This is to certify that the

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RESPONSE OF WILDLIFE TO LAND
APPLICATION OF SEWAGE SLUDGE

presented by

David Kent Woodyard

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Major professor

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RESPONSE OF WILDLIFE TO LAND
APPLICATION OF SEWAGE SLUDGE

By

David Kent Woodyard

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ABSTRACT

RESPONSE OF WILDLIFE TO LAND
APPLICATION OF SEWAGE SLUDGE

by

David Kent Woodyard

Municipal sewage sludge obtained from the Cadillac, Michigan sewage treatment facility was applied to study areas in a 4-year-old jack pine clearcut. Six - 2 ha plots were delineated in the clearcut, 3 of which were randomly selected and treated with sludge at a level of approximately 11 metric dry tons/ha during May, 1980. During the 2 years following treatment, small mammal populations were censused monthly by live trapping in the spring, summer and fall. Changes in vegetative structure and composition were determined by examining annual productivity, horizontal cover and vertical cover in both sludge-treated and control plots during the 2 growing seasons following treatment. Browsing by white-tailed deer (*Odocoileus virginianus*) and snowshoe hare (*Lepus americanus*) was also determined.

Results indicated succession may have been accelerated on sludge-treated plots. Annual production available for consumption and foliage height diversity were significantly greater on sludged areas. Small mammal species diversity was significantly higher on sludge-treated plots, primarily

due to increased colonization by meadow-voles (*Microtus pennsylvanicus*), eastern chipmunks (*Tamias striatus*), and meadow jumping mice (*Zapus hudsonius*). Browse removal from sludged areas by deer and hare was significantly greater than control plots. Small mammal diversity was highly correlated with foliage height diversity.

In essence, the vegetative resource available for wildlife exploitation was altered through:

1) the increased horizontal distribution of cover,
2) the increased vertical distribution of cover,
3) increased production,
4) increased nutritional quality.

The results from this study suggest municipal sewage sludge may be applied to nutrient-poor forest soils to benefit wildlife. However, additional research is necessary to evaluate the problem with potentially toxic metals accumulating in the wildlife food chain.

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# INTRODUCTION

Accelerated production of sewage waste poses a serious disposal problem for most communities. In 1972, the Federal Water Pollution Control Act Amendments were enacted and a multi-billion dollar program was authorized to aid local communities in construction of sewage treatment facilities including those for land treatment (Sullivan 1973). Provision of such cost-sharing grants was a governmental response to the increasing degradation in quality of our water resources. Ultimately, the goal is to halt the direct discharge of sewage waste into water systems.

Subsequent increased interest in land treatment of sewage waste has produced considerable research concerning the application of sewage effluents and sludges on agricultural lands (Sopper and Kardos 1972, Wright _et al_. 1973, Elliot and Stevenson 1977, Loehr 1977). These studies have shown that under carefully controlled and managed conditions sewage waste can be recycled on selected croplands with remunerative effects. Dual benefits are received by lessening water quality problems while providing an alternative source of fertilizer for intensive crop farming.

However, sludges may contain high concentrations of certain potentially toxic metals, most notably cadmium, lead, nickel and copper. Serious problems could arise from both phytotoxicity and the possible accumulation of toxic metals in the human food chain. Consequently, guidelines have been developed which limit the metal concentrations for sludge which can be used in the production of food crops (Chaney 1973).

Forest lands are not subject to many of the legal constraints that limit the application of sewage sludge on agricultural lands. According to Zzsoski et al. (1977), Brockway (1979) and Zzsoski (1981), human exposure to the health risks and food chain hazards of sludge recycling is minimized with forest lands. Forests are generally remote, and the recreational activities associated with these lands are most often dispersed. Thus there would occur little contact between people and the sludge. Furthermore, mostly non-edible wood products are produced on forest lands, which could prevent the direct contamination of the human food chain.

While the application of sewage sludge to forest lands is the object of growing interest, the effect nutrient enrichment from sludge addition may have on temperate forest ecosystems is unclear. Temperate forests have not evolved under nutrient enrichment, and communities may not respond in an organized, normal manner. Thus, ecosystem processes such as nutrient and mineral cycling and succession may be altered.

When compared to other ecosystem disturbances, nutrient enrichment is strikingly different. Unlike such factors as fire, flood, and windthrow, which physically set back succession, nutrient enrichment is a nondestructive perturbation. In most cases, neither individual plants nor animals are directly decimated.

Knowledge concerning the effects of sewage sludge application on forest ecosystems is inadequate. For certain facets of some ecosystem processes information is known about the effects incurred from sludge addition. Current research has focused on changes in ground water quality, primary productivity, biomass accumulation and nutrient concentrations in soils and plant parts.

Studies observing different ecosystems have demonstrated that the composition of both plant and animal communities may be altered by nutrient enrichment. Investigations of short-grass prairie (Grant et al. 1977, Abramsky et al. 1980), old field (Hurd 1974, Mellinger and McNaughton 1975, Reed 1977, Bakeler and Odum 1978) and tropical forest ecosystems (Harcombe 1977) have shown nutrient enrichment can influence community composition through niche expansion by some species and loss of others from intensified competition. But information concerning changes in community structure and consumer trophic level (wildlife) responses to sludge application is relatively scarce.

The only reported study conducted on forest lands (West _et_ _al_. 1981) reported small mammal community response to sludge recycling under 40-year-old Douglas fir. Early results from their work indicated herbivore numbers were lower on sludge-treated sites than controls. As a result, diversity indices for trophic groups collected from sludged areas were lower than controls. The reduction of herbivores was thought to be a trophic and not a toxicological based response, and it was hypothesized that plant species necessary as food and cover for this small mammal group were reduced or absent on sludge-treated sites. No data were presented reflecting vegetative response. Concurrent observations of black-tailed deer (_Odocoileus_ _hemionus_ _columbianus_) response to sludge application were made in the same area. Radio-tracking of individual black-tailed deer indicated preferential selection for areas treated with sludge in all months other than the growing season.

What little information is available suggests sludge addition can have a pronounced effect on some forest trophic groups. But, more research is needed to enhance our knowledge of how consumer trophic levels (wildlife) respond over time to changes in plant community structure and ecosystem processes incurred from sludge addition. This information must be obtained before the practice of sludge recycling on forest lands can be truly evaluated.

# OBJECTIVES

The primary objective of this study was to evaluate the response of a plant and small mammal community to perturbation by sludge addition. A second objective was to identify possible modification in the vegetation which influence small mammal populations. Another aspect of the study was to measure browsing use of the area by white-tailed deer (*Odocoileus virginianus*) and snowshoe hare (*Lepus americanus*) to determine if preferential foraging occurred on sludged areas.

## SITE DESCRIPTION

This study was conducted in the Manistee National Forest in southeast Wexford County. The 20 ha study area was located 6 km northwest of Cadillac, Michigan in S½, N¼, Sec. 15, T 22 N, R 10 W (Figure 1).

The area lies in the Cadillac Hilly Upland physiographic region (Sommers 1977), where the surface topography ranges from nearly level to gently rolling hills. Drainage is by the Muskegon River watershed, which empties into Lake Michigan.

Soils on the study site are of the Graycalm and Montcalm series. Graycalm soils are sandy, somewhat excessively drained and very strongly to slightly acidic. Montcalm soils are sandy, well drained and medium to slightly acidic (Corder 1979). Slope is gradual and to the west with the lowest point situated in the southwest corner of the area. The humus layer is poorly developed with an overlying litter layer of matted jack pine needles. Absence of an $A_2$ horizon suggests cultivation may have occurred within the last century.

Vegetation is in an early successional stage after being clearcut in 1976. Present overstory vegetation consists of widely dispersed clumps of regenerating jack pine

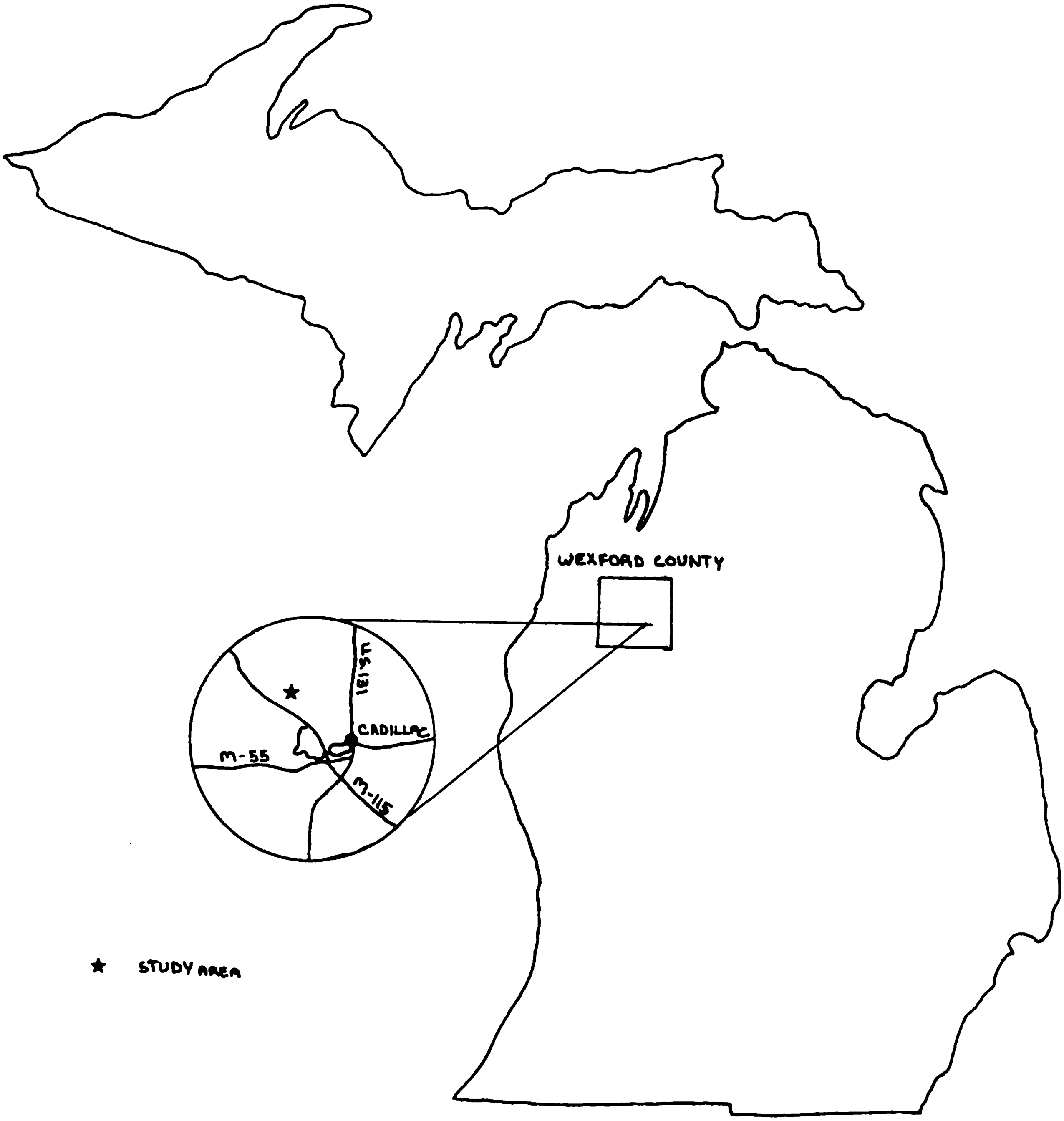


Figure 1. Study area in relation to Cadillac, Wexford County, and Michigan.

(*Pinus banksiana*) dominated by black cherry (*Prunus serotina*), choke cherry (*P. virginianus*) and pin cherry (*P. pennsylvanica*). Brambles (*Rubus* spp.) dominate the understory. The most common annuals include panic grass (*Panicum virgatum*), sedges (*Carex* spp.) and orange hawkweed (*Hieracium aurantiacum*). The study area supports a mosaic pattern of vegetation consisting of clumps of cherries and brambles interspersed with gaps of no vegetation and exposed soil. The cause of these gaps is unclear, but their existence provides an additional micro-environment for species exploitation.

The climate at Cadillac (44° 16'N latitude, 85° 20'W longitude) is influenced by its proximity to Lake Michigan, 64 km to the west. Mean annual temperature for the area is 5.8°C with monthly extremes in January (-7.8°C) and July (18.9°C). Precipitation is well distributed throughout the year with 58% received between May and October. Mean annual precipitation is 82.1 cm. Average annual snowfall is 180.8 cm, as the area lies in the Lake Michigan Snow Belt (Michigan Weather Service 1974). During the study period the average monthly temperature was similar to the long-term average while average precipitation was higher than the long-term average (Figure 2).

