Ecological cascades emanating from earthworm invasion and forest productivity

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Minnesota Forest Resources Council
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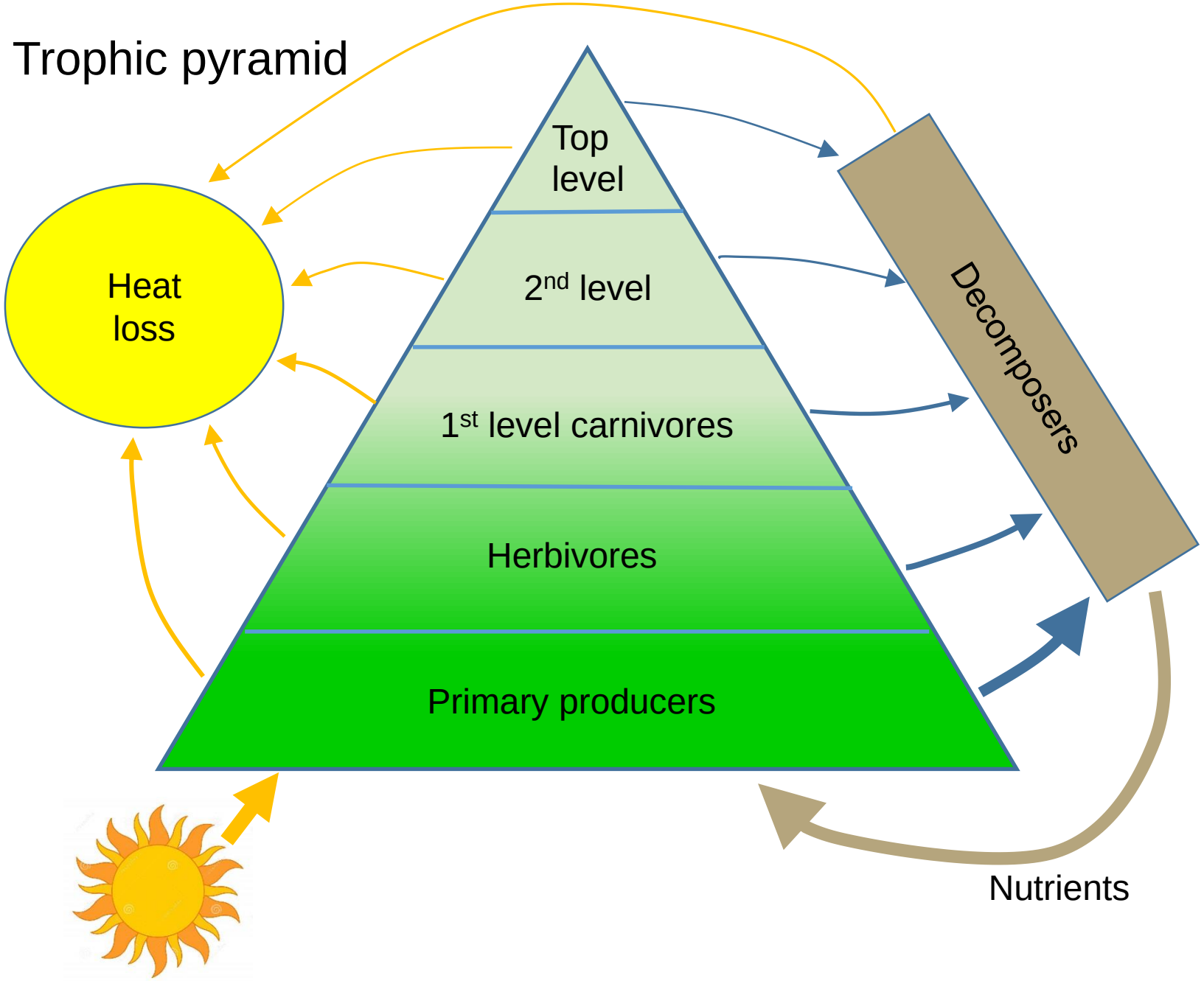
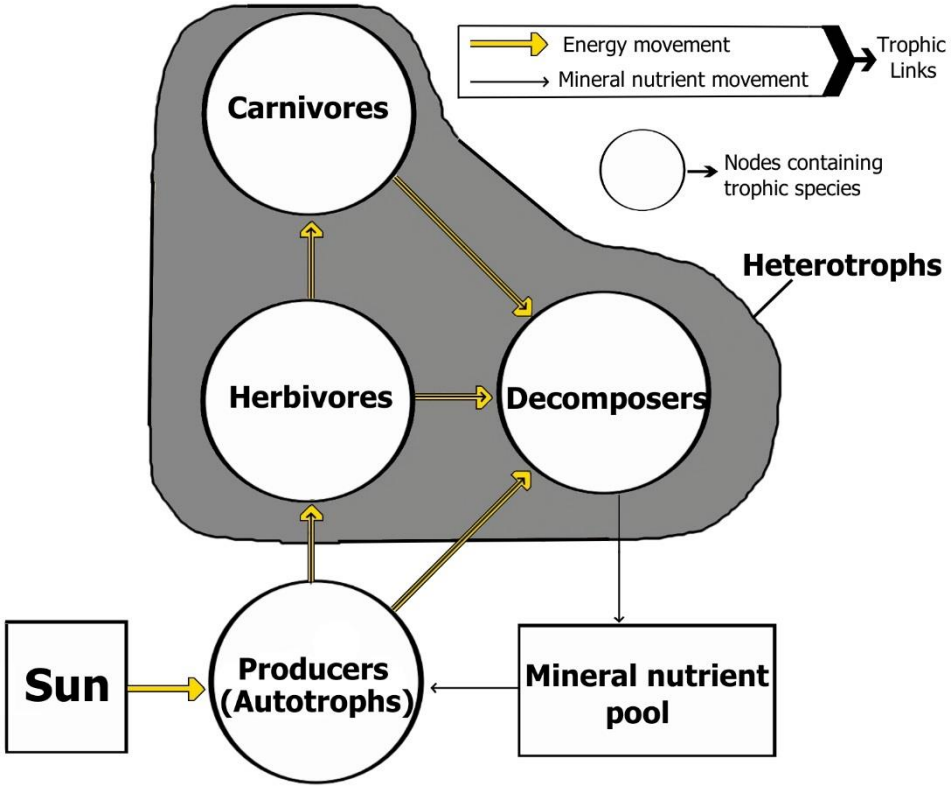
Photo, Alex Roth

Trophic pyramid



What happens when we step on the gas pedal that controls rate of decomposition?

Earthworms provide that experiment on a grand scale!



From Wikipedia

Earthworms are also engineers that alter energy flow, but also physical environment within the soil (density, temp, H_2O, nutrients)

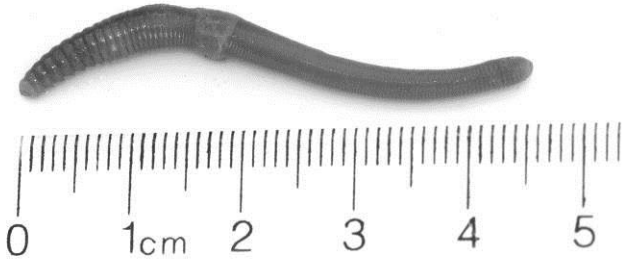
Earthworms eat the habitats of other species

What trophic and ecological cascade effects will this combination of many types of change cause?

