frontiers | Frontiers in Forests and Global Change

TYPE Editorial
PUBLISHED 17 September 2025
DOI 10.3389/ffgc.2025.1665993

Editorial: Biotic pest disturbance - risk, evaluation, and management in forest ecosystems

Roman Modlinger[1]* and Milica Zlatković[2]

[1]Faculty of Forestry and Wood Science, Czech University of Life Sciences in Prague, Prague, Czechia,
[2]Institute of Lowland Forestry and Environment (ILFE), University of Novi Sad, Novi Sad, Serbia

KEYWORDS

biotic disturbance, bark beetles, forest insects, invasive insects, forest pathogens, early detection, remote sensing, RNAi

OPEN ACCESS

EDITED AND REVIEWED BY
John Robert Healey,
Bangor University, United Kingdom

*CORRESPONDENCE
Roman Modlinger
modlinger@fld.czu.cz

RECEIVED 14 July 2025
ACCEPTED 21 August 2025
PUBLISHED 17 September 2025

CITATION
Modlinger R and Zlatković M (2025) Editorial: Biotic pest disturbance - risk, evaluation, and management in forest ecosystems. *Front. For. Glob. Change* 8:1665993. doi: 10.3389/ffgc.2025.1665993

Editorial on the Research Topic
Biotic pest disturbance - risk, evaluation, and management in forest ecosystems

Introduction

Forests are complex, adaptive ecosystems whose resilience depends on their capacity to withstand and recover from disturbances. Historically, forest ecosystems have always been shaped by a diverse array of disturbance agents, from storms to fires and fungal and insect outbreaks, that are integral parts of natural forest dynamics (Seidl and Turner, 2022). However, the past few decades have witnessed a dramatic rise in the frequency and intensity of biotic pest disturbances (Patacca et al., 2022); this has overwhelmed the adaptive capacity of the forests (Forzieri et al., 2024). Invasive insects and pathogens pose a growing threat to health, productivity, biodiversity, ecosystem services, and socio-economic function of forests (Hartmann et al., 2025) and can cause extensive tree mortality (Senf et al., 2020). These biotic threats are interacting with a complexity of other environmental challenges, such as rapid climate change (Ramsfield et al., 2016), global increase in travel and trade (Fenn-Moltu et al., 2023), and monocultural plantations to reshape the structure, composition (Forrester and Bauhus, 2016), and ecosystem services of forests around the world (van Lierop et al., 2015). Windstorms, drought, fire, and human interventions exacerbate the spread and impact of insects and diseases (Seidl et al., 2017), while climate change is altering pest population dynamics, extending ranges and outbreak periods (Jactel et al., 2019), and introducing new risks such as novel disease vectors and pest-pathogen interactions (Franic et al., 2023).

This Research Topic, *Biotic Pest Disturbance - Risk, Evaluation, and Management in Forest Ecosystems*, provides a timely synthesis of current research that offers a multifaceted perspective on how science and practice can respond to these forest threats and challenges. Biotic Pest Disturbance includes all living agents that damage a forest, mainly insects and pathogens. The Research Topic of 15 studies exemplifies the diverse strategies needed to better understand, detect, and respond to biotic threats in forests. It emphasizes the need for improved risk identification, robust evaluation of the impact of biotic pest disturbance agents under changing environmental conditions, and the deployment of innovative, sustainable management solutions. Together, these contributions advance our understanding of how to maintain resilient forests in an era of multiple global change pressures, reflecting the need for a comprehensive, multidisciplinary, and innovative approach to safeguarding forests for future generations.

Below, we synthesize the accepted articles under three main sections, i.e., Risk: recognizing emerging threats from pests and pathogens, Evaluation: understanding host-pest interactions under climate change and advancing pest detection, and Management: toward innovative, integrated solutions for sustainable forest health that move beyond traditional chemical control.

