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Are horses responsible for introducing non-native plants along forest trails in the eastern United States?

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ABSTRACT

Non-native plant species pose a serious ecological and economic threat to managed and natural ecosystems; therefore, there is a great need to identify sources for the introduction of non-native species and develop management plans to reduce or eliminate their introduction. Horses have been suggested to be an important source for the introduction of non-native plant species along trails, but the conclusions were based on anecdotal evidence. In this study, horse hay, manure, and hoof debris samples were collected from 12 to 24 horses at five endurance ride events in North Carolina, Kentucky, Illinois, Wisconsin, and Michigan. One sub-sample of each material from each horse was sown in pots and grown under ideal conditions to determine if horse hay, manure, and hoof debris samples contained seeds from non-native species. A second sub-sample of each material from each horse was placed back on their respective trail to determine what plants would germinate and establish on the trail. Vegetation surveys were also conducted along 50 m transects perpendicular to horse and hiking (horses not permitted) trails at three of the five sites to compare species composition of native and non-native plant species. On average, non-native plant species germinated in 5.2% of the hay samples in the pots, but non-native species did not germinate from the manure or hoof debris samples. Only 3 of the 288 (≈1% of total samples) hay, manure, and hoof debris plots established on horse trails at the five sites contained plants, all of which were native plants, at the end of the first growing season and no plants were observed at the end of the second growing season. Non-native species composition and percent of total plants species did not differ significantly ($p = 0.56$) between horse and non-horse trails, and non-native plant species were only found within 2 m of the trail. The results of this and another study [Campbell, J.E., Gibson, D.J., 2001. The effect of seeds of exotic species transported vie horse dung on vegetation along trail corridors. Plant Ecology 157, 23–35] demonstrate that horse hay and manure does contain seeds of non-native plant species, but native and non-native plant species rarely become established on horse trails because of the harsh environmental conditions. Management and policy implication of this study are discussed.

1. Introduction

Conservation biologists, natural resource managers, and private landowners are increasingly concerned with the invasion of non-native species in natural ecosystems (Mooney and Drake, 1986; Soule, 1990; Williamson, 1996; Vitousek et al., 1997). Non-native species, also known as alien, non-indigenous, noxious, or exotic, are species or strains that become established in natural ecosystems and replace native species. Non-native species pose ecological and economic concerns. Non-native plants can decrease biodiversity by replacing native plant species and other organisms that may depend on the plants. The loss of species diversity makes the ecosystem "unhealthy" or susceptible to degradation (Mooney and Drake, 1986; Williamson, 1996).

Non-native species also have a pronounced economic impact. Weeds cost the U.S. economy $32 billion a year by decreasing crop production by 12% (Pimentel et al., 1999), and 73% of the weeds are non-native (Pimentel, 1993). The costs estimates provided by Pimentel and his colleagues excluded costs of (i) producing the herbicides ($4 billion); (ii) programs to control non-native plant species ($3 billion); and (iii) environmental and public health damage caused by herbicides ($9 billion). Pastures for livestock are especially susceptible to invasion by native and non-native, with an estimated 45% of the invading species being non-native plants (Pimentel, 1993). Forage production from pasture is a $10 billion industry in the U.S. with losses from yield caused by non-native species totaling $1 billion annually (USDA, 1998).

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Table 1
Study site, respective location and AERC region, and the states and provinces from which horses were selected for study

Site/(ride name)	Location	AERC region	States and provinces represented
Biltmore Estates (Biltmore Estates Challenge)	Asheville, NC	SE	GA, IN, KY, NC, ME, MN, ON, PA, TX, VA
Land Between the Lakes National Recreation Area (LBL Express)	Golden Pond, KY	SE	MO, KS, KY, TN, IN,
Kickapoo State Recreation Area (AHDRA I)	Oakwood, IL	MW	IL, MI, WI
South Kettle Moraine State Forest (Glacier Trails)	Eagle, WI	MW	IA, IL, MI, WI
Hiawatha National Forest (Grand Island)	Rapid River, MI	MW	IL, MI, WI

Given the large adverse effects non-native species can have on the ecological and economic integrity of ecosystems it is critical to prevent further degradation of natural and managed ecosystems. Policy and management plans should be based on scientific studies that quantify modes of invasion of non-native species into ecosystems and identify opportunities to reduce or eliminate their sources of introduction (Varva et al., 2007).