Earthworm functional groups

Epigeic: *Dendrobaena octaedra*

Anecic: *Lumbricus terrestris* (nightcrawler)



Epi-endogeic: *Lumbricus rubellus*

Endogeic: *Aporrectodea caliginosa*

Earthworm functional group—fundamental engineering effects

Epi-endogeic and epigeic (*L. rubellus, Dendrobaena, Dendrodrillus*)
Speed up litter decay—loss of litter habitat, loss of physical effects of litter, loss of water absorption capacity, insulation of soil temperatures

Endogeic—(*Aporrectodea rosea*, *caliginosa*, *longa*, *trapezoides*, *Allobophora chlorotica*, *Octolasion cynaeum,* O. octaedra); loss of litter, compact soil, integrate OM into thick black A horizon, leaching, soil mineralogy effects leading to effects on N, P, K, Ca, Mg availability

Anecic—*L. terrestris*. Eat fresh litter, maintain bare soil, predator on seedlings

Giant Gippsland earthworm (*Megascolides australis*) photo: Beverly Van Praagh

Sampling earthworms in the field

Photos: Alex Roth

Five stages of invasion

Stage 1
Worm free

Stage 2
Epigeic only

Stage 3
Endogeic and epi-endogeic invade

Stage 4
Increasing Biomass and a few *L. terrestris*

Stage 5
High biomass,
L. terrestris dominated

Loss, Hueffmeier, Frelich, Host, Sjerven and Hale. 2013
Natural Areas Journal
33: 21-30

Stage 2, *Dendrobaena* only

Stage 3, + *Aporrectodea ssp.* and *L. rubellus*

Stage 5, + *L. terrestris*

2000

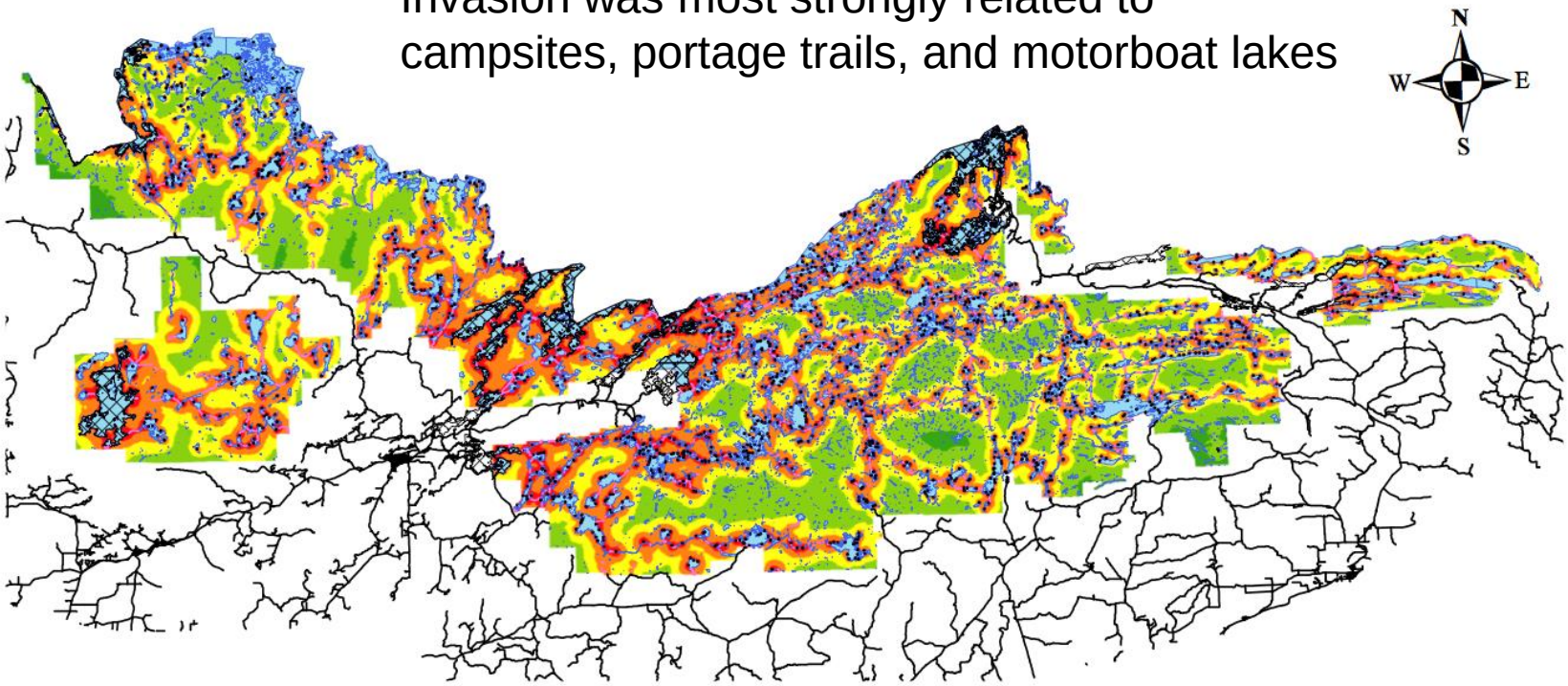
2010

Soil cores from the same location in 2000 and 2010…

note color change and reduction in thickness of organic horizon

Photos: Dave Hansen and George Schlaghamersky

Invasion was most strongly related to campsites, portage trails, and motorboat lakes



BWCAWOnlyCampsites
merged_rds_win_20k_BWCAW
PortageTrailsOnly
MotorLakes
BWCAWLakes
fullwpmap5

IERAT Rank
1
2
3
4
5

Extent And Pattern Of Invasion By Earthworms In The BWCAW

0 15 30 60 Kilometers

Map by David Chaffin

Base of balsam fir, stage 5 earthworm invasion, and European earthworms in the BWCAW. Photos: Doug Wallace, David Chaffin

World-wide distribution of earthworm invasions by taxonomic families

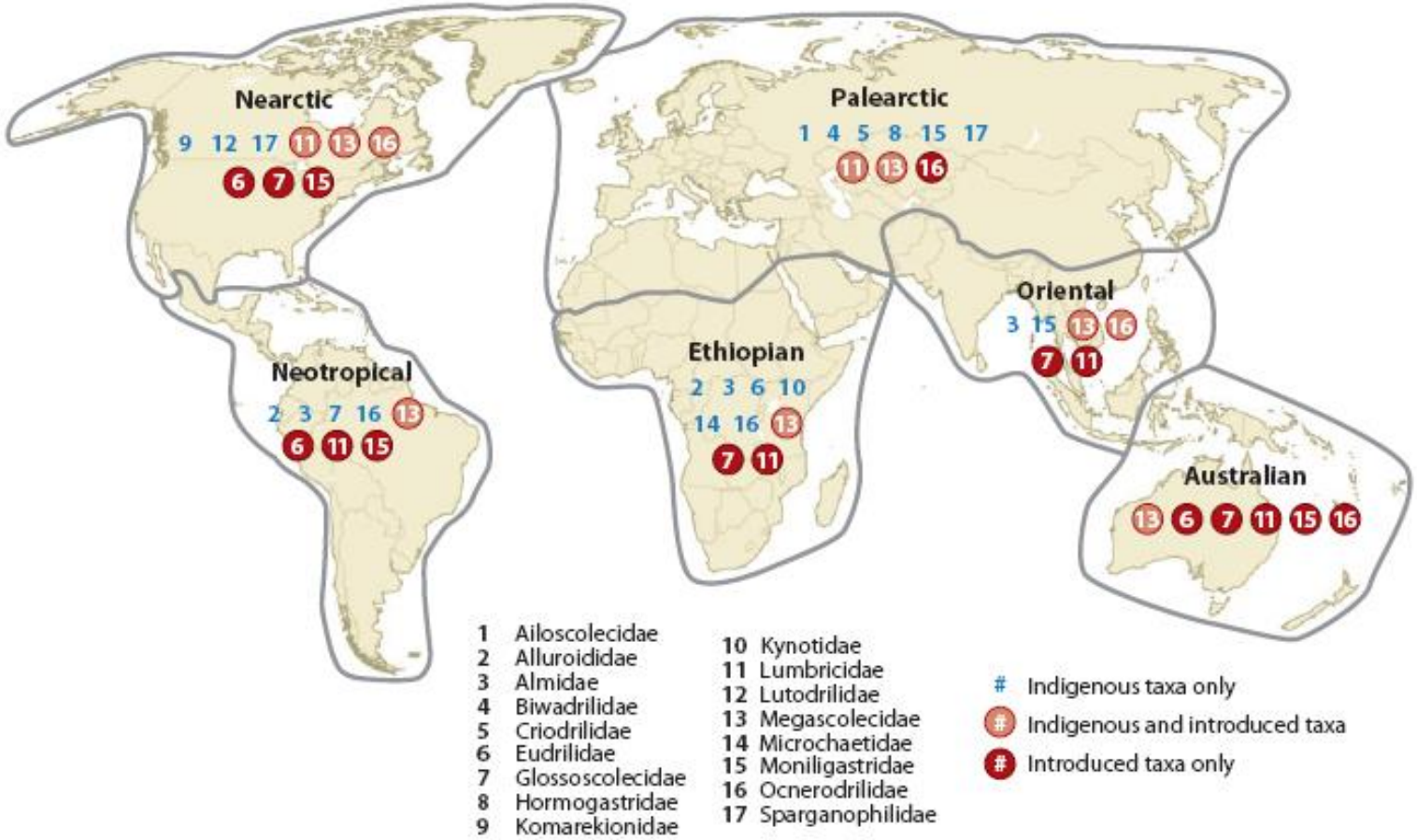


Figure 1

Global distribution of indigenous and introduced species within earthworm families in each biogeographic realm (modified from Reynolds 1994, with data from Gates 1982, Jamieson 1981, Omodeo 2000, Sims 1980).

