Impacts of Acidic Deposition and Calcium Depletion on Terrestrial Biodiversity and Food Webs in Northern Forest Ecosystems

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- Soil aluminum limits abundance and diversity of forest snails, but tolerant species persist that provide vital calcium sources for songbirds and other predators
- Redback salamanders can persist in acidified forests, despite previous findings
- Calcium pools in soil food webs are not sensitive to variation in soil and vegetation Ca pools, suggesting trophic interactions may stabilize Ca flows

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http://www.nsrcforest.org

Project Summary

- **Rationale**

Acid rain has depleted calcium from forest soils. Because calcium is essential to all organisms, we studied how calcium depletion affects biodiversity, and whether food webs are sensitive to calcium loss.

- **Methods**

We studied upland forests ranging from nutrient-rich (less acidic) to nutrient-poor (very acidic). We collected invertebrates and salamanders from the forest floor, and analyzed their abundance and diversity, and nutritional value in the food web, in relation to soil and plant nutrition.

- **Major findings/outcomes**

Acid rain has likely reduced biodiversity in some places, but functioning soil communities and food webs persist on acidified sites. Generalist species tolerant of acid-mediated changes in soil chemistry and plant nutrition may be essential for maintaining calcium supply in food webs.

- **Implications for the Northern Forest**

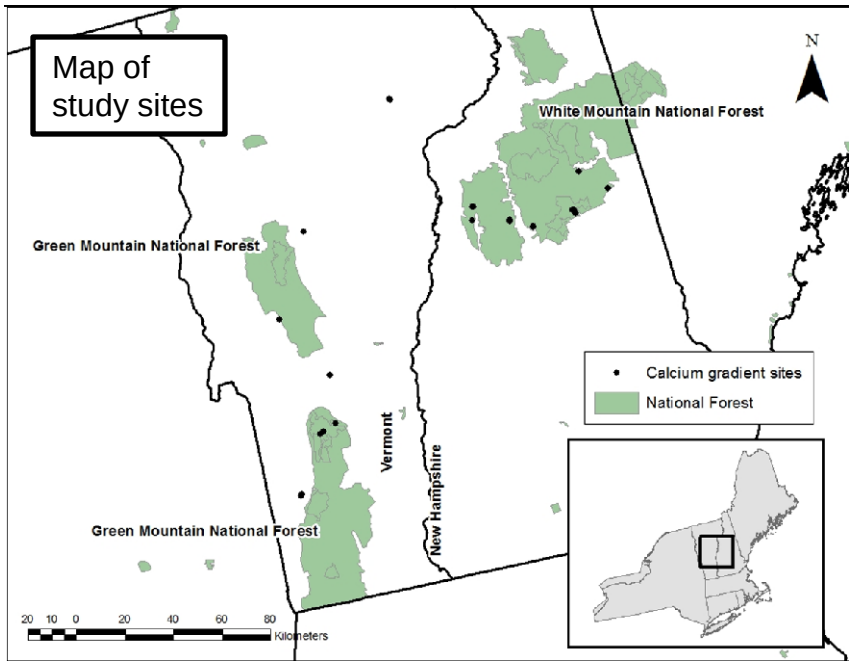
Soil biodiversity supports ecosystem resilience to acid rain as well as changes in forest composition. Land use and forest management practices should consider impacts on soil fauna and food webs.

Background and Justification

- Decades of **acid rain** have resulted in the acidification of forest soils across the Northern Forest region, causing **depletion of calcium** (Ca) – an essential nutrient for nearly all organisms – from the ecosystem.
- A **wide variety of forest taxa**, including plants, invertebrates, amphibians and songbirds may be **threatened** by loss of Ca from acidified ecosystems.
- Despite this vulnerability, the **consequences of Ca depletion for the diversity, health and productivity of biological communities** across the Northern Forest remain largely **unknown**.
- Our study was focused on **soil fauna** and **food webs** because of their fundamental roles in **decomposition** and **nutrient cycling**. Acid-mediated changes in forest nutrition and soil habitat quality that **degrade or change soil communities** could generate feedbacks that **exacerbate nutrient losses**.
- Our research objectives were to: 1) identify species and community types that are **sensitive to acidification**, as well as those **tolerant to pollution** impacts; 2) to characterize **changes** in **soil communities** and **food web nutrition** (Ca availability to herbivores, detritivores, and predators) resulting from **acid rain**; 3) evaluate how **biodiversity** influences **movement of Ca** through the ecosystem; and 4) **identify** where highly-buffered **Ca-rich forests** serve as **refugia**.