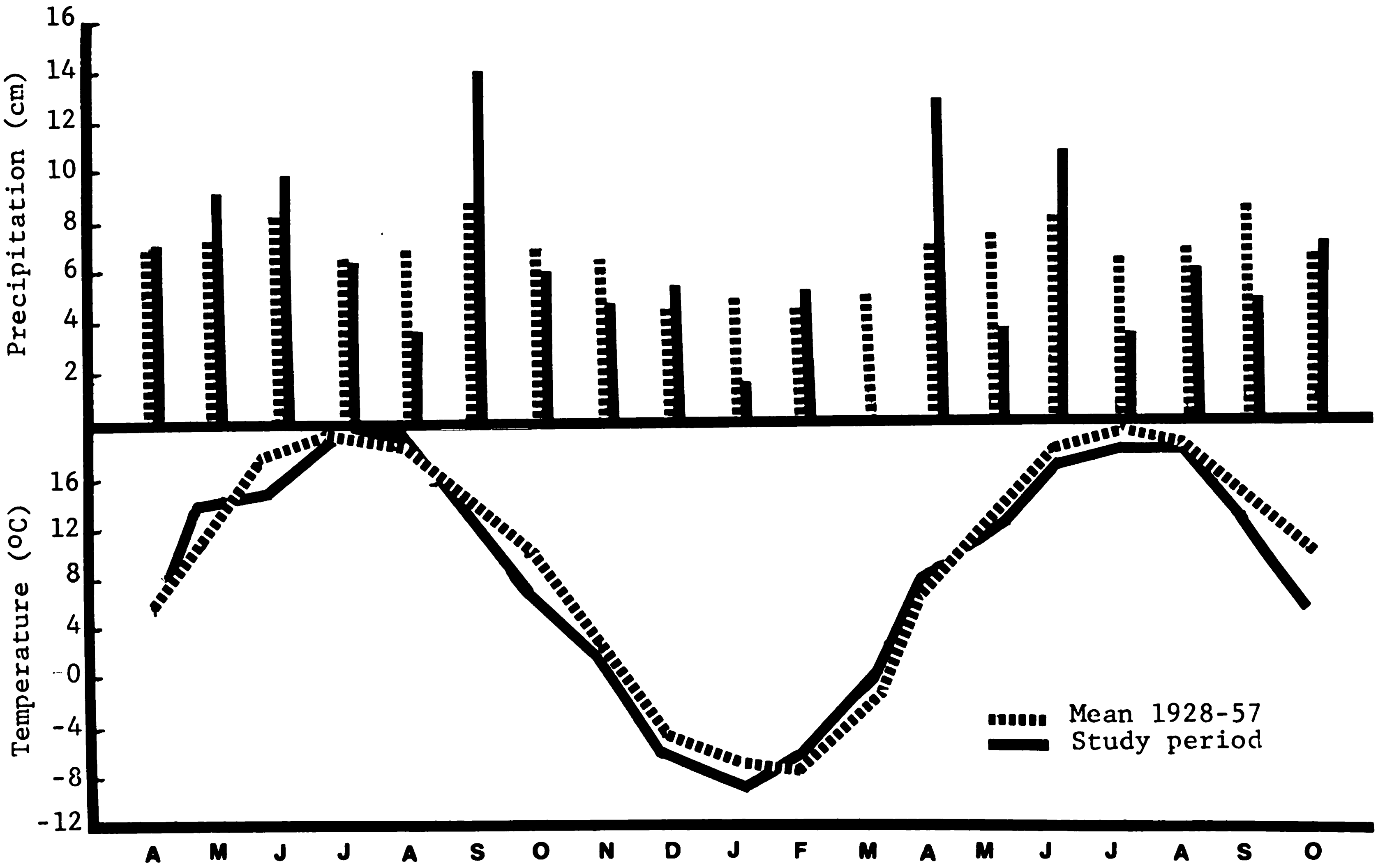


Figure 2. Mean monthly temperatures and precipitation during the study period.

# METHODS AND MATERIALS

## Experimental Design

This study utilized a completely randomized experimental design. Six plots were established on the study site (Figure 3). Three plots were randomly chosen for sludge application.

## Sludge Treatment

In May 1980, each of the 3 treatment plots received approximately 340,000 liters of digested municipal sewage sludge. The sludge was obtained from the Cadillac, Michigan sewage treatment facility. Sludge was transported to the site in tanker trucks, pumped into a holding pit, and distributed over the plots via irrigation guns and portable irrigation pipe. Application was completed in 3 weeks.

Elemental composition of the applied sludge was determined by the North Central Forest Experiment Station Forest Hydrology Laboratory at Michigan State University. Total Nitrogen (TKN) and Phosphorus were determined by Kjeldal digestion and a Technicon Autoanalyzer II (Tecator, Inc., Boulder, Co). All other elements were measured with a coupled plasma emission spectorphotometer (Spectrametrics, Inc., Andover, MA).

Figure 3. Map of the study area with plot locations.

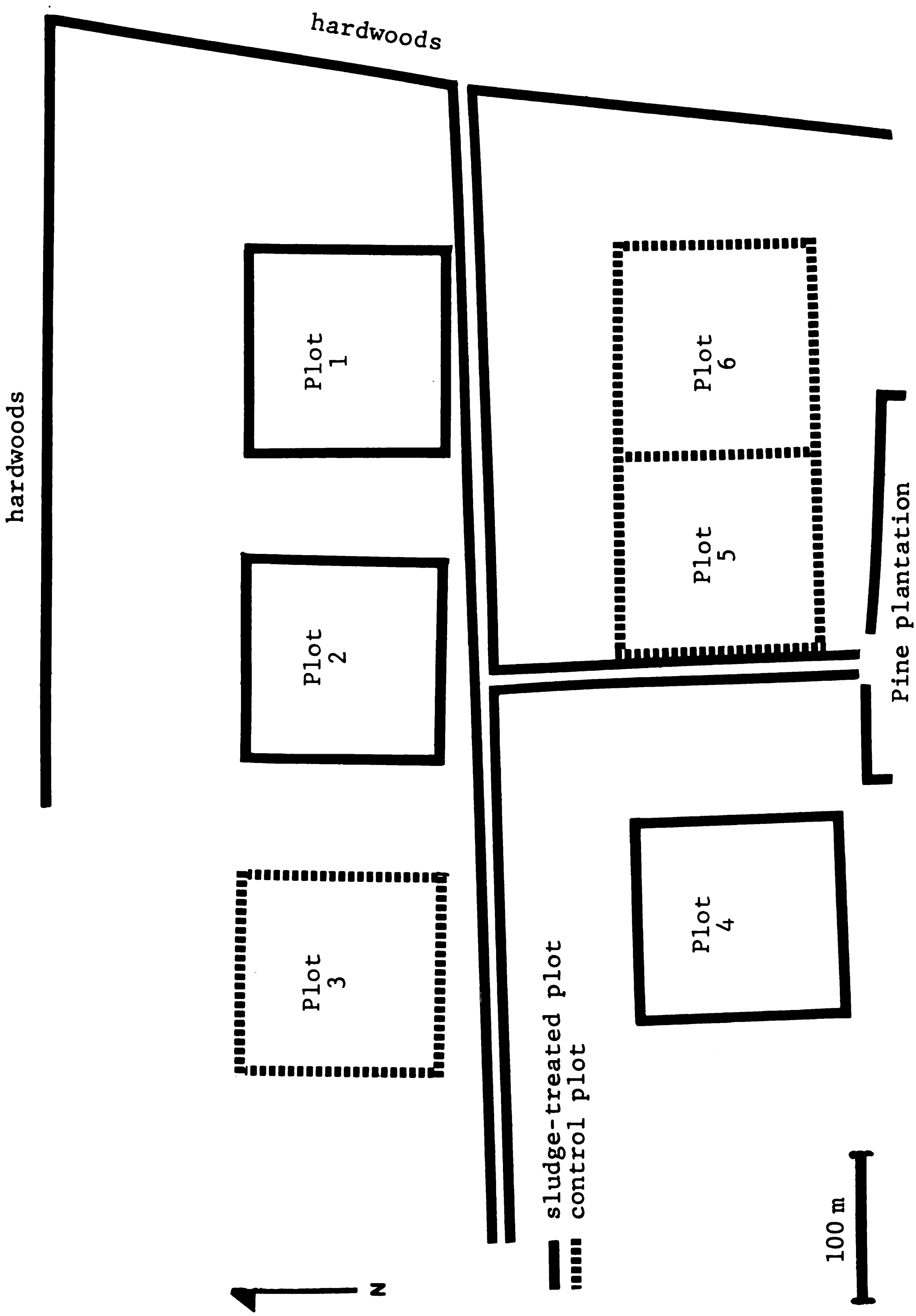
hardwoods
hardwoods
Plot 1
Plot 2
Plot 3
Plot 4
Plot 5
Plot 6
Pine plantation
sludge-treated plot
control plot
100 m
N

Figure 3.

None of the elements contained in the sludge (Table 1) exceeded levels described as potentially hazardous (Chaney 1973). Compared to sludge composition surveys (Kardos *et al*. 1977, Sommers 1977, Jacobs *et al*. 1981) nutrient concentrations were relatively low. Sludge was applied to obtain a loading rate of 481.5 kg/ha of nitrogen. The application rates of other selected elements in the sludge are listed in Table 1. Application rates used in this study were within the limits determined for similar sandy soils and ensured that ground water nitrate levels would meet the USPHS (United States Public Health Service) standard of 10 ppm (Brockway 1980).

## Annual Primary Productivity

Annual production of plants was measured within each plot between mid July and early August. By this time period, peak productivity had occurred but loss of foliar tissue by sloughing did not appear substantial. Annual above ground production $< 2$m was determined for 5 plant groupings. Cherries, jack pine, brambles and grasses were each grouped separately. All other understory species were combined together into a fifth grouping for sampling. Overstory species other than the cherries and jack pine were not included due to their extremely rare presence and the time consuming techniques used for estimating tree production.

Table 1. Mean elemental concentrations in municipal sewage sludge from Cadillac, Michigan and mean application rates of elements to soil.

| Element | Concentration dry wt. (ppm) | Application rate (Kg/ha) |
|---|---|---|
| TKN | 43800.0 | 481.5 |
| P | 52000.0 | 571.4 |
| K | 378.3 | 4.2 |
| Ca | 36700.0 | 403.7 |
| Mg | 6787.5 | 75.0 |
| Na | 1545.0 | 17.0 |
| Al | 5387.5 | 59.0 |
| Cd | 55.8 | 0.6 |
| Cr | 238.8 | 2.6 |
| Cu | 665.0 | 7.3 |
| Fe | 68400.0 | 752.4 |
| Mn | 671.3 | 7.4 |
| Ni | 69.3 | 0.8 |
| Zn | 1535.0 | 17.0 |

A limit of 2m was used as it was assumed primary production occurring above this height was unavailable for small mammal, snowshoe hare, or deer consumption.

For the overstory groupings (cherries and jack pine) annual production was determined by clipping all present year's growth (<2m) from individual trees. Eight trees from each of the 2 overstory groupings were randomly sampled on each plot with 2 individuals selected from each of 4 height strata (0-30 cm, 30-60 cm, 60-90 cm and >90 cm for jack pine, 0-60 cm, 60-90 cm, 90-120 cm and >120 cm for cherry). All plant material was stored in paper bags. The total tissue collected from each tree was wet weighed, and samples from each were oven dried at 60°C to determine wet:dry weight ratios for calculation of total dry weights.

To determine overstory annual production <2 per area, stem densities for all height classes were measured for both jack pine and cherry. In 1981, 2m X 40m quadrats were randomly located within each plot. In each quadrat, stems of both plant groups were counted for all height classes by measuring individual tree heights and recording each tree in the appropriate height class. To obtain densities for 1980 height classes, tree height was also measured at the apical node where 1980 growth ended. Density values were then combined with the mean annual production values within each height class for each plot to give estimates for cherry and jack pine annual production/area.

For brambles and grasses, annual production was determined by randomly locating 1m X 10m quadrats within each plot and clipping samples at ground level. In 1981, these plots were enlarged to 1m X 20m to reduce the variability between samples. Also, sampling was stratified by separately sampling in the gaps to again reduce the variability between samples. For brambles, present year's growth was separated from old growth before weighing. The other understory group was sampled from 1m X 40m plots.

Total production/area was determined for each plot by adding the production estimates for all plant groups.