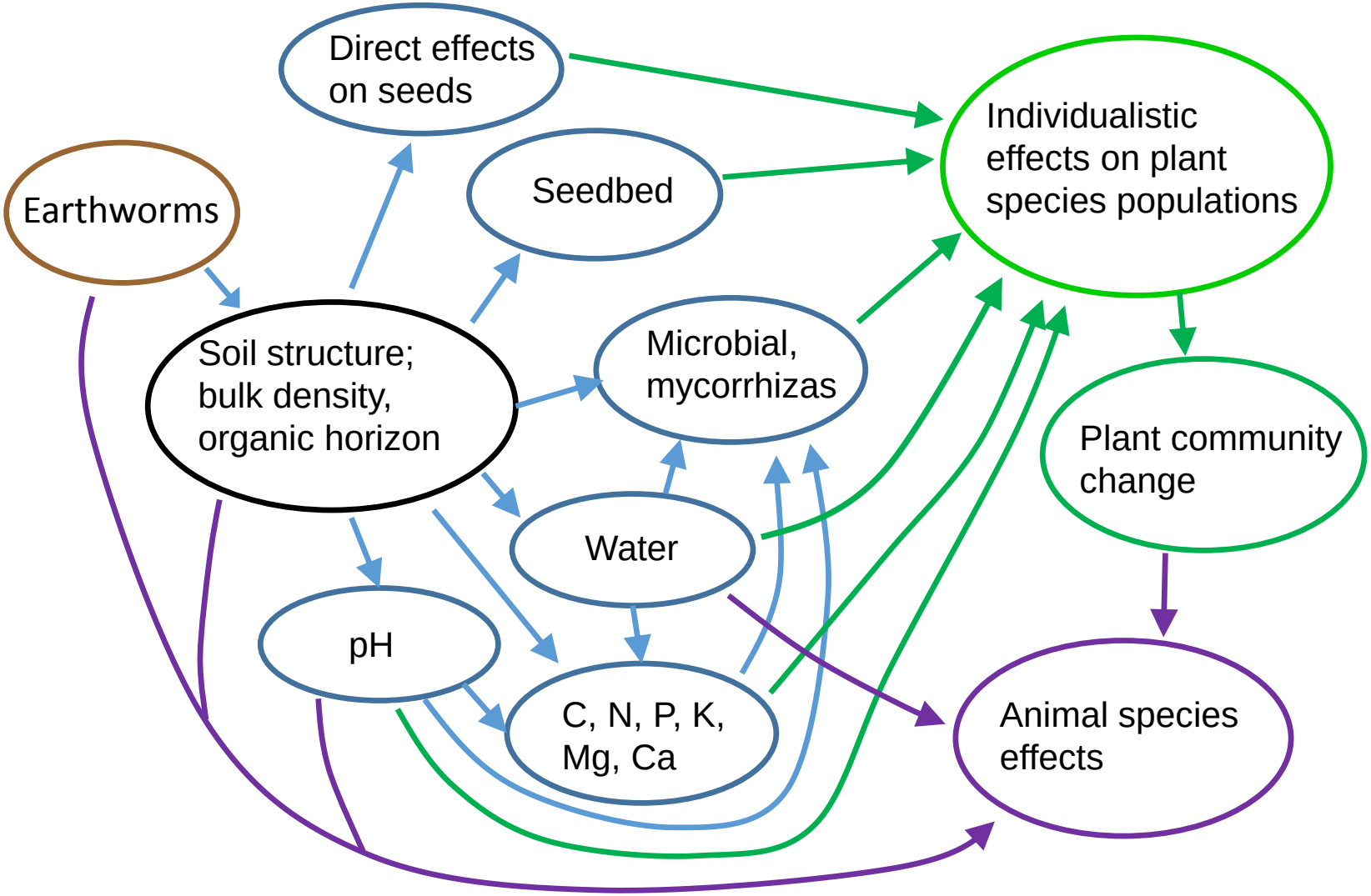
Hendrix et al. 2008 *Annu Rev Ecol Evol Syst*

How earthworm invasion affects the environment

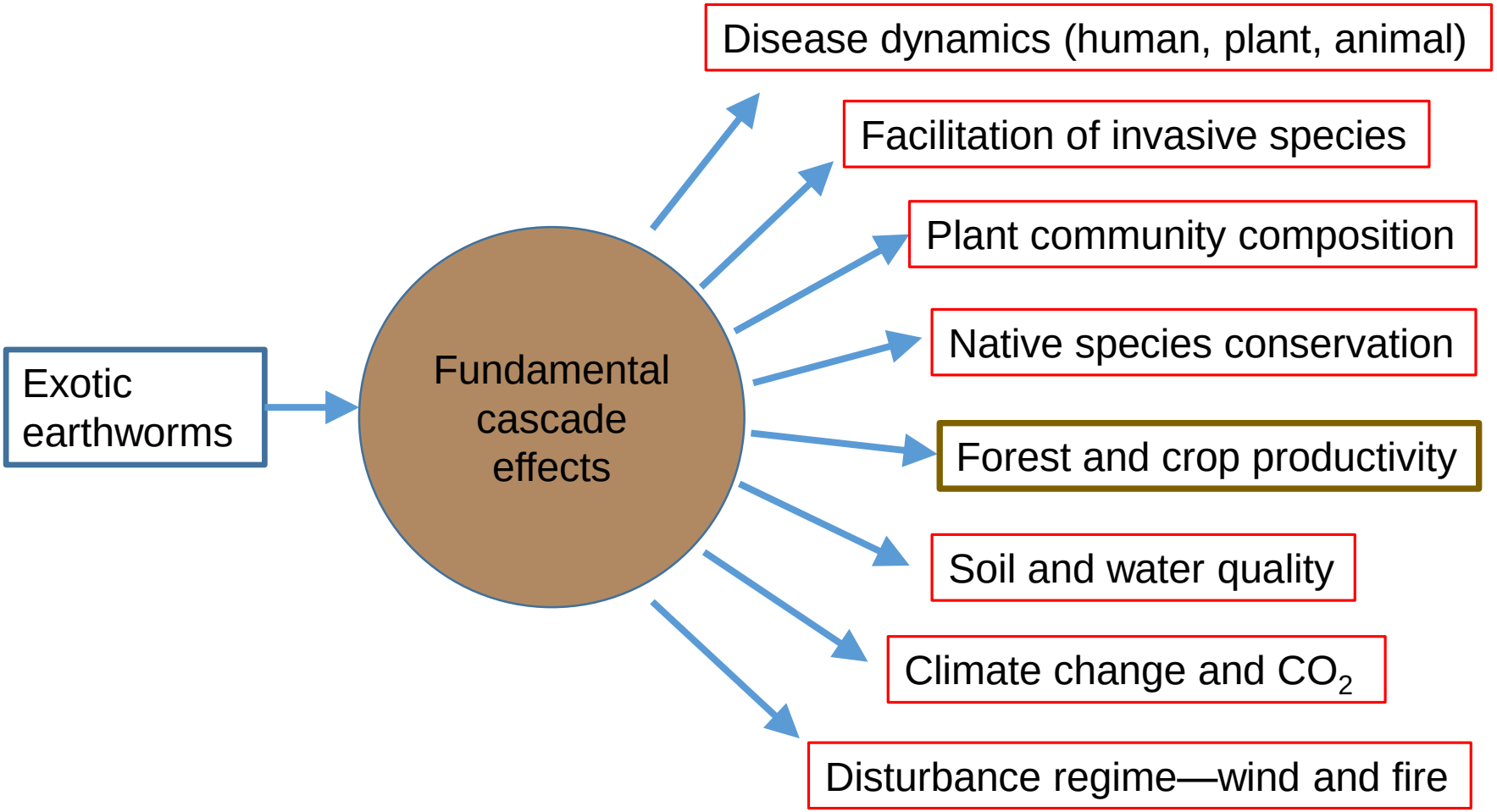
Micro cascades—small-scale ecosystem processes that are related to fundamental engineering effects, e.g. loss of O horizon, soil BD, water, temperature and nutrient cycles

Macro cascades—extended ecological cascade effects and trophic changes of concern to human society at large spatial extents

The complex of micro cascades leading to fundamental effects on soils (blue arrows), and secondary/tertiary effects on plants (green arrows), and animals (purple arrows)



