COO-2758-2

MASTER

STRIP MINE RECLAMATION: AN ISLAND BIOGEOGRAPHICAL AND ECOSYSTEM ENERGETIC APPROACH

Progress Report

for Period June 1, 1976 - May 31, 1977

James E. Carrel, Clair L. Kucera,

Arthur P. Harrison, Jr., and Robert W. Blanchar

University of Missouri-Columbia

Columbia, Missouri 65201

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Energy Research and Development Administration, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

February, 1977

Prepared For

THE U.S. ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION

UNDER CONTRACT No. EY-76-S-02-2758.000

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Energy Research and Development Administration, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product or process disclosed or represents that its use would not infringe privately owned rights.

III. ABSTRACT

During the second contract period additional study sites were established in west central Missouri, the major mining area of the state. Since some site surveying and soil sampling had already been performed in this second region, only up-to-date site information remains to be obtained in Spring 1977. Biotic inventories in central Missouri were largely completed in the first half of the period and detailed analyses of specimens and data derived from them are underway. Floristic studies in western Missouri were also initiated. Acidification of fresh mine spoil occurred in 8 mo under controlled laboratory conditions. The role of bacteria and abiotic factors in spoil aging continues to be studied. Vegetative cover measurements made from aerial photographs of central Missouri mines between 1938 and 1976 indicate revegetation in hilly, acidic mines tends to follow a logistic pattern ($r = .97$) and hence, it can be relatively fast (90% cover in 32 to 100 yr), contrary to previous predictions. Fine-grained analysis of island communities showed mutual exclusion of woody and herbaceous species, which suggests plants themselves might slow the successional process. Litter samples placed on the ground within and outside herbaceous vegetation had rapid loss of weight and radioactive carbon ($t_{\frac{1}{2}} \approx 1$ yr) during the latter part of 1976. Artificial habitat islands consisting of sections of prairie hay bales were established in two mines. Preliminary evidence from one set of hay islands suggests that several prairie species became established in about 25% of the units after 1 yr.

TABLE OF CONTENTS

	Page
I. COVER SHEET	i
II. LEGAL NOTICE	ii
III. ABSTRACT	iii
IV. SCOPE OF INVESTIGATIONS	1
V. SIGNIFICANT RESULTS	11
VI. EFFORT OF SCIENTIFIC PERSONNEL	28

IV. SCOPE OF INVESTIGATIONS

I. Ecological Inventory

Collection of information pertaining to natural restoration of coal strip mines by volunteer organisms was initiated in June, 1975.

a) Site Selection and Procurement

Study sites are located in three regions of Missouri (Figure 1). A brief description of these areas and specific sites within them are presented below.

Region I: Central Missouri

This area consists of two sets of surface mines. Those in the southern part are mostly old, pre-1970 mines, whereas those in the northern part are mostly small, active mines.

Eleven permanent study sites are located in privately owned, orphaned surface mines along the Boone-Callaway Co. border. They were chosen for initial and pilot studies because they could be conveniently visited on a day-to-day basis.

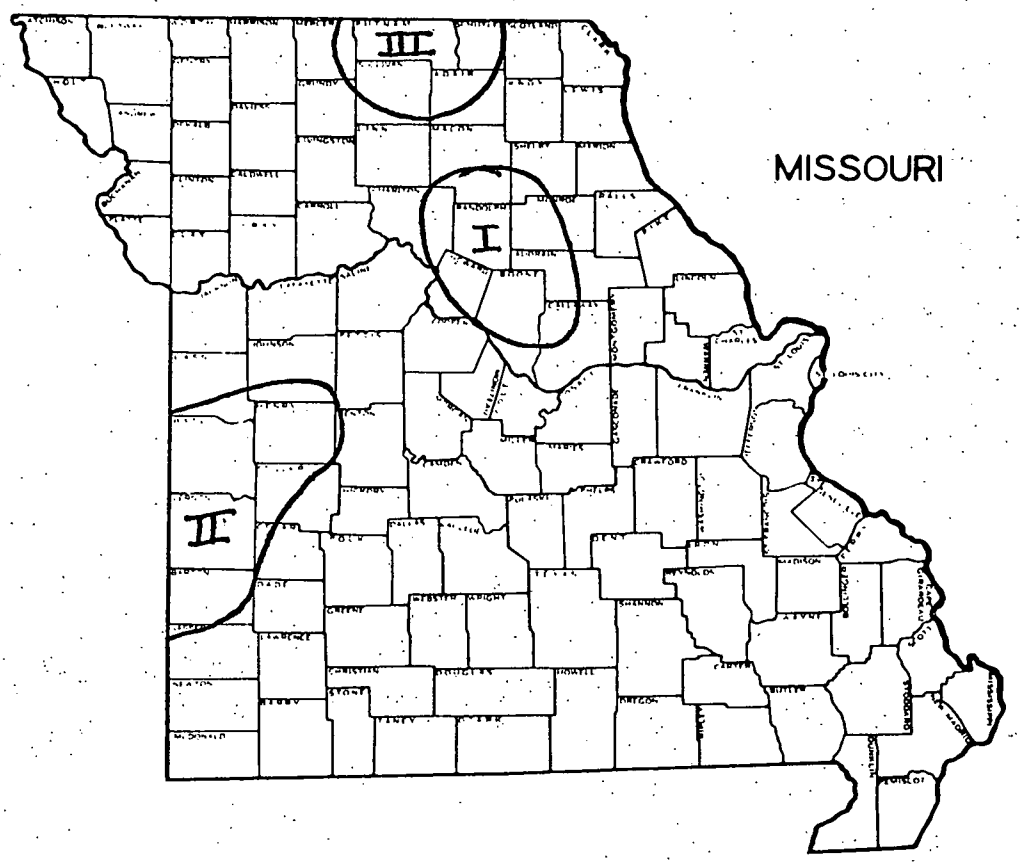
No permanent study sites have been established in active mines of Region I for several reasons. Most of them are too small (less than 5 ha.) for operators to put aside an area for natural revegetation. Furthermore, most of them are located in upland forests, which contradicts our emphasis on grassland re-establishment.

