NUTRITIONAL, WILDLIFE, AND VEGETATIVE COMMUNITY RESPONSE TO MUNICIPAL SLUDGE APPLICATION OF A JACK PINE/RED PINE FOREST

By

Elena Marie Seon

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ABSTRACT

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Municipal sewage sludge from Alpena, Michigan was applied, in late June 1982, to a 40-year-old jack pine/red pine forest in Montmorency County, Michigan. Trails 5m wide were constructed at 20m intervals, in 6 of the 9 1.5ha study plots (3 control, 3 trails only, 3 sludge-trails), to facilitate application. Small mammal and vegetative communities were monitored, via live-trapping and vegetative sampling techniques, with respect to composition, structure, and productivity. Nutritional quality of selected summer and winter forages were analyzed for ash, ether extract, in vitro digestibility, phosphorus, crude protein and fiber content.

Results indicated significant increases in vertical cover, woody stem density, and woody and herbaceous annual production, in the understory on both treated plots for both years, and nutritive quality (crude protein, phosphorus) on sludged plots in both seasons. Small mammals declined on all plots both years, but species diversity increased on sludged plots 1983.

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INTRODUCTION

Little research has been conducted on the effects of sludge disposal in forests on wildlife communities and their habitat. Some problems that might be encountered with disposal on forest lands are: site disturbance due to road construction and application of the sludge;alteration of wildlife populations due to disturbance and habitat modification;changes in vegetative structure and composition;and transmission of toxic elements through wildlife food-chains. There is also the danger of nitrate pollution of the watertable (Brockway 1979). Another problem that might be encountered with sludge disposal on forest lands is public attitude. Forests are considered clean natural environments and treatment with sewage sludge may be aesthetically unappealing (Schmid et al. 1975).

In the past our sewage wastes have been dumped into oceans, rivers and other waterways. The Federal Water Pollution Control Acts Amendments (PL-92-500) of 1972 and 1977 are "to restore and maintain the chemical, physical, and biological integrity of the nation's waterways." To achieve this goal, the dumping of all pollutants into navigable waterways must be stopped by 1985. The amendments were enacted to encourage alternative management techniques for the treatment and disposal of municipal and industrial sewage wastes (Schmid et al. 1975, Torrey 1979, D'Itri 1982). Current methods of sewage disposal include landfills, incineration, storage in lagoons, and composting. These methods of disposal are costly, inadequate, damaging to the environment, and a cause for public concern (Dalton 1968, White 1979). Land application of sewage wastes has been recognized as an alternative, cost-effective method of treatment and disposal. The wastes can be recycled naturally within the environment.

Sewage wastes are a mixture of water (effluent) and organic and inorganic solids. Sludge is the solid material removed from sewage wastes during primary, secondary, and advanced stages of sewage treatment (Dalton 1968, Vesilind 1979). Sewage sludge contains large amounts of micro-nutrients, organic matter, heavy metals, toxic organic compounds, and pathogenic organisms (King and Morris 1972). It is a nutrient-rich organic fertilizer, which contains considerable quantities of calcium, magnesium, phosphorus, potassium, and nitrogen, which are important plant nutrients. It has been used to improve soil conditions for plant growth on nutrient-poor forest sites. Soil amendements include improved structure, humus content, productivity, fertility, water-retention capacity, and organic matter (Carroll et al. 1975). Sludge has also been used in agriculture as a cost-effective fertilizer by doubling crop yields, improving nutrient quality, and increasing organic matter and trace elements (Hinesly and Sosewitz 1969, Milne and Graveland 1972, Gagnon 1973, West et al. 1981). However, because many municipal sludges contain a variety of toxic metals in various concentrations use of sludge in agriculture is limited. There has been some evidence of metal accumulation by various plant and animal species (Chaney 1973, Williams et al. 1978, Anderson et al. 1982). This disadvantage makes forest lands favorable to sludge application because they are generally remote, readily available, of low cost, and the opportunity for human contact with any odors, pathogens, or food-chain transfers of toxic metals or chemicals is minimal (Breuer et al. 1979, Brockway 1979, Urie 1979).

Land application of sewage wastes has proven beneficial to forests through the addition of nutrients which enhance plant growth, the production of wood, timber, and biomass, and an increase in site quality and profits (Hilmon and Douglass 1967, Weetman and Hill 1973).

The effects of sewage sludge application on forest vegetation has been investigated in a number of studies. Berry (1977) observed that a low application rate (17 dry metric tons/ha) of dried sewage sludge to nutrient-poor forest sites increased weed biomass production and survival rates of shortleaf pine (*Pinus echinata*) and loblolly pine (*P. taeda*). Total weed biomass production was 5 times greater on plots receiving a higher loading rate (69 dry metric tons/ha), but competition from the weeds reduced the survival rates of the pines on these plots. Edmonds and Cole (1976) reported increases in tree growth and foliar nitrogen with 1 application of sewage sludge containing 2-4% nitrogen. The sludge decomposed rapidly on the area and 1 year after application there was noticeable improvement in the soil structure. A 30% increase in height growth was observed 4 years after dried sludge was applied to a 10-year-old white spruce (*Picea glauca*) plantation (Gagnon 1973). Municipal sewage sludge applied to a 4-year-old jack pine (*P. banksiana*) clearcut produced significant increases in woody and herbaceous annual production and foliage height diversity (Woodyard 1982). Industrial sludge applied to a 40-year-old red pine (*P. resinosa*) and a 36-year-old mixed red and white pine (*P. strobus*) plantation, significantly increased needle length and dry weight, and foliar nitrogen concentrations. Understory and overstory biomass production also increased, by as much as 92% and 132%, respectively over controls. However, much of the understory increases were due to thinning of the overstory. Total nitrogen and phosphorus levels, as well as other nutrients, increased in the foliage and litter layer (Brockway 1979).

In addition to improving forest lands, sewage sludge has also been used to revegetate strip-mined lands (Berry 1977, Torrey 1979, Hinkle 1982, Sopper et al. 1982). Lejcher and Kunkle (1973) observed increases in pH of acid spoil and the establishment of herbaceous vegetation on strip mined study plots that were treated with municipal sludge. Sopper (1970) concluded that strip mine spoil banks could be revegetated with municipal sewage sludge and effluent. The establishment of groundcover could result in stabilization and reduction of soil erosion as well.

Sewage sludge and effluent fertilization have also been shown to improve habitat quality for wildlife through nutrient enrichment and enhanced browse production (Weetman and Hill 1973, Brockway 1979, Woodyard 1982). Chlorinated effluent sprayed at a rate of 5cm per week appeared to have a favorable influence on the nutritive value of rabbit and deer forages (Wood et al. 1973). The amount of browse increased on the treated areas and deer were observed feeding on these areas as well. Nutrient (P,K,Mg, and N) levels were higher on the irrigated sites than on the controls. Dressler and Wood (1976) also noted increases in deer activity on sites irrigated with sewage effluent. Concentrations of crude protein (N), P,K, and Mg increased in forages on irrigated sites as did production of herbaceous plants. Bierei et al. (1975) found that irrigation of sewage effluent resulted in higher populations of white-footed mice (Peromyscus leucopus) during the fall, but not the spring. He hypothesized that the increase in fall was due to changes in vegetative structure.

Thomas (1983) observed significantly higher numbers of Peromyscus spp. in a northern hardwoods forest treated with municipal sewage sludge. Anderson and Barrett (1982) reported increases in meadow vole (Microtus pennsylvanicus) population densities, on sludge treated wheat and old field enclosures, were due to improved plant species diversity and productivity. Sludge fertilization of a Douglas-fir (*Psuedotsuga menziesii*) plantation produced no significant responses in small mammal populations, but herbivores were always less abundant on treated sites. West et al. (1981) hypothesized that plant species necessary as food and cover for herbivorous small mammals were reduced on treated sites. No data, as yet, have been provided to support this hypothesis. Black-tailed deer (*Odocoileus hemionus*) densities were higher on sludged sites apparently due to increased nutrient levels in the browse (West et al. 1981). Campa (1982) and Woodyard (1982) also observed increased use of sludge treated plots, in a jack pine clearcut, by deer and small mammals. Sludge application significantly enhanced the nutritive quality, *in vitro* digestibility and productivity of wildlife forages.

Forests require some site preparation before sludge can be applied. Roads must be cut in order to facilitate application. Thinning and clearcutting strips in the forest alters the vegetative structure, wildlife populations (Gashwiler 1970), and nutrient content of the vegetation (Laycock and Price 1970). These changes are the result of opening the overstory, allowing light to penetrate through the canopy, thereby stimulating production of herbaceous browse. Hooven (1973) observed an increase in the number of small mammals and big-game animals such as, Roosevelt elk (*Cervus elaphus canadensis*), on a clearcut logging of Douglas fir plantations. Deer mice (*Peromyscus maniculatus*), in particular, will colonize disturbed areas such as clearcuttings (Tevis 1956, LoBue and Darnell 1959, Kirkland 1977, Ream and Gruell 1980), and powerline right-of-ways (Schreiber et al. 1976, Johnson et al. 1977). This has been attributed to changes in the structure and diversity of the understory, which provided an increased availability of food and cover (Black and Hooven 1974, Hooven and Black 1976).

OBJECTIVES

Vegetation is the main structural feature of ecosystems and the basis for community energy and nutrient flows (Chew 1978). Small mammals, as strict habitat selectors, respond to changes in the vegetative structure and can be used as indicators of habitat change (West et al. 1981). They also represent a range of trophic groups, including herbivores, granivores, insectivores, and omnivores (West et al. 1981), and may serve as regulators of ecosystem processes (Chew 1974). Small mammals are readily sampled from the community, because they are often present in high numbers (West et al. 1981).

The objectives of this study were:

1. To observe small mammal response to changes in vegetative structure on treatment and control plots.
2. To determine the benefits of sewage sludge application on the nutritive quality of selected plant species.
3. To determine the levels of selected nutrients, digestibilities, and structural components of selected plant parts and species on treatment and control plots.

STUDY SITE DESCRIPTION

The study area is an approximately 20ha, jack pine (Pinus banksiana) and red pine (P. resinosa) forest. It is located in the N½ of the SE¼ of section 34, T32N, R3E of Montmorency County, and is a part of the Mackinac State Forest in northern lower Michigan (Fig. 1). Vegetation consisted mostly of 50-year-old jack pine plantings interspersed with some red pine. A small percentage of red oak (Quercus rubra) and red maple (Acer rubrum) were also present. Groundcover is dominated by several species of blueberry (Vaccinium spp.), sweetfern (Comptonia asplenifolia), bracken fern (Pteridium aquilinum), and sedges (Carex spp.).

Much of the land is level or gently rolling. The soils are characterized by excessively drained sandy soils of the Grayling series (MSU Forestry Dept., unpubl. data).

The climate is typical of northern lower Michigan, with long severe winters, short cool summers, and an abbreviated growing season. Average annual precipitation is 76.65cm and is well distributed throughout the year along with an average annual snowfall of 152.4cm. The mean annual temperature is 5.83°C. Average temperature extremes range between -7.4°C in January, to 19.6°C, in July (NOAA 1981). During the study period (Aug. 1981-Aug. 1983), temperatures closely followed the average except during the winter (1982) was unusually cold. Precipitation from Sept.- January was close to the normal, but winter and spring levels were unusually low (Fig. 2) (NOAA 1982).