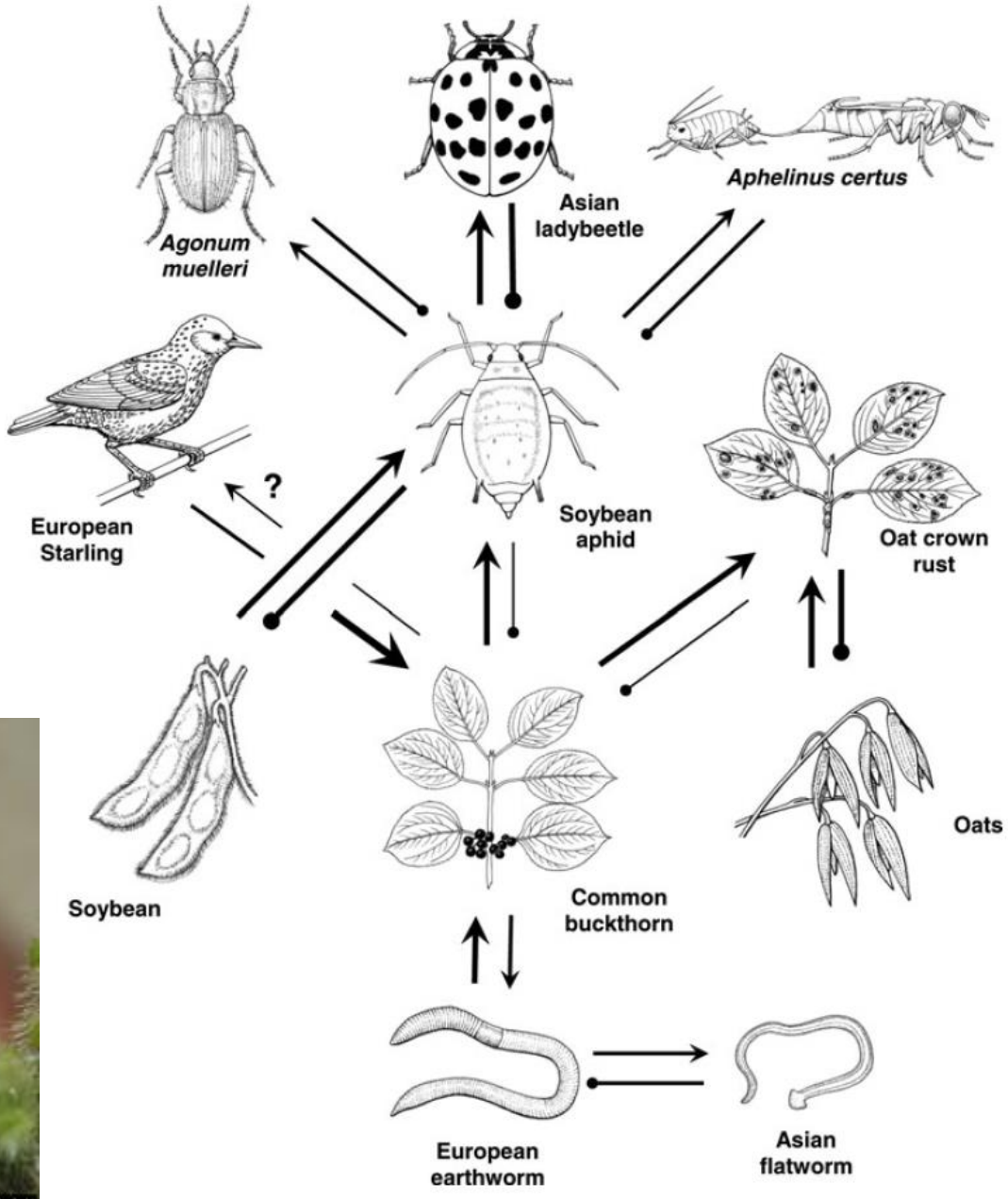
Earthworm macro-cascade effects of concern to human society



A case study of invasional meltdown

Heimpel, Frelich, Landis, Hopper, Hoelmer, Sezen, Asplen, and Wu, *Biological Invasions*, 2010

Art Work by Julie Martinez



Forest and crop productivity

Invasive plants that may be facilitated by earthworm invasion:

Buckthorn (common and glossy)
Garlic mustard
Tatarian honeysuckle
Black swallowwort (*Cynanchum*)
Japanese barberry
Hemp nettle (*Galeopsis tetrahit*)
Veronica ssp.
Stiltgrass (*Microstegium*)

Earthworm invasion and disturbance

- Fire—2-6 T less fuel per ha, and lower contiguity to carry fire once forest floor is gone
- Wind—thinner crowns of trees, smaller trees and higher bulk density of soil could increase tree stability

Figure 1.1. Sugar maple crown dieback in Keweenaw County, MI, 2009.
Photo by Tara Bal

Ecosystems
DOI: 10.1007/s10021-014-9814-0

ECOSYSTEMS
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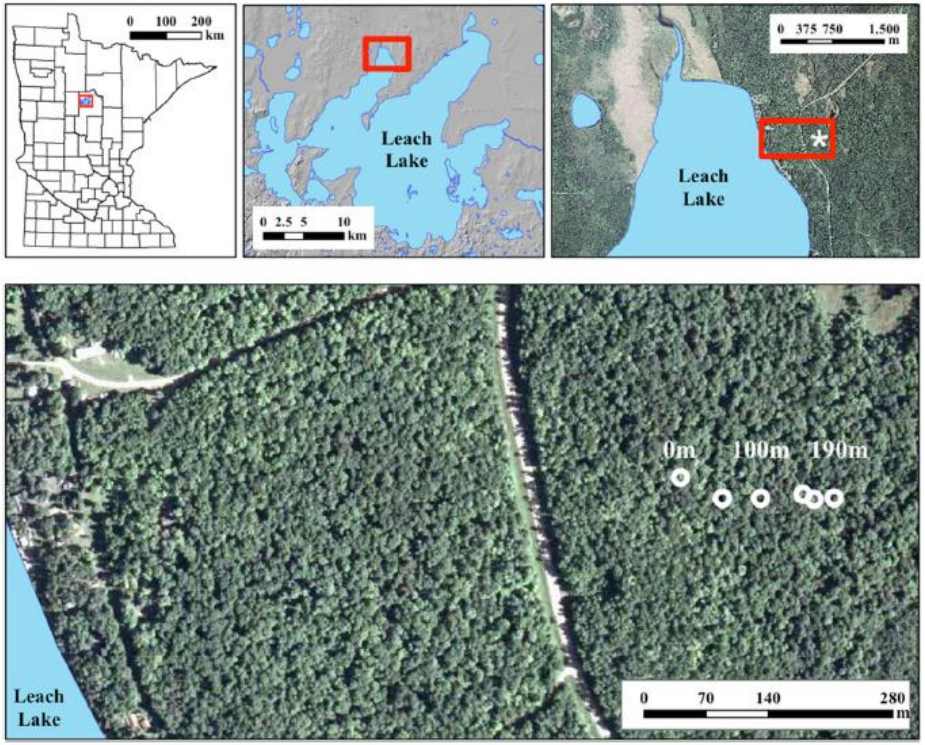
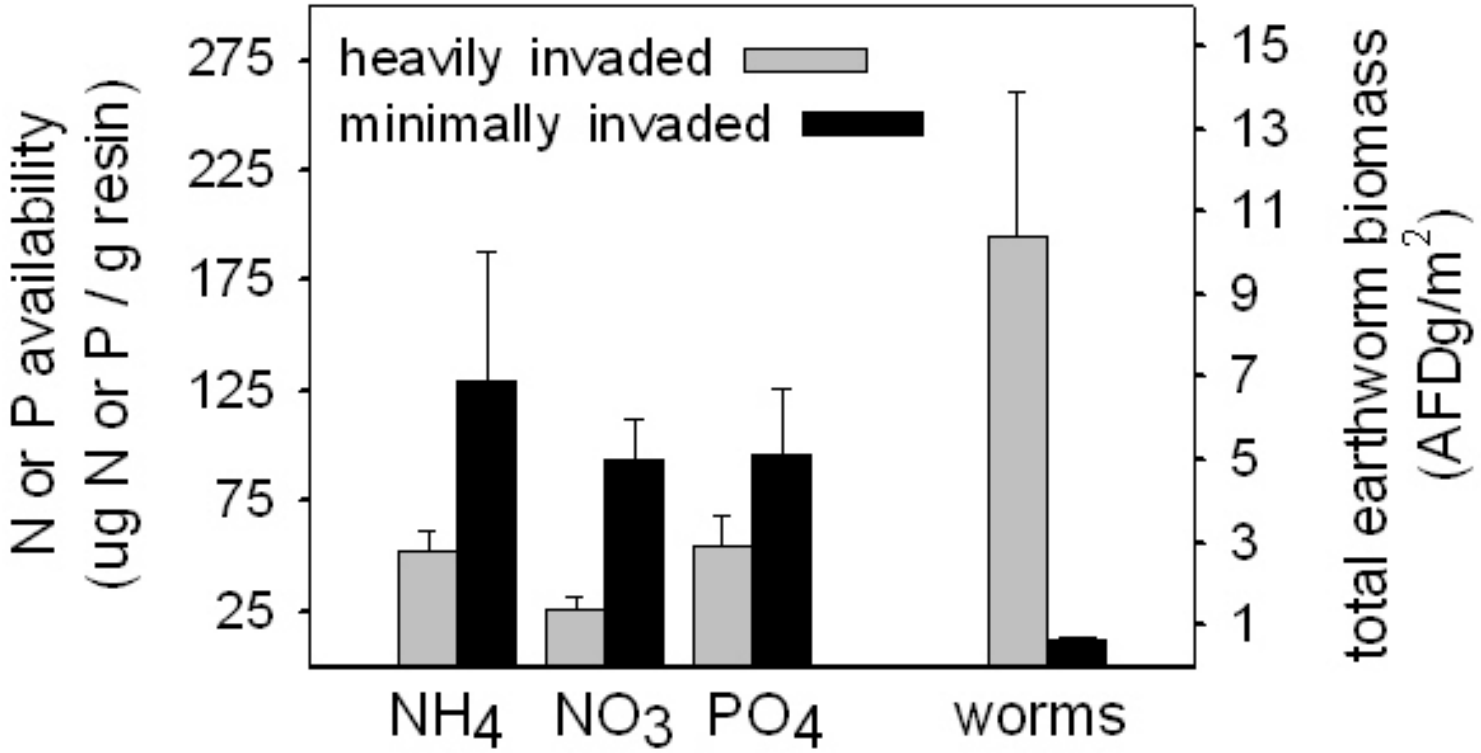
Invasive Earthworms Deplete Key Soil Inorganic Nutrients (Ca, Mg, K, and P) in a Northern Hardwood Forest

