Exotic Earthworms Impact Forests: Increase Awareness and Integrate Impacts into Forest Management Decisions

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Abstract.—The introduction of nonnative earthworm species into northern hardwood forests negatively affects overall forest health, vegetation dynamics, and soil biogeochemistry. Though they have a long introduction history in some urbanized areas, earthworms continue to invade new forested areas, with new species and additional biomass. Both understory regeneration and overstory canopy trees are negatively impacted by earthworm activity. These "ecosystem engineers" are creating novel systems by affecting both the biotic composition and environmental conditions in northern hardwoods. The condition of the forest floor can be quickly visually assessed during a site visit or timber cruise, but forest management plans rarely record earthworm presence/absence or consider their potential impacts. We argue that earthworms should be explicitly incorporated into hardwood forest management, highlight recommended best-management practices, and describe next steps to fill important research gaps.

BACKGROUND

Although European and Asian earthworms have been repeatedly introduced to northern hardwood forests and new species continue to arrive (Laushman et al. 2018), they have received relatively little research attention (Bohlen et al. 2004a, McCay and Scull 2019). While earthworms naturally move less than eight meters a year, they are rapidly spread by human activity. Common spread events include dumping bait near boat launches, road building activities, and carriage in soil or mud on vehicle tires or shoes (Cameron et al. 2007, McCay and Scull 2019). Earthworm densities, species, and number of species are patchily distributed across invaded regions, and not all species have the same ecological effects (Hale 2013, Shartell et al. 2015). Still, studies since the 1990s have demonstrated significant impacts of earthworm invasions, including significant shifts to soil nutrient cycling and carbon sequestration, decreased pedobiological diversity, and reduced regeneration or poor condition of desirable tree and plant species (e.g., Bal et al. 2018, Bohlen et al. 2004b, Dobson et al. 2017, Ferlian et al. 2018). Further research is required to fully characterize the top-down and bottom-up "cascade complex" caused by earthworms in forest ecosystems (Frelich et al. 2019).

Forest Management Considerations

Awareness of exotic earthworms is increasing among professionals, but this has yet to translate into actionable, applied-decision models and forest management plans rarely record earthworm presence/absence or consider their potential impacts. Although identifying earthworm species can be difficult, this should not be a barrier as other strategies are available for evaluating site condition. Field surveys can visually assess the forest floor, evaluate the depth of organic duff layers, or note earthworm sign (Bal et al. 2018, Loss et al. 2013). Forest management decisions should regularly consider future effects of high earthworm activity as they would any other

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invasive, especially in areas at significant risk of impacts from climate change or where overall forest health is already stressed. Managers will need to continue to think outside of the box of traditional silviculture and be open to experimental trials, as biotic and abiotic environmental factors are influenced by earthworms, creating novel conditions (Seastadt et al. 2008).

Best management practices (BMPs) for exotic earthworms that could be more easily applied in forest management decisions in northern hardwoods are similar to those for introduction prevention of exotic plant species (e.g., LeDoux and Martin 2013). These include:

- Power washing vehicles and harvesting equipment between new field sites
- Installing boot scrubbers at trailheads
- Using local material for road building or road grading activities
- Recording and monitoring presence and impacts or condition of the forest floor
- Public awareness and signage

ONGOING AND RECOMMENDED FURTHER INVESTIGATIONS

Ongoing research highlights the widespread and complex effects of exotic earthworms, from the short-term physiological impacts on individual trees to the long-term impacts on overall forest health. For example, we are currently evaluating sugar maple (*Acer saccharum* Marsh.) dieback and decline in the northern Great Lakes region and relating it to evidence of earthworm activity. Our work takes place in an extensive network of 120 evaluation plots established 12 years ago on public and private lands in predominantly maple forests (Bal et al. 2018). Previous surveys found variable amounts of canopy dieback (i.e., between 0.8 percent to 75.7 percent) and mortality across the landscape (Bal and Storer 2015). Dieback and decline continue to be a concern for federal, state, and industry managers, yet there are not well developed support tools for land managers to anticipate or mitigate earthworm impacts in northern forests. Our current efforts will characterize rate of change in maple dieback and decline and rate of change in forest floor condition—over a decade after initial plots were established—as well as evaluate additional variables potentially being exacerbated by earthworm impacts, including climate change, invasive European Lecanium scale (*Parthenolecanium corni* Bouché) (MI DNR 2017), and deer herbivory. Ultimately this will allow us to create model support tools and improve risk assessment for managers to plan activities more easily with respect to current and predicted exotic earthworm impacts.

Many questions relating to earthworm impacts on long-term forest management still exist. We recommend large, interdisciplinary, experimental silviculture trials. These should combine field observations, field experiments, and lab and greenhouse studies to better understand consequences of earthworm invasion on multiple tree species and identify more efficient mitigation strategies. Studies of currently present introduced earthworm species assemblages can yield valuable insights that may be applied to newly introduced species or those that may be introduced in the future that are potentially more damaging, such as the more recently introduced jumping worms (*Amynthas* spp). It is important to continue supporting efforts to evaluate and understand earthworm invasion progression and understand their relationship to other factors impacting northern hardwood forests.

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