MASTER

STRIP MINE RECLAMATION: CRITERIA AND METHODS FOR MEASUREMENT OF REVEGETATION SUCCESS

Progress Report

for Period April 1, 1979 - March 31, 1980

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3. ABSTRACT

During this contract period we initiated research aimed at finding suitable methods and criteria for determining the success of revegetation in Midwestern surface coal mines. Particularly important to our experimental design was the concept of reference areas, sites from which the performance standards for reclaimed areas are to be derived. Because permanent rules and regulations for Public Law 95-87, the Surface Mine Control and Reclamation Act, were not yet promulgated, we tested direct and remote sensing techniques for measuring plant ground cover, productivity, and species diversity in 9 mine and 3 reference sites of our own choosing. At the same time we arranged with 4 mine operators and state regulatory officials to begin working early in 1980 in about 12 matched pairs of mine and reference sites permitted under the new surface mine regulations.

Data gathered by us in the 1979 growing season show that most unmanaged mineland pastures had lower average ground cover and production than reference pastures. No two sites, not even any reference areas, had plant species similarity indices greater than 75%. Remote sensing by digital computer image analysis of color infrared aerial photographs, when compared to ground level measurements, is a fast, relatively inexpensive way to determine plant ground cover and possibly biomass yields. But a remote sensing approach is inferior to standard surface methods when a detailed description of plant species is needed.

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4. SCOPE OF INVESTIGATIONS AND SIGNIFICANT RESULTS

4.1. Objectives

As proposed in 1978, we plan to do the following things:

1. To establish objective methods to measure and criteria to judge the diversity, effectiveness, and permanence of vegetation in reclaimed surface coal mines and in reference areas as required under Public Law 95-87.
2. To determine the cost-effectiveness, generality, and utility of our methods and criteria.
3. To transfer our information to interested parties, particularly mine operators and governmental regulators.

4.2. Research Program

4.2.1. Introduction

Our research approach is to study strip mine and reference sites prepared and managed by mine operators under the approval of state land reclamation officials. We intend to stay informed about reclamation activities pertinent to our chosen sites for several consecutive years, going from pre-mining planning to post-mining termination. Thus, we are not responsible for the actual grading, seeding, or cropping of any area. Instead, we exploit the systems created by mine operators who are attempting to comply with state and federal strip mine regulations. This fact is important because it means that all of our data are derived from large scale, legally permitted plots rather than from small experimental plots of the sort commonly used by agronomists.

Our study sites are located at 4 active surface coal mines, 3 in Missouri and 1 in Illinois(Figure 1). Most of the acreage in these regions is classified as pastureland or cropland. Hence, after being stripped the land will usually be returned to high agricultural capability. However, since the permanent surface mining rules and regulations are being promulgated in 1979 and 1980 at the state and national levels, mine operators now are waiting to draft final reclamation plans for areas to be permitted in 1980. Thus, at all 4 mines we are encountering a transitional situation.

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Figure 1. Location of 4 active surface coal mines (closed circles) in which we are doing research. An asterisk marks the site of our laboratory.

To adjust for the drastic changes in reclamation techniques destined to occur in 1979-80, we adopted a dual research strategy. First, from April to October, 1979 we thoroughly tested our techniques for sampling vegetation in mine and reference sites for which we had already obtained floristic and geologic descriptions. Second, from October, 1979 to February, 1980 we worked closely with mine operators and state officials to identify at least 12 matched pairs of new mine and reference sites, as described under PL 95-87, for examination annually by us starting in 1980. Hence, having perfected most of our techniques, we now are embarking on the early phases of our long term, comparative studies as diagrammed in Figure 2.