Risk: recognizing emerging threats from pests and pathogens

Risk in forest pest management is the probability of an outbreak or the likelihood of damage in a particular stand, considering pest population density and stand susceptibility (Wainhouse, 2008). Early and accurate pest risk assessment is fundamental for preventing and mitigating large-scale insect and pathogen outbreaks, and it forms the cornerstone of any proactive pest management strategy. Understanding risk begins with recognizing which insects and pathogens threaten forests, and how multiple agents can act synergistically. Life history characteristics offer a general insight into the damaging potential of pests, providing a starting point for comprehensive risk assessment. The characteristic features of an outbreak vary depending on the type of pest involved. While the timing of outbreaks remains difficult to predict, estimating the risk to specific forest stands holds considerable practical value. Anticipating where outbreaks are most likely to occur enhances the likelihood of early detection during pest evaluations.

Effective forest pest management begins with understanding and anticipating risk—not only from individual agents but from multi-faceted, interacting threats under changing environmental conditions. The contributions in this section collectively underscore how pathogen complexity, pest interactions, climate-induced shifts, and human-mediated pathways are reshaping our understanding of forest health risks.

Several papers highlight the increasing relevance of multiple agents acting simultaneously. For instance, Zlatković et al. and Marković et al. both focus on pedunculate oak *Quercus robur*, a keystone species in European lowland forests, demonstrating how co-occurring foliar pathogens and insects significantly impact tree health and regeneration. Zlatković et al. reveal a complex of pathogenic fungi, such as *Tubakia* spp., *Didymella macrostoma*, and *Apiognomonia errabunda*, that contribute to anthracnose and leaf spot on *Q. robur* leaves in riparian forests. This article underscores how even well-studied species can harbor previously underrecognized pathogen complexes, raising questions about latent risk and the importance of accurate species-level diagnostics. Complementing this, Marković et al. show how multiple foliar pests, including oak powdery mildew *Erysiphe alphitoides* and oak lace bug *Corythucha arcuata*, can collectively suppress growth in young trees—especially when compounded by environmental stressors like drought and groundwater decline. Together, these studies emphasize the need for integrated risk frameworks that account for synergistic interactions and cumulative stress.

Climate change as a modifier of pest risk emerges as another critical cross-cutting issue. Macháčová et al. offer compelling evidence that elevated atmospheric CO_2-a hallmark of future climate scenarios –can influence host-pathogen interactions. Their study on *Alnus glutinosa* responses to *Phytophthora* bark infections reveals that disease outcomes vary under different CO_2 levels, suggesting that future pest dynamics may shift in non-linear, species-specific ways. These findings reinforce the necessity of integrating climate variables into risk assessments, expanding from pest virulence to also consider host physiological responses and ecosystem-level vulnerabilities.

Climate change is a driving factor for shifts in the distribution areas of many species. Gao et al. use predictive modeling to project the expansion of *Monochamus saltuarius*, a vector of Pine wilt disease in China, under current and future climate scenarios. Their results point to a marked northward and regional expansion of risk zones, offering important insights for biosecurity planning. The study reflects the growing importance of bioclimatic modeling in forecasting risk trajectories—especially invasive species—but also illustrates the uncertainty that accompanies such projections across decadal timescales.

Various preventive actions must be applied to minimize the threat of invasive species to forests. Budzyn et al. evaluate a firewood transport campaign in Michigan, revealing that campaign awareness slightly decreased between the survey years, personal firewood transport has decreased, and knowledge of invasives remains low. Their findings call attention to the behavioral dimension of forest pest risk, suggesting that outreach should be paired with stronger regulatory mechanisms to meaningfully mitigate spread.

Despite differences in taxa and regions, all four studies point to the need for early detection, cross-disciplinary approaches, and multi-agent monitoring systems. They also reveal that pest risk is no longer a static or localized concept—it is dynamic, multi-scalar, and increasingly shaped by climate, connectivity, and complexity. The emergence of underestimated pathogen complexes, the cumulative impact of mild but chronic stressors, and the interaction between human behavior and pest movement are key themes that emerge across the studies.

In sum, this section demonstrates that risk assessment must evolve toward flexible, integrative, and anticipatory models—ones that account for biological complexity, environmental change, and human activity in concert.

