Snakeworms

Invasive earthworms in horticulture and forests

Josef Gorres
Maryam Nouri-Aiin
Seen this?
History of Earthworm invasions in N. America

No native earthworms

Extend of last glaciation

First wave of invasions:
European worms
Lumbricidae: e.g. night crawler, Red worm, Etc.
Earthworm invasions kick off a cascade of events

• Starting with the modification of soil structure

• May end with or include
  • modifications of decomposer community
  • reduction in the abundance of larger fauna (birds, salamanders)
  • reduction in forest plant biodiversity
  • more invasive plants
Effect of European Earthworms on Forest Soil Structure

Before Invasion

Mor-type (duff) forest floor: Seed bank and germination medium

After Invasion

Mull-type forest floor
Dense A-horizon

Photo credits: Great Lakes WormWatch whose web page is a great resource
Second Wave: Snake Worms Invasions?

The looks and the moves

Some facts

- a.k.a pheretimoids
  - A group of species in several genera
  - 16 species in North America
- Invasive pheretimoids in Vermont are from Japan and Korea
- Species of concern in northern New England are
  - Amynthas agrestis
  - Amynthas tokioensis
  - Metaphire hilgendorfi
- Thought of as parthenogens, but a small number may be able to have sex.
How can you tell them apart?

FIGURE 1. Color photographs of live individuals of (A) *Amythas agrestis*, (B) *Amythas corticis*, (C) *Amythas gracilis*, (D) *Amythas hupeiensis*, (E) *Amythas minimus*, (F) *Amythas morrisi*, (G) *Amythas tokioensis*, (H) *Metaphire californica*, (I) *Metaphire hilgendorfi*, (J) *Metaphire posthuma*, (K) *Pithemera bicincta*, and (L) *Polypheretima elongata*, showing interspecific variations in colorations and body shapes. Specimens are from the US (A, B, D, G, I) and Taiwan (C, E, F, H, J, K, L). Photo credit: Chih-Han Chang (A, B, D, E, G, H, I) and Wen-Jay Chih (C, F, J, K, L). The photographs of *A. minimus* and *M. californica* have been previously presented in Chang et al. (2009a).
Typical external layout of a pheretimoid worm (ish)

a. Clitellum – annular, goes all the way around the body (A)
b. A single female pore (ventral)
c. Spermathecal pores forward of the clitellum (not shown here, usually found as pairs between segments 5, 6, 7, 8, but number differs among species) ventral
d. Pheretimoid arrangement of setae (little hair that propel the worm), loads on each segment and go all around the body.
e. Male pores on segment 18 (D)
f. Usually some genital markings forward of clitellum (not shown)

Image modified from https://www.researchgate.net/profile/Jiangping_Qiu
External markings that allow identification to species for the three species most likely found here. Problem is they are not always present.

Spermathecal pores (where sperm is deposited if there is sex). Left panel A. agrestis, middle A tokioensis Right panel M. hilgendorfi) images from Chang et al., 2016
Most interesting points

Annual life cycle for the three snake worm species we are most concerned with

Adults first appear between beginning of July and late August.

Steep increase in abundance in spring/early summer varies also

There is a decrease in late early/mid July

There appear to be some hatchlings in October

In nurseries they are 3 weeks ahead of forest populations. Sometimes 2 generations in nurseries.

Richardson et al 2009: Die below 40 F and above 90 F

Unpublished data
Cocoons Dry and Moist
Cryptic part of the populations

Drought and cold dehydration

Rehydrated cocoons

Hatchlings emerge between 40 and 50 F, but ....
Cold Hardiness and Drought Resilience, Cocoon bank? – they hatch year round.