## Vertical Vegetative Cover

The line intercept method (Gysel and Lyon 1980) was used to measure vertical cover above 40m-long line-transects within 3 height strata (0-10 cm, 10-30 cm and >30cm). At randomly selected points within each study plot, a line was established, and for each strata the intercept of all vegetation was recorded by species. Slash cover was also measured. Intercepts were measured to the nearest cm using 1 edge of a tape for the line. Gaps in cover of less than 10cm were ignored. The 3 strata chosen for analysis correlated with the general heights of the plant life forms found on the study site and fell within those ranges proposed in the literature (Rosenzweig and Winakur 1969).

## Browse Removal

Estimates of relative browse removal from cherries and brambles were determined in late October. Line transects were established and the first 200 stems intercepted under 2m for both groups were recorded as being browsed or unbrowsed. Jack pine was not included with the other browse-producing groups as this species has a low nutritional value for deer (Ullrey et al. 1967) and evidence of browsing was not observed.

## Small Mammal Trapping

Small mammal populations were estimated for each of the 6 2-ha plots through the use of live traps. Live trapping was initiated in June 1980, 1 month after sewage sludge was applied to the treated plots. A 5 X 5 trapping grid was centrally located in each plot with each trap station spaced 23.5m apart. Two sherman live-traps (H. B. Sherman Co., Tallahassee, FL) (13 X 13 X 38cm) were placed at each station.

Small mammals were trapped for 5 continuous days per month during the summer and fall of 1980 and spring, summer and fall of 1981. In April and October 1981, because of severe weather, small mammals were sampled for only 4 consecutive days. Because of higher trap mortality in late fall, cotton for bedding material was added to the traps during this time.

Traps were set on the first day of the trapping period and were left open throughout the sampling period. A mixture of oats, peanut butter, beef fat, raisins and anise extract was used for bait.

Traps were checked early each morning. Each newly trapped individual was ear tagged or toe clipped and released with species, ID number, and location on the grid recorded for each capture. On the last day of each trapping period, 2 to 3 individuals of the most abundant species were collected for future elemental analysis.

## Data Analysis

The linear model for the study design was

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

$\mu$ = mean of all observations

$T$ = Treatment source of variability (control or sludge-treated)

$\varepsilon$ = variability due to errors.

The required sample size for estimating cover and annual production for the major plant groups was determined by Stein's two-stage sample equation:

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

$t$ = the tabulated t value for the 90% confidence level

$s^2$ = sample variance

$d$ = mean multiplied by an allowable error of 20 percent.

One-way analysis of variance was used to test for difference between control and sludge-treated plots in cover, annual production, foliage height diversity indices, and cherry and jack pine densities (Steel and Torrie 1960). A 90% confidence level was used in all tests. A Bartlett's test was conducted on all data to test for a homogenity of variance.

Regression equations were determined for the relationship between height class and annual production of cherries and jack pine. The individual trees from all 3 plots of a treatment were combined in order to obtain 1 line/treatment. Thus, 32 trees were used to derive the regression equation for each treatment. F-tests were conducted to test for significant in the regressions. Analysis of covariance was conducted to test for significant differences in tree production between control and sludge-treated plots.

One-way analysis of variance was used to test for differences in small mammal total numbers, total species numbers, and diversity indices for each sampling period. Profile analysis (Morrison 1976) was used to test for an unequal response between treatments for small mammal numbers and diversity over time.

Because small mammal numbers were low, conventional capture-recapture populations estimators could not be used. Therefore, enumeration was the alternative method for population estimation (Krebs 1966). The minimum 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. Since this study was concerned with relative differences between plots, absolute population densities were not essential.

The index used to measure the diversity of vertical cover and small mammals was the Shannon-Wiener index (Krebs 1972): $H = -\Sigma p_i \log_{10} p_i$, where $p_i$ was the proportional abundance of the i category (stratum cover or small mammal species).

# RESULTS

## Vegetative Community Composition

Control and sludge-treated plots were similar in vegetative composition with cherries, brambles and jack pine being the dominant species. The only species found to be not common to both control and treated plots was the domesticated tomato plant (*Lycopersicon esculentum*). Occurence of this species on all 3 sludged plots can be attributed to the presence of viable seeds in the sludge. Tomato plants were not found in 1981. A list of all plant species found on the study area appears in the appendix.

## Vegetative Cover

Total percent cover was significantly greater on treated plots than control plots for both years within the 2 higher strata, but not for the 0-10 cm stratum (Figure 4). The greatest difference was observed in the 10-30 cm stratum where the mean % cover was 3.2 and 2.7 times greater on treated plots in 1980 and 1981, respectively.

Brambles demonstrated the greatest response to sludge addition. Between 1980 to 1981, the mean % cover significantly increased ($P>0.01$) over 80% in the 0-10 cm stratum,


Figure 4. Mean total percent cover and SE within 3 height strata in 1980 and 1981.

100% in the 10-30 cm stratum, and 350% in the >30 cm stratum on the treated plots. Bramble cover was significantly higher ($P<0.10$) on sludge-treated plots than controls for all strata in both years except for stratum 1 in 1980 (Figure 5).

Of the 2 overstory groups, the cherries demonstrated the greatest response to sludging with significant differences in cover occurring in the lower 2 strata (Figure 6). Cherry cover within the >30 cm stratum significantly increased ($P < 0.05$) 68% on sludged plots indicating canopy expansion was occurring on these sites.

Jack pine cover was significantly different between treatment and control plots in only the 0-10 cm stratum in 1981, where sludged plots supported 8 times more jack pine cover than controls (Figure 7). While control plots showed no change between years, jack pine cover on treated plots significantly increased ($P < 0.10$) almost 400 percent in the lowest strata.

There was no significant difference in grass cover between control and treated plots within the 0-10 cm stratum in either year (Figure 8). However, percent grass cover was significantly greater on treated plots within the 10-30 cm stratum in 1981 and within the >30 cm in both years.

No difference was found in orange hawkweed cover between control and sludge-treated plots (Figure 9). Carex and the group of combined understory species provided less than 0.5%

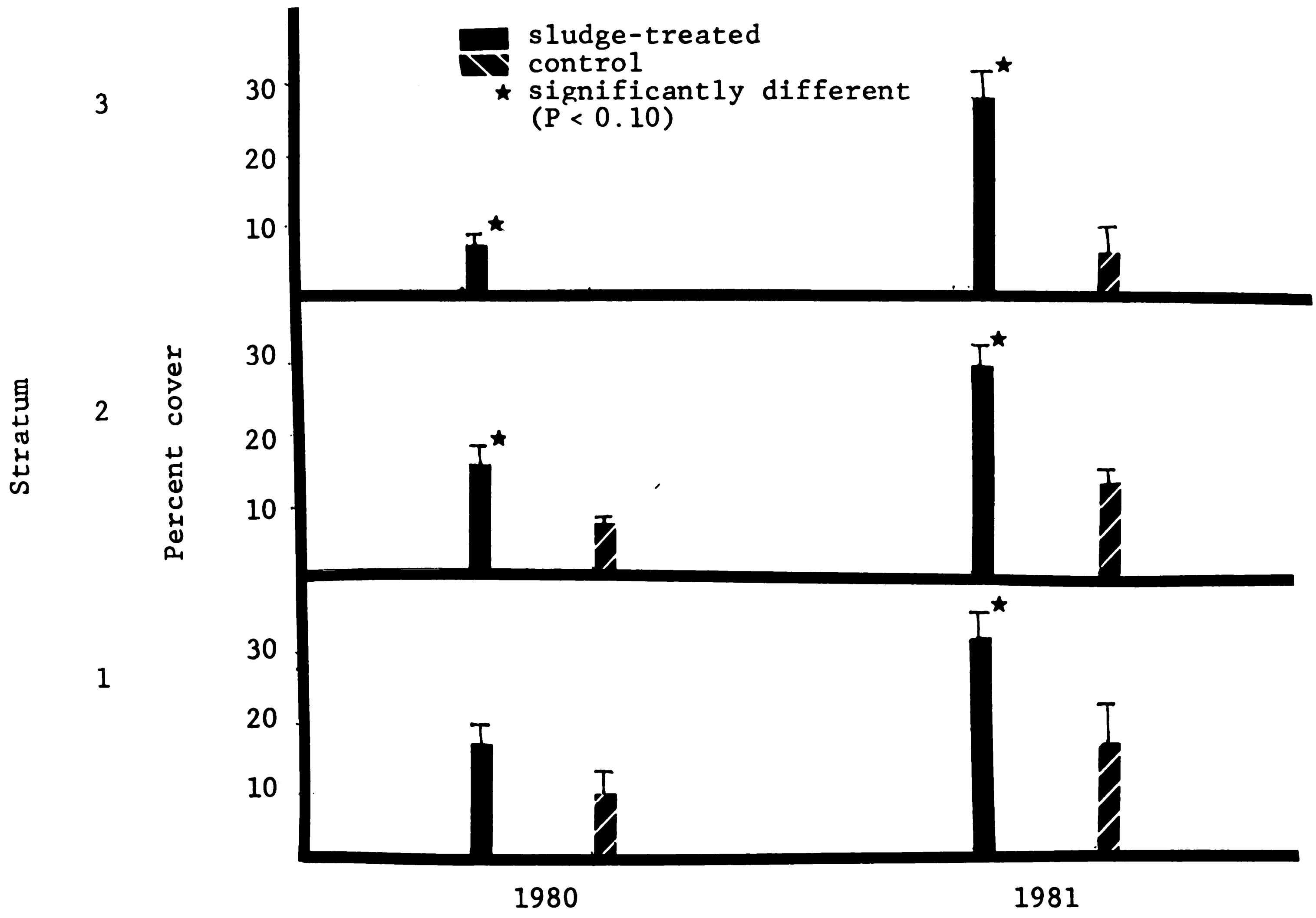


Figure 5. Mean bramble (<u>Rubus</u> spp.) cover and SE within 3 height strata in 1980 and 1981.

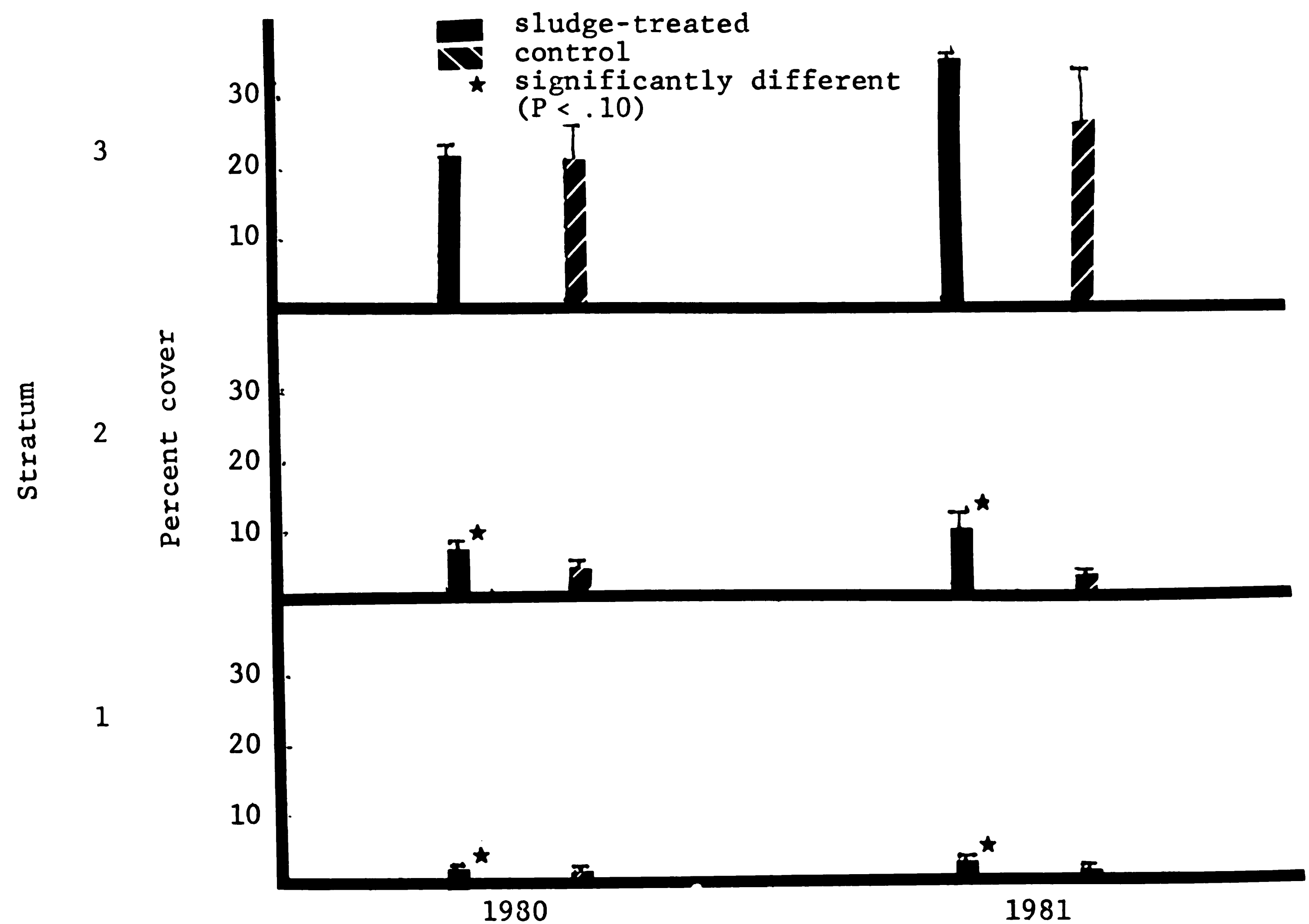


Figure 6. Mean cherry (<u>Prunus</u> spp.) cover and SE within 3 height strata in 1980 and 1981.

