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Methodology for estimating deer browsing impact

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Abstract: Because there were no reliable indicators of deer browsing on tree seedling regeneration, we developed methodology that can be used to measure deer browsing impact. We compared 11 years (2002 to 2012) of annual estimates of deer density with coarse (percent-plots-no-regeneration, percent-plots-no-impact) and fine (3 levels of impact on 6 indicator seedling species) indicators within a 29,642-ha study area in northwestern Pennsylvania. Coarse and fine measures met established criteria for indicators of environmental stress (e.g., high deer density); they were predictive of stresses that can be: avoided by management; integrative with causes of stress; responsive to disturbances and changes over time; and of sufficiently low variability to be significantly responsive to changes in stressors. Time spent and equipment required to collect indicator data were minimal. Data were collected at the same time and on the same plots as deer density data, producing a significant savings of time and capital. Indicators tested had potential as proxies for deer impact on other forest resources.

Key words: browse indicator species, deer browsing impact, human–wildlife conflicts, *Odocoileus virginianus,* white-tailed deer

Overabundant white-tailed deer (*Odocoileus virginianus*) herds are a leading cause of regeneration failures in northeastern hardwood forests (Alverson 1988, Tilghman 1989). Deer can eliminate or severely suppress regeneration of tree species and overall plant diversity and enhance invasion of weedy exotic species (Frerker et al. 2013, Russell et. al 2001). New York fern (*Thelypteris noveboracensis*) and hay-scented fern (*Dennstaedtia punctilobula*) may dominate understories in thinned or final-harvested stands, greatly reducing the value of the resulting stand when it matures because of understocking and predominance of less valuable tree species (Horsley and Marquis 1983). Inventories conducted prior to timber harvest can determine whether the potential for an adequately-stocked stand exists in the form of diverse and abundant regeneration. However, unless such inventories determine whether reduced stocking is caused by deer and can gauge the severity of deer impact, forest managers cannot address the deer impact situation or even determine whether it exists.

Dale and Beyeler (2001) stated that indicators (metrics) of stressors (e.g., white-tailed deer) affecting structure, composition and function of ecological systems should be: easily measured; sensitive to stresses; respond to the stresses in a predictable manner; anticipatory; able to predict changes that can be avoided by management; integrative; have known response to disturbances and changes over time; and have low variability. Chevrier et al. (2012) stated that such metrics should respond predictably and sensitively to changes in relative deer density. Currently, few methodologies for assessing deer impact on forest vegetation possess more than one of these qualities, and none are compared with deer density.

Early measures of deer browsing on woody plants utilized counts of stems browsed (Shafer 1963), but such studies did not relate these measures to actual impact on plants, nor did they relate levels of browsing to deer density. Frerker et al. (2013) developed methodology for combining proportion of browsing on woody plants with relative browsing preferences for those plants to monitor browsing, but did not relate either to survival or fitness of impacted plants or to deer density. Chevrier et al. (2012) used 10 years of field data with roe deer (*Capreolus capreolus*) to develop an oak (*Quercus* sp.) browsing index that increased linearly with increases in deer density, but it was for only 1 impacted species (oak) and did not predict levels of impact based on deer density.

In 2000, a consortium of forest landowners,

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biologists, government scientists, hunters, and local recreation organizations initiated a deer demonstration project, the Kinzua Quality Deer Cooperative (KQDC) in northwestern Pennsylvania, to determine whether public hunting could reduce deer density to the point where it no longer threatened regeneration of tree species and forest understory in general (deCalesta 2012, Stout et al. 2013). Scientists from KQDC refined methodology for estimating deer density (deCalesta 2013) and developed associated methodology for measuring deer impact.

Because the KQDC was designed to provide information and techniques managers could use in managing forest resources, the methodology had to be relatively inexpensive, utilize existing field equipment, represent impact on multiple resources, be amenable to integration with other relevant information (e.g., deer density), and preferably be collected at the same time and on the same plots used to measure deer density. We demonstrate how this technique, in conjunction with other methodology developed within the KQDC, meets the requirements for indicators of environmental stress (in this case deer browsing) described by Dale and Breyer (2001).

The intended application of the technique is as a tool for recommending levels of deer harvest required to reduce deer impact sufficiently to result in significant improvement in tree seedling regeneration and in recovery of heavily-impacted understories. Objectives were to: (1) develop and field test methodology for identifying multiple levels of severity of deer impact; (2) determine whether the developed methodology could be used in conjunction with concurrent collection of data for estimating landscape levels of deer density; (3) determine the precision of the methodology being tested; and, (4) determine whether the methodology could use data for woody species to provide proxy assessment of deer impact on other woody species and other forest communities.