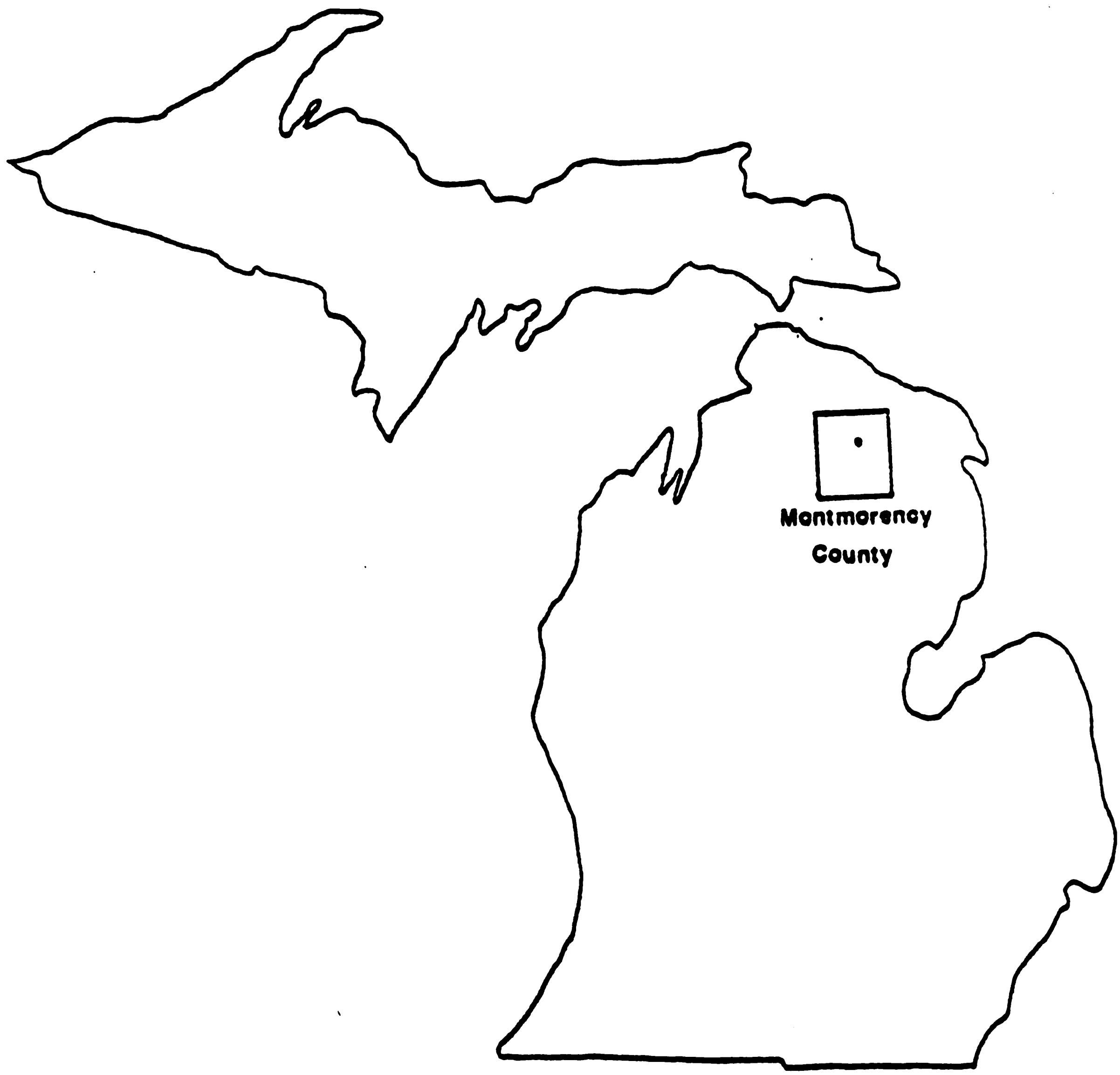

Figure 1. Map showing location of study site in Montmorency County, MI.

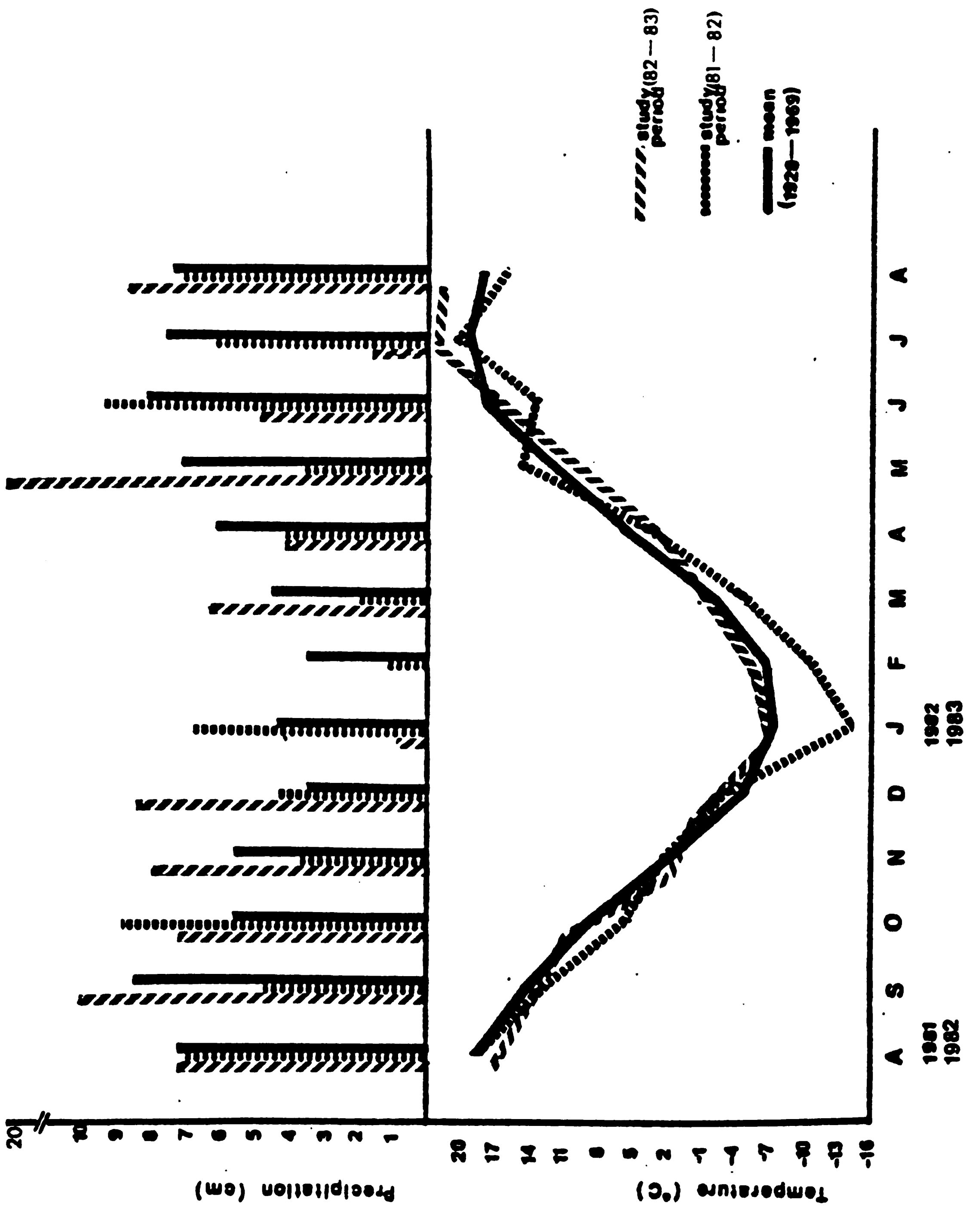

Figure 2. Average precipitation and temperature, by month for normal period and study period, 1981-1983, Atlanta, MI.

METHODS and MATERIALS

This study employed a completely randomized experimental design. The study area was divided into 9, 1.5ha rectangular plots. Plots were separated from each other by 20m buffer zones. Treatments were randomly assigned to study plots (3 controls, 3 trails only, and 3 sludge and trail plots) (Fig.3).

Sludge and Trail Treatment

In September 1981, application trails were cut in 6 study plots, as well as an east-west access trail(Fig. 3). Trails were 5m wide, 20m apart and ran in a north-south direction. Sludge application, orginally scheduled for fall 1981, was postponed until summer 1982. In late June 1982 anaerobically digested, municipal sewage sludge from Alpena, Michigan was applied to the sludge designated treatment plots. Each plot received approximately 370,930 liters of sewage sludge. Sludge was transported to the site in tanker trucks and then transfered into a smaller tank pulled by a tractor (Gator) originally designed for logging operations. The sludge was sprayed on to the adjacent forested 'interiors' from the tanker. Sludge was applied several times to each interior in order to achieve the desired nitrogen loading level on the forest floor. The application trails themselves did not receive any sludge. The sludging operation was completed in approximately 2½ weeks.

Sludge samples were analyzed for element content and loading levels (Table 1) by the US Forest Service-MSU Cooperative Analytical Laboratory. None of the elements present in the sludge exceeded the maximum allowable

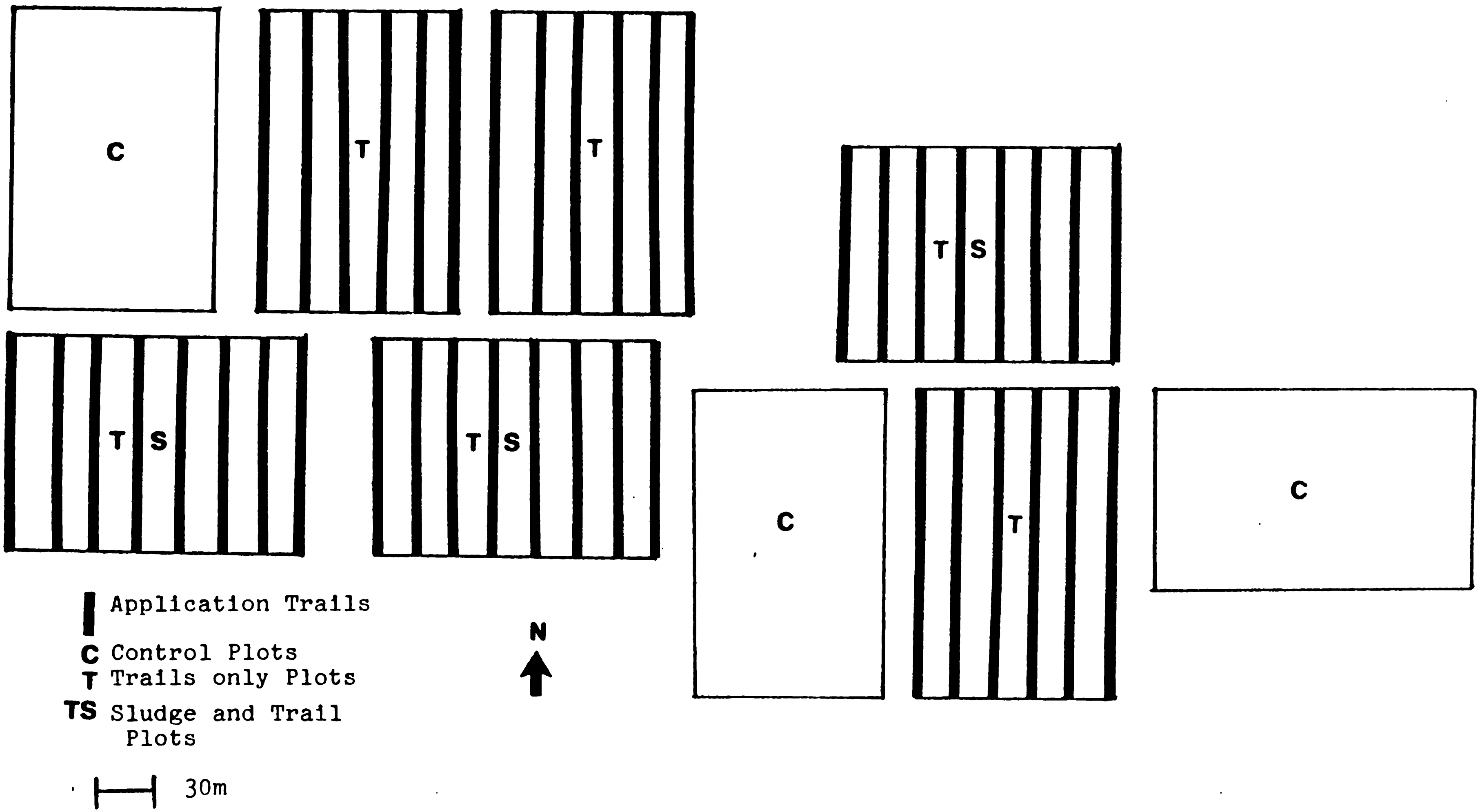

Figure 3. Map showing location of study plots within Jack pine/red pine study area.

Table 1. Mean chemical concentrations of wet sludge and mean loading levels of nutrients, heavy metals, and trace elements that were applied to jack pine study area in June 1982.

Element	Chemical concentration	Loading levels (kg/ha)
Solids (%)	2.62	8199.00
Nitrogen(%)	0.12	379.40
Phosphorus (%)	0.08	252.90
Zn (ppm)	24.40	7.61
Cd	1.57	0.36
Mn	10.92	3.80
B	2.25	0.71
Fe	1597.70	500.90
Al	440.70	137.80
Mg	106.10	32.25
Cu	13.50	4.22
K	70.27	22.14
Ca	1192.30	373.50
Ni	1.12	0.35
Cr	2.77	0.86
Na	95.60	30.18

(MSU Forestry Dept. unpubl. data 1982)

levels for food crops as described by Chaney (1973) as being potentially hazardous. Heavy and trace metals were present in low levels.

Small Mammal Trapping

Small mammal populations were monitored on all plots through the use of live traps. A 6x7 trapping grid was centrally located within each plot, with each trap station spaced 10m apart. Two Sherman live-traps (H.B. Sherman Co., Tallahassee, Fl.) (13x13x38cm) were placed at each station. Traps were evenly distributed between the trails and the interiors, in order to observe differential use of the study area. Traps were checked once a day each morning for 5 consecutive days each month (May-Aug. 1982, June-Aug. 1983) excluding June 1982 when the sludge application took place. Bait consisted of whole oats, anise extract, and beef fat. Cotton nesting material was also placed in each trap.

Traps were set on the first day of the trapping period and left open throughout the 5 day sampling period. Traps were checked and reset each morning. All newly captured animals were marked with a numbered metal ear-tag or toe-clipped and released after its species, ID number, trap station, sex, age, and condition were recorded.

