

Changes in Soil Properties of Forests Rooted by Wild Boar

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Abstract: In order to devise an ecologically sound management plan for the wild boar herd in Great Smoky Mountains National Park, data on the impact of these animals on the environment are essential. Soil chemical properties and nutrient concentrations were examined for possible boar impact from 9 high elevation beech gap communities ranging in severity of boar disturbance. Levels of soil organic matter, cation exchange capacity, and acidity, increased on boar-rooted sites, whereas percent base saturation declined. These changes suggested that boar rooting stimulated organic matter decomposition and soil nutrient mobilization; both A and B horizons were susceptible with the extent of change being a function of the intensity and length of disturbance. Potential long-term implications for the growth and productivity of these forest communities are presented.

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Management of the introduced European wild boar \times feral hog hybrid (*Sus scrofa*) population is a serious problem in the Great Smoky Mountains National Park (GSMNP). Wild suids presently occur in 13 locations within the National Park system, with populations at stable densities in all areas except GSMNP (Singer 1981). Omnivorous food habits, high reproductive potential, and protection from hunting all have contributed to rapid expansion of the boar population in the park. Currently, 75% of the park is occupied by boars (Howe and Bratton 1976). Control measures imposed by the National Park Service have been ineffective in removing a significant portion of the herd (Reiger 1978) and at times have produced an unfavorable public response (Wood and Barrett 1979). The apparent inability to reduce the boar herd or to limit its expansion suggests that eradication of boars from the park is unlikely. Furthermore, surrounding public lands in North Carolina and Tennessee are managed actively for boars as game animals so that dispersal into the park will probably continue.

Many problems resulting from boar populations have been documented including alterations in water quality, spread of disease, and depredation of agricultural crops, native vegetation and wildlife (Wood and Barrett 1979). Boar impact on non-woody vegetation in GSMNP has been studied (Bratton 1974, Bratton 1975, Howe and Bratton 1976), and more recently, Singer et al. (1984) examined boar impacts on forest soils. Foraging by wild boars substantially disrupts forest floor structure by mixing the surficial organic layers with A₁ and A₂ horizons and reducing litter layer cover (Bratton 1975, Singer et al. 1984). Because major stores of nutrients in temperate forest ecosystems are in the organic layers and upper mineral soil horizons (Duvigneaud and Denaeyer-De Smet 1970), effects due to boar rooting could have significant impact on the cycling of nutrients. Furthermore, an exogenous disruption of nutrient cycles may have long-term consequences for ecosystem stability.

Designated as an International Biosphere Reserve, GSMNP is a unique ecological bench-mark in the southeastern United States and thus is a vital resource of the region. Determination of the impact of wild boar on the stability and function of ecosystems is essential to the management of GSMNP. Consequently, the objectives of our study were: (1) to determine if changes in soil nutrient dynamics were occurring on sites disturbed by boar rooting, and (2) to document any changes in soil chemical properties on these sites. These data would help provide a better overall assessment of impacts on nutrient cycling and would contribute to development of a sound management plan for this exotic species in GSMNP.

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Methods

Soil samples were collected during July and August 1982 from 9 sites located in pristine high elevation beech (*Fagus grandifolia*) gaps in GSMNP. These gaps occurred predominantly on south aspect slopes of mountain ridges

intermingled among expanses of spruce-fir forest. Annual migrations of boars in the spring to high elevations resulted in dense concentrations, thus making beech gaps the most heavily disturbed habitat in GSMNP. Sites were located above 1,487 m in elevation with a SE to SW aspect. Slope ranged from 16.5% to 59.5%. For more detailed information about the community type, consult Russell (1953).

Soils at high elevations in GSMNP were classified in the Ramsey soil series as a silt or sandy loam (McCracken et al. 1962). The underlying parent material was feldspathic sandstone or siltstone, and the soils were highly weathered, very acidic, and thus low in percent base saturation (McCracken et al. 1962). Soil samples were obtained using a push-tube soil probe and were separated into A and B horizons. We collected samples to a depth of 25 cm because boar rooting reaches only to this depth (Belden 1972), and sampling to a depth of 15 to 25 cm is recommended for analysis of soil nutrient availability (Townsend 1973). On each site, 15 square plots, 10 m × 10 m in size, were randomly located, and 10 push-tube samples were randomly collected from each plot. Soils were air-dried, pulverized to pass through a 2-mm sieve, and submitted to the North Carolina Department of Agriculture Agronomic Division, Soil Testing Laboratory for analysis. Exchangeable acidity and pH value were determined using a buffer-pH method (Mehlich 1976). A colorimetric procedure was used in organic matter analyses (Mehlich 1983). Cation exchange capacity (CEC); percent base saturation (BS); and exchangeable phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg) were determined using Mehlich III extraction methods (pers. commun., N.C. Dep. Agric. Agron. Div.).

