RESEARCH ARTICLE

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Assessing the Impacts of Deer Browsing, Prescribed Burns, Visitor Use, and Trails on an Oak-Pine Forest: Pinery Provincial Park, Ontario, Canada

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ABSTRACT: An effective approach to increase forest health is to identify and validate a suite of indicators for monitoring forest conditions. We sought indicators of impacts due to deer browsing, prescribed burn, visitor use, and trails on understory plants beside trails in an oak-pine savanna in Pinery Provincial Park, Ontario, Canada. Six commonly used ecological indicators were studied in 216 1-m x 1-m quadrats located 0, 3, and 15 m from nine trails: plant species richness, stern density, species cover, proportion of native species, median height of selected tree seedlings, and proportion of foliar damage (insect herbivory) on leaves of neighboring trees. Three levels of visitor use, two of deer densities, and two of prescribed burns were used in analysis. Plant stem density and cover per quadrat were sensitive to the effects of deer density, prescribed burn, and visitor use. The proportion of native species per quadrat was affected by prescribed burn, distance from trail edge, and visitor use. The number of nonnative species increased along trail edges, but numbers of native species were similar throughout. Plant species richness, median seedling height, and proportion of foliar herbivory per quadrat were only sensitive to deer density. Higher deer densities led to significant declines in species richness, stem density, cover, and median seedling height. Prescribed burns proved to be beneficial to the forest, with stern density and cover increasing in burned areas, although the proportion of exotic species also increased in burned areas. Surprisingly, high visitor use had a moderately positive impact on the forest, with density and cover increasing on trails with high visitor use, and proportion of native species highest on trails with moderate visitor use. Of the indicators studied in the park, stern density, cover, and the proportion of native species responded strongly to browsing, fire, visitor use, and trail impacts. Similar studies at other parks would help managers to focus long-term monitoring efforts on the most sensitive site-specific indicators.

Index terms: ecological indicators, ecosystem health, oak-pine savanna, Ontario, vegetation

INTRODUCTION

Worldwide, conservation of forests has focused laudably on preservation of habitat, namely, on efforts to protect as much intact forest as possible (Goodland 1987, Shaffer and Saterson 1987, Ceballos and Garcia 1995, Mittermeier et al. 1998, 01-son and Dinerstein 1998). However, issues of quantity and of quality are of concern in these efforts. As increasing numbers of ecosystems become altered by humans, there is a greater need to monitor managed ecosystems to maintain, achieve, or re-verse a particular state (Grumbine 1990, 1994; Bengston 1994; Brunson and Kennedy 1995; Brunson 1996).

Several stand-level indicators have been proposed internationally to measure the condition of forests (United Nations Conference on Trade and Development 1983; Anonymous 1994, 1995), and many of these are already being used in monitoring activities (Riitters et al. 1990). However, there are few published studies of indicators that are responsive to a combination of stresses including human activity.

We measured six indicators of forest condition to determine whether one or more indicators were particularly sensitive to multiple stresses. As a case study, we selected Pinery Provincial Park, in southwestern Ontario, Canada. This park receives a high number of visitors per year (almost half a million), has high deer density directly or indirectly due to human activity, and has been subject to prescribed burns as part of management efforts to restore the historic, natural burn regime. For the purposes of our study, areas that did not undergo prescribed burns were considered "stressed," because fire has historically been a natural force shaping oak-pine savanna (Tester 1989, Guyette and Cutter 1991).

The six indicators we selected have been used in prior studies of forest condition, but not all have been used in all studies. They are (1) species richness, (2) plant density, and (3) species cover (Chappell et al. 1971, Dickman 1978, Madany and West 1983, Tester 1989, Tilghman 1989, Anonymous 1994, Kevan et al. 1995, Parikesit et al. 1995, Nuzzo et al. 1996, Smith 1996), (4) proportion of native species (Anonymous 1994), (5) height of individual plants (Tilghman 1989, Anonymous 1994, Covington and Moore 1994, Balgooyen and Waller 1995), and (6) foliar damage by insect herbivory (Riitters et al. 1990, Wick-man 1992). We selected primarily indicators associated with vegetation, for logistic reasons and because we were interested in the lay public's reactions to particular indicators related to forests (part of a larger study; see Patel et al. 1999).

We expected that species richness, density, cover, and the height of plants would increase with increasing visitor use (Bur-den and Randerson 1972, Dale and Weaver 1974, Lance et at. 1989, Parikesit et al. 1995), and decline at very high levels of visitor use. We expected the proportion of native species to decline with increasing visitor use (Dale and Weaver 1974, Cole 1978). We expected these results based on the assumption that high visitor use would result in increased light near trail edges (due to opening of the canopy, and bent or snapped branches, for example) and in-creased nutrient inputs (from pet urine, for example [Parikesit et al. 1995]). Further, we expected that indicator values would increase in areas with a past (not recent) history of prescribed burns, compared to areas that had not undergone burns in the past (Oswald and Covington 1984, Tester 1989, Nuzzo et al. 1996), and that all indicator values except foliar herbivory would decrease in areas with higher deer populations (Tilghman 1989, Strole and Anderson 1992, Anderson 1994, Balgooyen and Waller 1995, Maun and Crabe 1995). Foliar herbivory by insects was expected to increase in prescribed burn areas (because the plants there would tend to have younger and more tender leaves than those of unburned areas), but was not expected to be altered significantly by visitor use, distance from trail, or by relative deer population size. In addition, we expected that species richness, plant density, cover, and height of plants would decrease, and the proportion of native species increase, with increasing distance from the trail.