A 5 day, pretreatment trapping period was conducted in August 1981, in order to gather baseline information on the study area's small mammal community. Trapping was conducted in a similar manner as that in 1982. A 5x5 trapping grid, with traps spaced 15m apart was used. A single Sherman trap was placed at each station. Bait consisted of rolled oats, raisins, and anise extract.

Vegetative Sampling

A stratified randomized sampling design was used to measure the components of the vegetative community. Stratification reduced variation of the estimate of the population mean. The variation within the strata was minimized, while that among strata was maximized (Steel and Torrie 1980).

Vertical Vegetative Cover

The line intercept method (Gysel and Lyon 1980) was used to estimate vertical cover and foliage height diversity in 4 strata (0-10cm, 10-30cm, 30cm-2m, ≥ 2m) above 15m and 30m-long line-transects. The 4 strata chosen for analysis have been found to correlate with the density of small mammals (M'Closkey and Lajoie 1975).

Transect lines were located at randomly selected points within each study plot. For each strata, intercepts were measured to the nearest cm, using 1 edge of a meter tape for the line. Gaps in the cover of less than 10cm were ignored. Transect lines were placed both in the application trails and across the forested interiors. Edge profiles were constructed by measuring cover across the forested interiors. Line intercepts were placed perpendicular to the trails and intercepts were recorded in 5m segments. Vegetation measures were collected in Mid-July 1982 and 1983, after full leaf-out, but prior to senescence or significant leaf loss.

Vegetative Composition

Vegetative composition (density) was characterized using nested quadrats (plots), These were randomly placed in both the forested interiors and the application trails. Density of woody species was estimated and recorded in 4 size and height classes: I (≤ 30cm), II (30cm-2m), III (≥2m ≤ 10cm dbh), IV (≥2m ≥10cm dbh). Long narrow retangular plots were used to estimate the vegetation in the 4 height and size classes; class I used 1mx10m plots, class II used 2mx20m plots, classes III and IV used 4mx20m plots. Frequency of herbaceous vegetation was recorded in 1 meter-square plots randomly located within each study plot.

Annual Productivity

Above ground annual primary productivity, ≤2m in height, was measured in late August of 1982 and 1983. At this time peak productivity had occurred, but loss of foliar tissue by sloughing was not substantial. Only vegetation ≤2m in height was collected, as production above this height is generally unavailable to wildlife. Quadrats ½m wide and 20m long (2m long in 1983) were randomly located, in all study plots, across a whole interior (15m) and an adjacent trail (5m). Control plot quadrats were ½m x 15m long (2m long in 1983). All current annual herbaceous and woody vegetation was clipped at ground level to a height of 2m. Plant material collected from the interiors was kept separate from that of trails.

Collected vegetation was separated into 6 plant groups based on their relative abundance throughout the area: red oak, red maple, bracken fern, and sedges (Carex spp.). All other woody species were combined into 1 group, as were all other herbaceous species. Collected samples were stored in paper bags, and oven dried at 60°C to a constant weight, after which dry weights were recorded. Total production for each plot was determined by adding the production estimates for plant groups.

Nutritional Sample Collection

Selected plant species were collected from all study plots for nutritional analyses. Selection was based upon relative abundance and availability to wildlife. Samples were collected in late summer 1982 and winter 1983 to allow for seasonal comparisons. Spring samples were not collected in 1982 due to the late application of the sludge. Summer samples consisted of red oak, red maple, bracken fern, and sedge (Carex spp.). Summer samples were obtained from samples collected for annual productivity estimates. Three subsamples of approximately 100g dry weight, were selected at random, for each species, from each plot. Samples were collected from a large number of individuals to minimize individual plant variations in nutritional content. Samples were collected in late August 1982. Winter samples were collected in January 1983. Belt transects were randomly established in each treatment plot. Only the twigs of the woody species red maple and red oak were collected, as herbaceous species were unavailable for wildlife consumption. One sample of each species was collected. Approximately 100g dry weight of each sample was collected for each species.

Collected samples were stored in paper bags and were oven dried at 60°C until a constant weight was maintained. Dried samples were then ground in a Wiley Mill to pass a 1mm sieve and stored in plastic Whirl Paks.

Chemical Analyses

All vegetation samples were analyzed for various nutritional components: percent dry matter, ash, ether extract (EE), crude protein (CP), *in vitro* dry matter digestibility (IVDMD), neutral-detergent fiber (NDF), acid-detergent fiber (ADF), acid-detergent lignin (ADL), and selected elements.

Ash content and ether extract (crude fat) were determined by methods described in AOAC (1975). Ether extract methods were modified by weighing ground samples into tared filter paper 'packets' instead of thimbles. This allowed for a larger number of samples to be analyzed per extraction. Percent EE was calculated as the weight loss in samples after extraction.

To determine the percentage of dry matter in a sample, 1.0-1.1g of dried ground sample was weighed into pretared porcelain crucibles and oven dried at 100°C for 24hrs. After drying, samples were cooled in a desiccator and reweighed. The original sample weights used in all analyses were multiplied by this percentage in order to determine the actual amount of vegetation used.

Total nitrogen and phosphorus were determined by Kjeldahl digestion (AOAC 1975). Samples were digested on a Tecator Block Digestor, model DS-40 (Tecator, Inc., Boulder, Co), values were obtained using a Technicon Autoanalyzer II (Technicon Industrial Systems, Tarrytown N.Y.). Crude protein values were determined using the total Kjeldahl nitrogen values (AOAC 1975).

In vitro dry matter digestibility (IVDMD) was determined using a modified Tilley and Terry (1963) procedure. The modification consisted of the use of a phosphate-carbonate buffer solution to reduce foaming, and reducing the amount of solution from 40ml to 10ml. Rumen fluid was obtained from a fistulated Holstein cow fed alfalfa hay and owned by Michigan State University's Dept. of Dairy Science.

Fiber analyses (NDF, ADF, ADL) were conducted according to the procedures of Goering and Van Soest (1970). Hemicellulose, cellulose, and lignin are the cell wall constituents (CWC) determined through NDF analysis. Cell solouble material (CSM) consisting of soluble carbohydrates, starches, organic acids, proteins, and pectin were determined by subtraction of CWC values from 100 (Goering and Van Soest 1970). Hemicellulose values were calculated by subtracting ADF (cellulose and lignin) values from NDF values. Cellulose content was calculated by subtracting ADL (lignin) values from ADF values.

Quality control of the nutritional and elemental analyses were checked by running duplicates for 10% of the samples. Any duplicate samples that were not within 10% of the first sample 90% of the time were retested. In addition, any sample yielding what appeared to be spurious results were retested.

Data Analysis

The linear model for the field study design was

$$X_{ij} = u + T_i + \varepsilon_{ij}$$

u = mean of all observations

T = treatment source of variability (control, trails only, or sludge-trails)

ε = variability due to errors

One-way analysis of variance was used to compare vegetation data and identify significant differences among treatment means in percent cover, density, annual production, and foliage height diversity indices. ANOVA was also used on nutrition data. T-tests were used to isolate specific treatment differences. A 90% confidence interval was used in all tests. Bartlett's test was used to test for homogeneity of variance. Heterogeneous vegetative data were subjected to a log transformation and heterogeneous nutritional data to an arc sine transformation, which resulted in homoscedasity (Steel and Torrie 1980).

The required sample size for estimating percent cover, density, and annual production for each plot was calculated using Snedecor's (1956) formula:

$$n = \frac{s^2 t^2}{d^2}$$

n = required number of sampling points

t = tabulated t value ($\alpha = 0.10$)

s^2 = sample variance

d = margin of error (sample mean x allowable error of 20%)

The number of small mammals captured were too low to use conventional capture-recapture population estimators. Enumeration was the alternative method for population estimation. The minimum number of individuals of each species alive at time t on each plot was obtained by summing the actual number caught at time t and the number of previously marked individuals caught after time t, but not at time t (Krebs 1966). This study was concerned with relative differences between treatments, therefore density estimates were unnecessary. T-tests were used to compare small mammal captures among treatments, trails and interiors on a monthly basis for 1982. Profile analysis (Morrison 1976) was used to test for an unequal response over time between treatments for small mammal numbers, diversity, and location of capture, in 1983. This method was not appropriate in 1982 because sludge application occurred midway through the trapping season.

Small mammal species and foliage height diversity indices were estimated using the Shannon-Wiener index: $H' = -\Sigma\, pi \log pi$, where pi is the proportional abundance of the ith category (stratum cover or small mammals species) (Brower and Zar 1977).

Linear correlation was used to test for relationships between mammal species diversity and foliage height diversity (FHD) and total numbers of mammals captured and annual productivity.

RESULTS

Small Mammals

In August 1981, prior to any treatments, 3 species of small mammals were captured on all 3 treatment plots; the white-footed mouse (Peromyscus leucopus), boreal red-backed vole (Clethrioncmys gapperi), and the eastern chipmunk (Tamias striatus). A single individual of 3 additional species were also captured; the red squirrel (Tamiascurius hudsonicus), woodland jumping mouse (Napaeozapus insignis), and the southern flying squirrel (Glaucomys volans). A total of 222 individuals were captured on the study area in 1981, in 1982 the total number decreased dramatically to less than half (Table 2). Three new species were captured in 1982, the pine vole (Pitymys pinetorum), 13-lined ground squirrel (Citellus tridecemlineatus), and the meadow jumping mouse (Zapus hudsonius), two of which (the vole and the ground squirrel) were caught on all 3 treatment plots. Few Peromyscus spp. were captured during this trapping season. The meadow and woodland jumping mice and the red squirrel were caught on 2 of the 3 treatment plots (Table 2). In 1983. one individual of 3 addition species was captured on sludged plots; the meadow vole (Microtus pennslyvanicus), short-tailed weasel (Mustela erminea), and the masked shrew (Sorex cinereus). Total numbers captured in 1983 were approximately half those caught in 1982.

T-tests were used to compare treatment populations for each month, pre- and post-treatment, in 1982 (Tables 3 and 4). No significant

Table 2. Number of individuals known to be alive on the jack pine study area in 1981, 1982, 1983.

Treatment	Species	81	82	83
Control	*Clethrionomys gapperi*	34	11	0
	Tamias striatus	14	19	7
	Citellus tridecemlineatus	0	1	1
	Peromyscus leucopus	27	0	4
	Pitymys pinetorum	0	7	0
	Napaeozapus insignis	0	3	4
	Zapus hudsonius	0	3	0
	Tamiascurius hudsonicus	1	1	1
	Glaucomys volans	0	0	0
Total		76	45	15
Trails Only	*Clethrionomys gapperi*	32	5	0
	Tamias striatus	5	5	5
	Citellus tridecemlineatus	0	2	5
	Peromyscus leucopus	49	2	2
	Pitymys pinetorum	0	4	1
	Napaeozapus insignis	1	2	5
	Zapus hudsonius	0	3	0
	Tamiascurius hudsonicus	1	1	0
	Glaucomys volans	1	0	0
Total		89	24	17
Sludge and Trails	*Clethrionomys gapperi*	13	13	1
	Tamias striatus	10	5	6
	Citellus tridecemlineatus	0	7	12
	Peromyscus leucopus	34	4	1
	Pitymys pinetorum	0	5	1
	Napaeozapus insignis	0	0	9
	Zapus hudsonius	0	0	1
	Tamiascurius hudsonicus	0	0	0
	Glaucomys volans	0	0	0
	Misc.	0	3	0
Total		57	34	31

Table 3. Total animals captured and species diversity ($\bar{x}\pm$s.e.) on the jack-pine study area.

Treatment	May 1982	July 1982	August 1982
Control			
Total individuals ($\bar{x}\pm$s.e.)	3.33±2.85	6.33±3.18	5.33±0.67
mammal species diversity	1.27±1.27	0.31±0.18	0.41±0.14
Trails only			
Total individuals	0.67±0.67	3.33±0.88	4.00±0.58
mammal species diversity	0.00±0.00	0.23±0.14	0.40±0.05
Sludge and Trails			
Total indivduals	2.00±1.15	4.00±2.52	5.33±0.88
mammal species diversity	0.08±0.08	0.18±0.18	0.25±0.02

$\bar{x}$ values within a column with the same letter are not significantly different ($P < 0.10$).

Table 4. **Average number of individuals captured, by species, for major species, ($\bar{x}$±s.e.).**

Treatment	May 1982	July 1982	August 1982
Control			
Clethrionomys gapperi	1.67±1.20	1.67±0.88	0.33±0.33
Tamias striatus	1.00±1.00	3.00±1.15	2.33±0.67[a*]
Pitymys pinetorum	0.00±0.00	0.67±0.67	1.67±0.88
Citellus tridecemlineadus			
Trails only			
Clethrionomys gapperi	0.00±0.00	1.33±0.33	0.33±0.33
Tamias striatus	0.00±0.00	1.33±1.33	0.33±0.33[b]
Pitymys pinetorum	0.00±0.00	0.33±0.33	1.00±0.58
Citellus tridecemlineadus	0.00±0.00	0.00±0.00	0.00±0.00
Sludge and Trails			
Clethrionomys gapperi	1.00±1.00	1.00±0.58	2.33±1.20
Tamias striatus	0.33±0.33	1.33±1.33	0[b]
Pitymys pinetorum	0	0.33±0.33	1.33±0.33
Citellus tridecemlineatus	0.67±0.67	0.67±0.67	1.00±1.00

* $\bar{x}$ values within a column with the same letter are not significantly different ($P < 0.10$).

differences were observed in captures between whole plots or between plots with trails. However, in August (1 month after sludge application) there were significantly more captures of chipmunks on control plots. Profile analysis of 1983 population data indicated sludge treated plots supported the greatest number of total individuals (Table 7). A significantly greater number of 13-lined ground squirrles were captured on sludged plots.