4.2.2. Direct and Remote Sensing Methods

Plant ground cover, productivity, and species diversity were determined in 9 mine sites and in 3 reference sites seeded with a mixture of grasses and legumes. Measurements made midway in the 1979 growing season were repeated at the end of the season to

Figure 2

SCHEDULE OF RESEARCH ACTIVITIES: A CASE STUDY

assess the affect of temporal differences in pasture quality on our results. Costs and times required for all components of the study were logged daily and then a preliminary comparison of various methodological approaches was performed.

Two very different methods for measuring plant growth were tested at the 12 study sites.

Method 1: Direct, manual measurements

Twenty-five replicate, permanent 0.5m^2 plots were staked out at random intervals along parallel transects spaced at regular intervals across each site. We visited each plot, estimated visually the percent ground covered by plants within it, and then harvested all standing material by clipping it at ground level. Plant samples were separated to species, bagged in the field, and brought back to the laboratory where they were dried and weighed. Data for percent vegetative cover, species composition, and species abundance were calculated for each plot and for each study site. The area of each study site was measured from a recent aerial photograph using a hand-operated planimeter.

Method 2: Remote, computer measurements

Vertical aerial photographs of a mine or reference site were subjected to digital computer image analysis. Color infrared (CIR) photographs at a scale of almost 1:12,000 were taken in an airplane flown over the 12 study sites in June and again in September when ground level measurements were being made. Computer interpretations of CIR imagery involved a rapid, multi-step process which is shown in Figure 3. In brief, the photograph was converted to a two-dimensional, black-and-white video image consisting of nearly 250,000 tiny picture points or cells. The grey value of each picture cell was measured on a digital scale ranging from 0 for absolute white to 256 for pitch black. Boundaries delineating a mine or reference site were drawn in the digital video image using a sonic pen, whereafter all points outside the area of interest were disregarded. All spatial and contrast information was stored on magnetic disk and tape. Classification of cover

INTERACTIVE GRAY LEVEL SLICING

Figure 3. Interactive grey level slicing routine in computer image analysis.

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into various categories was achieved interactively by slicing the spectrum of grey level values into two or more subgroups and then by displaying the resultant, simplified digital image for visual verification with the more complex, analog CIR photographic inputs. Once a classification scheme was established, a spatial rendition of the picture cells was printed and plotted to scale on paper (Figure 4). Also printed was a summary of the computer results that included boundary values for each grey level slice and the absolute and relative areas of each cover class.

4.2.3. Results and Discussion

Data on plant ground cover, productivity, and species composition have been collected and tabulated. More complex analyses, such as calculation of similarity indices, will be completed in the first quarter of 1980.

4.2.3.1. Area and cover determinations

Total area for 7 sites was measured both by digital computer image analysis and by a manual planimeter. Computer analyses of summer and fall CIR aerial photographs were averaged. Manual measurements of the same aerial photographs were repeated 5 times and an average was calculated. The data, as summarized in Table 1 and Figure 5, show that there is a systematic difference between the two methods: computer values tend to be slightly less than planimetric ones and this discrepancy increases as sites become larger. We think this relationship is due to a computer bias because as the area of study sites grows, the absolute area represented by single picture cells also increases. Also, small errors in boundary delineation on the digital video screen become progressively greater as study sites become larger. For example, with a small, 5.0 ha reference site there are 1.1 m^2 / picture cell, whereas with a large, 59.7 ha mine site, there are 3.8 m^2 / cell. We can, if we wish, correct a computer area measurement (Y) by

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SITE NUMBER = DP:FC6.CLS;1

OUTLINE NUMBER = DP:FC6

SCALE = 1: 3000.0

Figure 4. Scale plot by computer of three cover classes as determined by digital image analysis. Normally there is one color allocated for each cover category.