Study area

The 29,642-ha deer demonstration area was in the northwestern corner of Pennsylvania within the northern portion of the Allegheny National Forest. The heavily forested landscape was managed by 2 public organizations (Allegheny National Forest and Bradford Water Authority) and 3 private landowners (Collins Pine, Forest Investment Associates, and Ram Forest Products). The composite landscape was comprised of a mix of age classes of northern hardwood forest originally dominated by shade-tolerant tree species, including American beech (*Fagus grandifolia*), sugar maple (*Acer saccharum*), and eastern hemlock (*Tsuga canadensis*). The landowners utilized a mix of even- and uneven-aged silviculture for sustainable production of timber and other forest products, resulting in co-dominance of less shade tolerant trees, such as red maple (*Acer rubrum*), black cherry (*Prunus serotina*) and black and yellow birch (*Betula* spp.).

Methods

Deer impact

We laid a grid of numbered points 1,610 m apart in north-south and east-west orientation over the deer demonstration area and selected 26 of these points randomly as sites for collecting deer impact across the study area. At each of the selected points, we placed a grid of 5 transects 1,610 m long spaced 300 m apart such that the selected point formed the mid-point of the middle transect. We constructed 5 replicate samples by assigning each transect within each of the 26 grids of 5 transects a number, 1 to 5, randomly. Replicate 1 was comprised of all transects assigned the number one from the 26 grids, replicate 2 was comprised of all transects assigned the number two from the 26 grids and so on for 5 replicates of 26 transects. We laid out all transects on a compass bearing of 0^{o} (true north, corrected for declination of 12^{o} NW). We estimated deer impact on woody species within 26 circular plots (1.2 m radius) 60 m apart along each transect. Each year the same experienced foresters collected impact and deer density data during March to May when there was no snow cover or fern growth to obscure seedlings. We recorded browse impact data only within maturing forest stands. Harvested sites within grids were fenced; data were not collected from them.

Within each plot, we recorded levels of coarse- and fine-grain impact on plants $\geq$15 cm tall and <2 m tall. Because seedlings <15 cm tall reflect current germinants that may not survive due to multiple factors (drought, disease, heat, insect defoliation), seedlings <15 cm tall were not assessed for impact except in the case where the seedling had been severely browsed for years, preventing it from growing >15 cm in height. Impact on seedlings with all twigs higher than 2 m was also not recorded, as these seedlings were considered to have grown out of the reach of deer. We recorded impact data only on seedlings with twigs browsed by deer, which is characterized by ragged ends of browsed twigs unlike the sharp, 45° cut typical of rabbit and hare (*Sylvilagus* spp., *Lepus americanus*) browsing. We recorded data only for green, live twigs browsed in the current year; previous year's browsing is characterized by a length of dead, discolored twig between the browse point and current year's growth (Figure 1).

Figure 1. Appearance of twigs browsed by deer. Twigs on left reflect previous year's browsing; twigs on right reflect current year's browsing.

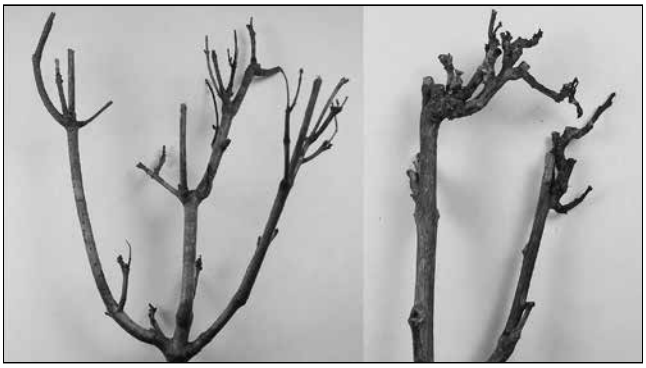

Figure 2. Appearance of twigs hedged by deer. Twigs on left reflect heavy hedging; twigs on right reflect severe hedging.

Coarse browse impact was assessed for 2 categories: no regeneration present for any of 6 indicator woody seedlings (red maple, striped maple [*Acer pensylvanicum*], eastern hemlock, American beech, black cherry, and birch); and no impact on any woody seedlings of any species, tree or shrub. Plots with no regeneration were devoid of regeneration for a variety of reasons (deer browsing, germination failure because of restricted light levels, disease, drought, or insects). Plots with no impact represented plots where deer had not browsed any woody species within the specified height interval.