METHODS

Study Site

We selected Pinery Provincial Park (43° 15'N, 81° 50' W) in southwestern Ontario as the study site for several reasons: (1) the park contains nationally and globally rare forest types (Grossman et al. 1994); (2) human (recreational) use is high (approximately 450,000 visitors per year); (3) some historical (presettlement) records on the park exist; and (4) multiple impacts on vegetation include not only visitor presence and trails, but also prescribed burns and heavy browsing by white-tailed deer (*Odocoileus virginianus* Zimmerman).

Pinery Provincial Park (also known as the Pinery) is located at the northernmost limit of the nationally rare Carolinian forest (Fox and Soper 1955, Thaler and Plow-right 1973). The park is bordered by the Lake Huron shore, and the Old Ausable Channel (an old anthropogenic channel) divides the park in two along its length. Much of the 2,532-ha park is composed of oak-pine savanna, growing on the older sand dunes of Lake Huron (Bakowsky 1995). On these old dunes, *Quercus rubra* L., *Q. velutina* Lam., and *Q. alba* L. occur abundantly along with *Pinus resinosa* Ai-ton and *P. strobus* L. (Morrison and Yarranton 1974, Gleason and Cronquist 1991). Surveyors' records indicate that the pre-settlement forest was oak savanna (see Morrison and Yarranton 1973). However, over a million pine trees (*P. resinosa* and *P. strobus)* were planted by the Parks Division, Department of Lands and Forests, in the 1950s, and several portions of the park still contain stands of planted pine. Pinery Provincial Park is mainly used for recreation, and visitor use on individual trails varies from less than 2000 visitors per year (on the new Heritage Trail and two ski trails) to over 9000 visitors per year (T. Crabe, unpubl. data). Some sections of the Pinery were burned in 1989, 1990, and 1993 as part of a prescribed bum plan (Bakowsky 1995). Deer browsing is heavy throughout the park (Bakowsky 1995) and is especially heavy in the part of the park that lies between Lake Huron and the Old Ausable Channel.

Sampling

In June and July 1996, we measured the six indicators on nine trails in Pinery Provincial Park. These indicators were intended to measure the impact of visitor use, trails, deer browsing, and fire on forest condition. Trails ranged from 1 km to 9.6 km in total length, were 1–2 m in width, and all were covered with crushed stone. The nine trails selected for study were evenly divided into three levels of visitor use—low (< 4000 visitors per year), medium (4500–6500 visitors per year), and high (8500–10,500 visitors per year)—based on visitor sign-up books on each trail (T. Crabe, unpubl. data). During the two-month study, we observed that visitor sign-up books were frequently (but not always) used, and the pattern of visitor sign-ups appeared similar among trails (A. Patel and D. J. Rapport, pers. obs.). Therefore,

Table 1. Characteristics of trails in Pinery Provincial Park, Ontario, Canada, selected for study.

Trail	Visitor Intensity	Prescribed Burn	Deer Browsing
Dune Ridge	Low	Yes	High
Heritage	Low	Yes	Very high
Huron	Low	Yes	Very high
Bittersweet	Moderate	No	Very high
Carolinian	Moderate	No	Very high
Lookout	Moderate	Yes	High
Cedar	High	No	Very high
Nipissing	High	Yes	High
Wilderness	High	No	Very high

the sign-up data appeared to be a reason-able proxy for actual visitor use. Five trails were affected by prescribed bums carried out between 1989 and 1993 (T. Crabe, Resource Management Supervisor, Pinery Provincial Park, Grand Bend, Ontario, Canada, pers. corn.) and six were affected by especially heavy deer browsing (Table 1). Deer density in Pinery Provincial Park was estimated at 860 deer in 1996, or 34 deer **km-**^{2} (estimated by pellet counts; T. Crabe, pers. corn.). For our statistical analyses, we defined the three trails lying between Lake Huron and the Old Ausable Channel as affected by "very high" deer browsing, while the other six trails were defined as affected by a "high" level of deer browsing (deer populations in these two sections of the park consistently differ, with approximately 60% [i.e., 516 deer] occurring on the side adjacent to the lake, and approximately 40% [i.e., 344 deer] occurring on the side away from the lake; T. Crabe, pers. corn.). No areas of the park were free from deer browsing. The oak-pine forests on each side of the Old Ausable Channel are similar in vegetation and soil mineral content (Bakowsky 1990), hence we made the reasonable assumption that any differences we observed would indeed be due to deer browsing, and not inherent vegetation differences.

We set up eight 15-m-long transects on each of the nine trails (total of 72 transects). Transect positions were selected randomly, but were restricted to forest areas (i.e., dune areas were avoided). We established three 1-m^{2} quadrats on each transect, at three distances perpendicular to the trail: (1) adjacent to trail, (2) 3 m from trail, and (3) 15 m from trail. We set up these quadrats because the response of understory vegetation has been shown to vary with distance from trail (Taylor et al. 1993). Because we intended to study understory vegetation, we shifted quad-rats laterally if necessary to include only plants less than 4 m tall. This method did not introduce a large amount of bias into the study because fewer than 10% of all quad-rats needed lateral shifting, and shifted quad-rats were approximately equally distributed among trails.

In each quadrat, we collected data on number of species, stem density, species cover, number of native and nonnative species, and height of seven species of tree seedlings. Each plant above 2 cm in height was identified to species. Nomenclature and native/nonnative status followed Gleason and Cronquist (1991). Density was measured as the number of individuals of each species per m^{2}. However, density of stems such as grasses and sedges was measured by counting each upright stem as an individual, because it was not possible to as-certain whether an individual stem was a ramet or a genet. Cover was measured by visually estimating percent area occupied by each species per quadrat: 0%–5%, 6%–25%, 26%–50%, 51%–75%, and 76%–100%. In many quadrats, total cover of all species exceeded 100% because of layering of vegetation. Visual estimates were justified despite possibility of observer bias, because the visual estimate method compares favorably with point-frequency and subplot-frequency methods (Brakenhielm and Qinghong 1995).

