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Influence of skid trails and haul roads on understory plant richness and composition in managed forest landscapes in Upper Michigan, USA

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Abstract

We evaluated impacts of disturbance in interior haul roads and skid trails on understory vegetation by documenting the areal extent of these features and plant composition along 10 m × 100 m belt transects. Ten belt transects were sampled in each of three comparable northern hardwood forests under even-aged management. These forests were approximately 80 years old and were last entered for thinning 4–6 years prior to sampling. Soil compaction, canopy cover, and the richness and composition of trees, shrubs, and herbs were quantified within each feature (i.e. haul roads, skid trails, and forest without soil disturbance) encountered along transects. These variables were also quantified in unmanaged northern hardwood stands of comparable age. Differences in photosynthetically active radiation (PAR) and soil moisture between haul roads and adjacent patches of forest were measured along line transects placed across haul roads, perpendicular to their main axis.

On average, haul roads and skid trails comprised 1 and 16% of total managed stand area, respectively. Compaction, PAR, and soil moisture were highest in haul roads. Understory plant richness was significantly greater in haul roads than in skid trails and forest, and resulted from significantly greater percentages of introduced species (13%) and wetland species that were native to the area, but not normally abundant in northern hardwood stands (23%). Skid trails had a greater percentage of wetland species (9%) than in forest, but differences in richness between skid trails and forest were not statistically significant. Up to the present time, the impact of haul roads on understory vegetation has received far less attention than impacts on soil properties and water quality. Although haul roads comprise a relatively small proportion of total stand area, they serve as primary conduits for the dispersal of introduced species into the interior of managed stands and contribute to significant shifts in plant richness and composition at the stand level.

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1. Introduction

Access provided by forest roads is required for a variety of activities including timber management,

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wildlife management, recreation, and the management of fire, insect pests, and pathogens (Smith, 1986; Queen et al., 1997; Fedkiw, 1998). Potential ecological impacts of roads have received a great deal of attention in recent years (Forman and Alexander, 1988; Bengtson and Fan, 1999; Forman, 2000). Particularly prominent management issues and research problems include effects of roads on soil erosion, hydrology, and aquatic ecosystems (McCashion and Rice, 1983; Amaranthus et al., 1985; Jones and Grant, 1996; Elliot et al., 1999; Taylor et al., 1999; Findlay and Bourdages, 2000; Jones et al., 2000; Trombulak and Frissell, 2000). The influence of roads on a wide range of wildlife species have also been investigated (Sarbellio and Jackson, 1985; Van Dyke et al., 1986; McLellan and Shackleton, 1988; Bangs et al., 1989; Brody and Pelton, 1989; Mech, 1989; Thurber et al., 1994; Cole et al., 1997; Gibbs, 1998). Effects of roads on forest plant communities are less well-documented. Studies focused on exotic plant invasions in roadside plant communities along main forest and grassland roads and in adjacent communities have been completed (Forcella and Harvey, 1983; Tyser and Worley, 1992; Greenberg et al., 1997; Parendes and Jones, 2000), but changes in plant composition *within* interior haul roads and skid trails have received little attention. Given the extent of haul road and skid trail networks in managed forests and linkages between understory vascular plant communities and other flora and fauna, the impact of these features on ecosystem properties and processes could be substantial.

Hereafter, haul roads are defined as secondary roads constructed with heavy equipment that connect gravel-surfaced main forest routes with skid trails and interior log landings. These roads extend into the interior of management compartments and are leveled and improved in some areas by bringing in gravel and other fill materials. Haul roads are mainly traveled by semi-trailers during logging operations. Skid trails are defined as tertiary roads that are used by skidders and forwarders that move logs from the point of felling and bucking to log landings. Apart from the felling of occasional trees to provide a clear path, few improvements are made to skid trails. Typically, far fewer equipment passes are made on skid trails than haul roads. Haul road and skid trail networks are integral components of both managed forest stands and landscapes that include forests under management.

In 1994, we established a study designed to compare the biological diversity of northern hardwood forests representing unmanaged second growth, even-aged management, uneven-aged management, and old growth in Michigan's Upper Peninsula (Crow et al., 2002). Results of an initial reconnaissance of plant species conducted in 1994 and subsequent understory vegetation surveys conducted in 1997 and 1998 indicated important shifts in understory plant richness and composition between features within stands such as embedded wetlands, haul roads, skid trails, and upland areas of forest without soil disturbance. These differences in understory plant composition and richness represented some of the most substantial differences between actively managed and unmanaged northern hardwood forests. Results of Detrended Correspondence Analysis (DCA) of understory vegetation data collected in 1998 indicated that sampling plots located on or near skid trails and haul roads were strong outliers (Crow et al., 2002).

