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RESEARCH ARTICLE

Surveillance of ash trees under multiple threats: Integrating emerald ash borer and ash dieback dynamics with stakeholder behaviour

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Abstract

1. Across the world, emerging pests and diseases are increasing in number, range and co-occurring with other invasive biotic factors. Ash trees (*Fraxinus excelsior* L.; Oleaceae) in Great Britain face the potential invasion of the emerald ash borer (EAB; *Agrilus planipennis* Fairmaire; Coleoptera: Buprestidae) and the ongoing impact of ash dieback (ADB; *Hymenoscyphus fraxineus* T. Kowalski (Helotiales: Helotiaceae)). Surveillance and management strategies accounting for land manager behaviour are crucial for improved control.
2. We developed a spatially explicit model that integrates (i) the estimated prevalence of ADB, (ii) the dynamics of EAB arrival and spread and (iii) a socio-dynamics model, based on a values-driven theory that simulates land manager decision-making in relation to surveillance and tree management. In the model, if EAB is detected, contingency measures—including tree felling and intensified monitoring—are enacted, with the potential to eradicate or slow its spread. We used the model to assess whether targeting high-risk sites with traps, using routine tree inspections by land managers, or encouraging volunteer surveillance (with or without subsidised trapping) could significantly slow EAB spread.
3. Interviews ($n = 45$), a survey ($n = 368$), and three workshops ($n = 27$) informed the socio-dynamics model's structure and parameterisation. The interaction between EAB and ADB is complex, with potential positive effects (e.g. increased perceived value of ash) and negative effects (e.g. belief that ash cannot be saved, misidentification of decline causes).
4. Results showed that if land managers are made aware of EAB, health and safety inspections have a substantial role to play in slowing the spread but are unlikely

to lead to eradication due to the pest's cryptic larval phase. Official trapping at a limited number of locations is similarly unlikely to succeed in early detection and eradication unless entry pathways are well-defined, and ash connectivity is low. Volunteer trapping is important for early detection and if this is subsidised, EAB eradication becomes more likely.

5. *Synthesis and applications*. Tree-health policies must balance identifying likely entry points and deployment of traps, targeted information campaigns and surveillance subsidies for land managers. Our unique, cross-disciplinary approach can be applied to other pest/pathogen systems to inform tree-health plans and how to balance resources.

KEYWORDS

biosecurity, eradication and containment, invasive pest, modelling behaviour, tree health

1 | INTRODUCTION

Globally, forests, hedgerows and other amenity trees are threatened by a growing number of invasions by pests and pathogens (hereafter pests) (Jactel et al., 2023; Liebhold et al., 2017). The loss of individual trees and potentially whole populations will have widespread impacts on ecosystems. For example, trees form essential habitats, support wide networks of dependent insect, fungal and microbial species, control water flows and importantly store carbon as they grow (Freer-Smith & Webber, 2017). Plant–pest invasions are often aided by trade and movement of plants and plant products across countries and continents (Brasier, 2008; Liebhold et al., 2017). Tree and forest surveillance and management are paramount for timely mitigation. The effectiveness of surveillance and management approaches strongly depends on the biology of the pest or pathogen and the take-up by land managers, and so both should be accounted for when assessing the potential effectiveness of strategies to limit the impact of invading pests and diseases.

To address this challenge, we examine the case of ash trees in Great Britain (GB), which are currently impacted by ash dieback disease (ADB; *Hymenoscyphus fraxineus* (T. Kowalski) Baral, Queloz & Hosoya, 2014 (Helotiales: Helotiaceae)) and threatened by the potential invasion of the emerald ash borer (EAB; *Agrilus planipennis* Fairmaire, 1888 (Coleoptera: Buprestidae)). Ash dieback has caused large-scale declines in European ash (*Fraxinus excelsior* L., 1753 (Lamiales: Oleaceae)) across Europe, with significant ecological, social and cultural consequences (Hall et al., 2021; Hultberg et al., 2020). It is estimated that ash dieback could cost GB up to £15 billion over the next 100 years, with the largest cost associated with ecosystem services losses (Hill et al., 2019), although evidence suggests that some ash trees are showing resistance to the disease (Metheringham et al., 2025). Similarly, the emerald ash borer has become the most significant insect pest for ash species (*Fraxinus* spp.) following incursions in Canada, the USA, Russia, Ukraine and Belarus (Zviagintsev et al., 2025), destroying hundreds of millions of trees, costing well over $25 billion in the USA alone (Epanchin-Niell, 2017).

EAB is a bright green jewel beetle native to North-East Asia that feeds on ash species. In its native range, it is typically found at low densities and does not cause significant damage to its hosts (*Fraxinus chinensis* Roxb. 1832 (Lamiales: Oleaceae), *Fraxinus mandshurica* Rupr. 1857 (Lamiales: Oleaceae)); however, outside its native range, where it encounters North American and European ash species, it becomes extremely destructive (Evans et al., 2020). Females lay eggs in the bark crevices of ash trees, and larvae feed on the phloem underneath the bark before emerging as adults in semi- and/or univoltine lifecycles. Adult beetles can fly up to a few kilometres, facilitating range expansion into new areas (Mercader et al., 2009, 2016). Additionally, the movement of firewood and other forestry products aids its dispersal, allowing the beetles to invade regions hundreds of kilometres away from an infested location (Ward et al., 2020; Webb et al., 2021). In response to this threat, the European and Mediterranean Plant Protection Organization (EPPO) established a network to facilitate the exchange of EAB monitoring data and to enhance understanding of the pest's current distribution and spread across Europe (EPPO, 2022).

When new pests are identified as potential threats, contingency strategies are developed to prevent their introduction, establishment and spread (DEFRA, 2024). The aim is to minimise the impact on natural ecosystems, ideally through prevention, but if not then by eradicating the problem; however, slowing the spread can also be valuable as it allows time for mitigation. Initial strategies often involve implementing a surveillance programme for early pest detection, which may also involve public awareness campaigns or volunteer networks (Pocock et al., 2020, 2024). Once a detection is confirmed, if eradication is considered feasible, measures such as treatment of the infested area, host removal, quarantine and movement restrictions are implemented. There are several examples where contingency plans have led to successful eradication; key examples include the Asian longhorned

BRITISH ECOLOGICAL SOCIETY Journal of Applied Ecology

beetle (*Anoplophora glabripennis* (Motschulsky, 1853) (Coleoptera: Cerambycidae)) after an outbreak in south-east England in 2012 (Eyre & Barbrook, 2021), and the Mediterranean fruit fly (*Ceratitis capitata* (Wiedemann, 1824) (Diptera: Tephritidae)) in Mexico after its' first incursion in 1977 (Enkerlin et al., 2015). However, eradication can fail, and if so, the focus usually changes to impact mitigation.

The success of eradication depends on several factors, including the pest or pathogen's cryptic period and spread rate, the conduciveness of the new environment, the pests' host availability and the responses of the organisations or people involved. For the successful examples above, key behaviour factors included rapid reporting, removal of affected hosts and compliance with movement restrictions of potentially infected material.

Several modelling studies have explored the impacts of surveillance and management on the invasion and spread of pests (Gilligan & van den Bosch, 2008; Montgomery et al., 2023; Parnell et al., 2017; van den Bosch et al., 2023) but few have considered how human behaviour affects the success of detection and subsequent eradication. In this study, we examine the threat of EAB invasions on ash trees in GB and how the combination of pests (ADB and EAB) and human behavioural factors might affect the success of any contingency plan.

