Journal of Forest Economics 27 (2017) 91–98

Contents lists available at ScienceDirect

Journal of Forest Economics

journal homepage: www.elsevier.com/locate/jfe

The role of restoration in the prevention of a large-scale native species loss: Case study of the invasive emerald ash borer

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ARTICLE INFO

Article history:
Received 20 January 2016
Accepted 15 March 2017
Available online 14 April 2017

JEL classification:
Q20
Q23
Q57

Keywords:
Invasive species
Prevention
Restoration
Ash trees
Emerald ash borer

ABSTRACT

Prevention and restoration are two options for minimizing environmental and economic damages caused by invasive species. Prevention lowers the probability of an invasive species arriving. However, once invasive species have invaded an ecosystem, it is rarely economically or physically viable to eradicate them. Policy after invasion then focuses on restoration or returning habitats to their un-invaded states. We determine the optimal prevention of invasion of the emerald ash borer in Colorado, given the timing of invasion is uncertain and that managers may be able to restore the invaded ecosystem upon an invasive species arrival. Results are used to generate a switching frontier where it is optimal to invest (or not) in prevention given combinations of the probability of invasion, effectiveness of prevention efforts, and restoration possibilities.

Introduction

Once invasive species have become established in an ecosystem, it is rarely economically or physically feasible to eradicate them, often resulting in a large-scale decline of native species and ecosystem services (Clavero et al., 2009; Fritts and Rodda, 1998). Ecologists estimate over 50,000 invasive species within the U.S. generate $137 billion in ecosystem and environmental damages annually (Pimentel et al., 2005). To combat these damages and to avoid having to adapt to the invader over the long term, policy makers typically place an emphasis on *ex ante* management or prevention. However, the net benefits of any pre-invasion or prevention strategy, and hence optimal levels of prevention, depend on the expected post-invasion management strategy; that is, optimal *ex ante* management depends on the expected adaptation to the invader following establishment and spread. We examine the optimal expenditures to prevent (or at least delay) an Emerald Ash Borer (EAB) invasion in Colorado, U.S.A, given that managers would attempt to restore wooded areas, parks and streets to such an extent that society may continue to derive economic and environmental services from it. Indeed, if prevention fails, policymakers often invest in restoring habitats to a semblance of their un-invaded states, especially habitats that provide ecosystem services to society (Ranjan, 2008). Restoration techniques require either eradicating the pest and rehabilitating the eroded environment, or substituting the affected species in an ecosystem with a pest-resistant species (Hobbs et al., 2009; Merkle et al., 2007; Bakker and Wilson, 2004; Berger, 1993). While restoration and substitution are costly, both can reduce the loss of ecosystem services.

Prevention has been shown to be an optimal policy even for areas where the probability of infestation is low (Pimentel et al., 2005; Horan et al., 2002). It has also been shown that even a moderate reduction in the probability of an invasion could likely save the U.S. millions of dollars (Leung et al., 2002; Keller et al., 2008). However, prevention itself is uncertain, it is often not 100% effective, and its success (prevented invasion) is not observed, leading managers to focus on tangible, observable control efforts (Finnoff et al., 2007).

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http://dx.doi.org/10.1016/j.jfe.2017.03.002
1104-6899/

Determining how, when, and by how much to invest in prevention in the state of Colorado therefore is a complicated problem. Providing insights to policy makers requires three key pieces of information; an understanding of how the probability of EAB invasion might be changing over time, an understanding of the effectiveness of preventative strategies, and insight into how the state can adapt to the invader if it is able to establish, spread and cause damage. This paper uses available data and scenario analysis to provide policy makers with clarity on whether or not to invest in prevention, and if so, by how much, and when. Although the generalized framework considering invasive species is now well known (following Shogren, 2000), we combine several important features from the literature to provide meaningful policy insight for EAB (Horan et al., 2002; Shogren, 2000; Fenichel et al., 2010; Horan et al., 2011; Knowler and Barbier, 2005; Olson and Roy, 2002; Perrings, 2005). The analysis combines *ex ante* decision making to influence the likelihood of invasion (Horan et al., 2002) with the ability of policy makers to make *ex post* investments in adaptation to lower realized losses (Fenichel et al., 2010; Horan et al., 2011; Knowler and Barbier, 2005; Olson and Roy, 2002; Perrings, 2005).

Our results indicate that optimal prevention of the emerald ash borer from invading the Denver metro ecosystem would cost $595,000 annually. We find that preventive investments in quarantines and inspections could potentially save the Denver metro area a total of $807 million in discounted expected future benefits relative to an invasion followed by the current management program called Slow Ash Mortality (SLAM – details provided in the following section). We find that a benefit maximizing manager would also find it optimal to invest in prevention even when the post-invasion strategy involves restoring the system with a close substitute such as Asian ash, rather than relying entirely on a post-invasion SLAM program. Prevention may not be optimal in scenarios with both very low probability of invasion and extremely ineffective prevention. Results highlight that prevention must play a leading role in invasive species management over a wide range of probabilities of infestation, and leads to expected savings several orders of magnitude larger than its cost.