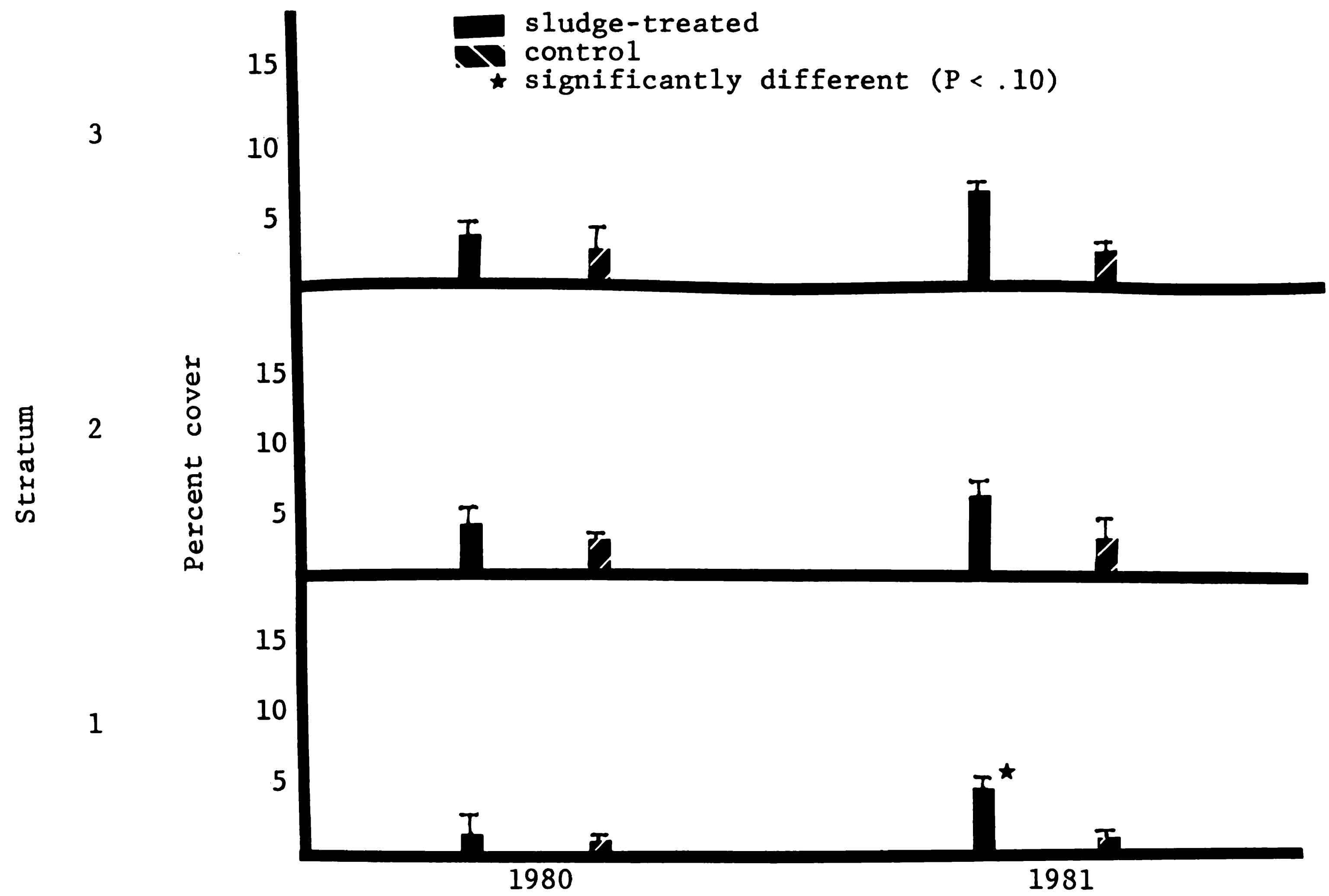


Figure 7. Mean jack pine (Pinus banksiana) cover and SE within 3 height strata in 1980 and 1981.

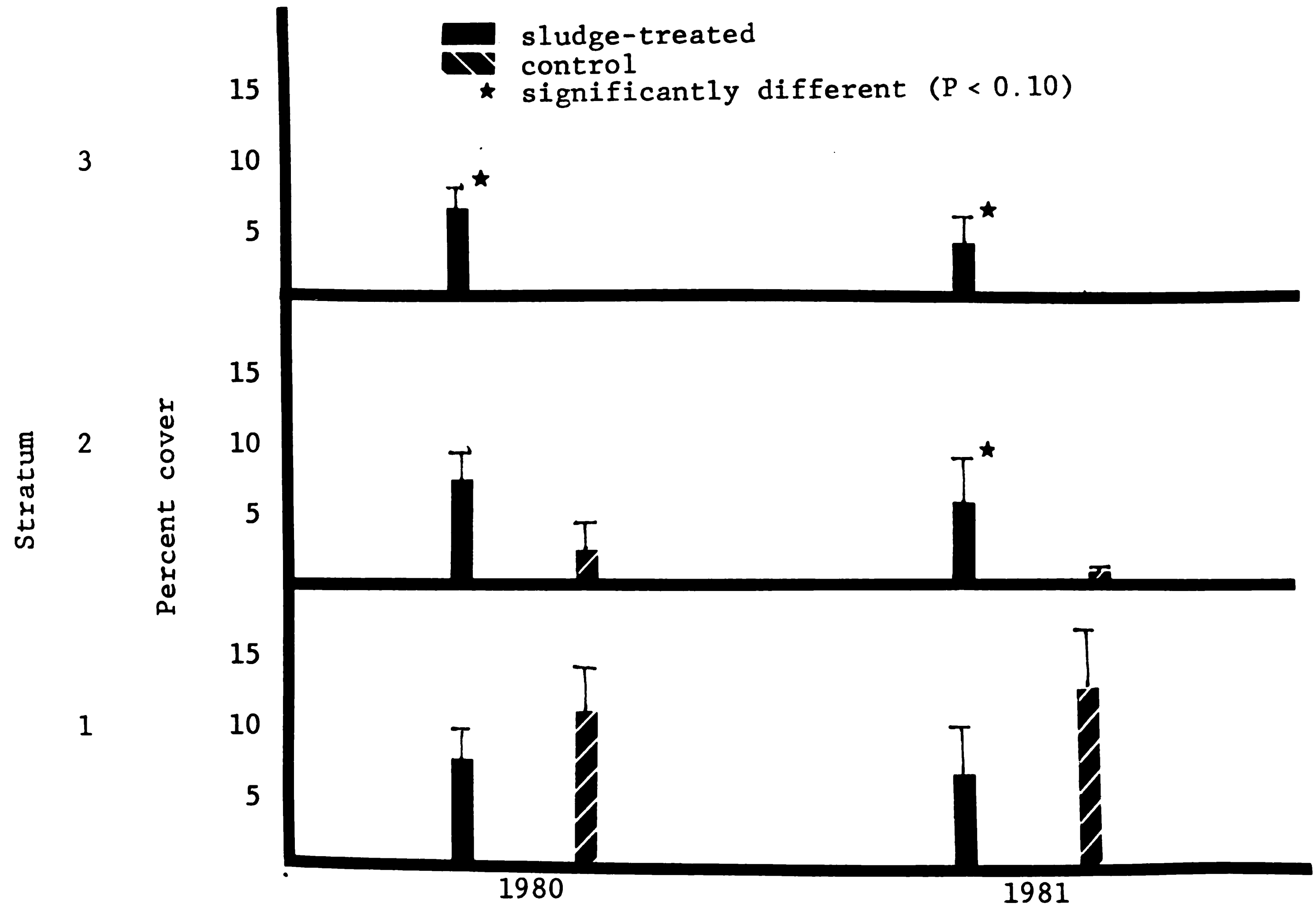


Figure 8. Mean grass cover within 3 height strata in 1980 and 1981.

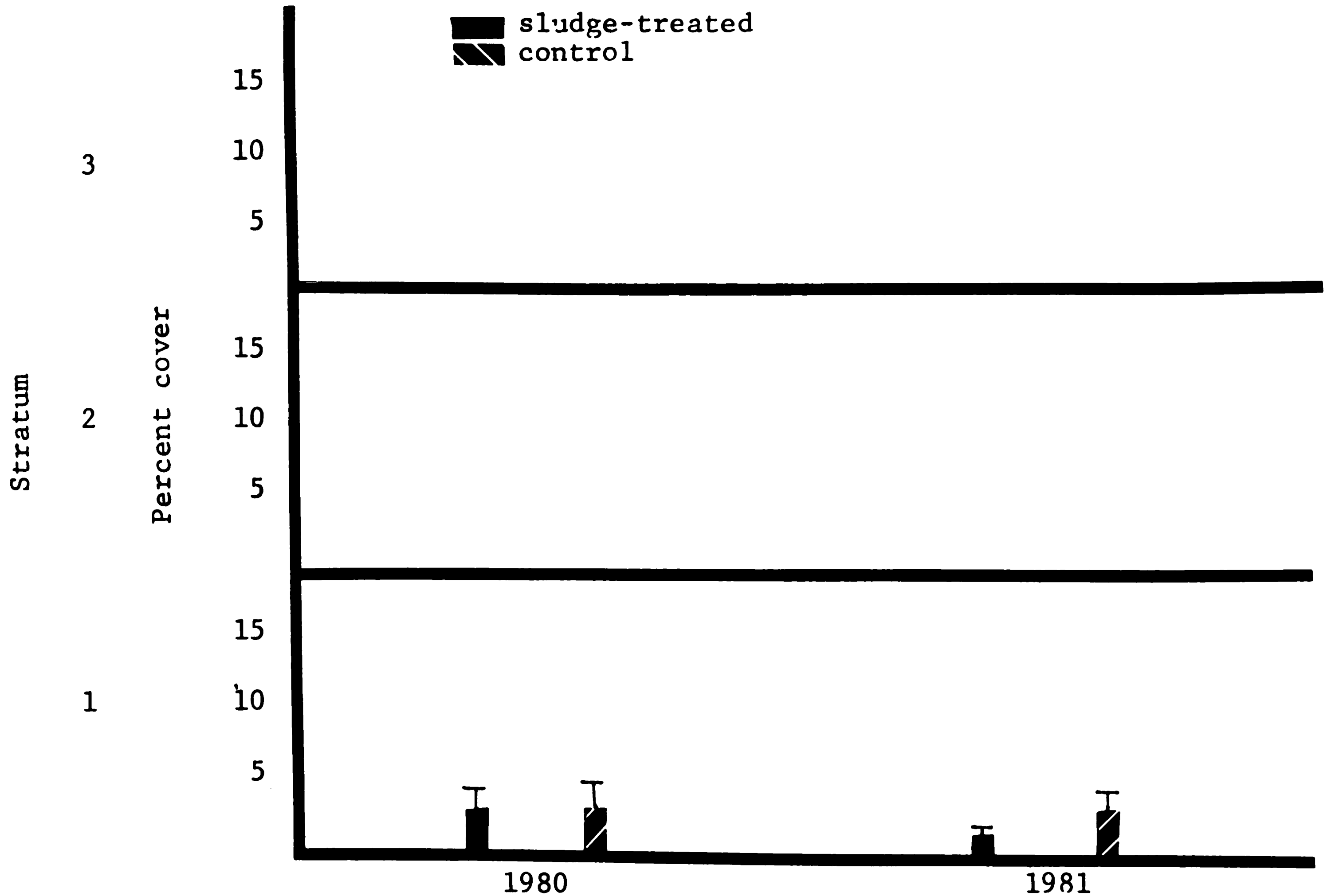


Figure 9. Mean orange hawkweed (<u>Hieracium avantiacum</u>) cover and SE within 3 height strata in 1980 and 1981.

cover and were not significantly different within any stratum in either year. No significant difference was found for slash cover between control or treated plots (Figure 10).