Authorities in GB and the European Union (EU) have developed contingency plans to respond to EAB outbreaks (Inward & Straw, 2021; Schrader et al., 2020). These include restrictions on the importation of ash trees, wood, and related materials from regions where EAB is present, and surveillance programmes to detect any potential introductions. In GB, surveillance includes visual inspections of trees and, since 2024, the deployment of sticky traps near ports and wood distribution depots where EAB is thought most likely to enter. This approach to deciding where to deploy traps is near optimal for the early detection of EAB when trap numbers are limited (Alonso Chávez et al., 2025). What remains unclear is whether standard tree health and safety (tree-H&S) inspections, such as voluntary removal of hazardous trees by landowners, or additional traps deployed by landowners, could significantly add value to early detection, and if so, how incentivising trap deployment will affect this value.

We considered three case study areas from GB: Kent and Suffolk in the south and east of England, and North Wales. These areas were chosen because they differ in terms of their risk of first entry and history with ADB. We used a model of EAB's potential for arrival and spread to simulate the process of detection and attempted eradication. In our model, observations of EAB can occur at defined locations where inspections are made. Should EAB be identified and reported, then eradication is attempted. To determine the type of inspection (deploying traps or visual surveys) and location, we developed a sociological model of surveillance uptake by land managers. This model included a data layer describing ADB severity, enabling us to capture possible interactions with existing tree health status. We used the model to explore the following questions:

- Would deploying traps at a limited number of high-risk locations lead to actions that could significantly slow the spread of EAB?
- Would reports from routine tree-H&S inspections by land managers potentially lead to interventions that slow the spread of EAB?
- Could volunteer-based surveillance significantly impact spread rates and what impact would subsidising trapping costs have on this?

2 | METHODS

2.1 | Model of EAB

2.1.1 | Case-study regions host maps

We identified three case study areas. The county of Suffolk in the East of England has a major port (Felixstowe) that imports wood products from Eastern Europe, thus representing a high-risk pathway. The county of Kent (in the south-east of England) represents another high-risk pathway as it is a major entry point for international trade due to its proximity to continental Europe and has been significantly impacted by ADB. North Wales, in contrast, is less likely to be a point of first incursion, and ADB was detected later across this region.

We imposed a grid of cell size 300 m × 300 m across each case-study region. The density of ash in each cell (Figure 1) was estimated by combining various data layers building on the UKCEH landcover map (Morton et al., 2021). We converted ash density into numbers of trees per cell using an estimate of 889 trees per ha (Forestry Commission, 2013), see also (Brown et al., 2023).

2.1.2 | Emerald ash borer model

We used the spatially explicit model of the spread of EAB developed by Alonso Chávez et al. (2025). The model is stochastic and describes univoltine and semivoltine populations of EAB, capturing both natural short-range dispersal and long-range human-mediated dispersal. The simulated first incursion of EAB into GB is sampled from a probability distribution informed by high-risk pathways for the wood imports from continental Europe (see Appendix S8). Our entry point probability accounts for GB ports that receive firewood from Europe, depots that distribute this firewood, and the estimated locations of domestic wood-burning fires.

2.1.3 | Ash dieback model

Ash dieback disease prevalence was estimated using a deterministic compartmental model. For this study, we treat ADB disease prevalence as a static layer, defining prevalence as the percentage of symptomatic or dead trees in a cell (see Appendix S1).

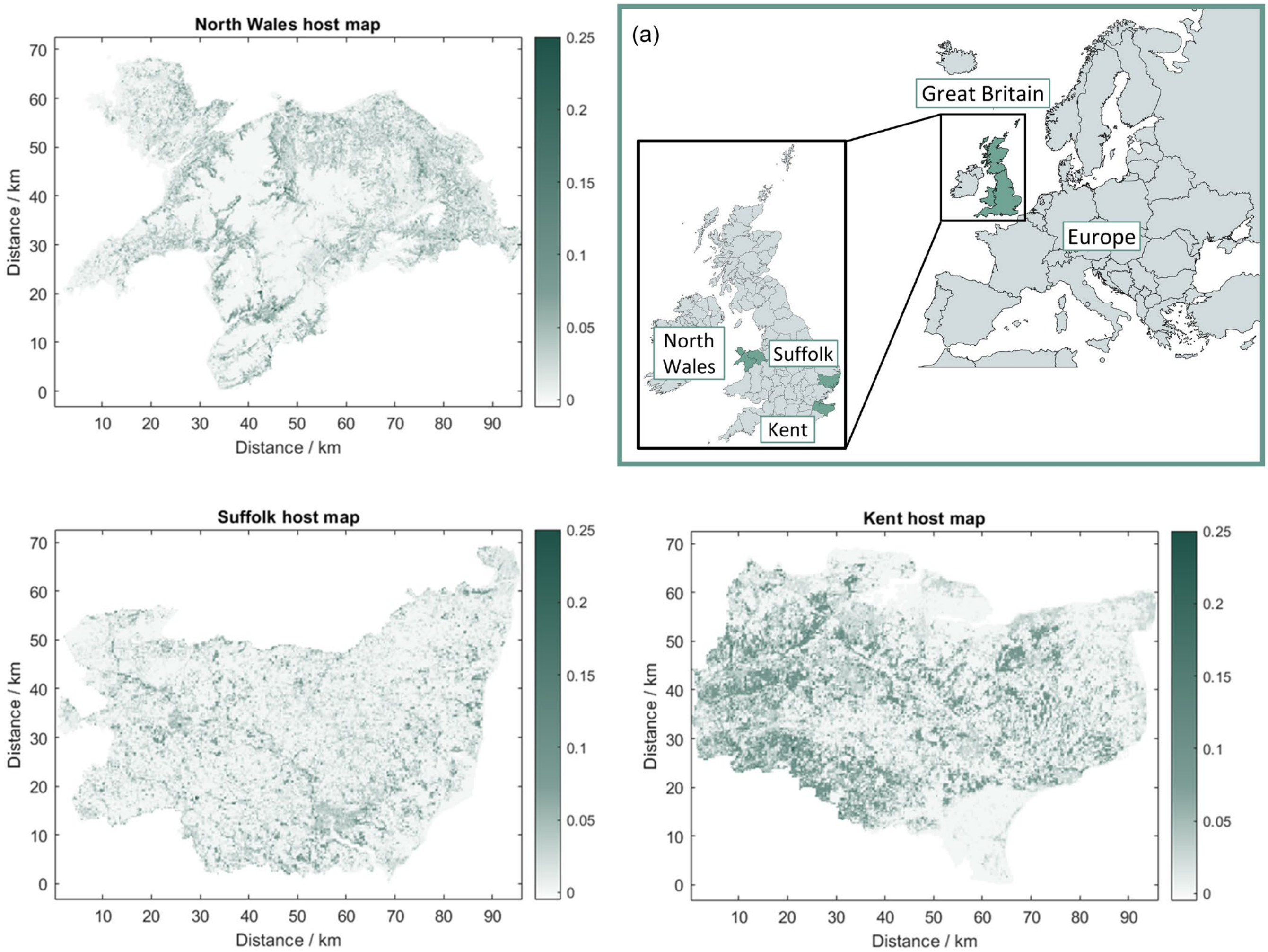


FIGURE 1 (a) Study case regions within GB and Europe. Ash distribution maps for (I) North Wales, (II) Suffolk and (III) Kent are estimated at the scale of 300 m × 300 m. The colour bars indicate the percentage coverage of ash per cell. Maps of Europe and GB were created using KoenB and MapChart respectively.