Evaluation: understanding host-pest interactions under climate change and advancing pest detection

Evaluation of forest pests includes characterizing the symptoms of pest infestation, developing an appropriate detection method for monitoring, and establishing specific critical thresholds. In general, two primary methods of evaluation are distinguished: population sampling and damage monitoring. For both approaches, stand-level risk rating can help identify priority areas for targeted monitoring. In the case of invasive species, presence–absence strategies are commonly employed, with detection methods requiring high sensitivity—such as pheromone traps—to provide rapid confirmation of species presence. Population data are frequently evaluated to classify pest levels as above or below critical thresholds, often using sequential assessment methods. Damage monitoring is a rapidly evolving field, driven by technological advances in unmanned aerial vehicles (UAVs), satellite imagery, remote sensors, and classification algorithms. One of the main functions of monitoring is to support decision-making in forest pest management by providing timely and actionable information.

Evaluating forest pest outbreaks is a crucial step toward timely management interventions, particularly under the pressures of climate change and increasing global trade. The studies in this section explore innovations in early detection—from physiological and biochemical responses in trees to remote sensing technologies and pheromone-based trap networks. Collectively, they reinforce that successful pest evaluation will combine early physiological signals, volatile chemical detection, and spatial monitoring tools into an integrated approach.

Several papers focus on the devastating impact of the spruce bark beetle *Ips typographus*—the most important pest in Central Europe, responsible for the loss of ca. 100 mil. m^3 of growing stock in Czechia between 2016 and 2022 (Washaya et al., 2024). Stríbrská et al. assess physiological and biochemical changes in *Picea abies*, identifying reduced sap flow, stem increment, and increased monoterpene emissions in freshly infested trees. These biological responses, along with bark temperature measurements and trap catches, could enhance early warning systems. Similarly, Hüttnerová and Surový test three electronic nose devices for their ability to detect bark beetle-induced volatile organic compounds. Their findings confirm that infestation can be detected within 1 week of attack onset, pointing to the potential of chemical sensing for rapid, non-invasive diagnostics.

In parallel, Klouček et al. explore UAV-borne multispectral imaging to distinguish between healthy and infested spruce trees at early infestation stages. Vegetation indices, particularly NDVI and BNDVI, proved more effective than individual spectral bands, and detection accuracy improved as infestation progressed. These results underscore the growing utility of remote sensing technologies for large-scale forest health evaluation, especially when integrated with on-ground physiological and chemical indicators.

While much focus is placed on *I. typographus*, Fiala and Holuša broaden the scope by proposing a national-scale monitoring network targeting invasive bark and ambrosia beetles in Czechia. They recommend 24 high-risk locations based on proximity to borders, trade hubs, airports, and botanical gardens, using ethanol-baited traps as a sensitive detection method. This proactive approach provides an early warning infrastructure aimed at intercepting invasive species before establishment, reinforcing the need for geographically targeted surveillance.

Together, these studies demonstrate that forest pest evaluation is evolving into a multi-level and multi-method discipline, bridging physiological measurements, chemical ecology, spatial modeling, and biosecurity infrastructure. They also highlight the importance of early signals, both from trees and pests, as well as the need for flexible monitoring strategies that can adapt to shifting pest dynamics in a changing climate.

The research article Modlinger et al., "*Ectomycorrhizal response to bark beetle attack: a comparison of dead and surviving trees*", contributes insights into the ecological consequences of bark beetle infestations on below-ground interactions, offering a deeper understanding of forest ecosystem responses to widespread tree mortality. In this study, the dynamics between tree root systems of the Norway spruce and ectomycorrhizal fungi in the aftermath of bark beetle-induced tree mortality were investigated. The density of vital mycorrhizal tips (VM) on living trees gradually increased, peaking in the 2nd and 3rd years after the surrounding forest decay. VM on bark beetle snags was significantly lower compared to living trees, with minimal variation over time. Most of the fine root biomass decomposes within the first half year after tree death.