In 1999, we established a follow-up study with the objectives of (1) documenting the proportions of managed stands comprised of haul roads, skid trails, and forest patches without soil disturbance, (2) characterizing growth conditions (i.e. canopy cover, soil compaction, light, soil moisture) in each of these features, and (3) comparing the richness and composition of trees, shrubs, and herbs in the understory between features within managed stands, and also between managed and unmanaged stands.

2. Methods

2.1. Study sites

Study sites were established in Michigan's Upper Peninsula in the vicinity of Watersmeet, MI. All northern hardwood stands studied were located on the Ottawa National Forest, Watersmeet and Iron River Ranger Districts. All sites occurred within Albert's (1995) Sub-Subsection IX.3.2, which is the Winegar Moraine. This moraine is a prominent glacial feature in the western Upper Peninsula that extends southwestward into northern Wisconsin. The Winegar Moraine was formed during the late Wisconsin glaciation by the Ontonagon Lobe and is a rolling, sandy and loamy terminal moraine complex with strongly

collapsed hill and swale topography and a large number of embedded wetland depressions. Soils are acidic, rocky, sandy loams or loamy sands derived from iron-rich Precambrian parent material.

Variation in the physical environment among study sites was minimized by limiting all sites to ecosystems mapped as Ecological Landtype Phase (ELTP) 38 within Sub-Subsection IX.3.2. ELTP 38 is characterized by moderately well-drained sandy loams and loamy sands with a fragipan 45–90 cm below the surface. When present, this fragipan may significantly influence local soil moisture (Jim Jordan, pers. commun., Ottawa National Forest).

The overstory of all stands was heavily dominated by sugar maple (*Acer saccharum* Marsh.), with lesser amounts of yellow birch (*Betula alleghaniensis* Britton), American basswood (*Tilia americana* L.), eastern hemlock (*Tsuga canadensis* (L.) Carr.), red maple (*Acer rubrum* L.), and ironwood (*Ostrya virginiana* (Mill.) K. Koch). Common understory species in patches of forest without soil disturbance included Canada mayflower (*Maianthemum canadense* Desf.), star-flower (*Trientalis borealis* Raf.), sweet-cicely (*Osmorhiza claytonii* (Michaux) C.B. Clarke), Solomon-seal (*Polygonatum pubescens* (Willd.) Pursh), twisted-stalk (*Streptopus roseus* Michaux), false spikenard (*Smilacina racemosa* (L.) Desf.), several species of violet (*Viola*), several species and varieties of clubmoss (*Lycopodium*), shield fern (*Dryopteris spinulosa* Mueller), and lady fern (*Athyrium filix-femina* (L.) Roth). Sugar maple seedlings and saplings were also ubiquitous in the understory stratum, accompanied by seedlings and saplings of the additional woody species listed above.

2.2. Experimental design

Two sets of stands were incorporated in the experimental design. The first set of stands consisted of three 79–84-year-old northern hardwood forests under even-aged management, and the second set of stands consisted of three unmanaged, second growth northern hardwood stands of comparable age. Comparisons were made in the study between (1) skid trails, haul roads, and patches of forest without soil disturbance within managed stands, (2) patches of forest without soil disturbance in managed stands and forest in the unmanaged stands, and (3) richness over all feature

types combined in managed stands and richness in unmanaged stands.

Stands representing even-aged management were thinned but not completely harvested prior to establishment of the study in 1994. Under even-aged management, several thinnings precede the final harvest, which is a clearcut. All replicate stands under even-aged management were thinned using methods that approximated Erdmann's (1987) guide for small saw-log-sized forests dominated by sugar maple. In this treatment, forests were thinned to about 90% crown cover, with the goal of leaving 150–180 dominant and co-dominant crop trees per hectare. High risk trees (likely to be lost to mortality before the next entry), cull trees, and subcanopy trees were harvested during the thinning to obtain 90% canopy cover. A crop tree release was conducted in the first replicate in 1979, followed by thinning of 75% of the total area in 1981 and thinning of the remainder in 1993. The second and third replicates were thinned in 1993 and 1995, respectively. Both the second and third replicates had received only one thinning prior to the study.