In each quadrat, we recorded the height class of seven common tree species (woody plant) seedlings— <10 cm, 11–30 cm, 31–60 cm, 61–90 cm, 91–120 cm, and 120–400 cm—and calculated the median height for all the seedlings in a quadrat. Median height was used instead of the mean, be-cause plant heights were not normally distributed (Sokal and Rohlf 1981). The species selected for height measurements represented a sample of understory and canopy trees common in the Pinery and -therefore important for forest regeneration: *Fraxinus americana* L., *Prunus serotina* Ehrh., P. *virginiana* L., *Quercus alba, Q. rubra, Q. prinoides* Willd., and *Q. velutina* (white ash, cherry, and oak species). We selected common species rather than all species because we wished to determine whether the height of "typical" oak-pine savanna plant species was responsive to the impacts measured.

Data on herbivory were measured from four trees with relatively low branches (< 4 m above the ground) occurring around each quadrat. The four trees chosen for each quadrat were those closest to the quadrat in any direction, but within 1 m distance on either side of the quadrat as measured from the trail edge. For example, trees chosen for the 3-m quadrat were those lying in the area between 2 m and 5 m from the trail edge. Often, the trees were at some distance from the quadrat itself, but we assumed that these trees' environment was similar to the environment (light, proximity to trail) of the quad-rat with which they were associated. One leaf on each of eight branches, in eight directions, was selected at random and scored for the presence or absence of in-sect herbivory (eight leaves per tree). Tree diameter at breast height was also measured to determine whether insect herbivory on leaves was related to the size of the tree.

To analyze how all indicators performed under the impacts of visitor use, deer browsing, and fire, individual ANOVAs were performed for each indicator (PROC GLM; SAS Institute 1989) using quadrat totals. The units of measurement for the indicators were number of species (plant species richness), number of individuals of each species (stem density), total species cover (total of all species), number of native species, height of seedlings of selected species, and number of leaves showing insect herbivory. For each ANOVA, therefore, the dependent variable was the total number of plant species in a quadrat (species richness), the sum of the number of individuals of each species (stem density), the sum of the midpoints of cover values for each species in a quadrat (species cover), the proportion of native species in a quadrat, the median height of seedlings in a quadrat, or the proportion of tree leaves showing foliar herbivory for the four trees associated with a quadrat.

Because all combinations of visitor use, deer density, and fire were not present (Table 1), six mixed-model ANOVAs were performed using visitor use (visitor), deer browsing (deer), and distance from trail (distance) as fixed effects, along with the interactions visitor x deer, visitor x distance, deer x distance, visitor x deer x distance, and trail (nested within visitor and deer). Transect (nested within trail, visitor and deer), was also included but was considered a random effect. In addition, six mixed-model ANOVAs were per-formed using prescribed burn (fire), dis-

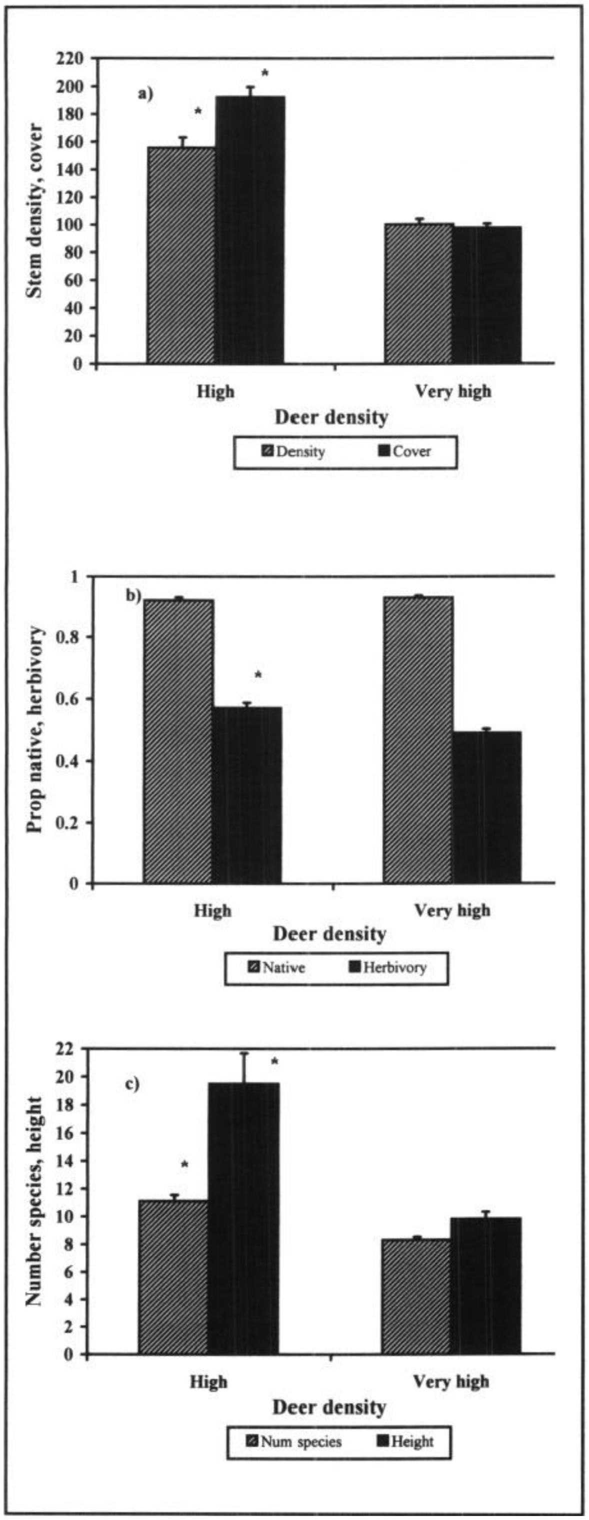

Figure 1. Mean and standard error of indicator values (per quadrat) for high and very high deer densities. Indicators are presented in pairs solely for the sake of abbreviation. Values are (a) total stem density (number of individuals) and total species cover (percent), (b) proportion of native species and proportion of foliar herbivory, and (c) total number of species and mean seedling height (cm). An asterisk above an indicator implies a statistically significant difference for that indicator between high and very high deer densities.