Management: toward innovative, integrated solutions for sustainable pest control

Knowledge of risk from emerging pests and pathogens and advanced impact assessment and detection methods must be paired with practical strategies and new technologies to manage pest outbreaks in forests. Managing biotic disturbances demands novel, innovative solutions that are effective, sustainable, and ecologically responsible. Recent cutting-edge advances in biotechnology and biological control offer promising new avenues for managing pest outbreaks while minimizing environmental impacts. Early stages of pest detection improve the efficiency and effectiveness of management. However, in most forest areas of Europe, the key changes should lie in modifying forestry practices and mitigating the impacts of climate change in forests.

The review Sharan et al. "*Transgenic poplar for resistance against pest and pathogen attack in forests: an overview*" explores advances in genetic engineering aimed at enhancing tree resistance against multiple pests and pathogens, an approach that could potentially reduce reliance on chemical treatments and safeguard plantation productivity. It explains how *Populus* spp., a model genus for forest biotechnology, can be engineered to express resistance genes targeting key pests and pathogens and reviews transformation techniques (*Agrobacterium*-mediated, CRISPR/Cas, RNA interference). It also reminds us of the need to navigate regulatory, ecological, and ethical considerations surrounding the deployment of genetically modified trees in natural and plantation forests.

Complementing this technological approach, Gupta et al., in "*Prospects for deploying microbes against tree-killing beetles (Coleoptera) in the Anthropocene*", explore the potential and challenges of using microorganisms as nature-based biopesticides to combat devastating bark beetle outbreaks. By targeting bark beetle symbiotic bacteria and fungi and their microbial volatile organic compounds (VOCs), beneficial microbes in forest soil and plants, entomopathogenic fungi, and even symbiont-mediated RNA interference (RNAi), researchers could develop biocontrol tools that work in synergy with tree defenses. Given the destructive power of bark beetles globally, microbial biocontrol presents a sustainable alternative that can be integrated with existing forest management practices.

Finally, the perspective by Mogilicherla and Roy, "*RNAi-chitosan biopesticides for managing forest insect pests: an outlook*", presents an exciting frontier of how precision-targeted biopesticides such as RNA interference technology (RNAi) that can silence essential species-specific pest genes combined with biodegradable carriers like chitosan could revolutionize pest management by offering precision pest control with minimal off-target effects. RNA interference (RNAi) enables highly targeted pest suppression, and chitosan-based carriers improve environmental safety and application efficiency. If further developed for field applications, these innovations that offer high specificity could serve as next-generation biopesticides that align with ecological conservation and sustainability goals, offering an alternative to broad-spectrum insecticides that harm beneficial insects and forest microbiota.

Mass trapping of bark beetles is a traditional pest management approach, which has many supporters but also a lot of criticism in terms of the actual impact on the population density of the pest (Kuhn et al., 2022). One of the current scientific directions is developing an anti-attractive blend and using it to protect vulnerable forest stands. Various compounds behaviorally active for spruce bark beetle were tested in research by Moliterno et al. in "*Field effects of oxygenated monoterpenes and estragole combined with pheromone on attraction of Ips typographus and its natural enemies*". Based on the catches to the traps at low, medium, and high doses of the compounds, they found that all 1,8-cineole doses and the high estragole dose acted as anti-attractants for *I. typographus*, whereas all (+)-isopinocamphone doses enhanced attraction to the pheromone. The compounds 1,8-cineole, isopinocamphone, and estragole may play vital roles in tritrophic interactions among spruce trees and *I. typographus* and its natural enemies, and these compounds may be developed into new or enhanced semiochemical-based pest control methods.

