A silent spring, or a new cacophony? Invasive plants as maestros of modern soundscapes

Jacob N Barney[1*], Grace O'Malley[2], Gabrielle N Ripa[1], Joseph Drake[2], David Franusich[3], and Meryl C Mims[2]
[1]School of Plant and Environmental Sciences, Virginia Tech, Blacksburg, VA[*](jnbarney@vt.edu); [2]Department of Biological Sciences, Virginia Tech, Blacksburg, VA; [3]Institute for Creativity, Arts, and Technology, Virginia Tech, Blacksburg, VA

Front Ecol Environ 2024; 22(3): e2729, doi:10.1002/fee.2729

Sound plays a key role in ecosystem function and is a defining part of how humans experience nature. In the seminal book *Silent Spring* (Carson 1962), Rachel Carson warned of the ecological and environmental harm of pesticide usage by envisioning a future without birdsong. Soundscapes, or the acoustic patterns of a landscape through space and time, encompass both biological and physical processes (Pijanowski *et al.* 2011). Yet, they are often an underappreciated element of the natural world and the ways in which it is perceived. Scientists are only beginning to quantify changes to soundscapes, largely in response to anthropogenic sounds, but soundscape alteration is likely linked to many dimensions of global change. For example, invasive non-native species (hereafter, invasive species) are near-ubiquitous members of ecosystems globally and threaten both natural and managed ecosystems at great expense. Their impacts to soundscapes may be an important, yet largely unknown, threat to ecosystems and the human and economic systems they support.

The proper functioning of sound-based cues depends on the overall soundscape of an environment, which is determined by a range of biological and physical factors, many of which may be influenced by invasive species. To date, research on the effects of invasive species on sound focuses primarily on specific invasive species that make sounds or the loss of sound-making native biota (Hopkins *et al.* 2022) rather than on the soundscape overall.

For instance, invasive amphibians, such as the American bullfrog (*Lithobates catesbeianus*), can dominate a soundscape, resulting in alterations to vocalizations, increased energy expenditure, and reduction in breeding success of native amphibians (Both and Grant 2012). The arrival of sound-making invasive species may thus increase the overall diversity of a soundscape, but with negative consequences for native species. Alternatively, invasive species may eliminate the most dominant and recognizable parts of soundscapes. The invasive brown tree snake (*Boiga irregularis*) has driven the functional extinction of an entire avian community, resulting in Guam's "silent forests" with cascading effects on ecosystem function (Rogers *et al.* 2017). In some cases, invasive species may change soundscapes by driving community turnover and diversity through environmental change. Through alterations in the physical environment, invasive beavers (*Castor canadensis*) in South America shifted avian community composition, subsequently changing the soundscape (Francomano *et al.* 2021). Even when beaver dams were removed, the original composition of the avian community, and resulting soundscape, remained altered (Francomano *et al.* 2021).

As Hopkins *et al.* (2022) noted in their review of contemporary studies on invasive species and their effects on soundscapes, current knowledge is limited to vertebrates and insects, with a focus primarily on one or a few species at a time. This limited scope may miss important pathways through which invasive species alter ecosystem processes and biodiversity, either directly or indirectly, through their effects on sound. What remains is the need for defining mechanisms and consequences that capture the diversity of invasive species (including non-sound-making species) across the globe, and their effects on soundscapes of entire ecosystems.

It makes intuitive sense that invasive plants—given their diversity, abundance, and effects on biological communities and the physical landscape—may change soundscapes, though this has yet to be measured (Figure 1). For example, invasive plants are known to influence the richness, abundance, and fitness of native vertebrates and insects—many of which generate sound. We suggest four mechanisms through which invasive plants may change native soundscapes: (1) reducing or (2) increasing the abundance and/or richness of sound-making species, (3) prompting behavioral changes to sound-making species that result in spatiotemporal changes in their activity, or (4) facilitating physical changes to the architecture of a place that alters the way sound travels. These changes may occur independently or in combination, and are likely to be modulated by a range of factors including seasonality, time of day, environmental conditions, and degree of biological complexity. The four mechanisms and the additional factors are each discussed in more detail below.

