Feature

Biological Invasions and International Trade: Managing a Moving Target

Rebecca Epanchin-Niell*, Carol McAusland†, Andrew Liebhold‡, Paul Mwebaze§, and Michael R. Springborn‖

Introduction

Humans move species around the globe, both intentionally and unintentionally, and biological invasions have been accelerating for many species groups (Seebens et al. 2017). While most nonnative species (NNS) have little impact within their invaded habitat, many exhibit extraordinary population growth and adversely affect species with which they share no evolutionary history.[1] NNS can also have significant negative economic impacts, estimated at $162 billion ($2019) annually in the United States (Pimentel, Zuniga, and Morrison 2005) and up to 12 percent of GDP in some developed countries (Marbuah, Gren, and McKie 2014). Harmful impacts of NNS include disrupting agriculture and other managed landscapes (e.g., forests, aquatic systems), ecosystem service loss, and disease spread (Eiswerth, Lawley, and Taylor 2018). For example, the emerald ash borer beetle—likely introduced to the Unites States via wood packaging material—has spread to at least 35 states, killing hundreds of millions of ash trees. Its impacts on US residential housing values alone are estimated at $452 million ($2019) annually (Aukema et al. 2011), with total discounted damages of $24.9 billion ($2019; Epanchin-Niell and Liebhold 2015).

In this article, we examine the processes underlying the relationship between trade and NNS, interventions aimed at preventing NNS introductions, and the role of policy and economic

*Resources for the Future (email: epanchin-neill@rff.org) and Department of Agricultural and Resource Economics, University of Maryland; †Department of Food and Resource Economics, University of British Columbia (email: carol.mcausland@ubc.ca); ‡Northern Research Station, US Department of Agriculture Forest Service and Faculty of Forestry and Wood Sciences, Czech University of Life Sciences (email: andrew.liebhold@usda.gov); §Department of Environmental Science and Policy, University of California and Commonwealth Scientific and Industrial Research Organization (email: pmwebaze@ucdavis.edu); ‖Department of Environmental Science and Policy, University of California, Davis (email: mspringborn@ucdavis.edu)

This work was supported by the National Socio-Environmental Synthesis Center (SESYNC) through funding from the National Science Foundation DBI-1639145. We thank L. Dunlap for figure assistance and anonymous reviewers for helpful suggestions.

[1] We limit our focus to NNS that are potentially damaging in the importing region; we do not consider introductions of beneficial species.

Electronically published March 4, 2021

Review of Environmental Economics and Policy, volume 15, number 1, winter 2021.

Published by The University of Chicago Press for AERE. https://doi.org/10.1086/713025

research in managing and reducing trade-related NNS risk.[2] We begin by describing factors and processes affecting the introduction of NNS through trade. Then we discuss how economics helps to quantify NNS impacts, elucidate the dynamics of trade and NNS risk, and inform biosecurity interventions. Finally, we outline future priorities for economic research and policy.

Overview of the Introduction of NNS through Trade

Various processes influence how trade facilitates NNS introductions, including changes in global species distributions, volumes and types of traded commodities, trade partners and technologies, and investments in biosecurity (i.e., the measures aimed at reducing NNS risk). Introductions can occur through a range of trade-related pathways (routes and means). Unintentional introductions include organisms arriving accidentally, such as invertebrates and pathogens transported with imported plants and animals, marine organisms living in maritime ballast water, terrestrial snails arriving with imported tile, and wood-boring insects arriving with wood packaging (e.g., Costello et al. 2007; Liebhold et al. 2012; Leung et al. 2014). Invasions also can occur directly through the escape and spread of intentionally imported plants and animals (Lockwood et al. 2019). While international passenger travel is beyond this article's scope, such travel is also a key pathway for transporting NNS.[3] NNS risks are heterogeneous across imports and regions, with higher risks tied to trade among regions with similar climates (Costello et al. 2007; Dalmazzone and Giaccaria 2014).

Figure 1 illustrates the dynamics and management of NNS in trade. NNS can be introduced to country A via exports from its trading partner (country B). The species present in B that form a pool of potential invaders to A include those native to B (black circles), as well as species from "bridgehead" regions (black squares), which were introduced to B from elsewhere (country C).[4] Country A has a range of interventions (dark, shaded boxes) available to manage risk across the biosecurity continuum: preborder biosecurity measures that are applied in B and inhibit organisms from contaminating B's exports, biosecurity interventions applied at A's ports to identify and remove NNS "hitchhiking" on imported goods, postborder biosecurity measures by A to mitigate damages from introduced NNS.[5] The remainder of this section discusses these key factors governing NNS risk in more detail.