Region II: Western Missouri

West Central Missouri is the state's leading coal producing district. It has experienced large scale mining on almost a continuous basis since

COO-2758-2
Carrel et al-1a
Feb 1977

Figure 1



the 1920's. Most of the region is well suited for our research because it naturally consists of typical tall grass prairies.

Ten permanent study sites are located in Vernon and Henry Counties. They range in age from the 1920's up through 1960. None of these areas have been fertilized or reseeded.

Currently we are forming additional study sites in places identified earlier by Project REUSE. Established in 1972 by the Ozarks Regional Commission, Project REUSE documented the acreage and ownership of all 40,369 acres of land mined before 1972 in Region II and it set up 25 demonstration projects. Each demonstration area consists of a discrete mine which is divided into two sections. One section having an area of approximately twenty acres was subjected to systematic soil analyses and recommendations for fertilizing and reseeding to pastures were made. The other section, consisting of the remaining acerage in the mine, was to be left untouched as a control for the seeded section. Because Project REUSE failed to recieve additional funding in 1974, no one knows whether the private owners followed the recommendations for revegetation of the demonstration areas. We now are working with County Extension Agents to find out what, if anything, has been done to rehabilitate these defunct demonstration areas. We view this as an unique opportunity for our research because all the necessary site surveying and soil testing is already done and various treatments on a realistic scale may have been done in a systematic fashion after 1974.

Our studies on freshly mined and graded spoils in Western Missouri are slated to begin in March and April. Last year an agreement was reached with Peabody Coal Company and the Missouri Land Reclamation

Commission that would release the mine operator from immediate revegetation of several sizeable acreages, as is stipulated by State law. Instead, these areas will be set aside to permit our studies of natural recolonization or variations of it. Final legal arrangements between Peabody Coal Company and the University of Missouri need to be formalized in early March, sites selected in late March or April, and subsequently routine observations will commence by late April or early May.

Region III: Northern Missouri

Northern Missouri is experiencing an increase in coal mining focused in Putnam County. The native vegetation for this area, unlike that in Region I, is dominated by central tallgrass prairies and upland forests are restricted mainly to river valleys.

Currently we are exploring the possibility of establishing study sites next year in this area. However, since most of our time and resources in the ensuing year will be directed toward research in Region II, we are not prepared to make a firm commitment to work in Region III until 1978.

b) Description of Soils

Soils in mines in Region I and II have been tested for organic matter, total nitrogen, pH, ion conductivity, and mineral content. The microbiological assay for available nitrogen has been perfected and Dr. Harrison plans to publish his results in the near future.

Nitrogen fixation studies have been suspended because the levels of activity in soil extracts and legume root extracts are below levels of detection using the Burris acetylene reduction technique.

Routine monitoring of rainfall and air and soil temperatures has been performed in a continuous fashion.

c) Description of the Biota

Microbial, plant, and arthropod species as propagules in strip mines have been ascertained by periodic sampling since June, 1975. A summary of methods and results is given by taxon.

1) Microbes

The fire fly luminescence (FFL) assay for ATP in living cells and hence for numbers of living cells in soils and water has proved to be of limited value when applied to strip mines. Data obtained from acidic spoils or very dry spoil material in the summer were negative, which is what we anticipated from previous plating experiments. Thus, we do not find the graded level of ATP activity/g soil in surface mines that one finds in agricultural or prairie soils of varying quality. Therefore, we have reverted to more conventional enrichment assays to measure gross microbial activity or abundance in mine spoils.

Bacterial and fungal assays have been made over the past years on soils and lagoon water from coal-mine spoil in Callaway County, Mo. Since it has been standing for thirty-five years, it represents therefore a suitable reference for microbial flora in an old spoil. Three soil sites have been routinely examined on various plating media at 30 degrees and 40 degrees Centigrade under aerobic incubation. These soils are (1) a "greasy" area with a pH in the range of 2, (2) a barren area of pH in the range of 3, and (3) an area of "Poverty grass", genus Aristida, growth, where the pH is in the range of 4. Representative bacterial

and mold isolates have been stored for future classification, but one prevelant mold has been identified as Aspergillus fumigatus. It grows from ambient to around 45 degrees Centigrade and is noteworthy as having been, on occasion, a human pathogen.

This work has been hampered by the abrupt changes in weather that cause a shift in location of the "greasy" area of low pH, and of course does not permit an analysis of microbial changes from the fresh condition. Accordingly, an artifical "spoil" has been set up in an environment room with a constant temperature of 30 degrees Centigrade under a 12 hour period of light followed successively by a 12 hour period of darkness.

A fresh sub-soil-shale-coal "mix" has been prepared from newly excavated components obtained at a coal excavation site near Harrisburg, Mo., presently mined by the Columbia Coal Company. One-hundred pounds of mix were prepared, and moisted with diluted lagoon water from the old Callaway spoil. The mix comprised 1 part powdered coal, 2 parts pulverized shale (the stratum immediately above the coal seam), and 4 parts of the overlying sub-soil. These components were passed through a sieve to remove coarse material, moisted with the lagoon water as inoculum and formed in a conical mound in a plastic tray 32 inches in diameter. The mound, called A, was 12 inches high and was kept moist by daily additions of distilled water to the tray at a 3 to 4 inch depth. The mound acted as a "wick"; the evaporation rate from the mound and water "lagoon" in which it lay was approximately 1.5 liters per day. A second 100 pound mound, called B, was prepared from the same "mix" on the dame day with the same old spoil inoculation, but containing an addition of 5 pounds of calcium carbonate, and served for comparison.