Methods: site selection

- Existing study sites of Scott Bailey, Steve Horsely, Bob Long, Rich Hallett
- Intensive sampling of soils, vegetation and plant nutrition in 2004-2005
- Sites were selected to represent different parent materials in relation to calcium cycling and availability
- We selected 17 of these sites to add to a regional network representing a wide gradient (range) in calcium availability
  - Includes experimental sites in NH and Adirondack Park, NY
- We resampled forest vegetation and ground cover in 2012
- We intensively sampled forest floor and soil fauna in 2011 and 2012:
  - Snails (litter and timed search)
  - Arthropods (litter Berlese funnels)
  - Salamanders (timed search)



Foliar calcium nutrition across sites, ordered by soil aluminum [Al]

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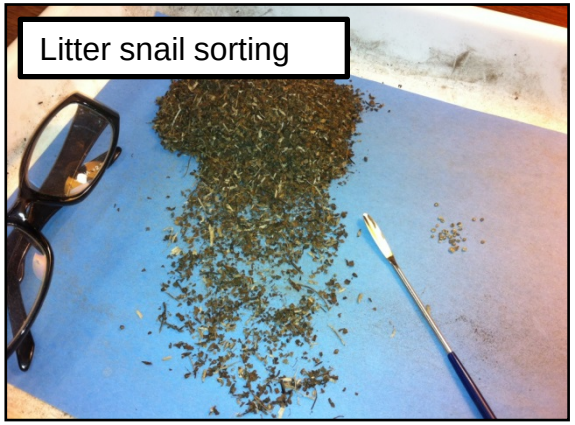
Methods: sampling biodiversity

- **Snails**: We collected 1 m^2 leaf litter, dried and sieved the material, and sorted through fractions for snails. We also conducted 120 minutes timed search under logs and cover objects. All specimens identified to species level.

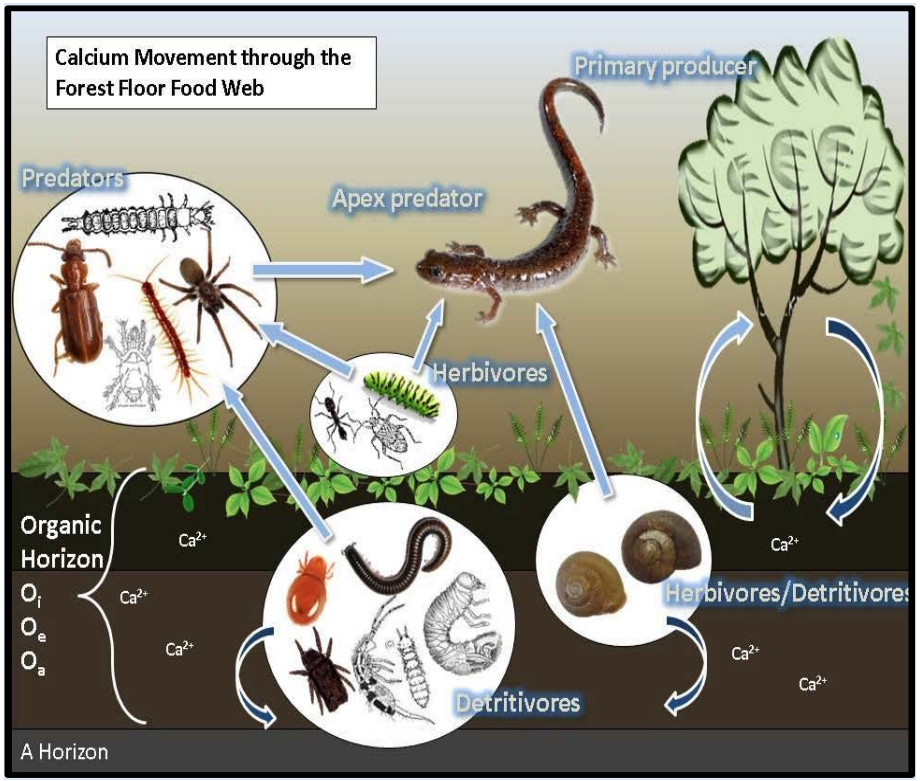
- **Soil invertebrates**: We collected 1 m^2 leaf litter, extracted animals using Berlese funnels