Changing Trade Patterns Can Pose New NNS Risks

Quite simply, a larger import volume means a larger potential for introducing NNS. The associated risk to an importer depends in part on the pool of potential invaders that resides

[2] For reviews concerning managing postborder invasion, see Büyüktahtakin and Haight (2018), Eiswerth, Lawley, and Taylor (2018), and Epanchin-Niell (2017).

[3] Tourists and business travelers can also serve as unwitting vectors for novel communicable diseases (Early et al. 2016), as shown by the global spread of COVID-19. However, tourists may also transport agricultural goods and wildlife—sometimes intentionally—via baggage.

[4] Bridgehead regions are regions that species invade and then become jumping-off points for invading other regions.

[5] As we will discuss, the management of NNS is supported by analysis (the dashed boxes in figure 1), including policy design and assessment, predicting species movement in trade, and pest risk assessment.

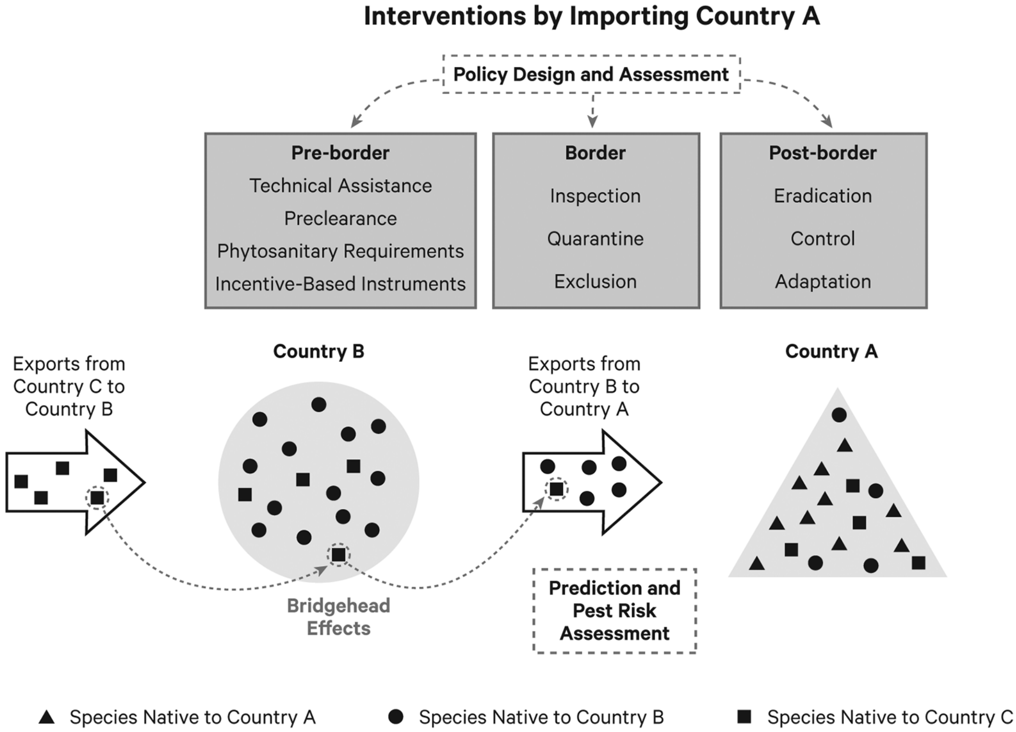

Figure 1 Overview of the dynamics and management of NNS in trade. Source: The authors.

among its trade partners. The size of this potential NNS pool is dynamic: once a new species establishes in an importing country, it is no longer a potential future invader for that country. Thus, the pool of potential new NNS may diminish as more introductions occur (Liebhold, Brockerhoff, and Kimberley 2017). However, if the growth rate in imports is sufficient, species can still establish at an increasing rate. Moreover, as shown in figure 1, new trading relationships, commodities, and transport pathways can expand potential NNS pools. In fact, changing trade patterns help explain the continued emergence of new NNS, with one-quarter of NNS discovered from 2000 to 2005 having never been previously discovered as alien anywhere else in the world (Seebens et al. 2018).