Disturbances, particularly unnatural ones, appear to make ecosystems more susceptible to biological invasions (Braithewaite et al., 1989; Binggeli, 1996). No ecosystem is free from disturbance, and since European settlement, the forest landscape has experienced increased logging, wildfire, road building, and the introduction or accidental release of non-native animals that transport invasive plants and/or their seeds. Trail horses have been accused of being an important source for the spread of invasive or non-native plant species (Bates, 1935; Land, 1994). Given that non-native plant species commonly occur in pastures and horses consume pasture grasses and defecate on trails, it is plausible that horses may be a source for the introduction of non-native species. However, there are few data to support or refute this assertion (but see Campbell and Gibson, 2001).

The availability and viability of non-native seeds is a biological bottleneck that prevents the spread of non-native plants into forest ecosystems. Environmental and physical conditions of the trail are additional bottlenecks that may prevent non-native germinated seedlings from establishing and colonizing ecosystems adjacent to horse trails. The objectives of this research project are to: (i) assess the importance of different sources of material (i.e. hay, manure, and hoof debris) by which horses may introduce non-native plant seeds; (ii) determine if seeds of non-native species introduced by horses can germinate and establish on horse trails in forest ecosystems; (iii) determine if non-native plant species established on trails colonize into forest ecosystems; and (iv) compare the presence and abundance of invasive plant species along horse trails to other recreation activities that may also be responsible for the spread of non-native species in forest ecosystems. The systematic study will provide valuable data to help land managers develop policy to mitigate the introduction of non-native plant species by horses, if horses are an important source for non-native species.

2. Methods

2.1. Study sites and experimental design

The study was conducted in five locations along a south–north gradient from North Carolina to Michigan that encompasses two of the American Endurance Ride Conference (AERC) regions (Table 1). The selection of sites was based on an effort to encompass a large geographic region, timing of various rides, proper experimental controls, financial resources, and logistics. The five rides encompassed a large geographic region of riders (15 states and one Canadian province) and environmental conditions that make the results have greater policy relevance. Twenty rider/horse teams were selected, except for the Biltmore Estates ride where 24 horses were sampled, and the AHDRA I ride where only 12 horses were sampled. Horses were selected randomly at each ride. The owner of each horse provided information on his/her home location so the travel time could be approximated. Information was also obtained on the horse's access to pasture versus dry paddock.

At each ride, a representative sample of hay, or hay substitute, was collected from each owner and the sample was sub-sampled and placed in two labeled bags. A manure sample was collected from the horse paddock, divided into two sub-samples and placed into two labeled bags. Hoof scrapings were collected from all four feet of the horse (except when horses had pads), combined, thoroughly mixed, and divided into two sub-samples (Photo 1). One sub-sample of each material was placed in a larger labeled bag and transported back to Madison, WI for the pot germination study and the second sub-sample of each material from each horse was placed on the trail within 24 h of sample collection. I originally planned to quantify the role of epizoochory for each horse at each ride; however, none of the horses selected contained any visible seeds.

The hay, manure, and hoof debris sub-samples for the pot germination study were transported back to Madison, Wisconsin and added to 15 l plastic potting buckets filled with commercial potting soil. Pots were randomized and placed in a common garden that had similar environmental conditions. The pots were placed outside and watered twice per week with a complete Hogland's

Photo 1. (a) A transect containing the hay, manure, and hoof debris samples collected from 20 horses participating in the Land Between the Lakes (LBL) Express endurance ride in 2005; (b) close-up of a hay sub-samples placed on the trail; and (c) close up of a manure sub-sampled placed on the trail.

nutrient solution to ensure the germinating plants had adequate water and nutrients. Plants were grown to the end of August and each germinated plant was identified by species and classified as native or non-native (USDA Natural Resources Conservation Services, 2007). I used this source because it is a recognized federal source that most states use, and they provide additional information on the life history and origin for most species.

The second sub-sample of hay, manure, and hoof debris was placed in a 50 cm diameter plot located every meter along a transect at five random locations along a trail designated for horses (Photo 1). The start and end point of each transect was marked with a large plastic stake driven flush to the ground so the transect could be re-located. At the end of the 2005 and 2006 growing season each plot was surveyed and each germinated plant was identified by species and status (native or non-native).