In July 1982, a significantly greater number of small mammals were captured in the interiors (as compared to trails) of trails only plots and in August 1982 and 1983 on sludged plots (Table 8). August 1982 and July 1983 captures on sludged plot interiors were significantly greater than on non-sludged plot interiors. Mammal species diversity (H') did not differ significantly, in either year, between plots with either treatment or between treatments and controls (Tables 5 and 7).

Correlation between small mammal diversity and foliage height diversity (FHD) was not significant for either year. The association was positive in 1982 ($r = 0.357$) and negative in 1983 ($r = -0.216$).

Total annual production was negatively correlated ($r = -0.167$) with the combined total number of small mammals captured in 1982. However, there was a significant positive correlation with small mammals in 1983 ($P \leq 0.1$ $r = 0.596$).

A positive correlation was found between total number mammals captured and percent cover in the 0-10cm stratum in 1982 ($r = 0.306$) and 1983 ($r = 0.331$). There was a significant correlation in the 10-30cm stratum in 1982 ($P \leq 0.01$ $r = 0.801$) but not in 1983 ($r = 0.497$).

Correlations between 13-lined ground squirrels and FHD were negative for both years ($r = -0.276$ in 1982 and $r = -0.057$ in 1983). A significant

Table 7. Profile analysis (Morrison 1967) of small mammal numbers and diverstiy for the jack pine study area in 1983.

Species	Control**	Trails only	Sludge and trails
Clethrionomys gapperi	0.00 ± 0.00	0.00 ± 0.00	0.33 ± 0.00
Tamias striatus	2.33 ± 0.27	2.33 ± 1.20	2.00 ± 1.53
Citellus tridecemlineatus	0.33 ± 0.33^a	1.67 ± 0.88^a	5.00 ± 2.31^b
Peromyscus leucopus	1.67 ± 0.88	0.67 ± 0.33	0.33 ± 0.33
Pitymus pinetorum	0.00 ± 0.00	0.33 ± 0.33	0.33 ± 0.33
Napeozapus insignis	1.33 ± 0.67	2.00 ± 1.00	3.67 ± 2.18
Zapus hudsonius	0.00 ± 0.00	0.00 ± 0.00	0.33 ± 0.33
Tamiascurius hudsonicus	0.33 ± 0.33	0.00 ± 0.00	0.00 ± 0.00
MP	0.00 ± 0.00	0.00 ± 0.00	0.33 ± 0.33
SW	0.00 ± 0.00	0.00 ± 0.00	0.33 ± 0.33
SC	0.00 ± 0.00	0.00 ± 0.00	0.33 ± 0.33
Total species	5.00 ± 1.73	5.33 ± 0.88	7.33 ± 0.88
Total individuals	6.00 ± 1.53^a	6.33 ± 0.88^a	13.00 ± 2.31^b
Small mammal diversity	$.612 \pm .354$	$.736 \pm .161$	$.900 \pm .148$

* $\bar{x}$ values with a row with the same letter are not significantly different ($P < .10$).
** $\bar{x}$ sum from 3 plots of each treatment with standard error.

Table 8. Total number of animals captured in the application trails and interiors on the jack pine study area in 1982 and 1983 ($\bar{x} \pm s.e.$).

Season	Location	Trails Only	Sludge-Trails
May 82	Trail	0.33±0.33	0.33±0.33
	Interior	0.33±0.33	1.67±0.88
July 82	Trail	0.33±0.33A*	1.33±0.33b**
	Interior	3.00±1.00B	2.67±2.67
August 82	Trail	2.00±1.00b**	0.33±0.33A*
	Interior	2.00±0.58a	5.00±0.58B
June 83	Trail	0.67±0.33	2.33±0.88
	Interior	1.33±0.67	3.33±1.45
July 83	Trail	2.00±0.58	2.67±1.33
	Interior	2.00±0.58a**	6.00±1.53b
August 83	Trail	1.33±0.67	0.67±0.33A*
	Interior	2.00±1.00	3.33±0.67B

* $\bar{x}$ values within a column, within a season, with the same letter are not significantly different ($P < 0.10$).

** $\bar{x}$ values within a row, within a season, with the same letter are not significantly different ($P < 0.10$).

correlation with total herbaceous annual production was expressed in 1983 ($P \leq 0.01$ $r = 0.577$), but not in 1982 ($r = 0.013$).

Vertical Vegetative Cover

Total percent cover was significantly greater in 3 height strata on control plots in 1982 (Fig. 4). In 1983, sludged plots supported a significantly greater total percent cover, within the first 2 strata, over control and trails only plots (Fig. 5). In addition, significant differences existed between plots with trails and control plots within the 10-30cm stratum.

Cover within the application trails was sparse in 1982, but significantly greater within the second and third strata for trails of unsludged plots (Fig. 6). Percent cover in 1983 was considerably greater than observed for the first year.

Foliage height diversity (FHD) indices were significantly greater on control plots than on the other treatment interiors in 1982 (Table 9). No differences were observed between sludged and non-sludged plots, however, sludged plot interiors were significantly greater than sludged plot trails. In 1983, control plots continued to support a greater diversity of vertical cover than trails only plots. However, sludged plots had a significantly greater FHD value than control or trails only plots.

Woody Plant Densities

Woody stems on both controls and treatment plot interiors were quite similar with respect to composition and density in 1982 (Tables 10-13). Red oak stems were significantly greater on sludged plot interiors in the 0-1m height class. Stem densities remained similar among the treatments in 1983 (Tables 14-16). The total number of stems in the 1-2m height class decreased for all species on all treatments and were significantly

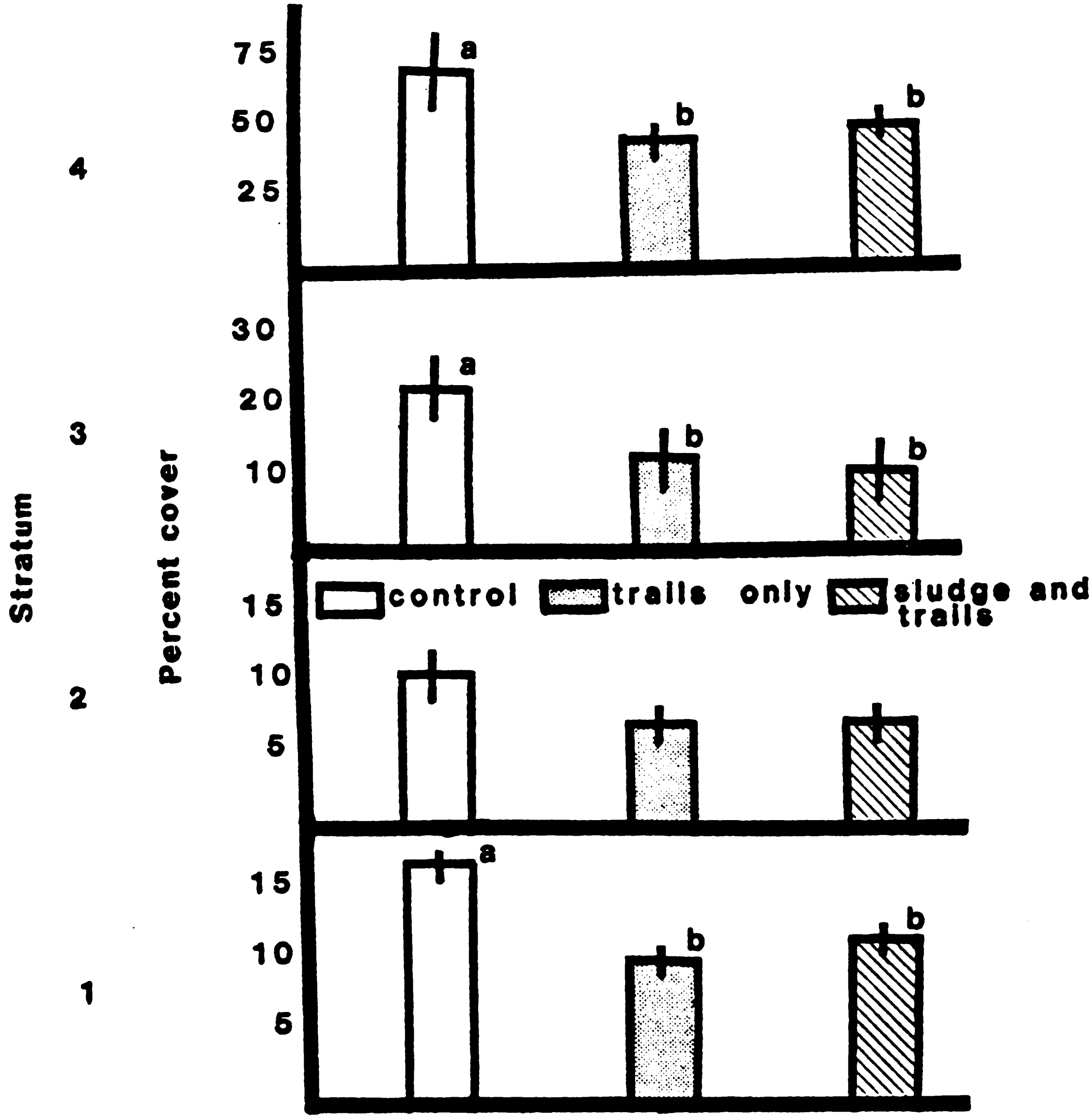

Figure 4. Mean total percent cover and standard error within 4 height strata Jack pine 1982. Means within a stratum with same letter are not significantly different (P < 0.10).

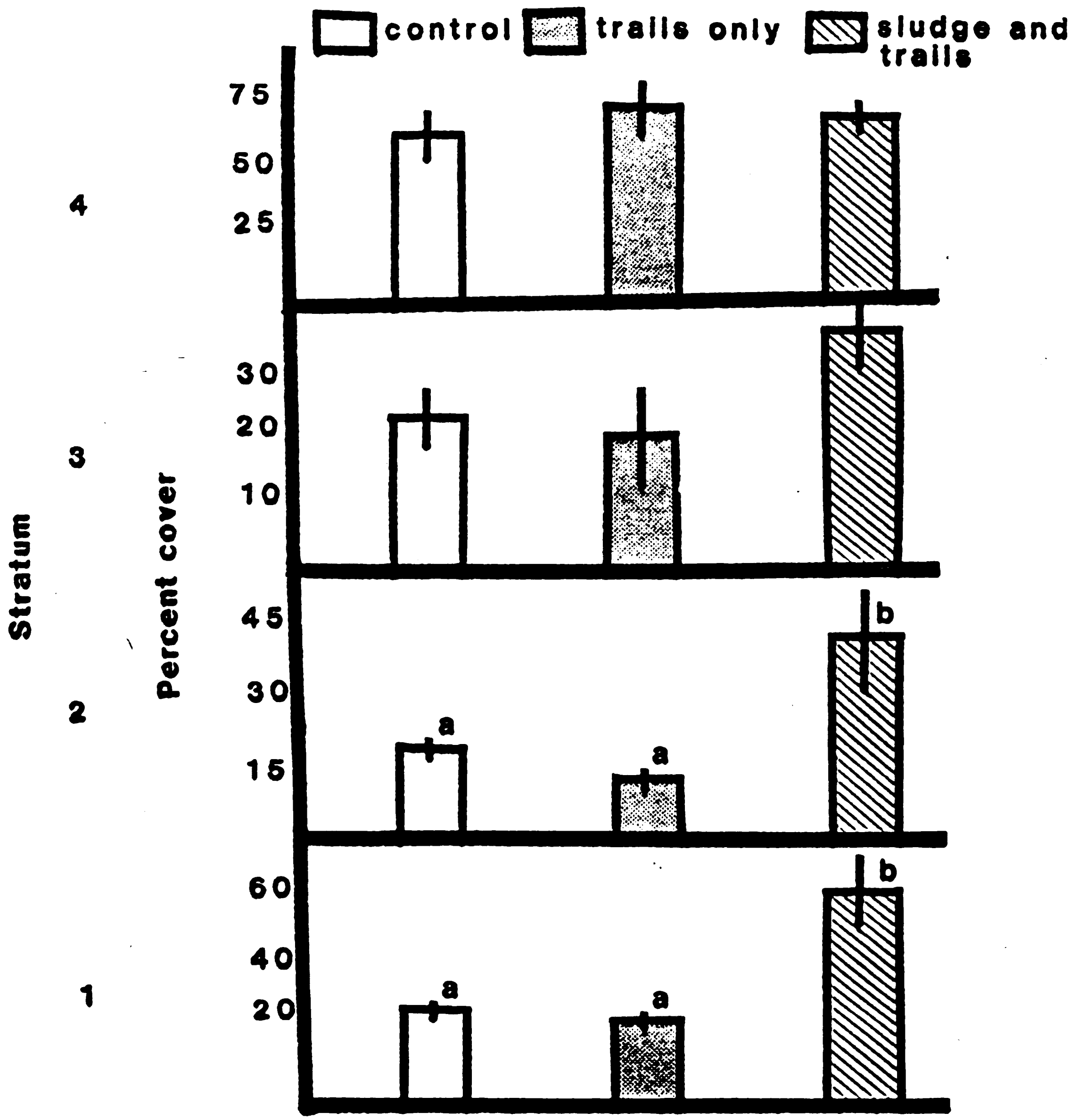

Figure 5 . Mean total percent cover and standard error within 4 height strata Jack pine 1983. Means within a stratum with same letter are not significantly different ($P < 0.10$).

