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LAND SNAILS AND SOIL CALCIUM IN CENTRAL APPALACHIAN MOUNTAIN FOREST

KENNETH P. HOTOPP [1]

ABSTRACT — Few studies have attempted to quantify the association between land snail communities and calcium (Ca) in upper soil horizons. If soil Ca is important to land snails, then land snail communities may be sensitive to reductions in soil Ca, including those caused by atmospheric acid deposition. In this study, snail density was estimated at ten 200m^2 plots in mature forest using a litter sieving technique, and species richness was determined from litter sieving and timed searches. The most abundant snail species was the small spot, *Punctum minutissimum* (I. Lea), representing 34% of the specimens collected. Land snail density and species richness were positively correlated with extractable Ca, water soluble Ca, and pH in the Oe soil horizon and in the horizon below. Basal area of sugar maple, *Acer saccharum* Marsh., was positively associated with snail density and Ca in the Oe horizon, while basal area of red maple, *Acer rubrum* L., was negatively associated with snail density and Ca in the Oe horizon.

INTRODUCTION

Recent work has raised concern that land snails may suffer impacts due to anthropogenic changes to soil calcium. A decline in Ca at the soil surface on poor sites in Sweden was correlated with a decline in land snail abundance (Wäreborn 1992). Atmospheric acid deposition and timber harvest have been identified as two mechanisms by which soil Ca can be reduced (McLaughlin and Wimmer 1999). Further, because land snails play a role in cycling Ca to higher trophic levels, ripple effects through ecosystems can occur. On poor soils in the Netherlands, a dearth of snail shells linked to acid deposition limited reproductive success in the great tit (*Parus major*) (Graveland 1996, Graveland et al.1994). Some birds did not obtain sufficient Ca to develop healthy eggshells.

Land snails (Mollusca: Gastropoda) are ubiquitous in the eastern United States, where there are at least 500 native species (Hubricht 1985), including both shelled animals and slugs (which lack shells). In forest habitats, snails generally live among low plants, leaf litter, and woody debris in the upper soil horizons, though they may also climb trees or follow crevices deeper underground. Most land snails feed

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[1] Appalachian Conservation Biology, 83 Frost Avenue, Frostburg, MD 21532; khotopp@hereintown.net.

upon plant matter including live vegetation, rotting leaves and wood, sap, and fungi (e.g., Grime and Blythe 1969; Pilsbry 1939-40, 1946-48). Some land snails also feed upon animal scats and carcasses, or other snails, nematodes, or other invertebrates. Many snails ingest small soil particles and rasp larger rocks or snail shells in order to obtain the Ca essential to reproduction, shell development (snail shells are composed mostly of calcium carbonate, $CaCO_3$), and other physiological needs (Fournié and Chétail 1984). In times of Ca demand, such as egg laying, snails mobilize Ca from their own internal organs and shells (Fournié and Chétail 1984).

In plants, calcium is present throughout leaves and wood, where it is important in regulating nutrient and water movement, cell division, and construction of cell walls (McLaughlin and Wimmer 1999). However, Ca content of plant parts varies greatly among species. Tree species with relatively high leaf Ca concentrations include basswood (*Tilia americana* L.), cucumber tree (*Magnolia acuminata* L.), eastern redcedar (*Juniperus virginiana* L.), flowering dogwood (*Cornus florida* L.), and pignut hickory (*Carya glabra* (Mill.)), while low leaf Ca species include pines (*Pinus* spp.), eastern hemlock (*Tsuga canadensis* (L.) Carr.), and chestnut oak (*Quercus prinus* L.) (Chandler 1937, Plice 1934, Thomas 1969). As a result of these differences, tree species composition influences the Ca content of upper soil horizons through leaf litter (Boettcher and Kalisz 1990, Plice 1934, Vesterdal and Raulund-Rasmussen 1998).

Land snails are consumed by a variety of predators: larvae of lampyrid beetles (Schwalb 1961), adult ground beetles (especially Pterostichine and Cychrine beetles; Digweed 1993, Ingram 1950, Sturani 1962), salamanders, shrews (Ingram 1942), birds (e.g., various sparrows, blackbirds, thrushes, ruffed grouse (*Bonasa umbellus*), and wild turkey (*Meleagris gallopavo*); Martin et al. 1951). Millipedes and squirrels may also opportunistically prey upon snails (Hotopp, pers. obs.). In animals, Ca is vital for fluid regulation, muscle contraction and cell wall function, and is a major structural component of bone and eggs. Snail predators vary widely in the proportion of Ca-rich snail shell they consume, depending upon the size and defenses of the snail and the type of predator. For example, a beetle may attack a snail through the aperture without eating any shell, while a wild turkey may eat a snail whole. Even the foraging experience or physiological state of an individual predator may influence the proportion of snail shell consumed.

