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Fuel characteristics of forests invaded by non-native plants

in the Northeastern and Mid-Atlantic U.S.

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Abstract: In the wildland-urban interface of the eastern U.S., non-native plants are abundant in many forests, and they could alter fuel loads. We characterized fuels at 12 sites in MA, MD, ME, NJ, NY, VA, and VT, mostly on public lands, and compared heavily invaded stands to nearby uninvaded stands. We included four forest types that are common in the region: hardwoods (50 plots), mixed woods (30), pitch pine (30), and soft woods (20). Of these, only pitch pine is fire-adapted. In t-tests, few patterns held across all forest types. Nonwoody litter was less abundant in the presence of invasive plants in hardwoods and pitch pine. Fuel in the one- and ten-hour size class was less in invaded pitch pine compared to nearby uninvaded stands. Duff was not as deep in

invaded hardwoods, softwoods, and mixed woods. Fuel depth was greater in invaded mixed woods. Shrubs were taller, had higher cover, and were more frequent in invaded conditions, except in pitch pine. Invasive shrubs in forests often form a continuous live fuel bed. Our emphasis was on woody plants, and except in pitch pine, uninvaded conditions typically have little to no graminoid cover. However, we found that invasive grasses in forests, especially exotic grasses such as *Microstegium vimineum, Poa nemoralis, Anthoxanthum odoratum,* and *Festuca filiformis* present abundant fine fuels. At five sites, invasive grasses significantly increased graminoid cover in invaded conditions, up to seven times higher than in nearby uninvaded conditions. In a drought these fine fuels could increase wildfire spread potential, heat intensity, and likelihood of crowning in conifer dominated forests. If invasive plant fuels are allowed to persist without control, fire regime changes are likely to be permanent.

Introduction

Invasive, non-native plants degrade habitat for wildlife, outcompete native plants, and could make a difference in the fuels that a wildfire might consume (Richburg et al. 2001). The eradication of some invasive plants seems unlikely, and their control could be economically unfeasible. With a warming climate in eastern North America, invasive plants are projected to continue their spread, and droughts, catastrophic wind, and wildfire are likely to increase (IPCC 2001). The invasive plants could represent an added fuel or could be associated with reduced fuel loads; this has not yet been quantified. Invaded forests can be either more likely or less likely to burn than similar uninvaded forests. The latter case is detrimental in pitch pine (*Pinus rigida*) dominated forests because this fire-adapted ecosystem requires occasional fire to keep the pitch pine as the dominant tree species.

In other forest types, including mixed hardwoods, red spruce-balsam fir, and oak-pine, fuels comprised of invasive plants might also change potential for wildfire. The relatively open understories of the forest types of the northeast and mid-Atlantic states have, in some places, been replaced by dense stands of invasive shrubs (Collier and Vankat 2002, Woods 1993, Ehrenfeld et al 2001, Ehrenfeld 1999). With the additional standing biomass of these shrubs, we might expect a corresponding increase in leaf litter and small diameter fuels. Invasive shrubs are sometimes described as forming nearly impenetrable or dense thickets (Ehrenfeld 1999, Woods 1993, Kourtev et al. 1998) implying that not only has the volume of potential fuel increased over uninvaded conditions, but that the continuity of fuel has likewise increased.

Despite a relative lack of perception of fire risk by the general public in our region, hundreds of small fires are reported every year. There have been catastrophic fires in excess of hundreds of hectares. A 336,710 ha conflagration occurred in October 7, 1825 in Piscataquis County, northern Maine, in northern hardwoods and spruce-fir. This fire happened on the same day as the famous Miramichi Fire in spruce-fir, which burned two million ac or about 20% of New Brunswick, Canada. By 1856, vast spruce forests in northern Maine had burned to bare rock, and were reduced to birch and poplar stands. Numerous fires in the Northeast since the drought of the 1890s led to establishment of state forest protection programs (Wilkins 1978). In June 1903, 258 ha burned in the Adirondack and Catskill Mountains in New York. A series of 136 fires in 1903 burned simultaneously and totaled more than 81021 ha in Maine. In October 1947 in Maine, ca. 86,201 ha burned, 35 towns were affected, 851 year-round residences were destroyed, and 397 seasonal cottages were lost. The largest single fire that year was 60,700-72,850 ha in southern Maine, and it stopped only when it reached the Atlantic Ocean. During April 1963, Massachusetts had 4,861 forest fires. In 1995 two of the largest fires in the region were the almost 8,094 ha Greenwood Fire in NJ and the 2023 ha Rocky Point fire on Long Island, NY.

