Cryptic Degradation in Urban Forests: Decoupled Collapse of Soil Methane Sink and Understory Regeneration

A Synthesis and Hypothesis

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Abstract

Urban forests are typically assessed by canopy metrics, assuming that tree persistence indicates ecosystem health. We present evidence of "cryptic degradation" (a functional decoupling between canopy biomass and belowground processes) using 25 years of data from the Baltimore Ecosystem Study (BES). We document two concurrent phenomena: (1) a 59% reduction in soil methane (CH_4) uptake beginning abruptly circa 2008 ($p < 0.001$), and (2) a 70% decline in forest floor regeneration (seedlings and saplings) between 1998 and 2015, despite a 29% increase in tree basal area over the same period. We propose that these patterns reflect a common theme: degradation of soil physical structure reducing both gas diffusivity and seedling establishment. Drawing on invasion ecology literature, we hypothesize that the replacement of deep-burrowing earthworms (Lumbricus spp.) by surface-feeding invasive earthworms (Amynthas spp.) has altered soil architecture, though we acknowledge this mechanism remains untested at these sites. This is a hypothesis requiring field validation, and we invite collaboration from soil ecologists, invasion biologists, and the BES research community to test these predictions.

1. Introduction

Forest ecosystem health is commonly assessed through canopy metrics (basal area, canopy cover, and tree mortality). These measures are practical and are correlated with many ecosystem services. However, they may miss degradation occurring belowground. Changes to soil structure, microbial communities, and biogeochemical cycling that occur beneath an *apparently* healthy canopy.

This paper documents such a case. Using long-term data from the Baltimore Ecosystem Study (BES), we show that urban forests in the Baltimore metropolitan area have experienced simultaneous collapse of two belowground functions (soil methane uptake and seedling regeneration) while canopy biomass continued to increase. We term this pattern "cryptic degradation": the forest looks healthy from above, but the soil system has fundamentally changed.

We propose a mechanistic hypothesis to explain this pattern, centered on changes to soil physical structure. However, we emphasize that this mechanism is inferred from literature, not directly observed at these sites. Our goal is not to claim proof, but to document a striking pattern, propose a testable explanation, and invite collaboration to evaluate it.

2. Background: The Soil Methane Sink

Well-drained forest soils constitute the only significant biological sink for atmospheric methane, consuming an estimated 30–40 Tg CH_4 annually through the activity of methanotrophic bacteria (Dutaur and Verchot, 2007). These obligate aerobes require both atmospheric methane diffusing into soil pore spaces and sufficient oxygen to drive oxidation. Soil gas diffusivity (mainly governed by macropore structure) determines whether methanotrophs can access their substrates.

Ni and Groffman (2018) documented a striking global pattern that methane uptake by forest soils declined by 77% between 1988 and 2015, with the steepest declines in Northern Hemisphere mid-latitude forests. Their analysis included sites in Baltimore, Maryland (the same sites examined here). They attributed the decline to increased precipitation reducing soil gas diffusivity. However, soil permeability is not a passive property. In forest soil, it is actively maintained by bioturbation--the physical reworking of soil by burrowing fauna.

3. Methods

3.1 Study Sites and Data Sources

We analyzed publicly available data from the Baltimore Ecosystem Study (BES) Long-Term Ecological Research program. Three reference forest sites were selected for continuous data records: Hillsdale (HD), Leakin Park (LEA), and Oregon Ridge (ORM). These sites span an urban-rural gradient within the Baltimore metropolitan area.