The plots on the trails were re-surveyed in summer 2006 to verify 2005 results and obtain ancillary data needed to explain why survivorship rates were so low. To test the hypothesis that resource(s) limitation were limiting the successful establishment of plant species, soil water holding capacity (percent by volume), soil bulk density (mass per unit volume), and fraction of incoming photosynthetic active radiation, or visible light (F_{IPAR}) were measured at each of the five transect locations at the five study sites. Photosynthetic active radiation was measured simultaneously outside the forest along a nearby road and in the middle of transects using a sunfleck ceptometer (Decagon Devices, Pullman, WA) equipped with 40 integrated sensors that measure visible light (400–700 nm). Field measurements and data analysis followed (Fassnacht et al., 1994; Gower et al., 1999). Soil bulk density was measured for 0–20 cm depth at a random location along each of the five transects using standard method (Elliott et al., 1999). Soil water holding capacity was indirectly estimated from soil texture analysis. A 5 cm diameter core (0–20 cm depth) was collected at a random location along each of the five transects and soil texture was measured in the laboratory using the hygrometer technique (Bouyoucos, 1962).

To answer the third objective, 0.25 m × 0.25 m vegetation survey plots were established along a transect that was perpendicular to the same horse trail where sub-samples were placed. Plots were established at 0.25, 0.5, 1.0, 2.5, 5.0, 10.0, 15.0, 25.0, 37.5 and 50.0 m from the trail. Five transects were established at each study site. The number of non-native invasive species was recorded in each plot and data was expressed as a percentage of total species present. Data were not expressed on a percent cover, area, biomass, or other criteria because these latter variables are extremely sensitive to phenology of each species. Repeated measurements over several years would be needed to better quantify the likelihood of the non-native invasive species to become established and out-compete native species.

At three study sites (Land Between the Lakes National Recreation Area, KY; Kickapoo State Recreation Area, IL; and Southern Kettle Moraine State Forest, WI) five additional transects were established on trails open to hikers but closed to horses. The KY, IL and WI sites were the only study sites where horse and non-horse trails were close to each other (i.e. similar environmental, ecological and edaphic conditions). Ten similar locations were identified and five were randomly selected for study.

2.2. Statistical analysis

No formal statistical analyses were performed to determine if the presence of invasive species composition in the pot study was significantly greater than zero (Objective 1) because the occurrence of invasive species was very low, or if the presence of non-native invasive species in plots in the trail transects was significantly greater than zero (Objective 2) because invasive species were absent in years 1 and 2. A paired *t*-test was conducted to determine if invasive species composition differed significantly between horse and non-horse trails for plots of similar distance from the trail (Steel and Torrie, 1980). This analysis is based on the assumption that the biophysical condition for transects perpendicular to horse and non-horse trails were similar, except for type of use. This assumption is reasonably valid but difficult to validate. Analyses were done using SAS version 9.1 (SAS Institute 2003). An alpha = 0.05 was used to test for statistical significance for all analyses.

Table 2
Summary of non-native plant species present in the pot study

Study site (scientific name)	Common name	Federal weed status	Nativity location and status	%
Biltmore Estates, NC				
Cirsium arvense (L.) Scop.	Canada thistle	NW	L48 (I), CN (I)	2
Carduus nutans L.	Musk thistle	NW	L48 (I), CN (W)	1
Total				3
Land Between the Lakes National Recreation Area, KY				
Cirsium arvense (L.) Scop.	Canada thistle	NW	L48 (I), CN (I)	2
Setaria faberi Herrm.	Giant foxtail	NW	L48 (I), CN (I)	1
Total				3
Kickapoo State Recreation Area, IL				
Cirsium arvense (L.) Scop.	Canada thistle	NW	L48 (I), CN (I)	<1
Total				<1
South Kettle Moraine State Forest, WI				
Cirsium arvense (L.) Scop.	Canada thistle	NW	L48 (I), CN (I)	1
Total				1
Hiwatha National Forest, MI				
Cirsium arvense (L.) Scop.	Canada thistle	NW	L48 (I), CN (I)	2
Total				2

Classification of non-native, invasive status was based on NRCS 2007. State weed status: CBW = class B noxious weed; NW – noxious weed; nativity status: (I) = introduced; nativity location: L48 = lower 48 states in the U.S., CN = Canada.