2.3. Establishment of transects and plots

To document the proportion of total area occupied by haul roads, skid trails, and forest without soil disturbance, ten 10 m × 100 m belt transects were established in each replicate stand by selecting starting points and azimuths at random. During sampling, 100 m tapes were stretched along each transect to delineate plot boundaries and aid mapping. The boundaries of skid trails, haul roads, and patches of forest without soil disturbance were mapped to scale on graph paper for each transect. Following the mapping of features, ten 1 m × 1 m quadrats were established at randomly selected locations within each type of feature to document understory plant richness and composition. Thus, a 10 m × 100 m belt transect in a managed stand would contain ten 1 m × 1 m quadrats in haul roads, 10 quadrats in skid trails, and 10 quadrats in forest patches without soil disturbance. Transects for sampling understory photosynthetically active radiation (PAR) and soil moisture were located at three randomly selected points along the major haul road leading into each of the three managed stands. Each transect was oriented across the road, perpendicular to its main axis. Transects began 20 m from the

road edge in adjacent forest without soil disturbance, and terminated in the forest 20 m from the road edge on the opposite side.

2.4. Data collection

Maps of haul roads, skid trails, and forest without soil disturbance within belt transects were constructed in the field by using the 100 m tapes and an additional tape laid perpendicular to the long axis of the belt transect to form a system of *X* and *Y* coordinates. The boundaries of features were carefully drawn to scale on graph paper. The graph paper contained a 10×100 grid of 1000 squares representing 1 m^2 each. The area occupied by each feature per belt transect was determined in square meters by counting the number of grid squares occurring within each feature on the map.

All trees, shrubs, and herbs <1 m in height within all $1 \text{ m} \times 1 \text{ m}$ quadrats assigned to each feature were identified and recorded. Species richness was calculated as the total number of all vascular plant species occurring within a given quadrat. In addition, due to the ubiquitous occurrence of sugar maple reproduction in the understory, percent cover of sugar maple seedlings and saplings <1 m in height was determined in each $1 \text{ m} \times 1 \text{ m}$ quadrat. Percent cover of sugar maple was obtained through ocular estimation to the nearest 1%. Due to chance, haul roads did not intersect any belt transects in two of the replicate stands under even-aged management. To provide an adequate sample of haul roads, 40 additional $1 \text{ m} \times 1 \text{ m}$ quadrats were located at random distances and positions along the major haul road in each managed stand. These quadrats were sampled for understory plant richness, composition, and sugar maple cover in the same manner as those within the belt transects. All vegetation sampling was conducted between early June and mid-August 1999.

Soil compaction was measured in g cm^{-2} with an engineering-grade Lang Penetrometer (Lang Penetrometer, Gulf Shores, AL). One soil compaction measurement was taken at the center of each $1 \text{ m} \times 1 \text{ m}$ quadrat established for vegetation sampling. Canopy cover was measured with a concave spherical densiometer (Lemmon Forest Densiometers, Bartlesville, OK). One densiometer reading was taken in each of the four cardinal directions at the center of each $1 \text{ m} \times 1 \text{ m}$ quadrat established for vegetation sam-

pling. PAR was measured along line transects across haul roads with an Accupar Sunfleck Ceptometer (Decagon Devices, Pullman, WA). A PAR measurement in $\mu\text{mol s}^{-1} \text{ m}^{-2}$ was taken 1 m above the ground at each meter along the transect. Measurements of PAR were taken in all replicates between 10:45 a.m. and 3:00 p.m. CDST on 3 June 1999, which was a day with minimal cloud cover. Soil moisture was measured along line transects across haul roads with a Trase Time Domain Reflectometry (TDR) probe (Soil-moisture Equipment Corporation, Goleta, CA). Percent volumetric soil moisture was measured to 15 cm depth at each meter along the transect. All soil moisture measurements were conducted on the same date, 3 June 1999.

2.5. Analysis

Differences in the total number of plant species, number of introduced species, number of wetland species, number of species within species groups, sugar maple cover, soil compaction, and canopy cover were analyzed with one-way ANOVA using statistical models appropriate for the comparison desired. For comparisons between feature types within managed stands, skid trails and haul roads were considered treatments and patches of forest without soil disturbance were considered controls. Patches of forest without soil disturbance in managed stands were considered the treatment, and the forest in unmanaged stands was considered the control for comparisons between patches of forest without soil disturbance in managed stands and forest in unmanaged stands. Data for all variables were averaged across $1 \text{ m} \times 1 \text{ m}$ quadrats within transects and across transects to provide single treatment means for each replicate stand. Therefore, all richness values reported represent mean richness per square meter, and all ANOVA was carried out using stand level means for each replicate. *F*-tests were conducted at the $\alpha = 0.05$ level. All pairwise comparisons were conducted using Tukey's honestly significant difference (HSD) with $\alpha = 0.05$.

3. Results

Skid trails comprised as much as 22% of the 1 ha area sampled within each managed stand (Table 1).