Bridgeheads Can Accelerate Global NNS Spread

Another dynamic factor that can expand the pool of potential invaders involves bridgeheads: an NNS from one region establishes in a new region, from where it can then be introduced to additional regions (see figure 1). For example, although the majority of ant species detected at US ports of entry are native to Africa, most of these ants arrive on goods being imported from Central America (Bertelsmeier et al. 2018). NNS can become exceptionally abundant in an invaded region—for example, as result of release from predation, competition, and disease pressures—and thus have a higher likelihood of being transported with traded goods. When combined, high abundance in invaded regions and bridgehead dynamics can amplify the risk of further NNS spread globally.

Biosecurity Policies to Manage NNS Risk

Variation in NNS risk also arises from differences in the prevalence and types of biosecurity measures over time and space. Measures to prevent NNS introductions can be implemented preborder (i.e., in the country of origin) and at the border (see figure 1). The earliest government responses to NNS risks occurred in the late 1800s, targeting traded produce and livestock (Eiswerth, Lawley, and Taylor 2018), followed by legislation to limit risk from trade in live plants (Liebhold and Griffin 2016). The World Trade Organization (WTO) Agreement on the Application of Sanitary and Phytosanitary[6] (SPS) Measures guides interventions globally. The 1995 multinational SPS agreement mandates that quarantine measures be scientifically justified and based on documented risk to the importing country, establishes processes to identify inappropriate protectionist policies, and requires adherence to international SPS standards. SPS signatories also agree to facilitate biosecurity technical assistance to developing countries. However, even under the SPS agreement, biosecurity practices vary greatly among countries, reflecting differences in risk perceptions and technical capacity (Eschen et al. 2015; Early et al. 2016).

Contributions of Economic Analysis

Economics can provide important analysis, tools, and insights for managing NNS associated with trade. Indeed, valuing NNS impacts and intervention costs is critical for efficient policy design so that policy costs can be weighed against their benefits. In addition, prescriptive and descriptive economic analysis can also be used to optimize biosecurity policies and predict changes in trade patterns and stakeholder behaviors in response to economic shocks or policy changes. Moreover, economic analysis can identify the incentives that arise from trade and biosecurity interventions; this is important because trade benefits are often immediate and concentrated, whereas NNS impacts can be diffuse and delayed, and they can accrue to different stakeholders. We discuss these contributions from economics in more detail below.

Quantifying Impacts

Economists have developed and applied a range of methods to value both market and nonmarket impacts from harmful NNS and to estimate management costs. These methods go beyond early cost-based approaches, which have been widely criticized for measuring expenditures rather than actual impacts (see, e.g., Eiswerth, Lawley, and Taylor 2018). Despite advances in economic valuation methodologies, invasion damages are notoriously difficult to estimate comprehensively and with precision. This is because impacts span diverse and imperfectly observed sectors, and total costs change over time as NNS spread across a landscape and ecosystems and people adapt. Thus, while economists can rigorously estimate the costs a specific invader imposes on a particular resource, only rough estimates are available for total impacts for an individual (or collection of) species (Pimentel, Zuniga, and Morrison 2005).

[6] "Phytosanitary" means relating to the health of plants.

Dynamics of Trade and NNS Risk

Most economic analyses of trade and NNS introduction have focused on trade volumes, often treating all imports from a particular partner as equally risky but recognizing that risk varies by partner. For example, using historic shipping and NNS data, Costello and colleagues (2007) estimate that the marginal invasion risk facing the San Francisco Bay from additional imports triples when goods arrive from more recent rather than long-standing trade partners. Nong and colleagues (2019) use a computable general equilibrium model to predict changes in NNS risk to the United States arising from ice loss along Arctic routes and find that increased imports from China and Japan pose the largest threat (see also Countryman, Warziniack, and Grey 2018).