We recorded fine grain impact on individual indicator species within 3 impact intervals. Zero-light impact (<50% of stems browsed) represented minimal deer impact on seedlings that would not result in reduced recruitment of seedlings into the sapling class. Moderate impact (>50% of stems browsed but seedling not hedged) represented deer impact that should result in recruitment of less preferred deer seedlings and may result in reduction in recruitment of preferred forage seedlings. Heavy-severe impact (>50% of seedling twigs are browsed and stunted by hedging) represented repetitive and destructive deer browsing that would prevent seedlings from growing into sapling-sized seedlings. Hedging refers to height suppression related to repeated deer browsing—hedged plants are stunted in height, and stems are browsed back to short, thick stubs (Figure 2).

For every plot with 1 or more indicator species, a single impact value was assigned per indicator species based on most prevalent impact level. For example, if 3 of 5 seedlings were moderately browsed and 2 were heavily browsed, the impact value recorded for that species was moderate. In case of ties (e.g., 2 stems moderately browsed, 2 stems heavily browsed), the higher level was assigned.

Rather than record deer impact on all woody species, which would have been time-consuming and fraught with high variability (low occurrence of many woody species), we selected 6 woody species as being representative of a wide range of deer impact based on locally-observed deer preferences and resistance to browsing. Preferred indicator species were red maple and eastern hemlock; moderately preferred indicator species were black and yellow birches as a single indicator species (birch) and black cherry. Browse-resistant indicator species were American beech and striped maple.

Deer density

We estimated deer density using the pellet group technique (deCalesta 2013). Deer pellet groups were counted on each impact plot, as well as on additional plots located half-way between impact plots on all transect lines at the same time impact data were collected. We estimated deer densities by transect and for the deer demonstration area, by year.

Calculation of percent impact

We calculated percent-plots-no-impact and percent-plots-no-regeneration per transect line by dividing number of plots with no impact and with no regeneration by total plots taken per transect line and multiplying by 100. We calculated percent-plots-no-regeneration and percent-plots-no-impact for the study area by averaging impact data from the 5 replicates. We tested the assumption that impact values collected among transect lines within individual grids were independent by making pairwise comparisons of adjacent and non-adjacent individual transect lines; none were correlated ($P > 0.05$).

Percent plots with each of 3 levels of impact were calculated for each indicator species at transect and deer demonstration area levels as described for coarse grain impacts.

Analysis

We compared impact levels for coarse and fine grain measures of impact among years with analysis of variance (Systat Software Inc., Chicago, Ill., 2007) to determine whether they were sensitive ($P \leq 0.05$) to changes over time as caused by deer browsing and other (unknown) factors. We regressed coarse- and fine-grain impact measures against deer density to determine whether impact levels were related ($P \leq 0.05$) to deer density (Systat Software Inc., Chicago, Ill., 2007).

Stout et al. (2013) characterized deer impact on herbaceous plants on the same grids in 2001, 2003, 2007, and 2011. Because abundance and occurrence of herbaceous plants are highly variable, Stout et al. (2013) measured only characteristics of plants present on plots that represented responses to stress (deer browsing): plant height; leaf length; and percent flowering for 3 indicator herbaceous plants (Trillium [*Trillium* spp.], Canada mayflower [*Maianthemum canadense*], and Indian cucumber root [*Medeola virginiana*]) known to be sensitive to deer browsing. We visually compared mean values of deer coarse and fine impact with values collected by Stout et al. (2013) for the 3 years of data overlap.

Results

Data collection spanned 11 years (2002 to 2012) when deer density and coarse and fine measures of deer impact varied considerably. Data sets representative of historical ranges of parameters over extended time periods are essential for detecting trends and significance of responses of dependent variables to independent variables.

We collected impact data from an average of 3,237 plots/year. Total potential plots for annual data collection was 3,380, but data were not collected from all plots every year; some fell within fenced harvest sites, and in a few years technicians were unable to collect data from a small number of transects. Most plots contained seedlings for <3 of the indicator species tall enough to be tallied. Many plots contained myriad germinants of indicator and other species >15 cm in height that were too small for inclusion in data sets. Time spent on individual plots tallying impact levels on indicator and other seedlings was generally <1 minute; most of the time spent recording deer impact was in traveling from plot to plot and from transect line to transect line (and walking from access roads to grids and back).