tance from trail (distance), trail (nested within fire), the interaction fire x distance, and trail (nested within fire) as fixed effects and transect (nested within trail and fire) as a random effect. Because each indicator was used in two ANOVAs, the probability level for a significant result was halved, to 0.025 (Bonferroni correction for multiple comparisons). Those dependent variables with non-normal distributions were transformed to normality (species richness, cover, and median seedling height were log transformed; stem density was square-root transformed); proportion of native species and proportion foliar damage had approximately normal distributions and were not transformed). All plants in quadrats were divided into six growth form categories (fern, forb, graminoid, shrub, tree, vine), and distribution of growth forms across distance from trail was examined.

RESULTS

Plant Species Richness, Stem Density, and Cover

A survey of 216 quadrats yielded a total of 117 plant species (104 native and 13 nonnative). An average of 9 species (SD=3) were found in each quadrat (range=2–22 species). Mean stem density was 119 stems m^{-2} (SD=60; range=3–347), with a mean of 101 native and 18 nonnative stems m^{-2}. Among the 216 quad-rats, species with the largest number of stems in each quadrat were, in decreasing order of stem density, *Calamovilfa longifolia* (Hook.) Scribn., *Poa compressa* L., and *Car-ex pensylvanica* Lam.. Several species were represented by one individual only, for example, *Pinus resinosa* Aiton, *P. strobus* L., *Osmorhiza claytonii* (Michx.) Clarke, *Viburnum lentago* L., and *Liriodendron tulipifera* L. Species occurring most frequently in quadrats (i.e., in most number of quadrats) included *Carex pensylvanica, Maianthemum canadense* Desf., and *Toxicodendron radicans* L., in de-creasing order of frequency.

Stem density was sensitive to the effects of deer browsing, fire, and visitor use, with fewer individuals occurring in quadrats with very high deer densities (Figure 1 a), and more individuals occurring in burned areas (Figure 2a) and in areas of high visitor use (Table 2, Figure 3a). The interaction terms, visitor use x deer, and visitor use x distance from trail, were statistically significant but are unlikely to be biologically significant. Stem density increased with visitor use and was highest on high visitor use trails in high deer density areas. However, in very high deer density areas, stem density was highest on low visitor use trails. Stem density increased with visitor use in quadrats 0 and 3 m from trail edge, and was highest in high visitor use areas, except in quadrats 15 m distant from trail edge, where stem density was highest in low visitor use areas. Stem density also differed significantly among transects.

The number of species per quadrat decreased significantly in quadrats with very high levels of deer browsing (Table 2, Figure lc), but not with visitor use, fire, or distance from trail edge (Table 2, Figures 2, 3, 4). Species number also varied significantly among transects.

Cover, like density, varied greatly and ranged from 5% to 334% (mean and SD = 129% and 67%, respectively, per quadrat, with 120% native and 9% nonnative). Total plant cover per quadrat was a sensitive indicator, decreasing in areas with very high deer densities (Figure 1 a), and increasing in burned areas (Figure 2a) and areas of high visitor use (Table 2, Figure 3a). None of the above three indicators (species richness, stern density, percent cover) was sensitive to distance from trail edge (Figures 4a, 4c). The interaction term visitor use x deer was sig-

Table *2*. **Results of individual ANOVAs. Indicator values were the dependent variables. The corresponding variable *F* values are presented: the overall *F* value for the analysis ("Total"), and the individual *F* values for the fixed effects of deer browsing, prescribed burn, visitor use, and distance from trail ("Distance"). Other effects are discussed in the text. Significant *F* values are accompanied by asterisks indicating the corresponding *P* value. Percent variance explained by the model *is* shown in the column titled "Percent Variance." Two ANOVAs were performed per indicator because the design was unbalanced.**

Indicator	Total	Deer	Burn	Visitor Use	Distance	Percent Variance
Total species richness	2.77***	22.16***		3.43	0.39	64%
Total species richness	2.98***		3.14		0.96	61%
Total stem density	4.32***	38.36***		8.60**	0.92	73%
Total stem density	4.33***		33.62***		1.10	70%
Total species cover	7.55***	98.20***		14.86***	2.90	82%
Total species cover	8.36***		44.14***		1.64	82%
Proportion of native species	2.84***	1.17		5.18*	28.96***	64%
Proportion of native species	3.04***		8.94*		21.83***	62%
Proportion of foliar damage	2.42***	8.42*		2.78	0.29	60%
Proportion of foliar damage	2.60***		3.29		0.09	58%
Median seedling height	1.09	6.86*		0.77	0.87	41%
Median seedling height	1.19		1.70		0.72	39%

*P<0.025, **P<0.001, ***P<0.0001

nificant; cover increased with visitor use in high deer density areas, but did not increase linearly in very high deer density areas (cover was lowest at moderate visitor use; Figure 3a). Cover also varied significantly among transects.