Biosecurity Interventions to Manage Risk

Optimal policy to reduce NNS risks equates the marginal costs of prevention with the marginal benefits from reduced introductions (e.g., Olson and Roy 2010). Though border interventions may be motivated by the objective of preventing arrivals of a specific species, many of the available tools are applied to an entire pathway (e.g., fumigating incoming shipments of fruit). Because such interventions may simultaneously destroy nontargeted NNS, prevention measures may provide benefits that go well beyond those that arise from reducing risks from a single NNS. However, prevention benefits are greatly influenced by discounting, as the date when an NNS is introduced (and the time frame during which prevention costs accrue) can be years or even decades before the species causes damage (Epanchin-Niell and Liebhold 2015). We next describe the general classes of policy interventions to manage NNS risk from trade, including pest risk assessments, preborder biosecurity interventions, incentive-based instruments, and border inspections. We then highlight insights from economic analysis regarding combining policy interventions and the unintended consequences of trade restrictions.

1. Pest risk assessments (PRAs) evaluate the probability of a species arriving and establishing and estimate likely damages (Andersen et al. 2004). PRAs aim to inform exclusion, quarantine, and control policies for specific commodities that are themselves NNS (e.g., plant, bird, reptile imports) or for specific pathways—such as using wood packaging materials—that may unintentionally transport NNS. Economic analyses that weigh trade impacts against expected NNS costs have found positive net benefits from PRAs (e.g., Keller, Lodge, and Finnoff 2007; Springborn, Romagosa, and Keller 2011; Lieli and Springborn 2012).

2. Preborder biosecurity interventions are efforts to reduce NNS risk from trade prior to arrival in a recipient port and include phytosanitary treatments (such as fumigating imported plant material), preexport clearance inspections, and deploying risk-reducing procedures during production and transport (see figure 1). For example, international phytosanitary standards developed by the International Plant Protection Convention require that wood materials be treated prior to use as packaging for exported goods; Leung and colleagues (2014) find that these measures provide positive net benefits to importing countries, despite costly implementation and incomplete efficacy.

3. Incentive-based instruments for reducing NNS risk include price-based instruments (e.g., Pigouvian taxes, tariffs), tradeable risk permits, liability insurance, and environmental performance bonds, among others. These mechanisms incentivize risk reduction and finance mitigation, but the challenges of quantifying ex ante risk and assigning ex post liability have hindered their widespread application (Epanchin-Niell 2017).

4. Border inspections play several beneficial roles, including (*a*) gathering information about risks across commodities that can be used to identify the need for quarantine measures; (*b*) incentivizing producers to abate NNS risk in exported goods (to avoid interception penalties; Ameden, Cash, and Zilberman 2007; Springborn, Lindsay, and Epanchin-Niell 2016); and (*c*) identifying infested shipments so they can be mitigated (Epanchin-Niell 2017). Inspection strategies tend to target higher-risk commodities (e.g., Surkov et al. 2009; Chen, Epanchin-Niell, and Haight 2018) and can be designed to elicit learning that will help importers improve targeting over time (e.g., Springborn 2014).

5. Combining interventions (e.g., inspections, preborder interventions, SPS measures) has been shown by economists to be more cost-effective than single interventions. For example, providing technical assistance to exporting countries, together with inspections and penalties, can enhance abatement efforts by exporters (Fernandez and Sheriff 2013), and tariff efficacy can be improved when applied in combination with other tools such as inspections (McAusland and Costello 2004) and fines on infested products (Mérel and Carter 2008).

6. Unintended consequences of trade restrictions have also been identified through economic analyses. For example, adjustments in production, consumption, imports, and land use in the importing country can, in some cases, counteract a tariff's benefits by increasing susceptibility to invasions (Costello and McAusland 2003; Tu, Beghin, and Gozlan 2008). Similarly, when interventions limit trade, unmet demand may be fulfilled through unauthorized trade, which may increase NNS risk by evading NNS-mitigating interventions. Exclusions may also divert trade to new regions (Reino et al. 2017), potentially connecting new species pools or creating new bridgeheads.

Future Priorities for Economic Research and Policy

We next suggest four interrelated priorities for economic and policy research to reduce the risk of NNS introduction through trade. First, we recommend expanded economic analysis to more comprehensively consider interventions across the biosecurity continuum (pre- to postborder). Second, new data systems should be leveraged for real-time prediction so that inspection effort can be allocated accordingly. Third, economic analysis should be applied to anticipate and respond to emerging trade trends, including e-commerce. Finally, strategic and behavioral responses must be understood and leveraged so that new policies can augment desired behaviors and avoid unintended consequences.