Nutrient concentrations in the upper soil have been long presumed to indicate nutrient availability for snails because these horizons contain snail food and are derived from potential snail food. In an early observation of the affinity of certain land snails for various soil characteristics, qualitative associations were reported between several snail species, soil chemistry, and soil moisture in Great Britain (Boycott 1934). In North America, correlations were found between certain snail species and soil Ca, Mg, and pH in Illinois (Riggle 1976). Only *Strobilops labyrinthicus* (Say 1817) was significantly correlated with soil Ca. Similarly, though measuring pH rather than Ca directly, species-specific associations with pH were shown in the southern Appalachian Mountains (Coney et al. 1982). In many studies of the relationship between snails and soil the researchers have examined pH rather than soil Ca, possibly because it is more easily and inexpensively measured.

While the above studies observed species-specific associations, few have examined the relationship between soil Ca, or pH, and snail communities. In two counties in Virginia, more snails were found on sites with higher Ca, Mg, K, and organic matter (Burch 1955). However, in this early study, snail and soil sampling techniques were not clearly controlled. In Finland, land snail abundance and species richness were positively correlated with soil pH, though snail abundance declined slightly above pH 6.5 (Valovirta 1968). On Wisconsin carbonate cliffs, pH, but not Ca, was positively correlated with land snail species richness in the narrow range of pH 7 to 8 (Nekola and Smith 1999). In Sweden, a strong positive association was found between soil Ca and land snail abundance and species richness (Wäreborn 1969,1992).

At least three soil parameters related to calcium may be of interest with regard to land snail communities — extractable Ca, water-soluble Ca, and pH. Extractable Ca, which includes calcium oxalate, is one measure of Ca potentially available to consumers such as snails. Water-soluble Ca includes calcium citrate, which has been shown in vitro to increase snail reproduction more than calcium oxalate (Wäreborn 1979). Calcium citrate is the dominant Ca compound in ash (*Fraxinus* spp.), maple (*Acer* spp.) and basswood (*Tilia* spp.) leaves, while calcium oxalate is more prevalent in oak (*Quercus* spp.) and beech (*Fagus* spp.) leaves. Soil pH has been shown to have a positive effect upon land snail reproduction independent of Ca levels. This pH effect was demonstrated in a laboratory experiment (*Cochlicopa lubrica* (Müller, 1774) Wäreborn 1979), and may be suggested for North American species in a field study in Wisconsin (Nekola and Smith 1999). Soil organic matter had a positive association with land snail densities on sites in Virginia (Burch 1955).

The central Appalachian Mountain project presented here examines whether there is an association between the land snail community and soil Ca similar to that found in Scandinavia.

STUDY AREA

Land snail and soil samples were collected at ten sites within an approximately 1,000 km^2 area of the Allegheny Plateau of the Appalachian Mountains, Garrett County, Maryland, during the summer of 1996 (Fig. 1). The sites ranged from 270m to 1,100m, and no study sites were <3km apart. The National Weather Service Station, at Oakland, Maryland, 740 m elevation and within the study area, reports an average annual temperature of 9°C and average annual precipitation of 119cm (Owenby and Ezell 1992).

The study area lies on the Eastern Continental Divide, with the eastern portion draining east into the Savage River and then the Potomac River, and the western portion draining northward into the Casselman and Youghiogheny Rivers, and from there into the Ohio River. The typically rocky and acidic soils of the study area (largely Inceptisols and Ultisols; Stone and Mathews 1974) are derived from sedimentary rock of Permian, Pennsylvanian, Mississippian and early Devonian origin. Characterizing the region's topography are parallel ridges of resistant Pottsville sandstone (trending southwest-northeast), with major streams lying in the intervening anticlines and synclines.