**Winter Hatching, El Niño winter, 2015/2016 (Gorres et al, 2017)**

**Summer: cocoons from previous year**
Unpublished data

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**Diagram:**
- **X-axis:** Dates from December 21, 2015, to May 30, 2016.
- **Y-axis:** Fraction of intact cocoons.
- **Data Points:**
  - A. agrestis
  - A. tokionesis
- **Graph Title:** Cocoons on August 1
- **Axes:**
  - Y-axis: Cocoon Abundance (m⁻²)
  - X-axis: Species

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**Note:**
- The graph shows the decline in the fraction of intact cocoons over time, with separate lines for A. agrestis and A. tokionesis.
Reproduction

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Parthenogenetic

- Most pheretimoids in USA are parthenogenetic (Gates, 1958).
- Single worm can found a colony if conditions are right.
- Expect low genetic diversity.

- But, there is genetic diversity in populations (Keller et al. 2017, Nouri Aiin, unpublished data).
- Of 130 A. agrestis analyzed there were 80 different genotypes.
- Both clones and “singletons” in populations.

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<th>Table 1. Measures of genetic diversity for two species of <em>Amythnas</em> earthworms at three sites (locations detailed in text).</th>
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<th>Table 2. The number of groups of clones at three sites in Vermont, USA (locations detailed in text) for each species of <em>Amythnas</em> earthworms, where doublet refers to two clonal individuals, triplet refers to three individuals, etc.</th>
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- Mixed reproductive system?
Reproductive morphs

In each population

- Morphs that are potentially hermaphrodites (have all the parts) ~ 1% - H- morph
- Morphs that are definitely parthenogens (have none of the male parts) ~ 80% - R - morph
- Remainder somewhere in between (~20%) and may be capable of sex
Biogeography

Original Range
• Japan
• Korea
• Taiwan
• China

Canada
• 1 single report of 2 species in southern- most Ontario

US
• 37 States (Reynolds, in press)
• 16 pheretimoid species (Chang et al., 2016)

Red - main sources of the three species we are most concerned with at this point in time
When were they first reported in some states?

• California - 6 species 1860s to 1950s  
• Connecticut – 7 species 1950s  
• Delaware – 3 species 2014  
• DC – 1 species 1937  
• Florida – 13 species 1950 – 2010s  
• Georgia -12 species 1936 – 1969  
• Illinois – 5 species 1914 – 2014  
• Maine – 7 species 1954  
• New York – 6 species 1940 - 1999  
• Vermont – 3 species 2011 - 2012

Reynolds, in press
In Northeast, co-invasion of three species

Pheretimoid communities at some selected survey sites, color means presence of species, 30 sites ...

Pheretimoids that travel together, succeed together?

- **Amynthas tokioensis, T**
  - 2 – 8 cm length
  - Usually, most abundant in community

- **Amynthas agrestis, A**
  - 7 – 14 cm length
  - Next most abundant

- **Metaphire hilgendorfi, H**
  - 12 – 25 cm length
  - Least abundant

Chang et al., 2017
In Maine: Penobscot and Hancock Co., 7 species reported. Reynolds et al, 2015
Forest Soil Modifications by *A. agrestis*

- **A Horizon**
- **B Horizon**
- 5 cm castings

B- Horizon
What is the concern?

Forests: Reduced biodiversity, reduced tree regeneration.

Horticulture: plant damage?
Is there hope for maple syrup?

No saplings
The three most common vectors

Horticulture, Waste Recycling/Reuse, Bait
Universal Repurposing of Organic Waste

• Fall yard waste collections

• Perfect way to move these earthworms

Composts

• Heating pile to 60 C may not kill worms – they move to the outside.

• Forestry Division of Wisconsin DNR works with composters specifically
Waste Recycling/Reuse

The Waste Pyramid

The Problem

- Recycling products of yard waste
  - Compost
  - Leaf mulch (uncomposted)
- Reuse
  - On-site (in your backyard)
  - Off-site (elsewhere)

Reuse and Recycling

Near my neighborhood. At least 3 of these blocks of houses have pheretimoids.

Where to reuse the leaves in the Fall? Most have small gardens and lots of lawn. Not enough space to recycle/reuse in place.
Many Gardens

Google maps

Raised beds

Forest edge...

https://www.fs.usda.gov/detailfull/r4/fire-aviation/?cid=fseprd526615&width=full

Many Gardens
What is the risk?