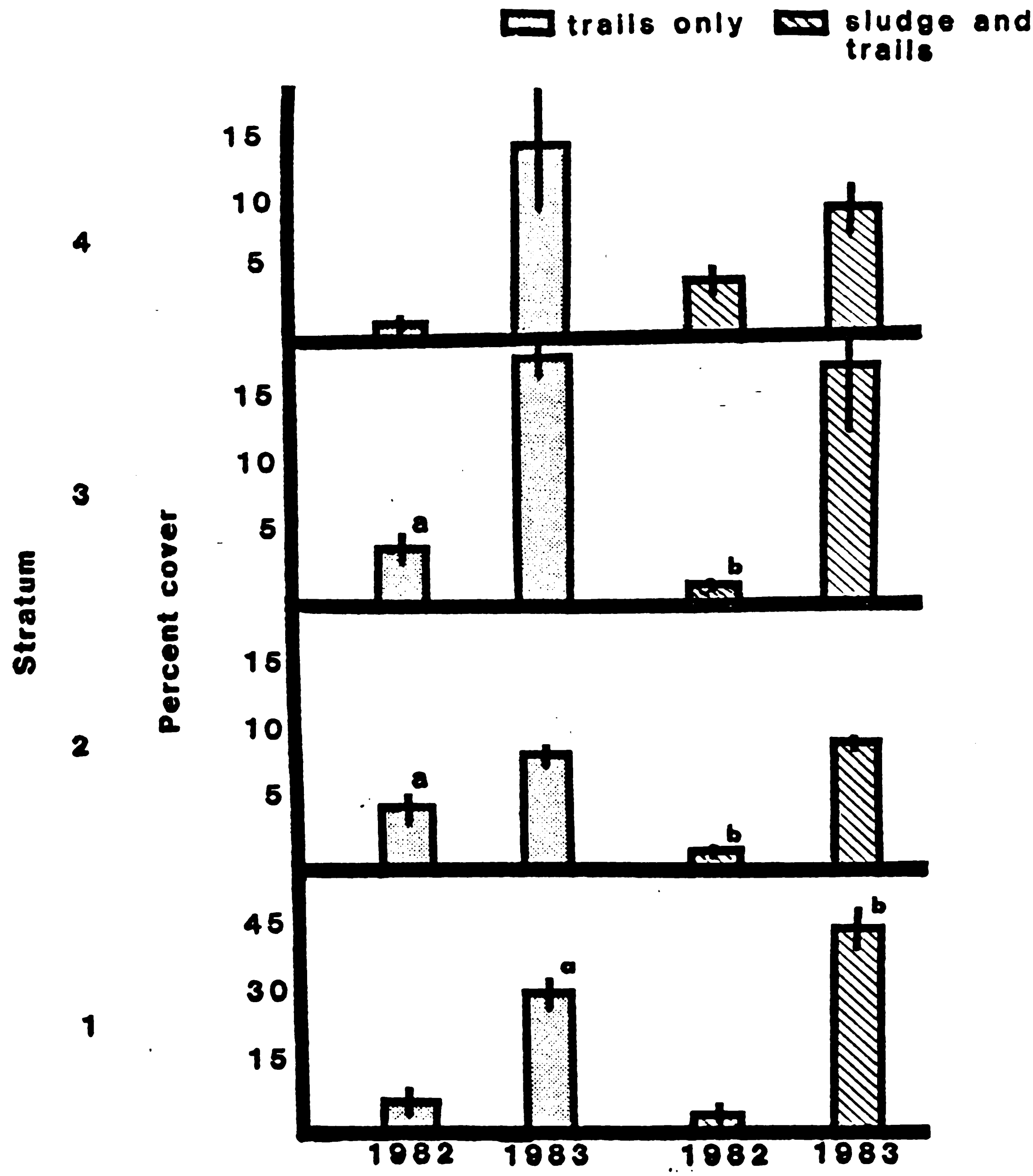

Figure 6. Mean total percent cover and standard error within 4 height stratum on the trails of the jack pine study area in '82,'83. Means within a stratum with the same letter are not significantly different.

Table 9. Foliage height diversity values of the jack pine study area.

Treatment		1982**	1983
Control		.435±0.21[a*]	.408±.026[a]
Trails only	Interior	.320±.023[b]	.364±.023[b]
	Trail	.321±.035[b]	.378±.005[b]
Sludge and Trails	Interior	.338±.021[b]	.471±.012[c]
	Trail	.230±.037[b]	.303±.063[b]

* $\bar{x}$ values within a column with the same letter are not significantly different ($P < 0.10$).

** $\bar{x}$ sum from 3 plots of each treatment with standard error.

Table 10. Density (stems/ha) of woody species within the 0-1m height class in the interiors and control plots of the jack pine study area 1982.

Species	control**	trails only	sludge and trails
Pinus banksiana	386±202	409±147	122±48
Pinus resinosa	102±54	144±48	37±9
Quercus rubra	3640±308[a*]	4533±1157[ab]	6208±389[b]
Acer rubrum	9300±7852	14083±3945	4750±3705
Prunus serotina	2072±538	1355±392	970±202
Amelanchier spp.	1420±630	887±178	1069±439
Other	436±144	428±69	371±87
Total	17900±8660	22000±3117	13833±4459

* $\bar{x}$ value within a row with the same letter are not significantly different ($P < .10$).
** $\bar{x}$ sum from 3 plots of each treatment with standard error.

Table 11. Density (stems/ha) of woody species within 1 m - 2 m height class in the interiors and control plots of the jack pine area in 1982.

Species	Control*	Trails only	Sludge and trails
Pinus banksiana	250±150	176±55	126±48
Pinus resinosa	36±25	19±8	18±13
Quercus rubra	573±143	349±41	483±33
Acer rubrum	638±644	118±26	76±60
Prunus serotina	118±26	87±52	30±14
Amelanchier spp.	76±60	38±17	30±15
Other	218±105	87±26	184±148
Total	1825±528	1193±129	902±65

* $\bar{x}$ sum from 3 plots of each treatment with standard error.

Table 12. Density (stems/ha) of woody species with > 2 m but < 10 cm dbh height class in the interiors and control plots of the jack pine study area in 1982.

Species	Control*	Trails only	Sludge and trails
Pinus banksiana	36±26	25±11	21±5
Pinus resinosa	17±7	5±3	11±0.75
Quercus rubra	138±48	56±11	40±4
Acer rubrum	254±250	37±9	31±20
Prunus serotina	--	--	--
Amelanchier spp.	--	--	--
Other	40±14	12±4	34±32
Total	495±250	135±21	139±16

* $\bar{x}$ sum from 3 plots of each treatment with standard error.

Table 13. Density (stems/ha) of woody species within the > 2 m and > 10 cm dbh height class in the interiors and control plots of the jack pine study area 1982.

Species	Control*	Trails only	Sludge and trails
Pinus banksiana	492±73	241±22	274±26
Pinus resinosa	147±18	104±75	107±11
Quercus rubra	15±9	10±10	3±2
Acer rubrum	42±30	17±9	27±27
Prunus serotina	--	--	--
Amelanchier spp.	--	--	--
Other	18±14	--	--
Total	776±128	398±20	442±24

* $\bar{x}$ sum from 3 plots of each treatment with standard error.

Table 14. Density (stems/ha) of woody species with 0-1m height class in the interiors and control plots of the jack pine study area in 1983.

Species	Control**	Trails only	Sludge and trails
Pinus banksiana	667±334	1071±399	305±82
Pinus resinosa	200±100	44±29	149±66
Quercus rubra	4867±1467	3189±515	3127±645
Acer rubrum	10000±7475	12055±6492	6913±5369
Prunus serotina	2033±418	953±455	704±357
Amelanchier spp.	1750±82	564±212	751±308
Other	350±160	400±164	227±33
Total	19867±5974	18277±6504	12175±6530

** $\bar{x}$ sum from 3 plots of each treatment with standard error.

Table 15. Density (stems/ha) of woody species within 1 m - 2 m height class in the interiors and control plots of the jack pine study area in 1983.

Species	Control**	Trails only	Sludge and trails
Pinus banksiana	58 ± 30	146 ± 63	62 ± 14
Pinus resinosa	75 ± 38	6 ± 6	29 ± 29
Quercus rubra	300 ± 126	219 ± 56	192 ± 12
Acer rubrum	$233 \pm 93^{a*}$	287 ± 120^{a}	67 ± 34^{b}
Prunus serotina	17 ± 8	29 ± 21	6 ± 6
Amelanchier spp.	17 ± 8	0 ± 0	0 ± 0
Other	0 ± 0	6 ± 6	6 ± 6
Total	100 ± 75^{a}	691 ± 80^{a}	361 ± 11^{b}

* $\bar{x}$ values within a row with the same letter are not significantly different ($P < 0.10$).
** $\bar{x}$ sum from 3 plots of each treatment with standard error.

Table 16. Density (stems/ha) of woody species within > 2 m but < 10 cm dbh height class in the interiors and control plots of the jack pine study area in 1983.

Species	Control**	Trails only	Sludge and trails
Pinus banksiana	13±7	39±3	28±8
Pinus resinosa	67±55	0±0	17±5
Quercus rubra	179±94	73±13	104±15
Acer rubrum	108±11	180±78	48±15
Prunus serotina	0±0	3±3	17±10
Amelanchier spp.	0±0	0±0	0±0
Other	4±4	3±3	299±67
Total	371±138	299±67	218±5

** $\bar{x}$ sum from 3 plots of each treatment with standard error.

lower on sludged plots (Table 15). Interior stem densities in the ≥2m but ≤10cm dbh size class increased from 1982-1983 on treatment plots, but decreased on control plots. Increases were due to red maple and red oak saplings. Black cherry also increased on sludged plots, while red maple and jack pine stems decreased on control plots. Densities were not significantly different.

Stem composition in trails varied considerably between plots, but no significant differences were observed in stem densities ≤1m in 1982 or 1983 (Tables 17 and 18). No stems were recorded in the ≥1m height class in 1982, but scattered individuals were observed in 1983 (Table 19).

Frequency of Herbaceous Vegetation

Sedges (Carex spp.) and sweetfern were more frequent in the interiors of plots with trails than on controls in 1982. Bearberry (Arctostaphylos uva-ursi) was significantly less frequent within interiors of sludged plots (Fig. 7). Species did appear to respond to trail construction. There was little change in frequencies in 1983, with the exception of grasses being less frequent (Fig. 8). Bearberry was significantly greater on unsludged plots. Sedges and sweetfern were significantly greater on trails only and sludged plots.

Annual Production

Annual production ≤2m in height was not significantly different between treatment and control plots in 1982 (Table 20). Significant differences were observed between interiors and trails of all plots with trails. Herbaceous and woody production on control plots was significantly greater than on treatment plot trails. Trails only and sludged plot interiors had significantly greater production than the trails of both treatments. In 1983, total annual production in trails was double the levels found in control and unsludged plot interiors. Total production on sludged plot

Table 17. Density (stems/ha) of woody species within the 0-1m height class in the application trails of the jack pine study area in 1982.

Species	trails only**	sludge and trails
Pinus banksiana	54±35	9±9
Pinus resinosa	11±6	9±5
Quercus rubra	4166±189	5837±1330
Acer rubrum	9900±3272	2750±2117
Prunus serotina	1039±87	750±143
Amelanchier spp.	343±44	590±241
Other	394±75	365±79
Total	16000±3426	10300±2290

** $\bar{x}$ sum from 3 plots of each treatment with standard error.

Table 18. Density (stems/ha) of woody species within the 0-1 m height class in the application trails of the jack pine study area in 1983.

Species	trails only**	sludge and trails
Pinus banksiana	49±31	33±33
Pinus resinosa	35±21	22±11
Quercus rubra	2818±1307	3711±372
Acer rubrum	6913±1380	6818±6311
Prunus serotina	869±200	802±254
Amelanchier spp.	24±24	1376±1375
Other	338±130	1953±1119
Total	11211±903	13200±6043

** $\bar{x}$ sum from 3 plots of each treatment with standard error.

Table 19. Density (stems/ha) of each species in the 1-2 m size class in trails for plots with trails, and plots with trails and sludge application for 1983 jack pine.