Impact of coarse grain

Both measures of coarse-grain impact differed among years (Table 1). These differences tracked deer density (Figure 3): percent-plots-no-impact varied inversely with deer density; percent-plots-no-regeneration varied directly with deer density (Table 2). Deer density accounted for much of the variability in coarse grain measures ($r^2 > 0.60$; Table 2). There was no apparent lag time between changes in deer density and changes in measures of coarse grain impact; changes in both measures tracked changes in deer density on a real time basis.

When deer density reached and remained more or less at goal (~6 deer/km²; 2005 to 2012) percent-plots-no-impact and percent-plots-no-regeneration stabilized until deer density plummeted in 2012, at which point percent-plots-no-impact rose, while percent-plots-no-regeneration dropped.

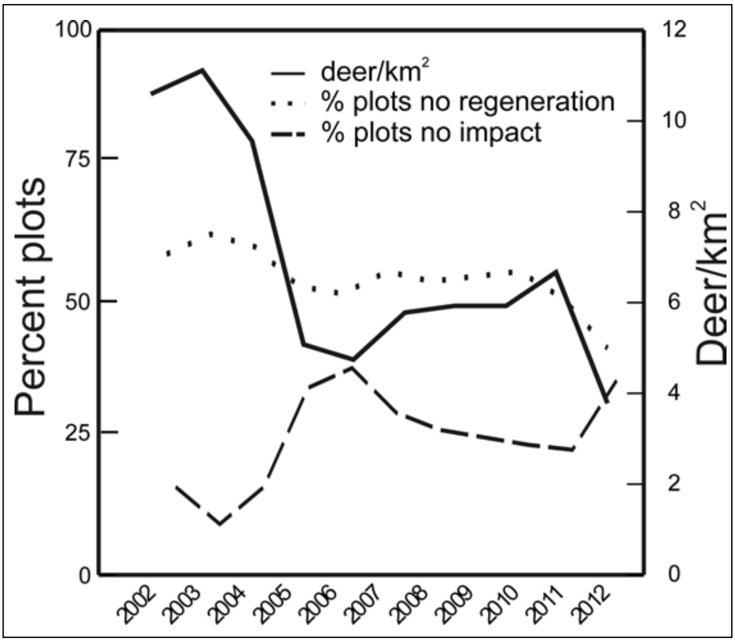

Figure 3. Relationship between deer density and percent-plots-no-impact and percent-plots-no-regeneration.

Fine grain impact

Measures of fine grain impact differed among years for the 3 levels of impact with few exceptions (black cherry, heavy-severe; eastern hemlock, moderate; birch, heavy-severe; Table 3).

These differences tracked deer density (Figure 4). Of the 6 indicator plant species, the 4 most commonly-occurring on plots (red maple, American beech, striped maple, black cherry) demonstrated similar responses to changes in deer density. As deer density increased, percent plots with indicator species decreased at zero–light and moderate impact levels (Table 4). The relationship between deer density and indicator species was not significant at the highest impact level, excepting American beech.

Regardless of deer density, including when density was at goal, mean percent plots for individual indicator seedling species summed over all levels of impact was never >30%; we assumed that the closed overstory canopy suppressed germination and development of advanced regeneration. Proportion of plots with zero–light impact increased when deer density declined to goal level. Proportion of plots with heavy–severe impact level was highest when deer density was highest and lowest when deer density reached goal levels. When deer density declined to goal level only a small proportion of plots were so heavily impacted that regeneration would fail, and proportion of zero–light impact plots predominated, suggesting that all indicator species would be recruited into the overstory.

Table 1. ANOVA for coarse-grain indicators among years.

Species	df	*F*	*P*
% plots no regeneration	10,44	163.5	<0.00001
% plots no impact	10,44	74.3	<0.00001

Table 2. Regression coefficients for coarse-grain indicators veersus deer density.

Indicator	α	β	df	r^2	*P*
% plots no impact	47.4	-3.38	1,9	0.86	0.00004
% plots no regeneration	42.1	1.8	1,9	0.62	0.004

Percent-plots-moderate and heavy–severe impact levels were much lower than for zero–light impact (Figure 4). Despite differences ($P < 0.01$) among years, mean values were so low (<2% plots) that pairwise comparisons for percent-plots-moderate and heavy–severe impact between years were different ($P \leq 0.05$) only for more abundant species (red maple, American beech, striped maple)

Table 3. ANOVA for indicator species among years at 3 impact levels.