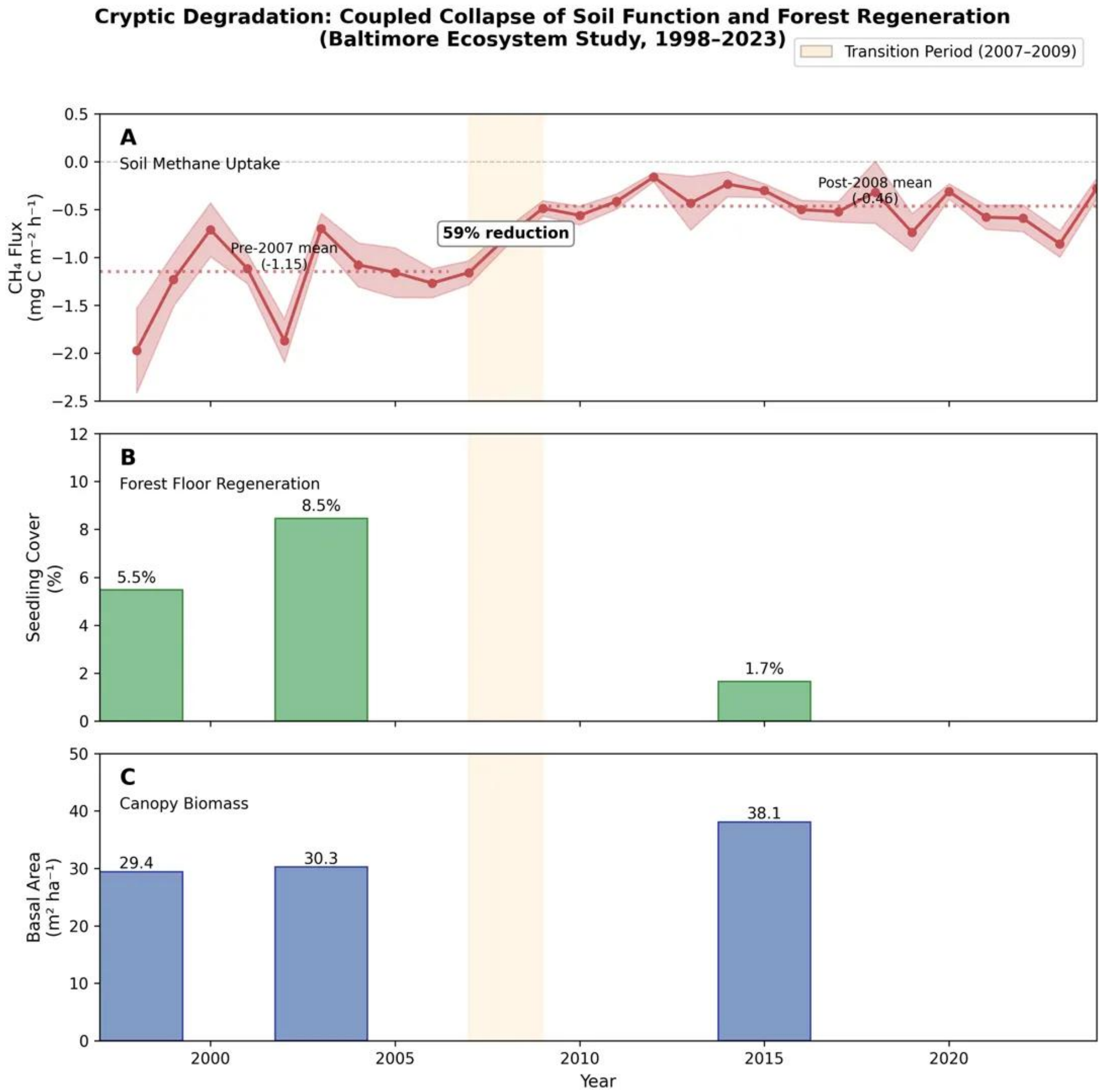
Trace gas flux data (1998–2023) were obtained from the BES data repository. Monthly soil CH_4 flux measurements were made using static chamber methods. Error codes (-9999.99) were excluded from analysis. Vegetation census data (1998, 2003, 2015) included seedling cover, sapling density, and tree basal area.

3.2 Statistical Analysis

Methane flux data were aggregated by year and tested for temporal breakpoints using two-sample t-tests comparing pre- and post-breakpoint periods. We tested breakpoint years from

2004–2011 to identify the year maximizing between-period variance. Vegetation metrics were compared across census years using percent change calculations.