2) Terrestrial Plants

The floristics of strip mined areas in Regions I and II are being studied on a regular basis. As described in the previous progress report, three types of information are being collected.

a) The first is a regional flora of three habitats: the surface mines, a relatively undisturbed native habitat, and a disturbed, old field successional habitat. This is being done in order to compare succession in surface mines to two well studied habitat types. Hence, much of the information for outside the mines is obtained from literature citations. We plan to complete this type of comparison in Region I by April and we have commenced upon a similar analysis in Region II.

b) The second study concerns the gross spatial floristics in entire mines. As described in detail last year, we use low scale aerial photographs and a novel application of a leaf area meter to ascertain total vegetative cover in mines. We are also examining the affect of slope,aspect, and degree of isolation upon the relative distribution of plants in a mine. To check the accuracy of this method, a series of ten or more 30 by 30 m quadrats are chosen at random in the mines and ground-truth data are obtained.

Using a television camera interfaced with a computer, we plan to categorize individual habitat islands according to size, frequency, and spatial distribuion. This analysis will permit us to decribe past changes in vegetation in orphaned mines and to project future ones with some confidence.

We intend to finish the manual phases of this analysis in Region I

by June 1977 and in Region II by August 1977. Data for computer analysis is complete for Region I and in preparation for Region II. We hope to perform a pilot run in March with cooperation of people in Electrical Engineering and a rigorous analysis if all works well by April or May.

c) The third study deals with minute spatial floristics within mines. Using the randomly selected 30 by 30 m quadrats, which were previously mentioned, a detailed distribution of individual plants is recorded in June and August. Thus, the first and second sorts of floristic information are integrated and species associations and exclusions are determined. In Region I much of this analysis is complete for 1976. We intend to continue it in Region I during 1977 and to initiate it in Region II during May, 1977.

3) Terrestrial Arthropods

During June - August 1976 we continued to collect cursorial and arborial arthropods in Region I strip mines. The methods employed are described in the original proposal and the previous progress report.

Because most of our effort and interest is focused on plants and microbes, we have not been able to sample and process arthropods on a routine basis. Currently this situation is being improved and in March we intend to resume routine sampling of cursorial arthropods in mines of Region I. Most of this information will be applied to habitat island studies described in the ensuing section.

d) Measurement of Plant Nutrient and Energy Flux

The study of plant litter decomposition and organic matter turnover

was initiated in March, 1976. Kentucky 51 variety of fescue was grown, labeled with $^{14}CO_2$, dried, and aliquots were enclosed in envelopes made from aluminum screening. After an inordinate six month delay in processing our application, in the summer of 1976 we received permission to place our samples in local surface mines.

Two substrates were selected for deposition of screened packets with litter: dense, herbaceous habitat islands and adjacent barren, nonvegetated areas, both of which had similar slope, aspect, and mildly acidic (pH 5.5) spoil. A total of 288 identical samples were placed in triplicate in each of four mines for quarterly sampling (2 vegetation conditions X 3 replicates X 12 sample periods). Since we anticipated an unusually rapid loss of plant material, the first samples were retrieved 1½ months after deposition.

Four parameters are being determined for each sample:

1. Dry weight
2. Carbon-14 radioactivity
3. Total nitrogen
4. Total carbon

To date we have developed preliminary curves for dry weight and ^{14}C activity. We have experienced persistent problems with the analysis of ^{14}C by burning samples because the analytical service in the Agronomy Department was unreliable and many subsamples were irretrievably lost. Now we are using a nondestructive, planchet counting method to determine ^{14}C activity levels. Total nitrogen and carbon assays remain to be conducted.

II. Habitat Island Formation and Manipulation

Several studies dealing with habitat island formation and manipulation were initiated during the current contract year. They are briefly described below.

a) Organic Food and Cover Islands

Baled prairie hay was placed in surface mines on an expanded scale compared to the first year's work. Nonsterilized and methyl bromide-sterilized sections of square bales were arranged alternately in 12 transects that spanned three east-west mine ridges at 50 m. intervals. Each bale section was anchored with a wooden stake driven through its center into the ground. This work was completed in July 1976. We intend to expand upon it in March 1977 if suitable prairie hay is available.

The results of a pilot study using whole bales of prairie hay at another site are reported in the results section.

b) Ground Cover Islands

Our attempts to measure colonization of barren areas by plants and arthropods met with limited success. The major problem was the refinement of methods to trap seeds. The considerable effort expended in construction of seed boards with adhesive surfaces was wasted. Heavy rains and intense winds introduced soil particles onto sticky trap surfaces, thereby fouling them. We modified this technique by elevating replacable culture dishes on pedestals 6 inches above the soil surface. This technique will permit frequent analysis of aerial dispersal by seeds and insects.

Arthropod colonization of cryptoboards was not continued during the beginning contract year because species identifications of many

groups were very incomplete. However, during January and February 1977 sufficient progress has been made that we are prepared in March 1977 to resume systematic collections of cursorial arthropods on a regular basis.

V. SIGNIFICANT RESULTS

Most of our data pertain to microbial and botanical aspects of natural recolonization of abandoned surface mines.

I. Ecological Inventory

a) Microbiological Bioassay for Available Nitrogen

Our assay for available nitrogen exploits a differential growth response of *Klebsiella pneumoniae* in proportion to the amount of usable inorganic and organic nitrogen. Details of the test and preliminary results were presented in the previous progress report. During the current contract period we have perfected the technique. A description of the method and results obtained using it are in preparation for submission in Spring, 1977.

b) Mineralization, Microbial Colonization, and Acid Production in Mine Spoil Under Controlled Conditions.

Preliminary results of studies with the two mounds of fresh mine spoil are quite striking. The initial microbial counts were 2×10^4 bacteria per gram (determined on trypticase-soy-glucose agar) and less than 10^3 molds per gram determined on the same plating medium. Platings for sulfur-oxidizing bacteria were made on special plating media periodically. Within one week the microbial count had risen to its final value, remaining relatively unchanged to date: 1 to 2×10^6 per gram (on the trypticase-soy-glucose agar). Numerous representative bacterial and mold isolations have been made, and are being held for future identification.