Invasive plants may influence the soundscape through an increase or decrease in richness or abundance of sound-making species. Insect populations have documented direct positive, neutral, and negative responses to invasive plants; however, they are most often negatively affected by invasive plants through reduced fitness, increased larval mortality, and overall population reductions (Tallamy *et al.* 2021). Conversely, positive impacts of invasive plants on native communities have been observed. Avian and arthropod richness, abundance, and diversity were greater in Amur honeysuckle (*Lonicera maackii*)–invaded vegetation as compared to native vegetation (Serniak *et al.* 2023), potentially due to increases in foraging resources.

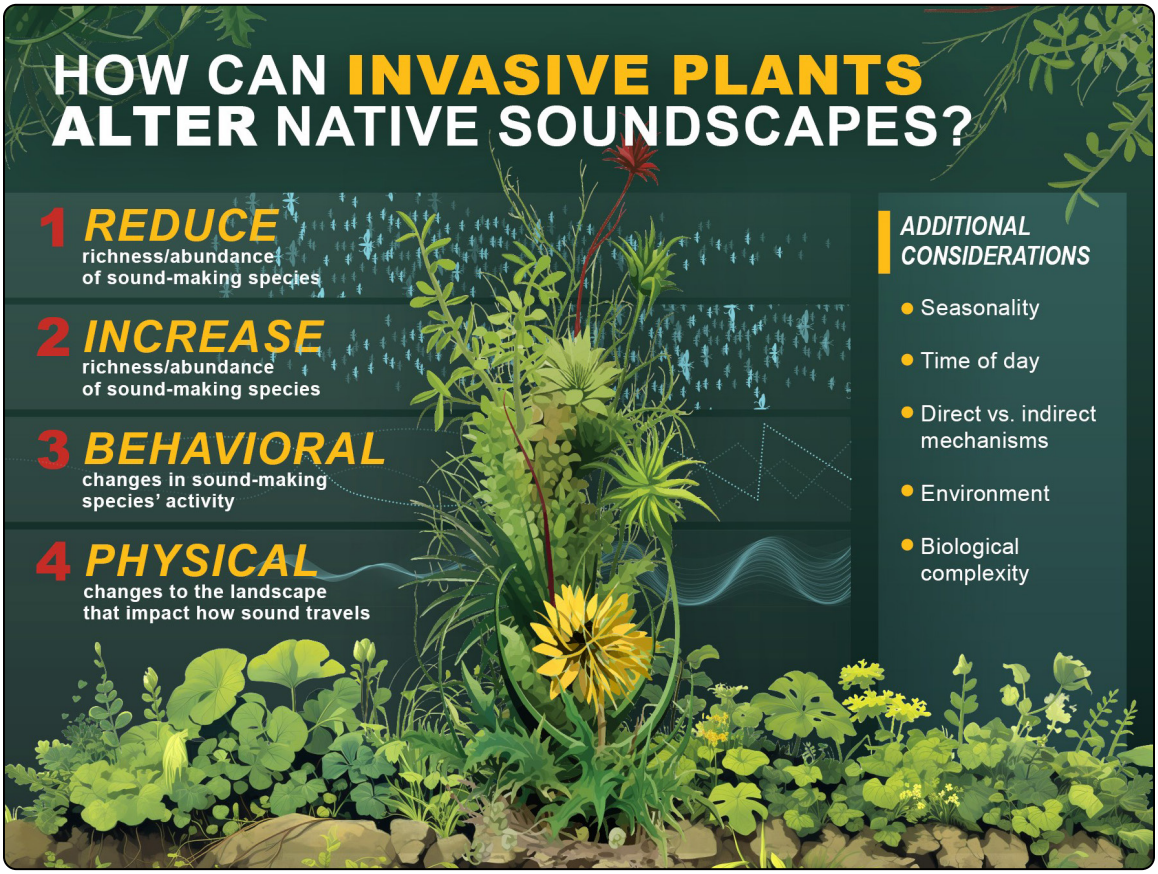

Figure 1. Proposed mechanisms (left column) by which invasive plants impact the soundscape. Each mechanism may occur singly or in combination, and can be modified by additional factors (right column). Graphic by D Franusich.