2.2 | Model of stakeholders' motivations towards surveillance

2.2.1 | Social science data collection summary

A rapid evidence review was undertaken to identify key themes affecting the management of ash trees, and in particular surveillance for pests (Hall et al., 2021). The emerging themes comprised the cultural, economic, and environmental value of ash; health and safety (H&S) concerns, particularly where diseased trees posed a hazard to the public (e.g. along transport links and walking paths); risk perceptions, and previous experience with other pests and diseases. Through our review, we identified that limited knowledge about pest threats may influence decisions about whether to take action. The review outcomes informed an initial concept for the model which was further refined and parameterised through interviews, workshops and an online survey as follows.

Forty-five qualitative semi-structured interviews were conducted between August 2021 and December 2022; 10 with key informants and 35 with land managers (Karlsdóttir et al., 2025). Generally, stakeholders were very knowledgeable of ADB, while the opposite was true for EAB. We found that while remaining ash trees were considered more valuable, and the potential arrival of EAB was seen as 'pretty tragic' (*manager of a public woodland*), this did not always translate into increased intentions to manage EAB due to, at times, fatalistic perceptions of the effectiveness of actions. The interviews further revealed that decisions about surveillance and management actions were influenced predominantly by costs and resources, perceptions of effectiveness, and availability of support. Most managers were willing to engage in some sort of surveillance. However, there was an expectation that at the point of early detection, any eradication, containment and surveillance would be government-led.

Three interactive online workshops were delivered to ash stakeholders, where participants role-played scenarios of EAB arriving in the UK (see Appendix S2). As with the interviews, resource constraints were a key issue for undertaking EAB surveillance, and the expectation was that the government would lead and absorb surveillance costs. Participants from locations where

BRITISH ECOLOGICAL SOCIETY Journal of Applied Ecology

ADB was prevalent and had been in the landscape the longest (south-east England) were fatalistic about the future of ash trees. Stakeholders from areas where ADB is more recent (Wales) were more optimistic.

We developed an online questionnaire about the surveillance and management of GB's ash trees, which was completed by 368 tree-health stakeholders between September and November 2021 (Hall et al., 2025). The questionnaire's design was based on the key themes identified in the rapid review (Figure 2). The format comprised checkbox questions, multiple-response and Likert scale questions with only a small number requiring free text. Analysis of the responses revealed that management aims, perceived importance of ash (value), risk perception, and acceptability of surveillance method significantly impacted intentions to conduct surveillance (see Appendix S9). This analysis, along with the findings from the interviews and workshops, refined the structure of the behaviour model (Section 2.2.2; Figure 3). The social surveys also provided data to initialise and parameterise it (Section 2.2.3; see also Appendix S3). Prior to the data collection, the survey, workshop and interview schedules were submitted for ethical approval through the Environment and Geography Ethics Committee at the University of York. All research activities with participants received a favourable ethics review from the committee. Written free prior informed consent was obtained from those attending workshops and interviews. Interviewees were sent a participant information sheet and then signed a consent form prior to participating in the interview. Scenario workshop participants were provided with a project information sheet and asked to consent by completing an online consent form using the Menti polling tool at the beginning of the workshop. For the survey, participants gave informed consent through a check box question where they confirmed that they understood that their responses would be anonymised and that they could withdraw at any point.

2.2.2 | Behaviour model structure

In the model, land managers face the decision of whether to implement voluntary surveillance or not. Based on the social research (Section 2.1.1), for land managers to adopt voluntary surveillance: (i) they must perceive there is a risk of EAB arriving in their region (x_R) and causing a significant impact to ash given local ADB status (x_P) (ii) they must value ash trees (x_V) (iii) they must have sufficient time or financial resources to implement surveillance (x_F) and (iv) they must believe that surveillance will lead to actions that stop or slow the spread of EAB (x_B) (Figure 3a). Note that x_P is a function of the ADB status of the landowners' trees and x_R. In the model, each land manager i has variables $x_R(i,t), x_V(i,t), x_F(i,t)$ and $x_B(i,t)$ relating to each behaviour factor, and these may change over time. These variables may take a value between zero and one, where for example, $x_R = 0$ represents a perception that there is no risk of EAB and $x_R = 1$ represents a perception that their trees will certainly become infested. In the model, variables $x_P(i,t), x_V(i,t), x_F(i,t)$ and $x_B(i,t)$ are associated with a stochastic threshold Υ_k that must be exceeded for the land managers to undertake surveillance, where subscript $k \in \{P, V, F, B\}$.

If landowners decide not to implement surveillance, they may still visually assess their trees for damage to determine whether they should be pruned or felled. This is driven largely by H&S concerns. In our model, if land managers observed significant tree damage and their H&S (x_H) concerns and risk perception (x_R) exceed a threshold they will visually inspect damaged trees for signs of EAB (Figure 3b).

We modelled the dynamics of each variable (x) over time using opinion dynamics (Hegselmann & Krause, 2002; Moussaïd et al., 2013). These models simulate opinion formation within a group of interacting individuals. The opinion $x(i,t)$ of an individual i changes from one time-step t to the next according to the equation

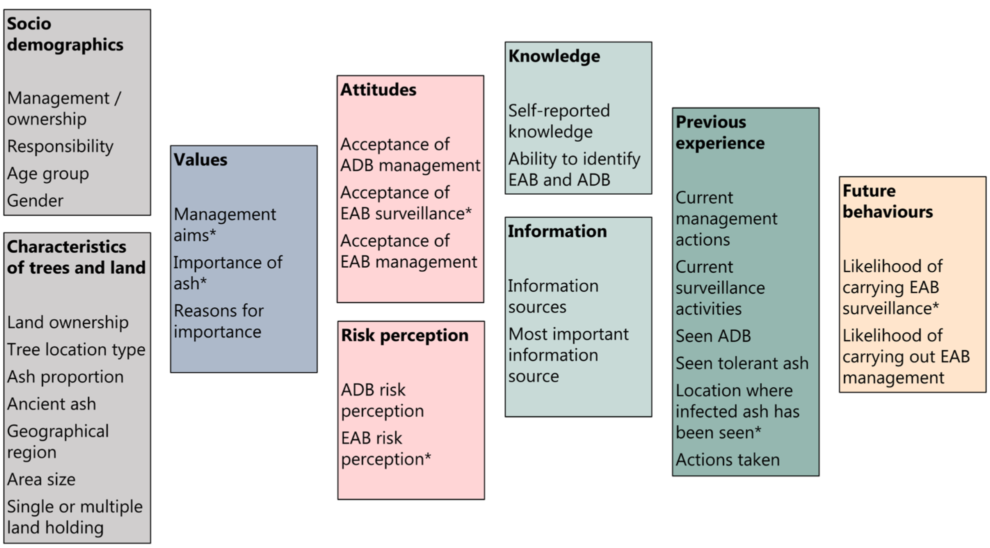
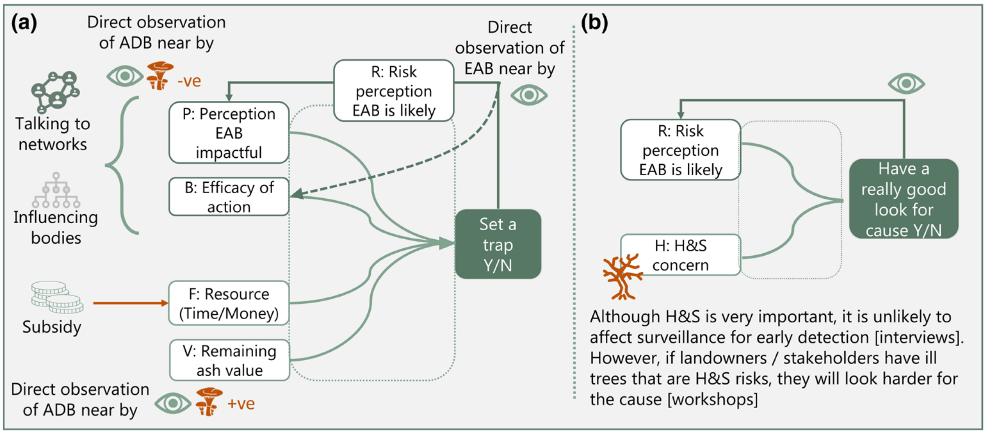


FIGURE 2 The questionnaire's structure was based on a rapid evidence review. Analysis of the questionnaire using generalised mixed linear models showed significant associations between the factors marked with asterisks and the likelihood that stakeholders would adopt voluntary surveillance for EAB (Hall et al., 2025).