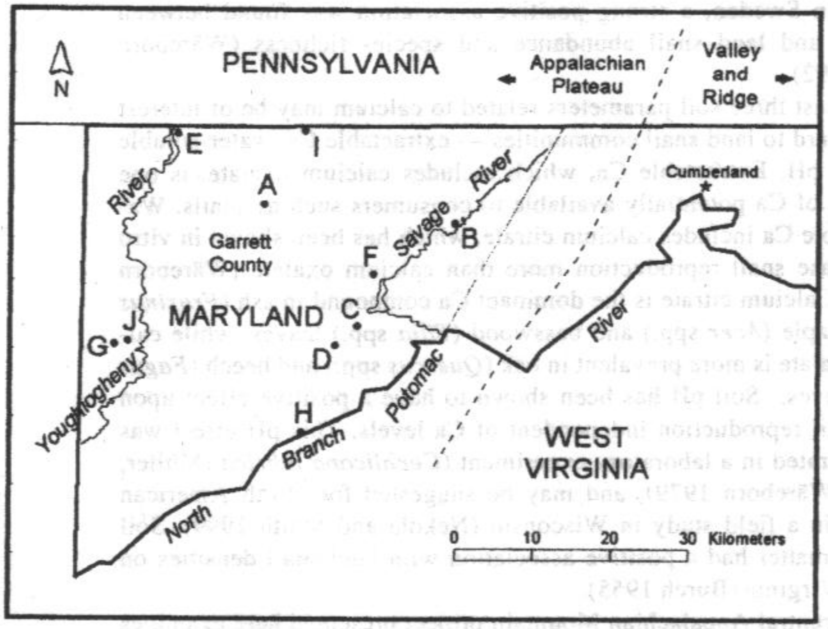

Figure 1. Land snail study sites. A, Bear Creek; B, Bear Pen Run; C, Crabtree Slope; D, Migrating Rocks; E, Mill Run; F, Monroe Run; G, Murley Run; H, North Branch; I, Puzzley Run; J, Unnamed Tributary. Map by Emily White.

Mid-Pleistocene vegetation of the study area was a tundra-like community of sedges (Cyperceae), with spruces (*Picea* spp.) and pines (*Pinus* spp.) probably in river valleys (Maxwell and Davis 1972), but by 5,000 BP deciduous trees dominated, with oaks (*Quercus* spp.) the most common. Today the forests of the study region are dominated by hardwood communities: oak/hickory forest (upland oaks and red maple (*Acer rubrum* L.)) and northern hardwoods (sugar maple (*Acer saccharum* Marsh.)), American beech (*Fagus grandifolia* Ehrh.), yellow birch (*Betula allegheniensis* Britton), red maple and black cherry (*Prunus serotina* Ehrh.); Frieswyk and DiGiovanni 1988). All of the study sites were mature (> 60 year) oak/hickory or northern hardwood forests. Northern red oak (*Quercus rubra* L.), sugar maple, red maple, basswood, serviceberry (*Amelanchier* cf *arborea* Michx.), and black cherry are each found at four or more of the sites.

Nomadic Native Americans were present in the region as early as 12,000-8,5000 BP with settlements appearing around 5,000 BP and land clearing for agriculture occurring 3,000 BP along the major river valleys (Wall 1981). European settlement began in the 1760's but logging and clearing for agriculture was localized until the mid-1800's, when portable steam-powered sawmills arrived (Brown 1896). All of the study sites indicate a history of logging, but at least two sites contain some trees that predate the turn-of-the-century commercial logging boom. None of the sites were plowed or logged over the past several decades.

METHODS

Ten sites were selected to represent a range of topographic positions and soil types in relatively undisturbed, apparently mature forests (>60 years). At each, a 10m x 20m area with representative and homogeneous vegetation, topography, and aspect was selected. Study sites were sampled for land snails and soil between July 24 and September 10, 1996. In order to control for land snail activity, samples were collected at midday, following a period of at least 48 hours without rain. Leaf litter volume measurements, for the purpose of estimating litter volume and snail density on each site, were taken on September 6 and 7, 2000. Two techniques for sampling land snails were employed at each site: timed search and sieved litter. A ten-minute timed search of the leaf litter surface, rocks, woody debris, and live plant stems was conducted across the 200 m^2 sample plot. Live snails that were found were placed in tap water for 24 hours then transferred to 70% isopropanol. Litter was gathered randomly from the Oi and Oe across the sample site, placed on a 10mm sieve to a depth of approximately10 cm, shaken 50 times, turned over, and shaken 50 more times. This process was repeated until approximately two liters of sieved material, including snails, were collected. This method was intended to approximate the protocol of Wäreborn (1969, 1992). The litter (with snails) was stored in plastic bags until the snails could be sorted and identified. Only half of each homogenized, two-liter sample was sorted for snails.