Proportion of Native Species

Each quadrat had an average of 8 (SD=3, range=2-19) native species, and one nonnative species (SD=1, range=0-6). The mean proportion of native species per quadrat was 0.93 (range 0.62-1.00). The proportion of native species (0.88, 0.94, and 0.96, respectively) increased with increased distance from trail (Table 2, Figure 4b), reflecting higher presence of nonnative species near trails (Table 3). The number of nonnative species increased at trail edges (a mean of 1.1 species per quadrat at trail edge, vs. 0.6 species at 3-m and 0.4 species at 15-m distance). The number of native species was similar at all distances from the trail, while the number of nonnative species increased at trail edges. The mea number of native species increased with increasing visitor use (averaging 8, 8, and 9.5 at low, medium, and high visitor use, respectively; but see Figure 3 for pr(portion of native species. However, there was no similar trend with number nonnative species (mean 0.9, 0.4, 0.7 at low, medium, and high visitor use respectively). Fire was also a significant effect, with mean of 8 native and 0.4 nonnative species in areas that were not burned, compared with a mean of 9 native and 1 nonnative species in burned areas (Figure 2b shows effect of flu on proportion of native species). The interaction terms deer x quad and fire x quad were statistically significant. Proportion of native species was fairly similar at 3-m and 15-m distance in high and very high de, density areas, with a larger difference at I m distance (0.85 in high density and 0.90 very high density areas). The proportion of native species in burned areas was much lower than that in unburned areas at the 0-quadrat distance (0.85 vs. 0.92), showing that alien species increased at trail edges burned areas. Proportion of native species differed significantly among trails and transects.

Nonnative species found commonly beside trails, and occurring more than five

Table 3. **Comparison of mean number (rounded** to **nearest integer) and percent (in parentheses)** of native vs. **nonnative plant species richness, stems, and cover per quadrat,** in **the three distances from trail edge (see text for statistics).**

	Mean Number, Percent of Species		Mean Number, Percent of Stems		Mean Number, Percent of Cover	
Distance from Trail	**Native**	**Nonnative**	**Native**	**Nonnative**	**Native**	**Nonnative**
adjacent to trail	8.4 *(30.2)*	1.1 (4.0)	*96 (27.0)*	*30 (8.5)*	107 *(27.6)*	16 (4.1)
3 m from trail	*8.8* (31.6)	*0.6 (2.2)*	103 *(29.0)*	13 (3.7)	122 (31.4)	*8 (2.1)*
15 m from trail	*8.5 (30.6)*	*0.4 (1.4)*	103 *(29.0)*	10 (2.8)	130 *(33.5)*	*5 (1.3)*

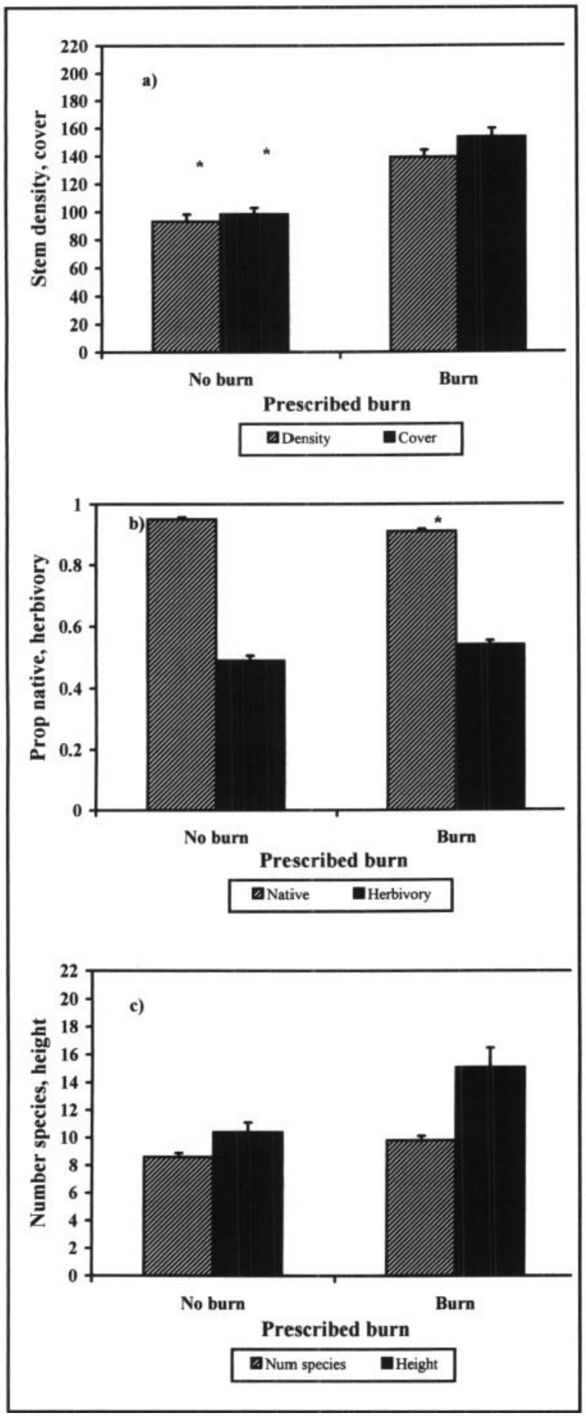

Figure 2. Mean and standard error of indicator values (per quadrat) for areas without and with prescribed burns. Indicators presented in pairs solely for the sake of abbreviation. Values are (a) total stem density (number of individuals) and total species cover (percent), (b) proportion of native species and proportion of foliar herbivory; and (c) total number of species and mean seedling height (cm). An asterisk above an indicator implies a statistically significant difference for that indicator between areas without and with prescribed burns.