## Foliage Height Diversity

Foliage height diversity indices ($H'_{FHD}$) were significantly greater ($P < 0.05$) on sludge-treated plots than controls in both years. The mean index for sludge-treated plots was 1.060 and 1.090 for 1980 and 1981, respectively. The mean index for control plots was 0.843 in 1980 and 1.037 in 1981. The diversity indices of the control plots for 1981 were significantly greater ($P < 0.05$) than for 1980.

## Annual Production

Total annual production >2 m was 130% greater on sludged plots than controls in 1980 and over 180% greater in 1981 (Table 2). Increases in productivity were primarily seen in the cherries in 1980 and cherries, jack pine and brambles in 1981.

Jack pine and brambles demonstrated the greatest response between years to sludge addition. Jack pine production increased 130% between 1980 and 1931, while bramble production increased over 100%. Little change between years was observed for these 2 species on control plots.

The analysis of tree annual production by height (cm) indicated the relationship between increasing height and


Figure 10. Mean slash cover and SE within 3 height strata in 1980 and 1981.

Table 2. Above-ground net annual production (kg/ha) 2m on study plots in 1980 and 1981.

| Plant group | 1980 | | 1981 | |
|---|---|---|---|---|
| | Control[a] | Sludged | Control | Sludged |
| Cherry | 950±393 | 2364±125* | 954±352 | 2366±225* |
| Jack pine | 268±145 | 469±135 | 278±120 | 1093±235* |
| Brambles | 214±93 | 341±48 | 188±60 | 690±398* |
| Grasses | 55±15 | 167+61 | 47±6 | 74±25 |
| Other | 11.6±3.42 | 6.5±1.55 | 9.21±3.49 | 8.23±3.60 |
| Total | 1416±278 | 3347±108*** | 1477±223 | 4232±423*** |

* significantly different ($P < 0.10$) from controls

*** significantly different ($P < 0.01$) from controls

a $\bar{X}$ value from 3 plots of each treatment with standard error productivity was linear ($P < 0.10$) for both cherries and jack pine (Table 3). Covariance analysis showed individual tree production on sludged plots was significantly greater ($P<0.0001$) for both tree groups in both years.

Total cherry stem density was similar in 1980 and 1981 for control and treated plots (Table 4). The relative distribution of stems within height classes was similar for both treated and control plots and demonstrated no change between years.

Total jack pine stem density was not significantly different between treated and control plots (Table 5), but a large variance between plots may have masked possible differences. Changes in the relative distribution of stems within height classes occurred on both treated and control plots. The percentage of stems in the >120 cm height class increased on all plots and decreased in the 0-60 cm height class.

## Small Mammals

Six small mammal species were regularly caught on the study area, the Peromyscus deer mouse (*Peromyscus* spp.), 13-lined ground squirrel (*Citellus tridecemlineatus*), meadow vole (*Microtus pennsylvanicus*), meadow jumping mouse (*Zapus hudsonius*), eastern chipmunk (*Tamias striatus*), and masked shrew (*Sorex cinereus*). Two more species, short tailed shrew (*Blarina brevicauda*) and woodland jumping mouse

Table 3. Regression equations and covariance analysis for net above-ground annual production (g dry wt) per tree height (cm) of jack pine (<u>Pinus banksiana</u>) and cherry (<u>Prunus</u> spp.) in 1980 and 1981.

| Plant group | 1930 control | | 1930 sludged | | 1981 control | | 1981 sludged | |
|---|---|---|---|---|---|---|---|---|
| Jack pine | $y=83.6+3.7x$ | $r^{2a}=.77$ | $y=242.2+9.6x$* | $r^2=.86$ | $y=189.0+5.8x$ | $r^a=.75$ | $y=398.3+12.0x$* | $r^2=.85$ |
| Cherry | $y=23.0+1.9x$ | $r^2=.49$ | $y=345.7+8.8x$* | $r^2=.56$ | $y=6.8+1.2x$ | $r^2=.48$ | $y=306.6+4.4x$* | $r^2=.74$ |

* production per tree was significantly different ($P < 0.0001$) from controls

a $r^2$ values were significant for both groups in 1930 and 1981 ($P < 0.10$)

Table 4. Density (stems/ha) of cherry (*Prunus* spp.) trees on study plots per height stratum in 1980 and 1981.

| Height class (cm) | 1980 | | | | 1981 | | | |
|---|---|---|---|---|---|---|---|---|
| | control[a] | %[b] | sludge | % | control | % | sludge | % |
| 0-90 | 803±205 | 24.9 | 1051±427 | 31.7 | 727±282 | 22.5 | 1239±413 | 34.6 |
| 90-120 | 190±54 | 5.9 | 215±60 | 6.5 | 185±38 | 5.7 | 229±46 | 6.4 |
| 120-150 | 183±41 | 5.7 | 144±33 | 4.3 | 227±66 | 7.1 | 150±33 | 4.2 |
| >150 | 2052±720 | 63.5 | 1906±175 | 57.5 | 2089±708 | 64.7 | 1963±191 | 54.8 |
| Total | 3228±816 | 100 | 3316±210 | 100 | 3228±860 | 100 | 3581±183 | 100 |

a $\bar{x}$ value from 3 plots of each treatment with standard error

b percentage of total stems in each height class

Table 5. Density (stems/ha) of jack pine (*Pinus banksiana*) trees on study plot per height stratum in 1980 and 1981.

| Height class (cm) | 1980 | | | | 1981 | | | |
|---|---|---|---|---|---|---|---|---|
| | control[a] | %[b] | sludged | % | control | % | sludged | % |
| 0-60 | 90±16 | 13.8 | 99±24 | 11.9 | 49±11 | 7.5 | 40±10 | 4.8 |
| 60-90 | 69±9 | 10.6 | 91±16 | 11.0 | 29±7 | 4.4 | 34±10 | 4.1 |
| 90-120 | 94±49 | 14.4 | 130±38 | 15.6 | 76±19 | 11.7 | 90±10 | 10.7 |
| > 120 | 399±236 | 6.2 | 511±132 | 61.5 | 498±275 | 76.4 | 674±163 | 80.4 |
| Total | 652±277 | 100 | 831±136 | 100 | 652±298 | 100 | 838±190 | 100 |

a $\bar{x}$ value from 3 plots of each treatment with standard error

b percentage of total stems in each height class

(*Napaeozapus insignis*), were caught on 1 plot in only 1 trapping period, November 1980 and July 1981, respectively.

Although the 6 plots were adjacent and the entire study area encompassed only 20 ha, small mammal community composition differed between control and sludge-treated plots (Table 6). Three species were captured only on sludge-treated plots, the meadow vole, short-tailed shrew and woodland jumping mouse. Only the meadow vole was captured often enough on all 3 treated plots to be considered an inhabitant.

Deer mice were the most commonly captured small mammal on both sludged and unsludged plots. With 13-lined ground squirrels being second in abundance. Meadow voles, although never caught on control sites, made up over 9% of the total capture on treated plots. This species did not appear on the study site until November 1980 but were continually captured thereafter.

Profile analysis of small mammal numbers found 3 species, meadow vole, meadow jumping mouse, and masked shrew, were captured in greater numbers in sludged plots than controls in 1980 (Table 7). In the first year, 7 species were captured on treated plots as compared to 3 species on control plots; consequently, total species captured and small mammal diversity ($H'_{sm}$) were also greater on sludged plots in 1980. Meadow voles and eastern chipmunks were captured in greater numbers on sludged plots than control in 1981. Also, total

Table 6. Number of individuals known to be alive on study plots in 1980 and 1981.

| Treatment | Species | 6/21 | 8/2 | 9/3 | 10/5 | 11/6 | 4/28 | 6/1 | 6/22 | 7/27 | 8/18 | 9/23 | 10/20 | Total 1980 | Total 1981 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Control | *Peromyscus* spp. | 18 | 22 | 12 | 19 | 13 | 6 | 13 | 11 | 20 | 18 | 19 | 22 | 64 | 97 |
| | *Citellus tridecemlineatus* | 9 | 20 | 9 | 1 | -- | -- | 8 | 6 | 7 | 1 | -- | -- | 25 | 15 |
| | *Microtus pennsylvanicus* | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| | *Zapus hudsonius* | -- | -- | -- | -- | -- | 1 | 5 | 3 | 3 | 1 | 2 | -- | -- | 10 |
| | *Tamias striatus* | -- | -- | -- | -- | -- | -- | -- | -- | -- | 2 | 1 | -- | -- | 2 |
| | *Sorex cinereus* | -- | -- | -- | 2 | 1 | 4 | -- | 2 | 1 | 1 | 1 | 1 | 3 | 6 |
| | *Blarina brevicauda* | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| | *Napaeozapus insignis* | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Total | | 27 | 42 | 21 | 22 | 14 | 11 | 26 | 22 | 31 | 23 | 23 | 23 | 92 | 130 |
| Sludge-treated | *Peromyscus* spp. | 24 | 22 | 25 | 22 | 17 | 4 | 13 | 22 | 29 | 14 | 24 | 15 | 67 | 112 |
| | *Citellus tridecemlineatus* | 9 | 29 | 14 | 4 | -- | 6 | 7 | 4 | 12 | -- | -- | -- | 32 | 26 |
| | *Microtus pennsylvanicus* | -- | -- | -- | -- | 4 | 4 | 5 | 4 | 5 | 5 | 9 | 5 | 4 | 13 |
| | *Zapus hudsonius* | -- | -- | 2 | 3 | -- | -- | 19 | 4 | 5 | 5 | 3 | -- | 3 | 25 |
| | *Tamias striatus* | -- | 2 | 2 | -- | -- | -- | 1 | 6 | 3 | 7 | 4 | -- | 3 | 12 |
| | *Sorex cinereus* | -- | -- | 2 | 3 | 2 | 2 | -- | -- | 4 | 1 | -- | 1 | 7 | 8 |
| | *Blarina brevicauda* | -- | -- | -- | -- | 1 | -- | -- | -- | -- | -- | -- | -- | 1 | -- |
| | *Napaeozapus insignis* | -- | -- | -- | -- | -- | -- | -- | -- | 3 | -- | -- | -- | -- | 3 |
| Total | | 33 | 53 | 45 | 32 | 24 | 16 | 45 | 40 | 61 | 32 | 40 | 21 | 117 | 199 |

Table 7. Profile analysis (Morrison 1967) of small mammal numbers and diversity.

| Species | 1980 control[a] | 1980 sludged | 1981 control | 1981 sludged |
|---|---|---|---|---|
| *Peromyscus* spp. | 28.00±2.52 | 36.67±4.63 | 36.33±1.86 | 40.33±1.45 |
| *Citellus tridecemlineatus* | 13.00±6.51 | 19.00±1.20 | 7.33±5.36 | 9.67±1.33 |
| *Microtus pennsylvanicus* | 0.00±0.00 | 1.33±0.77* | 0.00±0.00 | 12.33±4.33***[b] |
| *Zapus hudsonius* | 0.00±0.00 | 1.67±0.66** | 5.00±2.89 | 11.667±1.86 |
| *Tamias striatus* | 0.00±0.00 | 1.33±0.88 | 1.00±.577 | 7.00±1.53**[b] |
| *Sorex cinereus* | 1.00±0.58 | 2.33±0.33* | 3.33±3.33 | 2.67±2.19 |
| *Blarina brevicauda* | 0.00±0.00 | 0.33±0.33 | 0.00±0.00 | 0.00±0.00 |
| *Napaeozapus insignis* | 0.00±0.00 | 0.00±0.00 | 0.00±0.00 | 1.00±1.00 |
| Total species | 9.00±0.00 | 14.00±1.00** | 16.00±3.61 | 27.00±1.00*[b] |
| Total species | 42.00±5.51 | 62.67±4.81 | 53.00±10.02 | 84.67±1.45**[b] |
| Small mammal diversity | 2.062±0.057 | 3.948±0.372** | 3.948±1.407 | 7.71±0.264*[b] |

* significantly different (P <.10) from controls
** significantly different (P <.05) from controls
*** significantly different (P <.01) from controls
a $\bar{x}$ sum of each trapping period from 3 plots of each treatment with standard error
b data transformed by log (x+1) to achieve equal variance

species, total individuals and small mammal diversity were all significantly greater ($P < 0.10$, 0.05 and 0.10, respectively) on sludged plots than controls.

Total small mammal numbers were consistantly higher on treated plots for each sampling period but were significantly different at only 3 times over the study period (Figure 11). Total numbers on both treated and control plots demonstrated similar trends over time.