Physical characteristics recorded at each site were slope, aspect, distance to permanent stream, and distance to seasonal water (as indicated by dry channels). The diameter at breast height (dbh) of all trees (>5 cm dbh) on the plot was recorded and the smaller shrubs and vines identified. Trees within two meters of the perimeter of the plots were also recorded, as they may contribute to on-site litter. Basal area for the tree species appearing at five or more sites was calculated. To estimate the density of snails collected in the procedures described above, the depths of the Oi and Oe horizons were measured in 10 locations dispersed across the site, and the volume of sieved litter resulting from sieving 10 liters of these horizons (employing the previously described protocol) was also measured.

Snails were removed from the sieved litter by spreading out a thin layer of sieved litter and examining it with the aid of a magnifying visor. Snails collected in this study were identified primarily by external characteristics using a dissecting microscope and the keys of Burch (1962), Emberton (1988, 1991), and Pilsbry (1939-40, 1946-48). The loss of four Philomycid slug specimens prevented species identification of some of the ten slugs collected. F. Wayne Grimm, Eastern Ontario Biodiversity Museum, reviewed identification of some smaller species, including *Glyphyalinia* spp. After sorting, sieved litter samples were dried for 24 hours at 35°C prior to re-measuring their mass and volume. All snail specimens are on deposit in the Delaware Museum of Natural History.

At each site half a liter of material from each of the O to B soil horizons was removed from each of six pits, one each at the center of a rectangular one-sixth division of the site. During dry periods, such as those in this study, most land snails are encountered in damp lower layers of leaf litter, but above mineral horizons in which movement would be difficult. As a result the soil horizons of greatest interest were Oe, the Oa or A (referred to as Oa_a/A), depending on the site. The distinction between an Oa and A horizon was made based on the amount of organic matter (Oa > 50% LOI; Soil Survey Staff 1998).

Soils were analyzed by the Maryland State Soil Testing Laboratory (University of Maryland, College Park). Extractable Ca was measured with a flame photometer (Technicon version 4) after extracting with

Mehlich I Double Acid Extract for two hours (Flannery and Markus 1980, Mehlich 1953). Water-soluble Ca was measured with a flame photometer after extracting with distilled water for two hours (Flannery and Markus 1980), Mehlich 1953. Measurements of pH were made electrometrically using a 1:1 volume of sample to water (McLean 1982). Organic matter was determined by ashing at 350 C° (Storer 1984). Results are expressed on an oven-dried basis.

The density of land snails was calculated from the sieved litter samples by taking the volume of material searched, which varied from 0.9 to 1.4 liters, and converting it to an area basis using the measurements of litter described above. For species richness in sieved litter samples, numbers uncorrected for the volume sieved are reported, as the relationship between species richness and litter volume is unknown for these sites. The number of species from each site includes both those collected by the sieved litter and timed search techniques.

Correlation analysis was used to test associations between land snail abundance, species richness, and soil chemistry measurements and tree species basal area.

RESULTS

A total of 618 snails, including shelled animals and slugs, representing at least 39 species were collected from the 10 Garrett County sites (Table 1). These include snails found using both sieved litter and timed search techniques. The most abundant snail species was the small spot, *Punctum minutissimum* I. Lea, representing 34% of the specimens collected (Fig. 2). The second most frequent category was unidentified snails, mostly immature or broken specimens. Land snail numbers collected by sieved litter technique ranged from 2 to 206 per sample, and those collected using the 10-minute timed search ranged from 0 to 14 (Table 2). Estimated snail densities ranged from 2 to 485 per m^2. Land-snail species richness of sites ranged from 2 to 20. Because some species were found with both sieved litter and timed search techniques, the total number of species for each site is not additive. Slugs were encountered only in timed searches.

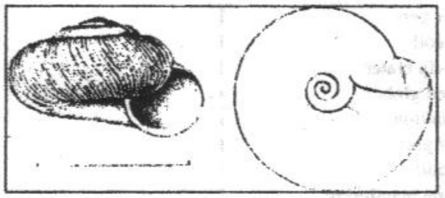

Figure 2. *Punctum minutissimum* (I. Lea 1841), from Pilsbry (1948). Reprinted with permission, Academy of Natural Sciences of Philadelphia. Scale line = 1mm.

Site characteristics included distance to permanent streams, which varied from 15m to more than 200m, and distance to seasonal streams, which varied from 0m to more than 200m (Table 3). Leaf litter volumes estimated from litter depth measurements ranged from 9,780 to 4,720

Table 1. Land snails collected at 10 Garrett County, Maryland sites by timed search and sieved litter sampling. Common names are mostly from Turgeon et al. (1988).