Emerald ash borer application

Native to Asia, the emerald ash borer (EAB) was discovered in southern Michigan in 2002 and has been killing all affected adult and sapling ash trees within three to five years after infestation.[1] An analysis of the EAB has found that it is the most costly forest insect to invade the United States (Aukema et al., 2011). Damages from the loss of ash trees impact economic activity, including a reduction of inputs into hard wood goods and a reduction in local esthetic and property values as ash is one of the most commonly planted trees in urban and suburban environments. Ash mortality in developed areas also induces expenditures on tree removal and replacement. Aukema et al. (2011) estimate removal expenditures from the expanding EAB range will exceed $1 billion annually 2009–2019. The loss of ash trees has also been linked to an increased rate of mortality and cardiovascular disease due to reduced air quality, physical activity, and esthetic value (Donovan et al., 2011), and a loss of cultural benefits as black ash is used in Native American basket making, medicinal remedies, and as a central figure in some religious stories.

EAB management in the Midwest has relied heavily on the prevention techniques of quarantines (prohibits the movement of ash outside a confirmed EAB-infested area), random monitoring of firewood, and destroying an 800 m radius of ash trees around an EAB infested ash tree (this practice was stopped in 2006 once EAB was discovered in numerous ash stands). These efforts have proven unsuccessful as outlier populations beyond containment zones are regularly detected. As a result, "SLow Ash Mortality" or SLAM was initiated in 2008 to slow EAB population growth after an invasion and to subsequently slow (but not eliminate) ash mortality. SLAM heavily depends on the insecticide emamectin benzoate, which has proven highly effective in trials and spatial simulations at slowing overall rates of ash decline (McCullough and Mercader, 2012; Herms et al., 2014). Simulation studies have shown that treating 20% of the ash population annually with insecticide can save 99% of at risk trees (McCullough and Mercader, 2012). Ultimately, however, SLAM cannot completely stop all ash mortality nor completely stop the spread of EAB in every case. In cases where SLAM is found to be insufficient, jurisdictions may begin the process of restoration by removing native ash and planting Asian ash. Asian ash is considered a close substitute to native ash trees and is resistant to EAB attacks.[2]

In this paper we consider Colorado's recent plight with EAB. City planners in the Denver metro area are currently determining how much to spend on prevention given that the EAB has been found in Boulder; a city located about 30 miles from Denver. Additionally, ash trees represent 15% of the tree canopy in Denver and surrounding Front Range cities, which will make SLAM and possible restoration activities costly.

The EAB decision model

Consider the decision problem facing a risk-neutral, expected net benefit-maximizing resource manager tasked with trying to prevent an EAB outbreak, given that managers will invest in restoring the system following invasion. Prevention decisions will take into account the potential *ex post* economic consequences of invasion. Therefore, although our focus is on *ex ante* prevention, we begin by describing the *ex post* setting.

The model assumes that a risk neutral planner knows with certainty the expected loss in benefits due to infestation, the efficacy of preventive measures and SLAM, that a suitable substitute species exists, and the costs associated with tree removal and replacement. The manager does not know when the invader will arrive, although the manager does have sufficient information to assess the hazard rate.

The ex post *setting*

The net benefits in the *ex post* setting are specified as the benefits provided by the trees less the costs of restoration. Trees have beneficial effects on air quality as well as overall temperature control in metropolitan areas (Donovan et al., 2011; Freer-Smith et al., 2004; Sydnor and Subburayalu, 2011). Ash trees, in particular, provide benefits in the form of existence value as well as improving quality of life through health impacts and landscaping value (Donovan et al., 2013; Sydnor et al., 2007). For our numerical exercise, we assume the present value of the benefits provided by each ash tree is PV = $848.96 (Sydnor et al., 2007). Using a discount rate of 3% for our benchmark scenario ($r = 0.03$; Table 1), the flow value (i.e., the per period benefit) of an ash tree is $B = rPV = \$25.47$ (Jones et al.,

[1] Most scientists hypothesize the EAB entered the United States through the solid wood packing materials transported on cargo ships and on planes (Strutt et al., 2013) EAB larvae feed on the inner bark of ash trees, which destroys a tree's ability to translocate water and nutrients (Poland and McCullough, 2006).

[2] EAB in its native East Asia is considered a minor pest, where it attacks only weakened or dying ash trees.(Baranchikov et al., 2008).