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# Managing outbreaks of invasive species – A new method to prioritize preemptive quarantine efforts across large geographic regions

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ABSTRACT

In pest risk assessment it is frequently necessary to make time-critical decisions regarding management of expanding pest populations. When an invasive pest outbreak is expanding rapidly, preemptive quarantine of areas that are under imminent threat of infestation is one of only a few available management tools that can be implemented quickly to help control the expansion. The preemptive quarantine of locations that surround an infested area also acts as a safeguard to counteract the risk of failed detections of the pest in field surveys. In this paper, we present a method that assesses the suitability of preemptive quarantine measures at the level of small geographical subdivisions (U.S. counties). The cost of a preemptive quarantine in a given county is weighed against the protective benefit of delaying the spread of an outbreak to other neighboring counties. We demonstrate the approach with a decision support model that estimates the suitability of preemptive quarantine across multiple counties that surround areas infested with the emerald ash borer (Agrilus planipennis Fairmaire (EAB), Coleoptera: Buprestidae), an emerging major threat to ash tree species (*Fraxinus* spp.) in North America. The model identifies the U.S. counties where the installation of preemptive quarantine would most effectively slow the spread of EAB populations and reduce risk to high-value areas.



## 1. Introduction

Management of large-scale outbreaks of invasive exotic species relies on timely detections to minimize the effects of initially undetected spread and impact. Unfortunately, detection efforts for such species can be imperfect, especially in instances of low-density pest populations (Marshall et al., 2009). This results in uncertainties in the detection of new populations. Such is consistent with many other aspects of invasive species management, which tend to involve risk analyses under uncertainty (Bartell and Nair, 2003; Burgman et al., 1999; Caley et al., 2006). Consequently, there is a pressing need, both internationally and domestically, for the development of scientifically sound risk assessment methods under conditions where the supply of empirical data is below demand (Andersen et al., 2004; Justo-Hanani et al., 2010).

Quarantines implemented along and around establishment zones and dispersal pathways have been recognized as effective tools that help to address the typical lack of knowledge about new invaders and the common inability to detect them in a timely fashion (Hennessey, 2004). The implementation of quarantine depends on some understanding of a species' key spread vectors and geographic factors that may contribute to the successful movement of the pest through the landscape. Human-mediated spread has been recognized as an important vector for many forest and agricultural pests (Shigesada and Kawasaki, 1997), hence any action that limits the human activities that cause the movement of invasive organisms over distances beyond the species' natural spread range could, in theory, increase the amount of time available for early detection and the development of an appropriate mitigation strategy. Furthermore, if the ability to detect a pest in the early stages of invasion is limited, it is quite possible that populations could already be established in areas deemed uninfested (i.e.,

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where the pest survey did not yield positive finds). In such cases, a preemptive quarantine in the regions adjacent to areas with positive detections of a pest of interest is believed to be one of the few available management options that could potentially help slow the pest's expansion and protect locations with high-value host resources (Lodge et al., 2006).

Imposing a quarantine is a costly action. Quarantines disrupt economic activities in the affected areas and impose additional local costs related to monitoring, shipping restrictions, and preventative treatments (e.g., USDA APHIS, 2010). In addition, costs are also experienced on the federal level. The United States Department of Agriculture (USDA), for example, in 2007 allocated $1.2 billion USD towards the management of invasive species, with approximately 22% directed towards early detection, rapid response, and preemptive measures (NISC, 2007). Thus, minimizing the potential costs of quarantine is always a concern, and a preemptive quarantine should only be imposed when it is sufficiently advantageous to do so. Several techniques have been proposed to estimate the suitability of a quarantine action as a measure to slow the spread of invasive pests (Sharov and Liebhold, 1998; Soliman et al., 2010), with risk and threat analyses among the most widely used. Risk and threat analyses usually involve the assessment of various consequences of a quarantine action, direct assessment of the factors that influence the spread of an outbreak (such as the abundance of a susceptible host species, proximity to already infested sites, anticipated spread rate of an outbreak), as well as potential costs associated with imposing a regulatory action (Venette et al., 2010). Several studies have applied cost-benefit calculations to estimate the suitability of strict regulatory measures (Cooke and MacDonell, 2008; Mehta et al., 2010; Maguire, 2004) to mitigate the likelihood of severe pest outbreaks, however these assessments are difficult to implement at the level of fine-scale geographical subdivisions (U.S. counties) due to a lack of geographically explicit data about the size and spatial allocation of economic activities that may be associated with the pest of interest.