Species	Impact level	df	*F*	*P*
Red maple	Zero–light	10,44	82.2	<0.00001
Red maple	Moderate	10,44	7.6	<0.00001
Red maple	Heavy–severe	10,44	4.5	<0.00001
American beech	Zero–light	10,44	45.8	<0.00001
American beech	Moderate	10,44	17.9	<0.00001
American beech	Heavy–severe	10,44	15.1	<0.00001
Striped maple	Zero–light	10,44	28.4	<0.00001
Striped maple	Moderate	10,44	6.9	<0.00001
Striped maple	Heavy–severe	10,44	10.6	<0.00001
Black cherry	Zero–light	10,44	19.3	<0.00001
Black cherry	Moderate	10,44	2.8	0.01
Black cherry	Heavy–severe	10,44	0.9	0.51
Eastern hemlock	Zero–light	10,44	16.6	<0.00001
Eastern hemlock	Moderate	10,44	0.6	0.78
Eastern hemlock	Heavy–severe	9,39	29.5	0.00001
Birch	Zero–light	7,32	29.0	<0.00001
Birch	Moderate	7,32	3.4	0.008
Birch	Heavy–severe	7,32	2.0	0.09

Table 4. Regression coefficients for percent plots indicator species versus deer density by browse intensity level.

Species	Browse level	α	β	df	r^2	*P*
Red maple	Zero–light	12.3	-1.1	1,9	0.47	0.02
Red maple	Moderate	2.74	-0.21	1,9	0.4	0.04
Red maple	heavy–severe	0.25	0.12	1,9	0.24	0.12
American beech	Zero–light	31.3	-2.2	1,9	0.56	0.008
American beech	Moderate	30.3	-1.8	1,9	0.43	0.03
American beech	Heavy–severe	-1.9	0.48	1,9	0.83	0.00009
Striped maple	Zero–light	13.6	-1.04	1.9	0.63	0.004
Striped maple	Moderate	13.9	-0.9	1,9	0.51	0.02
Striped maple	Heavy–severe	-0.68	0.25	1,9	0.43	0.33
Black cherry	Zero–light	9.7	-0.71	1,9	0.45	0.02
Black cherry	Moderate	9.3	-0.72	1,9	0.51	0.01
Black cherry	Heavy–severe	0.01	0.03	1,9	0.22	0.15
Eastern hemlock	Zero–light	2.3	-0.2	1,9	0.49	0.02
Eastern hemlock	Moderate	-0.15	0.05	1,9	0.04	0.61
Eastern hemlock	Heavy–severe	1.69	-0.16	1,9	0.06	0.51
Birch	Zero–light	3.02	0.03	1,6	0.01	0.82
Birch	Moderate	0.68	-0.03	1,6	0.10	0.76
Birch	Heavy–severe	3.0	0.3	1,6	0.01	0.82