Variable	Concept	Associated dynamics
Risk perception (R)	Land managers' perception that EAB could infect their trees	Updated through interaction with information sources and social networks. If a land manager observes EAB on their land, R=1. This will influence other land managers opinions in their network
Perception EAB will be impactful (P)	Land managers' perception that EAB could cause tree mortality	If trees already infected with ADB then additional impact of EAB limited
Health and safety concerns (H)	Land managers' concern that infected trees could be a risk to public safety	Updated through interaction with information sources and social networks. A function of tree location
Value (V)	The value the land manager attributes to the ash trees they manage	Stakeholders' inherent property that does not change dynamically (i.e. M=1). Healthy ash will become more valuable as ash become rare
Resources (F)	Financial or time resource available to undertake surveillance	Stakeholder's inherent property that only changes with outside investment (i.e. $\omega_G = 1$)
Efficacy of surveillance (B)	Land managers' perception that surveillance will be effective	Updated through interaction with information sources and social networks. Decays over time if no EAB trapped

FIGURE 3 Schematics of the sociological model with an explanation of the variables within the model. (a) If a land manager's perceptions that EAB is impactful (x_P), surveillance is effective (x_B), the value they hold for ash trees (x_V) and their resource for surveillance (x_F) all exceed a threshold (Υ_k), then they adopt surveillance using traps. (b) If a land manager's risk perception that EAB is likely (x_R) and their concern for health and safety (x_H) exceeds a threshold (Υ_k), then they carry out visual health and safety inspections which can identify EAB. If EAB is detected, then the contingency strategy is enacted, and trees are felled and destroyed including EAB larvae. Observations of EAB and ADB impact the behaviour variables (see Table above) resulting in dynamic feedback between the socio-dynamics model and the model of EAB spread.

$$x(i,t+1) = M(i)x(i,t) + (1 - M(i))\left\{ (1 - \omega_G(i)) \sum_{\substack{j=1 \\ i \neq j}}^{\eta} w_j x(j,t) + \omega_G(i) I_G \right\} \tag{1}$$

where the individual i interacts with η individuals in their network, weighting the opinion of each by w_j. The sum of the weights is one. The variable I_G denotes the influence of external sources of information, such as professional forestry bodies, which is weighted by ω_G, and M is the weight of the land manager's own opinion. The weights are constrained such that $0 \leq \omega_G, M \leq 1$. The perceived value (x_V) is considered personal attributes unaffected by networks (i.e. $M = 1$). Available resource (x_F) is assumed to only be affected should financial support be introduced ($\omega_G = 1$) (Figure 3a).

We followed (Milne et al., 2020) and randomly selected η individuals from the land managers network according to distance apart, d, in the landscape. The probability of selection is proportional to $\exp(-d/\kappa_D)$, where κ_D is the range parameter. For the distance calculation, we allocated the land managers' residences to one of the cells they manage at random. The weights then depend on closeness of opinions (i.e. individuals with quite different opinions may never be influenced by one another (Hegselmann & Krause, 2002)). The weights w_j are calculated by

$$w_j = \frac{\exp\left(-\frac{|x(i,t) - x(j,t)|}{\kappa_O}\right)}{\sum_{\substack{l=1 \\ l \neq i}}^{\eta} \exp\left(-\frac{|x(i,t) - x(l,t)|}{\kappa_O}\right)}, \tag{2}$$

where κ_O is the opinion range parameter (see Appendix S3). Risk perception that EAB will be impactful to ash, x_P, is negatively impacted by ADB prevalence (Figure 3a) yet the value of healthy ash x_V increases with ADB prevalence as ash becomes rarer. These relationships are modelled by linear functions. If EAB is detected by a landowner their risk perception, x_R, increases to a maximum value.

BRITISH ECOLOGICAL SOCIETY Journal of Applied Ecology

2.2.3 | Land manager types

The behavioural characteristics of land managers vary depending on their type. Based on the survey and regional ownership data, we categorised land managers into seven types *T* (see Appendix S4): (I) Council (including urban and green space), (II) Transport (e.g. roads or rail tracks), (III) Public forest estate (e.g. Forestry Commission), (IV) Private green space (e.g. golf courses, historic parks, religious grounds), (V) Private woodlands, (VI) Third sector (e.g. National Trust (NT), RSPB and Woodland Trust (WT)), and (VII) Agricultural (farms with woodland). Each 9-ha cell was classified and assigned to a specific land manager (Figure 4) with land allocations informed by ownership data (see Appendix S4). For the council typology, we allocated a land manager for each county council and one for each council-run park. For transport, we allocated one land manager for rail and one for road. For public forests, we allocated one land manager to each forest estate, for private green space and the third sector we allocated one land manager per site. We had no information on ownership for woodlands and farmland, so we randomly allocated land areas to our modelled woodland and farmland managers based on statistics describing the variation and expected areas in each region (Table 1).

2.2.4 | Information networks

We categorised the types of influencing bodies as either (i) farmers' professional organisations, for example the National Farmers Union (NFU), (ii) foresters' professional organisations, e.g. Institute of Chartered Foresters, (iii) tree-health-focused charities, such as the Woodland Trust, (iv) government authority for forests, for example Forestry Commission and Natural Resources Wales, (v) local authority tree officers, (vi) the government Department for Environment, Food and Rural Affairs (Defra), (vii) internet search, (viii) the Forest Research Agency, (ix) tree professionals, (x) personal contacts. We