Species	trails only**	sludge and trails
Pinus banksiana	0±0	0±0
Pinus resinosa	0±0	0±0
Quercus rubra	37±11	37±18
Acer rubrum	29±4	0±0
Prunus serotina	38±28	6±6
Amelanchier spp.	0±0	0±0
Other	0±0	0±0
Total	102±21	42±22

** $\bar{x}$ sum from 3 plots of each treatment with standard error.

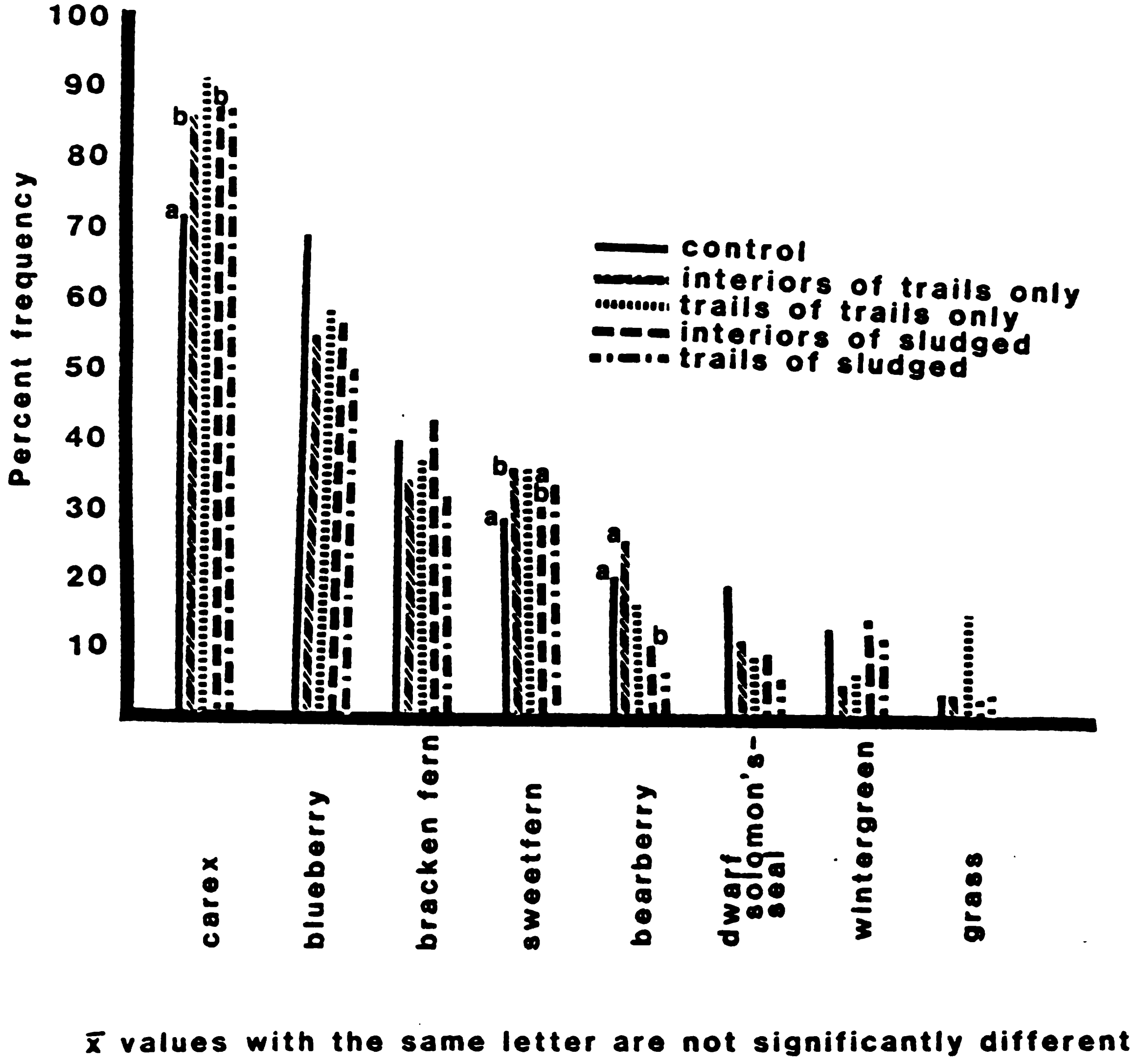

Figure 7 . Frequency ($\overline{x}$+se) of commonly occurring herbs on the jackpine study area in 1982.

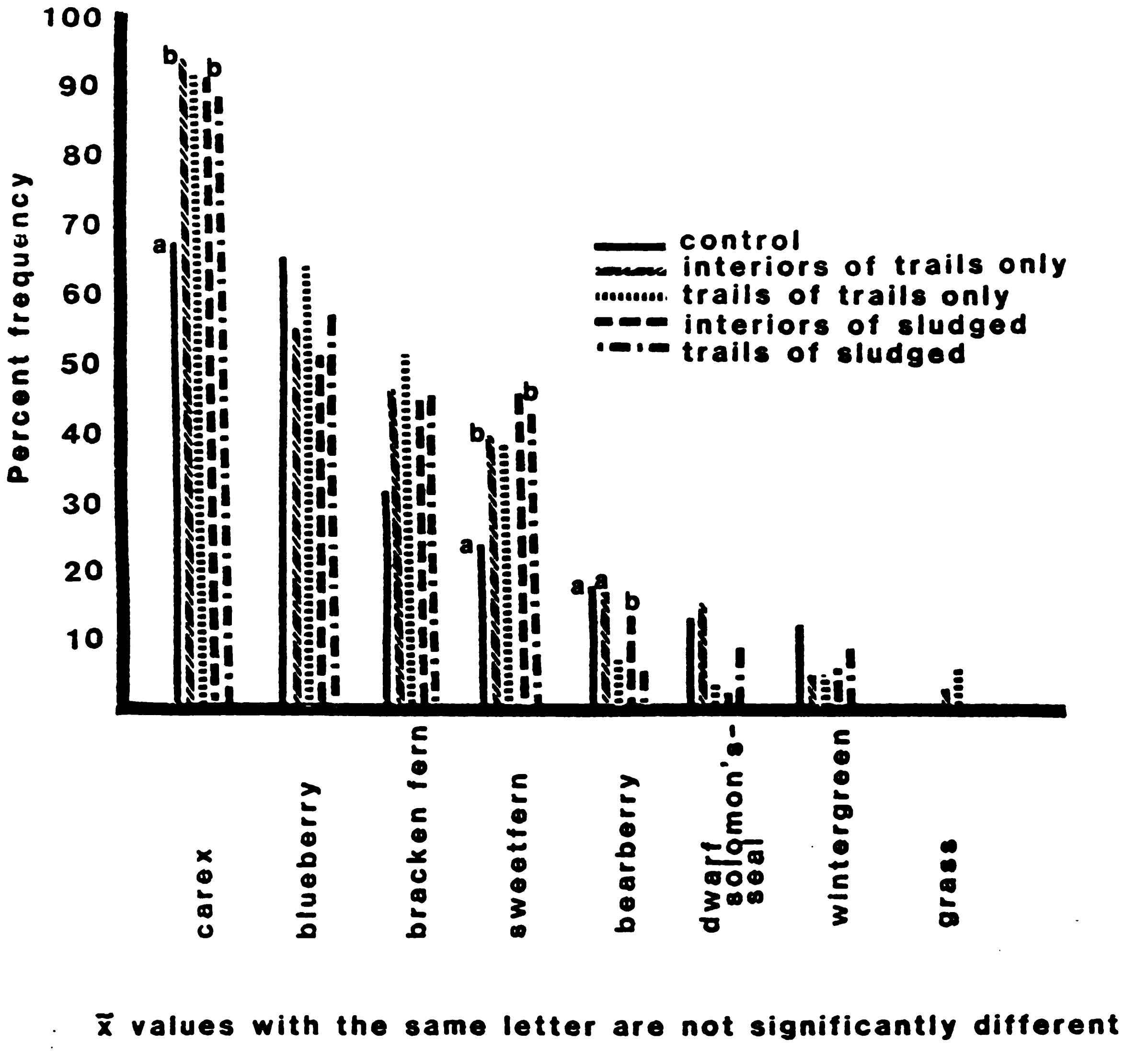

Figure 8 . Frequency ($\overline{x}\pm se$) of commonly occurring herbs on the jackpine study area in 1983.

Table 20. Annual primary production (< 2 m in height) on the jack pine study area in 1982 and 1983.

Treatment		Woody*		Herbaceous*		Total	
		1982	1983	1982	1983	1982	1983
Control		39±13.1A**	35.1±5.7^{a}	71±8.5A	193.1±64.4^{a}	109±6.8A**	228.2±60.7^{a}
Trails only	interiors	39±11.3A***	62.4±12.9^{b}	81±24.4A***	184.9±20.4^{a}	120±20.4A***	235.1±43.3^{a}
	trails	4±1.6B	35.3±7.37^{a}	8±2.3B	403.1±62.8^{b}	11±2.5B	438.4±69.9^{b}
Sludge and trails	interiors	52±11.7A***	72.6±26.4^{b}	132±61AB***	798.5±169.7^{c}	184±41A***	871.1±177.9^{c}
	trail	2±1.3B	48.9±13.8^{a}	7±4.5B	555.2±137.1^{bc}	9±5.6B	604.1±150.6^{bc}

* kg/ha

** $\bar{x}$ values within a column with the same letter are not significantly different ($P < 0.10$).

*** $\bar{x}$ values within a treatment, in a column, with the same letter are not significantly different ($P < 0.10$).

interiors exceeded that of 1982 by 373%. Production of herbaceous species on treatment plots more than tripled in 1983, while woody production showed only a slight increase in treatment plot interiors.

Nutritive Analyses

Ash

Summer samples of red oak, on sludge treated plots, had significantly greater ash content than on unsludged plots (Table 21). Winter samples had no significant differences in ash content (Table 22).

In Vitro Dry Matter Digestibility

There were no significant differences for IVDMD between treatment and control plots for either summer or winter samples (Tables 21 and 22). However, summer samples of sedges and bracken fern, on sludge treated plots, had slightly higher digestibilities than trails only or control plot samples.

Ether Extract

There were no significant differences in ether extract content between treatment and control plots for either summer or winter samples (Tables 21 and 22). However, red maple summer samples, had greater EE content on trails only plots.

Phosphorus

Phosphorus content was significantly greater in summer samples of sedges, red oak, and bracken fern on sludged plots (Table 21). Phosphorus content was slightly greater on sludge treated plots for red maple summer samples. Winter samples had no significant differences in phosphorus content (Table 22).

Table 21. Comparisons of percent ash, *in vitro* digestibility (IVD), ether extract (EE), phosphorus (P), and crude protein (CP) content, between control and treatment plots, for summer 1982 samples.

Treatment	Test	Sedge**	Red Maple	Red Oak	Bracken Fern
Control	ASH	5.50±1.07	5.74±0.16	5.65±0.36A*	10.36±0.46
Trails only		5.46±0.35	5.34±0.51	4.54±0.32B	9.62±1.0
Sludge and trails		6.99±0.25	5.43±0.52	5.82±0.16A	10.12±0.71
Control	IVD	35.79±1.21	28.71±1.46	23.21±1.94	16.39±2.25
Trails only		36.61±0.93	33.19±4.30	27.46±2.75	20.71±3.77
Sludge and trails		40.28±2.90	33.52±3.36	27.65±2.08	26.31±3.66
Control	EE	3.37±0.90	8.30±0.57	4.26±0.64	2.68±0.44
Trails only		3.26±0.35	11.03±1.75	3.52±0.32	2.40±0.33
Sludge and trails		3.58±0.27	8.68±0.33	3.18±0.44	3.72±0.64
Control	P	0.09±0.01A	0.18±0.02	0.20±0.03AB	0.25±0.06AB
Trails only		0.10±0.02A	0.16±0.01	0.17±0.01A	0.18±0.02A
Sludge and trails		0.27±0.02B	0.19±0.03	0.26±0.01B	0.39±0.04B
Control	CP	7.95±0.49A	11.80±0.72	14.71±0.63A	14.77±3.16
Trails only		9.86±0.63B	11.66±0.76	15.77±0.06A	11.41±0.10
Sludge and trails		17.49±1.64C	16.08±2.36	22.06±0.16B	19.91±1.16

* $\bar{x}$ values within a column, within a test, with the same letter are not significantly different ($P \leq 0.10$).

** $\bar{x}$ sum from 3 plots of each treatment with standard error.

Table 22. Comparisons of percent ash, in vitro digestibilty (IVD), ether extract (EE), phosphorus (P), and crude protein (CP) content, between trails only and sludge-treated plots, for winter 1983 samples.