Expand Economic Analysis to More Comprehensively Consider Interventions across the Biosecurity Continuum

Historically, NNS prevention efforts have focused mainly on biosecurity measures at the border (e.g., exclusion policies, inspecting shipments). However, increased trade volumes, limited inspection capacity at ports, and competing demands on inspection resources (e.g., to address smuggling and security concerns) have all made border inspection less feasible. Moreover, a growing premium on delivery speed makes inspection delays costlier to industry, increasing the need to intervene elsewhere to reduce risks.

In response, policy makers have been expanding the use of interventions across the biosecurity continuum, particularly preborder measures (see figure 1). Economic research is needed to assess the design and cost-effectiveness of preborder interventions, especially with respect to bridgehead dynamics. For example, growth in trade among developing countries may increase the returns to building biosecurity capabilities in developing countries (e.g., SPS technical capacity), and an increase in such capabilities could reduce the threat of new bridgehead invasions, decrease domestic inspection costs, and facilitate trade with developing countries.[7]

More generally, economic research on NNS and trade needs to recognize the broader set of dynamics and the interdependency of policies across the biosecurity continuum. For example, we know that trade volumes, species-specific attributes, bridgeheads, and changing species pools are all important drivers of NNS introductions (Costello et al. 2007; Bertelsmeier et al. 2018), but these factors have not yet been integrated into a comprehensive empirical analysis. In terms of policy, research is needed to distribute investments across the biosecurity continuum in a way that considers the interdependence of their payoffs, including how resources should be allocated across preborder, border, and postborder interventions (Epanchin-Niell 2017).

Leverage New Data Systems for Real-Time Decision-Making

Emerging trends in data collection create opportunities for designing and targeting biosecurity interventions. For example, commercial shipments are now being tracked by integrated electronic interfaces, such as the International Trade Data System Automated Commercial Environment in the United States. These new tracking systems replace dispersed, paper-based tracking methods and generate data streams that can inform real-time decision-making regarding interventions. Economic analysis can guide how best to leverage these ever-expanding data sources to allocate scarce border-inspection resources. For example, demand surges may encourage imports from nontraditional suppliers, who may send substandard or contaminated product. A possible corollary is that commodity- and partner-specific contamination probabilities are sensitive to market fluctuations such as price swings, and thus price data could be used to inform decisions about the allocation of surveillance effort across importers and time.

Apply Economic Analysis to Anticipate and Respond to Emerging Trade Trends

The marked changes in international trade over the past century have significant consequences for NNS introductions. For example, new transport technologies like intermodal

[7] Bioeconomic models may also help identify existing bridgeheads that have not yet been detected.

containers[8] have fostered global supply chains for manufactured goods (Ortiz-Ospina, Beltekian, and Roser 2018), which has accelerated introductions of bark- and wood-boring insects that hitchhike in wood packaging.[9] E-commerce also poses dynamic challenges for managing NNS introductions. Indeed, from 2017 to 2023, global retail e-commerce sales are expected to increase from \$2.4 to \$6.5 trillion (Lipsman 2019), and e-commerce's cross-border share will rise from approximately 15 to 20 percent (Kaplan 2017). Products such as pet and aquarium species, horticultural and agricultural species, live food and bait, scientific and educational supplies, firewood and biofuel stocks, and herbal or medicinal products all present invasion risk (Monaco 2019). Yet a wide array of NNS and other risky products are available for sale on online platforms, even though many are prohibited by national law or international treaty. NNS risks from international business-to-consumer pathways are difficult to manage, as internet sellers may lack legal registration, location information, and expertise in their products (Monaco 2019). Moreover, researchers and governments have little sense of either the substitutability between e-commerce and traditional trade or how different border controls affect that elasticity. Economic analysis could help quantify this substitutability and identify policies that might unintentionally shift trade flows toward delivery modes that are difficult to manage.

Shifts in trade modes—with direct-to-consumer deliveries replacing large consignments to wholesalers—exacerbate the inspection targeting and coverage problem.[10] Indeed, conventional border inspection and sanitary measures cannot comprehensively address the sheer volume of small packages of uncertain origin and contents (Marker 2018). Thus, regulators in Australia, Europe, and the United States are engaging with e-commerce platforms to monitor online trade, launch information campaigns, and identify buyers and sellers of regulated items and prevent sales (Marker 2018; Monaco 2019). Increased data collection should make understanding and managing the introduction risks associated with e-commerce easier, but only if the data are made available to policy architects. Moreover, as we discuss next, it is crucial to anticipate strategic and behavioral responses to policy interventions.