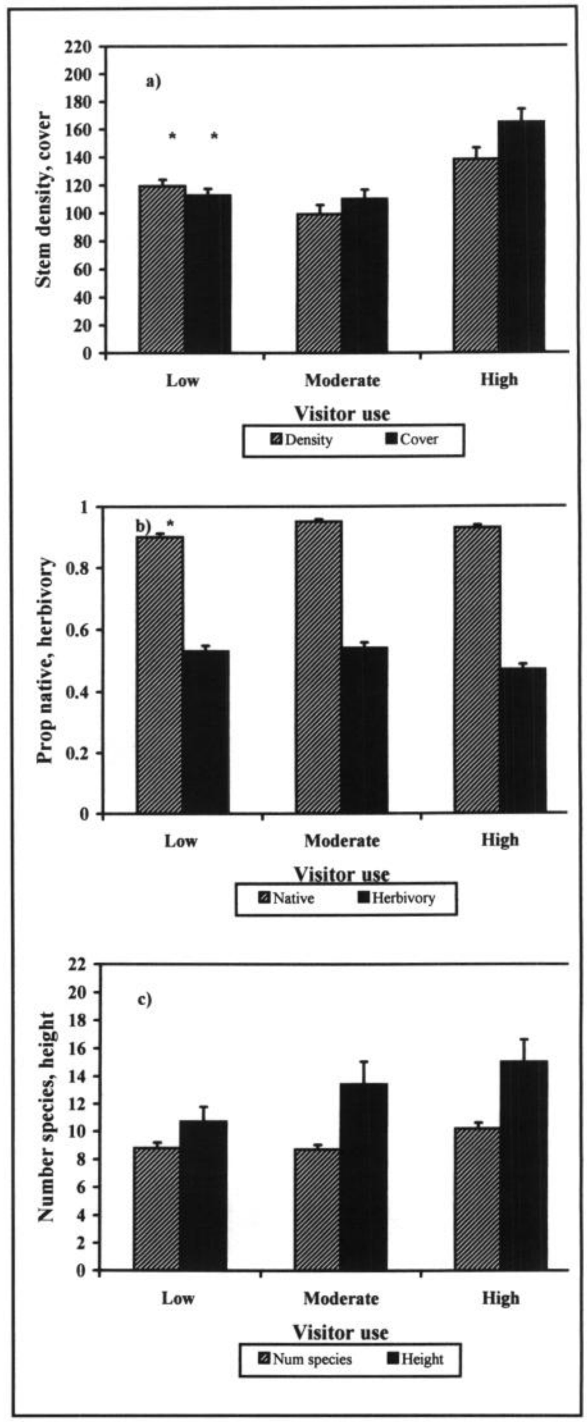

Figure 3. Mean and standard error of indicator values (per quadrat) for low, moderate, and high levels of visitor use. Indicators presented in pairs solely for the sake of abbreviation. Values are (a) total stem density (number of individuals) and total species cover (percent), (b) proportion of native species and proportion of foliar herbivory, and (c) total number of species and mean seedling height (cm). An asterisk above an indicator implies a statistically significant difference for that indicator among low, moderate, and high levels of visitor use (note: asterisk does not indicate which of the differences is significant).

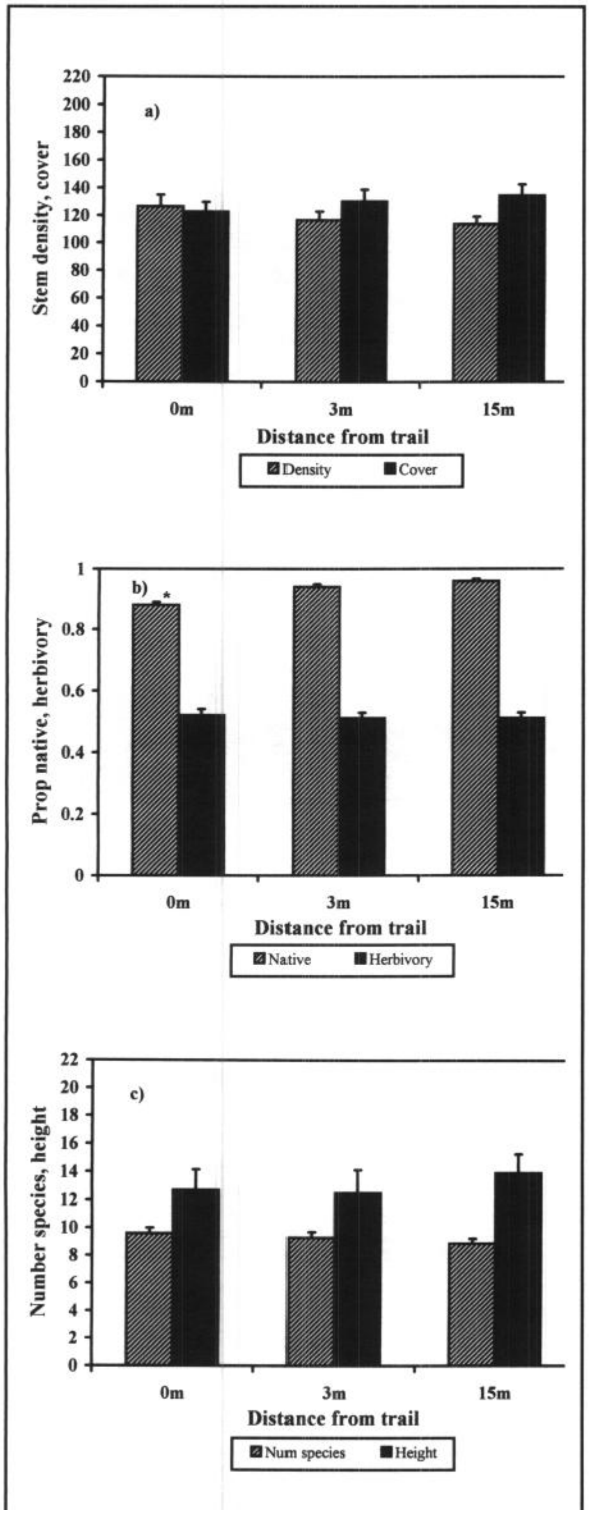

Figure 4. Mean and standard error of indicator values (per quadrat) for 0-m, 3-m, and 15-m distance from trail. Values are (a) total stem density (number of individuals) and total species cover (percent), (b) proportion of native species and proportion of foliar herbivory, and (c) total number of species and mean seedling height (cm). An asterisk above an indicator implies a statistically significant difference for that indicator among 0-m, 3-m, and 15-m distances.

times in different quadrats, were *Poa compressa, Taraxacum officinale* Weber, and *Hieracium pratense* Tausch. (most to least frequent). *Poa cornpressa* accounted for most of the stem density (mean=29, 12, and 10 stems/ quadrat at 0, 3, and 15 m, respectively) and cover (mean=13, 6, and 4/ quadrat at 0, 3, and 15 m, respectively) of nonnative species at the three quadrat distances (compare with Table 3).