**Composting**
- Several cycles at 140 - 160 F.
  - Theoretically kills the worms and their cocoons. (cocoons and worms die at 90 and 105 B. Herrick, UW Arboretum)
  - Practically, the pile near the surface is cooler than the hot interior and worms tend to move towards the more clement micro-climate or even leave the pile.
  - Requires QC/QA
- My best **guess** on the risk:
  - Medium (wind rows)
  - Low (hotter, aerated static pile)

**Uncomposted leaf mulch**
- Does not undergo composting ...
- My **best guess** on risk: High ...

**Wood mulch**
- Does not undergo composting
- My **best guess**: low risk
  - But depends on the supply, is it contaminated?

Emphasis is on **GUESS**
Vermicomposting

Internet Sales of composting worms

• Vendors used to be unaware of problems
  
• Now, their sales are a bit more nuanced
  

• Some factual mistakes in this sales pitch.
**Horticulture**

**Commercial**

- Plant exchanges
  - Be responsible...
  - Exchange with bare roots..
  - Don’t exchange when you have these worms in your garden
Horticultural trade

An example of purported plant damage

- Cindy Hale: Here’s a guy in Pennsylvania who has 30,000 Hosta varieties and this Asian worm came in with mulch he imported and it destroyed half of his nursery. In Minnesota, we’ve seen them at a few places in the Twin Cities and a handful of places in Wisconsin. They’re not well-established in the western Great Lakes region yet but they’re poised to be coming. They have the potential for even more of a heavy impact on our native forests, but also having very negative consequences to ecosystems where you traditionally think of earthworms being good, like gardens and landscapes.
Things to consider when designing horticultural practices

The worms themselves

A. agrestis on woody mulch, up to 200 juveniles per Square meter

The very hardy cocoons (egg casings)

1000 to 2000 per square meter
If there were an intervention point when would that be?

Total earthworms in a forest

Adults in a forest

In gardens and nurseries the worms tend to become adults earlier
Possible Interventions

**Chemical – Physical measures**

- No legal vermicides
- Irritants drive the worms to the surface and some kill them
  - Mustard solution
  - Early Bird ® contains molluscicide
- Maybe use them as a pot drench.
- Admix sharp edged (angular) biochar/sands
- Solarization on impervious ground
  - Prescribed burns don’t directly kill these worms in forests!!!! Don’t let them escape!

**However**

- Efficacy on pheretimoids not been tested at large scale
- Non-target effects
  - Maybe effective on pheretimoids but potential target effects (molluscicides may act on fish)
  - Effective on worms but what of the cocoons

More interventions

Naturally occurring microbial pathogens

- Maryam Nouri and Aisin have isolated some agents from dead cocoons and worms.
- Need to replicate last year's bio-assays.
- Were effective on juveniles.
- Not so much on adults.
- Need to better characterize the pathogens.
- Flat worms, geckos and others
  - Flat worms (planeria) are worm predators.
    - But exotic species themselves.
    - Now found in northeastern USA regularly.
    - May not work on pheretimoids.
  - Some lizards are vermivores.
  - Birds eat them (American Woodcock – obligate vermivore).

Arun T.P., Bugwood.org, www.invasive.org/browse/detail.cfm?&imgnum=5379895
The other challenge

Working with horticulture
• Fear of consequences of having crazy worms
  • Wisconsin and New York have regulations
  • Customers are becoming more sensitive to these issues
• We need an accurate assessment of the problem
• There is an interest especially by greener green industry folks – encourage it.

Getting Funding
• Earthworms are good! What is your problem?
• Assessment of the problem
  • How severe is the problem in horticulture
  • What are economic damage thresholds (is there plant damage)
• Convince State and Federal funders that it is important and that it is not a lost cause.
Take home message

**Spread**
- These worms are currently making the leap into the wild
- There are common vectors
  - Horticulture
  - Waste use, transport of earthmaterials
  - Maybe bait and other leisure activities

**Control**
- Best done at the sources
- But no effective best management practices, yet
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