Understand and Leverage Strategic and Behavioral Responses

Strategic and behavioral responses to NNS-mitigating interventions have received only modest attention to date. Consider firms—because inspections are costly, many countries examine only a subset of imported units. Exporters have responded strategically, directing exports to ports with less intensive inspections, timing shipments for arrival when inspection staff are scarce, and intentionally mislabeling in order to circumvent SPS measures (Ameden, Cash, and Zilberman 2007). Springborn, Lindsay, and Epanchin-Niell (2016) find that when firms

[8] Intermodal containers are large, standardized shipping containers that can be used for ship, rail, and truck transport. This technology has led to more rapid transport, as imports can be easily moved across transport modes.

[9] Recent trends and events, including the spikes in protectionism during the Trump presidency (Khan 2019), the United Kingdom's withdrawal from trade agreements (Brown et al. 2019), and the COVID-19 pandemic, may also have long-run implications for NNS and trade. Possible impacts include reduced government budgets (including for SPS initiatives) and sustained reductions in international trade volumes (and NNS propagule pressure).

[10] For example, a 2018 US law requires tracking for all packages arriving from abroad (mainly motivated by illicit opioid shipments), but the law has yet to be fully implemented by the US Postal Service, which has argued it would be "impractical and too costly" (Horwitz and Higham 2019).

are assigned to differentially inspected, high- and low-risk groups (based on recent inspection outcomes), firms have an incentive to clean up shipments to avoid placement in the high-risk (targeted) group, thereby increasing phytosanitary investments by both targeted *and* nontargeted exporters. More broadly, there are rich opportunities for future research into designing incentive-compatible (and incentive-harnessing) biosecurity protocols.

On the consumer side, behavioral economics may be helpful for facilitating and designing effective NNS interventions, particularly for e-commerce. Interventions can take many forms, including expediting customs clearance for low-risk goods, devising algorithms that prioritize low-risk commodities in internet searches, and introducing pop-up notices on e-commerce platforms that inform consumers about the ecological risks associated with purchasing particular goods. Behavioral economics may also help determine the penalties necessary to deter risky purchases, as observed behaviors in the presence of risk often deviate from those predicted by typical economic models (Shogren and Taylor 2008).

Conclusions

Economics has already provided many important insights to help reduce NNS risk. However, many challenges remain, especially given the ever-changing nature of international trade. Some changes in NNS risk are difficult to predict—such as those associated with supply chain disruptions accompanying COVID-19 outbreaks. Other changes, such as shifts in trading partners and commodities as a result of climate change or trade agreements or changes in NNS risk arising from price shocks, may be more easily anticipated and thus warrant a proactive policy response. Similarly, assessing new methods to reduce the threats posed by dispersed NNS introduction pathways, such as e-commerce, is critical for adapting to these trade shifts. Economic analysis that is integrated with insights from ecology and other disciplines has a key role to play in designing and assessing current and future policy responses to the risk of introducing NNS through trade.

References

Ameden, H. A., S. B. Cash, and D. Zilberman. 2007. Border enforcement and firm response in the management of invasive species. *Journal of Agricultural and Applied Economics* 39: 35–46.

Andersen, M. C., H. Adams, B. Hope, and M. Powell. 2004. Risk assessment for invasive species. *Risk Analysis* 24 (4): 787–93.

Aukema, J. E., B. Leung, K. Kovacs, C. Chivers, K. O. Britton, J. Englin, S. J. Frankel, et al. 2011. Economic impacts of non-native forest insects in the continental United States. *PLoS ONE* 6: e24587.

Bertelsmeier, C., S. Ollier, A. M. Liebhold, E. G. Brockerhoff, D. Ward, and L. Keller. 2018. Recurrent bridgehead effects accelerate global alien ant spread. *Proceedings of the National Academy of Sciences of the USA* 115 (21): 5486–491.

Brown, D. H., D. C. Aldridge, C. Rhodes, and W. Sutherland. 2019. Brexit threatens biosecurity: From data to strategy. *Nature* 567: 461.