- **Salamanders**: 60 minutes timed search, gastric lavage (stomach contents), body size and body condition,



Methods: food web nutrition

Conceptual model of calcium flows in the forest floor food web, including focal taxa at each trophic level



- Organic and mineral soil, sugar maple foliage, and soil fauna were analyzed for **nutritional content** of calcium (Ca) and other nutrients

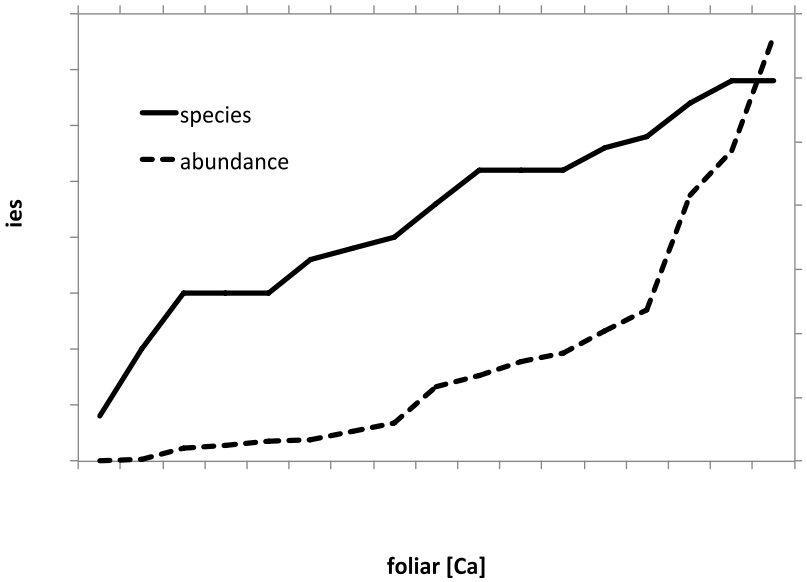
- Together, these samples represent a **food web**: producers (plants), primary consumers / detritivores (e.g., snails, springtails, some mites), secondary consumers (e.g., spiders, some mites) and apex predators (salamanders)

- Snail nutritional content assayed by species by site
- Other soil invertebrates assayed by functional groups by site
  - Ants, beetles, larvae, mites, springtails, flies, spiders, etc.
- Salamanders were collected at 9 study sites for tissue nutrition assays
- We also sampled salamander diets at all sites using gastric lavage

Results: forest snails

Species-area and cumulative abundance of snails

- Over 13,600 snails collected, ID-ed
- Range: from 10 to 4700+ per site
- Species richness and abundance increases with the calcium nutrition of foliage and soils
- However, much diversity persists (15 of 34 spp.) at Ca-poor sites



- Soil aluminum (Al) has the strongest overall effects on snail species richness and abundance (explains > 70% of variance)
- Al occurs naturally in soils but is increased by acid pollution
- Aluminum is toxic to snails, but some species tolerant of high Al

