Tree insect pests and pathogens: a global systematic review of their impacts in urban setting; Urban Ecosystems; Raum, S. et al., Technical University Munich / Imperial College London, susanne.raum@tum.de

Supplementary Information SI1- Systematic Review Protocol

Urban tree insect pests and pathogens: a systematic review of impacts and emerging risks in a changing climate

1. Introduction

Urban trees are a key type of green infrastructure in many towns and cities around the globe (Pearlmutter et al., 2017). Trees can be some of the most prominent natural features in urban areas from both visual and functional perspectives (Wolf et al., 2020). Urban trees can remove certain air pollutants (Bottalico et al., 2017), help reduce the severity of urban flooding (Berland et al., 2017), contribute to urban residents' wellbeing (Pearlmutter et al., 2017), and provide recreational opportunities (Jennings et al., 2016) and valued landscape features (Price, 2003). A healthy canopy cover of the urban forest (i.e., all trees within an urban area) is also vitally important to adapt to rising temperatures (Rahman et al., 2020) as trees can provide substantial cooling (Werbin et al., 2020). Because of these significant contributions, cities worldwide (e.g., Beijing, Singapour, New York, Porto) have been investing resources to maintain existing trees and expand current tree canopy cover (Campbell, 2015; Pinto et al., 2016; Yao et al., 2019; Turrell, 2020).

Urban areas, however, also present a challenging environment for trees (Pauleit et al., 2002). Urban trees can be exposed to greater extremes and variability of biophysical stresses than that typically encountered by trees in rural environments (Malthus & Younger, 2000). They are also threatened by growing incidences of biotic and non-biotic disturbances, including tree pests and diseases, storms, droughts, and fire (Referowska-Chodak, 2019). Insect pests, fungal pathogens, high temperatures, and drought are amongst the greatest disturbance threats to urban trees at present (Ordóñez & Duinker, 2015; Rötzer et al., 2021). Tree insect / pathogen outbreaks, in particular, have already had significant consequences for many towns and cities, including large-scale tree losses (Sjoeman & Oestberg, 2019). A wide range of native and non-native pests and diseases, including invertebrates (e.g., beetles, moths) (Smith & Wu, 2008), helminth (Bergseng et al., 2012), bacteria (Halbert & Manjunath, 2004), viruses (Hue et al. 2020), fungi (Hardwood et al., 2011) and oomycetes (Cooke et al., 2000) can affect trees in urban areas. Prominent examples are the fungal pathogens Chalara ash dieback *(Hymenoscyphus fraxineus)* (Hardwood et al., 2011) and canker stain (*Ceratocystis platani*) (Tsopelas et al., 2017), the Asian long-horned beetle (*Anoplophora glabripennis*) (Haack et al., 1997), and the oak processionary moth (*Thaumetopoea processionea*) (Mindlin et al., 2012). These may affect trees through defoliation, staining, boring, and loss of branches or a combination of these; they may also cause tree mortality and have negative impacts on human health and visual aesthetics (Boyd et al., 2013; NASEM, 2019). Insect / pathogen outbreaks may also affect the ability of trees to contribute to climate mitigation and adaptation, especially their capacity to cool the urban temperature, and their ability to help mitigate against air pollution, landslides and flooding (Anderreg et al., 2020).

The development of successful new urban tree policies and practical management measures, not only requires a better understanding of the causes and types of growing tree insects / pathogens invasions in urban areas, but also of the extent of the damage, their social-, economic-, and environmental impacts, and emerging risks. This information, to date, appears to be fragmented amongst a range of case studies from different fields. Although several comprehensive reviews examined the threats of tree insect / pathogen outbreaks (e.g., Boyd et al., 2013; Freer-Smith & Webber, 2015; Graziosi et al., 2019; Hlásny et al., 2021; Tubby & Webber, 2010) or the interactions between insect pests and other disturbances (e.g., Canelles et al., 2012; Dale et al., 2001; Temperli et al., 2013), most of these focus on forests in the wider environment. The bulk of the studies on which these reviews are based, have focused on the impacts of individual tree insects / pathogens on the structural and functional components of the effected forest environments (e.g., Bearup et al., 2014; Carnegie et al., 2016; Fukasawa & Seiwa, 2016). Others investigated the economic costs of single tree insects or pathogens, especially in terms of timber (e.g., Aukema et al., 2011; Ayres & Lombardero, 2000; Hill et al., 2019) or fruit tree products (e.g., Alvarez et al., 2016; Cambra et al., 2006; Hadidi et al., 2017). None of these studies assesses the socio-economic and environmental impacts concurrently and in an urban context. Likewise, knowledge of the potential risks due to new invasive tree insects / pathogens or new interactions between urban tree insects / pathogens and other factors appears to be fragmented.