A direct trapping and tree protection experiment with an anti-attractant blend containing 1-hexanol, 1-octen-3-ol, 3-octanol, eucalyptol, trans-thujanol, and trans-conophthorin (see Jakuš et al., 2024) was reported in an article by Korolyova et al., "*Mitigating Norway spruce mortality through the combined use of an anti-attractant for Ips typographus and an attractant for Thanasimus formicarius*". The anti-attractant blend was compared with commercial pheromone bait and attraction lure for *Thanasimus formicarius*, an important spruce bark beetle predator. Tree mortality was observed exclusively among trees treated only with *T. formicarius* attractant and in their vicinity, suggesting a unique bark beetle response to the mixture of predator's attractant and host tree kairomones, a phenomenon that was not previously reported. Application of anti-attractant and *T. formicarius* treatment effectively prevented tree mortality, demonstrating the repellent potential of anti-attractant against bark beetles.

Outlook and future directions: toward resilient, innovative, and integrated forest pest management

Taken together, the contributions in this Research Topic illustrate complex challenges of biotic pest disturbances in a rapidly changing world. They remind us that while disturbances are natural and often necessary drivers of forest renewal, their increasing frequency and severity, exacerbated by climate change, pose unprecedented risk. They also show how Risk, Evaluation, and Management of biotic disturbances must be viewed as interdependent and interconnected elements of forest resilience strategies. The growing complexity of forest threats demands interdisciplinary integrated approaches that bridge pathology, entomology, ecophysiology, microbiology, biochemistry, molecular biology and biotechnology, remote sensing, climate science, forest policy, and silviculture. To address these challenges, we must continue to expand our knowledge of disturbance agents and their complex interactions, develop advanced monitoring and evaluation tools, and pursue integrated management strategies that enhance the resilience of our forests.

Looking forward, priorities for research and practice should include the following:

- Expanding monitoring networks and early-warning systems that combine traditional field methods with remote sensing and molecular diagnostics.
- Developing predictive models that integrate climate projections, multiple disturbance agents, and forest stand dynamics.
- Advancing biotechnology and biocontrol, ranging from natural enemy enhancement, semiochemicals, and microbial biocontrol to precision biotechnology and transgenic trees while ensuring safety, efficacy, and societal acceptance.
- Promoting forest management practices that enhance species diversity, structural heterogeneity, and adaptive capacity.

The diverse articles in this Research Topic show that addressing forest pest disturbance demands research that is holistic, anticipatory, integrated, and socially accepted. Amid rapid environmental challenges, no single discipline can tackle this challenge alone. By fostering collaboration across disciplines and bridging fundamental science with technological innovations, we can better understand the role of disturbances while developing innovative tools and practices that maintain forest health and the vital ecosystem services forests provide.

Author contributions

RM: Writing – original draft, Writing – review & editing. MZ: Writing – original draft, Writing – review & editing.

Funding

The author(s) declare that financial support was received for the research and/or publication of this article. The work on the Research Topic management and the editorial was supported by the EU project "EXTEMIT-K", No. CZ.02.1.01/0.0/0.0/15_003/0000433 financed by OP RDE, Technology Agency of the Czech Republic under grant no. SS02030018, the Internal project of CZU FLD no. 43970/1322/3202, Ministry of Science, Technological Development and Innovations of the Republic of Serbia (Contract No. 451-03-136/2025-03/200197), the Ministry of Agriculture, Forestry and Fisheries – Forest Service (Monitoring and Forecasting Service – PIS, Contract No. 001917146 2025), and the Centre of Excellence Agro-Ur-For (Contract for 2025).

Acknowledgments

We sincerely thank all contributing authors for their outstanding research and the reviewers for their constructive feedback. We hope this Research Topic will inspire further research and cross-disciplinary collaboration, helping forest managers, policymakers, and researchers in addressing the complex challenges facing forests today.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

The author(s) declare that no Gen AI was used in the creation of this manuscript.

Any alternative text (alt text) provided alongside figures in this article has been generated by Frontiers with the support of artificial intelligence and reasonable efforts have been made to ensure accuracy, including review by the authors wherever possible. If you identify any issues, please contact us.