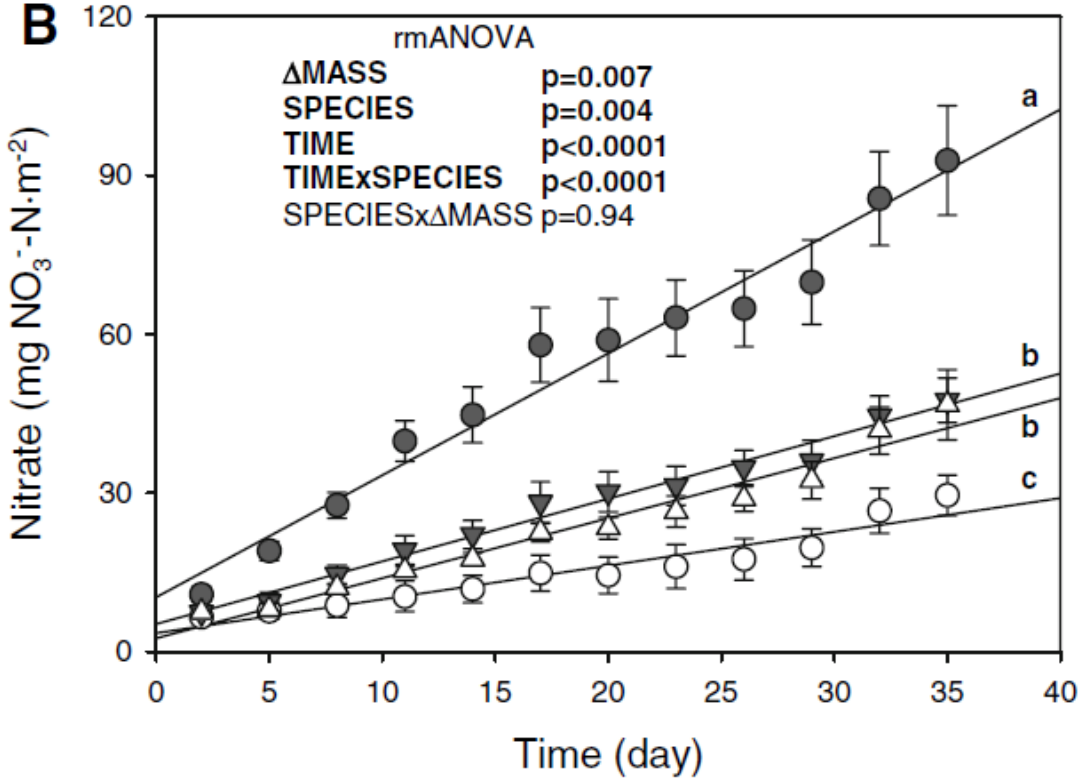
Kit Resner,[1] Kyungsoo Yoo,[1]* Stephen D. Sebestyen,[2] Anthony Aufdenkampe,[3] Cindy Hale,[4] Amy Lyttle,[1] and Alex Blum[5]



Availability of N and P is reduced, and bulk density INCREASED when earthworms invade forest soils. (Hale, Frelich, Reich and Pastor, *Ecosystems*, 2005)



Nitrate leaching rates in riparian forest, northern WI



- *A. caliginosa*
- *L. terrestris*
- *L. rubellus*
- none

Oecologia (2008) 158:499–510
DOI 10.1007/s00442-008-1149-0

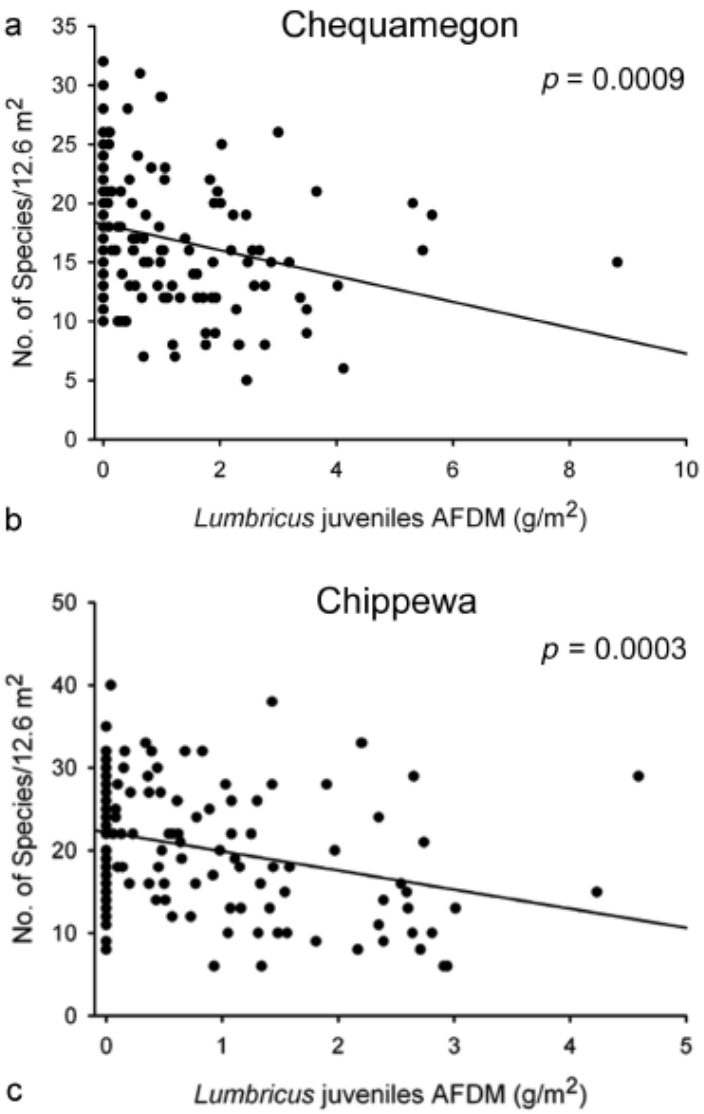
ECOSYSTEM ECOLOGY - ORIGINAL PAPER

Non-native earthworms in riparian soils increase nitrogen flux into adjacent aquatic ecosystems

David M. Costello · Gary A. Lamberti

Negative impacts on native plant species richness

(Holdsworth, Frelich and Reich, *Conservation Biology*, 2007)