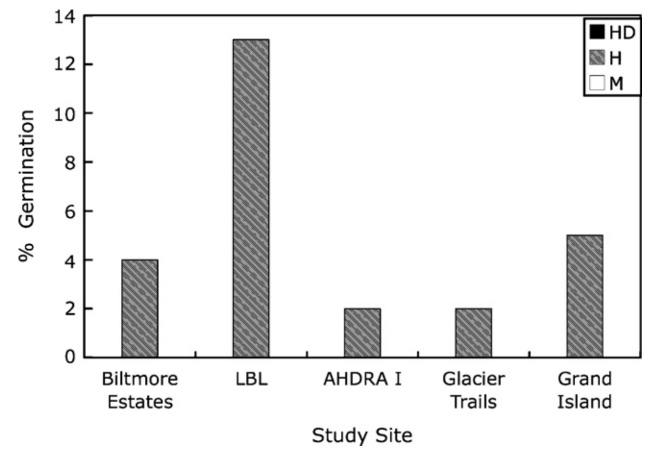

Fig. 1. Percent of germinated plants in the pots that were non-native species. Values are based on the 26, 20, 20, 20, and 12 samples of hay, manure, and hoof debris collected at the Biltmore Estates, Land Between the Lakes (LBL), Arabian Horse Distance Rider Association I (AHDRA), Glacier Trails, and Grand Island rides, respectively.

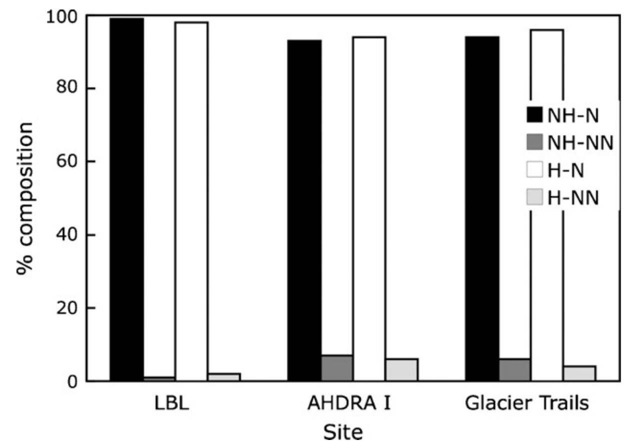

Fig. 3. Comparison of the percent composition of native (N) and non-native (NN) plant species observed for the five transects perpendicular to trails where horses are prohibited (NH = no horse) and allowed (H = horses allowed). All values are based on the average of all plots along the 50 m transect that was perpendicular to the trail.

3. Results

Non-native invasive plant species only occurred in the potting buckets that contained hay samples (Table 2). Non-native plants comprised 3, 3, <1, 1, and 2% of the total plants in the pots from the Biltmore Estates, Land Between the Lakes, AHDRA I, Glacier Trails and Grand Island rides, respectively (Fig. 1).

The germination and survivorship of plants on the trail was extremely low. Based on resurvey of the plots along the five transects on the trail at each site in late summer 2005, only one hay plot at Biltmore Estates and two hay plots at Land Between the Lakes sites contained plants, and the plants at both sites were native grasses (Fig. 2). In other words, 3.8, 10, 0, 0, and 0% of the hay plots on the trails contained plants in 2005, and no plants grew in the manure and hoof debris plots. A resurvey of transects in 2006 revealed no plants were alive in any plots and the presence of non-native plants did not differ significantly from 0 at all five study sites.

Vegetation composition of transects perpendicular to the trail was dominated by native species both along the horse trails (94–98%) and trails where horses are prohibited (93–99%) (Fig. 3). Non-native species composition did not differ significantly ($p > 0.05$) between horse and hiking (i.e. non-horse) trails, and ranged from 1 to 7% for hiking trails and 2 to 6% for horses trails. All non-native plants occurred with in 2 m of horse and non-horse trails.

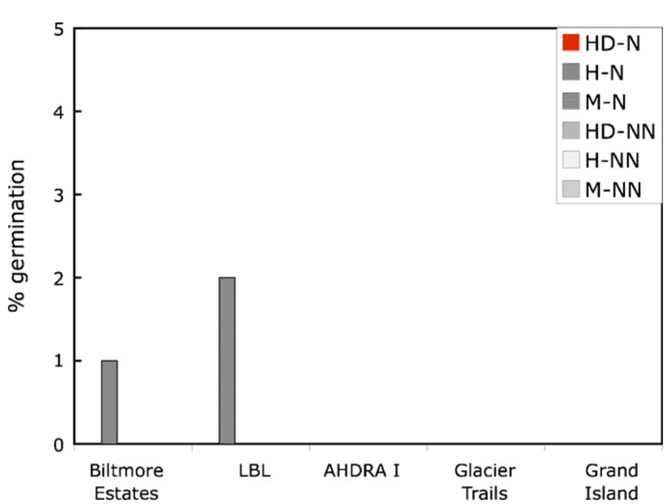

Fig. 2. Percent of all (hay, manure and hoof debris) plots at each study site that contained germinated native and non-native plants. Legend is as follows: hay = H; manure = M; hoof debris = HD; native = N and non-native = NN.