The number of species captured and small mammal diversity were greater on treated plots for all sampling periods (Figures 12 and 13) but both were significantly greater at only 3 times. Species captured and small mammal diversity displayed similar trends over time for treated and control plots, except during the fall of 1980 when these measurements increased for the treated plots.

## Relationships Between Small Mammals and Vegetative Structure and Production

The correlation between small mammal diversity and foliage height diversity was significant in both years ($P < 0.1$ in 1980, $P < 0.01$ in 1981) (Figure 14). The association was positive ($r=0.75$ in 1980, $r=0.94$ in 1981).

Combined total numbers of small mammals known to be alive at all sampling periods showed a significant positive correlation with total annual production <2 m in 1980 ($P < 0.1$, $r=0.74$) but not in 1981.

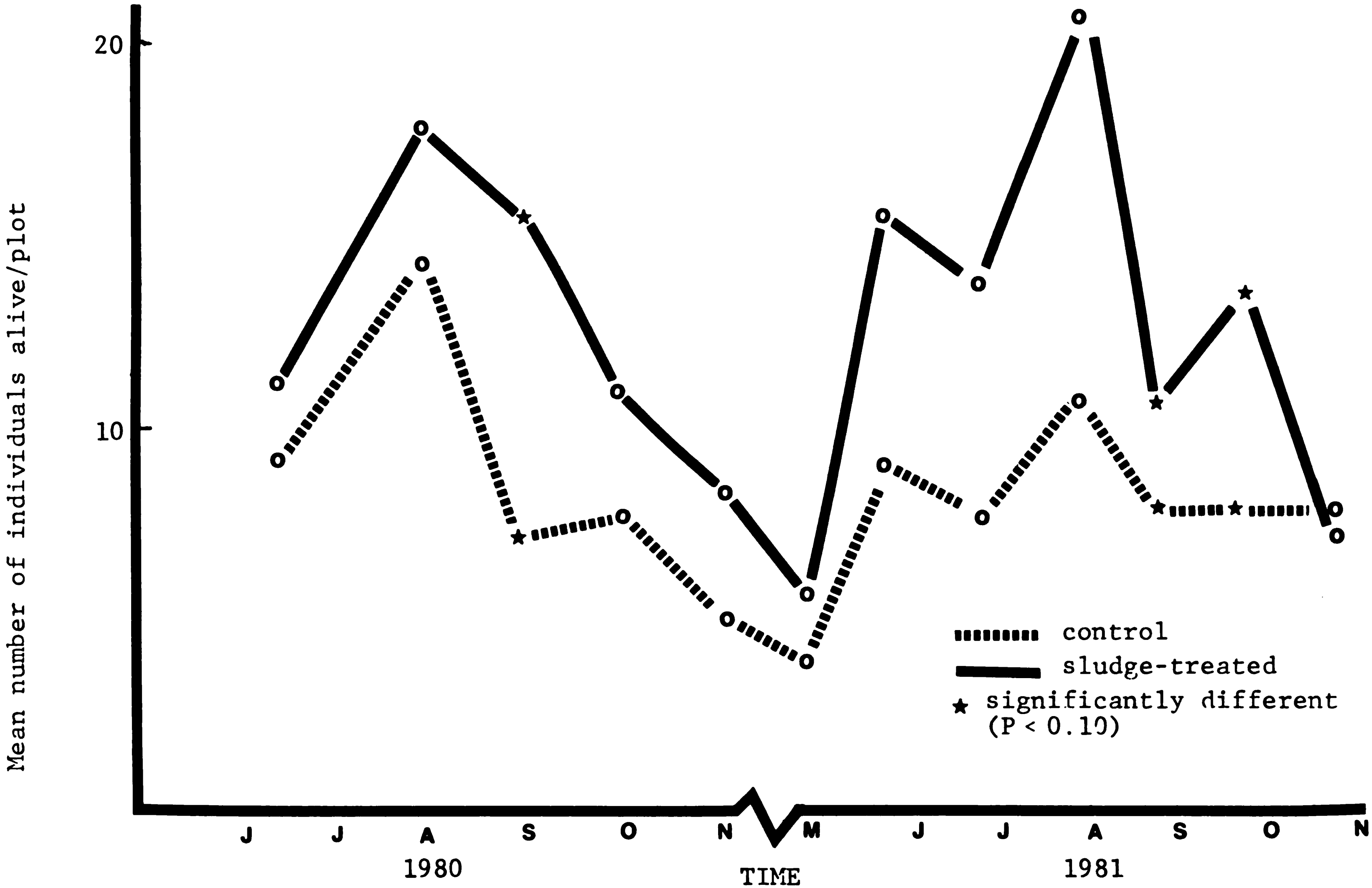


Figure 11. Mean total number of individuals known to be alive on the study plots in 1980 and 1981.

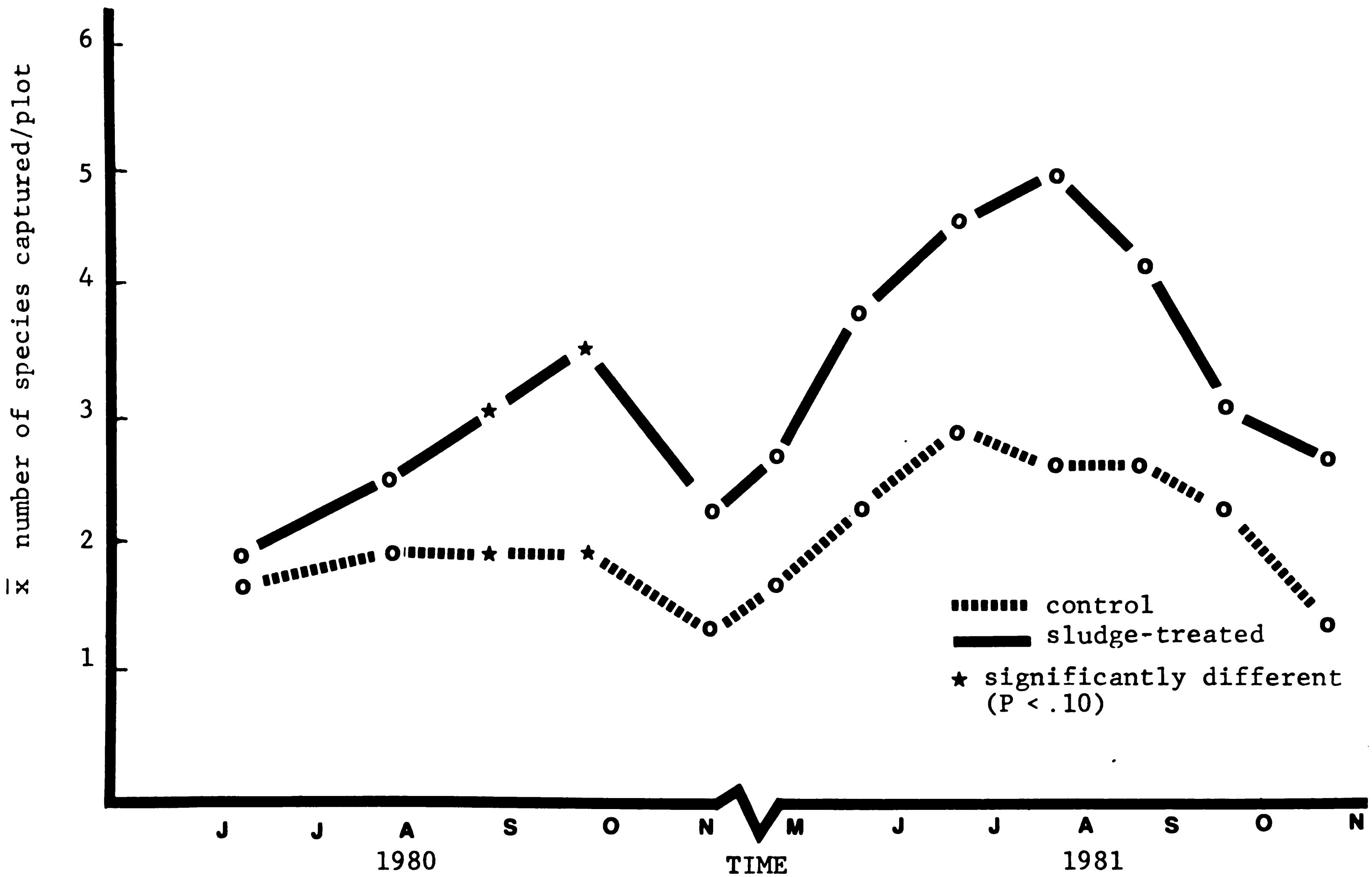


Figure 12. Mean total number of species captured on the study plots in 1980 and 1981.

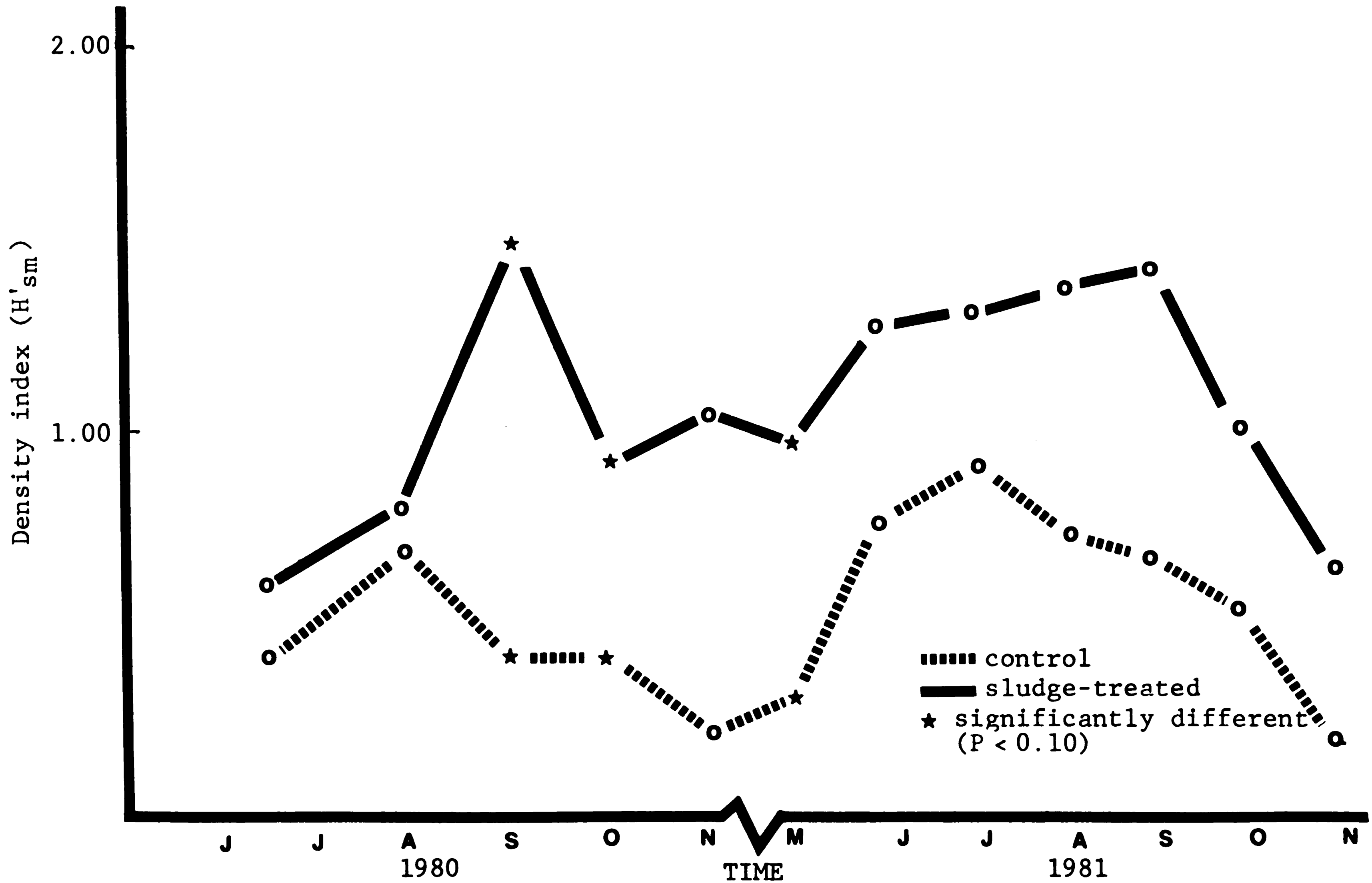


Figure 13. Mean small mammal species diversity for study plots in 1980 and 1981.