Species	Common name	Number
Punctum minutissimum (I. Lea, 1841)	Small spot	212
Unidentified specimens		90
Striatura meridionalis (Pilsbry and Ferriss, 1906)	Median striate	51
Carychium exile I. Lea, 1942	Ice thorn	36
Polygyridae	Polygyrids	23
Glyphyalinia spp.	Glyphs	21
Cochlicopa morseana (Doherty, 1878)	Appalachian pillar	20
Zonitoides arboreus (Say, 1816)	Quick gloss	20
Euconulus polygyratus (Pilsbry, 1899)	Fat hive	13
Glyphyalinia cumberlandiana (G.H. Clapp, 1919)	Hill glyph	11
Pupillidae	Pupillids	11
Striatura ferrea E.S. Morse, 1864	Black striate	10
Glyphyalinia picea Hubricht, 1976	Rust glyph	9
Striatura milium (E.S. Morse, 1859)	Fine-ribbed striate	9
Philomycidae	Mantleslugs	8
Discus patulus (DeShayes, 1830)	Domed disc	7
Gastrocopta pentodon (Say, 1829)	Comb snaggletooth	7
Strobilops aeneus Pilsby, 1926	Bronze pinecone	5
Euconulus fulvus (Müller, 1774)	Brown hive	4
Glyphyalinia rhoadsi (Pilsbry, 1899)	Sculpted glyph	4
Guppya sterkii (Dall, 1888)	Granule	4
Haplotrema concavum (Say, 1821)	Gray-foot lancetooth	4
Striatura exigua (Stimpson, 1850)	Ribbed striate	4
Helicodiscus parallelus (Say,1817)	Compound coil	3
Helicodiscus shimeki Hubricht, 1962	Temperate coil	3
Mesomphix perlaevis (Pilsbry, 1900)	Smooth button	3
Pallifera dorsalis (A. Binney, 1842)	Pale mantleslug	2
Triodopsis tridentata (Say, 1816)	Northern threetooth	2
Ventridens demissus (A. Binney, 1843)	Perforate dome	2
Ventridens arcellus Hubricht, 1976	Golden dome	2
Ventridens ligera (Say, 1821)	Globose dome	2
Allogona profunda (Say, 1821)	Broad-banded forestsnail	1
Anguispira alternata (Say, 1816)	Flamed disc	1
Euconulus sp.	Hive	1
Glyphyalinia indentata (Say, 1823)	Carved glyph	1
Glyphyalinia solida H.B. Baker		1
Hawaiia miniscula (A. Binney, 1840)	Minute gem	1
Helicodiscus cf *notius* Hubricht, 1962	Tight coil	1
Appalachina sayana (Pilsbry, 1906)	Spike-lip crater	1
Mesodon zaletus (A. Binney, 1837)	Toothed globe	1
Mesomphix inornatus (Say, 1821)	Plain button	1
Nesovitrea electrina (Gould, 1841)	Amber glass	1
Paravitrea sp.	Supercoil	1
Philomycus flexuolaris Rafinesque, 1820	Winding mantleslug	1
Stenotrema sp.	Slitmouth	1

Table 2. Numbers of snails and snail species at ten central Appalachian Mountain sites.

Site	Sieved litter volume searched (liters)	No. snails sieved litter	Estimated snails/l	Estimated snails/m^2	No. snails timed	No. species sieved search	No. species timed litter	Total no. Species search
Bear Creek	0.9	2	0.07	2	0	2	0	2
Bear Pen Run	1	107	9.10	257	10	13	8	20
Crabtree Slope	1	103	9.01	441	14	11	6	14
Migrating Rocks	1.2	2	0.07	3	1	2	1	3
Mill Run	1.4	71	4.69	111	3	8	2	9
Monroe Run	1.1	17	1.16	43	6	8	5	12
Murley Run	1.2	37	2.62	62	4	11	3	13
North Branch	0.9	206	11.4	485	10	11	5	13
Puzzley Run	1.2	11	0.53	16	1	6	1	7
Unnamed Trib	1	9	0.63	21	4	1	4	5

Table 3. Some characteristics of ten central Appalachian Mountain land snail sampling sites.