Table 1

Comparison of Areas of Study Sites Using Digital Computer Image Analysis vs
Manual Planimeter

Site	COMPUTER* (N = 2)		PLANIMETER (N = 5)
	Total Area $\bar{X} \pm SE$ (acres)	Total Area $\bar{X} \pm SE$ (hectares)	Total Area $\bar{X} \pm SE$ (hectares)
C1	133.86 $\pm$ 1.99	54.17 $\pm$ 0.81	59.68 $\pm$ 0.11
C2	129.51 $\pm$ 1.44	52.41 $\pm$ 0.58	58.01 $\pm$ 0.50
C3	127.16 $\pm$ 0.48	51.46 $\pm$ 0.19	57.81 $\pm$ 0.20
C4	70.17 $\pm$ 2.42	28.40 $\pm$ 0.98	30.44 $\pm$ 0.03
C5	33.95 $\pm$ 0.49	13.74 $\pm$ 0.20	15.37 $\pm$ 0.08
C6	15.89 $\pm$ 0.18	6.43 $\pm$ 0.07	4.71 $\pm$ 0.05
MP-R3	13.69 $\pm$ 0.55	5.54 $\pm$ 0.22	5.01 $\pm$ 0.01

* Calculated from analysis of summer and fall aerial photos in which different outlines were used for each aerial image.

Figure 5. Comparison of area determination techniques. Means $\pm$ SE for both techniques are indicated, as well as ideal and real best fit regression lines.

by using the equation $Y = 1.36 + 0.88X$, in which X is the planimetric value. But for finding relative ground cover values, such a transformation procedure is not necessary.

Vegetative ground cover was measured by visual estimation at ground level and by digital computer image analysis of CIR vertical aerial photographs in summer and fall, 1979 (Table 2). Three main conclusions can be extracted from the data.

A. There is a high degree of correspondence between direct ground level and remote aerial estimates of plant ground cover in all sites. Correlation coefficients for the summer, fall, and the combination of summer and fall values are all statistically significant ($p < 0.05$). Moreover, 13 of 19 cover values lie within 10% of the ideal 1:1 regression line (Figure 6). Thus, at most sites computer estimates of cover equal at least 90% of the mean for visually determined values with a statistical confidence greater than 90%.

B. Computer derived estimates of vegetative cover might be more accurate when made in the fall than in early summer. Inspection of Figure 6 reveals a lateral shift at 5 of 7 sites from the left to right. This type of vector analysis indicates that seasonal variation in visual estimates of cover at ground level is greater than in computer generated values. We suspect this shift in apparent ground cover during the growing season may result mainly from phenological and morphological differences between legumes and grasses. Annual growth by alfalfa, sweet clover, and many other leguminous species seeded in mine and reference sites peaks in June or July, and by September predominantly dead, defoliated stems are to be found. In contrast, fescue, orchard grass, and other seeded graminaceous species reach their greatest abundance in August or September and die back in November. By itself this phenological difference would not necessarily be important in ground cover estimates, except that when legumes are inspected closely, their thick stems and circular, triple leaves appear to blanket less of the soil surface than do the long, continuous blades in an equal-sized clump of most grasses. This discrepancy is not easily detected in CIR aerial photographs, so in most instances it goes unnoticed.

C. Vegetative ground cover in all reference sites we examined exceeds 94%, but in only a single mine site, one that had been partially top-soiled and possibly over-seeded several years before, is the same performance level

Table 2
 Summary of Cover Calculations from Aerial Photographs and Direct Estimates

Season	Site	% Vegetative Cover	
		Computer Analysis	Visual Analysis* ($\bar{X} \pm SE$)
Summer (June)	C1	53.19	58.72 $\pm$ 8.14
	C2	62.43	44.52 $\pm$ 7.86
	C3	86.89	68.24 $\pm$ 6.47
	C4	67.35	51.92 $\pm$ 8.28
	C5	84.55	50.92 $\pm$ 7.18
	C6	84.43	80.56 $\pm$ 5.13
	MP = R3	97.72	99.08 $\pm$ 0.44
Fall (September)	C1	51.97	53.20 $\pm$ 9.16
	C2	55.10	53.92 $\pm$ 9.38
	C3	88.65	88.60 $\pm$ 4.62
	C4	63.97	74.00 $\pm$ 6.58
	C5	76.09	58.64 $\pm$ 6.84
	C6	80.48	89.48 $\pm$ 5.56
	B1	54.14	42.32 $\pm$ 8.76
	B2	94.49	97.00 $\pm$ 1.53
	B3	94.24	85.60 $\pm$ 5.78
	MP = R3	98.17	100.00 $\pm$ 0.00
	R1	99.11	97.88 $\pm$ 0.94
	R2	93.55	100.00 $\pm$ 0.00