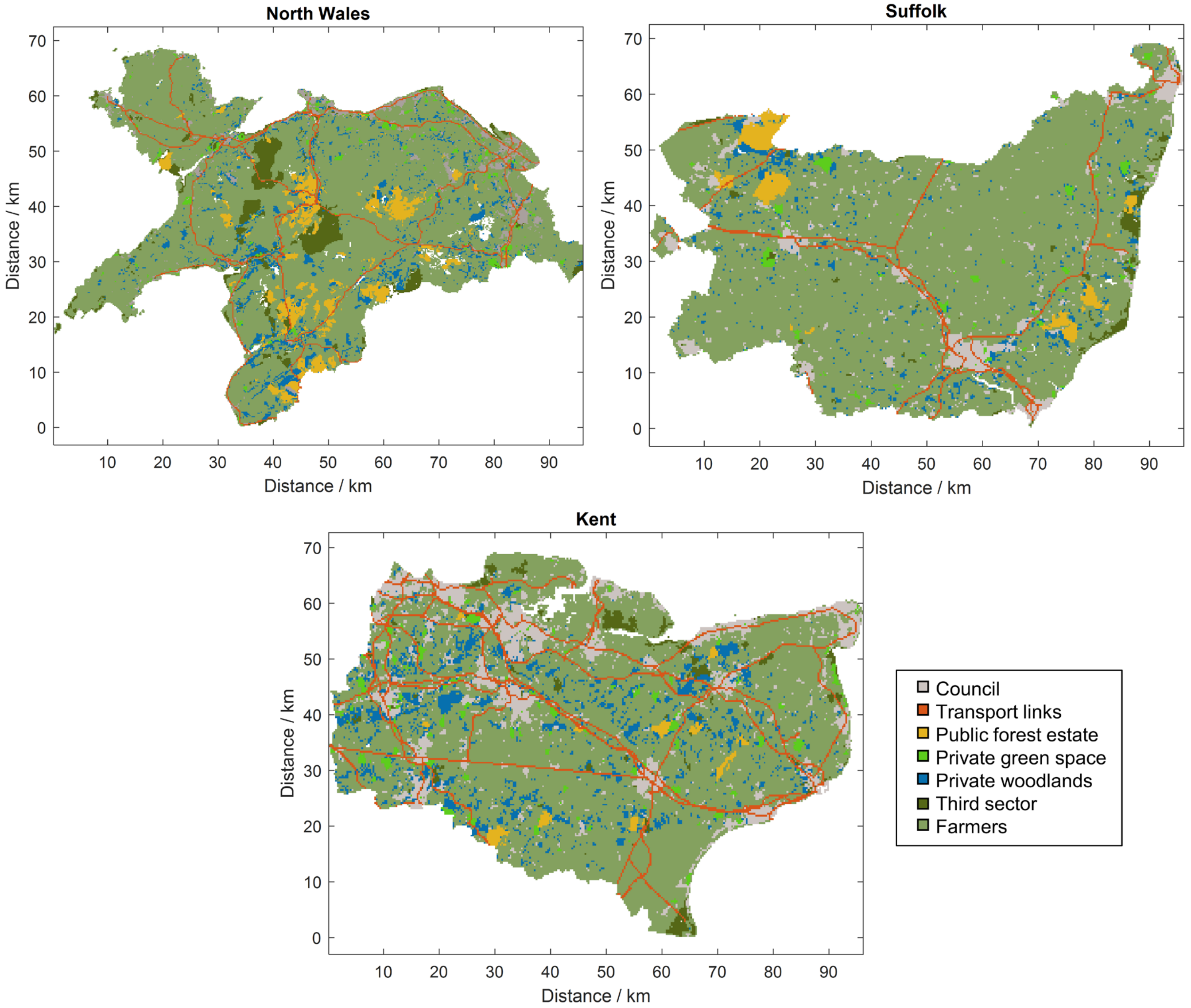


FIGURE 4 Case study regions with areas by land manager type.

TABLE 1 The number of land manager agents modelled for each case study.

	Kent	Suffolk	North Wales
Council	38	17	19
Transport	2	2	2
Public forest estate	9	8	22
Private green space	144	86	180
Private woodland (non-farming)	825	633	1114
Third sector	68	45	108
Farmers	3211	2602	7411
Total	4297	3393	8858

assume that each influencing body has an opinion on each of the key factors. For personal contacts, these opinions are simply $x_k(j,t)$ where $k \in \{R, B, H\}$ and these are combined through the weights w_j as described in Equation (1). For other influencing bodies, the opinions B_m, where $m \in \{i, ii, \ldots ix\}$ (i.e. relating to the nine other categories listed above), are combined stochastically to give the influence of external sources of information in land manager i:

$$I_G(i) = 1 - \prod_{m \in \{i,ii,\ldots ix\}} \left\{ \left(1 - B_m\right) \mid \delta_{mi} > p(m,T) \right\} \quad (3)$$

where δ_{mi} is drawn from a uniform distribution and $p(m, T)$ is the probability that a landowner of type T is influenced by influencing body m. The values of $p(m, T)$ were informed from the questionnaire data about where land managers reported getting information from (Appendix S5a).

The weights ω_G (Equation 1) are a property of the individual and these are sampled from the observed distributions for each land manager type in the survey data. The values of B_m relate to the strength of messaging about each of the decision factors each influencing body presents where a value of zero suggests 'no messaging about the topic' and a value of one suggests "extreme concern in messaging". Drawing on ADB experience, we anticipate that messaging around EAB risk and surveillance would intensify if EAB were detected in GB. We therefore modelled two states: a 'current' state (no detection) and one following detection in GB. A website search showed a spike in ADB-related content after its 2012 discovery (see Appendix S5).

2.2.5 | Initialising behaviour variables and defining thresholds

Initial values for the variables $x_R(i,t), x_V(i,t), x_F(i,t), x_H(i,t)$ and $x_B(i,t)$ (see Section 2.2.2; Figure 3) were derived from responses to the questionnaire (Figure 2; Appendix S6). The responses we used were recorded on a five-point Likert scale. For each landowner type, we rescaled the Likert scale to between 0 and 1 and fitted a Beta distribution to describe the distribution of responses. Initial values for each modelled landowner were sampled from the relevant distributions (Figure 5). There was no direct question for the perceptions of the efficacy of surveillance, so we used the response on intention to enact surveillance as the initial condition (standard parameters) and assessed a second set of parameters with these values reduced by 20%.

2.3 | Linking models

The social (Section 2.2) and biological models (Section 2.1) were linked through the feedback between observations of ADB and EAB, and the effect of felling on the spread of EAB. Specifically, if EAB is detected, then the model jumps into contingency plans that parallel those defined by the Forestry Commission (Inward & Straw, 2021). Trees are felled in the affected cell and the eight surrounding cells, destroying the ash and EAB populations in those cells. Ash in a 1-km radius is subject to intensive survey by visual inspection, and to account for quarantine restrictions, human-mediated dispersal is assumed not to occur. If after 4 years EAB is undetected, then the statutory measures cease.

To model the act of surveillance we adopt the approach of Alonso Chávez et al. (2025) where the probability that EAB is detected at time t is

$$P_{i,t} = 1 - \exp\left(-c_i N_i Q_t\right) \quad (4)$$

where c_i is the detection efficacy dependent on the monitoring method ($i = T, V$ denote trapping and visual inspection, respectively), N_i is the number of traps or observations per unit area and Q_t is the insect density at time t in its adult or larval stage. We take $c_T = 0.052$ for traps and $c_V = 0.026$ for visual assessment.

We assume that all positive sightings are reported. If EAB is repeatedly detected across the case study area, we assume that x_B declines. This reflects the social dynamics observed for other pests where attempted eradication failed (Milne et al., 2020). Within the model, we scale the external influence I_G by $0.95^{n_{\text{fell}}}$ where n_{fell} is the number of times trees felling has occurred for eradication.

2.4 | Scenarios

We consider six scenarios: (i) a baseline whereby the presence of EAB does not affect management; (ii) deployment of official traps at a limited number of 'high-risk' locations (in our simulations between two to four trap locations per case study area, see Appendix S7); (iii) detection that results from tree-H&S inspections (iv) combined official traps and tree-H&S inspections (v) combined official traps, tree-H&S inspections and volunteer trapping without resource support from the government (vi) combined official traps, tree-H&S inspections and volunteer trapping with resource support from the government. In our model, if landowners choose to adopt surveillance, they do so at a density of one trap per 2 km^2 (based