Site	Slope (°)	Aspect (°)	Distance to stream (meters)	Distance to seasonal channel (m)	Average litter depth (mm) N=10	Average sieved litter (l) from ten l site litter N=2	Estimated litter volume (l/ha^{-1000})	No. tree species
Bear Creek	15	290	100	100	27	0.325	272	6
Bear Pen Run	25	50	40	40	28	0.850	283	8
Crabtree Slope	25	40	>200	10	49	0.875	489	3
Migrating Rocks	20	325	>200	>200	39	0.425	387	6
Mill Run	10	10	>200	2	24	0.925	237	9
Monroe Run	10	40	15	0	37	0.750	369	7
Murley Run	10	90	50	12	24	0.850	236	6
North Branch	10	150	100	0	42	0.500	424	5
Puzzley Run	10	245	>200	5	30	0.575	296	4
Unnamed Trib	0	-	15	15	34	0.700	340	4

Table 4. Soil parameter averages of two upper soil horizons for ten central Appalachian Mountain sites. Ca in g/kg oven-dried soil.

Site	Extractable Ca (g/kg soil) Oe	Extractable Ca (g/kg soil) Oa/A	Water soluble Ca (g/kg soil) Oe	Water soluble CA (g/kg soil) Oa/A	pH Oe	pH Oa/A	Organic matter (%) Oe	Organic matter (%) Oa/A	Lower soil horizon
Bear Creek	4.38	1.03	0.08	0.04	4.3	3.7	80	62	Oa
Bear Pen Run	15.1	9.59	1.19	0.58	6.1	5.7	67	34	A
Crabtree Slope	11.7	6.39	1.59	0.38	5.9	5.6	56	19	A
Migrating Rocks	4.81	2.34	0.13	0.04	4.7	4.0	84	81	Oa
Mill Run	7.25	2.82	1.04	0.35	5.1	4.5	61	25	A
Monroe Run	6.78	3.98	0.33	0.26	5.2	4.5	78	52	Oa
Murley Run	6.11	2.81	0.34	0.20	5.1	4.4	78	52	Oa
North Branch	11.2	8.08	1.36	0.66	6.1	5.8	66	31	A
Puzzley Run	3.77	1.91	0.15	0.03	4.2	4.0	79	51	Oa
Unnamed Trib	4.07	1.58	0.10	0.03	4.5	3.8	84	67	Oa

Table 5. Correlation coefficients of land snail community metrics and soil parameters from ten central Appalachian Mountain sites.

	Estimat. no. snails /m^2	No. snails timed search	No. snail species	Ca Oe	Water soluble Ca Oe	pH Oe	Organic matter Oe	Ca Oa/A	Water soluble Ca Oa/A	pH Oa/A	Organic matter Oa/A
Estimated # snails/m^2	1										
# snails timed search	**0.894**	1									
# snail species	**0.646**	**0.797**	1								
Ca Oe	**0.826**	**0.869**	**0.871**	1							
Water soluble Ca Oe	**0.926**	**0.864**	**0.721**	**0.881**	1						
PH Oe	**0.870**	**0.895**	**0.861**	**0.949**	**0.884**	1					
Organic matter Oe	**-0.811**	**-0.748**	-0.630	**-0.768**	**-0.959**	**-0.749**	1				
Ca Oa/A	**0.836**	**0.857**	**0.864**	**0.971**	**0.826**	**0.950**	**-0.668**	1			
Water soluble Ca Oa/A	**0.848**	**0.786**	**0.823**	**0.910**	**0.883**	**0.950**	**-0.776**	**0.923**	1		
pH Oa/A	**0.925**	**0.914**	**0.861**	**0.95**	**0.925**	**0.975**	**-0.803**	**0.961**	**0.943**	1	
Organic matter Oa/A	**-0.765**	**-0.722**	**-0.704**	**-0.725**	**-0.901**	**-0.709**	**0.955**	**-0.646**	**-0.778**	**-0.779**	1

Correlation coefficients > 0.632 are significant at $p = 0.05$ and in bold; Correlation coefficients > 0.765 are significant at $p = 0.01$.

Table 6. Basal areas of trees found at five or more sites (m^2/ha).

	A. rubrum	*A. saccharum*	*A. arborea*	*Q. rubra*
Bear Creek	1.70	0	0	8.73
Bear Pen Run	0	5.53	0	2.70
Crabtree Slope	0	8.55	0	4.65
Migrating Rocks	6.22	0	0.38	13.38
Mill Run	0	4.40	0.44	0
Monroe Run	0	0	0	0
Murley Run	2.14	0	1.26	0.31
North Branch	0	7.73	0	0
Puzzley Run	5.02	0.69	1.32	7.54
Unnamed Trib	2.26	0	8.86	0

Table 7. Tree species basal area correlation with Oe soil horizon chemistry and land snail community metrics.

