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FOREST INVASIONS

Biological invasions in forest ecosystems: a global problem requiring international and multidisciplinary integration

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Abstract The world's forests are crucial biological resources that provide a variety of ecosystem services such as nutrient cycling and provisioning of resources to society. But forests are particularly affected by biological invasions, with regions around the world experiencing invasions by species from virtually every kingdom. Many of these species have severely disrupted forest ecosystem processes, thereby interrupting the provisioning of ecosystem services that societies depend upon. The problem of biological invasion in forests has many facets, and a large diversity of scientific disciplines addresses these issues. To make progress in solving the problems forest invasions pose, developing interdisciplinary collaborations is crucial because the causes of invasions and many of the measures for prevention or management require expertise in biology, economics, and social sciences. The goal of this special issue is to compile a series of articles summarizing various biological, sociological, and policy subject areas associated with forest invasions from a global perspective. These papers were prepared by the task force, "Forests and Biological Invasions," organized by the International Union of Forest Research Organizations. Publication of this special issue is intended to advance the integration of scientific knowledge and development of solutions to this very serious and growing problem.

Keywords Forest research · Invasive species · IUFRO · Special issue · Synthesis · Task force

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Forests are key biological resources in vast portions of the world. They provide a wide range of ecosystem services such as through their critical roles in nutrient cycling and provisioning of resources to both rural and urbanized societies. Forests comprise a large fraction of the world's native biodiversity. Worldwide, forest stability is threatened by a variety of factors including habitat destruction and climate change. But forests are also particularly affected by biological invasions, with regions around the world experiencing invasions by species from virtually every taxon including vascular plants, mammals, invertebrates, and birds, as well as a variety of microorganisms such as fungi, oomycetes, bacteria, and viruses. (Liebhold et al. 2017).

Many of these invasions profoundly alter forest ecosystem properties; sometimes they cause massive economic impacts on forest resources. These impacts are not limited to market resources (e.g., timber) but also affect a variety of ecosystem services valued by societies. This problem is being experienced worldwide, both in economically developed nations and in developing countries. Examples of the devastating impacts of invasions in forests are shown in Table 1.

There is an urgent need to understand the drivers of biological invasions, characterize their effects on forests, and develop strategies for minimizing future invasions and their impacts. Past work on invasions has mainly focused within individual disciplines; the lack of synthesis among fields focusing on specific invasive taxa has hindered the development of integrative knowledge and comprehensive management policies. In particular, a strong social component to the invasion problem has largely been neglected. Globalization is inherently driven by social processes, and the mechanisms that translate globalization into invasions require elucidation. Information is also lacking on how society perceives biological invasions in forests. This information is key to developing solutions to the problem, because stakeholders may have conflicting beliefs that either promote or mitigate invasions. Ultimately, policies that address the problem must account for economics, but work is needed on how to address the costs and benefits of various strategies.

Given its global nature, the problem of biological invasions in forests demands international cooperation among researchers. Such scientific collaborations are needed to support development of improved strategies for managing invasions conducted unilaterally by individual countries and multilaterally through international conventions. In 2016 a task force was formed by the International Union of Forest Research Organizations (IUFRO) to synthesize current knowledge about the ecology and management of biological invasions in forests. IUFRO is the preeminent international scientific forest research society that facilitates networking among researches worldwide. The task force is comprised of 23 researchers from 13 countries, and their expertise spans the spectrum of forestry, botany, entomology, plant pathology, invasion ecology, quarantine policy, sociology, and economics.

In July 2016, the task force organized a workshop in Shepherdstown, WV, USA, where participants summarized the current state of knowledge on various components of the forest invasion problem. The workshop was attended by a variety of participants, including government and university researchers, but also government policymakers and stakeholders. This meeting was funded by the OECD Co-operative Research Programme: Biological Resource Management for Sustainable Agricultural Systems, the USDA National Institute of Food and Agriculture (NIFA) Agriculture and Food Research Initiative (AFRI), USDA APHIS PPQ Science and Technology, the IUFRO Special Programme for Development of Capacities, US Forest Service Northern Research Station, US Forest Service International Programs, and US Forest Service Forest Health Protection.

The 23 papers in this special issue correspond to the summary presentations during the 2016 IUFRO workshop. They constitute reviews on subsets of the problem of biological invasions in forests. Some of these reviews focus on the ecology of invasions by specific taxa of invading organisms. Brockerhoff and Liebhold (2017) focus on the ecology of forest insect invasions, and within this group, Csóka et al. (2017) particularly focus on invasions by gall-forming insects. Latham et al. (2017) review mammal invasions in forests. Wavrek et al. (2017) cover invasions of herbaceous plants, and Nuñez et al. (2017) summarize work on invasive Pinaceae. Ghelardini et al. (2017) review the ecology of tree pathogen invasions, while Wingfield et al. (2017a) consider forest pathogens with regard to fundamental principles of invasion ecology.