5 –

-

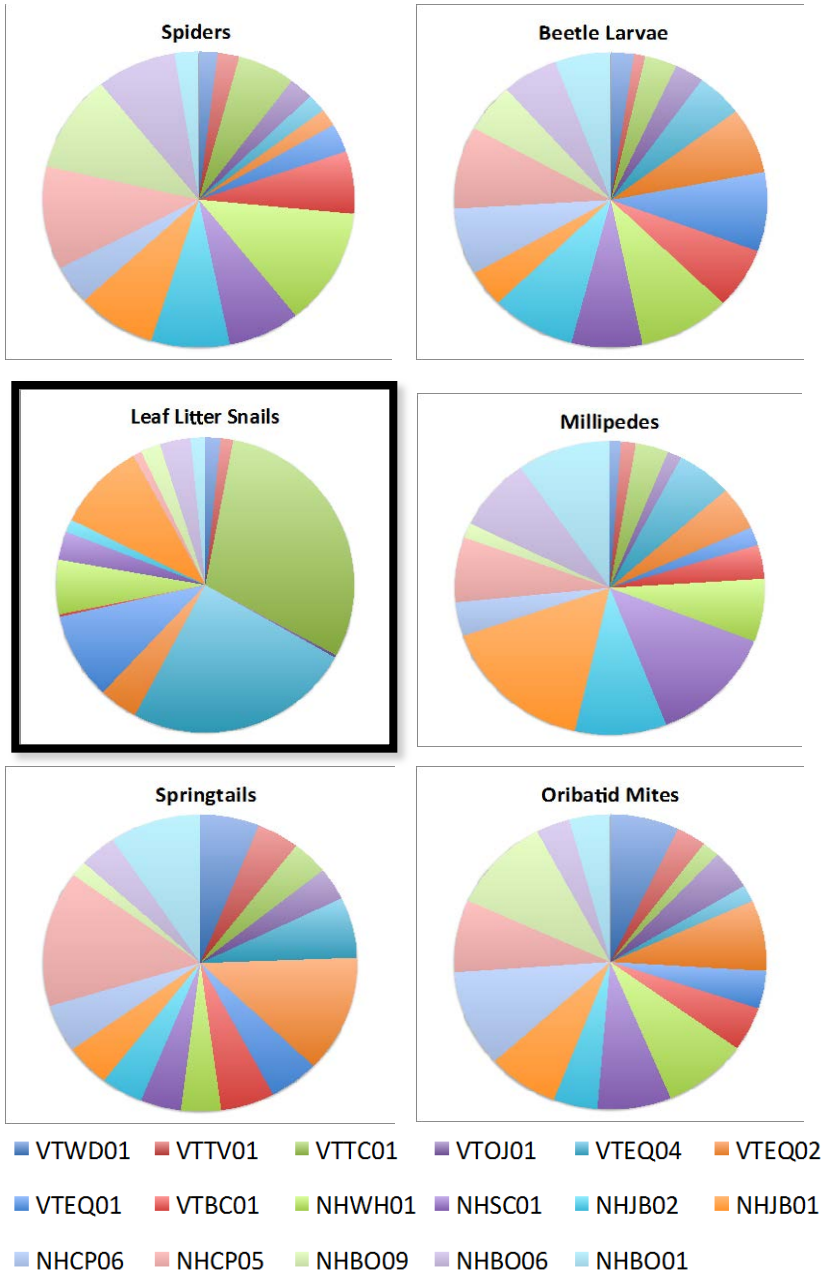
-500 –

Models of snail species richness (top) and snail abundance (bottom) as a function of soil extractable [Al]

Results: soil arthropods

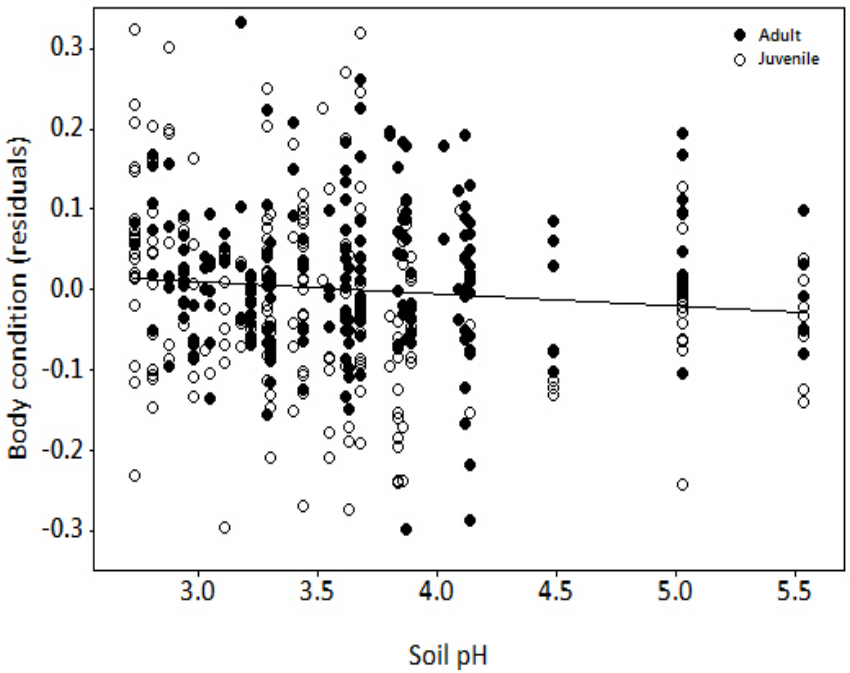
Relative abundance of soil arthropods (by functional group) by site