Droughts are increasingly frequent in past decades and projected to increase in the future. The context for invasive plant fuels and increased drought is a Wildland Urban Interface in which the human population is high, new development is proceeding at a rapid pace, and fuels are mostly un-quantified. Often, invasive plants are present in this matrix. In 2002, the Maine Forest Service reported 990 wildfire ignitions resulting in 899 ha burned, 174 structures threatened, 6 damaged and 13 destroyed. About 93 percent of these fires were caused by human activity, and nearly half occurred in the southern part of Maine where the WUI is most reticulated. Fire managers in National Parks and Wildlife Refuges have limited resources to prioritize and carry out fuel reduction.

Our objectives were to compare fuel characteristics in invaded and uninvaded conditions across various forest types in the Northeastern and Mid-Atlantic regions of the U.S. We hypothesized that the presence of invasive plants do not make a difference in fuels available to a wildfire, at least regarding dead, detached fuels and live biomass in the shrub and grass layers. Alternatively, we sought to identify fuel variables that are influenced by invasive plants and to rank them according to their importance. We also sought to provide to fire behavior modelers, i.e., users of BEHAVE NEWMDL, the data to better represent fuel conditions in the northeastern United States.

Methods

Study Sites – In 2000-2003 we established study sites on federal, state, and private land in seven eastern states (Maine, Maryland, Massachusetts, New Jersey, New York, Vermont, and Virginia; Appendix I).

Sampling layout – At each study area we sought a forested stand that was invaded with at least one woody non-native species and an adjacent or nearby stand that was similar in overstory composition, history, soils, slope and aspect, but was uninvaded. Ideally, the uninvaded stands were mature forest and represented conditions toward which managers would seek to restore degraded stands. Where truly uninvaded stands were not present, we categorized stands that had invasive plants present but at low density and low stature as uninvaded. At eight of our sites, we found invaded conditions adjacent to uninvaded conditions. At five of our sites we had to search further for uninvaded stands. None of the comparison stands were more than 4.5 km apart. Average basal area in the stands of various forest types excluding pitch pine were 18 - 39 $m^2 ha^{-1}$, and in stands dominated by pitch pine were 6 - 32 $m^2 ha^{-1}$. We made this distinction because pitch pine is a fire-adapted forest type while the other types we studied were not.

Stand survey -- We used parallel, 4-m-wide belt transects spaced 30-m apart to survey the vegetation in a stand. We compiled a species list along each transect and subjectively ranked portions of the transect as (1) heavily invaded, with invasive plants dense or common; (2) uninvaded (or in some cases slightly invaded), with invasive plants either absent or present at low numbers of seedlings or small individuals, and low density; and (3) transitional, and so excluded from sampling with plots. We also disqualified segments of each transect where conditions varied greatly such as where the transect crossed a road, trail or stream. Transects varied from 50-300 m long, depending on size of the stand, but we sampled a minimum of 100 m in each condition.

Fuel sampling -- We randomly chose five locations each along the designated heavily invaded and uninvaded portions of the transects as sampling locations. Each location was to be a minimum of 10 m away from another or the end of the transect segment although this was not possible in all cases (one pair of locations was 5 m apart and another pair 9 m apart). These locations represented plot centers and associated sampling locations. We collected a 40 x 40 cm sample of litter and dead fuel down to the top of the duff layer at a previously specified location 1 m from plot center. These samples were dried to constant temperature, sorted into nonwoody litter and hour size classes and weighed to the nearest 0.1 g.

At each plot we chose two random numbers between 1 and 360 to represent the azimuth of a planar intercept line (Brown 1974). We disqualified azimuths that would result in a line less than 10 degrees away from the azimuth of the transect to minimize sampling fuels that we may have trampled on the transect. At 1 m on each side of plot center, along the transect (Fig. 1), we established starting points for these randomly-radiating Brown Lines (except in some of the sites sampled in the first season where line origins were up to 25 m away from plot centers.)

On each Brown Line we recorded the random bearing of the line and the slope along the bearing. We tallied the number of dead, detached, woody fuels in each diameter size category (0-0.64 cm (1 hr fuels), 0.64-2.54 cm (10 hr fuels), 2.54-7.62 cm (100 hr fuels) (Brown 1974). We sampled 1 hr fuels for either 1.85 m or 3.7 m, 10 hr fuels for either 3.7 or 7.3 m and 100 hr fuels for 7.3 or 14.6 m. We doubled the length of the sampling plane in many cases to reduce variance in the data. We recorded fuel depth, litter depth and shrub height at three to eight points along the sampling plane and duff depth at two points. We measured fuels to a maximum height of 1.2 m and shrubs to a maximum height of 3 m.

We calculated fuel loads for each site according to Brown (1974). To obtain average diameter of hour size class fuels needed for these calculations, we averaged diameters of individual fuel particles collected on the 40 x 40 cm biomass plots. We estimated specific gravity for shrub species not listed in USDA (1974) by measuring diameter of dried twigs at their midpoint, measuring their length and calculating their volume. We summed the volume of twigs of each species and divided by the total mass of each species. Throughout the study we encountered the majority of fuels either on the ground or parallel to it, so we did not use a correction factor to account for nonhorizontal fuels.