Table 1
Percentage of total 1 ha area sampled in each managed stand occupied by each feature

Stand	Forest without soil disturbance	Skid trail	Haul road	Embedded wetland
1	76	20	0	4
2	71	22	3	4
3	87	6	0	7

Haul roads were present in all three managed stands and comprised 3% of the area sampled in one of the stands. Due to chance, haul roads did not fall within any of the randomly located transects in the two remaining managed stands. Each managed stand contained one to two primary haul roads that directly

connected with the improved, main forest routes serving the area. These haul roads were 10–15 m wide and several hundred meters in total length.

Measurements of PAR, volumetric soil moisture, and compaction indicated increased levels of all variables within and along the edges of haul roads relative to adjacent forest patches (Fig. 1). Differences in PAR between haul roads and adjacent forest were more pronounced than differences in soil moisture and compaction, which tended to be more variable. Levels of PAR within haul roads (ca. $1800 \mu\text{mol s}^{-1} \text{m}^{-2}$) approached levels of PAR that were measured in large openings with no canopy influence just outside each stand before and after sampling haul roads. Similar patterns in PAR, soil moisture, and compaction were observed across all transects sampled.

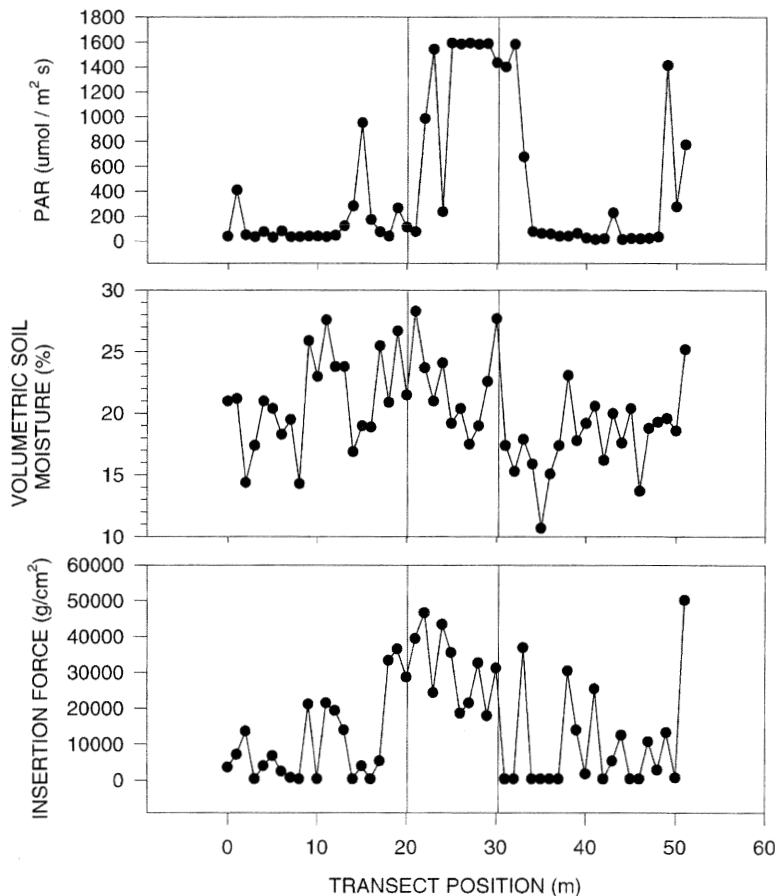


Fig. 1. PAR, soil moisture, and compaction across a representative haul road transect. Vertical lines represent physical edges of road at the soil surface.

Results of canopy cover measurements taken at the center point of $1\text{ m} \times 1\text{ m}$ quadrats indicated significantly lower mean canopy cover in haul roads (54.7%, S.E. = 2.1) than in skid trails (88.0%, S.E. = 0.6) and forest without soil disturbance (90.6%, S.E. = 0.9). Though differences were not statistically significant, mean canopy cover was slightly lower in skid trails than in forest. There was no significant difference in canopy cover between forest without soil disturbance in managed stands and forest in the unmanaged controls.

Levels of soil compaction measured at the center of $1\text{ m} \times 1\text{ m}$ quadrats were highest in haul roads ($33,968.5\text{ g cm}^{-2}$, S.E. = 1429.3), lowest in forest without soil disturbance (5853.0 g cm^{-2} , S.E. = 225.1), and intermediate in skid trails ($16,861.0\text{ g cm}^{-2}$, S.E. = 902.6). All differences in soil compaction between features in managed stands were statistically significant. There was no significant difference in compaction between forest without soil disturbance in managed stands and forest in the unmanaged controls.