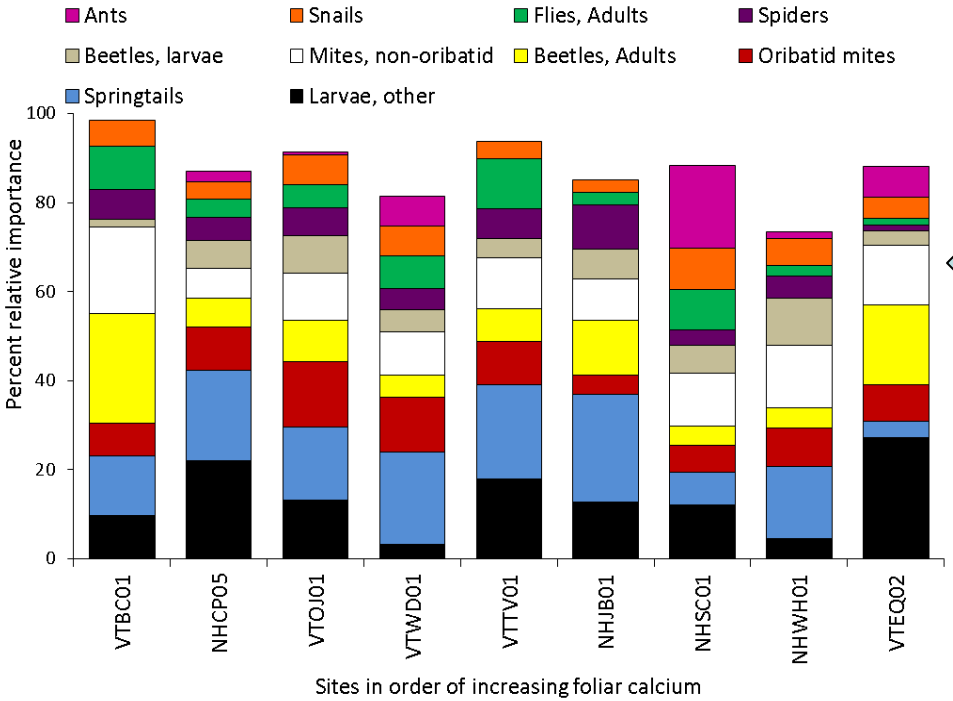
- Over 337,000 arthropods (!!) collected and sorted to groups
- Unlike the litter snails, which vary significantly across sites…
- The most common arthropod functional groups are more evenly distributed across sites and calcium gradient
- Results suggest an overall lack of sensitivity to soil chemistry at the level of functional groups (Order or Family)
- Total arthropod abundance does not vary significantly among sites



Results: woodland salamanders

- Redback salamanders are **NOT** sensitive to acidified soils
- No trends in abundance, body condition or size, along a 34-site gradient in soil pH and Ca, from the ADKs (NY), VT and NH
- Population density of northern dusky explains ADK results*





- Salamander diets are largely consistent, may contain more Ca-rich larvae at Ca-rich sites
- No differences in tissue nutrition based on soil Ca or pH
- No evidence that acidified forests are limiting to redbacks

* See Beier et al. 2012 Can. J. For. Res

Results: acid rain and biodiversity

- Native diversity of snails in the Northern Forest (NF) includes 10-15 species capable of persisting on acidified soils
- Several species are relatively large-bodied, and represent key sources of Ca for the food web

- Redback salamander populations persist in chronically acidified soils
- Salamander diets are consistent across Ca-rich and Ca-poor sites

- Diversity and composition of soil invertebrate groups are not sensitive to soil chemistry
- Many Ca-rich insect prey (e.g., larvae) persist in habitats with low Ca nutrition and low pH

Results: calcium in food web

- Snails are the most concentrated source of calcium in food web
- The '**snail calcium pool**' equals the estimated total amount of dietary calcium available to predators that consume snails
- We found that the snail Ca pool varied among sites – and was **weakly correlated with soil chemistry and plant nutrition**