Animal behavior can also be altered by invasive plants. In a meta-analysis of the impacts of invasive plants on avifauna, 45% of selected studies showed evidence of preference for nesting in invasive plants (Nelson *et al.* 2017). Furthermore, impacts of invasive plant species on avian body condition (eg body mass, corticosterone levels) can alter the soundscape, given that calling is an energetically costly behavior and reduced fitness could impact calling frequency, calling duration, and song quality. For example, because younger male chipping sparrows (*Spizella passerina*) were relegated to spotted knapweed (*Centaurea stoebe*)-invaded, "lower quality" habitat, likely due to intraspecific competition, younger males were unable to learn songs from older males, resulting in decreased song diversity (Ortega *et al.* 2014).

The effects of invasive plants on the physical structure of habitats have also been well established. Woody plant encroachment of grasslands is a global risk to biodiversity (Londe *et al.* 2022), adding an entirely new structure to this imperiled biome. Likewise, invasive kudzu (*Pueraria montana*) blankets much of the southern US. Such structures likely alter how sound travels.

Additional factors may influence the ways in which invasive plants alter native soundscapes. Biological communities and their soundscapes change naturally through time, exhibiting both seasonal and diurnal fluctuations (Ribeiro *et al.* 2022). These temporal changes are likely to shift with the seasonality of invasive plant cover as well. Invasive shrubs are known to leaf out earlier and retain their leaves longer than native species (Fridley 2012), which may impact animal patterns. Moreover, invasive species may alter soundscapes through both direct and indirect mechanisms. For instance, many insects have coevolutionary relationships with native plants, and invasive plants may directly cause a breakdown in symbiotic associations (Tallamy *et al.* 2021). Indirect impacts are also evident; invasive Japanese stiltgrass (*Microstegium vimineum*) has been documented to reduce native frog populations through changes to predatory spider and prey density (DeVore and Maerz 2014). Further considerations of the degree to which invasive species alter soundscapes may include the underlying biological complexity and environmental characteristics of native landscapes.

To investigate how invasive plants may be altering soundscapes, scientists could rely on whole-ecosystem acoustic monitoring to improve our ability to quantify potential changes to biodiversity through time and beyond specific species (Alcocer *et al.* 2022). The collection and processing of acoustic data through passive acoustic monitoring is quickly becoming a relatively low-cost method for large-scale biodiversity monitoring efforts (Bradfer-Lawrence *et al.* 2019). Long-term passive acoustic monitoring may be an important tool for detecting the arrival of invasive biota, as well as changes in the composition of native species by tracking potential changes in soundscapes

over time. Given the complexity of the soundscape, many studies are using acoustic indices to convert acoustic data into quantifiable measurements of diversity and complexity (Alcocer *et al.* 2022). Just as we can ascribe changes in native species diversity to plant invasions, we may be able to attribute changes in acoustic diversity to invasive plants through space, time, and biological complexity. Thus, soundscape analysis can provide a passive, sentinel monitoring system for detecting and tracking the impacts of invasive plants in ecosystems at previously unattainable spatiotemporal scales (Alcocer *et al.* 2022).

Given the diversity and abundance of invasive plants globally, as well as the impracticability of their eradication, understanding the full breadth of their consequences is paramount both to scientific rigor and to mounting mitigation campaigns (Barney 2016). We have presented four possible mechanisms and additional modulating factors (Figure 1) for how invasive plants may alter soundscapes—all of which should be part of a research agenda to fully understand the direct and indirect ecological consequences of invasion. We also propose the following questions as a starting point:

- How do invasive plant species vary in their impact and context to soundscapes?
- What sound-making animals have been impacted, and why?
- What are the diurnal and seasonal changes in plant invasion and associated soundscapes?
- How are environmental conditions (eg fire, drought) modulating these changes?
- How is animal behavior and fitness impacted?
- Do changes to the soundscape impact human perception and appreciation of an invaded landscape?