Journal of Applied Ecology

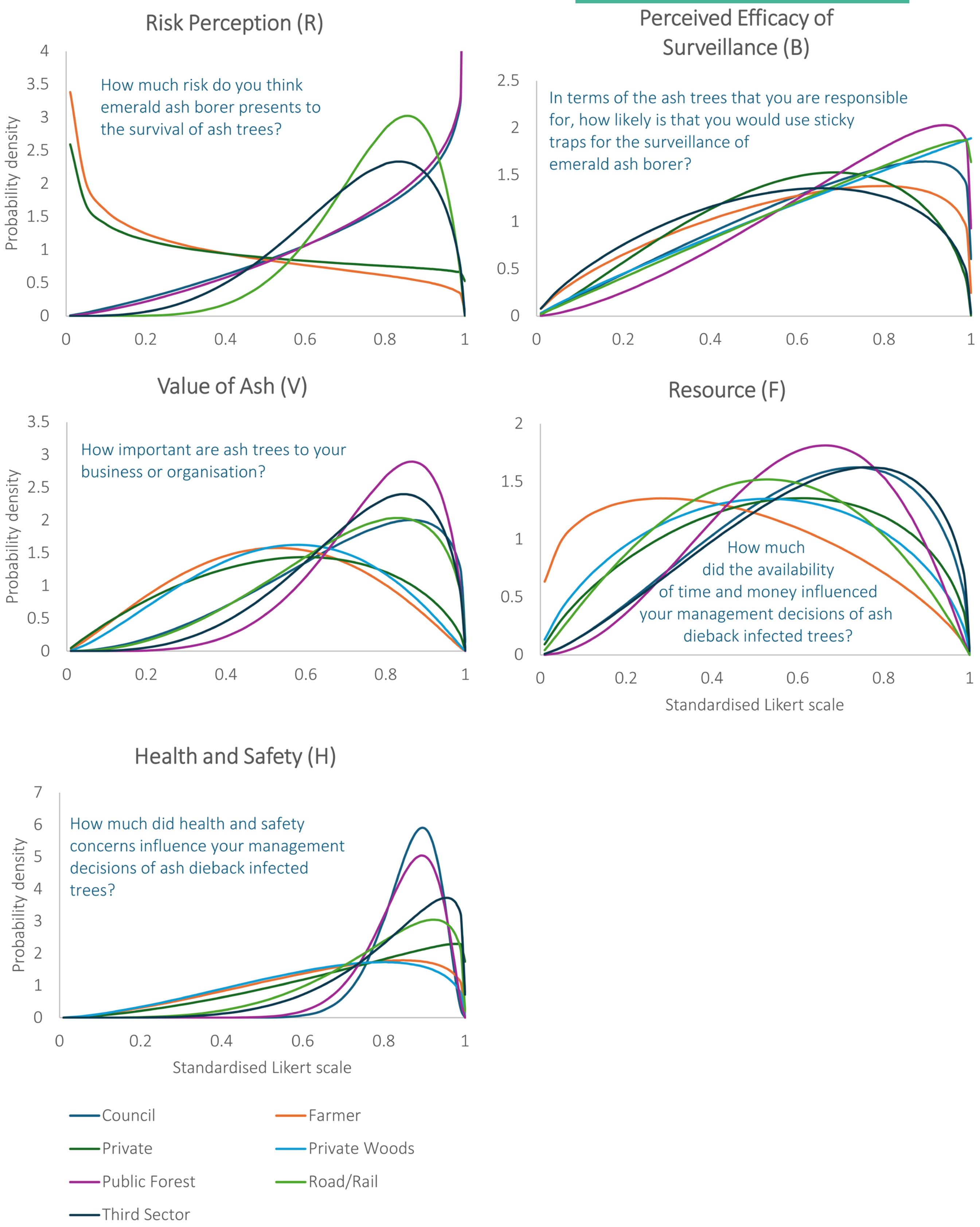


FIGURE 5 The beta distributions used to sample the initial conditions for the behaviour model variables. The distributions were fitted to responses to the questions on a five-point Likert scale ranging from highly unlikely = 0 to highly likely = 1 (Hall et al., 2025).

on Abell et al., 2014). Each scenario is run for 30 realisations to determine the variation in response.

Our EAB model parameters are based on data from the United States, but there is evidence to suggest that spread may be more limited in the GB because of the differences in ash species' susceptibility, climate and interactions with ADB (Webb et al., 2021); therefore, we consider the potential effects of more limited spread dynamics and the impacts of any improvements in detection sensitivity. For each of our two spread rates, the data from our six scenarios were used to address our four key questions.

3 | RESULTS

To quantify the results of the simulations we consider our response variable to be the number of hectares where EAB have been observed 15 years after first incursion (including felled trees). A variety of response dynamics was observed across the 30 stochastic simulations run for each scenario (e.g. see Figure 6), leading to a wide range of values for our response variable (Table S7a). For the baseline scenario, the number of cells with EAB presence could be assumed to be normally distributed, but data from the other scenarios tended to be positively skewed due to a few scenarios where EAB escaped early detection and invaded the landscape to similar levels observed for baseline (Figure 7; Table S7). We therefore used a Kruskal–Wallis *H* test to test for significant differences between the medians of the response variables that resulted from the different scenarios.

The analysis showed that official trapping in the Suffolk case study generally reduced the number of hectares where EAB was found compared with baseline (significant difference in median χ^2 probability <0.001 both parameter sets) but the difference was not significant for Wales (χ^2 probability = 0.114) or Kent (χ^2 probability = 0.734) (Figure 7; Table S7). This is related to the distribution of incursion probabilities which describe the relative risk associated with entry pathways. For Suffolk, the risk is concentrated around a few high-risk pathways whereas for the other case studies the risk was more spread (see Appendix S8).

For the standard parameter set in all case studies, tree-H&S inspections led to reporting and felling that slowed the spread of EAB compared with baseline (significant difference in median χ^2 probability < 0.001) but in none of these cases was EAB fully eradicated. In comparison, using the constrained spread parameters, tree-H&S inspections could theoretically lead to eradication.

For the standard parameter set, the improvement observed by incorporating volunteer trapping with official trapping (compare 'Official traps (OT) only' with 'OT, H&S and volunteer' in Figure 7) was not significant for Suffolk (χ^2 probability = 0.248) unless trapping was subsidised (χ^2 probability = 0.023). For Wales, the improvement was not significant in either case (χ^2 probability = 0.359 without and 0.156 with subsidy) but was significant for both cases in Kent (χ^2 probability < 0.001). For all sites, when a subsidy was included, we observed some instances where simulated incursions were completely eradicated (Table S7). The results for the constrained spread showed a similar pattern (see Appendix S7).

The effect of reducing the initial conditions for the perceived effectiveness of surveillance had no significant effect (see Appendix S7).

4 | DISCUSSION

4.1 | Analysis of scenarios

4.1.1 | Would deployment of traps at limited high-risk locations significantly slow the spread of EAB?

We found that deployment of official traps at high-risk entry points alone was unlikely to detect EAB in time to support successful eradication, but these actions were likely to slow the spread, although not significantly compared with the baseline scenario for two case studies. The predicted differences are dependent on the distribution of likely entry locations. For Suffolk, likely pathways are concentrated around ports and depots, and official trapping was predicted to be more effective than the other case studies where the risk landscape was more spread (see Appendix S8). Out of the three case studies, Suffolk is the most likely to be first affected by EAB because of firewood trade links to Eastern Europe.

4.1.2 | Would reports related to regular tree-H&S inspections by land managers have the potential to significantly slow the spread of EAB?