Several arbitrary decisions had to be made, since every parameter could not be examined on this first try with an artifical "spoil". First (a fortunate decision) it was decided not to provide an artifical rain, but to allow the mounds to stand simply in contact with the water in the tray. Second (a less fortunate decision) was to sample at a constant height on the mound, mid-way between the "shore", that is the water level at the base of the mound, and the summit. The reason these choices have been designated fortunate and unfortunate, respectively, will become apparent below.

In addition to microbial assays, the pH of the soil and water was determined periodically. Also, microscopic examination of the water "lagoon" for infusiora was carried out, and of course, a search for any gross changes in the soil and water were undertaken. Initially the pH of the water and soil in both mounds was erratic, varying between 7.6 and 7.9.

After two months the soil pH of mound A, the mound lacking added calcium carbonate, had dropped to the range of 6.5, and thiosulfate-oxidizing bacteria were routinely isolated from plates at pH 7.

A striking change occured in mound A by the third month. A white, frosty crust appeared on the soil surface just above the sampling site, that is on the top half of the mound. It continuously increased in mass and samples were periodically collected. Reconnaissance analyses were made on this frosting. X-ray powder diffraction revealed the principle salts were magnesium sulfate heptahydrate (Epsom salt) and magnesium, with some sodium and calcium, with traces of nickle, cobalt, manganese, strontium, and copper. The dominant anion, of course, being sulfate. Periodically,

thereafter, samples of this growing crust were collected and dried for future quantitative analysis. By the fourth month infusiora were observed microscopically in the artifical lagoon of mound A. Protozoa, Ciliates, and algae appeared. Algae identified were of the order Chlorococcales, and blue-green algae of the genus Oscillatoria. Protozoa appeared in the lagoon of mound B, the mound containing the added calcium carbonate, at about the same time as in A, but the algae appeared later. (Some algae are inhibited by presence of calcium carbonate, for reasons unknown.) By the fifth month moss appeared near the water-level on mound B, and shortly thereafter also on mound A. Identification of the moss awaits formation of its sexual stage.

At the end of the fourth month a change occurred in the crust of mound A. Near the summit of the mound, rusty-red-brown discoloration, presumably due to iron, appeared and this component of the frosting has increased with time. To date (January, 1977, the eighth month), no such discoloration has appeared in the frosting of mound B which has retained its original pH in the range of 6 - 7. One may tentatively surmise that this difference is because the pH within mound B has remained high (low acidity). The rusty frosting on A has been collected for future assay. There is no information as to its composition at the present time. The pH of the soil at the sampling site and the pH of the water of the lagoon remained around 6 to 6.5. Suddenly at the seventh to eigth month, the pH at the sampling site on mound A dropped to 4.5. This lead to speculations as to why the rusty coloration appeared only near the summit, and whether the pH might be different at different heights. Soil pH in the rusty frosting area was found to be as low as 2.5! Yet the bacterial

count there was not appreciably lower than elsewhere. Also in the middle of the eighth month collembolans appeared in the lagoon of mound A, but were relatively rare on the lagoon of mound B.

With hindsite, we make the following comments. First, the choice of not providing artifical rain was fortuitous. Had we done so, the evidence of mineralization frosting would have undoubtedly been missed and the collecting of it for analysis unlikely. However, the choice of sampling sites at the half-way position up the mound was less fortunate because, unsuspecting the sudden new development we were unable to monitor it effectively. Several questions present themselves. One is: did the rusty deposit, presumably iron, arise at the locale where it was observed, or did it arise throughout the mound through mineralization by the bacteria therein, then by means of ion-exchange with soil particles migrate to the site where it was found? Did the elaborated sulfuric acid migrate to become concentrated in this area with subsequent mineralization at that locale?

c) Protozoan Abundance in Acid Mine Ponds

As part of our total inventory of microbes in strip mines, from Summer 1975 through Fall 1976 standard samples of water were systematically taken from interconnected acid and neutral mine ponds and, as a control, from a nearby farm pond of comparable size and age. The 38 genera and species identified are contained in Table 1. Although the precise data regarding relative abundance and diversity of different taxa are not currently available, two general trends are clear. First, total numbers of protozoa in acid mine ponds is somewhat lower than in neutral mine ponds, both in terms of species and individual abundance (Table 2).

TABLE 1

Protozoa of Central Missouri Strip Mine Ponds

Subphylum Sarcomastigophora

Superclass Mastigophora

Anisonema sp.

Chilomonas sp.

Chlamydomonas acidophilis

Chlamydomonas sp.

Chlorochromonas sp.

Cryptomonas reflexa

Cryptomonas sp.

Dinobryon sp.

Elvirea sp.

Euglena mutabilis

Euglena sp.

Haematococcus sp.

Pedinomonas sp.

Pleuromonas sp.

Polytoma sp.

Protochrysis sp.

Trichloris sp.

Subphylum Sarcomastigophora

Superclass Sarcodina

Acanthocystis sp.

Actinophrys sol

Actinophrys sp.

Amoeba sp.

Ciliophrys sp.

Metachaos sp.

Vampyrella sp.

Subphylum Ciliophora

Cyclidium sp.

Euplotes sp.

Holosticha sp.

Homalagastra sp.

Ochromonas sp.

Onychodromus sp.

Oxytricha sp.

Pleuronema sp.

Sphaerophyra sp.

Stylonycha sp.

Tachysoma sp.

Uroleptus sp.

Vorticella convollaria

Vorticella microstoma

Second, species diversity, as measured by the Shannon-Weaver Index, is drastically lower in acid mine ponds because a single species, such as *Cryptomonas reflexa* or *Euglena mutabilis*, predominates.