Effects on seeds

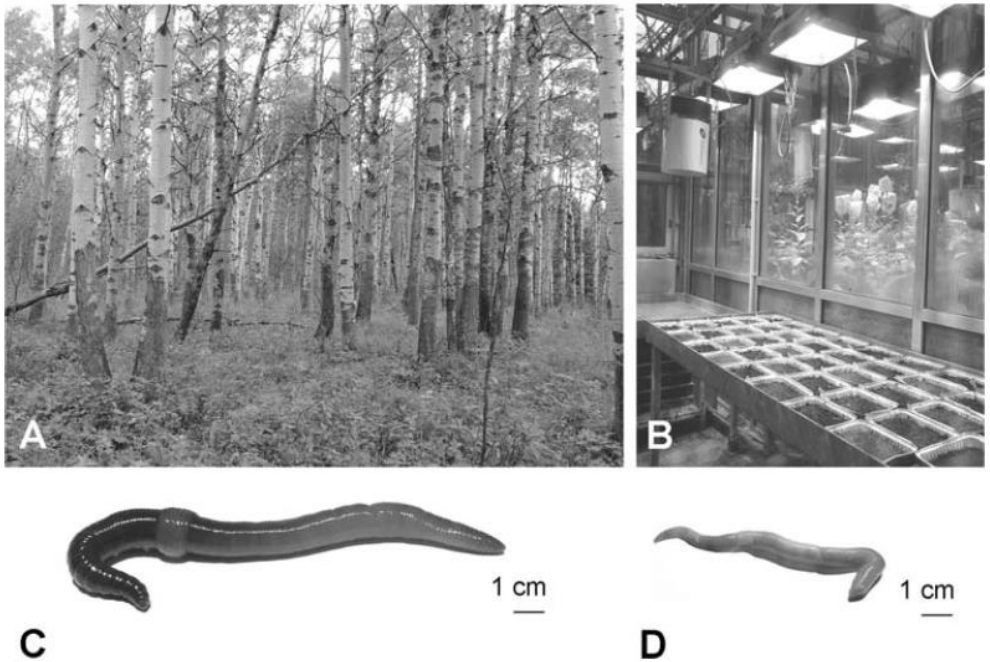
- Burial
- Decrease viability (small seeds if ingested)
- Change fungal environment (orchids, mycorrhizae, sugar maple)
- Change seedbed structure to favor small seeded species

Example:
Goodyera pubescens—McCormick et al 2008, Seeds cast into lower soil layers, some no longer viable, and *Tulasnella* fungus needed for symbiotic relationship negatively impacted by lack of O horizon

Botrychium mormo affected by earthworm invasion

L. rubellus was associated with extirpation of the plant for a survey of 28 sites on Chippewa NF, MN.

Gundale 2002, Conservation Biology 16: 1555-1561



Seed emergence experiment: With endogeic and anecic earthworms both present graminoids are favored

Ecosystems (2009) 12: 1008–1016
DOI: 10.1007/s10021-009-9275-z

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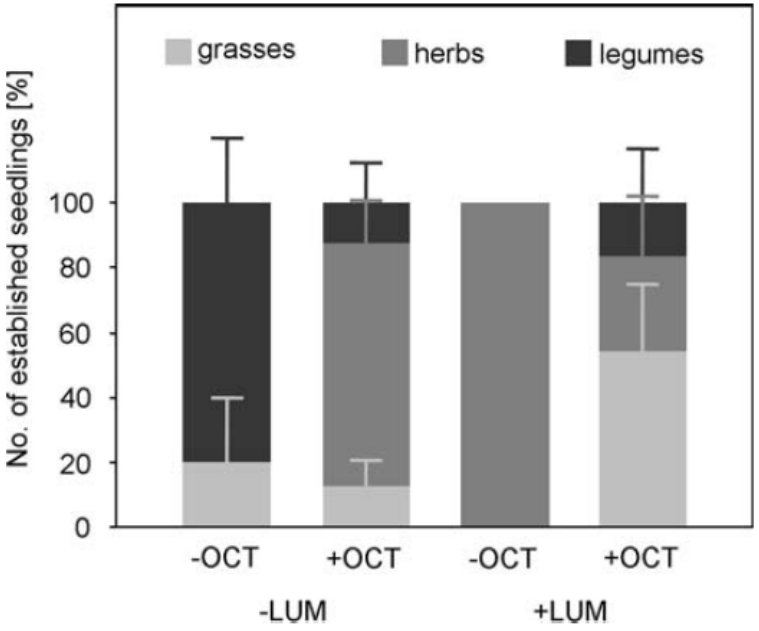
Exotic Ecosystem Engineers Change the Emergence of Plants from the Seed Bank of a Deciduous Forest

Nico Eisenhauer,[1,4]* Daniela Straube,[1] Edward A. Johnson,[2,3]
Dennis Parkinson,[2] and Stefan Scheu[1,4]



Earthworm-free sites.

Photos: Paul Ojanen, George Schlaghamersky

Heavily infested sites with sedge lawn (above) and bare soil (below).

Photos: Paul Ojanen

Invasive earthworms reduce productivity and amplify drought sensitivity in sugar maple trees of the Great Lakes Region

Evan R. Larson[1], Thomas Wilding[1], Ryan M. Hueffmeier[2], Kurt F. Kipfmueller[3], Cindy M. Hale[2], Lee E. Frelich[4], Peter B. Reich[4,5]