4. Discussion

4.1. Are horses important sources of non-native plants?

Non-native plants are a serious economic and ecological threat to natural ecosystems and therefore it is important to identify the major sources of non-native species, and implement management opportunities to reduce or eliminate their introduction. Animal-mediated spread of invasive plant species is a worldwide problem (Schiffman, 1997). The role of animals depositing seeds in environments where the germinating plants can successfully establish is important for the colonization of invasive plants in disturbed or fragmented landscapes (Schiffman, 1997; Varva et al., 2007). Domestic and wild livestock can potentially spread invasive plants by three main processes: endozoochory, epizochory, and synzoochory. Endozoochory is the dispersal of seeds by animals by transporting the seeds within the organisms (i.e. digestive tract). Epizochory is the dispersal of seeds by animals by transporting the seeds outside the organisms (i.e. seeds adhered to coat of the animal). Synzoochory is the dispersal of seeds by animals transporting to seeds in their mouth for consumption or cache. Equines can potentially transport seeds of non-native plants by endozoochory or epizoochory.

The results from the pot study clearly demonstrated that hay is the primary source of non-native plants, but non-native invasive plants comprised a maximum of 3% of the total number of plants germinated, and averaged <2% of total plants germinated for the five study sites. The two common plants encountered were Canada and musk thistle. Canada thistle is native to southeast Europe and Asia, and was likely introduced to the United States in the 1700s as a contaminant of crop seed. Musk thistle is a biennial plant that was introduced, by accident, from Europe in the 1800s. The seeds of both are animal and wind dispersed.

The results from this study suggest that non-native seeds were absent in horse manure, a finding that is consistent with the preliminary findings reported by Dominican University scientists (http://www.dominican.edu/dominicannews/weeds/index.html). Conversely, Campbell and Gibson (2001) reported that non-native species comprised 15% of all plant species that germinated from horse manure in a study in southern Illinois. Early studies reported that that non-native seeds are passed through horses (Harmon and Kiem, 1934; Benninger-Truaz et al., 1992), but there was no attempt to determine if the seeds were viable. Studies have shown that the mastication and digestion of viable weed seed reduces its viability by over 90% in a wide range of livestock (Cash et al., 2006).

Although non-native invasive plant species were present in hay samples, and germinated in the pots, the results from the trail plots were striking different. Of the 288 hay, manure and hoof debris samples placed on the trails, only three plots contained any living vegetation, and the three plants were not non-native species. The results from this study corroborate the results of Campbell and Gibson (2001) who also found successful germination and establishment of invasive plants was significantly lower in the trail plots (1 species) than greenhouse study (23 species). This study and other studies also observed that the presence of non-native species is greater immediately adjacent to trails and roads (Tyser and Worley, 1992; Parendes and Jones, 2000), but the presence of non-native plant species along the trail does not differ between horse trails and trails where horses are prohibited (Evans, 1981; Campbell and Gibson, 2001). Collectively, these studies provide compelling evidence that horses are not significant vectors for the introduction of non-native invasive species.

The 1% germination and establishment rate observed for plots on the horse trails illustrates the difficult physical and environmental conditions seedlings experience during the critical germination and establishment phase. Why do plants have such a low success rate of becoming established on horse trails? It is difficult to determine whether germination or establishment was the bottleneck for plant survival in this study because transects were surveyed only once in 2005 and 2006. Causes of seed mortality during the germination phase include (i) predation by vertebrates, invertebrates, fungi and bacteria; (ii) inadequate reserves in the seed caused by physiological aging; and (iii) alteration of the seed by organisms that passed the seed. Seeds at the surface of soil are very susceptible to loss of storage reserves because of warm soil temperatures and desiccation (Roberts, 1988; Mohler, 2001; Liebman et al., 2001). Seed predation is less likely because modest germination of seeds occurred when they were grown in pots under ideal environmental condition. The period of plant establishment, defined here as the stage between germination and the production of the first true leaf, is thought to be the major bottleneck for some species (Boutin and Harper, 1991). Causes for seedling mortality include exhaustion of seed reserves, improper environmental conditions (i.e. drought or low pH), seedling disturbance, seedling herbivory, or defects of seedlings. Several of these factors may explain the extremely low germination and/or survival rate of the samples placed on the trail. Horse trails are a highly disturbed system; the frequent disturbance of the soil of heavily used horse trails makes it difficult for seedlings to become established.