TABLE 2

Relationship between Water Acidity and Protozoan Species Abundance in 30 year Strip Mine Ponds

Site	pH	Protozoa Species ($\bar{x} \pm$ SE.)
Acidic Pond	3.25-3.55	34.6 ± 0.53
Neutral Pond	6.25-7.45	48.6 ± 0.62

d) Comparison of Flora in Region I

A list of herbaceous and woody vegetation extant at three sites shows that 35 year old strip mines in Callaway County have a species composition intermediate between nearby Tucker Prairie, a relatively undisturbed native tall grass prairie, and nearby Reform Prairie, an abandoned pasture at a local nuclear reactor site. This is evident when one examines the number of shared species (Table 3) and the index of species similarity (Table 4). The data suggest the two disturbed habitats are more similar to each other than to an undisturbed prairie. Furthermore, as one might expect in Region I, the flora of the mines is relatively high in woody species and depauperate in herbaceous ones, which suggests the mines are slowly turning into forests.

TABLE 3

Number of Plant Species in Three Habitats in Callaway County, Mo.

Vegetation Type	Locality*			Shared Species		
	Tucker Prairie	Reform Prairie	Strip Mine	TP:RP	SM:TP	SM:RP
Woody	18 (.087)	7 (.113)	21 (.214)	2	5	3
Herbaceous	189 (.913)	55 (.887)	77 (.786)	23	30	26
Total	207	62	98	25	35	29

*Values in parentheses represent the relative proportion of species at a site that belong to either vegetation type.

TABLE 4

Plant Species Similarity in Three Habitats in Callaway County, Mo.

Vegetation Type	Similarity Index (%)*		
	Tucker Prairie: Reform Prairie	Strip Mine: Tucker Prairie	Strip Mine: Reform Prairie
Woody	16	26	21
Herbaceous	19	23	39
Total	19	23	36

*Sørensen Index of Similarity = $\frac{\text{no. common species}}{\text{mean no. species}}$ X 100

e) Revegetation Rates in Region I Strip Mines

Additional data on the amount of vegetative cover in ten orphaned mines of different sizes and ages in Region I were obtained in 1976. Two sources were used. More aerial photos taken at different years were purchased from the U.S.G.S. Also, in May and July we flew our own missions using a motorized Hasselblad camera fitted with a planar lens that was vertically mounted in the belly of a single engine plane. The result was at least seven measurements of cover for each mine, and in most cases ten were available.

Originally we hypothesized that revegetation of barren mines should follow a logistic, or S-shaped curve. Our data support this idea (Figure 2). We reject the preliminary conclusions in last year's progress report.

Logit transformation of the cover values through time from ten old strip mines (Figure 2) yields a good fit ($\bar{r} = 0.97$) and this regression analysis gives a significantly better fit ($p < 0.05$) than most conventional transformations. More importantly, the time needed to achieve an acceptable level of ground cover in hilly, acidic mines seems to be surprisingly short. For ten mines which have areas ranging from 4 to 30 ha., we project that 50% ground cover is reached in about 27 to 62 years and 90% cover is attained in 32 to 100 years. Area has a negative affect, but it seems to be important only in smaller mines (Figure 3).

A more complete discussion of this material is being prepared for publication in April.

f) Habitat Island Characteristics

Because species-area relationships seem to exist generally in all habitats, we hypothesized that in strip mines the number of plant species