Treatment	Test	Red Maple**	Red Oak
Trails only	ASH	3.51±0.42	4.43±0.33
Sludge and trails		4.54±1.64	5.69±1.47
Trails only	IVD	33.65±0.44	23.92±1.68
Sludge and trails		33.05±2.93	22.43±1.90
Trails only	EE	3.80±1.29	3.43±0.79
Sludge and trails		3.53±1.33	2.44±0.97
Trails only	P	0.13±0.00	0.10±0.02
Sludge and trails		0.16±0.02	0.11±0.01
Trails only	CP	4.94±1.10A*	5.52±0.64
Sludge and trails		9.90±1.09B	6.75±0.81

* $\bar{x}$ values within a column, within a test, with the same letter are not significantly different ($P < 0.10$).

** $\bar{X}$ sum from 3 plots of each treatment with standard error.

Crude Protein

Sludge application increased crude protein content in all species in both sampling seasons (Tables 21 and 22). However, only summer samples of sedges and red oak and winter samples of red maple were significantly greater in crude protein content on sludge treated plots.

Neutral Detergent Fiber

Neutral detergent fiber (NDF) content was lowest on trails only plots. There were no significant differences in NDF content for either season, between treatment and control plots (Tables 23 and 24).

Cell Soluble Material

There were no significant differences in CSM content in either sampling season (Tables 23 and 24). However, trails only plots had greater CSM contents in all samples of species in summer and in red maple winter samples.

Acid Detergent Fiber

Cellulose and lignin content (ADF) was lowest on sludge treated plots in all summer species samples except red oak (Table 23). ADF content was significantly lower on trails only plots for red oak summer samples. There were no significant differences in winter samples (Table 24).

Hemicellulose

Hemicellulose content was significantly lower on trails only plots in red oak winter samples (Table 24). There were no significant differences for summer samples (Table 23).

Acid Detergent Lignin

Lignin content was significantly lower in red oak summer samples on trails only plots (Table 23). Lignin content was lowest on trails only plots for summer and winter red maple samples and bracken fern summer samples (Tables 23 and 24).

Table 23. Comparisons of fiber analyses (%) between control and treatment plots for summer 1982 samples.

Treatment	Test	Sedge**	Red Maple	Red Oak	Bracken Fern
Control	NDF	74.29±2.93	37.14±0.46	51.83±0.59	62.91±0.33
Trails only		70.19±0.71	33.45±1.36	48.36±1.86	58.87±4.60
Sludge and trails		71.81±1.22	35.66±1.24	52.13±0.86	57.93±2.37
Control	CSM	25.71±2.93	62.86±0.46	48.17±0.59	37.10±0.33
Trails only		29.81±0.72	66.55±1.36	51.64±1.86	41.13±4.60
Sludge and trails		28.20±1.22	64.39±1.24	47.87±0.86	42.07±2.37
Control	ADF	42.54±2.20	39.91±2.29	40.86±0.77A*	59.31±1.33
Trails only		41.19±1.25	36.03±2.48	33.46±0.91B	56.87±5.09
Sludge and trails		39.94±0.95	34.92±1.75	34.15±3.45AB	56.52±3.40
Control	Hemi	31.75±4.25	-2.78±2.42	10.97±1.32	3.60±1.15
Trails only		29.00±0.55	-2.58±1.27	13.06±3.86	2.01±0.56
Sludge and trails		31.87±1.59	0.68±2.32	17.98±2.68	1.41±1.03
Control	ADL	6.76±0.21	19.18±1.26	21.58±1.91A	31.30±0.81
Trails only		6.26±0.78	14.65±2.11	14.82±0.39B	25.69±3.89
Sludge and trails		5.65±0.56	17.21±1.40	15.83±1.79B	30.17±1.86
Control	Cell	35.78±1.99	20.73±1.18A	19.28±1.80	28.01±1.64
Trails only		34.94±0.39	21.38±0.86A	18.64±1.30	31.18±1.22
Sludge and trails		34.29±0.39	17.70±0.59B	18.32±1.97	26.35±1.89

* $\bar{x}$ values within a column, within a test, with the same letter are not significantly different ($P \leq 0.10$).

** $\bar{x}$ sum from 3 plots of each treatment with standard error.

Table 24. Comparisons of fiber analyses (%) between trails only and sludge-treated plots for winter 1983 samples.

Treatment	Test	Red Maple**	Red Oak
Trails only	NDF	56.14±1.13	63.84±0.14
Sludge and trails		56.83±3.57	63.45±1.74
Trails only	CSM	43.86±1.13	36.16±0.14
Sludge and trails		43.17±3.57	35.55±1.74
Trails only	ADF	48.15±1.22	51.77±3.30
Sludge and trails		50.96±3.74	52.79±3.40
Trails only	Hemi	7.99±2.29	12.07±3.24A*
Sludge and trails		5.88±2.48	26.28±2.71B
Trails only	ADL	21.55±0.94	27.02±1.70
Sludge and trails		21.60±2.17	26.50±0.81
Trails only	Cell	26.60±1.86	24.75±1.61
Sludge and trails		29.36±2.04	26.28±2.71

* $\bar{x}$ values within a column, within a test, with the same letter are not significantly different ($P \leq 0.10$).

** $\bar{x}$ sum from 3 plots of each treatment with standard error.

Cellulose

Cellulose content was significantly lower in red maple summer samples on sludge treated plots (Table 23). All summer species samples, on sludge treated plots, were lower than either control or trails only plots. However, winter samples were lowest on trails only plots (Table 24), but there were no significant differences.

DISCUSSION

The application of sewage sludge has had a pronounced effect on both the vegetative community (structure, composition, and nutritional quality) and wildlife community (density and composition).

Small mammal population densities were relatively low on the study area in 1981. This is not unexpected due to the small size of the plots and the low productivity of the site, which is characteristic of jack pine forests. Population densities declined steadily throughout 1982 and 1983. Small mammal populations were also observed to decline on other study sites within the area (Haufler et al. unpubl. data). There was a sharp decline in *Peromyscus* spp. numbers, in 1982, on this study area and on several other areas within the state. Beyer (1983) reported a very sharp decline in *Peromyscus* spp. populations in 1982 over the previous year, in aspen (*Populus* spp.) clearcut and uncut stands, in Midland, Michigan. In a northern hardwoods stand in Atlanta, Michigan, Thomas (1983) also observed a decline in *Peromyscus* spp. populations as did Woodyard (pers. comm. 1982) in a jack pine clearcut in Cadillac, Michigan.

The sharp decline in small mammal populations was thought to be the result of the severe winter of 1982, because populations declined statewide and was not a local occurence. Snowfall was greater than normal in both December and Janurary, and temperatures were well below the norm (NOAA 1982). Black and Hooven (1974) reported populations of deermice to almost disappear on some study sites in response to a severely cold winter.

Jameson (1955) reported variations in small mammal populations (mice and voles) could be due to a number of factors, such as food availability which can affect reproduction rates and population densities and weather, severe cold or wetness can increase mortality. Regional variations, within a species, both in good and marginal habitats, have also been reported.

Changes in habitat structure due to cutting trails may have also had some effect on changes in population density. Douglass (1977), studying the effects of a winter road in Canada, observed populations of red-backed voles to decrease when disturbed, due to a loss of habitat. Cutting application trails in the forest opened up the overstory and stimulated increased production of woody and herbaceous vegetation in the understory. Certain species of small mammals are adversely affected by logging, such as red-backed voles, red squirrels, and chipmunks. Tevis (1956) and Gashwiler (1970) observed a decline in red-backed voles in clearcut Douglas-fir forests. Ream and Gruell (1980) also noted a decline in voles after clearcut logging. Most species react favorably to clearcutting. Deermice, woodland jumping mice, and meadow voles are ususally the first species to colonize a recently cut area (Tevis 1956, Alhgren 1966, Krull 1970, Kirkland 1977). Alhgren (1966), however, observed an increase in red-backed voles, as well, on cut jack pine tracts. Kirkland also noted red-backed voles colonizing a recently cutover area.

Vertical cover, also altered by the application trails, can influence the numbers and diversity of species present. Cavanagh et al. (1976), Schreiber et al. (1976) and Johnson et al. (1979) observed the highest species densities were in the created edge bordering the forest and a powerline right-of-way. They hypothesized this was due to a greater percentage of cover in the understory. Vertical cover is an essential habitat variable for many species of small mammals (LoBue and Darnell 1959, M'Closkey and Lajoie 1975, Yahner 1983). White-footed mice, in particular, have been significantly correlated with vertical cover (M'Closkey and Lajoie 1975). The significantly greater captures of small mammals in the interiors of treated plots may have been influenced by the increase in vertical cover, although correlations between species diversity and FHD were weak in 1982 and negative in 1983. However, correlations of small mammals and percent vertical cover in the lower 2 strata were positive for both years.

The application of sewage sludge to the jack pine study site also altered habitat quality through enhanced and increased production of vegetation, added nutrients, and altered vegetative structure. Anderson and Barrett (1982) reported changes in habitat quality following sludge fertilization. Female meadow voles responded favorably to the increased ground cover and plant species diversity. No direct toxic effects were observed on vole population dynamics. Population growth increased on the sludge treated wheat fields.

Small mammal populations had no immediate response to sludge application in 1982. However, 1 year later populations continued to decline on control and trails only plots, but remained steady on sludged plots.

The number of small mammal species on sludge treated plots doubled from 1982 to 1983 and although an increase in species diversity was observed here, species numbers did not increase. However, small mammals were positively correlated with total annual production in 1983. Sludge application has had an indirect effect on mammal populations through changes in vertical cover, FHD, and annual production. Small mammals were negatively correlated with production in 1982. Production was much lower in 1982 than in 1983.

Abramsky (1978) stated that increases in productivity can either increase or decrease species numbers and diversity. An increase in productivity can alter habitat structure (e.g. incresed density of forbs is favorable to some species but not to others) and changes in habitat can cause new species to come in and displace or replace the resident species, which was observed to occur here. The dominant species captured on all plots in 1981 were the white-footed mouse, red-backed vole, and the eastern chipmunk. In 1983, both the mice and voles had almost entirely disappeared from the study area. The small mammal community appeared to be changing. Voles and chipmunks became the dominant species in 1982, as mice disappeared from the study area. However, in 1983 vole populations declined and chipmunks, never very numerous to begin with, were replaced by woodland jumping mice and 13-lined ground squirrels as the dominant species.

Thirteen-lined ground squirrels are commonly found in prairie-like habitats (Burt 1957). The increase in 13-lined ground squirrels on sludge treated plots in 1983 may have been in response to increased production of sedges and other herbaceous vegetation, with which they were positively correlated. Woodland jumping mice have also been observed to increase on recently clearcut forests in response to increased herbaceous cover (Krull 1970, Kirkland 1977). Whitaker (1963) found the greatest number of woodland jumping mice in wooded areas with herbaceous ground cover, as did Preble (1956) within grass and sedge habitats. Both species appear to be responding to increases in productivity enhanced by the sludge treatment and the trail cutting.

Vegetative Community Response

The structural composition of the vegetative community was altered through both the clearing of the application trails (selective thinning) and sludge application (fertilizer effect).

Trail cutting had the most obvious effect on the vegetative structure through the removal of the overstory and subsequent stimulation of the understory. Red oak and red maple trees sprouted vigorously on the cut plots, both in the trails and interiors. Sewage sludge acts as a slow release fertilizer, due to its nutrients being in the form of organic compounds. These nutrients enhance the growth and production of woody and herbaceous vegetation. Herbaceous vegetation often demonstrates the earliest effects of the added nutrients, by increased growth (production) and changes in species diversity.

There were no changes in species diversity through either additions of new species or loss of old, although tomato plants were observed sprouting on sludge treated plots, due to seeds in the sludge.

Sweetfern and sedges were significantly greater on treatment plot interiors in both 1982 and 1983. Sedges, in particular, greatly increased on treatment plots. Abrams and Dickmann (1983) reported significant increases, in biomass, of sedges and blueberries on fertilized blocks in both mature and clearcut jack pine stands. Bracken fern also increased in biomass on fertilized plots in mature jack pine stands.

Control plots had few sedges and other herbaceous forbs. Forbs were not evenly distributed throughout the study area. Control plots contained a greater amount of woody forbs (shrubs) e.g. blueberry, bearberry, and sweetfern — than the other treatment plots. Bracken fern was evenly distributed on all study plots for both years, although treatment plots were slightly greater.

Cover was greatest on the control plots in 1982; this is not unexpected as thinning of the overstory on the treated plots reduced the amount of cover present. However, in 1983 vertical cover was greatly enhanced on sludge treated plots. The late application of the sludge, in June 1982, had little effect on the vegetative community that year, although 1 month later herbaceous vegetation was observed to be darker in color and had a more lush appearance. Harris (1979) observed that sewage sludge applied in the summer, to a red and white pine forest, had little effect on soil enrichment or vegetative growth that year, but may be of more value the next year. FHD indices were greatest on control plots in 1982, but in 1983 they were greatest on sludge treated plots.

Thinning the plots also had an effect on the amount of vertical cover present. Cover in the understory on the trails was greatly enhanced through thinning of the overstory. Ahlgren(1966) reported increases in herbaceous vegetation following clearcutting a jack pine forest. Thinning creates temporary openings which create an edge effect and stimulates herbaceous and woody plant growth in the understory.