Averaging over all feature types (i.e. forest without soil disturbance, skid trails, haul roads, and embedded wetlands) and replicates, managed stands had twice the mean plant species richness (10.58, S.E. = 1.28) of unmanaged stands (5.74, S.E. = 0.58). This difference was statistically significant ($p = 0.0261$). On average, haul roads within managed stands contained 2.6 times the number of vascular plant species that occurred in forest without soil disturbance within managed stands (Fig. 2). The mean number of plant species in skid trails was significantly lower than the number of species in haul roads. Although the difference was not statistically significant, there was a slightly greater number of species in skid trails than in forest. Patterns in the mean numbers of introduced species and native wetland species among forest, skid trails, and haul roads were similar to the pattern for all species (Fig. 2). Haul roads had the highest mean numbers of introduced and wetland species, forest had the lowest, and numbers of introduced and wetland species were intermediate in skid trails.

The mean proportions of the total number of species comprised of introduced and wetland species were significantly greater in haul roads than in skid trails and forest (Fig. 3). Differences between skid trails and forest were not statistically significant, but there was a

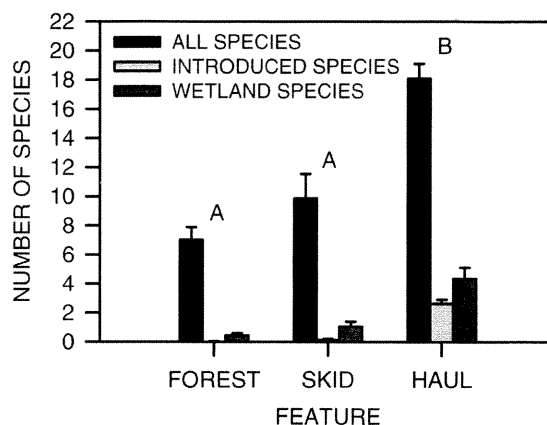


Fig. 2. Mean number of all, introduced, and wetland species by feature type. Means with the same letters are not significantly different at the $\alpha = 0.05$ level, and all three species groups (i.e. all species, introduced species, and wetland species) share the same pattern of significant differences. Error bars represent 1 S.E.

slightly greater proportion of wetland species in skid trails than in forest.

Overall, 22 introduced species were observed within the quadrats sampled (Table 2). Three additional introduced species were present on the study sites, but did not occur within the quadrats sampled. The most common introduced species found in the unmanaged stands and in the forest and skid trail features in managed stands were hemp-nettle (*Galeopsis tetrahit* L.), common speedwell (*Veronica officinalis* L.), and

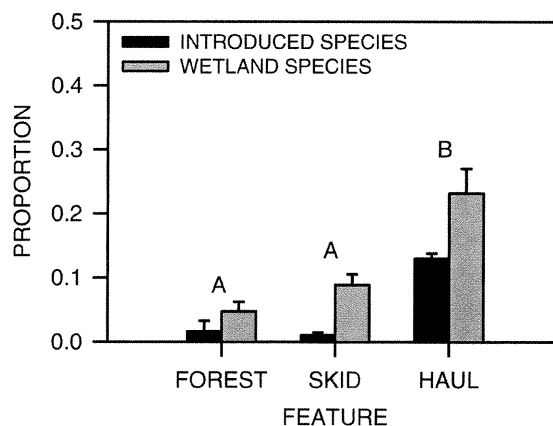


Fig. 3. Mean proportions of introduced and wetland species by feature type. Means with the same letters are not significantly different at the $\alpha = 0.05$ level, and both species groups (i.e. introduced and wetland species) share the same pattern of significant differences. Error bars as in Fig. 2.

Table 2
Introduced species sampled^a

<i>Agrostis gigantea</i> Roth	<i>Plantago major</i> L.
<i>Barbarea vulgaris</i> R. Br.	<i>Poa pratensis</i> L.
<i>Cerastium fontanum</i> Baumg.	<i>Polygonum hydropiper</i> L.
<i>Chrysanthemum leucanthemum</i> L.	<i>Rumex acetosella</i> L.
<i>Cirsium palustre</i> (L.) Scop.	<i>Silene pratensis</i> (Rafn) Godron and Gren.
<i>Cirsium vulgare</i> (Savi) Tenore	<i>Taraxacum officinale</i> Wiggers
<i>Galeopsis tetrahit</i> L.	<i>Trifolium aureum</i> Poll.
<i>Hieracium aurantiacum</i> L.	<i>Trifolium hybridum</i> L.
<i>Hieracium piloselloides</i> Vill.	<i>Trifolium pratense</i> L.
<i>Hypericum perforatum</i> L.	<i>Veronica officinalis</i> L.
<i>Lapsana communis</i> L.	<i>Veronica serpyllifolia</i> L.