	Ca Oe	Water soluble Ca Oe	pH Oe	No. snails /m^2	# snails timed search	No. snail species
Acer rubrum	**-0.656**	**-0.682**	**-0.689**	-0.514	**-0.665**	**-0.640**
A. saccharum	**0.841**	**0.980**	**0.830**	**0.824**	**0.843**	**0.627**
Amelanchier cf *arborea*	-0.404	-0.394	-0.407	-0.288	-0.188	-0.326
Quercus rubra	-0.318	-0.364	-0.435	-0.351	-0.422	-0.550

Correlation coefficients > 0.632 are significant at $p = 0.05$ and in bold; Correlation coefficients > 0.765 are significant at $p = 0.01$.

liters. A total of twenty tree species were encountered, with a maximum of nine species on or next to a single plot. The species found at five or more sites were *Acer saccharum*, *A. rubrum*, *Amelanchier* cf *arborea*, and *Quercus rubra*.

Average extractable Ca in the Oe horizon ranged from 3.8 g/kg of dry soil to 15.1 g/kg, average water soluble Ca from 0.08 g/kg to 1.6 g/kg, and pH from 4.2 to 6.1. In the Oa/A horizon, average extractable Ca ranged from 1.0 g/kg to 9.6 g/kg, average water soluble Ca from 0.03 g/kg to 0.7 g/kg, and pH from 3.7 to 5.8 (Table 4). Average organic matter in the Oe horizon ranged from 56 to 83%, and in the Oa/A horizon from 19% to 81%.

Land snail density, number of snails in timed search, and snail species richness were positively correlated with extractable Ca, water soluble Ca, and pH in the Oe and Oa/A soil horizons (Table 5). There was a negative correlation between percent organic matter and most land snail metrics. Extractable Ca, water soluble Ca, and pH were positively correlated with each other and negatively correlated with percent organic matter in both the Oe and Oa/A horizons. Land snail abundance was not correlated with species richness.

For the four most commonly encountered tree species, basal area of *Acer saccharum* was associated with estimated snail density and number of snails in timed search (Tables 6, 7). There was a positive trend between *A. saccharum* and number of snail species. *Acer rubrum* was negatively associated with estimated snail density, number of snails in timed search, and number of snail species. *Acer saccharum* was associated with Ca, water-soluble Ca and pH in the Oe horizon, while *A. rubrum* was negatively associated with these soil characteristics.

DISCUSSION

The results of this study demonstrate strong associations between extractable Ca, water soluble Ca, and pH in upper soil horizons and estimated land snail density and land snail species richness. This result is in agreement with that of Valovirta (1968) and Wäreborn (1992). As in Scandinavia, land snails in Maryland forests of the Appalachian Mountain Plateau appear to be linked to soil Ca.

The strong association between extractable Ca, water soluble Ca, and pH does not allow the relative importance of these parameters in determining the snail fauna to be identified. Because of the strong correlations and relatively small sample size, partial regression coefficients may be spurious. Larger sample sizes and experimental manipulation of these soil parameters, as Wäreborn (1979) demonstrated with two snail species, would be more effective in measuring their relative influence.

Organic matter tends to be negatively associated with land snail community metrics, in contrast with Burch (1955). However, this result appears to agree with the tendency for rich sites to have a relatively high rate of decomposition, reducing leaf litter depth and organic matter content of upper horizons.

The two snail collecting techniques used in this project resulted in very different collections. A higher proportion of large snails and all of the slugs found in this study were collected by timed search. The sieved litter technique collected a higher proportion of smaller animals and many more specimens. Each technique resulted in the collection of snail species not found by the other, which is supportive of the idea that the two techniques sample different snail habitats and thus complement each other in assessing species richness. In a Madagascan rainforest, Emberton, et al. (1996) concluded that although timed search is a more efficient technique, sieved litter sampling increased the number of species found.

The author did not attempt to collect snails using cardboard sheets placed on the ground, although this technique has been used in several studies (e.g. Hawkins et al. 1998). Cardboard traps used previously in this region by the author were disturbed or damaged by animals, ranging from mice to black bears (*Ursus americanus*). In addition, the efficacy of cardboard traps may vary due to site differences in slope and in surface texture due to rocks, coarse woody debris, and herb density. Snail collection by cardboard might also be more effective at trapping species that are active and near the surface, but not those that are less active or in deeper litter. McCoy (1999) suggests that cardboard traps may not be appropriate for studies requiring detailed species abundance information, though they can be useful in estimating community metrics.