We collected live fuel materials at 6 of our study sites on four or six Brown Lines per condition. We clipped all live vegetation in a plot 0.3 m wide by 1.85 m long and 1.2 m high. We labeled and bagged this material, dried it to constant weight and then sorted it into nonwoody and hour class sizes and weighed each portion. At sites where grasses were abundant (AC, FL, CC, and HI – see Appendix I for full names of sites) we further sorted the nonwoody material into grass, forb, shrub or moss and weighed these individually.

Vegetation sampling -- At each plot center we established overlapping fixed-area and variable radius plots. To estimate cover of forbs, grasses, low shrub, high shrub, tree, and slash we assigned each a cover class (Mueller-Dombois and Ellenberg 1974): <1%, 1-5%, 6-25%, 26-50%, 51-75%, 76-100% based on aerial cover within a 30 m^2 plot. At plot center we used a 10 basal area factor prism (10 ft^2/ac) to sample tree basal area. We tallied all trees by species and designated them as alive or dead. Also at plot center we used a convex spherical densiometer to assess canopy cover from 1.2 m above the ground, averaging readings from the four cardinal directions. We recorded aspect and slope of the plot using a compass.

Using the prism data obtained at the five plots per condition per site, we divided the data into various cover types (Appendix I). The pitch pine types were obvious. The softwood type has more than 50 percent of the basal area as softwoods (mainly white and red pine, red and white spruce). The mixed conifer-hardwood designation was assigned to sites that had between 50 and 25 percent softwoods, and the hardwood designation was used for sites with less than 25 percent softwoods.

Data Analyses – Preliminary diagnostics revealed that the data did not meet the assumptions of multivariate normality. Each data point in our summary dataset was the average of 4-15 measurements. To find those variables that best separated invaded from uninvaded conditions, we compared condition by forest type on untransformed data using the Mann-Whitney nonparametric test in the Kruskal-Wallis one-way ANOVA, with only two groups (invaded and uninvaded) ($\alpha = 0.05$). We then ran a confirmatory analysis using the two group t-test with Bonferonni adjustments ($\alpha = 0.05$). Analyses were performed using SYSTAT 10.2.01.

Results

Kruskal-Wallis test results (Table 1) provided more significant variables that showed differences between invaded and uninvaded conditions than did the results of the t-tests (Table 2). According to the Mann-Whitney U test, no variables were significant in all forest types, and only a few variables, duff depth and shrub cover, were important across the three forest types that are not dominated by pitch pine. Shrub frequency distinguished between invaded and uninvaded conditions in hardwoods, mixed woods.

The t-tests (Table 2) confirmed the significant variables revealed by the Kruskal-Wallis nonparametric results in nine variable-forest type combinations, but not in ten other combinations (total 60 possibly combinations). T-tests identified a few more significant variables than were found significant in the Kruskal-Wallis results: shrub frequency distinguished invaded from uninvaded conditions in the pitch pine types.

Most variables that were important for separating invaded from uninvaded conditions were related to fine fuels such as nonwoody litter (leaves, cones, etc.), duff, graminoids, and slash. Duff depth was significantly lower in invaded hardwoods, invaded mixed conifer-hardwoods and invaded softwoods. Nonwoody litter was lower in invaded hardwoods and invaded pitch pine. Another group of significant variables were related to live fuels in the shrub layer, including shrub cover, shrub frequency, and shrub height. In all these cases, shrub features were significantly greater in the invaded conditions. The graminoid layer was sparse at some sites (Fig. 2) and included native sedges, while at five of the study areas, invasive grasses were prominent. These were non-native species such as *Microstegium vimineum* in hardwoods and mixed woods, *Anthoxanthum odoratum* in pitch pine, and *Poa nemoralis* and *Festuca filiformis* in softwoods.

At three study areas -- Morristown National Historical Park (MO in Fig. 2), Rachel Carson National Wildlife Refuge (RC) and Albany Pine Bush Preserve Site 1 (AF) -- the native graminoids were mostly *Carex pennsylvanica*. At Cape Cod National Sea Shore, the invaded plots had *Anthoxanthum odoratum* while the uninvaded plots had *Carex pennsylvanica*. At other sites, most of the graminoids in the invaded plots were invasive, non-native grasses, including *Microstegium vimineum, Anthoxanthum odoratum, Poa nemoralis,* and *Festuca filiformis*.

Discussion

We selected sites that were as similar as possible with regard to overstory. However, we anticipated that we might uncover an association between fuel load of invasive plants and the amount of light in the understory, as reflected by percent tree cover, basal area, and percent canopy closure derived from densiometer readings. This association was not apparent in our data. On the hardwood sites our ocular estimate of percent tree cover was significantly greater in the uninvaded conditions than in the invaded, but this was not confirmed by the densiometer derived percent canopy closure or the prism derived basal area.