Figure 2

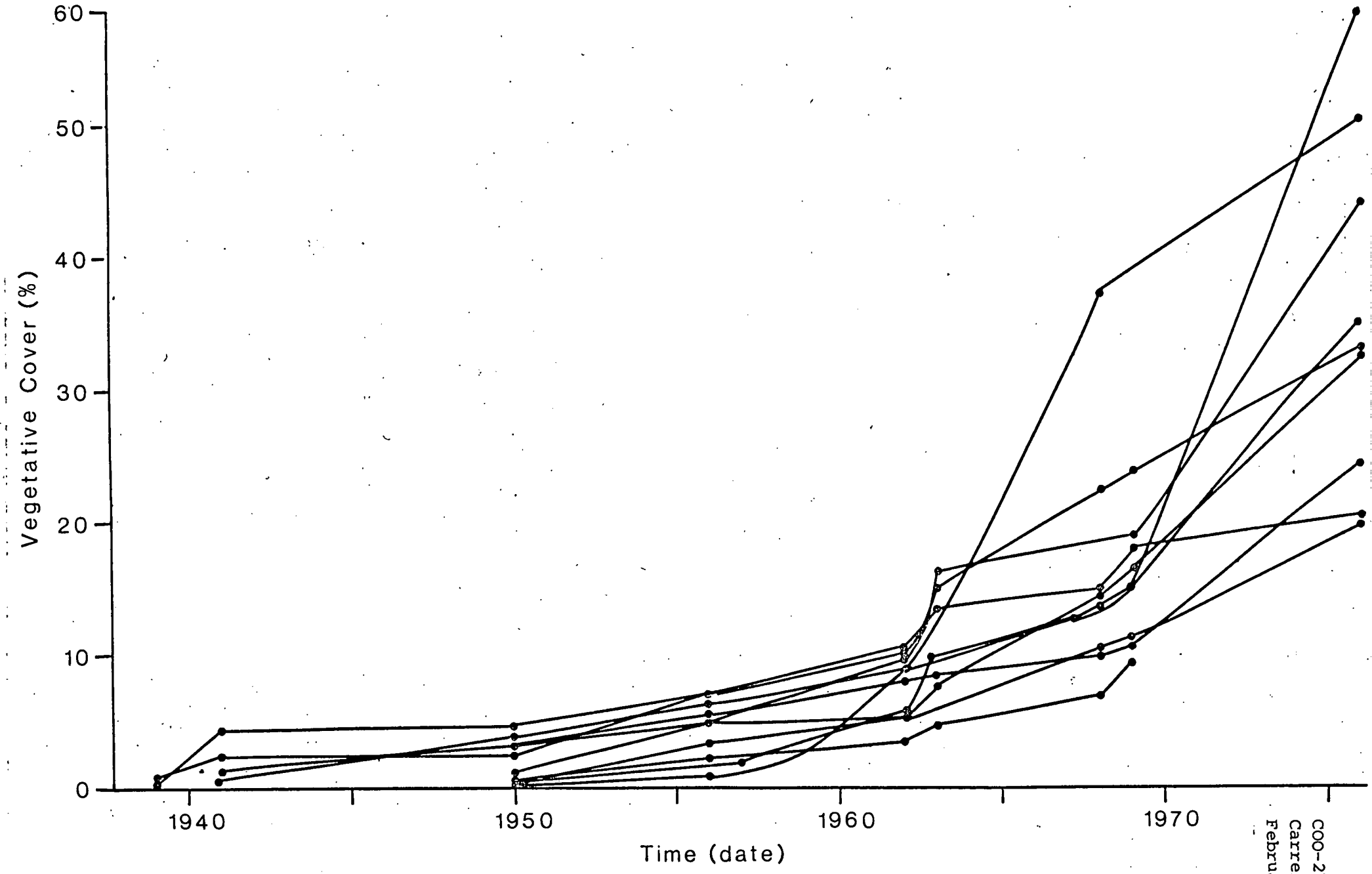
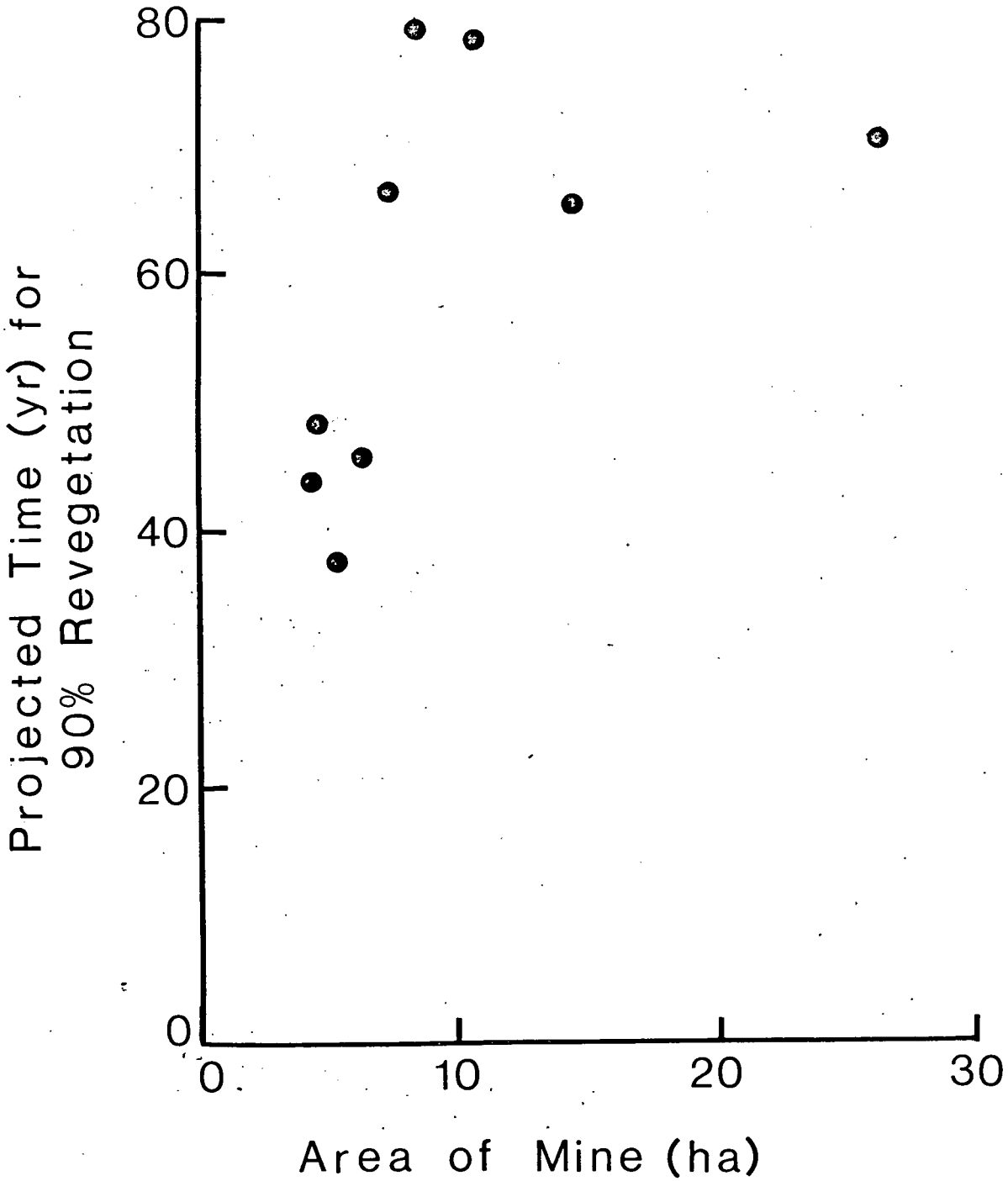

60
50
40
30
20
10
0
Vegetative Cover (%)
1940
1950
1960
1970
Time (date)

Figure 3


80
60
40
20
0
Projected Time (yr) for
90% Revegetation
0
10
20
30
Area of Mine (ha)

in a habitat island should be function of the island's area. Data to test this idea were obtained from 30 by 30 m quadrats which were originally established to corroborate the accuracy of our vegetative cover measurement technique.

We find two very distinct sorts of habitat islands in old, orphaned mines. The distinction is based on whether woody or herbaceous species are present in the patch of vegetation. If woody species are present, they exist usually as monospecific islands (Figure 4). If herbaceous species are present, they exist in multiple species associations, the size of which is proportional to area of the patch (Figure 5). In the few islands where woody and herbaceous species are present together, the species area curve resembles the herbaceous curve with the addition of one species. We therefore suggest that islands with mixed vegetation represent areas in which woody species have recently invaded. Tree ages determined from cores taken near the ground support this idea.