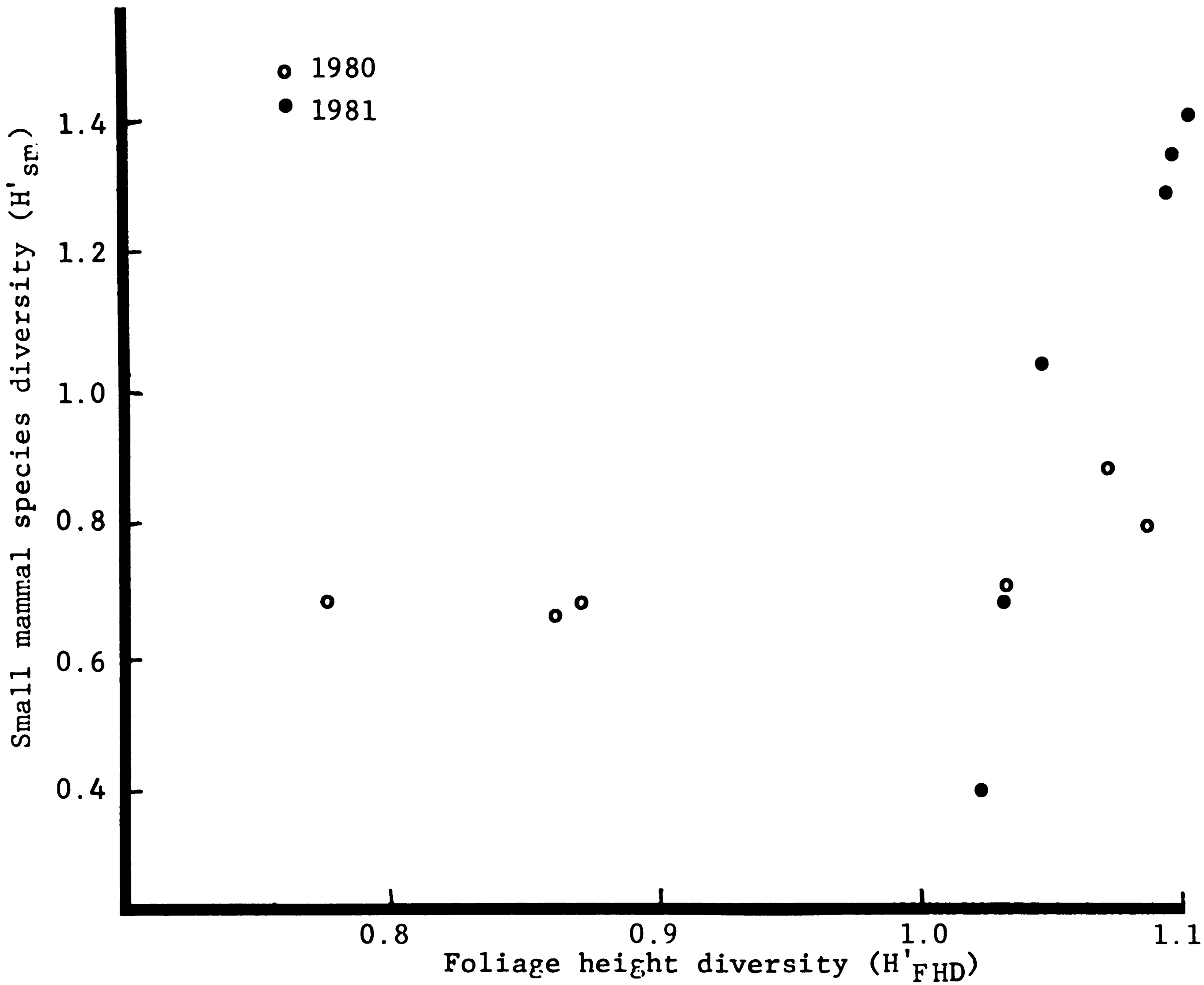


Figure 14. Small mammal diversity plotted against foliage diversity.

Total numbers of small mammals combined over all sampling periods were significantly correlated with the percentage of cover in the 10-30 cm stratum for both years ($P < 0.05$). The association was positive ($r=0.81$ in 1980, $r=0.82$ in 1981). There was no significant association between small mammal numbers and the 0-10 cm or >30 cm stratum in either year.

The linear regression analysis of meadow vole numbers in 1981 with percent grass cover in the 3 height strata showed grass cover in the 10-30 cm stratum explained a significant ($P < 0.01$) amount of the variation in meadow vole numbers. The relationship was positive ($r^2=86.5$). There was no significant relationship between meadow vole numbers and grass cover in the 0-10 cm stratum or the annual production of grasses.

## Browse Removal

The percentage of browsed stems for both cherry and brambles was significantly greater ($P < 0.01$) in both years on treated plots than controls (Figures 15 and 16). The only significant changes ($P < 0.01$) between years was observed in the percentage of bramble stems browsed on control plots. Browsing on brambles in control plots increased 170% in 1981 over 1980.

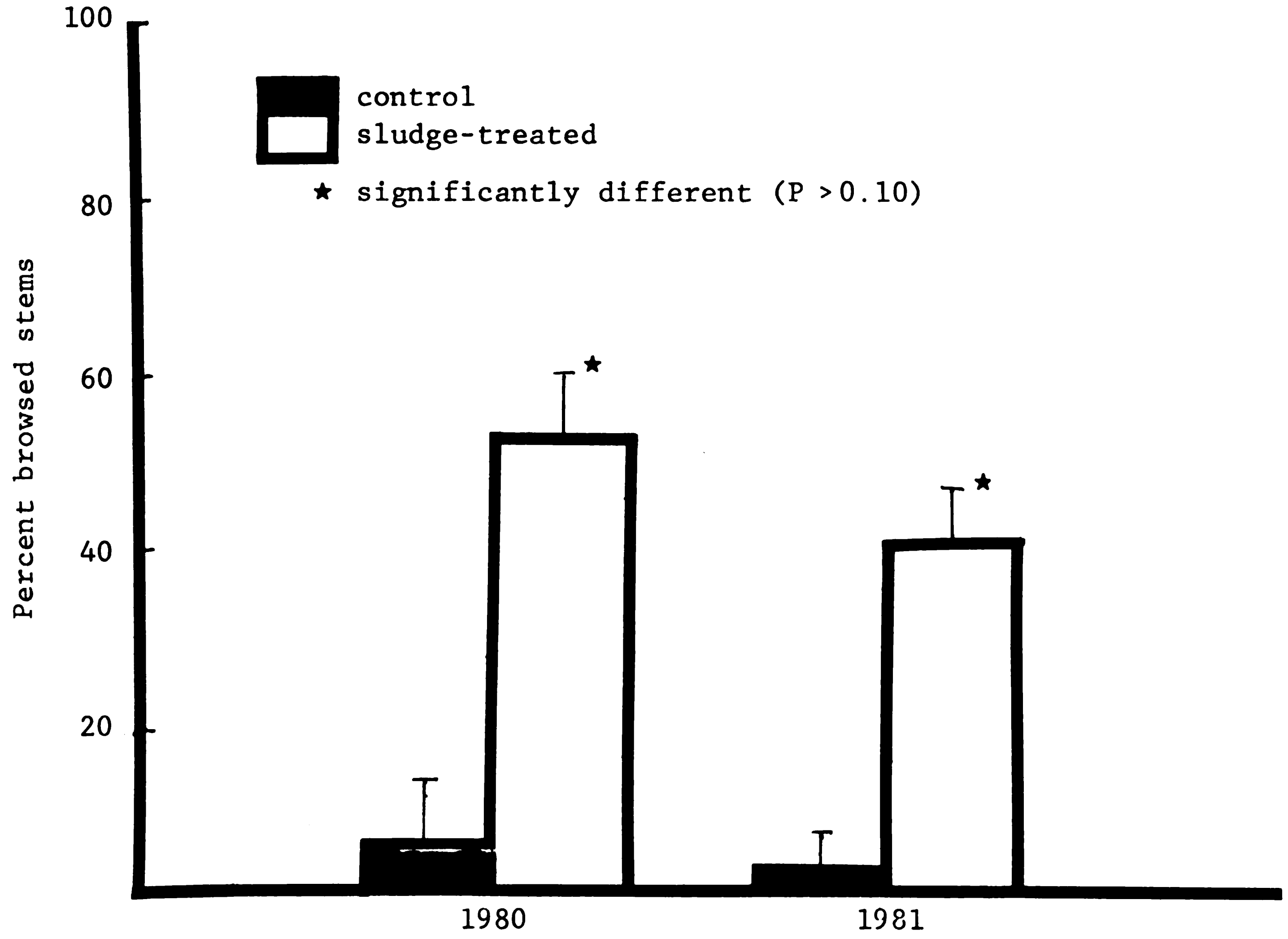


Figure 15. Mean percentage of browsed cherry (<u>Prunus</u> spp.) stems in 1980 and 1981.

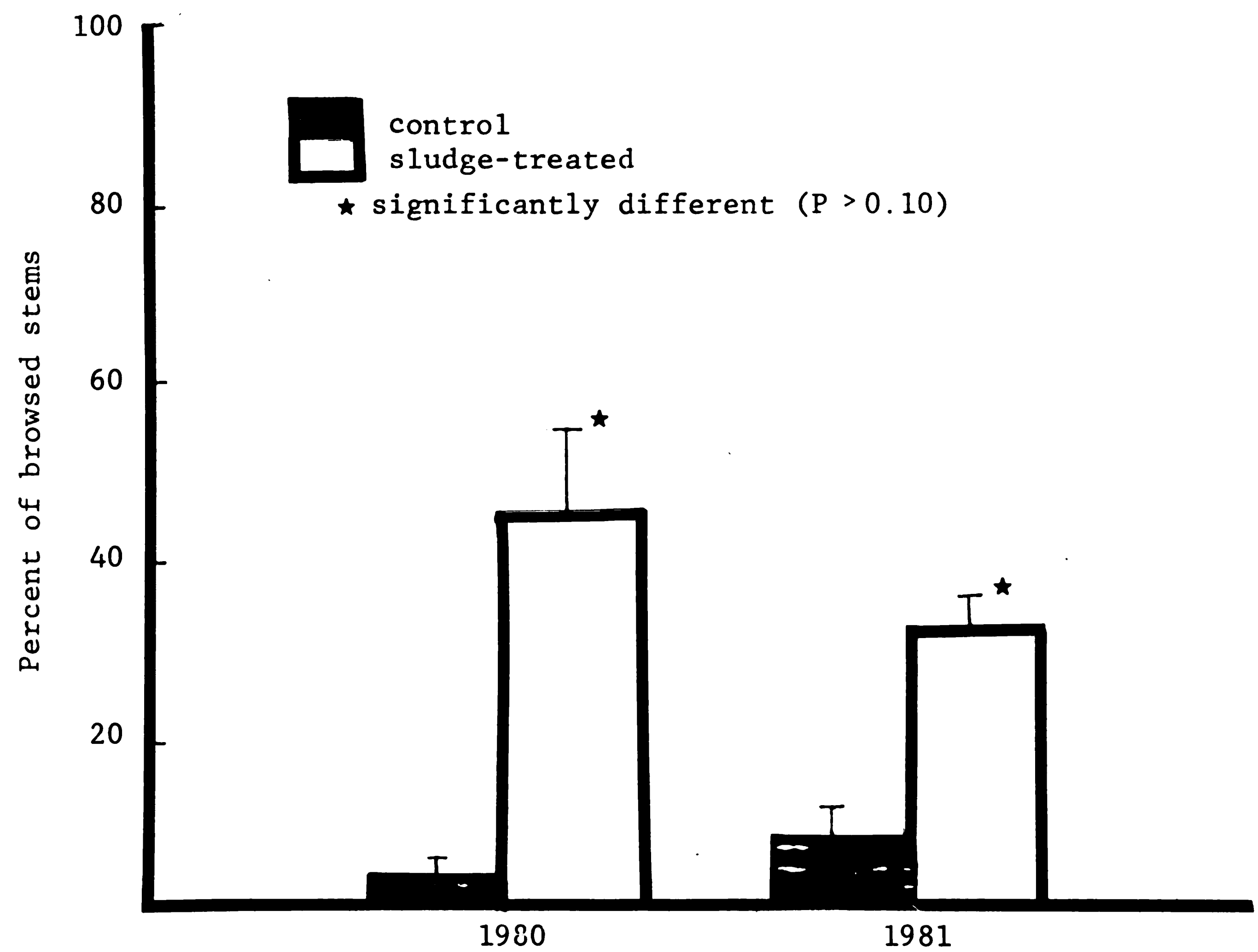


Figure 16. Mean percentage of browsed bramble (<u>Rubus</u> spp.) stems in 1980 and 1981.