* Visual estimates were made in 25 replicate, 0.5 m² plots.

Figure 6. Comparison of ground level, visual estimates and aerial, computer generated estimates of vegetative ground cover in mine and reference sites. Mean values for summer (S, open circles) and fall (F, closed circles) are given. Best-fit regression lines for summer, fall, and summer plus fall data are also indicated. Dashed arrows connect points for the same sites. The shaded region represents the region of at least 90% similarity between both measurements.

reached (Figure 6). This difference is even more impressive if the age of each site is considered (Figure 7). Even 6 yr after grading, liming, and reseeding as prescribed under Missouri's mine reclamation law the majority of strip mines have extensive barren spots. Three partially or completely top-soiled minelands, 4 to 6 yr in age, are not significantly more revegetated than several 2 or 3 yr minelands (Student's t-test, $p > 0.05$). In addition, 3 pre-law sites still are very barren, averaging approximately only 50% vegetative cover.

4.2.3.2. Productivity measurements

Plant productivity of 9 mine sites and 3 reference sites, as determined by a harvest method, ranged from 100 to 540 g / m² (Table 3). A number of patterns or trends are evident in the data.

A. All sites are dominated by forages seeded during reclamation and not by weeds or trees.

B. There generally are no significant changes (Student's t and ANOVA tests, $p > 0.05$) in average yields between June and September, 1979 (Figure 8). This likely is because cool season grasses supplant the biomass lost by legumes during the hot summer months.

C. There is a significant rank order among the 3 different types of study sites: mean yields of reference plots are highest, yields of post-law plots are intermediate, and those of pre-law ones are lowest (Kruskal-Wallis test, $H = 7.41$, $p < 0.025$).

D. Distributions of biomass in reference sites are more regular or uniform than in most mine sites (Figure 9). The variance to mean ratio in 3 reference pastures ranges from 25 to 50 g / m², whereas in most mineland it exceeds 100 g / m². Considering the time elapsed since seeding of strip mines as depicted in Figure 9, there seems to be a trend toward less patchiness or more uniformity. Post-law sites appear to approach the reference condition after 5 or 6 yr while adjacent pre-law ones may require more than a decade to develop. These interpretations agree with the temporal changes in plant ground cover shown in Figure 7.

E. Plant ground cover may be a good predictor of pastureland productivity. There is a strong regression between percent ground cover and dried biomass yields at all sites we studied in 1979 (Figure 10). Hence, either remote or

Figure 7. Changes in vegetative ground cover with time in 9 strip mines. Means $\pm$ SE for pre-law (closed triangles) and post-law (closed circles) mine sites are indicated. For comparison, the means for 3 reference sites (R1, R2, R3=MP) are also shown. All data are based on ground level, visual estimates made in September, 1979 at 25 replicate 0.5 m² plots per site.