The discreteness of woody and herbaceous habitat islands in our study sites raises some interesting ecological questions. Are the herbs and trees mutually excluding each other? Alternatively, does the present situation derive mainly from edaphic factors? Might allelochemics or allelopathic substances from plants be retained in microbially depauperate spoils in sufficient quantities to actually retard further succession? The strip mines offer an unique opportunity to answer these questions because there is not a biological legacy in the spoil to obscure matters.

g) Ecological Energetics

Litter decomposition and organic turnover using ^{14}C-labelled fescue grass in fine mesh screens are providing some early results on the decay

Figure 4

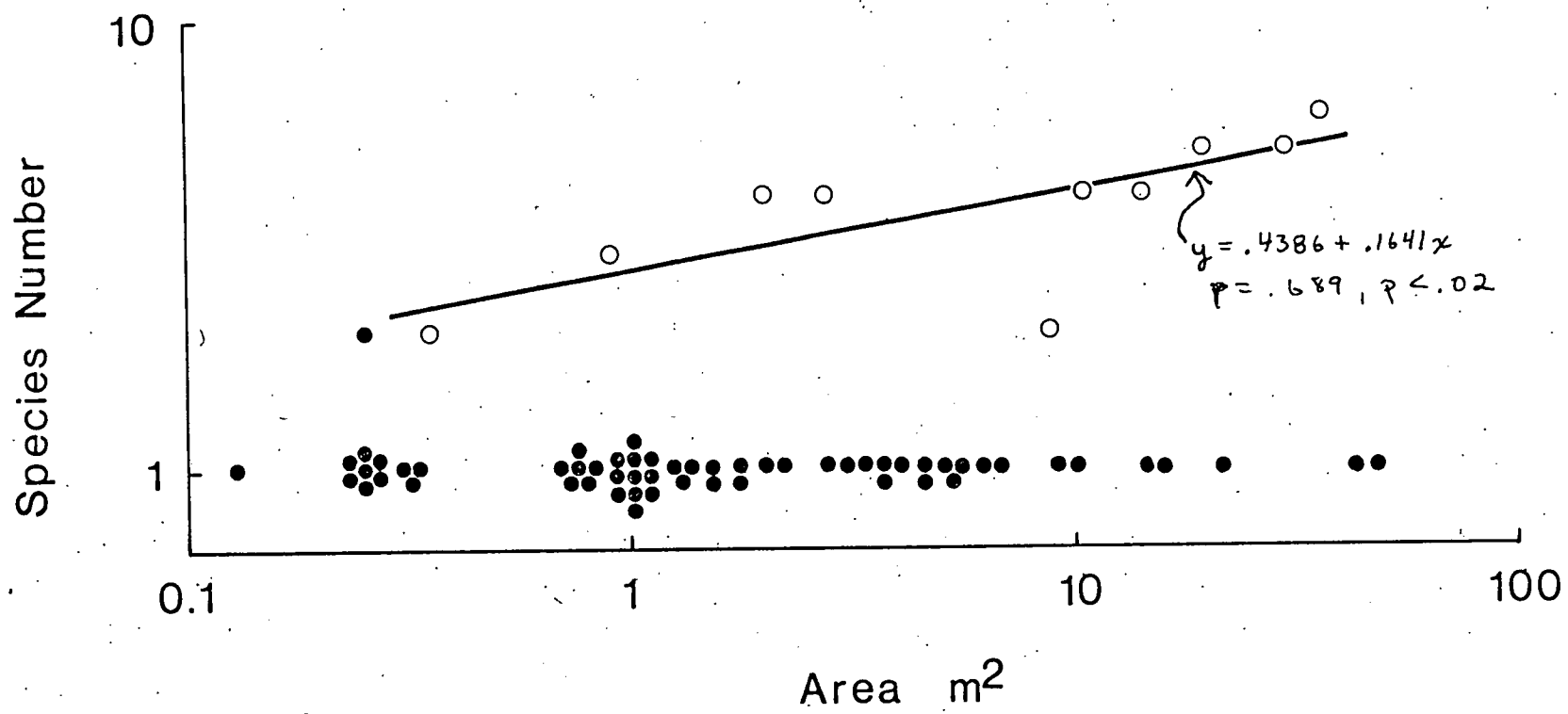
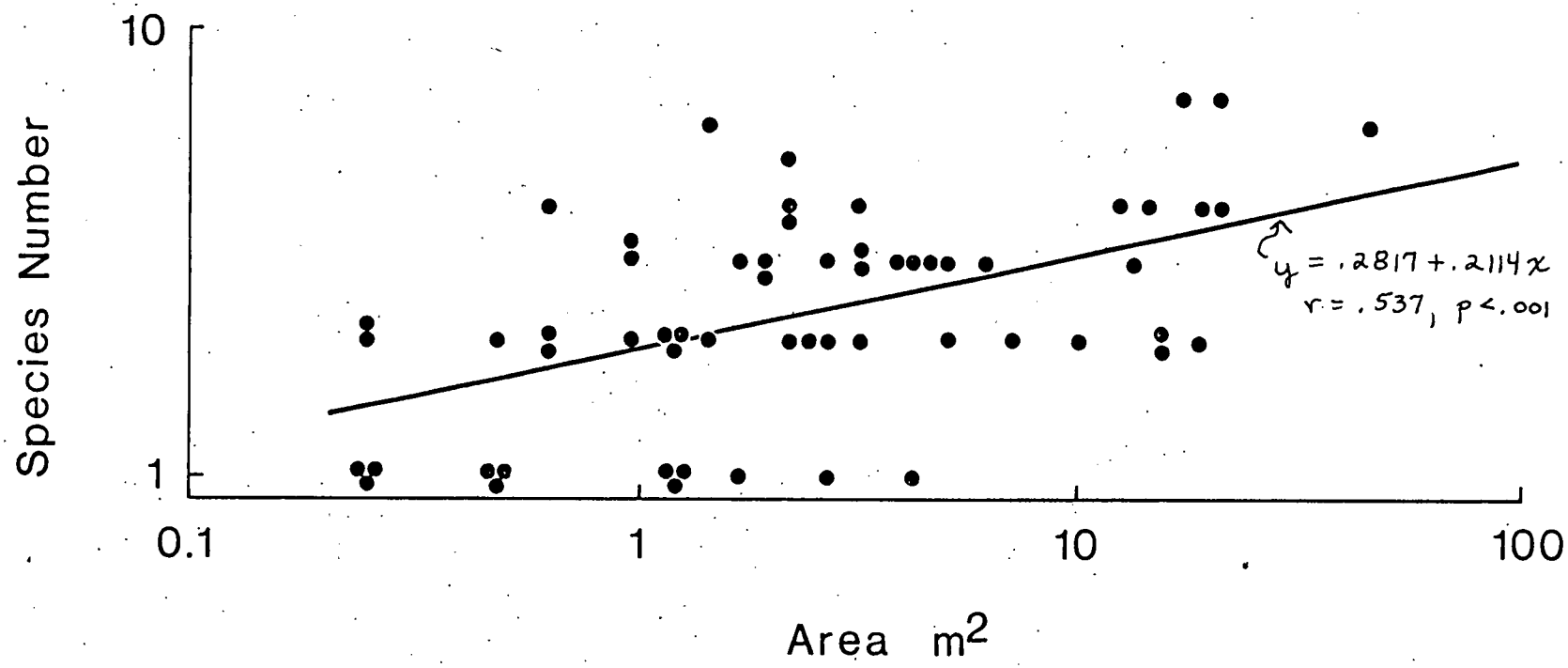