Environmental conditions of horse trails also adversely affect plant germination and establishment. Light is the most important environmental cue that promotes the germination of dormant seeds in the soil (Mohler, 2001). Plant germination responds to visible light in the red wavelength—the same wavelength that plants use for photosynthesis. Light passing through a heavy overstory canopy is depleted in the red wavelength, and as a result the germination of shade intolerant species is inhibited (Gorski, 1975). Moreover, adequate light is required by seedlings for photosynthesis and production of carbohydrates needed for plant growth. Many of the non-native weedy plants are extremely shade intolerant—that is to say they require modest to full sunlight (Fenner, 1978). The percent of incoming visible light reaching the soil surface averaged less than 10% at four of the five sites (Fig. 4a). Except for the Grand Island site, the light levels measured were considerably below the requirements for shade intolerant weed species.

A second factor that may have contributed to the poor germination and establishment of plants on the trails is water availability (Dale and Weaver, 1974). Soil water holding capacity was lowest at the Grand Island site because of the large fraction of the soil particles were sand (Fig. 4c). Young emerging seedlings are especially susceptible to desiccation and drought (Mohler, 2001). Soil compaction also decreases water infiltration in the soil,

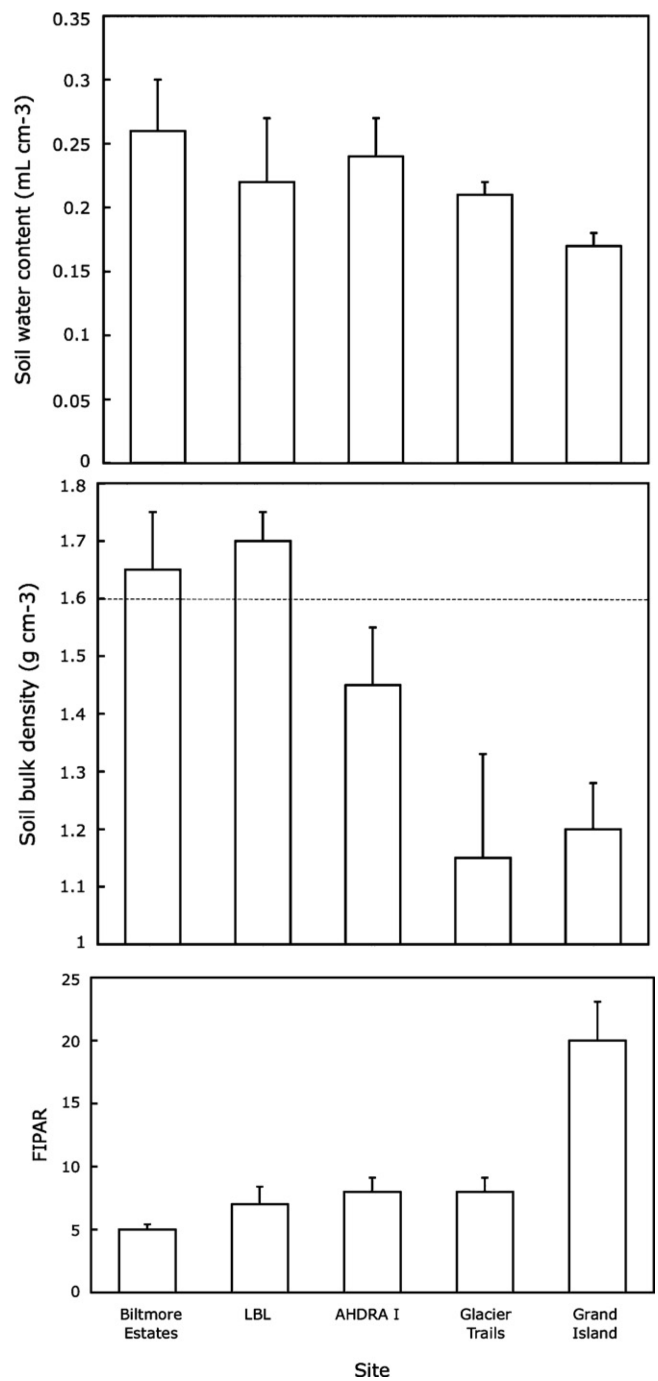

Fig. 4. Average (a) fraction of incident photosynthetic active radiation or visible light at the soil surface;(b) soil bulk density and (c) soil water holding capacity (% by volume) for the five transects at each study site.