This study responds to the need to systematically review the diverse literature on tree insects / pathogens in cities around the globe, while also identifying gaps in research to develop a research agenda. It aims to answer the following primary question: (1) What are the impacts of tree insects / pathogens outbreaks in urban settings (and other related factors that may shape the future of urban tree landscapes and their management)? Secondary questions are: (2) Which insects / pathogens cause damage to urban trees, to which species and to what extent? (2) (and (3) How these outbreaks have been addressed so far?) (4) Which lessons regarding urban tree policies and management practice can be derived? Framed as a knowledge synthesis, this review will offer the best available evidence of urban tree insect / pathogen impacts to guide recommendations for policy, management, and further research. It will enable us to better forecast how growing threats will affect the urban forest and plan for these eventualities.

2. Methods

2.1. Literature Review approach

In this study, we will use a systematic review approach (Moher et al., 2009) to assess the literature on urban tree insects / pathogens. 'A systematic review attempts to collate all empirical evidence that fits pre-specified eligibility criteria in order to answer a specific research question' (Higgins et al., 2019:1). This includes a systematic search process to minimise bias, as well as a systematic synthesis and presentation of the characteristics of the literature examined (Higgins et al., 2019). Systematic narrative reviews are particularly appropriate when a literature review is conducted with a collection of studies that have used diverse methodologies. The literature review will follow established procedures (PRISMA procedure) and reporting standards (Page et al., 2021) which will enable us to develop a strict protocol for searching and selecting articles, whilst minimising bias. It will also ensure that all the key decisions related to the review will be reported at sufficient levels of detail (Macura et al., 2019). The PRISMA procedure is one of the most widely used in different research areas (Siddaway et al., 2019).

Impacts are defined as: '*social, ecological / environmental, and economic effects of tree insect or pathogen outbreaks in urban settings*'. We will place a particular focus on negative effects as these, arguably, have more consequences for policy and practice. Risks are defined as: '*potential or emerging risks of current or potential future outbreaks of tree insect or pathogen outbreaks in urban settings*'.

Search query used for each database and detail description of document selection

1. Web of Science Core Collection
2. Scopus
3. Science Direct
4. (Google Scholar for scoping only)

Software to be used

- Covidence for article screening

- MAXQDA for article coding and analysis

2.2. Data Collection

The search aims to capture the available scientific evidence (quantitative and qualitative) relevant to the research question(s). Reflecting the multi-disciplinarity of the relevant body of publications, studies will be selected, using the academic databases Scopus, Web of Science Core Collection, and Science Direct to capture a spectrum of both the natural and social science literature. The scope of the review will be international in geographical extent. Given the scope of the project and the global scale of the review, the search will be limited to peer-reviewed research articles, excluding book chapters, conference papers, or other grey literature. No language limits will be placed on the search to allow for the capture of relevant foreign language studies with English abstracts. The final analysis, however, will be limited to English-language academic peer-reviewed articles.

The four main search term areas and their keywords, shown in Table 1, were derived from scoping searches in Google Scholar, through a reading of the identified literature, through discussion with other members of the study team, and the University's specialist librarians. They were further refined during scoping database searches to ensure that key articles identified beforehand were meeting the criteria used in the search.

Table 1: Search terms used in the bibliographic review in **Scopus, Web of Science (Core Collection), Science Direct,** (and Google Scholar)

Term 1	Term 2	Term 3	Term 4
urban	tree*	tree pest / pests	impact*
city / cities	forest*	tree nsect*	effect*
town*	street tree*	tree disease*	risk*
peri-urban	urban tree*	tree pathogen*	threat*
suburban	urban forest*		mortal*
metropol*	canop*		damage*

We also accept Latin and common names for cities, trees, insects, and pests.

A specific set of criteria will be used for each of the two screening phases to assess the relevance of the articles and determine their inclusion or exclusion from the synthesis. Table 2 shows the specific inclusion and exclusion criteria to be strictly adhered to during the different data collection and screening stages. Review articles in the database search will be included as scoping database searches revealed that empirical articles were occasionally wrongly attributed as review articles. The study selection process will be shown in a Preferred Reporting Items for Systematic Reviews Met-Analysis (PRISMA) diagram (Page et al., 2021).