Shrub layer -- Our hypothesis was that invasive shrubs would not contribute significantly to the fuel loads of invaded forest stands and this was confirmed by the data. Density of live fuels in the shrub layer at invaded sites has implications for fire managers because in severe drought conditions, the improved continuity of fuel could contribute to spread and intensity of a wildfire, and might increase likelihood of crowning in conifer types. We found that shrub cover and frequency in the invaded plots were greater than in the uninvaded plots and this is directly attributable to invasive exotic shrubs in most cases with the result that the shrub variables (percent cover, frequency and height) are not fully independent. Invasive shrubs do not appear to replace native shrubs at the areas we studied, but present a change in understory composition and structure for the invaded forest. When these live fuels are included in custom fuel models in BEHAVE (NEWMDL) they actually serve to reduce fire behavior with slower rate of spread and shorter flame length. We do not have other evidence of live fuels acting as ladders. Control of invasive shrubs in forests is thought to be especially challenging, and management concerns extend to regeneration of desirable forest trees, which might be outcompeted by the invasive shrubs.

The phenology of several of the invading shrubs also works to reduce fire behavior in invaded fuel beds. Leaf expansion of *Lonicera* spp., *Berberis thunbergii* and *Celastrus orbiculata* have been reported to be earlier than that of the canopy and native shrubs and leaf retention in the fall is later (Hutchinson and Vankat 1997; Woods 1993; Silander and Klepeis 1999; McNab and Loftis 2002). This results in a lengthened period when fuels are green with high moisture contents and a shortened period when fuels are brown.

Rapid decomposition of invasive leaf litter has been reported on invaded sites (Ehrenfeld 2001). Our observations of lack of accumulation of duff beneath invasive plants confirm those of Kourtev et al. (1998). The diminished duff depth and continuity of duff reduces the potential for ground fire in invaded areas. In a related study, Kourtev et al (2002) found that decomposition of native sweet birch (*Betula lenta*) tended to be more rapid when placed under exotic vegetation. Accelerated decomposition of leaf litter would reduces fire behavior both by reducing mass of 1 hour fuel available and by reducing continuity of litter thereby reducing intensity and spread of surface fire.

Pitch pine and black locust -- Separation of pitch pine areas from non-pitch pine was necessary because the invasive plant of interest was black locust , *Robinia pseudoacacia*, which is native farther south in North America. The species is considered by some managers to be nonflammable. Dominance by black locust has been observed to change the fire return interval and intensity. Under black locust, we found less nonwoody litter, 1-hour fuels, and slash. When pitch pine forests become invaded by black locust, fire is less likely and less intense. Leaves of black locust decompose more rapidly than pitch pine needles, at least initially, and thus result in less accumulation of non-woody litter (Broadfoot and Pierre 1939).

Fine fuels and graminoids -- Regardless of the distinction between pitch pine and other forest cover types, fine fuels were pinpointed in this study as some of the most discriminating features for distinguishing between invaded and uninvaded stands. This suggests that management of invaded lands should focus on preventing buildup of fine fuels.

However, eradication of exotic grasses from forested areas is a major challenge, especially where use of herbicides is not feasible. Among our study areas, native grasses were sparse and wherever exotic grasses were present, regardless of forest type, they added to the load of fine fuels. This suggests that during an extreme drought in autumn, a wildfire could spread more easily, have greater heat intensity, and increased likelihood of crowning than would be the case in a forest stand where such grasses are not present.

The nativeness of grasses does not affect fire behavior. At the study sites where we found native graminoids such as *Carex pennsylvanica* in abundance, we suspect that their effect on fuels might be little different from non-native grasses. Features in the non-native grasses that could influence fire behavior and fuels, such as browning phenology, stoloniferous vs. clumping habit, and presentation of a continuous fine fuel bed, were not measured in this study.

Fuel depth -- Although fuel depth is one of the most important variables for predicting fire behavior, we found dead detached fuels to be sparse and patchy in distribution. We did not find significant differences between the invaded and uninvaded conditions. Fuel depth had a high variance in our data and we do not know if more intensive sampling might have changed this. Dead material from the invasive plants does not significantly affect the fuel depth, and probably only a major disturbance or harvest could affect this variable.

Conclusions

Lack of consistent pattern from one site to another was due in part to the broad geographic range from which we sampled. In summary, we found significantly more fine fuels in the 1 hour size class in uninvaded hardwoods and pitch pine forest types that appear directly attributable to invasive plants. It is apparent that the fire regime in invaded forests has been altered and, unless it is managed, it is unlikely to return to that of uninvaded conditions on its own. Even in a region where rainfall is typically abundant, such as in northeastern North America, this could have consequences for fire spread and intensity in the wildland urban interface, particularly in a drought year when leaf-on vegetation is exposed to high fire danger from lightning or human activity.