When considering the imposition of a preemptive quarantine in regions surrounding the area already infested by a pest, the simplest approach is to prioritize regions based on the relative impact of a particular quarantine action on the local spread rate of the pest. These analyses may be guided by maps that depict the likelihood of pest arrival (or another risk metric) in the area of interest (Yemshanov et al., 2009; Venette et al., 2010). In this study, we undertake a somewhat different approach and consider not only the suitability of quarantine in a given geographical county but also the expected benefits of imposing the quarantine in the neighboring counties that surround the county of interest. We consider the spread of an invasive pest as a gradual geographic dispersal process, and estimate the capacity of a preemptive quarantine to block the potential spread pathways of the pest to other geographic domains. By adding the evaluation of potential benefits to other geographic counties, we essentially evaluate the ability of the quarantine action undertaken at a given locale to help slow the spread at a broader geographic scale. This total benefit is weighted against the cost of conceding the loss of host within the newly quarantined county. Using this cost-benefit analysis, we estimate an optimal quarantine allocation across multiple counties that surround the infested area, and we assign to each county (i.e., a potential candidate for preemptive quarantine) a quarantine priority rank.

### 1.1. Species of interest

This study assesses the priorities of a preemptive quarantine for the exotic invasive emerald ash borer (*Agrilus planipennis* Fairmaire (EAB), Coleoptera: Buprestidae), a major pest of all ash tree species (*Fraxinus* spp.) in North America (Jendek, 1994; Poland and McCullough, 2006). The first EAB population was discovered in the city of Detroit in the summer of 2002, and the pest has since spread throughout much of the eastern United States and eastern Canada (Poland and McCullough, 2006). A primarily semivoltine buprestid (Siegert et al., 2010), adult EAB females lay eggs on the exterior of the bark. Larvae hatch and bore into the phloem, where they develop through four larval instars. The larvae excise serpentine galleries through the phloem and score the outer xylem, resulting in an eventually lethal girdling of the tree (Cappaert et al., 2005). These factors, combined with the lack of coevolved host resistance and a diverse natural enemy complex, make EAB a significant threat to ash resources throughout North America. Ash constitutes approximately 7% of saw timber in the eastern United States, with a stumpage value estimated at $25 billion. In addition, with ash being one of the most prolific of all urban tree genera, potential costs of removing urban ash trees throughout the United States have been estimated to be as much as $20-60 billion, in addition to replacement costs (Raupp et al., 2006; Cappaert et al., 2005; Snydor et al., 2007).

Currently, no reliable methods of early EAB detection have been developed. The effective geographic range of trap lures is unknown at this time, and external symptoms on ash trees become apparent only after the local population density has increased to a degree by which time beetles have already dispersed (Herms and McCullough, 2014). Efforts have focused on the development of optimized sampling (e.g., Coulston et al., 2008) and trap characteristics (e.g., Marshall, 2009, 2010). The long-distance dispersal of EAB is often assisted by the movement of infested materials, such as firewood, nursery stock and logs (Tobin et al., 2010; Cappaert et al., 2005). For this reason, the management of EAB has relied heavily on the regulation of the movement of EAB-associated materials by way of quarantine measures on such materials at the county level (USDA APHIS, 2011).

### 1.2. Study objectives

In this study, we demonstrate how one can implement a cost-benefit suitability analysis for preemptive quarantine, using EAB as an example. We estimate the suitability of imposing a preemptive quarantine for EAB at the level of U.S. counties. For each county we consider the amount of susceptible host resource (ash) under risk of infestation, as well as the potential risk of infestation to neighboring counties if an outbreak were to be established in said county. Formally, we define the additional risk of infestation to the surrounding counties as the product of the total value of the susceptible host in surrounding counties and the probability that the pest population will spread to the neighboring counties. The latter component is depicted via an omnidirectional dispersal kernel that estimates the likelihood of spread across geographic space as a function of distance.

## 2. Methods

### 2.1. Model of pest invasion spread

Consider a landscape consisting of $m$ small territorial subdivisions (e.g., U.S. counties). Each county can be characterized as infested or uninfested with a given pest, i.e.:

$$\delta_i = \begin{cases} 0 & \textit{if county } i \textit{ is uninfested} \\ 1 & \textit{if county } i \textit{ is infested} \end{cases} \quad (1)$$

where $i \in \{1 \ldots m\}$. It is important to note here that the above variable describes specifically what counties are *known* to be infested and those that are not. In some cases detection is imperfect, and