Median Woody Plant Seedling Height

A total of 909 woody plant seedlings were recorded; average density was 4.2 seedlings m-^{2}. Seedlings of P. *serotina* and P *virginiana* were most abundant in the quadrats, numbering 470 (mean ± SD height = 14±11 cm) and 195 (mean ± SD height = 19±16 cm), respectively, followed by F. *americana* with 159 seedlings (mean ± SD height = 11±3 cm). Oak seedlings were not as abundant: *Q. velutina*, 26 (mean ± SD height = 20±9 cm); *Q. rubra,* 21 (mean ± SD height = 20±8 cm); *Q. alba, 20* (mean ± SD height = 31+14 cm); and *Q. prinoides*, 18 (mean ± SD height = 29±10 cm). Seedling height differed significantly among species (Kruskal-Wallis ***H*** = 216.7, P < 0.0001).

The height of seedlings was significantly lower in areas with very high deer densities (Table 2, Figure lc), averaging 10 cm (SD=6 cm) and 19 cm (SD=18 cm) in very high and high deer density areas, respectively (Figure lc). Seedling size was highly skewed: 63% of the 909 seedlings were less than 10 cm high, and fewer than 1% were over 60 cm high (Figure 5). Only one seedling was more than 120 cm high.

Proportion of Foliar Damage

The proportion of leaves on trees showing foliar damage because of insect herbivory was significantly higher in areas with high deer densities (Figure 1 b), but was not related to fire (Figure 2b), visitor use (Figure 3b), or distance from trail edge (Figure 4b, Table 2). The pro-portion of leaves showing foliar damage differed significantly among trails and among transects. The mean proportion of leaves with herbivory in high deer density areas was 0.57 (SD=0.15), whereas mean proportion in very high deer density areas was 0.49 (SD=0.16). Trees with larger girths had significantly more leaves showing insect herbivory (Pearson correlation, *r=0.22*, P<0.01, N=864).

Tree species varied in the number of leaves with foliar damage by in-sects (Kruskal-Wallis test with chi-square approximation, H=393.81, P<0.0001). Species with the great-

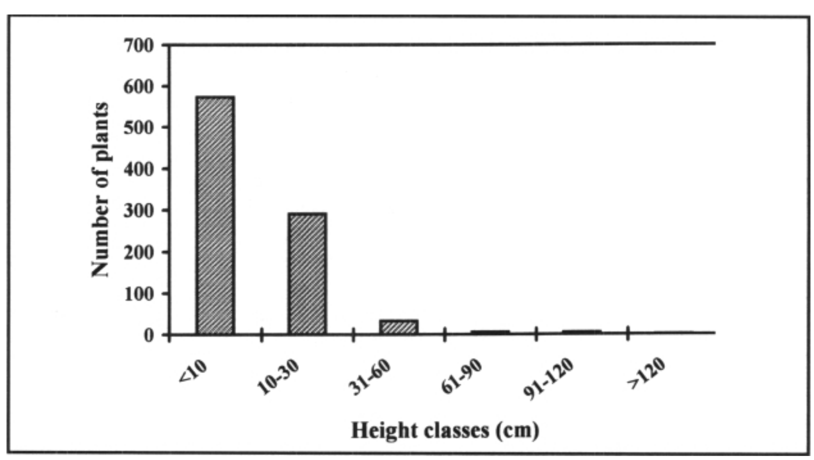

Figure 5. Number of woody plant seedlings found in various height classes.

est amount of foliar damage were oak species *(Quercus alba, Q. rubra,* and *Q. velutina),* and those with the least amount of insect herbivory were pine species (P. *resinosa* and P. *strobus).* Foliar damage per leaf ranged from approximately 5% to 80% of the leaf's surface.

Growth Form

The distribution of trees and vines was almost identical at distances of 0, 3, and 15 m from the trail edge (Table 4). How-ever, other components of forest structure were altered. Ferns occurred less frequently at trailside than at other locations. Forbs were more frequent at 0 and 3 m from the trail edge than at 15 m, whereas shrubs were more frequent at 15 m than at the other two distances. Graminoids were more frequently found at the trail edge than at any other location, as expected. A chi-square test of independence showed that growth form frequency was significantly related to the distance of the quadrat from the trail ($x2$ = 18.70, df = 10, $P < 0.04$).

DISCUSSION

When we compared expectations to results, we found that our expectations of indicator behavior were met in a majority of cases under the varied impacts of deer, fire, and visitor use. Deer browsing had a strong effect on the understory vegetation of Pinery Provincial Park. Five of the six indicators were sensitive to the impacts of deer browsing, and, as we expected, four of these (species richness, stem density, cover, and height of woody plant seedlings) were affected negatively in areas with very high deer densities.

As expected, species richness, stem density, cover, and seedling height increased in burned areas, although not always significantly. Contrary to expectation, the pro-portion of native species declined in burned areas, most likely because increased light allowed nonnative species to thrive (numbers of exotic species increased in burned areas). The incidence of foliar herbivory changed little in burned and nonburned areas. Although prescribed burns can favor understory growth (Nuzzo et al. 1996), they have been discontinued at the Pinery for some time because deer browsing of the increased seedling growth following a burn threatens to severely deplete the soil seed bank (T. Crabe, pers. com.). Unfortunately, we could not determine whether there were interactions between burn and deer browsing effects, or bum and visitor use effects, because our study design was unbalanced. Future studies in parks with large numbers of trails and multiple impacts may help clarify the complex inter-actions among the main impacts.