Table 3

Yield of Dried Plant Biomass ($\bar{X}$, g/m²) in Strip Mine and Reference Pasturelands During 1979

Summer (June) Harvest

Site	POST-LAW						PRE-LAW			REFERENCE		
	C6	C5	C4	C3	B3	B2	C2	B1	C1	R2	R1	R3=MP
Age (yr)	2.0	2.25	2.75	4	6	6	6	7	8	4	6	12
Grasses	281.8	37.4	109.3	242.9	201.7	242.7	172.5	75.8	182.2	NS	NS	359.4
Legumes	159.1	233.7	182.5	78.4	40.4	117.2	46.0	23.7	126.2	NS	NS	19.4
Weeds	2.1	33.8	5.7	5.8	32.1	8.2	4.2	7.3	0.7	NS	NS	39.9
Total	443.0	304.9	297.5	327.1	274.2	368.1	223.1	106.8	309.1	NS	NS	418.7

Fall (September) Harvest

Site	POST-LAW						PRE-LAW			REFERENCE		
	C6	C5	C4	C3	B3	B2	C2	B1	C1	R2	R1	R3=MP
Age (yr)	2.25	2.5	3	4	6	6	6	7	8	4	6	12
Grasses	189.0	31.6	156.4	301.0	131.5	294.4	184.9	80.9	162.6	520.1	322.0	355.7
Legumes	129.0	145.0	121.9	49.0	33.2	67.3	25.4	32.4	31.2	4.4	20.2	1.0
Weeds	16.0	68.3	26.7	15.6	35.6	25.1	24.1	25.6	5.9	12.3	8.4	63.4
Total	334.0	244.9	305.0	365.6	200.3	386.8	234.4	138.9	199.7	536.8	350.6	420.1

NS = not sampled

Figure 8. Comparison of summer and fall yields from mine and reference sites seeded to pastureland. Means $\pm$ SE are indicated by points and bars. Best-fit regression line is shown for pre-law (closed triangles), post-law (closed circles), and reference (open circle) sites sampled twice in 1979.

Figure 9. Variance to mean ratios for pre-law (closed triangles), post-law (closed circles), and reference sites with regard to yields of dried plant biomass in September, 1979.

Figure 10. Relationship between vegetative ground cover and yield in mine and reference pasturelands. Data for summer (closed squares) and fall (closed circles) , 1979 are shown.

direct measures of canopy cover might be used to deduce harvest values.

F. In comparison with other plant ecosystems, the annual above-ground yields of mineland pastures we studied this year in Missouri are low (Figure 11). The poor condition certainly is due to the absence of proper management. None of the pre-law or post-law strip mine haylands described herein have ever been fertilized or cropped. Yields undoubtedly would improve dramatically if nitrogen were applied and if periodic top-seeding and mowing were instituted. Harvests from improved mixed pastures established in other Midwestern mines rival the productivity of well managed haylands, which usually range from 400 to 1,200 g / m²/ yr (Weems, 1979).

4.2.3.3. Diversity and similarity measurements

The taxonomic identity, frequency, and abundance of all plant species were calculated for each of the 25 replicate clip quadrats within 9 mine and 3 reference sites sampled during June and September, 1979. An attempt to discriminate different types of plants by using computer image analysis of CIR vertical aerial photographs was started in December, 1979. This report contains only the results of ground level measurements.

A. All sites are dominated by 7 species of grasses and legumes seeded as a pasture mix. Grass species present are Festuca elatior, Dactylis glomerata, Poa pratensis, and Panicum virgatum. Legumes present are Medicago sativa, Lespedeza stipulacea, and Trifolium hybridum.

B. Although not necessarily abundant, weedy herbaceous species usually outnumber agronomic ones (Table 4).

C. Reference sites and top-soiled mine sites tend to have more weedy species and a higher density of all species than mine sites covered with spoil (Table 4).

Figure 11

TYPICAL ANNUAL YIELDS OF MINELAND AND OTHER AMERICAN HABITATS

Data are from Carrel, Rapp, Kucera, and Weems. 1980. Plant Biomass Production in Mineland Ecosystems. (In preparation).

D. Species similarity between any two of the sites we studied is generally less than 75% (Table 5). Using both Gleason's coefficient of community that expresses floristic similarity and Sørensen's index that expresses quantitative representation of plant species, we find most sites have a similarity of 20 - 60% when compared in a pairwise fashion. Hence, we suggest that a legal requirement of at least 90% similarity among species in mine and reference pasturelands may be unrealistic.