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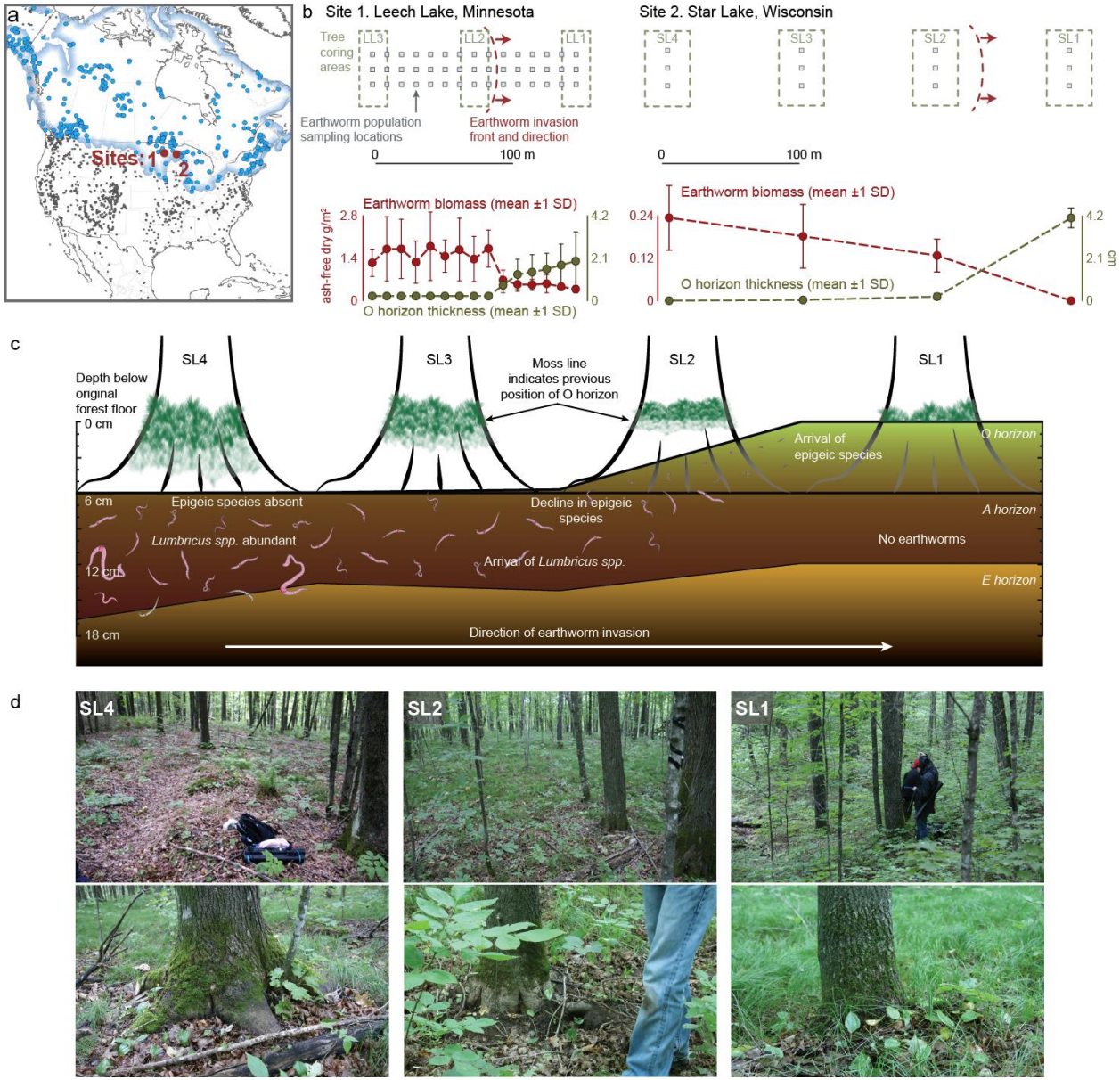
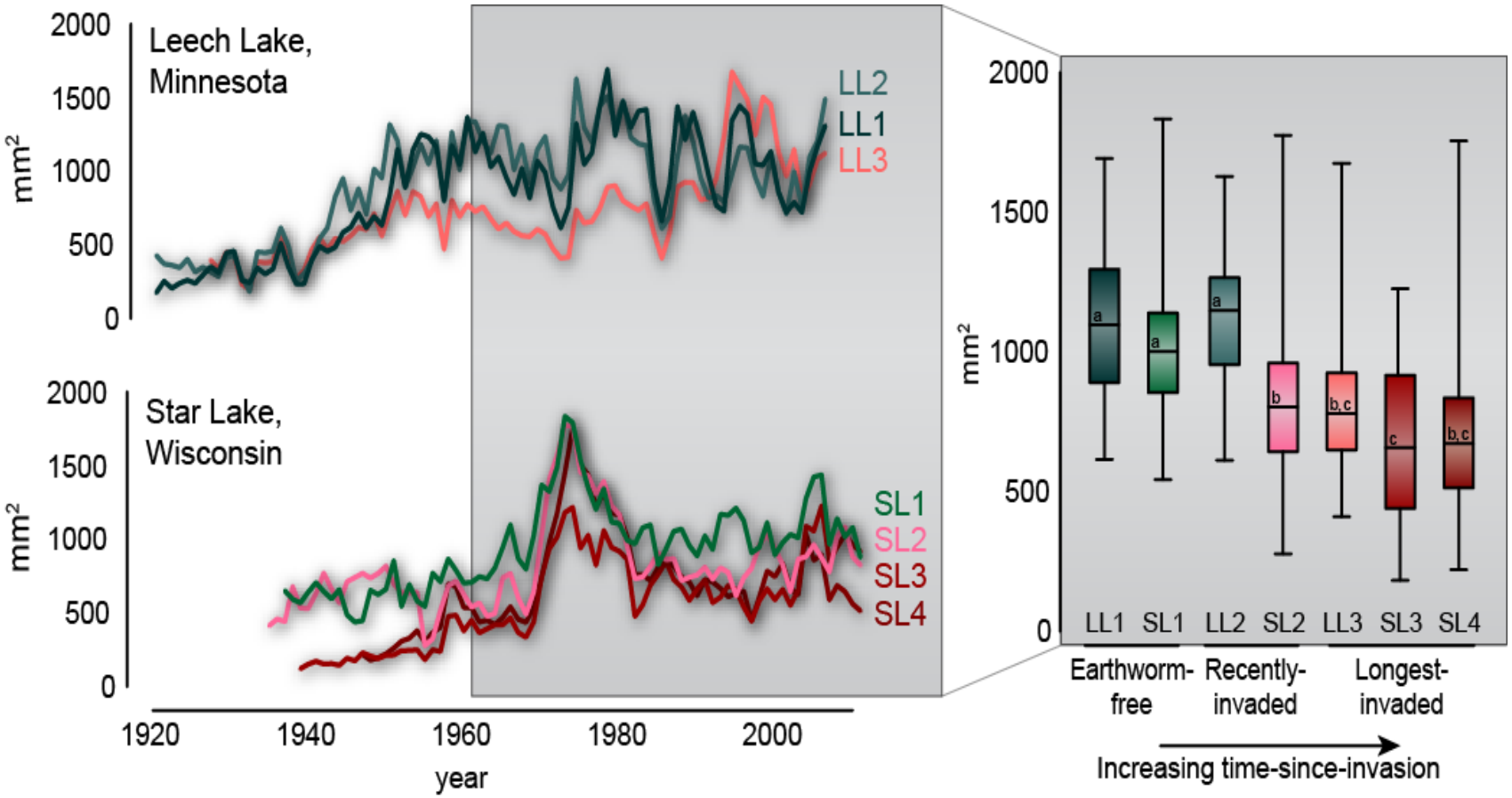
"it may be doubted whether there are many other animals which have played so important part in the history of the world as have these lowly organised creatures"

~Charles Darwin[1]