Invasive grasses are problematic. Where they are present, the invasive grasses are a prominent departure from nearby uninvaded forest conditions and must not be overlooked as a hazard fuel under dry circumstances.

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Table 1. Results of Kruskal-Wallis nonparametric tests by condition of invaded or uninvaded.

Forest type	Variable (units)	Rank sum, invaded (no. plots)	Rank sum, uninvaded (no. plots)	Mann-Whitney U test statistic	Probability	Chi-square approximation, with 1 df
Hardwoods	Nonwoody litter (kg/ha)	483.0 (25)	792.0 (25	158.0	0.003	8.986
Hardwoods	100 hour fuels (kg/ha)	758.0 (25)	517.0 (25)	433.0	0.019	5.468
Hardwoods	Duff depth (cm)	512.0 (25)	763.0 (25)	187.00	0.014	6.006
Hardwoods	Shrub cover (percent)	846.0 (25)	429.0 (25)	521.0	0.000	16.548
Hardwoods	Tree cover (percent)	575.0 (25)	700.0 (25)	250.0	0.044	4.070

Hardwoods	Shrub frequency	830.5 (25)	444.5 (25)	505.5	0.000	14.211
Conifer-Hardwoods	Duff depth (cm)	155.0 (15)	310.0 (15)	35.0	0.001	10.452
Conifer-Hardwoods	Fuel depth (cm)	166.0 (15)	299.0 (15)	46.0	0.006	7.615
Conifer-Hardwoods	Shrub cover (percent)	307.5 (15)	157.5 (15)	187.5	0.002	9.786
Conifer-Hardwoods	Slash cover (percent)	290.0 (15)	175.0 (15)	170.0	0.009	6.860
Conifer-Hardwoods	Shrub frequency	287.0 (15)	178.0 (15)	167.0	0.022	5.266
Pitch pine	Nonwoody litter (kg/ha)	168.0 (15)	297.0 (15)	48.0	0.007	7.157
Pitch pine	1 hour fuels	159.0 (15)	306.0 (15)	39.0	0.002	9.296

	(kg/ha)					
Pitch pine	Slash cover (percent)	181.5 (15)	283.5 (15)	61.5	0.024	5.078
Pitch pine	Shrub height (cm)	288.5 (15)	176.5 (15)	168.5	0.020	5.398
Softwoods	Duff depth (cm)	73.0 (10)	137.0 (10)	18.0	0.016	5.851
Softwoods	Graminoid cover (percent)	144.5 (10)	65.5 (10)	89.5	0.002	9.344
Softwoods	Shrub cover (percent)	129.0 (10)	81.0 (10)	74.0	0.047	3.947
Softwoods	Shrub height (in)	130.5 (10)	79.5 (10)	75.5	0.046	3.966

Table 2. Results of two-group t-tests by forest type. Groups are invaded and uninvaded conditions, based on five invaded and five uninvaded plots per study area.

Forest type	Variable	Mean invaded ± SD (N plots)	Mean uninvaded ± SD (N)	Bonferroni adjusted probability (df)	Difference in means C.I.
Hardwoods	Nonwoody litter (kg/ha)	3.610 ± 1.574 (25)	5.597 ± 2.797 (25)	0.049 (48)	-3.287 to -0.688
Hardwoods	Duff depth (cm)	0.396 ± 0.406 (25)	1.349 ± 1.375 (25)	0.025 (48)	-1.530 to -0.377
Hardwoods	Shrub cover (percent)	31.130 ± 21.647 (25)	8.300 ± 8.790 (25)	0.000 (48)	13.435 to 32.225
Hardwoods	Shrub frequency	64.588 ± 31.690 (25)	27.584 ± 30.621 (25)	0.002 (48)	19.283 to 54.725

Conifer-Hardwoods	Duff depth (cm)	0.243 ± 0.181 (15)	1.696 ± 1.583 (15)	0.022 (28)	-2.296 to -0.573
Conifer-Hardwoods	Shrub cover (percent)	42.050 ± 18.584 (15)	17.033 ± 18.506 (15)	0.014 (28)	11.146 to 38.888
Pitch pine	Nonwoody litter (kg/ha)	5.246 ± 2.731 (15)	8.750 ± 2.369 (15)	0.012 (28)	-2.297 to -0.430
Pitch pine	1 hour fuels (kg/ha)	0.342 ± 0.123 (15)	0.531 ± 0.158 (15)	0.015 (28)	-0.123 to -0.158
Soft woods	Graminoid cover (percent)	56.200 ± 36.736 (10)	7.800 ± 11.731 (10)	0.014 (18)	22.78 to 74.020