In sampling land snails in this study, no distinction was made between living snails and empty shells. This may have confounded results if the proportion of accumulated old shells varies with site Ca. On the other hand, small (3mm) shells in the leaf litter appear to be lost in a matter of months. For example, very few shells of small annual species are located the following spring, and the vast majority of shells in this study were from small species (e.g., *P. minutissimum* < 1.5mm; *C. exile* < 2mm). In addition, few of the larger shells collected had signs of weathering, such as a missing periostracum (protein coat), which often occurs when shells lie in the leaf litter.

Another potential problem is that leaf litter measurements used to estimate land snail densities were made four years after snail collections. This could have led to errors in estimating snail densities, which would be especially problematic if the relative amount of leaf litter between sites was much different from the year of snail collection. However, this was not expected for these mature, undisturbed forest sites. Due to the dramatic differences in snail numbers between sites, variations in leaf litter volume between sites are relatively less important.

The association of some snail community metrics with sugar maple was not surprising considering the specific site affinities of various trees, and the strong influence that differences in leaf litter exert upon soil chemistry. Sugar maple was positively associated with snail density, and snail numbers in timed search, and showed a positive trend with snail species richness. These results appear to be consistent with a study of six tree species in Connecticut, which found that sugar maple was associated with the highest soil pH and exchangeable Ca levels (Finzi et al.1998). Field collecting land snails is often more productive near sugar maples and sugar maple logs (Hotopp, pers. obs.), but sugar maple leaves have only intermediate leaf Ca content (Chandler 1937), so a potential link with land snails may involve other tree characteristics. The negative association between red maple and land snail density, snail numbers in timed search, and snail species richness, does not appear to be explained by a tree-soil connection, as red maple occurred on soils of intermediate pH (Finzi et al. 1998). However, red maple does appear to have relatively low leaf litter Ca content (Plice 1934). Because of the influence of tree species upon Ca in leaf litter and upper soil horizons, a closer look at how snail communities react to changes in stand tree species composition may be warranted.

While the present study provides a link between land snails and soil Ca for mature forests in the central Appalachian Mountain Plateau, further work is needed to determine whether they are more generally applicable in eastern North American forests. The work of Burch (1955) supports this land snail and soil Ca relationship for the Virginia piedmont and coastal plain. However, for land snails on an island in Lake Michigan, no apparent soil Ca association was found (T. Pearce, pers. comm., Delaware Museum of Natural History, DE), nor at Wisconsin carbonate cliffs (though over a narrow Ca range; Nekola and Smith 1999). The importance of soil Ca to land snails may vary with physiographic region, depending upon forest types and soil ecology, forest age and disturbance history, past glaciation, and climate.

Because of the snail-Ca linkage in central Appalachian Mountain forest ecosystems, temporal changes in soil Ca resulting from acid rain or timber harvest would be expected to affect land snail community metrics. Over a 20-year interval in Swedish spruce and oak forest sites, soil and litter-layer Ca loss was associated with an 80% decline in land snail numbers (Wäreborn 1992). At herb-rich forest sites snail decline averaged 60%. The average decrease in Ca was 31% at these unlogged sites. These declines were noted on soils with Ca levels similar to those in the present study (Garrett County sites had Ca values ranging from 4 – 15 g/kg of dry soil, acidic Swedish sites 4 – 12 g/kg and richer Swedish sites and 10 – 28 g/kg).

Acid precipitation is believed to be responsible for soil Ca declines in Europe (Graveland et al. 1994). Although some eastern North American studies have indicated soil Ca impacts related to acid rain and logging (Hornbeck 1990, Federer et al. 1989, Likens et al. 1996, Huntington et al. 2000), the extent and distribution of these impacts is unclear. Recent work in the Northeast suggests that forest soil Ca losses related to acid rain are not widespread at present, but may have previously occurred, and that stand age may also influence Ca content in unexpected ways (Yanai et al. 1999).

Ecosystem ripple effects due to snail community changes are also a possibility in central Appalachian Mountain forests. In the Netherlands a 40% reduction in great tit (*Parus major*) hatchlings is linked to land snail reductions in areas of nutrient-poor soils, and Ca limitation is suggested as a common phenomenon for birds on poor soils (Graveland 1996). In the Appalachian Mountains, bird predators of land snails include thrushes (Turdidae), ruffed grouse (*Bonasa umbellus*) and wild turkey (*Meleagris gallopavo*) (Martin et al. 1951), though the relative importance of snails as a calcium source for these species is unstudied.

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