- Mites, beetles, springtails and many types of larvae are the most important sources of Ca – aside from snails – in soil food web
- These prey are consistently common regardless of soil or plant Ca

- Salamanders exhibit no signs of calcium or dietary deficiency in Ca-poor forests – population metrics are unrelated to soil chemistry

- We are now estimating Ca available at each trophic level – primary consumer, secondary consumer, apex predator – to evaluate how they vary with the much larger Ca pools in vegetation and soils

Broader outcomes:
Acidity shapes forest communities

- Species richness of plant and soil fauna communities is higher on less acidic, calcium-rich sites
- Higher levels of aluminum – which is toxic – in very acidic soils may be the primary limitation to diversity
- However, it is unknown whether increased aluminum toxicity (due to acid rain) has caused local species extinctions
- Land snails are the most sensitive to aluminum and soil acidity, but numerous acid-tolerant species persist across the NF
- Major types of soil arthropods do not appear to be sensitive to soil chemistry or plant nutrition
- Redback salamanders – a keystone species in the Northern Forest – are not sensitive to soil acidity, as long believed
- Competitive interactions with northern dusky salamanders may determine how redbacks respond to forest biogeochemistry

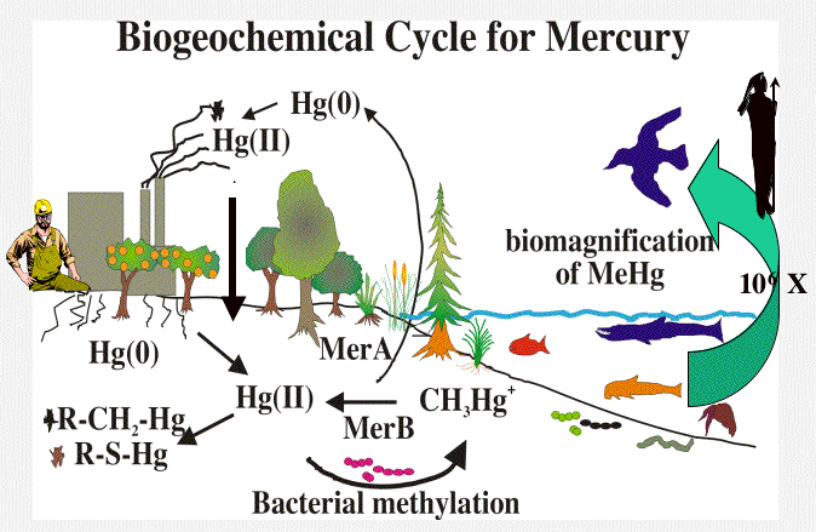
Broader outcomes:
Diversity may stabilize nutrient cycles and forest food webs

- Acidic conditions mean low pH, high [Al] habitats with lower nutritional quality of plant food sources (basis of entire food web)
- Native diversity of soil fauna in the NF region includes many species that are adapted to naturally acidic conditions
- We found that these species can tolerate – to varying degrees – the impacts of pollution-driven ecosystem acidification
- As a result, food webs can continue to function without dramatic losses in calcium availability, despite major changes in the calcium nutrition of soils and vegetation, in part due to acid rain
- Conservation of soil biodiversity may be essential to supporting songbird and mammal diversity, as well as the maintenance and recovery of key ecosystem processes affected by acid rain
- Land use change, use of pesticides, and introduced or invasive species could threaten some of these important soil fauna

Future directions

Mercury in Northern Forest Food Webs

Soil fauna being analyzed for mercury (total and methylmercury) in a pilot study linking acid and mercury pollution effects on forest ecosystems