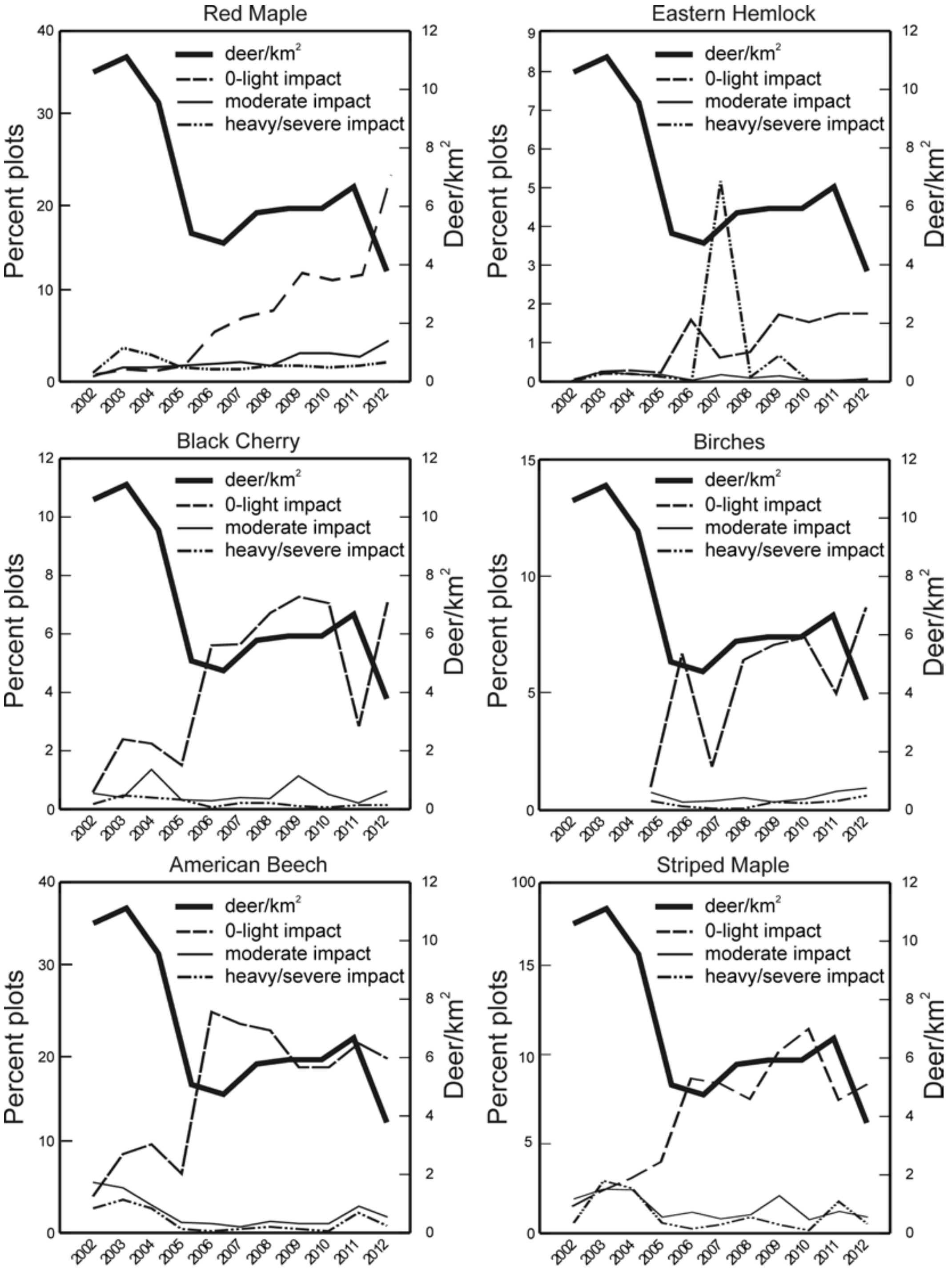

Figure 4. Relationship between deer density and level of fine grain deer impact (zero–light, moderate, heavy–severe) on 5 indicator seedling species.

and only between years of high versus low deer density.

Eastern hemlock at zero–light impact level was negatively related to deer density, but not at the higher (moderate; heavy–severe) impact levels. Percent-plots-birch was not related to deer density at any impact level ($P > 0.75$), but we did not begin to record impact on birch until 2005 when deer density had been greatly reduced; there was no gradient of deer density to correlate with impact levels on birch.

Because most plots with indicator species contained >1 indicator, summing percent plots with any level of regeneration over the 6 indicator species would over-represent percent plots with regeneration at some level (including zero) of impact. Subtracting percent-plots- no regeneration from 100 provides a value for percent plots with some level of regeneration for all woody species. Plotting this value for individual indicator species against deer density indicates the extent to which regeneration improved as deer density declined (Figure 5).

Comparisons between years for indicator species at moderate and heavy–severe levels were generally not different ($P > 0.05$). Deer impact was sufficiently low, even at highest densities recorded during 2002 to 2004, that there were few plots with these levels of impact, resulting in high variability in the small differences noted.