Table 2: Inclusion and exclusion criteria for document selection

Inclusion criteria	Exclusion criteria
Phase 1: initial keyword search	
All languages	None
Available in Scopus, Web of Science Core Collection, Science Direct	Not available in Scopus, Web of Science Core Collection, Science Direct
Primary research articles (peer-reviewed, scholarly journal publication)	Others (e.g., meetings, proceedings, theses, books, book chapters, reports, reviews)
Phase 2: keyword search in title and abstract review to select the studies on urban tree insects / pathogens	
Studies located in North America, South America, European region including Turkey and Russia, Asia, Africa, Oceania, Global	Unspecified
Studies located in urban, peri-urban, suburban, town, city, metropolis areas	Rural, villages, unspecified

Abstracts that use specified search terms or synonyms, including common and Latin names of tree species and insect / pathogens	Abstracts that do not meet the two criteria: use of specific terms or synonyms, and explicit indication of the use of natural trees (e.g. bronchial tree, arterial tree)
Abstracts that did not use key terms from the above four groups, but clearly indicate studied system	
The article must have electronically available abstracts and full texts	
Phase 3: Full-text review to select the studies whose impact and / risk description is sufficient for us to address the main research questions	
Apply content analysis techniques to the data to answer the research questions, using a set of predetermined coding parameters	

The documents resulting from the final search will be imported into Covidence (https://www.covidence.org) and then screened in two phases: 2) title / abstract screening and 2) full text screening. The use of Covidence, a web platform for managing the literature screening process endorsed by Cochrane, has the advantage of simplifying whilst also systemising the approach (Harrison et al., 2020). To enhance the quality of screening, two researchers will independently conduct a pilot screening round of 25 articles each during both screening phases, for which Randolph's Kappa statistic (Randolph, 2008) will be applied. In both rounds, disagreements in screening decisions will be resolved through discussion and consensus by the two researchers. As we do not anticipate to undertake a meta-analysis as part of this study, the quality of the studies will be solely determined due to them being obtainable from established academic databases, and being published in peer-reviewed academic journals; no other criteria will be used for the purpose of this review.

Selected articles will be exported in CSV format with their bibliographic information from EndNote to MAXQDA (a software for qualitative data analysis). The full texts of the articles will then be deductively coded, using the above set of predetermined parameters, informed by the review questions. The parameters are informed by an appraisal of existing relevant literature and will be finalised in consultation with the project team through email correspondence. The selected empirical research studies will be categorised and their main findings extracted onto an Excel spreadsheet. For each article, we will record the following information: bibliographic information; information relating to the inclusion criteria; information relating to the study itself (Table 3). The common analysis scheme will be applied to all the reviewed articles.

Table 3: Categories used for coding studies further described by respective type of data and information extracted from the selected articles

Category	Type of data
Bibliographic information	(a) Authors' names (b) Year of publication (c) Title (d) Publication source, i.e. journal (e) Countries, i.e. study location (f) City, i.e. study location
Information relating to the inclusion criteria	(a) Insect / pathogen species (b) Tree species affected (c) Type and extend of impact (d) Environmental impacts (qual / quan) (e) Social impacts (qual / quan) (f) Economic impacts (qual / quan) (g) Emerging/potential risks (h) Response measures
Information relating to the study	(a) Aim of the study

	(b) Methodology employed (e.g., experimental or observations) (c) Size and type of study location (d) Time / duration of study
Additional information	(a) Symptoms of insect / pathogen outbreak (b) Relevance and / or magnitude of impact (c) Recommendations (d) Comments

Table 4: Initial List of Literature used for scoping searches (obtained through Google Scholar) and to develop the final search string and criteria:

1. Annesi, T., Coppola, R., & Motta, E. (2003). Decay and canker caused by Inonotus rickii spreading on more urban tree species. Forest Pathology, 33(6), 405-412.
2. Bigsby, K. M., Ambrose, M. J., Tobin, P. C., & Sills, E. O. (2014). The cost of gypsy moth sex in the city. Urban Forestry & Urban Greening, 13(3), 459-468.
3. Bukowski, E. (2019). Using the commons to understand the Dutch elm disease epidemic in Syracus, NY. Geographical Review, 109(2), 180-198.
4. Ferrari, J. P. & Pichenot, M. (1976). The canker stain disease of plane tree in Marseille and in the south of France. European Journal of Forest Pathology, 6, 18-25.
5. Dzięgielewska, M., Adamska, I., Mikiciuk, M., Nowak, G., & Ptak, P. (2017). Effects of biotic and abiotic factors on the health of horse chestnut trees in an urban area of north-western Poland. Ecological Questions, 27, 25-38.
6. Haack, R. A., Law, K. R., Mastro, V. C., Ossenburgen, H. S., & Raimo, B. J. (1997). New York's battle with the Asian long-horned beetle. Journal of Forestry, 95 (12), 11-15.
7. Haight, R. G., Homans, F. R., Horie, T., Mehta, S. V., Smith, D. J., & Venette, R. C. (2011). Assessing the cost of an invasive forest pathogen: a case study with oak wilt. Environmental Management, 47(3), 506-517.
8. Hesler, L. S., Logan, T. M., Benenson, M. W., & Moser, C. (1999). Acute dermatitis from oak processionary caterpillars in a US military community in Germany. Military medicine, 164(11), 767-770.
9. Izhevskii, S.S. & Mozolevskaya, E.G. (2010). Agrilus planipennis Fairmaire in Moscow ash trees. Russian Journal of Biological Invasions, 1(3): 153-155.
10. Kondo, M. C., Han, S., Donovan, G. H., & MacDonald, J. M. (2017). The association between urban trees and crime: Evidence from the spread of the emerald ash borer in Cincinnati. Landscape and Urban Planning, 157, 193-199.
11. Lehtijärvi, A., Oskay, F, Doğmuş-Lehtijärvi, H.T., Aday Kaya, A. G., Pecori, F., Santini, A., Woodward, S. (2018). Ceratocystis platani is killing plane trees in Istanbul (Turkey). For Path., 48, e12375.
12. McKenney, D. W., Pedlar, J. H., Yemshanov, D., Barry Lyons, D., Campbell, K. L., & Lawrence, K. (2012). Estimates of the potential cost of emerald ash borer (Agrilus planipennis Fairmaire) in Canadian municipalities. Arboriculture and Urban Forestry, 38(3), 81.
13. Miyamoto, T., Masuya, H., Koizumi, A., Yamaguchi, T., Ishihara, M., Yamaoka, Y., ... & Ohara, M. (2019). A report of dieback and mortality of elm trees suspected of Dutch elm disease in Hokkaido, Japan. Journal of Forest Research, 24(6), 396-400.
14. Nowak, D. J., J. E. Pasek, R. A. Sequeira, D. E. Crane, and V. C. Mastro. 2001. Potential effect of Anoplophora glabripennis (Coleoptera: Cerambycidae) on urban trees in the United States. Journal of Economic Entomology 94 (1):116–22.
15. Perry, E. & McCain, A. H. (1988). Incidence and management of canker stain in London Plane trees in Modesto, California. Journal of Arboriculture 14, 1, 18 – 19.
16. Persad, A. B., & Tobin, P. C. (2015). Evaluation of Ash Tree Symptoms Associated with Emerald Ash Borer Infestation in Urban Forests. Arboriculture & Urban Forestry, 41(2).
17. Rossi, J. P., Imbault, V., Lamant, T., & Rousselet, J. (2016). A citywide survey of the pine processionary moth Thaumetopoea pityocampa spatial distribution in Orléans (France). Urban Forestry & Urban Greening, 20, 71-80.

18. Sardaro, R., Grittani, R., Scrascia, M., Pazzani, C., Russo, V., Garganese, F., ... & Porcelli, F. (2018). The Red Palm Weevil in the city of Bari: A first damage assessment. Forests, 9(8), 452.
19. Straw, N. A., Williams, D. T., Kulinich, O., & Gninenko, Y. I. (2013). Distribution, impact and rate of spread of emerald ash borer Agrilus planipennis (Coleoptera: Buprestidae) in the Moscow region of Russia. Forestry, 86(5), 515-522.
20. Sydnor, T. D., Bumgardner, M., Subburayalu, S. (2011). Community ash densities and economic impact potential of emerald ash borer (Agrilus planipennis) in four Midwestern states. Arboric. Urban For., 37, 84– 89.
21. Sydnor, T. D., Bumgardner, M., & Todd, A. (2007). The potential economic impacts of emerald ash borer (Agrilus planipennis) on Ohio, US, communities. Agriculture & Urban Forestry, 33(1), 48-54.
22. Vaughn, C. D., Straka, T. J., Ham, D. L., Hedden, R. L., & Thorpe, K. W. (1997). Costs associated with urban gypsy moth control by arborists: a case study. Journal of Arboriculture, 23, 173-180.