Appendix I. Details of twelve study sites with 13 study areas, including location, vegetation aspects, forest type category for analyses, sample size, and site characteristics. "i" = invaded conditions, "u" = uninvaded conditions

Site and abbreviation	Location	Ownership	Total ha	Study area	Cover	Forest Type designation	Target invasives	Transect Length (m)	Plots	Soil	Aspect	Slope (degrees)
Acadia National Park (AC)	Bar Harbor, Hancock Co., ME	National Park Service	14,165	Great Meadow (i) The Tarn (u)	Poplar species (i) Red oak/red spruce (u)	Hardwoods	Ninebark and Shrubby St. Johnswort	300 (i) 300 (u)	10	Silt loam (i) Fine sandy loam (u)	West (i) West (u)	0-10 (i) 0-20 (u)
Albany Pine Bush Preserve (AF)	Albany, Albany Co., NY	Albany Pine Bush Preserve Commission	809	Firebrand (i) Friendly (u)	Black locust (i) (u)	Pitch pine	Black locust	F:100 (i) F:235 (u)	10	Loamy fine sand (i, u)	Variable I and u	10-30 (i) 0-20 (u)
Albany Pine Bush Preserve (AL)	Albany, Albany Co., NY	Albany Pine Bush Preserve Commission	809	Locust (i) Chubb (u)	Black locust (i) (u)	Pitch pine	Black locust	L:227 (i) C:200 (u)	10	Loamy fine sand (i, u)	West (i) North (u)	0 (i) 0-17 (u)

Site and abbreviation	Location	Ownership	Total ha	Study area	Cover	Forest Type designation	Target invasives	Transect Length (m)	Plots	Soil	Aspect	Slope (degrees)
Antietam National Battlefield (AN)	Antietam, Washington Co., MD	National Park Service	394	Snavely Ford Woods	Oak/hickory hardwoods	Hardwoods	Japanese honeysuckle	184 (i) 142 (u)	10	Rock outcrop complex (i, u)	South (i) East (u)	0-20 (i) 20-30 (u)
Cape Cod National Seashore (CC)	Wellfleet, Barnstable Co., MA	National Park Service	17,647	Fresh Brook	Black locust (i) Pitch pine (u)	Pitch pine	Black locust	200 (i) 200 (u)	10	Coarse sand (i, u)	South (i, u)	3-14 (i) 2-50 (u)
Finger Lakes National Forest (FL)	Hector, Schuyler Co., NY	USDA FS	6,221	Mark Smith Rd	Oak/hickory hardwoods	Mixed woods	Multiflora rose		10	&&	Southeast (i) South (u)	3-12 (i) 5-20 (u)

Site and abbreviation	Location	Ownership	Total ha	Study area	Cover	Forest Type designation	Target invasives	Transect Length (m)	Plots	Soil	Aspect	Slope (degrees)
Holbrook Island Sanctuary (HI)	Brooksville, Hancock Co., ME	State of Maine Department of Conservation	498	Hutchins Estate	Red spruce/ Balsam fir	Softwoods	Norway maple	150 (i) 70 (u)	10	Fine sandy loam	West-north-west (i) South (u)	0-5 (i) 10-25 (u)
Manassas National Battlefield Park (MA)	Manassas, Prince William Co., VA	National Park Service	2,024	Brawner Woods (i) Carter Woods (u)	Oak/hickory hardwoods	Mixed woods	Japanese honeysuckle	158 (i) 260 (u)	10	&&	WNW (i, u)	5-10 (i, u)
Merck Forest and Farmland Center (MK)	Rupert, Bennington Co., VT	private, non-profit	1,275	Stone Lot	Mixed hardwoods	Hardwoods	Asian honeysuckle	94.5 (i) 102.5 (u)	10	&&	South (i) Southeast (u)	15-28 (i), 15-30 (u)

Site and abbreviation	Location	Ownership	Total ha	Study area	Cover	Forest Type designation	Target invasives	Transect Length (m)	Plots	Soil	Aspect	Slope (degrees)
Massabesic Experimental Forest (ME)	Lyman, York Co., ME	USDA Forest Service	1,488	Administrative Unit	Red oak – white pine	Mixed woods	Oriental bittersweet	144 (i) 70 (u)	10	Very fine sandy loam (i, u)	WSW (i, u)	2-10 (i, u)
Morristown National Historical Park (MO)	Morristown, Morris Co., NJ	National Park Service	686	Jockey Hollow	Oak – yellow poplar hardwoods	Hardwoods	Japanese barberry	150 (i) 150 (u)	10	Gravelly loam (i, u)	NE (i, u)	3-15 (i) 5-10 (u)
Penobscot Experimental Forest (PE)	Bradley, Penobscot Co., ME	University of Maine	1,538	Old Orchard	Oak – poplar &&	Hardwoods	Frangula alnus	96 (i) 100 (u)	10	&&	West (i, u)	0-5 (i) 0-5 (u)
Rachel Carson National Wildlife Refuge (RC)	Kittery, York Co., ME	Fish and Wildlife Service	1,902	Brave Boat Harbor Unit	Eastern white pine on old fields and mixed hardwoods	Softwoods	Japanese barberry	150 (i) 151 (u)	10	Fine sandy loam	Northeast (i) various (u)	0-5 (i) 0-16 (u)

Appendix II. Average fuel load by condition, forest type and study area, for nonwoody litter, hour fuels, duff depth, and fuel depth. For full names of study areas, see Appendix I.