Three classes of beech gaps were identified based on intensity and length of boar rooting: control, lightly rooted, and heavily rooted, and 3 sites were chosen in each class for study. Control sites, located at Mt. Kephart and Indian Gap, had less than 1 boar/km² (Singer et al. 1984), with evidence of boar rooting first noticed in 1975. Beech gaps that were comparable and had no history of boar activity were nonexistent within the park. The remaining sites were located at Double Springs Gap and the Spence Field area which have rooting histories of more than 10 years (lightly rooted) and 20 years (heavily rooted), respectively, and are used by 7 to 9 boars/km² (Singer et al. 1984).

Data were analyzed with a balanced nested 1-way analysis of variance and a Duncan's multiple comparison procedure of class means. All ANOVAs were treated as mixed effects models with boar rooting as fixed effects and sites as random effects. Tests were based on 2 and 6 df, with site mean square as the error term. A significance level of $P < 0.10$ was used for ANOVA tests and $P < 0.05$ for the Duncan's procedure. Data for percent BS were arcsine transformed prior to analysis. All data sets were tested for validity of the assumptions for ANOVA. Variances for organic matter and CEC in B horizon soils were significantly different among rooting classes based on a vari-

ance ratio F max test, therefore these class means were compared using 2-sample *t*-tests with unequal variance and a significance level of $P < 0.05$.

Results

Relative patterns for soil nutrients between horizons were consistent for all rooting classes; mean levels were higher in the A horizon than in the B horizon (Table 1). Inspection of means suggested a trend toward lower nutrient concentrations on rooted than control sites; however, only K was significantly different and only for the B horizon. Apparent differences among means for P were not significant probably because extremely high variation (SE) among all rooting classes prevented the detection of differences that may have been present.

Soil chemical properties were affected strongly by boar rooting in both A and B horizons and in most cases the longer the duration of boar impact the greater the effect (Table 2). Organic matter levels were significantly elevated in both A and B horizons of heavily-rooted soils. Increases in CEC, probably due to increased organic matter (Brady 1974), for soils on heavily-rooted sites were found also. Shifts in percent BS were related inversely to changes in CEC with higher BS on control sites. The lack of detectable changes in specific soil cation levels may be in part explained by the compensatory shifts in CEC and BS. A decline in BS, a measure of the combined change in K, Ca, and Mg, suggested that cations had been mobilized and lost from the soil column by leaching or accelerated uptake by plants. However, the incorporation of greater amounts of organic matter and subsequently higher CEC levels would tend to offset the nutrient removals and maintain soil cation abundance near pre-rooting levels.

The values for CEC in any soil can be partitioned not only into the percentage due to basic cations (BS), but also into the amount of the exchange sites held by acid cations such as hydrogen and aluminum, referred to as acidity. Significant declines in BS of soils on rooted sites should be accompanied by increases in acidity; our data substantiated this relationship. Boar disturbance did not alter soil pH value. The soils examined were extremely acid initially as indicated by control levels, and it appeared that changes in soil equilibrium reactions involving organic and carbonic acids provided sufficient buffer to prevent significant shifts in soil pH value.

Consistent patterns existed in soil chemical properties between horizons for all rooting classes. For all properties affected by boar rooting, (i.e., organic matter, CEC, BS, and acidity), higher mean levels were obtained in A horizon than in B horizon layers probably due to a greater interaction between A horizon soils and the forest floor litter layer. Only pH value was higher in the B horizon.

Table 1. Nutrient concentrations in the A and B horizons of soils of beech gaps rooted by wild boar in GSMNP, 1982.

Soil horizon and rooting class	P (mg/dm ³)		K (meq/100 cm ³)		Ca (meq/100 cm ³)		Mg (meq/100 cm ³)	
	Mean	SE ^a	Mean	SE	Mean	SE	Mean	SE
A horizon								
Control	53.6	10.3	0.25	0.03	0.80	0.18	0.37	0.04
Lightly-rooted	43.7	15.2	0.18	0.01	0.63	0.02	0.34	0.01
Heavily-rooted	34.2	4.28	0.21	0.01	0.69	0.01	0.35	0.01
B horizon								
Control	27.8	11.2	0.13A ^b	0.01	0.45	0.04	0.22	0.01
Lightly-rooted	22.5	9.12	0.10B	0.01	0.35	0.02	0.22	0.01
Heavily-rooted	14.4	2.40	0.12A, B	0.01	0.40	0.04	0.21	0.01

^a SE indicates standard error of the mean.

^b Means with common letters are not significantly different ($P > 0.05$).

Table 2. Soil chemical properties measured in the A and B horizons of soils of beech gaps rooted by wild boar in GSMNP, 1982.

Soil horizon and rooting class	Organic matter (g/100 cm ³)		CEC (meq/100 cm ³)		BS (% of CEC)		Acidity (meq/100 cm ³)		pH	
	Mean	SE ^a	Mean	SE	Mean	SE	Mean	SE	Mean	SE
	A horizon									
Control	0.98B ^b	0.17	6.93B	0.58	20.3A	2.12	5.50B	0.39	3.91	0.14
Lightly-rooted	1.21B	0.08	7.56A, B	0.12	15.2B	0.37	6.40A	0.08	3.74	0.06
Heavily-rooted	2.17A	0.24	8.39A	0.21	15.0B	0.35	7.14A	0.21	3.76	0.05
B horizon										
Control	0.63B	0.01	5.16B	0.16	15.1A	1.47	4.36B	0.20	4.10	0.10
Lightly-rooted	0.91A, B	0.12	5.52A, B	0.02	12.0A, B	0.27	4.85A, B	0.24	3.97	0.06
Heavily-rooted	1.73A	0.28	6.26A	0.30	11.4B	0.50	5.52A	0.28	4.08	0.03

^a SE indicates standard error of the mean.