^a *Rumex obtusifolius* L., *Trifolium repens* L., and *Verbascum thapsus* L. were also present on the study sites, but did not fall within sampled plots.

common dandelion (*Taraxacum officinale* Wiggers). The most abundant native wetland species observed in haul roads and skid trails included bulrushes (*Scirpus atrovirens* Willd. and *Scirpus cyperinus* (L.) Kunth), rush (*Juncus effusus* L.), and two large wetland sedge species (*Carex gynandra* Schw. and *Carex crinita* Lam.). Although far less abundant than the former species, common cat-tail (*Typha latifolia* L.) was also present along the edges of haul roads.

Haul roads had significantly greater mean numbers of summergreen herb, grass, sedge, rush, and tree species than skid trails and forest (Fig. 4). Although tree species richness was highest in haul roads, tree species were mainly represented by small seedlings in haul roads. Mean percent cover of sugar maple, the most abundant

tree species on the sites, was significantly lower in haul roads (8.6%) than in forest (35.0%). At 15.4%, the mean cover of sugar maple in skid trails was intermediate between haul roads and forest, but differences were not statistically significant. Sedges, rushes, and raspberry (*Rubus*) were the main contributors to herb layer vegetation structure in haul roads. The number of ferns and fern allies did not differ significantly between feature types. Haul roads contained a significantly greater number of shrub species than in forest, but not a significantly greater number of shrub species than in skid trails. Although differences were not statistically significant, there were slightly greater numbers of summergreen herb, grass, sedge, rush, shrub, and tree species in skid trails than in forest (Fig. 4).

Except for the mean number of shrub species, there were no significant differences ($p > 0.05$) found in richness and composition between forest without soil disturbance in managed stands and forest within the unmanaged controls. A significantly greater ($p = 0.0374$) mean number of shrub species (0.46) occurred in the forest without soil disturbance in managed stands than in the unmanaged controls (0.06).

4. Discussion

Networks comprised of skid trails and haul roads are requisite features of stands managed for timber in which standard equipment such as skidders, forwarders and semi-trailers are used during harvests. Our results suggest that haul roads and skid trails can comprise up to a quarter of total stand area in managed

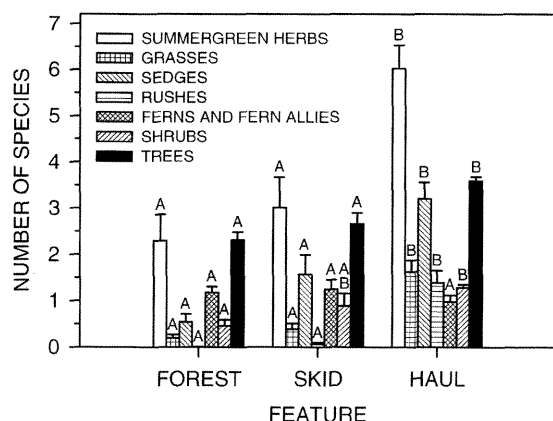


Fig. 4. Mean number of species by species group and feature type. Within each species group, means with the same letters are not significantly different at the $\alpha = 0.05$ level. Error bars as in Fig. 2.

northern hardwood stands. A number of factors, however, influence the extent of these features in a given managed forest. Variables such as the size and type of logging machines, the season of harvest, terrain, soils, training and experience of the loggers, efficiency constraints, the extent of road planning, and the management practices applied (e.g. even-aged versus uneven-aged management) will all tend to influence the extent and placement of skid trails and roads (Martin, 1988; Gullison and Hardner, 1993; Bettinger et al., 1994; Egan, 1999; Stone and Elioff, 2000).

Measurements of PAR, canopy cover, soil moisture, and compaction obtained on the study sites indicate that the creation of skid trails and haul roads introduces novel combinations of microsite conditions unique to managed forest ecosystems. The removal of trees in the construction of haul roads and some portions of skid trails clearly reduces canopy cover and increases levels of understory PAR. While the formation of natural canopy gaps can also increase understory PAR levels, the degree of forest floor disturbance and soil compaction associated with skid trails and haul roads does not occur in natural gaps. Effects of forest floor disturbance and soil compaction on soil physical and chemical properties are well-documented (Hatchell et al., 1970; Dickerson, 1976; Riley, 1984; Froehlich et al., 1985; Reisinger et al., 1988; Gardner and Chong, 1990; McNabb, 1994; Aust et al., 1995; Huang et al., 1996; Jurgensen et al., 1997). The disturbance or removal of the forest floor during the operation of logging machines can impact organic matter and nutrient content of the mineral soil (Jurgensen et al., 1997), and compaction usually results in a decrease in macropore space and reduced drainage (Hatchell et al., 1970; Dickerson, 1976; Greacen and Sands, 1980; Riley, 1984; Aust et al., 1995; Huang et al., 1996). The degree of soil compaction associated with timber harvesting and recovery rates have been shown to vary with the number of machine passes, soil type, and soil moisture content at the time of compaction (Froehlich et al., 1985; Reisinger et al., 1988, 1992; Bettinger et al., 1994; Aust et al., 1995). Rates of recovery from compaction can be quite slow, with documented examples of no recovery after 5 years (Stone and Elioff, 1998) and predicted recovery times ranging from 10 to 21 years in some cases (Corns, 1988).