For standard parameters, EAB was never fully eradicated under our tree-H&S inspection scenario. This is not surprising as these types of inspections would likely only alert the land manager once trees are dying or dead which is estimated to take at least 2 years, by which time EAB would have spread (BenDor et al., 2006). H&S measures are key motivators for landowners to manage their trees, particularly in areas that are accessible to the public. This is reflected in our behaviour variables (Figure 5) where land managers responsible for public areas prioritised tree-H&S inspections more than other groups, driven by the need to avoid the legal and financial consequences that result from falling branches causing injury. Although reported detections from tree-H&S inspections are unlikely to lead to EAB eradication, there is clear value for slowing the spread. It is therefore essential that land managers are aware of EAB and know what to look for and what to do. In our model, knowledge of EAB quickly escalates after the first positive observation via media channels. This reflects what has happened in the cases of other invasive pests and pathogens. Urquhart et al. (2017) investigated public awareness and concern regarding invasive tree pests and diseases, with research finding that media coverage, particularly during significant

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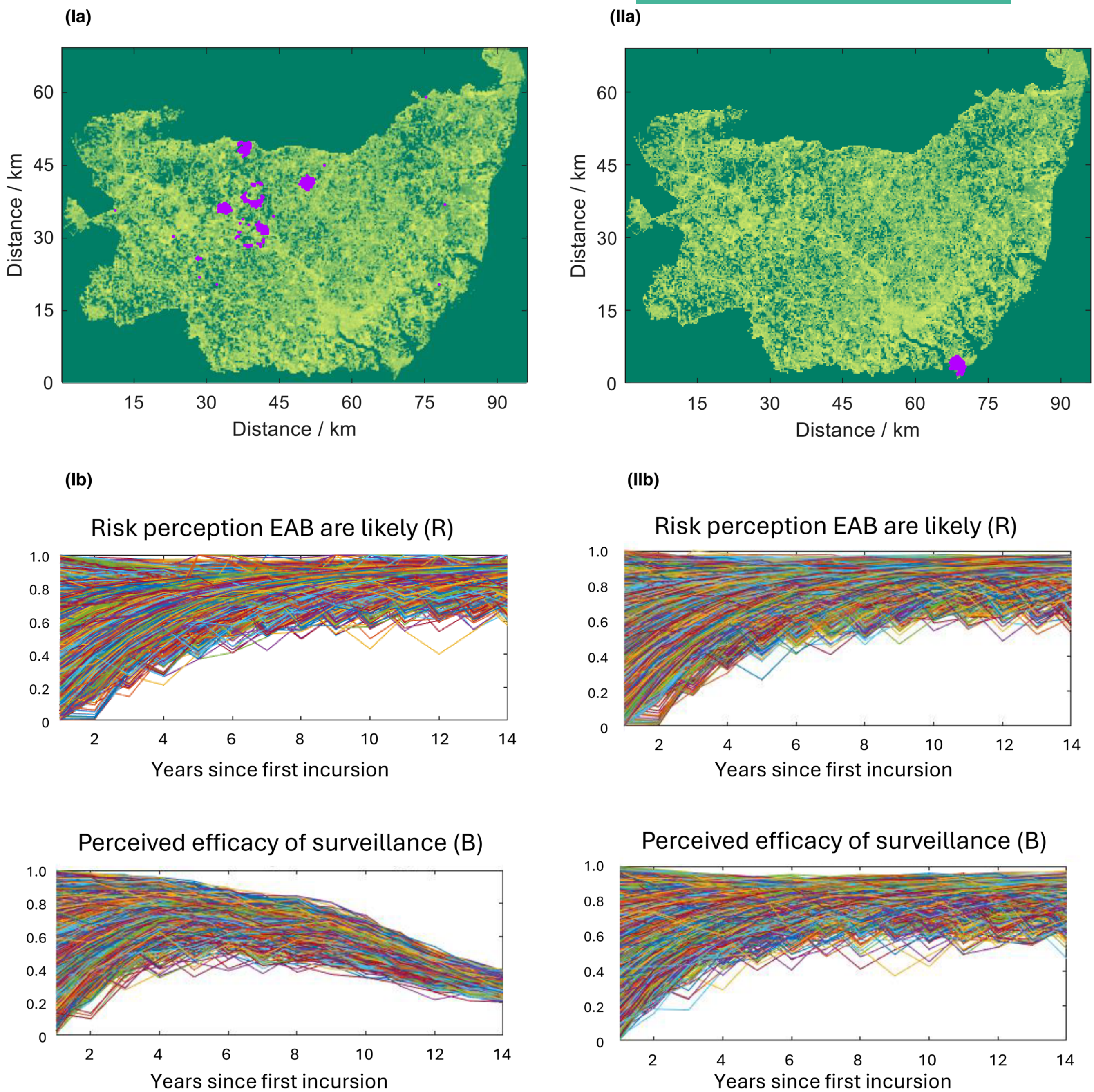

FIGURE 6 Two realisations of simulations (I) and (II) with official traps, tree-H&S inspections, and volunteer trapping. The maps (I a) and (II a) show the ash host distribution (yellow) with locations of EAB after 14 years (purple). For I 14.67 km^2 have been felled as part of the eradication strategy and for II 0.9 km^2 have been felled. (I b) and (II b) show the evolution of two of the opinion variables 'R' and 'B' over time. Each line represents the opinion of one land manager. We observe a natural convergence of opinion over time driven by media campaigns and social interaction. As time evolves in both realisations R increases over time. For realisation (I) as more incidences of EAB are reported the belief that surveillance can mitigate the impact of EAB diminishes.

outbreaks, plays a crucial role in informing the public, highlighting the media's influence on public perceptions and the importance of timely information dissemination. Ash dieback led to a strong initial response by the media in the UK due to the scale and impact of the disease and the status of ash as a native tree, raising the profile of tree pests and diseases within the public (Tomlinson, 2016). Future threats to ash trees could receive similar media attention.

Although knowledge among stakeholders and the public about tree pests is generally low, people tend to become concerned and willing to engage when provided with clear and accessible information (Marzano et al., 2015; Pocock et al., 2020; Urquhart et al., 2017). Public awareness and media campaigns can play a key role in shaping land managers' decisions and pest management strategies by enhancing stakeholder knowledge, shifting perceptions of risk, and

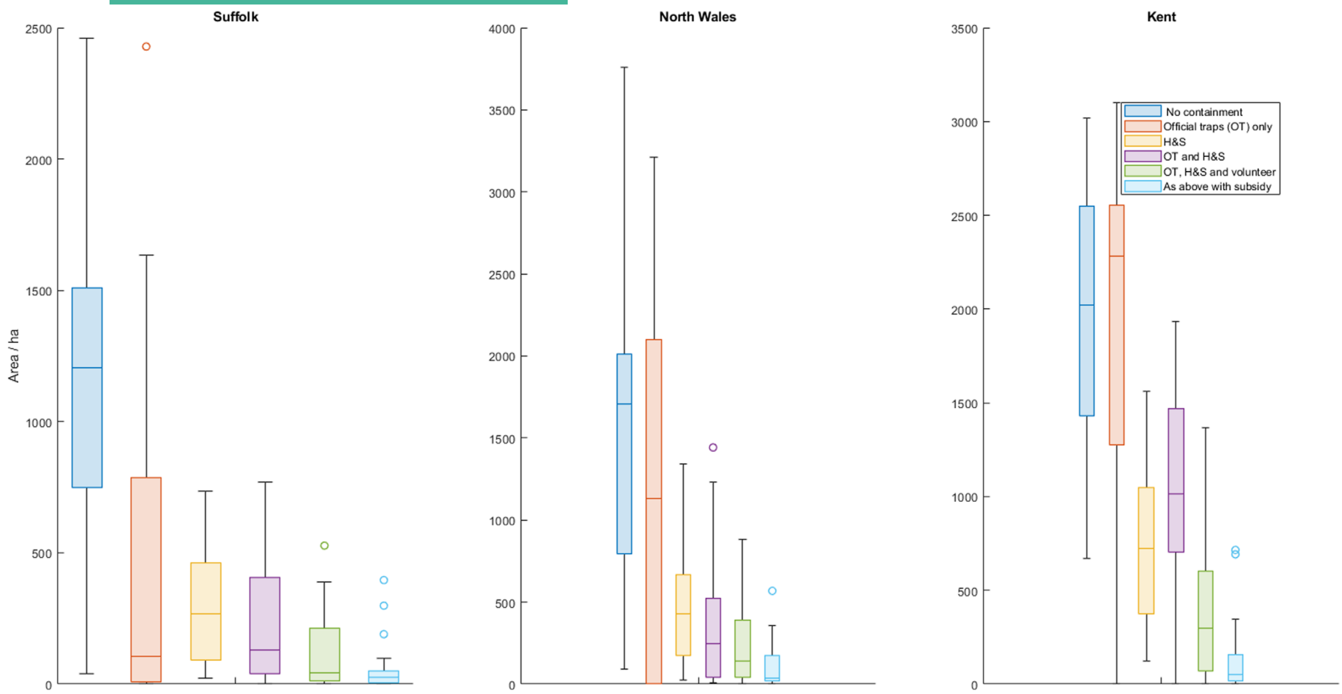

FIGURE 7 Box plots showing the simulated area over which EAB have spread within 15 years of first incursion (assuming in each case that this is the first incursion in GB) for six scenarios. The results are from 30 stochastic simulations.