Table 1 Examples of non-native species causing substantial impacts in forests

Species	Native range	Invaded range	Impacts	
Emerald ash borer, *Agrilus planipennis*	East Asia	N. America and east Europe (Russia)	Feeds on phloem, ultimately killing hosts. Most host *Fraxinus* spp. are being killed	 Photo: Debbie Miller, USDA Forest Service, Bugwood.org
Billy goat weed, *Ageratum conyzoides*	South America	Africa, Australia and Southeast Asia	Outcompetes native vegetation, reducing biological diversity	 Photo: Bryan Harry, National Park Service
Pinewood nematode, *Bursaphelenchus xylophilus*	North America	East Asia, Europe	Infects and kills large numbers of host pines	 Photo: L.D. Dwinell, USDA Forest Service, Bugwood.org
Myrtle rust pathogen, *Puccinia psidii*	South America, Central America	Florida, Hawaii, South Africa, Australasia	Infects and kills trees plants in the Mytaceae, with potential loss of biodiversity	 Photo: FABI
Brushtail possum, *Trichosurus vulpecula*	Australia	New Zealand	Selectively browse native vegetation causing particular damage to broadleaved trees leading to a loss of biodiversity and change in ecosystem structure. Possums also prey on bird eggs and chicks, and invertebrates, contributing to the decline of several species	 Photo: Hannah Windley, ANU
Douglas fir, Pseudotsuga menziesii	North America	New Zealand, South America	Replacement of native dominant trees and associated biota. Loss of native biodiversity	 Photo: Martin Nuñez

Forests are complex ecosystems exhibiting extensive food web structures. As such, the mechanisms by which various types of organisms affect each other during invasions may not be initially obvious, but recent work indicates varying levels of facilitation among species. For example, Wingfield et al. (2017b) describe complex mutualistic and antagonistic interactions among ophiostomatoid fungi, bark and woodboring insects, and tree hosts. Okabe et al. (2017) describe how accidental introductions of insects often arrive with other organisms, and these species may play key roles in the success of invading insects.

Many invasions have profoundly altered forests. Wardle and Peltzer (2017) describe mechanisms by which invasive plants and herbivores affect aboveground and belowground ecological properties of forests, including the loss of species and gain of species by facilitating additional invasions. Invasions may also cause substantial loss of revenue from forest products (Epanchin-Niell 2017). Hurley et al. (2017) discuss how plantations of forest trees in developing countries may be particularly prone to invasions, yet these countries may lack capacities to manage such problems. There are many facets to how the impacts of invasions in forests influence societal values, but these social aspects are critical to understanding how governments ultimately choose to manage invasions (Marzano et al. 2017).

Several options are available for managing the problem of invasions in forests. Prevention of initial arrival of species via quarantine is one of the most attractive options, since it can preclude a multitude of damage and management expenses. Ormsby and Brenton-Rule (2017) review existing international conventions and other instruments that govern plant quarantine, ultimately contributing to prevention of pest arrival. Among the tools available to policymakers wishing to exclude pests are phytosanitary treatments of wood, plants, and other commodities responsible for accidental introductions of invading organisms in forests (Allen et al. 2017).

Once invading species become widely established, other options may be available for minimizing their impacts. Sniezko and Koch (2017) discuss the use of tree resistance breeding to avoid the impacts of invasive forest insects and diseases. Kenis et al. (2017) review historical successes (and failures) in applying classical biological control for the management of invading forest insects. Muzika (in press) discusses how manipulating forest composition via silviculture can reduce the impacts of invasions. However, this is an area where great uncertainty still remains, since data conflict on how forest composition and diversity affect invasion processes (Nunez-Mir et al. 2017).

Though many options are available for managing forest invasions via quarantine, eradication, tree resistance breeding, silviculture, and biological control, it is often not clear which of these options, or which combination, provides the most relief from impacts. One aspect of selecting management options is characterizing risk associated with specific invading species or with specific invasion pathways. Gray (2017) illustrates how risk analysis can be used to estimate invasion risk associated with a specific pest and pathway. Eschen et al. (2017) developed a risk categorization approach for quantifying risk associated with importation of certain plant genera from specific exporting countries. Epanchin-Niell (2017) describes several economic methods that compare costs and benefits to select optimal approaches to manage invasions across the entire invasion continuum.

The problem of biological invasions in forests has many facets, and a large diversity of scientific disciplines currently addresses these problems. Increased development of interdisciplinary collaborations is crucial for making progress in solving the problems posed by forest invasions, since this subject spans a wide spectrum of biological and social science topics. The formation of the IUFRO Task Force on Biological Invasions and publication of this special issue is anticipated to improve integrative scientific knowledge and development of solutions to this very serious problem.

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