4. Results



4.1 Methane Sink Collapse

Soil methane uptake showed a distinct shift circa 2008 (Figure 1A). Pre-shift (1998–2006), soils functioned as a strong methane sink with mean uptake of -1.15 mg CH_4 m^{-2} h^{-1} (n = 1,650 measurements). Post-shift (2009–2023), sink strength stabilized at -0.46 mg CH_4 m^{-2} h^{-1} (n = 2,231). This represents a 59% reduction in sink capacity ($t = -16.77$, $p < 0.001$).

Breakpoint analysis identified 2008 as the optimal split year, though high variance characterized the 2007–2008 transition period. The post-2008 reduction persisted through 2023, indicating a sustained shift rather than transient fluctuation.

4.2 Regeneration Failure

Concurrent with methane sink collapse, forest floor regeneration declined dramatically (Figure 1B). Mean seedling cover across sites moved from 5.5% (1998) to 8.5% (2003) to 1.7% (2015),a 70% decline from baseline. The 2003 peak suggests initial conditions were not limiting; something changed between 2003 and 2015.

Site-specific patterns were consistent. At Leakin Park, seedling cover collapsed from 21.3% (2003) to 1.9% (2015), a 91% reduction. At Oregon Ridge Midslope, cover fell from 4.6% to 0.2%. Total sapling counts across all sites declined from 727 (1998) to 225 (2015), a 69% reduction.

4.3 Canopy Persistence

Despite these belowground changes, canopy metrics indicated continued forest growth (Figure 1C). Mean tree basal area increased from 29.4 $m^2\ ha^{-1}$ (1998) to 38.1 $m^2\ ha^{-1}$ (2015), a 29% increase. Tree counts increased from 409 to 452 individuals. The mature canopy persisted and grew while the regeneration pipeline collapsed beneath it.

5. Discussion: A Hypothesis of Cascading Failure

The simultaneous collapse of methane uptake and seedling regeneration, despite canopy persistence, suggests a common driver affecting the soil-atmosphere interface. We propose that this driver is degradation of soil physical structure--specifically, the loss of macropore networks that maintain gas diffusivity and root penetration.

5.1 The Soil Architecture Hypothesis

We hypothesize that multiple interacting stressors have converged to degrade soil architecture at these sites:

> *(i) Earthworm community shift:* Invasive Asian earthworms (Amynthas spp.) have spread throughout the Mid-Atlantic region. Unlike deep-burrowing Lumbricus species that create vertical macropores, Amynthas are epi-endogeic. They consume the organic horizon and deposit granular castings at the surface without creating subsurface channels (Chang et al., 2016). This would reduce both gas diffusivity

(limiting methanotroph substrate access) and root penetration (limiting seedling establishment).

(ii) Herbivore pressure: White-tailed deer populations have increased dramatically in Mid-Atlantic forests following the functional extirpation of large predators. Deer preferentially browse seedlings, which could directly explain regeneration failure independent of soil changes.

(iii) Climate shifts: Increased precipitation in the region (Ni and Groffman, 2018) would exacerbate any loss of soil drainage capacity, creating waterlogged conditions that inhibit both gas diffusion and aerobic root growth.

We emphasize that these mechanisms are *not* mutually exclusive. We suspect they interact: deer browsing reduces root biomass, which reduces bioturbation by root turnover, which reduces macropore maintenance, which increases waterlogging, which further inhibits regeneration. The system degrades through positive feedback.

5.2 Why Amynthas? A Mechanistic Rationale

We focus on earthworm community composition because it provides a mechanistic link between gas flux and regeneration that deer browsing alone cannot explain. Amynthas agrestis was first recorded in Baltimore in 1939 (Chang et al., 2016), but population expansion accelerated in the 2000s. The University of Maryland Extension explicitly notes that Amynthas "do not help with deep soil aeration, nutrient movement, or water infiltration" because they lack burrowing behavior.

The temporal alignment is suggestive--Amynthas population expansion in the 2000s precedes the 2008 methane cliff. However, we acknowledge this is correlation and not causation. We have found no earthworm survey data from these specific sites.

5.3 Limitations and Uncertainties

We acknowledge several critical limitations:

(1) No direct measurement of earthworm community composition exists for these sites. The Amynthas hypothesis is inferred from regional invasion patterns, not site-specific data.