Greater soil moisture levels measured in haul roads than in forest without soil disturbance on the study

sites are consistent with compaction resulting in reduced drainage. Additional qualitative evidence for reduced drainage was the presence of standing water in haul roads that persisted well into the growing season. It is also likely that some portions of haul roads were more xeric and nutrient poor than soils in forest patches without forest floor and soil disturbance, particularly where subsoil horizons were exposed by grading or layers of sand and aggregate were brought in as fill. The combined result of tree removal and disturbance of the forest floor and soil in haul roads and skid trails was the creation of microsites with substantially higher PAR levels and soil moisture regimes that were either more hydric or xeric than those in adjacent patches of forest. Based on the measurements of canopy cover and soil compaction obtained on the study sites, changes in PAR and soil properties were much more pronounced in haul roads than in skid trails.

The net effect of the novel combinations of light and soil conditions contributed by haul roads and skid trails was an increase in microsite diversity, which would explain, in part, the greater plant species richness observed in managed than unmanaged stands. It is likely that the high light levels and decreased drainage in compacted haul roads facilitated the influx of light-demanding wetland species native to the area, but usually excluded from the understories of northern hardwood stands by low light levels or soil moisture conditions. Similarly, greater amounts of PAR, soil moisture, and also exposed mineral soil may have contributed to the greater richness in tree species in haul roads. Seedlings of yellow birch, a species with exacting seedbed requirements (Tubbs, 1963; Erdmann, 1990), were abundant on the exposed mineral soil of haul roads.

Another important component of the difference in plant species richness between managed and unmanaged northern hardwood stands resulted from the influx of introduced species in managed stands. It is clear that humans have facilitated the dispersal of introduced species into managed stands, including the sowing of introduced species to stabilize areas of exposed mineral soil in haul roads and landings. On the Ranger District where this research was conducted, a mixture of annual rye (*Lolium multiflorum* Lam.), alsike clover (*Trifolium hybridum* L.), red fescue (*Festuca rubra* L.), and white clover (*Trifolium*

repens L.) is currently being sown after timber harvests to prevent erosion on haul roads and in landings. Similar mixtures are used on other Districts, and may also include red clover (*Trifolium pratense* L.) and perennial rye grass (*Lolium perenne* L.) (Bob Evans, pers. commun., Ottawa National Forest). Of these species, only alsike clover and red clover were found in the quadrats sampled (Table 2). A program involving production of native seed for rehabilitating haul roads and other areas with exposed mineral soil is currently being initiated collaboratively between the Ottawa National Forest and the Toumey Nursery in Watersmeet, MI (Bob Evans, pers. commun., Ottawa National Forest).

Removals of physical, environmental, and biological barriers have been hypothesized to have facilitated exotic plant invasions along roads in Montana and Oregon (Forcella and Harvey, 1983; Parendes and Jones, 2000). Similarly, it is likely that the invasion of haul roads and skid trails in the managed northern hardwood stands studied has resulted from (1) mechanical damage to the resident understory vegetation during timber harvesting, (2) the creation of suitable seedbeds with bare mineral soil and high levels of light, moisture, and nutrients that are required by some introduced species, and (3) the presence of multiple human and natural dispersal vectors.

The most successful invaders of patches of forest without soil disturbance in managed stands were hemp-nettle, common speedwell, and common dandelion. These species were also well established in the unmanaged controls. Due to the closed canopies in these areas, it is likely that these species were more tolerant of shade than the introduced species found only in haul roads. Further evidence for this is the fact that hemp-nettle, common speedwell, and common dandelion were also the most abundant introduced species in skid trails, which had amounts of canopy cover comparable to those in adjacent forest patches. It is also possible that these species were less inhibited by an intact forest floor than other introduced species on the sites. Hemp-nettle, however, was much more abundant on bare mineral soil along the cut banks of haul roads, and common speedwell was often observed on mineral soil associated with natural tipup mounds.