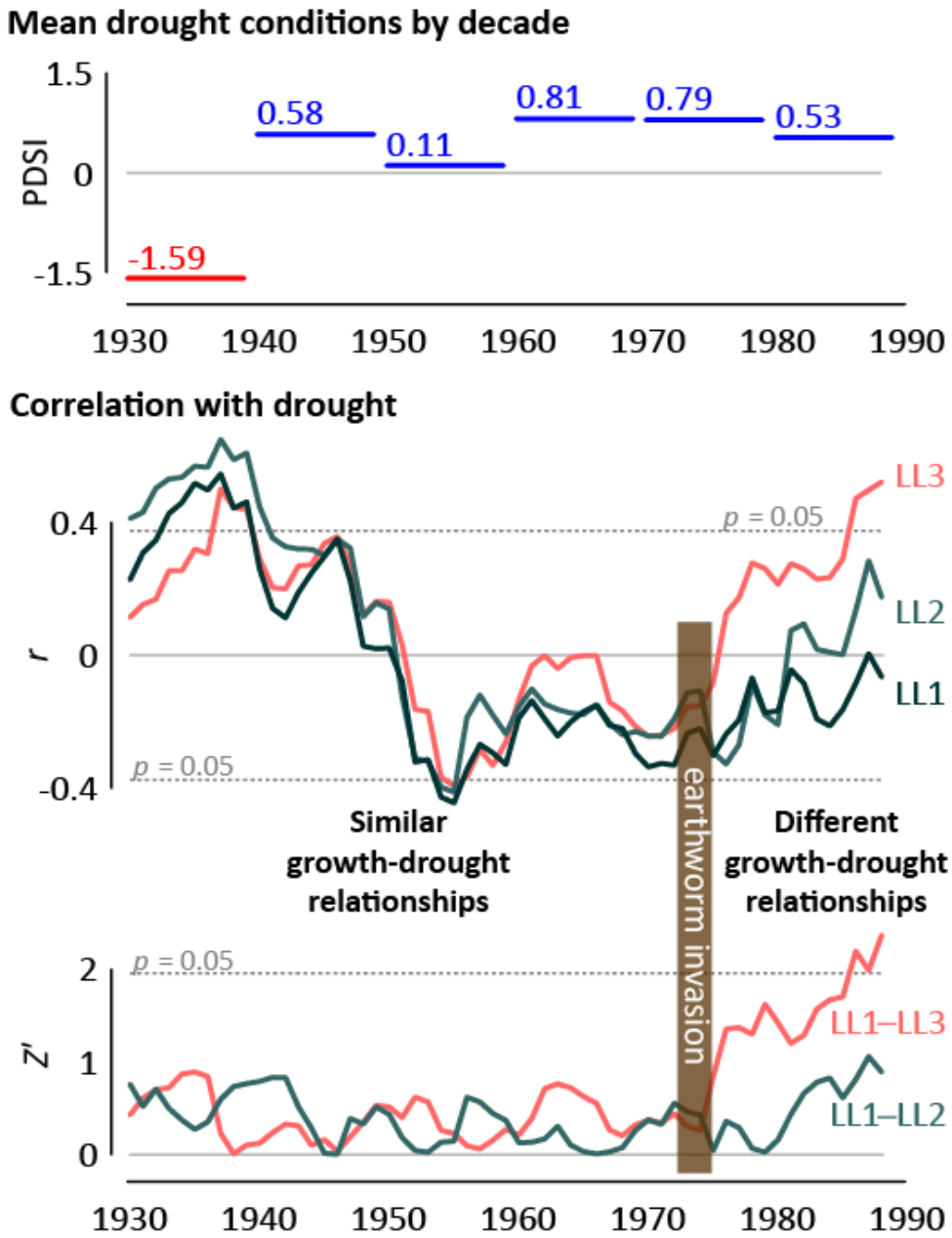
In review, PNAS



Impacts of earthworm invasions

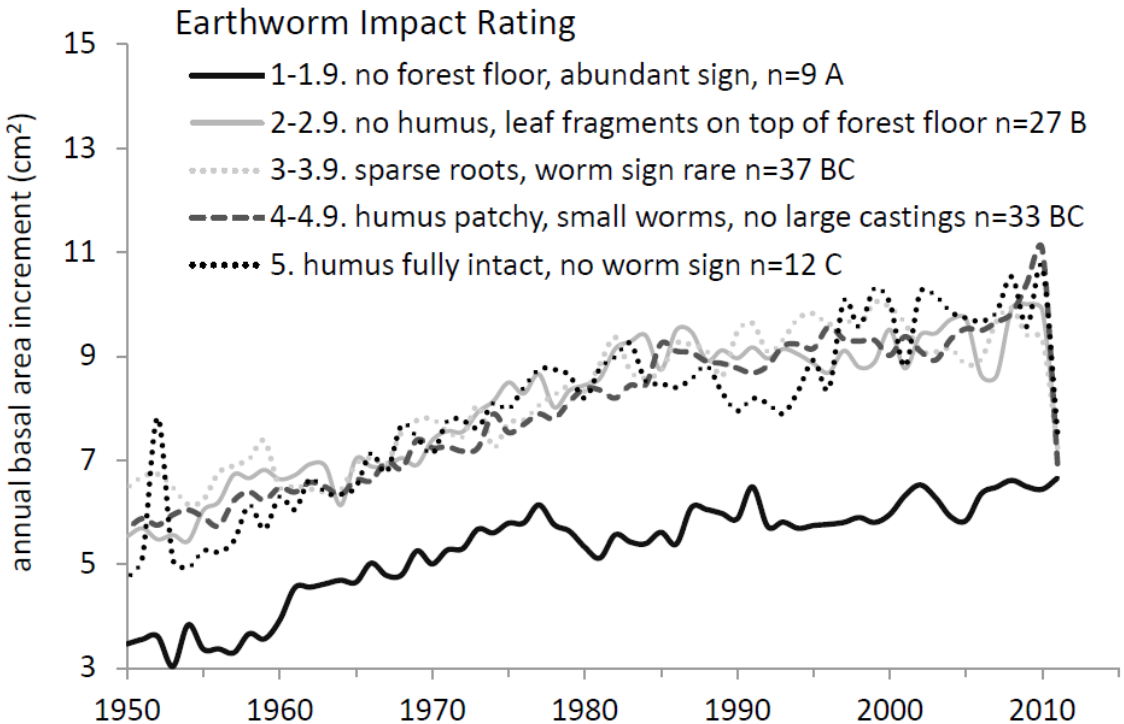


Influence of earthworms on tree productivity



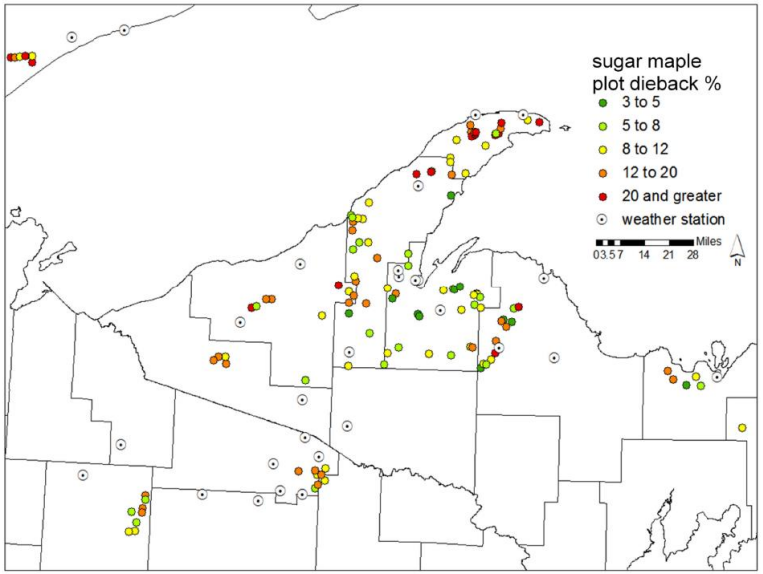
Amplified drought sensitivity following earthworm invasion at Leech Lake, Minnesota

Figure 1.1. Sugar maple crown dieback in Keweenaw County, MI, 2009.
Photo by Tara Bal

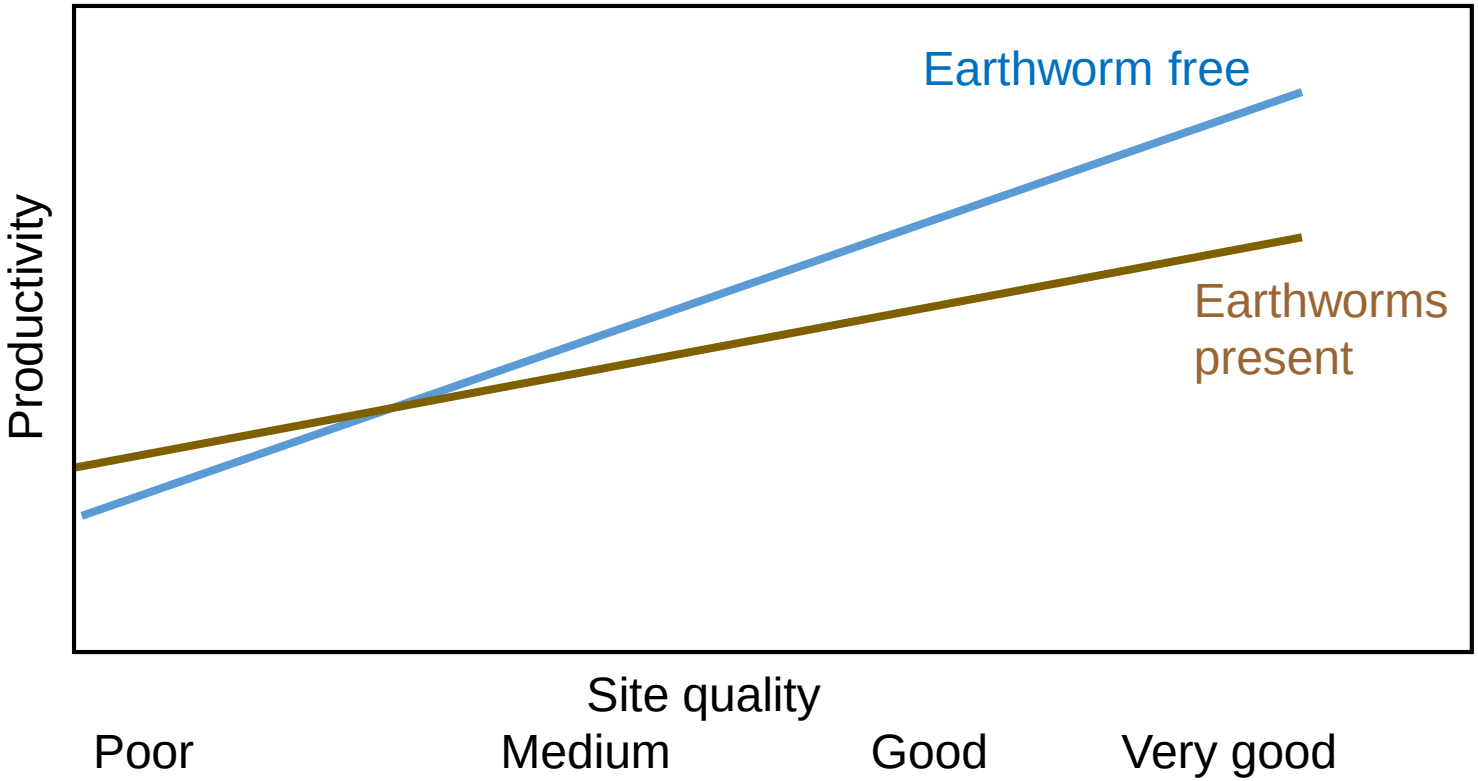


Earthworms were the most significant factor in sugar maple dieback in a study of 120 plots in MI, WI, and MN

Tara Bal, PhD Thesis, Michigan Tech, 2013



We hypothesize that earthworms will flatten the productivity-site relationship in forests



Conclusions

Earthworms have large fundamental effects on physical environment of the soil (temperature, moisture, nutrient content, structure) which ultimately tug on a lot of links in the food web, with multi-species and multi-effect invasions with strong trophic and long ecological cascades that run 4-5 links

Forest productivity—Reduction in productivity and increased drought sensitivity, With bigger impacts on productive sites, we can’t stop worms at this time, known control measures are damaging, e.g. coarse sand, chemicals, biocontrol not much Explored.

Acknowledgments:
Forest Ecology Lab group, Cindy Buschena, Peter Reich, Cindy Hale, Andy Holdsworth, Paul Ojanen, Alex Roth, Sascha Lodge, Nico Eisenhauer, many others.
Funding: Wood-Rill Foundation, Bruce and Ruth Dayton, Wally and Mary Lee Dayton, Jonathon Bishop, John and Charlotte Parish