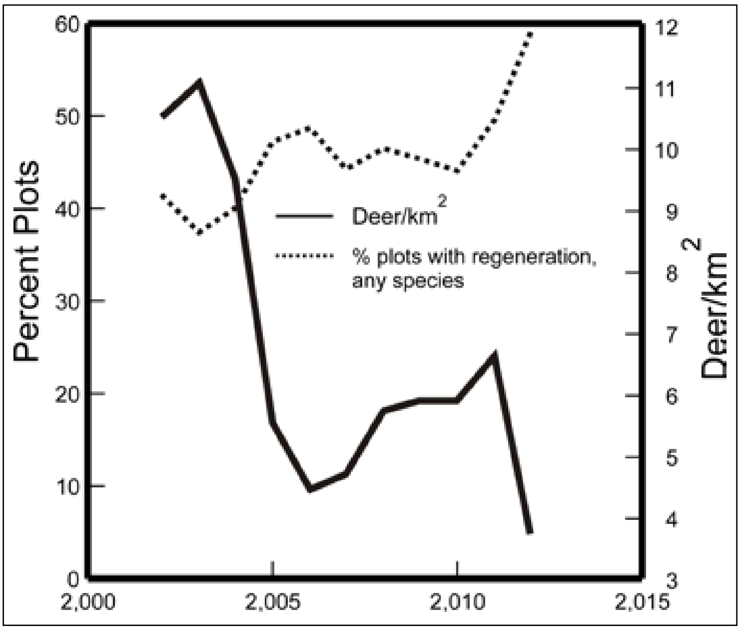

Figure 5. Relationship between deer density and percent plots regeneration by any species.

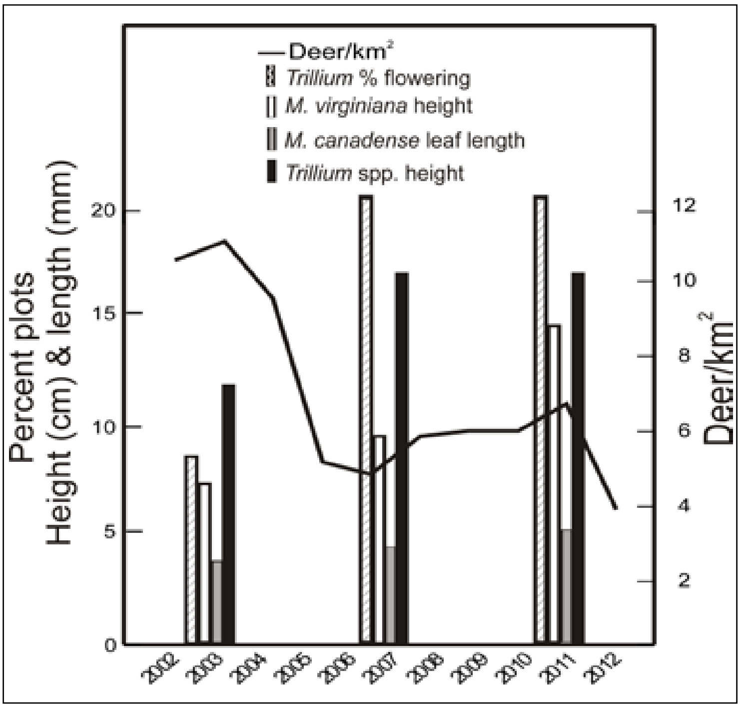

Figure 6. Comparison of deer density with deer impact on herbaceous species (from Stout et al. 2013).

Impact on herbaceous species

Values of characteristics of deer impact on herbaceous species (plant height and percent flowering) were low when deer density was high, increased when deer density reached goal level, and stabilized when deer density stabilized at goal density (Figure 6, adapted from Stout et al. 2013). Differences in impact characteristics were different between 2003 and 2007 and between 2003 and 2011, but not between 2007 and 2011.

Discussion

The coarse- and fine-grain measures of deer impact we tested met characteristics specified by Dale and Beyler (2001) for indicators of environmental stress. They responded predictably to stressors over time. Variability was sufficiently low that responses of dependent variables could be related significantly to independent variables. The measures were easily and inexpensively measured. They predicted changes that could be avoided by management (e.g., reduce deer density to reduce impact).

Additionally, the measures were sensitive to other stressors and disturbances. Percent plots with indicator seedlings plummeted in 2005 while deer density was declining, an unexpected result. Neither weather extremes nor insect defoliations occurred that might have explained why regeneration was so low in the presence of declining deer density. However, the winter of 2004–2005 was exceptionally cold, with reduced snow cover; possibly cold weather extending into March exhausted deer energy reserves and resulted in unusually high browsing impact on exposed seedlings. Another example of the indicator species' integrative capability occurred in 2007 regarding the high percentage of plots with heavy–severe impact levels for eastern hemlock. This phenomenon likely was caused by high germination of eastern hemlock seedlings in 2006 that survived to be monitored and heavily impacted (eastern hemlock is known to be highly preferred by deer) in 2007, with subsequent high mortality resulting in low occurrence on plots.

Differential responses of indicator species to differences in deer density confirmed our expectations regarding deer forage preferences. Based on higher proportion of heavy–severe impact plots through the range of deer density, red maple and eastern hemlock were considered preferred forage species for deer. Based on highest proportion of zero to light impact levels, American beech and striped maple were considered least preferred (most resistant). Black cherry and birches were probably intermediate in deer preference.