Shifts in the major components of understory vegetation structure from shade-tolerant tree saplings and

shrubs to sedges, rushes, and raspberry in haul roads and portions of skid trails suggests that these features will remain in graminoid and shrub (raspberry) cover for a protracted period. Although tree seedlings were often abundant and tree seedling species richness was highest in haul roads, the small size of tree seedlings 4–6 years after harvesting activity and the significantly lower cover of sugar maple seedlings and saplings (the most abundant tree species on the sites) in haul roads than in adjacent forest suggest that conditions for the long-term survival of tree seedlings were poor in haul roads. Heavy competition between tree seedlings and dense stands of sedges, rushes, and raspberry was likely, and the development of tree seedling root systems may have been impeded by soil compaction and layers of aggregate brought in to stabilize the roadbed. Detrimental impacts of soil compaction on tree seedling growth have been documented in a number of regions (Hatchell et al., 1970; Froehlich et al., 1985; Reisinger et al., 1988). The net effect of the construction and use of haul roads and also major skid trails is the creation of linear patches of early-successional habitat that will proceed through stages dominated by herbs and shrubs before returning to a stage dominated by tree species.

The increased microsite diversity, plant species richness, and changes in understory plant composition observed in the managed stands could be temporary, with microsite diversity and plant species richness declining with eventual closing of the canopy and recovery of compacted soils. Disturbance of haul roads and skid trails is, however, an ongoing process in managed forests. Forests under active management for timber are periodically re-entered for subsequent harvests and tending treatments, with the frequency of re-entry depending on the management practices applied (e.g. even-aged or uneven-aged management). Although much less intense, a certain amount of disturbance results from the use of haul roads and skid trails for various recreational activities in the interim periods between timber management activities. Thus, the altered habitat conditions required to sustain populations of many introduced and wetland species observed in the managed replicates are likely to persist over long periods. The presence of multiple dispersal vectors and the role of haul roads as conduits for dispersal will also facilitate continual arrivals of the propagules of these and other species.

The presence of introduced species on managed forest landscapes is symptomatic of various forms of human disturbance. The net impact of introduced species on ecosystem health, however, will remain uncertain until direct and indirect ecological interactions between these species and the resident species in managed stands are better understood. Certain aggressive exotics may displace some native plant species (Tyser and Worley, 1992; Woods, 1993), or be accompanied by additional exotic insect or pathogen species that have negative impacts on native plants or insects. Marsh thistle (*Cirsium palustre* (L.) Scop.) may prove to be one of the more aggressive introduced competitors of native plant species on the study sites due to its size and history of rapidly colonizing ditches, swamps, and other wetlands elsewhere in Michigan (Voss, 1996). Distribution of this species on the study sites appeared to be restricted, however, to the high light environments of haul roads. Low understory light levels were hypothesized to provide a barrier to invasion of old-growth forests in Indiana by many light-demanding exotic species that were present in adjacent areas (Brothers and Spingarn, 1992). Whether or not the species added by haul roads and skid trails are aggressive invaders, they do occupy a percentage of total stand area that could be utilized by tree seedlings, shrubs, and herbs native to the understories of northern hardwood forests. At the landscape level, this percentage represents a substantial amount of area.

5. Conclusion

On the surface, our results suggest that the creation of skid trails and haul roads may contribute to increased biodiversity in managed stands by increasing the diversity of microsites available for plant growth and plant species richness. However, the ecological roles and net effect of introduced and wetland species added by skid trails and haul roads are uncertain. The arrival of more shade tolerant introduced species such as garlic mustard (*Alliaria petiolata* (Bieb.) Cavara and Grande) in the area could have substantial negative impacts on native understory plant species. In addition, effects of haul roads and skid trails on soil properties and other site factors have been demonstrated to have detrimental impacts on

native flora and fauna (Hatchell et al., 1970; Froehlich et al., 1985; Reisinger et al., 1988; Haskell, 2000).

Haul roads, skid trails, and main forest routes provide critical access for the management of timber, wildlife, recreation, and other forest values, and also for forest protection. At the same time, haul road and skid trail networks are integral features of managed stands and landscapes that have microsite conditions and plant communities that differ from the surrounding patches of forest without forest floor and soil disturbance. Although haul roads only comprised 3% of the 1 ha area sampled in one of the managed stands, our results suggest that these roads serve as primary conduits for entry of introduced species into the interior of managed stands. Much more information is needed on the net effect of introduced understory plant species in managed forest ecosystems. Further investigations are also needed concerning competitive native plant species that could be sown to rehabilitate haul roads and skid trails rather than the introduced species that are widely planted, and identification of native species that would be successful in inhibiting the establishment and spread of introduced species. Above all, careful planning of haul road and skid trail networks remains critical for minimizing the proportion of total stand area with altered understory plant communities and soil compaction.

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