Figure 5



characteristics in the strip mine environment. Our preliminary results show that losses are occurring in both dry weight and ^{14}C-radioactivity and at a relatively rapid rate compared to steady state systems found in grasslands during the International Biological Programme. Weight losses in the present study were greater in the vegetated areas, while the reverse was measured for carbon-14 losses. It is suggested that the presence of higher plants provided an environment for faster decay based on the probability of endemic microfloras, whereas barren areas may lack a microbial community. Thus, carbon-14 losses may reflect simply a physical leaching process of greater intensity than under vegetation. Based on the exponential decreases in both weight and the radioisotope:

$$\frac{x_t}{x_o} = e^{-kt}$$

where: x_t = amount remaining after time t

x_o = amount at beginning of period of loss

k = decay constant (or turnover rate per year)

the latter was calculated from which a $T_{\frac{1}{2}}$ or 'half-life' was determined, where $T_{\frac{1}{2}} = \frac{0.693}{k}$. Decay constants and half-life values are shown below, based on approximately 7½ months of data for dry weights and 4½ months of data for carbon-14.

Site		Parameter	
		weight-loss	carbon-14 loss
Vegetated	$k\%yr^{-1}$	2.77	0.66
	$T_{\frac{1}{2}}$, years	0.25	1.05
Barren	$k\%yr^{-1}$	0.71	0.95
	$T_{\frac{1}{2}}$, years	0.98	0.73

The data in Table 5 based on three years of observation of Grassland IBP sites are submitted for comparision.

TABLE 5

Losses in Grass Litter

Placed in Grasslands for 3 Years

Grassland Location	weight loss		^{14}C loss	
	$k\%yr^{-1}$	$T_{\frac{1}{2}}$, yrs.	$k\%yr^{-1}$	$T_{\frac{1}{2}}$, yrs.
Saskachewan (Can.)	0.17	4.0	-	-
N.E. Colorado	0.20	3.5	0.69	1.0
Montana, 7000' elev.	0.22	3.1	0.84	0.9
S. Dakota	0.25	2.8	1.04	0.6
California, S.J. Valley	0.44	1.6	1.04	0.6
Missouri, Tucker Prairie	0.69	1.0	1.65	0.4
Tennessee, Oak Ridge	0.83	0.8	1.38	0.5
New Mexico	1.04	0.7	1.38	0.5

The general patterns of decay rates for stable grassland communities which illustrate correspondence in climatic trends as well, compared to marked departures with strip mine data suggest intra-habitat factors are involved in the latter with which we are unfamiliar at the present state of knowledge. Clearly more data are needed to better understand the turnover process of organics in an acid substrate such as land stripped for high sulphur coal. It should be pointed out that the ^{14}C-losses from IBP data show

a faster attrition than total weight losses. This was expected since the radiophotosynthate fixed after only three days of exposure was most probably still in the more soluble forms, ie., sugars, proteins, etc., compared to a greater preponderance of more resistant products such as cellulose and lignin compounds reflected in the dry matter losses. A possible explanation for the reversal in the present study concerning the lower k value for carbon-14 is the longer duration of exposure of nearly 3 weeks. During this time a relatively larger portion of the radiophotosynthate possibly was deposited as cellulose and lignin in structural features of the growing plants.

II. Habitat Island Formation

a) Organic Matter/Cover Islands

Despite subnormal rainfall in 1976, preliminary data indicate an increase in cover of vascular plants in response to mulching with prairie hay. Little bluestem (*Andropogon*) and goldenrod (*Solidago*) were recorded at about 25 percent of the hay innoculation sites which were arranged in checkerboard pattern on homogeneous topography. Both of these plants are perennials. In the control area on similar terrain, no prairie species were present. In addition, barnyard grass (*Echinochloa*), a European adventive annual also occurred. All plants were in close contact with the introduced material. Inasmuch as the hay was harvested after seed stalk formation, the presence of perennial prairie species was expected. The establishment of the exotic barnyard grass is attributed to superior microsites effected by introduced mulch through improved moisture conditions. Propagules of this species would necessarily have been transported

to the potential invasion zones from outlying sites. No assessment was made of the said fauna or of the microbial populations. These will be described and quantified during the '77 season.

These preliminary data would suggest that the creation of artificial islands or refuges of food, cover, and seed availability can accelerate the successional process and shorten the time to achieve biotic equilibrium. Ramifications of these site modifications should be explored, including minimal applications and most effective spacing to maximize the invasion and establishment potential.

VI. EFFORT OF SCIENTIFIC PERSONNEL

Identical to the renewal proposal, and as such it complies with the contractual agreement.