# DISCUSSION

The addition of sewage sludge had a pronounced effect upon vegetative structure. Changes in structure were due to reorganization and increased production by plant species present before treatment. Reorganization occurred when vegetative composition was changed through increased dominance by brambles and cherries. Composition was not altered by the establishment of new or the loss of existing plant species. The tomato plants observed on sludge-treated plots were few in number, produced little fruit and probably had little effect on the plant community's structure or production.

The response by brambles and cherries was expected from their role in succession in northern forest ecosystems. Pin cherry, common on disturbed sites, develops rapidly following the creation of openings in a forest. This tree species exhibits high net annual production, high nutrient accumulation, and early canopy closure (Marks and Bormann 1972, Marks 1974, Covington and Aber 1980). These attributes along with the abundant availability of viable seeds in forest soils makes for pin cherry's importance in regaining site stability following a disturbance.

When pin cherry density is low, as it was on this study area, brambles often share dominance and persist until canopy closure (Marks 1974). Previous evaluation of pin cherry and bramble response to commercial fertilization has shown these species to increase dominance and productivity even when in competition with birch and maple regeneration (Safford and Filip 1974).

Reorganization of vegetation occurred primarily through the expansion of brambles into the gaps of no vegetation. Absence of vegetation from the gaps before treatment suggests microclimatic conditions in these areas were not conducive for most plant species. Perhaps these conditions existed because of a lack of nutrients and suitable substrate due to previous windblown loss of top soil. The exclusion of cherry stems from these gaps before treatment and their continued absence afterwards suggest the species' seeds were not present in the soil. Nitrogen application, as low as 56 kg/ha, has been shown to stimulate germination of pin cherry seed (Auchmoody 1979). If the top soil along with any seeds had been lost before the previous jack pine stand was established, this might account for the existance of the gaps. The present availability of sludge-borne nutrients may have allowed brambles to invade the gaps by root propagation.

Changes over the 2 years in the structure of the plant community supported on control plots can be attributed to the normal rate of succession on the site. Increased net primary production and dominance by cherries and brambles on sludge-treated plots indicate the present successional rate on these areas may have been accelerated. The impact such early acceleration could have on future site succession can not be determined without continued investigation.

There were structural changes in the vegetation that were consistent with just an acceleration in succession. Increased cover by cherry in the 0-10 cm and 10-30 cm strata indicates the leaf/area index for this species was enlarged by sludge addition. A disproportionally high percentage of cover in the 0-10 cm stratum on sludged plots suggests jack pine may have had a similar response. Bramble and grass cover expanded into the 10-30 cm, and >30 cm strata, which would not have occurred in normal succession. Thus, as measured by the FHD indices, vertical distribution as well as the abundance of the vegetative resource increased on the sludge-treated plots.

Alteration in the vegetation also occurred through nutritional enhancement from changes in chemical composition. The nutritional value of 3 major plant groupings, cherry, brambles and grasses, was significantly increased (Campa unpubl. data).

In essence, the vegetative resource spectrum available to wildlife exploitation was altered through:

1) the increased horizontal distribution of cover,

2) the increased vertical distribution of cover,

3) increased production,

4) increased nutritional quality.

MacArthur (1972) predicted that species diversity would increase if an overall increase in primary production caused an increased abundance of all resources. Studies observing changes in production over a geographical gradient (Brown 1975, Davidson 1977) support this theory. However, when primary production is manipulated so to also change vegetative structure or other microclimatic variables, a prediction regarding species numbers or diversity could not be made (Abramsky 1978). Results of this present study indicate sludge recycling did alter many habitat variables besides primary production.

Small mammal numbers were low on the study area. The size (2 ha) of the study plots and their low-productivity, inherent from nutrient-poor soils, combined to limit the size of the population observed in this study.

In the initial trapping periods, small mammal community structure was similar between control and treated plots. Peromyscus mice and 13-lined ground squirrels were the dominant species. However, during the first year following sludge application, 3 additional species (meadow jumping mice, eastern chipmunks, and the meadow vole), were captured on some of the treated plots. The meadow jumping mouse was the only invading species caught at least once on each treatment during 1980. The meadow vole and eastern chipmunk were not captured on the same treatment plot (Plot 4). In the second year all 3 species were caught repeatedly on all sludge-treated plots. Also in 1981, jumping mice and eastern chipmunks were captured on 1 control plot (Plot 3).

Plot 3 was consistantly much more productive than the other 2 control plots. Observations on vegetation structure show this plot had a much greater percentage of understory cover especially by brambles. An intensive analysis for soil nutrients on control plots completed in fall 1980 indicated Plot 3 contained a more nutrient-rich soil. The greater availability of nutrients may explain the greater understory production and small mammal numbers found on the plot. The nonconformity of this 1 control plot may have moderated the true response of small mammals to the addition of sludge. Without base-line information any pretreatment variability cannot be evaluated.

Differences in total numbers captured per plot between control and sludge-treated plots were due to invading species which primarily utilized treated plots and not an increase in numbers within those species common to all plots (Peromyscus mice and 13-lined ground squirrels).

The small mammal community appeared to respond to the changes in vertical structure. Small mammal diversity indices were highly correlated with the vertical distribution of vegetative cover. Other studies have observed a similar correlation between small mammal diversity and vegetative structure (Rosenzweig and Winakur 1969, Dueser and Brown 1980). Sleeper (1980) explains how 3-dimensional structure may be correlated with the total number of species in micro-sympathy but may not be the major factor in individual species distribution. Several studies have found variables related to vertical vegetative structure to influence small mammal diversity (Holbrook 1972, Dueser and Shugart 1978, Price 1978, M'Closky 1979). Since variables other than vegetative structure and net above ground production were not examined, causal relationships with 1 exception could not be identified.

Distribution of the meadow vole has been found to be highly dependent on available grasses (Mossman 1955, Getz 1961). As an herbivore which utilizes open dense grasslands this species literally eats its available cover. It is not unexpected then, that the species responded to the increased height of the grasses supported on the sludged plots.

With the exception of the 13-lined ground squirrel, the small mammal community supported on the control and sludge treated plots were similar to those reported for other clearcuts (Trevis 1956, Labue and Durnell 1959, Krefting and Ahlgren 1974, Kirkland 1977, Sullivan 1979). Thirteen-lined ground squirrels have not been reported in any community studied on a forest clearcut. However, De Vos (1964) has reported this species was spreading its distribution by taking advantage of the opening up of forests after one time being restricted to the prairies.

Peromyscus mice and red back voles (Clethrionomys gapperi) consistantly invade sites almost immediately following perturbation. Numbers fluctuate from year to year but both species appear to exploit early successional stages for several years (Krefting and Ahlgren 1974, Kirkland 1977). Red back voles were absent from this study site because the southern border of their range does not include the area (Burt 1972). Meadow voles, meadow jumping mice, eastern chipmunks and masked shrews have also been reported to colonize sites immediately after disturbance (Ahlgren 1966). However their numbers remain consistantly low and erratic over many years after perturbation.

The loss of 13-lined ground squirrels from the entire study area suggests it was not a response to the sludge. If a change in some critical habitat variable did occur, it was not restricted just to the treated plots. Since 13-lined ground squirrels select for prairie-like conditions, perhaps the increased canopy closure over the entire area reduced the habitat quality for this species. If so the relationship was complex since no correlation could be found between the percentage of open canopy or bareground and the ground squirrel numbers for 1980. Thirteen-lined ground squirrels are also omnivorous and somewhat a generalist in their food habits (Criddle 1939, Whitaker 1972, Flake 1973). General observations of an almost complete collapse in 1981 of the local production of cherry fruit and grass-hoppers suggest an inadequate food source may have been a factor in their elimination from the area.

Successional trends or orderly replacement of small mammal species can not be detected from the literature. Those microclimatic variables which these species select for do not appear to occur consistantly with disturbance or with the subsequent advancement of succession. An example would be the selection by meadow voles for an adequate grass resource, which may or may not be present depending upon a multitude of variables including the previous stand structure and the grass resource available for re-vegetation.

The use of sludge-treated plots by a greater number of species supports MacArthur's (1972) hypothesis that an increase in scarce (or even new) resources can result in an increase in species number and diversity. Changes in vegetation structure did not alter MacArthur's prediction as Abramsky (1978) sometimes observed.

Brambles and cherries have been reported in the food habits of white-tailed deer in Michigan (Stormer and Bauer 1980) as well as New Hampshire (Philleo _et al_. 1978), New York (Webb 1959) and Ohio (Nixon et al. 1970). Evidence of these plant species in snowshoe hare diets have not been reported. In the deer food habit studies, brambles and cherry were never abundant in the study areas not did they make up a significant portion of the foods consumed. The intense browsing on cherry and brambles on the sludge-treated areas may have been a response to the increased production and nutritional quality of the browse on these sites. Other studies have shown different wildlife species to select individual plants of higher nutritional value including plants treated with fertilizers (Gibbens and Piepper 1962, Anderson et al. 1974, Dressler and Wood 1976, Barret 1979).

## SUMMARY AND RECOMMENDATIONS

Sludge addition may have accelerated the successional rate on the site as well as changed the vegetation in such a manner as to increase the numbers and diversity of small mammals using the site. In addition, browse removal by white-tailed deer and snowshoe hare increased significantly on sludge-treated areas in a response to increased browse production and greater browse nutritional value.

The results suggest municipal sewage sludge may be applied to nutrient-poor forest soils in an early successional stage to speed up succession while increasing the vegetative resource for wildlife use. The ability to increase forage production as well as enhance forage nutritional quality has positive implications for managing such species as small mammals and white-tailed deer, where specifically supplying energy demands is an important aspect of their management. Furthermore, in areas where acceleration of the successional rate is desirable, sludge may be a valuable instrument for wildlife managers. However, when a clearing is created for wildlife and sludge is applied to enhance forage production, acceleration of the successional rate may be counter-productive. In such a case, the value of enhanced vegetative production must be weighted against the shortened interval of the desirable successional stage.

This study identified the influence sludge amendment to forest soils may have on vegetative structure, production, and forage quality, and the corresponding response of wildlife. Wildlife may also be influenced by the introduction of sludge-borne potentially toxic metals into the wildlife food chain. Considering the attractiveness of sludge disposal sites to wildlife, a toxicity problem may exist. Further research is needed concentrating on the problems concerning the potential for bioaccumulation of such metals in the wildlife food chain. Such information is necessary before sludge addition to forest lands can truly be evaluated. Future research should also investigate sludge application to other vegetation types in order to identify the most appropriate sites for disposal with maximum wildlife benefits.

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# APPENDIX

Table 8. Species list of vascular plants on study area.

| Common name | Scientific name | Family |
|---|---|---|
| Jack pine | Pinus Banksiana, Lamb | Pinaceae |
| Bigtooth aspen | Populus grandidentata, Michx. | Salicaceae |
| Quaking aspen | Populus tremuloides, Michx. | Salicaceae |
| Red cedar | Juniperus virginiana, L. | Cupressaceae |
| White spruce | Picea glauca, (Moench) Voss. | Pinaceae |
| Black cherry | Prunus serotina, Ehrh. | Rosaceae |
| Choke cherry | Prunus virginiana, L. | Rosaceae |
| Pin cherry | Prunus pennsylvanica, L. | Rosaceae |
| Cinquefioil | Potentilla recta, L. | Rosaceae |
| Common blackberry | Rubus allegheniensis, Porter. | Rosaceae |
| American red raspberry | Rubus strigosus, Michx. | Rosaceae |
| Red maple | Acer rubrum, L. | Aceraceae |
| Mapleleaf viburnum | Viburnum acerfolium, L. | Caprifoliaceae |
| Panic grass | Panicum virgatum, L. | Gramineae |
| Sedge | Carex spp., L. | Cyperaceae |
| Red sorrel | Rumex acetosella, L. | Polygonaceae |
| Smartweed | Polygonum spp., L. | Polygonaceae |
| Goldenrod | Centaurea maculosa, Lam. | Compositae |
| Spotted knapweed | Cirsium vulgare, (Savi) Tenore. | Compositae |
| Pussytoes | Antennaria neglecta, Greene. | Compositae |
| Orange hawkweed | Hieracium aurantiacum, L. | Compositae |
| Aster | Aster spp., L. | Compositae |
| Pokeweed | Phytolacca americana, L. | Phytolaccaceae |
| Tomato | Lycopersicon esculentum, Mill. | Solanaceae |
| Common mullein | Verbascum Thapsus, L. | Scrophulariaceae |
| Common plantain | Plantago major, L. | Plantaginaceae |
| St. John's-wort | Hypericum performatum, L. | Hypericaceae |