^b Within properties and horizons, means with common letters are not significantly different ($P > 0.05$).

Discussion

Litter decomposition is the principal means by which nutrients enter forest soils (Aber and Melillo 1979). The increased levels of organic matter in soils rooted by wild boar suggested that boar rooting enhanced the decomposition rate. Beech litter has a very slow decomposition rate (Shanks and Olson 1961), therefore such an effect could expedite significantly the nutrient cycling process. Greater levels of acidity in soils from boar-rooted sites also suggested a higher decomposition rate, because hydrogen ions are a by-product of organic matter breakdown (Brady 1974). The strong affinity of hydrogen ions for soil colloid surfaces results in displacement of basic cations and is an essential process prior to cation leaching (Brady 1974).

The drop in BS for soils of boar-rooted sites indicated that cations had been lost from colloidal surfaces. Because these soils were already inherently limited in nutrient availability due to low CEC levels, loss of additional nutrients could severely affect site productivity. However, tests for changes in individual nutrients were not statistically significant except for a lower concentration of K in the lightly-rooted versus control sites. An explanation for a change in K based solely on boar rooting is not convincing because, of the major cations, K is the most mobile and most variable in concentration (Brady 1974). Increased inputs of soil nutrients as a result of elevated soil organic matter content in boar-rooted soils would have made detection of any changes in soil nutrient concentrations difficult. Significantly higher mean CEC in both A and B horizons of heavily-rooted soils supports this explanation.

Studies by Singer et al. (1984) on litter, soils, and stream runoff showed the accelerated loss of several nutrients including P, Ca, and Mg among others, but found CEC had decreased. Their values for CEC were presented by weight, whereas ours are on a volume basis. By measuring on a volume basis, we actually analyzed less (by weight) soil/sample from boar-rooted sites, because organic matter is less dense than mineral soil.

Additionally, Singer et al. (1984) detected a drop in bulk density with rooting. Assuming bulk density also declined on sites we examined, because lower bulk density is a consequence of elevated soil organic matter levels (Brady 1974), then we should have found reduced levels for CEC simply due to changes in weight per unit volume. Instead, we actually detected higher levels for CEC on heavily-rooted sites and an explanation for the differences between Singer et al. (1984) and our results is not clearly evident. Furthermore, Singer et al. (1984) found no changes in organic matter content of upper soil horizons on boar-rooted sites, despite reporting declines in weight of forest floor leaf litter and substantial increases in exposed mineral soil on boar-rooted sites. An explanation for the fate of disturbed leaf litter and the drop in bulk density was not provided.

Removal of cations from the soil column, as suggested by declines in BS,

meant that changes in anion availability must also have taken place, because cation movement requires an anion complement (Johnson and Cole 1980). Organic matter breakdown would increase gaseous CO_2 in soil air and subsequently shift equilibrium reaction rates toward bicarbonate production (Brady 1974). However, Johnson et al. (1977) indicated that soils in colder ecosystems produced organic acids which lower pH values and inhibit the production of bicarbonate. Another possibility has been suggested based on data collected from boar-rooted sites. Singer et al. (1984) found substantially higher concentrations of nitrate in soils of heavily disturbed localities. This anion is extremely mobile and could result in rapid nutrient transport (Brady 1974). Regardless of which anion is affected, data collected so far suggest that nutrient mobilization due to boar rooting has occurred. Whether most of these nutrients are leached through the soil column or incorporated into plant biomass is unknown.

Our data suggested that the presence of exotic wild boar in GSMNP has stimulated the decomposition rate in high elevation beech gaps, resulting in increased soil organic matter, CEC, and acidity, along with declines in BS. Further, these alterations were detectable in both A and B horizons and were intensified by duration of boar impact. With the exception of K, we did not find significant changes in soil nutrient concentrations. Because our study included a greater number of sites and used what we believe was a more appropriate experimental design than Singer et al. (1984), we suggest a more cautious evaluation of boar impact on the leaching of nutrients from forest litter and upper soil horizons.

Boars are believed to enhance the growth of pines on poorer European soils (Andrezejewski and Jezierski 1978), and boar removals from native habitats is now suspected to have decreased the rate of nutrient cycling and upset the stability of affected European forests (Grodzinski 1975). Therefore, boars appear to have an important function in assisting nutrient transfer in native forest habitats. The increased nutrient mobilization detected in our data and those of Singer et al. (1984) suggest that boar rooting has affected soils of high elevation forests in GSMNP similarly. These changes could lead to 2 possible long-term implications for forests of GSMNP, either: (1) tree growth and productivity will be enhanced through more rapid nutrient cycling and thus faster nutrient uptake by trees or (2) tree health and vigor will decline through continued drain of already limited nutrient supplies. Resolution between these 2 hypotheses requires further study.

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