Cover type	Fuel loading (dead)											
	nonwoody (Mg/ha)				1hr (Mg/ha)				10 hr (Mg/ha)			
	uninvaded	sd	invaded	sd	uninvaded	sd	invaded	sd	uninvaded	sd	invaded	sd
Hardwoods	**5.52**	2.77	**3.63**	1.57	**0.49**	0.38	**0.60**	0.42	**1.66**	1.12	**1.81**	1.27
AC	**5.23**	1.56	**2.62**	0.87	**0.69**	0.43	**0.62**	0.43	**2.48**	1.33	**2.21**	0.72
AN	**6.54**	4.03	**3.09**	1.25	**0.45**	0.12	**0.27**	0.34	**1.37**	0.70	**1.08**	0.80
MK	**5.45**	1.88	**2.97**	0.81	**0.44**	0.24	**0.75**	0.40	**1.94**	1.21	**2.01**	1.42
MO	**6.47**	4.43	**6.00**	1.29	**0.38**	0.25	**0.55**	0.26	**1.15**	0.74	**1.18**	0.67
PE	**4.18**	0.73	**3.54**	1.01	**0.47**	0.53	**0.63**	0.50	**1.26**	0.80	**2.21**	1.74
Conifers-												
hardwoods	**5.08**	2.60	**4.95**	3.47	**0.55**	0.61	**0.59**	0.46	**1.58**	1.26	**1.88**	1.77
ME	**6.70**	3.43	**7.69**	3.15	**0.26**	0.14	**0.61**	0.54	**1.04**	0.79	**2.17**	2.52
FL	**4.24**	1.97	**1.61**	0.88	**1.00**	0.83	**0.69**	0.44	**2.32**	1.59	**1.82**	1.38
MA	**4.28**	1.76	**5.55**	2.78	**0.33**	0.22	**0.43**	0.33	**1.34**	0.80	**1.60**	0.94

Cover type	Fuel loading (dead)											
	nonwoody (Mg/ha)				1hr (Mg/ha)				10 hr (Mg/ha)			
	uninvaded	sd	invaded	sd	uninvaded	sd	invaded	sd	uninvaded	sd	invaded	sd
Softwoods	**3.21**	1.96	**4.52**	2.17	**0.42**	0.25	**0.42**	0.33	**2.07**	1.50	**1.87**	1.28
HI	**2.71**	1.62	**4.48**	2.50	**0.46**	0.32	**0.37**	0.30	**2.56**	1.81	**1.95**	1.41
RC	**3.71**	2.33	**4.55**	2.08	**0.39**	0.16	**0.47**	0.36	**1.57**	0.91	**1.80**	1.16
Pitch Pine	**8.95**	2.49	**5.90**	2.50	**0.56**	0.33	**0.34**	0.23	**2.06**	1.21	**1.45**	1.23
AF	**7.02**	2.37	**7.11**	2.40	**0.54**	0.28	**0.37**	0.27	**1.67**	0.77	**2.21**	1.52
APL	**7.60**	0.60	**5.59**	3.10	**0.71**	0.32	**0.26**	0.16	**2.73**	1.37	**1.63**	0.80
CC	**11.45**	1.59	**5.48**	2.18	**0.42**	0.33	**0.39**	0.24	**1.77**	1.15	**0.51**	0.38