Jack pine typically grows on poor sites of low fertility. Soils are generally sandy, acidic, and have low water-retention capacity. Better quality sites support red and white pine as well. The successional trend is towards hardwoods red oak, red maple, and basswood (Tilia americana) (Harlow et al. 1979). Evidence of this trend is already present. Stem densities for all species in the 1-2m height class were highest on control plots in 1982. Red oak and red maple had the greatest number of stems in the 0-1m height class for both years, on all plots, and in the 1-2m height class on control plots only. Red oak stem denesties were greatest on all plots for both years in the 1-2m height class, although all species were observed to decline in the 1-2m height class, on all plots, from 1982 to 1983.

Jack pine and red pine are the dominant species in the 4th height class (≥2m ≥10cm dbh), as expected. However, red oak and red maple are dominant in the 3rd height class (≥2m ≤10cm dbh), as site quality continues to improve the hardwood species will eventually dominate both the understory and overstory due to the intolerant nature of jack pine. The number of hardwood stems increased in the 3rd height class in 1983. Woodyard (1982) reported an accelration in ecosystem succession as a result of sludge application. This may be occurring here as a result of both perturbations of sludge application and thinning, both of which have been shown to enhance site quality, alter species diversity and structural composition.

Stem densities in trails in the 0-1m height class were highest, in 1982, on trails only plots, but in 1983 were highest on sludge treated plots.

The addition of sewage sludge to forests has been shown to increase the productivity of a site (Berry 1977, Brockway 1979, Anderson and Barrett 1982, Haufler et al. unpubl. rep.). Harris (1979) reported production doubled when sewage sludge was applied to a red and white pine forest. Campa (1982) and Woodyard (1982) observed an increase in annual production when sludge was applied to a 4-year-old jack pine clearcut. Jack pine, wild cherries (Prunus spp.), and brambles (Rubus spp.) increased over 100% on treated plots.

Productivity in 1982 was very poor. This is not unexpected because of the low fertility of the sandy soils that characterize jack pine stands. Annual production was measured approximately 1 month after sludge application and was not expected to reflect any effects from the sludge. In 1983, however, herbaceous vegetation, in the trails of treated plots, increased substantially, as did production in the interiors. Sludged plot interiors had the most dramatic response. Herbaceous vegetation increased well over 100%. There was only a slight increase in woody production on treatment plots in 1983.

Total annual production was greatest on sludged plot interiors for both years. Trails only and control plots had similar production values in 1982, but sludged plots did not, which suggests that production was greater on sludge treated plots prior to any treatment. However, production of blueberries, bearberry, and sweetfern were not accounted for in either year, as collection was too difficult and time consuming. Production may actually have been more evenly distributed among plots, as these species occurred in greater frequency on both control and trails only plots.

Production of jack pine and red pine also were not collected, because production under 2m was too infrequent to permit an adequate sample.

Nutritional Response

Sewage sludge has also been observed to improve wildlife habitat quality by enhancing the nutritive quality of the vegetation (Wood et al. 1973, Dressler and Wood 1976, Brockway 1979, Campa 1982). Sludge produces responses in vegetation similar to those of inorganic fertilizers (King and Morris 1972, Harris 1979, West et al. 1981). Anderson et al. (1974) reported increases in crude protein and production, in nitrogen fertilized browse. Wood and Lindsey(1967) also observed increases in crude protein with increasing rates of nitrogen (ammonium nitrate) application. Deer were observed foraging in the fertilized plots more often than the unfertilized plots.

Ash

Ash content of both summer and winter samples ranged between 4-10% of the total composition. Ash is composed of inorganic elements presented as a group; specific elements are not isolated. To better observe any changes in the ash content, specific elements will need to be isolated. No significant differences were observed between treatment and control plots, with the exception of red oak. Campa (1982) noted increases in ash content, due to sludge application, were not expected because ash is such a small percentage of the total composition.

In Vitro Dry Matter Digestibility

Digestion coefficients vary considerably for a given species due to seasonal variations, site quality, age of specimen, and chemical composition (Maynard et al. 1979). Digestibility of sludge treated samples increased approximately 15% over controls, except bracken fern, which increased over 50%. None of these differences were significant. Dressler and Wood (1976) also reported no significant changes in digestibility of forages on effluent treated plots. Campa (1982), however, reported significant increases in digestibility of sludge treated plants. Sewage sludge was applied to the site prior to the growing season and therefore the vegtation was able to fully assimilate the added nutrients and responded with an increase in digestibility. Sludge was applied after the initial growing period on this site and as a result plant digestibilities were not significant.

Ether Extract

Ether extract (EE) is often referred to as crude fat, because it contains plant pigments, such as chlorophyll and carotene and volatile oils, as well as lipids (Maynard et al. 1979). Ether extract content was very low for both seasons, between 3-11%. Red maple had the highest content on trails only plots, possibly due to its high content of volatile oils and soluble phenolics (Mould and Robbins 1982). Herbaceous species had a higher EE content on sludge plots, while woody species were higher on trails only plots.

Phosphorus

Phosphorus is an essential element that is concentrated in the seeds of growing plants. Very little phosphorus is contained in the stem and leaves and this decreases as the plant matures. It binds with calcium to form bones and teeth and is very important in energy, fat, and amino acid metabolism, muscle contractions, and nucleic acid structure (Robbins 1983).

In addition to nitrogen, sewage sludge also contains large amounts of phosphorus. Vegetation on sludge treated plots responded favorably to the addition of phosphorus. Phosphorus content increased on sludge treated plots for all summer samples, except red maple. There were no significant differences in winter samples.

Crude Protein

Changes in crude protein are the most often reported nutritional response to sewage and fertilizer applications (Wood et al. 1973, Abell and Gilbert 1974, Dressler and Wood 1976, Campa 1982). This is not surprising as sludge and fertilizers add nitrogen, as well as other nutrients, to the plant, and crude protein is estimated from the nitrogen content within a plant sample.

Crude protein levels were highest on sludge treated plots for both seasons. Summer levels ranged between 16-22%, which is far greater than the recommended optimum for white-tailed deer maintenance requirements by Ullrey et al.(1967). Proteins are an essential dietary requirement for all animals and are the major constituents of an animals body (Robbins 1983).

Sludge application is an effective method of enhancing protein levels within plants and thereby improving habitat quality.

Fiber Analyses

Breaking plant material down into soluble and structural portions is necessary for determination of the nutritive value of ingested foods (Mould and Robbins 1981). Detergent analyses (Goering and Van Soest 1970) are used to breakdown plant material into structural (CWC - hemicellulose, cellulose, lignin, and cutin) and non-structural (CSM - soluble sugars, carbohydrates, starches, and proteins) components (Robbins 1983). Detergent analysis itself does not determine the nutritive value or digestibility of the various plant components. However, while digestibility cannot be determined by these analyses they are related because the amount of each structural component present in the cell wall can affect the digestibility of a plant sample, e.g. lignin has been found to decrease the digestibility of certain browse species. Lignin itself is undigestible and increases with the age of a plant, lowering its digestibility (Robbins 1983).

There were no differences in the fiber content in any of the plant samples tested. However, ADF and ADL was significantly greater in red oak on control plots during the summer.

The negative hemicellulose values are the result of higher ADF than NDF values. This is not uncommon when separate samples are used to determine ADF and NDF rather than a sequential analysis (Milchunas et al. 1978, Mould and Robbins 1981, Robbins 1983).

SUMMARY AND RECOMMENDATIONS

Municipal sewage sludge from Alpena, Michigan was applied, in late June 1982, to a 40-year-old jack pine/red pine forest, at commercial fertilizer loading levels, using heavy agricultural equipment. The machinery used required the construction of a series of application trails throughout the forest, which also produced significant effects upon the forest vegetative and wildlife communities that were independent of the sludging effects.

Small mammals may have been indirectly affected by trail cutting, through the alteration of habitat structure, ie., increases in vertical cover, density of woody stems, and production of forbs in the understory. Small mammal populations declined steadily throughout the 2 trapping seasons following trail construction and sludge application. Severe winter weather has been postulated as the cause for this decline in 1982. In 1983 however, winter temperatures (Jan. - Mar.) were well above the norm (NOAA 1983) and should not have been a major factor in the decline of small mammal populations. Reasons for the continued decline of small mammal populations on the study area are unknown.

There were alterations in species distribution within the small mammal community. The dominant species captured in 1981 white-footed mice, red-backed voles, and eastern chipmunks were succeeded by the woodland jumping mouse and the 13-lined ground squirrel. Although sludge application appeared to have no immediate effect upon small mammal populations, species diversity doubled on sludged plots in 1983 and population levels remained steady on these plots.

A significantly greater number of small mammals were captured in the interiors of treated plots in both trapping seasons. July (1983) and August (1982 and 1983) captures on sludged plot interiors were significantly greater than captures on unsludged plots.

Vegetative community composition and structure were altered through the removal of the overstory during trail construction and sludge application. Vertical cover and FHD values were significantly greater on sludge treated plots in 1983. Total percent cover was significantly greater, in 1982, on control plots. FHD was also greater on control plots in 1982.

Density of woody stems in the understory increased significantly on treated plots. Hardwoods species sprouted vigorously on plots with trails. Red oak and red maple stems were greatly enhanced on treated plot trails, in the 0-1m and 1-2m height classes.

Trail construction stimulated woody and herbaceous vegetation in the understory the first growing season after cutting. Annual production was significantly greater on control plots and treatment plot interiors in 1982. Sludge also enhanced production 1 year after application. In 1983 total production on sludged plot interiors increased over 300%, over 1982 production. Production in trails was double the levels found in control and unsludged plot interiors in 1983.

Sewage sludge also enhanced the nutritive content of selected browse species. Crude protein and phosphorus levels increased in all species on sludge treated plots for both sampling seasons.

Sewage sludge can be recycled safely and permanently with minimal damage to the environment.When applied to nutrient-poor forests it can be used to improve site quality by increasing woody and herbaceous annual production, vertical cover, and nutritive content of available browse and forages. These in turn will benefit wildlife populations through improved habitat quality. Herbivores such as deer and elk would be primary beneficiaries. Carnivores would benefit indirectly through increases in prey populations (in response to habitat enrichment brought about by sludge application). However, it is unknown whether or not wildife populations would increase in response to improved habitat quality brought about by sludge application.

Timing of application, soil structure, site quality, depth of water-table, age of stand, vegetation type, and method of application are all factors that must be taken into consideration prior to sludge application. In addition, sludge should be applied prior to the growing season, when plants are dormant to realize the most benefits and minimize destruction of growing vegetation. Determining what is an appropriate forest type for sludge application is difficult. Pine sites are favored because of the soil structure, which is generally dry, porous, and not susceptible to compaction from heavy machinery. However, production and species diversity on these sites is generally low. Other vegetation types such as aspen (preferably clearcuts), old fields, or thinned hardwood stands would realize greater benefits through enhanced production, increases in species diversity, and enhanced nutritional quality of the plant community.

Forest application of sludge is favorable because forests are generally remote, readily available, and are removed from the general population. However, while forests are removed from the mainstream of human populations many people hunt, trap, and forage (pick berries and mushrooms), as well as hike and backpack. The potential of exposure to the unsightly application of sewage sludge must be minimized by avoiding heavily trafficked areas. The general population in the area should also be educated as to what is occurring so as not to alarm or anger them.

Future studies of sewage sludge application to forest and other non-agricultural areas should examine; what plants and animals are most or least benefitted by sludging; are the effects to the vegetative and wildlife communities long-term or short-lived; what affects do repeated applications produce and how often can sludge be reapplied to an area; how serious a problem are toxic metal and organic compound accumulation in wildlife food chains; is forest application cost-effective and what is the best method of application; how does application affect the public's attitude and recreational use of the area.

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APPENDIX

Table 25. Species list of common vascular plants on the jack pine study area in 1982.

Common Name	Scientific Name
Jack pine	Pinus banksiana
Red pine	Pinus resinosa
Red oak	Quercus rubra
Red maple	Acer rubrum
Black cherry	Prunus serotina
Serviceberry	Amelanchier spp.
Hawthorn	Crataegus spp.
White oak	Quercus alba
Choke cherry	Prunus virginiana
Blueberry	Vaccinium spp.
Bearberry	Arctostaphylos uva-ursi
Sedges	Carex spp.
Sweetfern	Comptonia peregrina
Bracken fern	Pteridium aquilinum
Wintergreen	Gaultheria procumbens
Dwarf Solomon's seal	Maianthemum canadense
Starflower	Trientalis borealis
Violets	Viola spp.
Moccasin flower	Cypripedium acaule
Yellow hawkweed	Hieracium pratense
Rattlesnake-weed	Hieracium venosum
Pyrola	Pyrola spp.
Bedstraw	Galuim aparine
Fringed polygala	Polygala paucifolia
Indian hemp	Apocynum cannabinum
Cowwheat	Melampyrum lineare
Golden aster	Chryopsis spp.
Common strawberry	Fragaria virginiana
Brambles	Rubus spp.
Grass	