Büyüktahtakın, E., and R. G. Haight. 2018. A review of operations research models in invasive species management: State of the art, challenges, and future directions. *Annals of Operations Research* 271: 357–403.

Chen, C., R. Epanchin-Niell, and R. G. Haight. 2018. Optimal inspection of imports to prevent invasive pest introduction. *Risk Analysis* 38 (3): 603–19.

Costello C., and C. McAusland. 2003. Protectionism, trade, and measures of damage from exotic species introductions. *American Journal of Agricultural Economics* 85 (4): 964–75.

Costello, C., M. Springborn, C. McAusland, and A. Solow. 2007. Unintended biological invasions: Does risk vary by trading partner? *Journal of Environmental Economics and Management* 54 (3): 262–76.

Countryman, A. M., T. Warziniack, and E. Grey. 2018. Implications for US trade and nonindigenous species risk resulting from increased economic integration of the Asia-Pacific region. *Society and Natural Resources* 31 (8): 942–59.

Dalmazzone, S., and G. Giaccaria. 2014. Economic drivers of biological invasions: A worldwide, biogeographic analysis. *Ecological Economics* 105: 154–65.

Early, R., B. A. Bradley, J. S. Dukes, J. J. Lawler, J. D. Olden, D. M. Blumenthal, P. Gonzalez, et al. 2016. Global threats from invasive alien species in the twenty-first century and national response capacities. *Nature Communications* 7 (1): 1–9.

Eiswerth, M., C. Lawley, and M. Taylor. 2018. Economics of invasive species. In *Encyclopedia of environmental science*, ed. Shugart, H. New York: Oxford University Press. http://10.1093/acrefore/9780199389414.013.518.

Epanchin-Niell, R. 2017. Economics of invasive species policy and management. *Biological Invasions* 19: 3333–54.

Epanchin-Niell, R. S., and A. M. Liebhold. 2015. Benefits of invasion prevention: Effect of time lags, spread rates, and damage persistence. *Ecological Economics* 116: 146–53.

Eschen, R., K. Britton, E. Brockerhoff, T. Burgess, V. Dalley, R. S. Epanchin-Niell, K. Gupta, et al. 2015. International variation in phytosanitary legislation and regulations governing importation of plants for planting. *Environmental Science and Policy* 51: 228–37.

Fernandez, L., and G. Sheriff. 2013. Optimal border policies for invasive species under asymmetric information. *Environmental and Resource Economics* 56 (1): 27–45.

Horwitz, S., and S. Higham. 2019. The flow of fentanyl: In the mail, over the border. *Washington Post*. August 23.

Kaplan, M. 2017. The explosive growth of cross-border ecommerce. Practical Ecommerce, July 12. https://www.practicalecommerce.com/the-explosive-growth-of-cross-border-ecommerce.

Keller, R. B., D. M. Lodge, and D. C. Finnoff. 2007. Risk assessment for invasive species produces net bioeconomic benefits. *Proceedings of the National Academy of Sciences of the USA* 104: 203–7.

Khan, Y. 2019. China is sourcing more of its farm goods from other countries, and that's a bad sign for the US. *Business Insider*, July 31. https://markets.businessinsider.com/news/stocks/china-sources-more-farm-goods-brazil-us-trade-war-2019-7-1028403926.

Leung, B., M. R. Springborn, J. A. Turner, and E. G. Brockerhoff. 2014. Pathway-level risk analysis: The net present value of an invasive species policy in the US. *Frontiers in Ecology and the Environment* 12: 273–79.

Liebhold, A. M., E. G. Brockerhoff, L. J. Garrett, J. L. Parke, and K. O. Britton. 2012. Live plant imports: The major pathway for forest insect and pathogen invasions of the US. *Frontiers in Ecology and the Environment* 10: 135–43.

Liebhold, A. M., and R. L. Griffin. 2016. The legacy of Charles Marlatt and efforts to limit plant pest invasions. *Bulletin of the Entomological Society of America* 62 (4): 218–27.

Liebhold, A. M., E. G. Brockerhoff, and M. Kimberley. 2017. Depletion of heterogeneous source species pools predicts future invasion rates. *Journal of Applied Ecology* 54: 1968–77.

Lieli, R. P., and M. Springborn. 2012. Closing the gap between risk estimation and decision making: Efficient management of trade-related invasive species risk. *Review of Economics and Statistics* 95: 632–45.