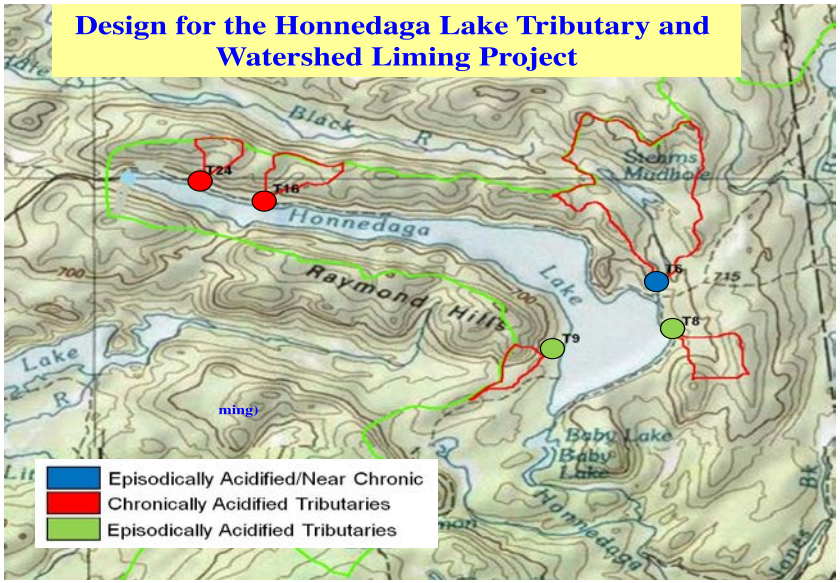
Reference Collection of Northern Forest Snails

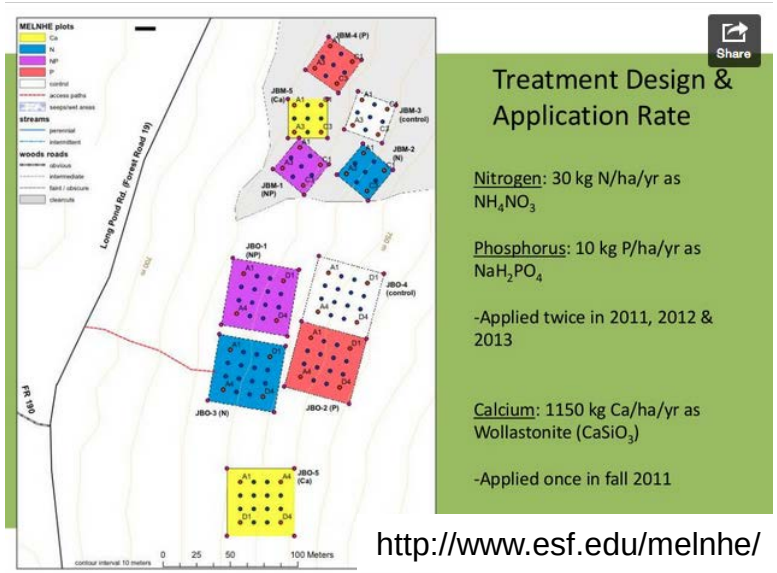
Our collection of over 13,300 land snails includes 34 common and rare species and is the most comprehensive available for upland hardwood forests in the NF region. Archived specimens are available for research and educational purposes.

Future directions

Honnedaga Lake Ecosystem Restoration

One of the most acid-impaired ecosystems in the Adirondacks, Honnedaga Lake watersheds and streams were limed in 2013. We are sampling soil biodiversity and food web responses to this experiment.





http://www.esf.edu/melnhe/

Bartlett Forest Multiple Nutrient Limitation Study

In collaboration with Ruth Yanai's group, our team collected soil invertebrates in 12 plots representing different stand ages and nutrient addition treatments at Bartlett Forest, NH. This field work was supported by the NSRC during the summer of 2012.

Products: Publications

- Beier CM, *Bondi CA, Hotopp K, Bailey S. In review. Biogeochemical controls on niches and community assembly of forest detritivores. *Soil Biology and Biochemistry*
- *Bondi CA, Green S, Ducey P, Beier CM. In review. Evaluation of the gastric lavage method to collect diet samples of northern redback salamanders. *Herpetological Review*
- *Yantachka-Corman J, Beier CM, Gibbs JP, Glennon M, Cohen J. In review. Comparison of point counts and automated digital recording systems as avian survey methods. *Journal of Field Ornithology*
- Beier CM, Woods AM, Hotopp K, Mitchell MJ, Gibbs JP, Dovciak M, Leopold DJ, Lawrence GB, Page B. 2012. Changes in faunal and vegetation communities along a soil calcium gradient in northern hardwood forests. *Canadian Journal of Forest Research* 42: 1141-1152.
- *Bondi CA, Beier CM, Caputo JD, Fierke M, Bailey S. In preparation. Functional redundancy in detritivore communities stabilizes trophic calcium availability in acidified forests. *Ecosystems* (to be submitted by 12/31/14).
- *Bondi CA, Beier CM, Ducey P, Bailey S. In preparation. Redback salamanders tolerate acidic habitats across their northern range. PLoS ONE (to be submitted by 12/31/14).