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

References

Fenn-Moltu, G., Ollier, S., Caton, B., Liebhold, A. M., Nahrung, H., Pureswaran, D. S., et al. (2023). Alien insect dispersal mediated by the global movement of commodities. *Ecol. Appl.* 33:2721. doi: 10.1002/eap.2721

Forrester, D. I., and Bauhus, J. (2016). A review of processes behind diversity-productivity relationships in forests. *Curr. For. Rep.* 2, 45–61. doi: 10.1007/s40725-016-0031-2

Forzieri, G., Jactel, H., Bianchi, A., Spinoni, J., Somasundaram, D., Feyen, L., et al. (2024). Ecosystem heterogeneity is key to limiting the increasing climate-driven risks to European forests. *One Earth* 7, 2149–2164. doi: 10.1016/j.oneear.2024.10.005

Franic, I., Allan, E., Prospero, S., Adamson, K., Attorre, F., Auger-Rozenberg, M. A., et al. (2023). Climate, host and geography shape insect and fungal communities of trees. *Sci. Rep.* 13:11570. doi: 10.1038/s41598-023-36795-w

Hartmann, H., Battisti, A., Brockerhoff, E. G., Belka, M., Hurling, R., Jactel, H., et al. (2025). European forests are under increasing pressure from global change-driven invasions and accelerating epidemics by insects and diseases. *J. Kultpflanzen* 77, 6–24. doi: 10.5073/JfK.2025.02

Jactel, H., Koricheva, J., and Castagneyrol, B. (2019). Responses of forest insect pests to climate change: not so simple. *Curr. Opin. Insect Sci.* 35, 103–108. doi: 10.1016/j.cois.2019.07.010

Jakuš, R., Trubin, A., Sing, V. V., Zabihi, K., Jirošová, A., Modlinger, R., et al. (2024). Spruce protection against ips typographus with anti-attractant blend of tree-based semiochemicals: from small experimental plots to stand scales. *Forests* 15, 1796–1806. doi: 10.3390/f15020356

Kuhn, A., Hautier, L., and San Martin, G. (2022). Do pheromone traps help to reduce new attacks of Ips typographus at the local scale after a sanitary cut? *PEERJ.* 10:e14093. doi: 10.7717/peerj.14093

Patacca, M., Lindner, M., Lucas-Borja, M. E., Cordonnier, T., Fidej, G., Gardiner, B., et al. (2022). Significant increase in natural disturbance impacts on European forests since 1950. *Global Change Biol.* 29, 1359–1376. doi: 10.1111/gcb.16531

Ramsfield, T. D., Bentz, B. J., Faccoli, M., Jactel, H., and Brockerhoff, E. G. (2016). Forest health in a changing world: effects of globalization and climate change on forest insect and pathogen impacts. *Forestry* 89, 245–252. doi: 10.1093/forestry/cpw018

Seidl, R., Thom, D., Kautz, M., Martin-Benito, D., Peltoniemi, M., Vacchiano, G., et al. (2017). Forest disturbances under climate change. *Nat. Clim. Change* 7:395. doi: 10.1038/nclimate3303

Seidl, R., and Turner, M. G. (2022). Post-disturbance reorganization of forest ecosystems in a changing world. *Proc. Nat. Acad. Sci.* 119:e2202190119. doi: 10.1073/pnas.2202190119

Senf, C., Buras, A., Zang, C. S., Rammig, A., and Seidl, R. (2020). Excess forest mortality is consistently linked to drought across Europe. *Nat. Commun.* 11, 1–8. doi: 10.1038/s41467-020-19924-1

van Lierop, P., Lindquist, E., Sathyapala, S., and Franceschini, G. (2015). Global forest area disturbance from fire, insect pests, diseases and severe weather events. *For. Ecol. Manage.* 352, 78–88. doi: 10.1016/j.foreco.2015.06.010

Wainhouse, D. (2008). *Ecological Methods in Forest Pest Management*. Oxford: Oxford University Press.

Washaya, P., Modlinger, R., Tyšer, D., and Hlásny, T. (2024). Patterns and impacts of an unprecedented outbreak of bark beetles in Central Europe: a glimpse into the future? *For. Ecosyst.* 11:100243. doi: 10.1016/j.fecs.2024.100243