Soundscapes are an emerging ecological discipline of increasing importance, and documenting invasive species impacts to soundscapes should be part of this enterprise. In a broader context, soundscape alterations may also impact human health and our experience of natural spaces (eg coqui frog [*Eleutherodactylus coqui*] invasion as noise pollution in Hawaii; Gonzalez-Pagan 2007) potentially eroding cultural significance, and reducing our connection to and value of those spaces (Dumyahn and Pijanowski 2011). Invasive animals and plants may be acting as modern maestros in nature's soundscapes, resulting in a modern silent spring or a new cacophony.

Acknowledgements

We thank the Virginia Tech Institute for Creativity, Arts, and Technology for providing seed funding that led to the development of this paper.

References

Alcocer I, Lima H, Sugai LSM, and Llusia D. 2022. Acoustic indices as proxies for biodiversity: a meta-analysis. *Biol Rev* **97**: 2209–36.

Barney JN. 2016. Invasive plant management must be driven by a holistic understanding of invader impacts. *Appl Veg Sci* **19**: 183–84.

Both C and Grant T. 2012. Biological invasions and the acoustic niche: the effect of bullfrog calls on the acoustic signals of white-banded tree frogs. *Biol Lett* **8**: 714–16.

Bradfer-Lawrence T, Gardner N, Bunnefeld L, *et al.* 2019. Guidelines for the use of acoustic indices in environmental research. *Methods Ecol Evol* **10**: 1796–807.

Carson R. 1962. Silent spring. Boston, MA: Houghton Mifflin.

DeVore JL and Maerz JC. 2014. Grass invasion increases top-down pressure on an amphibian via structurally mediated effects on an intraguild predator. *Ecology* **95**: 1724–30.

Dumyahn SL and Pijanowski BC. 2011. Soundscape conservation. *Landscape Ecol* **26**: 1327–44.

Francomano D, Valenzuela AEJ, Gottesman BL, *et al.* 2021. Acoustic monitoring shows invasive beavers *Castor canadensis* increase patch-level avian diversity in Tierra del Fuego. *J Appl Ecol* **58**: 2987–98.

Fridley JD. 2012. Extended leaf phenology and the autumn niche in deciduous forest invasions. *Nature* **485**: 359–62.

Gonzalez-Pagan O. 2007. Hawaii residents' attitudes towards the management of an invasive frog species (*Eleutherodactylus coqui*). Honor's thesis. Ithaca, NY: Cornell University.

Hopkins JM, Edwards W, and Schwarzkopf L. 2022. Invading the soundscape: exploring the effects of invasive species' calls on acoustic signals of native wildlife. *Biol Invasions* **24**: 3381–93.

Londe DW, Cady SM, Elmore RD, and Fuhlendorf SD. 2022. Woody plant encroachment pervasive across three socially and ecologically diverse ecoregions. *Ecol Soc* **27**: 11.

Nelson SB, Coon JJ, Duchardt CJ, *et al.* 2017. Patterns and mechanisms of invasive plant impacts on North American birds: a systematic review. *Biol Invasions* **19**: 1547–63.

Ortega YK, Benson A, and Greene E. 2014. Invasive plant erodes local song diversity in a migratory passerine. *Ecology* **95**: 458–65.

Pijanowski BC, Villanueva-Rivera LJ, Dumyahn SL, *et al.* 2011. Soundscape ecology: the science of sound in the landscape. *BioScience* **61**: 203–16.

Ribeiro JW, Harmon K, Leite GA, *et al.* 2022. Passive acoustic monitoring as a tool to investigate the spatial distribution of invasive alien species. *Remote Sens* **14**: 4565.

Rogers HS, Buhle ER, HilleRisLambers J, *et al.* 2017. Effects of an invasive predator cascade to plants via mutualism disruption. *Nat Commun* **8**: 14557.

Serniak LT, Rohloff P, and Agnew CCA. 2023. Amur honeysuckle (*Lonicera maackii*) increases abundance and diversity of shrub-dwelling arthropods and birds in forest edge habitat. *J Ornithol* **164**: 943–51.

Tallamy DW, Narango DL, and Mitchell AB. 2021. Do non-native plants contribute to insect declines? *Ecol Entomol* **46**: 729–42.