows little correlation between mitigated risk scores and the impact scores generated in this study, reflecting the Risk Register's policy-focused emphasis on entry likelihood and mitigation feasibility rather than realized ecological impact (Defra 2025).

Overall, the number of forest pests recognised in Britain has increased substantially since the reviews of Munro (1927) and Evans (1997). However, many recently detected species currently cause limited damage and relatively few require active control. Despite this, global trade, climate change, shifting silvicultural practices, and increasing tree stress are likely to increase future risks. Strengthening surveillance, preventative measures, and sustainable management approaches will therefore be essential for maintaining forest health and ensuring management capacity remains proportionate to emerging threats.

Conclusion

This study provides a comprehensive assessment of forest pests affecting British trees, identifying 56 species, the majority of which are introduced—originating predominantly from mainland Europe but also from Asia, North America, and Australia. The number of forest pests recognised in Britain has increased markedly over time, with a particularly pronounced rise since the early 21st century.

A structured scoring approach was used to quantify and compare the current impact of forest pests in Britain. Values from 0 to 3 were assigned for pest distribution, pest management effort, and tree damage severity, and summed to produce an overall impact score ranging from 0 (lowest) to 9 (highest). Two additional metrics were calculated by multiplying the distribution score by the management and damage scores. Native pests were generally associated with higher impact scores than many non-native pests, reflecting both their inherent damage and the bias in defining forest pests. Several non-native pests originating from Europe and Asia were also categorized as high impact, highlighting the continuing risks linked to global trade and species movement. Over half of the pests were classified as having low to medium impact (scores 0–5), 10 species had high impact (6–7), and only 2 species (large pine weevil and great spruce bark beetle) were classed as very high impact (8–9). Five species-green spruce aphid, large larch bark beetle, oak leaf roller moth, pine shoot beetle and winter moth-caused greater damage than expected given their distribution and management-effort levels, indicating ineffective or insufficient management. In contrast, oak processionary moth showed lower than expected damage relative to management effort, although it was not identified as an over-managed outlier. This likely reflects the importance of human and animal health considerations in management decisions.

Productive forests were associated with more pests than amenity or native forests, and conifers harboured more pests than broadleaves. Pine (*Pinus*), spruce (*Picea*), and oak (*Quercus*) supported the highest numbers of pests and faced the greatest threat levels. Key drivers of pest establishment and impact included trade, forest management practices, climate, and tree stress.

Forest management emerged as both a key driver and a critical mitigator of pest impacts. This study identified management practices that increased pest vulnerability, including planting extensive monocultures and clear-felling, as well as strategies that reduce tree stress, such as planting species in suitable climates and soils, and implementing targeted interventions, including species-specific biological control programmes.

Current forest pest management in Britain only partially meets the principles of IPM and SFM. Monitoring was identified for just 41% of forest pests, and preventative measures for 45%, indicating substantial scope to strengthen early-stage detection and risk reduction—particularly for cryptic species and long-established pests whose impacts may intensify under warmer climates or increased tree stress. The study also found a substantial reliance on biotic resistance, which was identified for 45% of pests, while active control measures were recorded for only 11%. Together, findings indicate that, despite the increasing number of recognised forest pests in Britain, relatively few currently cause severe impacts or require direct intervention. Forest pest management therefore remains predominantly preventative rather than interventionist, relying heavily on surveillance, biosecurity measures and natural enemy regulation. As climate change, international trade and biological invasions continue to increase pest pressures, strengthening monitoring, preventative measures, forest resilience and sustainable management options will be essential to maintain long-term forest health and ensure management capacity remains proportionate to emerging risks.

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Author contributions

Katrina Dainton (Conceptualisation, Data curation, Formal analysis, Writing—original draft, Writing—review & editing). Max Blake (Conceptualisation, Methodology, Writing—review & editing). Gail Jackson, Henry Creissen, Fiona Burnett and Mariella Marzano (Conceptualisation, Methodology, Supervision, Writing—review & editing)

Supplementary material

Supplementary material is available at *Forestry: An International Journal of Forest Research* online.

Conflicts of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

The data underlying this article are available in the article and in its online supplementary material.

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Review