Increase in proportion of plots with zero to light impact on fine-grain indicator species lagged behind decreases in deer density by ~1 year, unlike responses of coarse-grain indicators. Fine-grain indictors of deer impact may be more sensitive to changes in deer density than coarse-grain indicators. Additionally, even when percent-plots-no-impact and percent-plots-no-regeneration plateaued after 2005, percent plots zero–light impact for 3 indicator species (red maple, eastern hemlock, and birches) continued to increase, reinforcing our suggestion that these species may be more preferable as deer browse.

We measured deer density and impact over a time frame wherein large changes in impact occurred synchronously with large changes in deer density. High levels of deer density measured in 2002–2003 are known to be detrimental to understory vegetation; plateaued deer density 2006 to 2012 represents deer in balance with ecosystem resources. If we had not begun measuring impact when deer density was high, but rather when deer density was close to and remained at goal, it is likely that coarse- and fine-grain indicators would not have exhibited sufficient differences through time to satisfy specified characteristics, and we may have rejected them as measures of deer impact.

Another factor useful in evaluation of coarse and fine indicators of deer impact was the random and representative way in which data were collected within grids of transect lines distributed across the entire study area. We likely sampled areas that deer used for feeding, bedding, hiding from predators and hunters, travel, and thermal protection, capturing a full range of habitat use, pellet group deposition, and impact.

Finally, comparison of changes in coarse- and fine-grain indicators can indicate whether selected indicator species act as such; if changes in percent plots of individual indicator species do not change in the direction suggested by changes in coarse grain measures, the chosen indicator species may not be indicative of deer impact. Selection of indicator species should be based on local knowledge regarding differing deer preferences for candidate indicator species.

Comparison among indicator species' responses to deer density may be useful in managing indicator species. Percent plots zero–light impact for red maple continued to increase as deer density fell to 4 deer/km^2; percent plots zero–light impact black cherry plateaued (except for the 2011 decline) when deer density plateaued at a little over 6 deer/km^2. Black cherry is more valuable commercially than red maple. Forest managers wishing to provide black cherry seedlings with a competitive advantage over red maple seedlings may wish to maintain deer density at 6/km^2.

Chevrier et al. (2012) stated that the relationship between deer abundance and impact can only be determined through concurrent estimation of impact and density, suggesting that deer density estimates be obtained unless one was willing to assume, without verification, that impact tracks changes in deer abundance. They noted that the intended use of deer monitoring programs is for manipulating deer harvest to achieve desired responses in deer density and impact on vegetation. They added that large variation in response of impact indicators and deer harvest is required to fine-tune the process of adjusting deer harvest to achieve goals with vegetation. They decried the fact that many states do not estimate deer abundance in the belief that it is necessary only to measure 1 metric (impact) and not deer abundance to manage deer to meet goals for vegetation. They questioned whether this strategy leads to successful deer management or if it can even determine if goals for vegetation management have been met. We maintain that deer cannot be managed to reduce impact on vegetation unless estimates of deer density and impact are collected, and that it makes sense to collect the data at the same time and on the same plots.

Concurrent collection of deer density and impact data saves time and money and requires little more time than that required for collecting impact data. Time spent counting deer pellet groups and recording impact levels on coarse and fine indicators usually takes < 3 minutes per plot. We recommend initial data collection to establish baseline deer density and impact and, thereafter, annually with adjustments of harvest regulations designed to reduce deer density and impact. Once deer density and impact have stabilized at goal levels, monitoring of both may be performed at longer intervals and or when drastic changes in either may have occurred.

Because changes in measures of impact on herbaceous vegetation paralleled those of coarse- and fine-grain indicators, we contend that the latter can serve as indicators of deer impact on the former. Research indicated that deer density of >7 deer/km^2 in northern hardwood forests results in declines in songbird abundance and diversity (deCalesta 1994), similar to the deer density resulting in reduced impact on preferred deer browse species. Theoretically, monitoring indicators identified as preferred deer forage may serve as a proxy for determining when deer impact negatively affects a wider range of forest resources.

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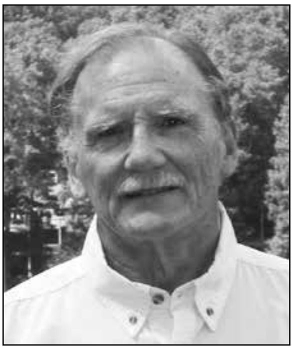

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