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Products: Publications

- Bondi CA, Beier CM, Bailey. In preparation. Interspecific competition mediates sensitivity of the redback salamander to habitat chemistry. *Ecology* (expected submission May 2015).
- *Bondi CA. In preparation. Salamanders and soil food webs in relation to calcium availability in northern hardwood forest ecosystems. PhD Dissertation (expected completion May 2015)
- **Dombrowski P, Bondi CA, Beier CM. In preparation. Evaluating the efficiency of snail extraction methods from leaf litter samples for community analyses. *Malacologia* (expected submission May 2015)
- **Capelli LR, **Mills JS. In preparation. Growth rates and age structure of redback salamander populations across a soil chemistry gradient in northern hardwood forests. Honors Thesis, Environmental and Forest Biology, SUNY ESF (expected completion May 2015).
- **Smith, D. 2014. Land snail diversity in northern hardwood forests with varying stand age and soil calcium. Senior Synthesis – Forest Health, SUNY ESF.

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Products: Presentations

- *Bondi CA, Beier CM., Fierke MK, Ducey PK. 2014 Can The Northern Redback Salamander (*Plethodon cinereus*) Persist In An Acidified Landscape? Northeast Partners in Amphibian and Reptile Conservation 2012 Annual Meeting, Salamanca, New York.
- *Bondi CA, Beier CM. 2013. Land snail assemblages in relation to calcium availability in northern hardwood Forests. 2013 Northeastern Natural History Conference, Springfield, MA.
- **Donato N, *Bondi CA, Beier CM. 2014. Leaf litter arthropod communities in relation to stand age and soil calcium in northern hardwood forests. *Spotlight on Student Research, SUNY-ESF, Syracuse, NY.*
- *Bondi CA, Beier CM. 2013. How does calcium depletion from forest soils affect trophic interactions and nutrient flows of terrestrial foodwebs? Northeastern Ecosystem Research Cooperative Annual Meeting, Saratoga Springs, NY.
- *Bondi CA, Beier CM. 2012. Are redback salamanders sensitive to soil calcium? Contrasting evidence from across the Northern Forest region. Eastern Canada and USA Forest Science Conference, Durham, NH.
- **Bullis D, *Bondi CA, Fierke M, Beier CM. 2013. Coleoptera Assemblages in Northern Hardwood Forests of the White and Green Mountains. *Spotlight on Student research, SUNY-ESF, Syracuse, NY.*

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Products: Presentations (cont.)

- **Green S, *Bondi C, Beier CM. 2013. Efficacy of the gastric lavage technique for sampling the diet of redback salamanders (*Plethodon cinereus*). *Spotlight on Student Research, SUNY-ESF Spring 2013.*
- *Bondi CA, Beier CM, Fierke M. 2012. Importance of Soil Calcium in the Distribution and Diet of Eastern Redback Salamanders: Contrasting Results from Across the Northern Forest Region. 2012 Northeastern Natural History Conference, Syracuse, NY.
- *Bondi CA, Beier CM. 2012. Are redback salamanders sensitive to soil calcium? Contrasting evidence from across the Northern Forest region. Northeast Partners in Amphibian and Reptile Conservation 2012 Annual Meeting, Crawford Notch, NH.
- *Yantachka J, Beier CM, Glennon M, Gibbs JP. 2012. Relationships among Adirondack songbird communities, calcium availability and acidic deposition. *2012 North American Ornithological Conference*, Vancouver, British Columbia, Canada.
- **Swider C, *Yantachka J, Beier CM. 2012. Bioacoustic monitoring of songbirds in the Adirondack Park, NY. *ESF Spotlight on Research*, SUNY ESF, Syracuse, NY.
- *Yantachka J, Beier CM. 2012. Relationships among Adirondack songbird communities, calcium availability and acidic deposition. *2012 Northeastern Natural History Conference*, Syracuse, NY.

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