promoting proactive behaviours such as early detection and reporting. Castagneyrol et al. (2025) evidenced the significant potential of mainstream media to attract public attention to forest health issues, highlighting this as an opportunity that could be more systematically leveraged to support early detection. Targeted information initiatives that include practical guidance, accessible tools, and institutional support can influence decisions about surveillance and management by raising awareness of pests, encouraging earlier reporting through tools such as TreeAlert and networks such as ObservaTree, and nudging land managers towards effective surveillance and management measures (Crow et al., 2020; O'Brien et al., 2021).

4.1.3 | Could volunteer surveillance significantly impact spread rates and how would subsidising trapping costs affect this?

We showed that involving land managers in surveillance is a practical way to achieve the sampling effort needed for the early detection of biological invaders. While land managers showed a strong willingness to comply with trapping, they expected government support. Notably, our self-selected sample was biased towards individuals concerned about tree health, likely inflating compliance levels.

Effective surveillance and eradication efforts are exemplified by cases such as the Mediterranean fruit fly in Mexico and the Asian longhorned beetle in the UK. For the beetle, an amateur entomologist's report led to successful containment—highlighting the value of public vigilance alongside formal surveillance. In contrast, despite government efforts to eradicate the oak processionary moth from the UK since its discovery in 2006 in South-East England, this pest has continued spreading to other regions (Suprunenko et al., 2021), illustrating the challenges posed.

Volunteer trapping may wane over time. This is partially captured in our model by reducing the trust in surveillance as trees are increasingly felled (i.e. as land managers observed eradication not working). In other systems, compliance fatigue has been linked to perceived burdens or lack of immediate benefits (Pocock et al., 2020). Zurbrigg and Van Den Borre (2013) investigated compliance associated with livestock disease surveillance and found that offering various data-recording methods and providing incentives were crucial in maintaining long-term participation.

In our Kent workshop, land managers showed less incentive to adopt surveillance due to extensive ash damage from ADB. We accounted for this in our model (Figure 3), but despite higher ADB impact (Appendix S1), adoption levels still slowed EAB spread. The picture is complex; however, as the mean rate of spread in Kent under the baseline scenario was significantly greater than that of the other case studies due to the greater connectivity of the treescape.

In other systems, land managers have been known to under-report outbreaks to avoid strict controls, economic losses, and the stigma of being identified as a source of infection (Ristaino et al., 2021). Although not evident in our research, this may apply to EAB, where eradication could mean significant loss of ash trees. Conversely, the threat of losing ash could galvanise action to save ash trees. Addressing such challenges requires supportive policies that balance control with social and economic concerns, including compensation and transparent communication between officials and land managers.

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Our EAB model is based on U.S. data, which may overestimate dispersal in GB since the climate may favour semivoltine populations (Webb et al., 2021). With standard parameters, eradication occurred in less than 1% of simulations. However, when univoltine populations were capped at 25%, success rose to about 8% across scenarios. Eradication is most feasible when invasive pests have limited spread and short cryptic periods. In contrast, pests with long cryptic stages and long-distance dispersal are harder to manage (Epanchin-Niell & Liebhold, 2015; Filipe et al., 2012). This underscores the importance of early detection and coordinated response efforts.

4.2 | Limitations

Models of pest dynamics are often limited because they do not consider anthropogenic interactions. We have addressed this by developing a socio-entomological model through an interdisciplinary approach. Hill et al. (2024) described several key challenges with behaviour modelling including understanding behaviour, building an evidence base and parameterisation.

Our approach to understanding behaviour involved in-depth social research, resulting in a value-based theory of land manager decision-making. This led to a preliminary structure which we parameterised using questionnaire data. Despite our staged and interdisciplinary approach, certain aspects were not well-defined and expert-based assumptions had to be made. In the absence of quantitative evidence, we intentionally limited model complexity.

5 | CONCLUSIONS

The effectiveness of pest management is highly sensitive to human behaviour. Therefore, to explore scenarios for effective management, models should integrate both the dynamics of the threat and the responses of individuals who can influence it. Through this approach, we show that, when land managers have knowledge of EAB, routine tree-H&S inspections can significantly contribute to slowing its spread. Full eradication was achieved only in approximately 5% of all simulation runs and this occurred only with subsidised volunteer trapping. To incentivise land manager participation in volunteer surveillance, targeted campaigns informing land managers and the public of pest threats, as well as highlighting successes of their contributions and open communication, can help reduce waning participation in tree health surveillance over time.

AUTHOR CONTRIBUTIONS

Alice E. Milne, Vasthi Alonso Chávez, Nathan Brown, Stephan Parnel, Mariella Marzano, Alison Dyke, Clare Hall and Liz O'Brien conceived the ideas and designed the methodology. Mariella Marzano, Clare Hall, Berglind Karlsdottir, Alison Dyke and Joanne Morris collected the social science data and advised on the structure of the behavioural model. Clare Hall and Mariella Marzano analysed the survey data. Mariella Marzano and Berglind Karlsdottir analysed the interview data. Alison Dyke and Joanne Morris analysed the workshop data. David Williams provided expertise on emerald ash borer. Vasthi Alonso Chávez, Nathan Brown, Alice E. Milne, Stephen Parnell and Matt Coombes developed the model. Vasthi Alonso Chávez and Alice E. Milne ran the model and analysed the model data. Vasthi Alonso Chávez and Alice E. Milne led the writing of the manuscript. Vasthi Alonso Chávez, Nathan Brown, Stephen Parnell, Matt Coombes, Alison Dyke, Clare Hall, Berglind Karlsdottir, Mariella Marzano, Joanne Morris, Liz O'Brien, David Williams and Alice E. Milne contributed critically to the original and revised drafts and gave final approval for publication.

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CONFLICT OF INTEREST STATEMENT

We have no conflicts of interest to disclose.

DATA AVAILABILITY STATEMENT

The code for the model analyses and results can be found at https://doi.org/10.5281/zenodo.18247729 (Milne et al., 2026).

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SUPPORTING INFORMATION

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

Appendix S1: Analysis of the ash dieback layers.

Appendix S2: Interactive scenario workshops exploring ash managers' actions in an emerald ash borer outbreak in the Great Britain (2023).

Appendix S3: Behaviour model parameters.

Appendix S4: Allocation of land managers in each case study region.

Appendix S5: Parameterising the influence of information networks.

Appendix S6: Parameterising the initial conditions of the behaviour variables.

Appendix S7: Results from the simulations for standard parameters and the parameter set associated with a constrained spread.

Appendix S8: Maps of the probability of first incursion on the natural log scale.

Appendix S9: Final online questionnaire.

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