Appendix II, continued

Cover type												
Study area	100 hr (Mg/ha)				Fuel depth (m)				Duff depth (cm)			
	uninvaded	sd	invaded	sd	uninvaded	sd	invaded	sd	uninvaded	sd	invaded	sd
Hardwoods	**2.54**	2.29	**4.29**	4.16	**0.09**	0.17	**0.10**	0.19	**0.01**	0.15	**0.00**	0.01
AC	**3.03**	1.97	**6.99**	4.64	**0.08**	0.05	**0.21**	0.01	**0.00**	0.19	**0.00**	0.00
AN	**3.43**	3.25	**2.22**	2.47	**0.04**	0.04	**0.11**	0.00	**0.00**	0.26	**0.00**	0.00
MK	**2.89**	3.14	**3.66**	2.86	**0.08**	0.17	**0.06**	0.01	**0.02**	0.10	**0.01**	0.01
MO	**2.02**	1.59	**3.31**	2.87	**0.03**	0.03	**0.03**	0.00	**0.00**	0.03	**0.00**	0.00
PE	**1.87**	1.49	**4.24**	5.31	**0.26**	0.32	**0.18**	0.02	**0.03**	0.29	**0.00**	0.01
Conifers-												
hardwoods	**3.69**	3.29	**4.15**	4.30	**0.05**	0.08	**0.03**	0.09	**0.01**	0.02	**0.00**	0.00
ME	**2.77**	2.53	**2.04**	2.25	**0.09**	0.14	**0.04**	0.03	**0.03**	0.05	**0.00**	0.00
FL	**4.18**	3.64	**6.33**	5.58	**0.03**	0.05	**0.02**	0.01	**0.00**	0.04	**0.00**	0.00
MA	**4.23**	3.61	**4.07**	3.13	**0.07**	0.07	**0.06**	0.01	**0.01**	0.16	**0.00**	0.00

Cover type												
Study area	100 hr (Mg/ha)				Fuel depth (m)				Duff depth (cm)			
	uninvaded	sd	invaded	sd	uninvaded	sd	invaded	sd	uninvaded	sd	invaded	sd
Softwoods	**3.66**	4.03	**4.67**	3.82	**0.14**	0.35	**0.17**	0.25	**0.05**	0.04	**0.02**	0.03
HI	**5.11**	5.18	**5.10**	4.05	**0.10**	0.09	**0.14**	0.05	**0.05**	0.25	**0.02**	0.03
RC	**2.20**	1.39	**4.24**	3.63	**0.18**	0.49	**0.21**	0.04	**0.05**	0.25	**0.03**	0.03
Pitch Pine	**3.92**	3.96	**4.46**	4.58	**0.14**	0.20	**0.12**	0.25	**0.03**	0.03	**0.02**	0.02
AF	**3.25**	4.88	**7.07**	6.23	**0.12**	0.18	**0.11**	0.00	**0.00**	0.10	**0.00**	0.00
APL	**4.95**	3.02	**4.07**	2.82	**0.20**	0.28	**0.14**	0.01	**0.02**	0.36	**0.04**	0.02
CC	**3.55**	3.75	**2.24**	2.43	**0.10**	0.06	**0.11**	0.02	**0.06**	0.22	**0.01**	0.02

Figure 1. Orientation of Brown lines for planar intersect sampling along random bearings and vegetation plot along a transect.

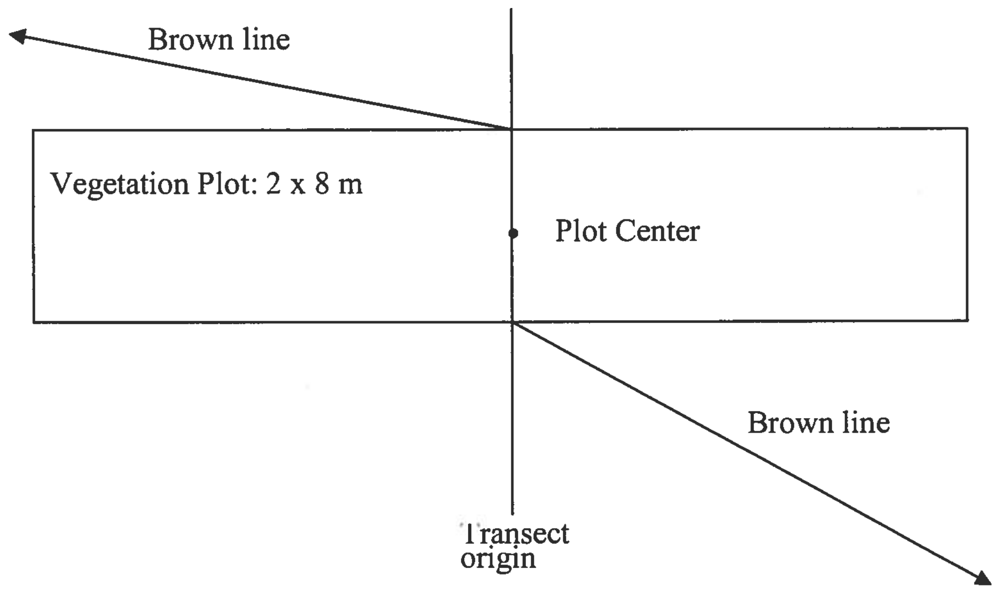

Figure 2. Graminoid cover at 13 study areas. Values are average midpoint for Braun-Blanquet cover classes in five plots (3 m radius) per condition as invaded or uninvaded at each area. Abbreviations for sites are given in Appendix I. AF, AL, and CC are pitch pine types. * = significant at alpha=0.05 in two-group t-tests.