thereby decreasing water available for plant uptake (Landsberg and Gower, 1997). The bulk density, or mass per unit volume of soil, was above 1.6 g/cm^3 (Fig. 4b)—a value that as a general rule of thumb impedes the growth of fine roots of most plants. Soil bulk density is typically greater for trails than forest interior (Bates, 1935; Weaver and Dale, 1978).

4.2. Management opportunities and policy implications

The invasion on non-native invasive plants is a serious problem, as illustrated by the quadrupling of western federal lands containing invasive species between 1985 and 1995 (Westbrooks, 1998). However, management and policy actions should be based on sound research that distinguishes the major sources and their major potential pathways of introducing non-native plants. For example, ungulate herbivory, particularly livestock, has a considerable detrimental impact of the species composition, structure, and function of native plant communities (Fleischner, 1994; Hobbs, 1996). There is increasing information that suggests herbivory by wild ungulates has negative impact on ecosystems (Augustine and McNaughton, 1998; Riggs et al., 2000; Kie and Lehmkuhl, 2001; Gill and Beardall, 2001). Hence, it is important to distinguish the potential adverse effects of grazing domestic and wild ungulates from other animal-related activities. Moreover, the relationship between grazing animals and invasive plants differs between ecosystems (see review by Varva et al., 2007). The results from this study may not be representative for other geographic regions in the United States, or for other types of horse activities (e.g. range grazing versus trail riding). Additional research is needed to determine if the results from this study are representative for other regions and equine activities. There is at least one other study underway in California (http://www.dominican.edu/dominicannews/weeds/index.html).

This study examined the role of horses as a source of non-native plants on trails in forest ecosystems in five study areas that spanned a broad geographic and environmental gradient in the eastern United States. Species composition of ''non-native invasive plants'' should be considered when using results from scientific studies to develop management policy. There is no consistent use of the terms invasive, exotic, and noxious plants. For consistency, I adopted the USDA National Resource Conservation Service classification system, but there are many other weedy and invasive plant species textbooks. Important commercial plant species used as forage for livestock and soil erosion control (e.g. lespedeza, *Kummerowia striata*) have been considered exotic (Campbell and Gibson, 2001), yet they are actively cultivated in adjacent ecosystems. Interestingly, none of the plants Campbell and Gibson classified as exotic (following Mohelenbrock, 1986) are not on the USDA NRCS noxious weed list for Illinois. The lack of consistent definitions and standard state or federal list creates unnecessary confusion in the scientific literature, which adversely affects management and policy decisions. It would seem prudent to concentrate on plant species that adversely affect ecosystems and ignore non-native plants that are actively used in agriculture and environmental engineering.

Several studies have reported that disturbances such as road and trails facilitate the invasion of non-native plant species (Bates, 1935; Hall and Kuss, 1989; Benninger-Truaz et al., 1992; Adkinson and Jackson, 1996; Campbell and Gibson, 2001, this study). The disturbance effect of the trails is estimated to be 1–2 m (Cole, 1987; Dale and Weaver, 1974). Adkinson and Jackson (1996) concluded that it is doubtful that trails exert a major influence on the functioning of adjacent communities.

Despite the extremely low germination and establishment rates of plants on the horse trails, the presence of non-native seed in the hay samples suggests horses pose a threat for the introduction of non-native plant species. Proper disposal of unused or spoiled hay would lessen the likelihood that seeds from non-native plants get established. Waste in the compost piles could be incinerated or allowed to decompose in a designated area at trail heads.

5. Conclusions

Horse hay and manure can contain seeds of non-native plant species; however, success of germinating and becoming established on active horse trails in forest ecosystems in the eastern USA is extremely low (this study and Campbell and Gibson, 2001). Future studies should use a standardized non-native weed list (i.e. USDA NRCS) to avoid confusion in the scientific literature and facilitate sound management and policy decisions.

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