Species richness, stem density, cover, and height of seedlings increased as expected only if we compared low and high levels of visitor use; however, the trends were not linear when moderate visitor use was included, and only species density and cover were significantly higher on high visitor use trails. Visitor use also had a significant effect on proportion of native species (opposite to that predicted), with more native species per quadrat at the high level of visitor use. Foliar herbivory did not change with visitor use, as expected. Our study showed that visitor use at the Pinery had a beneficial effect on some indicators, even though off-trail use is discouraged. The high density and cover on trails with high visitor use may be because high visitor numbers increase trailside soil disturbance or affect the magnitude of deer grazing (A. Patel and D.J. Rapport, pers. obs.). Our results contrast with other studies that show fairly strong, mostly negative effects of trampling on vegetation near paths (Dale and Weaver 1974, Liddle and Greig-Smith 1975, Cole 1978, Taylor et al. 1993, Kevan et al. 1995, Parikesit et al. 1995). We suggest that the reason visitor use has not affected plants negatively is because the wide, crushed stone paths at Pinery Provincial Park tend to favor on-trail behavior, by allowing people to walk abreast and providing clearly delineated trail boundaries. Although we noted some gravel displacement off the trail, it did not appear sufficiently large to affect vegetation significantly.

The proportion of native species increased farther from the trail edge, as predicted. Species richness and stem density did de-cline farther from the trail edge, as predicted, but the declines were not significant. Cover and seedling height, contrary to prediction, did not decline, but the changes in these indicators were also not significant. Foliar herbivory did not change with distance from trail edge, as expected.

Which of the indicators studied might be easiest to monitor? Our results indicate that, of the many possible indicators used for monitoring protected areas, several may turn out to be sensitive for measuring the combined effects of impacts at a particular site. In Pinery Provincial Park, stem density, cover, and proportion of native species were the most sensitive to the impacts of deer browsing, prescribed burns, visitor use, and trails. The presence of trails affected the number of nonnative species more than that of native species, perhaps through increased light or more disturbed substrate. Therefore, we suggest that number or proportion of nonnative species (rather than native species) might be an appropriate indicator for monitoring vegetation in parks. Measuring stem density or cover is likely to be extremely costly and time-consuming.

Although woody plant seedling height was significantly sensitive to deer density only, we suggest that it is likely to be the easiest indicator to measure, logistically. The

Table 4. Frequency and percent (in parentheses) of occurrence of each type of growth form, summed across all quadrats 0, 3, and 15 m from trail (all treatments combined).

Quadrat	Fern	Forb	Graminoid	Shrub	Tree	Vine
Adjacent to trail	15 (0.8)	246 (12.3)	194 (9.7)	96 (4.8)	66 (3.3)	71 (3.6)
3m from trail	30 (1.5)	247 (12.3)	159 (8.0)	99 (4.9)	69 (3.4)	68 (3.4)
15m from trail	23 (1.2)	193 (9.6)	165 (8.2)	115 (5.8)	66 (3.3)	79 (3.9)

strongly skewed seedling height distribution in our study matched that of an exclosure study in the nearby Rondeau Provincial Park that indicated that heavy browsing by deer affected the community structure of the forest, leaving few woody plants to grow above 1–2 m in height (see The Land-plan Collaborative 1992; see also Tilghman 1989, Anderson 1994). Further, a deer exclosure study in the Pinery revealed that *Q. prinoides* stems inside exclosures consistently attained heights of 30–120 cm, whereas those of control stems outside exclosures were unable to grow to more than 3–5 cm before they were browsed (The Landplan Collaborative 1992). In our study, most seedlings growing taller than 10 cm were browsed, as evidenced by browse marks on seedlings (A. Patel and D.J. Rapport, pers. obs.). The use of long-term deer exclosures, as at the Pinery, will help parks demonstrate very clearly the damage done by excessive browsing. The height of common seedlings is an indicator that the public can easily understand and even measure through casual observation (see also Anderson 1994, Balgooyen and Waller 1995; but see Williams et al. 2000), a factor important for public education.

Proportion of foliar damage was not a useful indicator of the multiple impacts at the Pinery. Although deer browsing level was the only impact to have a significant effect on proportion of foliar damage, it is not likely to be a strong indicator, partly be-cause it reflects only the presence of herbivory and not the actual amount of herbivory on leaves.

We suggest that a combination of indicators is likely to be ideal for monitoring and reporting forest health—a few that are sensitive to all the effects being measured, and a few that may not be as sensitive but are easily measured through casual observation. Early research that seeks to narrow the numbers of indicators to a few effective, site-specific ones will help reduce park management expenses and make long-term monitoring financially feasible and publicly palatable.

As our study of a protected park shows, the health of forested ecosystems already under protection can still be compromised, by over-browsing for example (Bratton 1979, Frelich and Lorimer 1985, Alverson et al. 1988, Tilghman 1989). Much recent discussion has revolved around measuring the health of large-scale, managed ecosystems (Schaeffer et al. 1988, Costanza 1992, Ehrenfeld 1992, Schaeffer and Cox 1992, Forest Ecosystem Management Assessment Team 1993, Kolb et al. 1994, Steed-man 1994, Karr 1995, O'Laughlin 1996, Yazvenko and Rapport 1996). However, we still have no universal protocols for monitoring forest condition, because little integrative field research has been published on evaluating the effects of multiple impacts on forested ecosystems. Our study is one step in the direction of monitoring multiple impacts, and future studies will help managers of protected areas in achieving their desired goals for forest condition.

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