Advancing Toward a General Theory of Invasive Species Impacts: How Do Ecological Effects Vary Across Time and Space?

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Symposium objectives

The global movement of species by humans to non-native ranges has provided important resources for food, fiber, and fuel but has, at times, resulted in widespread invasions that cause significant ecological and economic impacts (Pyšek et al. 2012). Given ongoing increases in global travel and trade, the introduction of species to new areas is expected to continue with consequences for biodiversity and ecosystem functions. The effects of biological invasions have been well quantified over the last few decades but studies have been limited in duration and spatial extent (Stricker et al. 2015), restraining our understanding of where and how long invasion impacts might occur and hampering predictive models of species likely to be invasive and habitats and ecosystems susceptible to invasion (Hulme et al. 2013).

Although it is now well known that invasive species can have significant ecological effects, it is often assumed that if an invader has documented impacts in one location, then the species will have equally negative (or positive) impacts elsewhere. At the same time, there is at least a conceptual recognition that the ecological impacts of invaders vary according to local environmental conditions and the ecological community with which they interact (Thomsen et al. 2011). The type and degree of differences in ecological impacts, however, are rarely empirically demonstrated. There is also growing recognition that we are largely ignorant of long-term ecological effects of invasive species (Flory and D’Antonio 2015), even to the extent of not fully understanding how persistent initially observed negative effects may be (D’Antonio and Flory 2017). We posited that the assumption that an invaders’ ecological effects can be adequately characterized based on information from one or a few ecosystems or locations and from studies that cover only a short time frame, requires critical evaluation. This symposium brought together ecologists who have collected unique empirical datasets on the spatial and temporal patterns in the ecological effects of invasive species, or had developed conceptual models and standardized metrics of impacts, and challenged them to consider how we might develop a general theory of invasive species ecological effects.

Presentation summaries

In the first presentation, Julie Lockwood (Rutgers University) provided a broad overview of why invasive species impacts garner much attention, highlighting that the field is driven by the need to mitigate ecological impacts. Lockwood emphasized that past efforts at building frameworks of the invasion process have intentionally excluded consideration of ecological impacts because of their complicated nature (e.g., Blackburn et al. 2011). Nevertheless, metrics for invader impacts are clearly needed in order to prioritize invasive species for management based on the magnitude and duration of impacts. Relaying the results of a systematic review of invader impacts for 1999–2016 that included thousands of studies, Lockwood concluded that the ecological effects of introduced species are underestimated because of the lack of data on long-term impacts.
of papers (Crystal-Ornelas and Lockwood 2020), she provided evidence that few ecological studies evaluated impacts for more than one year, most involved measurements taken over short durations, and almost no studies indicated the time since the focal species arrived at the site of research. Lockwood also highlighted other key findings such as pronounced biases in the biological scale (genes to ecosystem) at which invasive species impacts are measured, a highly skewed distribution of species and ecosystems that are regularly investigated, and the need to evaluate both ecological and economic impacts (Crystal-Ornelas and Lockwood 2020).

Then, David Strayer (Cary Institute of Ecosystem Studies) delivered a presentation that focused on the role of ecological context in shaping the scaling relationship between invader impacts and their abundance. Strayer reviewed evidence from several ongoing research efforts relating zebra and quagga mussel biomass, as indexed by mussel shell abundance, to ecological impacts on the freshwater ecosystems into which they have invaded. Strayer and colleagues showed clear evidence that impact can vary substantially across lake invasion sites, and through time, mostly mediated by the substantially different population sizes, these mussels can attain given local environmental constraints (e.g., Strayer et al. 2019). Strayer ended by emphasizing the need to better understand the relationship between invader abundance and impact and how such relationships might vary based on ecosystem characteristics.

Sean Menke (Lake Forest College, Illinois) evaluated long-term changes in invader geographic range and ecological impacts using the Argentine ant invasion in California as a highly pertinent and well-documented case study. Menke and colleagues resurveyed sites throughout the invasive range of Argentine ant that they had tracked over the past three decades. Their results revealed scattered and localized reductions of population abundance, and geographical range retreats where an original population was not found but a new population was found nearby (Menke and Holway 2020). However, their data suggested little overall change in urban and natural area ant populations over time. In total, their 30-year chronosequence of invasive ant impacts in northern California showed that population abundance was remarkably stable over the long term, and as a result, so too was the ant’s likely ecological impacts (Menke et al. 2018).

Aníbal Pauchard (Universidad de Concepción) evaluated the ecological impact of non-native trees across gradients of invasive species density and the feasibility of using such invasion gradients to address research on observed variation in impacts across environmental contexts. Pauchard and colleagues found that invasion patterns were driven primarily by dispersal, not by site conditions. However, the impacts of invasions on native species varied according to a complex interplay between local site characteristic and invasive species’ density (Franzese et al. 2017). Beside the displacement of native species, pines can produce profound changes in fire regimes (Cóbar-Carranza et al. 2014, Davis et al. 2019). Similar to the conclusions drawn by Strayer et al. (2019), Pauchard noted that the shape of the relationship between invader abundance and impact varied according to the environmental conditions experienced among sites along the gradient (Taylor et al. 2016, Franzese et al. 2017). He ended by highlighting two outstanding questions for this area of research: (1) How long can native species endure the negative ecological impacts of an invasive species? And (2) to what extent will native species responses to invader removal depend on invasive species density at the time of management initiation?

Stephanie Green (University of Alberta) discussed how to determine which invasive species to prioritize for management investments when the number and extent of invasions are rapidly increasing but the
resources available for management are stagnant (S. J. Green and E. Grosholz, *unpublished data*). A key issue she and her colleagues identified was that, for most invasive species, we lack an understanding of how their density relates to ecological impact. Thus, it is often not possible to set population threshold goals for suppression efforts that, once passed, decrease ecological impacts to the point where they are of low conservation concern (Green et al. 2014). As an example of this issue, Green presented her study of coral reef fishes in the Caribbean where they predicted the impacts of the invasive Pacific lionfish using information on functional traits of the native fishes (Green and Côté 2014). Green concluded that the effects of invasive species are likely to be the greatest where they have both extensive ranges and unique behaviors, or other traits, that expose exceptional vulnerability of native species.

Finally, Sabrina Kumschick (Stellenbosch University) outlined how our collective understanding of invasive species impacts is limited by a lack of data and by the various types of measures used to evaluate these impacts (Hawkins et al. 2015). Kumschick provided a cogent overview of the impact scoring scheme, the Environmental Impact Classification for Alien Taxa (EICAT), which has been widely adopted, including by the International Union for Conservation of Nature (IUCN). Kumschick worked through several data-informed EICAT scores across a variety of taxa, including birds and amphibians, and some plants, invertebrates, and vertebrates (Evans et al. 2018, Hagen and Kumschick 2018, Nkuna et al. 2018). The generalizability of the EICAT system for quantifying ecological impacts across taxa was highlighted as particularly valuable for management decisions and policy making (Hagen and Kumschick 2018).

**Conclusion**

As a group, the participants in this symposium brought research experience across biological realms and taxa, and each contributed a unique perspective in the nexus between ecological research and environmental policy. The presentations and end-of-session discussion identified gaps in data collection, conceptual understanding, and modeling that need to be addressed to more fully explain and predict spatial and temporal patterns in invasive species impacts. Given the widening gap between the number of problematic invaders and the resources available for management, these research needs must be addressed to optimize efforts toward vulnerable habitats and species with long-lasting impacts.

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