(2) No soil porosity or macropore density measurements are available. The structural mechanism is hypothesized, not observed.

(3) Deer browsing could independently explain regeneration failure without invoking soil changes. We cannot distinguish these hypotheses with available data.

(4) The vegetation census gap (2003–2015) spans the critical transition period. We cannot determine whether regeneration decline preceded, coincided with, or followed the 2008 methane shift.

6. Testable Predictions

The soil architecture hypothesis generates several falsifiable predictions:

Prediction 1: Amynthas should be present and dominant at the degraded BES sites, while Lumbricus should be rare or absent. A simple mustard-pour survey could test this.

Prediction 2: Soil macroporosity should be lower at sites with collapsed methane uptake compared to reference sites with intact function (if any exist).

Prediction 3: The "coffee ground" soil texture diagnostic of Amynthas activity should be observable at these sites.

Prediction 4: Deer exclosures at these sites (if any exist) should show whether regeneration recovers when browsing is excluded. If seedlings fail to establish even without deer, soil limitation is implicated.

Prediction 5: The O-horizon (organic layer) should be thin or absent at degraded sites, consistent with Amynthas consumption.

7. A Call for Collaboration

This paper documents a pattern and proposes a mechanism, but does not prove causation. Testing the soil architecture hypothesis requires expertise and resources beyond those available to an independent researcher: earthworm taxonomy, soil physics measurements, access to study sites, and institutional support for field campaigns.

We invite collaboration from:

- The Baltimore Ecosystem Study research community, who maintain these sites and may have unpublished data on soil fauna or structure

- Earthworm invasion ecologists (e.g., the JWORM working group) who can assess whether the Amynthas mechanism is plausible given regional invasion dynamics
- Soil physicists who can measure macropore structure and gas diffusivity
- Urban ecologists interested in the concept of "cryptic degradation" as a monitoring blind spot

The goal is to determine whether this pattern is real and mechanistically understood. If we are wrong, we would want to know. If we are right, the implications extend beyond Baltimore to any forest experiencing earthworm invasion.

8. Conclusion

The BES long-term data reveal a troubling pattern. Urban forests that appear healthy by canopy metrics have experienced functional collapse belowground. Soil methane uptake has declined by 59%, seedling regeneration has collapsed by 70%, and yet tree basal area continues to increase. The forest persists, but it has stopped breathing and stopped reproducing.

We propose that this "cryptic degradation" reflects changes to soil physical structure, potentially driven by invasive earthworm activity interacting with deer browsing and climate shifts. This hypothesis is testable but untested. We as a starting point. A pattern worth investigating, a mechanism worth evaluating, and/or a collaboration worth pursuing.

If the soil architecture hypothesis proves correct, it would suggest that forest conservation must attend what grows above ground *and* the invisible infrastructure that makes growth possible. As usual, the engineers that maintain that infrastructure may matter even more than we have recognized.

Data Availability

All data analyzed in this study are publicly available from the Baltimore Ecosystem Study data repository (https://beslter.org). Trace gas flux data: BES_trace-gas-collection_1998_2025.csv. Vegetation census data: BESLTER_1998_2003_2015_Veg_Data_1_Summary_Table.csv. Analysis code is available upon request.

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Acknowledgments

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Competing Interests

The author declares no competing interests. The author is an independent researcher with no institutional affiliation or funding that could be perceived as influencing this work.

Figure Legend

Figure 1. Cryptic degradation in Baltimore urban forests, 1998–2023. **(A)** Soil methane flux showing regime shift circa 2008. Negative values indicate net uptake (sink function). Shaded region indicates 95% confidence interval. Dotted lines show period means. **(B)** Mean seedling cover across census years, showing 70% decline from peak (2003) to final census (2015). **(C)** Tree basal area showing continued canopy growth (+29%) despite regeneration collapse. Orange shading indicates the 2007–2009 transition period. Data from Baltimore Ecosystem Study LTER sites: Hillsdale (HD), Leakin Park (LEA), and Oregon Ridge (ORM).