Lipsman, A. 2019. Global Ecommerce 2019: Ecommerce continues strong gains amid global economic uncertainty. Report, Insider Intelligence, June 27. https://www.emarketer.com/content/global-ecommerce-2019.

Lockwood, J. L., D. J. Welbourne, C. M. Romagosa, P. Cassey, N. E. Mandrak, A. Strecker, B. Leung, et al. 2019. When pets become pests: The role of the exotic pet trade in producing invasive vertebrate animals. *Frontiers in Ecology and the Environment* 17 (6): 323–30.

Marbuah, G., I. Gren, and B. McKie. 2014. Economics of harmful invasive species: A review. *Diversity* 6: 500–523.

Marker, C. 2018. Protecting agriculture on the internet—one click, one post, one sale at a time. US Department of Agriculture blog, April 24. https://www.usda.gov/media/blog/2018/04/24/protecting-agriculture-internet-one-click-one-post-one-sale-time.

McAusland, C., and C. Costello. 2004. Avoiding invasives: Trade-related policies for controlling unintentional exotic species introductions. *Journal of Environmental Economics and Management* 48: 954–77.

Mérel, P. R., and C. A. Carter. 2008. A second look at managing import risk from invasive species. *Journal of Environmental Economics and Management* 56: 286–90.

Monaco, A. 2019. Guidance document on e-commerce and IAS: First draft. Council of Europe, Strasbourg, France, May. https://rm.coe.int/guidance-document-on-e-commerce-and-invasive-alien-species-1st-draft/168093fdf9.

Nong, D., T. Warziniack, A. M. Countryman, and E. K. Grey. 2019. Melting Arctic sea ice: Implications for nonindigenous species (NIS) spread in the United States. *Environmental Science and Policy* 91: 81–91.

Olson, L. J., and S. Roy. 2010. Dynamic sanitary and phytosanitary trade policy. *Journal of Environmental Economics and Management* 60 (1): 21–30.

Ortiz-Ospina E., D. Beltekian, and M. Roser. 2018. Trade and globalization. Our World in Data, October. https://ourworldindata.org/trade-and-globalization.

Pimentel, D., R. Zuniga, and D. Morrison. 2005. Update on the environmental and economic costs associated with alien-invasive species in the United States. *Ecological Economics* 52 (3): 273–88.

Reino, L., R. Figueira, P. Beja, M. B. Araújo, C. Capinha, and D. Strubbe. 2017. Networks of global bird invasion altered by regional trade ban. *Science Advances* 3 (11): e1700783. https://doi.org/10.1126/sciadv.1700783.

Seebens, H., T. M. Blackburn, E. E. Dyer, P. Genovesi, P. E. Hulme, J. M. Jeschke, S. Pagad, et al. 2017. No saturation in the accumulation of alien species worldwide. *Nature Communications* 8: 14435.

Seebens H., T. M. Blackburn, E. E. Dyer, P. Genovesi, P. E. Hulme, J. M. Jeschke, S. Pagad, et al. 2018. Global rise in emerging alien species results from increased accessibility of new source pools. *Proceedings of the National Academy of Sciences of the USA* 115 (10): E2264–E2273.

Shogren, J. F., and L. O. Taylor. 2008. On behavioral-environmental economics. *Review of Environmental Economics and Policy* 2 (1): 26–44.

Springborn, M., A. R. Lindsay, and R. S. Epanchin-Niell. 2016. Harnessing enforcement leverage at the border to minimize biological risk from international live species trade. *Journal of Economics and Behavioral Organization* 132: 98–112.

Springborn, M., C. M. Romagosa, and R. P. Keller. 2011. The value of nonindigenous species risk assessment in international trade. *Ecological Economics* 70: 2145–53.

Springborn, M. R. 2014. Risk aversion and adaptive management: Insights from a multi-armed bandit model of invasive species risk. *Journal of Environmental Economics and Management* 68: 226–42.

Surkov, I. V., G. J. M. Alfons, O. Lansink, and W. Van der Werf. 2009. The optimal amount and allocation of sampling effort for plant health inspection. *European Review of Agricultural Economics* 36 (3): 295–320.

Tu, A. T., J. Beghin, and E. Gozlan. 2008. Tariff escalation and invasive species damages. *Ecological Economics* 67 (4): 619–29.