4.2.3.4. Cost and time measurements

Both the times and costs required to perform assorted tasks in the field and the laboratory were itemized and recorded. A preliminary compilation of the data is presented in Table 6. We expect to make minor revisions of these figures as our work progresses. Thus, overall the numbers should be reasonable, order-of-magnitude estimates of real costs.

We find that our remote sensing approaches for vegetation measurements are faster and cheaper than ground level methods. However, remotely sensed data do not presently afford much information about species composition and abundance. Thus, we anticipate that a combination of both approaches might prove to be the best strategy to gain accurate, timely information about reclamation success in strip mines.

Table 4

Plant Species Diversity Calculations For Mine and Reference Haylands in 1979

Site	SPRING				FALL				
	S	H	e	H _{max}	S	$\bar{S}/m^2$	H	e	H _{max}
C1	12	1.67	.6734	2.48	12	1.7	1.57	.6331	2.48
C2	11	1.37	.5708	2.40	13	1.9	1.51	.5898	2.56
C3*	22	1.92	.6214	3.09	21	3.3	1.84	.6054	3.04
C4	14	1.72	.6515	2.64	17	3.0	1.80	.6360	2.83
C5	23	2.10	.6688	3.14	18	NC	1.84	.6367	2.89
C6	15	1.71	.6310	2.71	17	NC	1.75	.6184	2.83
B1	20	1.93	.6433	3.00	18	2.3	2.08	.7197	2.89
B2*	28	2.13	.6396	3.33	16	2.8	1.52	.5490	2.77
B3*	38	2.37	.6511	3.64	39	5.4	2.55	.6967	3.66
R2	NS	NS	NS	NS	23	NC	1.80	.5732	3.14
R3=MP	37	2.43	.6727	3.61	49	10.9	2.68	.6889	3.89

S = Number of plant species

NC = Not calculated

$$H = -\sum p_i \ln p_i$$

NS = Not sampled

$$H_{\max} = \frac{H}{\ln S}$$

$$e = \frac{H}{H_{\max}}$$

Table 5

Similarity Coefficients for Plants Sampled in Mine and References Sites in
September, 1979

A. Gleason's Coefficient of Community : $2S_{ab} / (S_a + S_b)$

[illegible]

B. Sørensen's Coefficient of Similarity : $1 - 0.5 \sum |p_a - p_b|$

[illegible]

Table 6
 COST ANALYSIS FOR
 DOCUMENTATION OF REVEGETATION
 SUCCESS IN A 30 ACRE STRIP MINE IN MISSOURI

		<u>\$/site</u>	<u>\$/acre</u>
1. Ground level measurements			
a. Labor			
Field sampling	40 hr. x \$10.00/hr.	\$400.00	\$13.33
Lab sampling	5 hr. x \$10.00/hr.	\$50.00	\$1.67
Data analysis	8 hr. x \$10.00/hr.	\$80.00	\$2.67
Report writing	4 hr. x \$10.00/hr.	\$40.00	\$1.33
Subtotal	57 hr. x \$10.00/hr.	\$570.00	\$19.00
b. Supplies			
Bags, paper, pens, stakes, markers		\$25.00	\$.33
c. Travel			
120-1,000 miles x \$.20/mi.		\$25.00-	\$.80-
		\$200.00	\$6.87
d. Computer time			
Data reduction, plotting		\$5.00	\$1.17
	Total	\$624.00-	\$20.80-
		\$800.00	\$26.87
2. Remote aerial measurements			
a. Labor			
Photo mission setup	1 hr. x \$10.00/hr.	\$10.00	\$.33
Photo interpretation			
and computer analysis	4 hr. x \$10.00/hr.	\$40.00	\$1.33
Plot preparation	1 hr. x \$10.00/hr.	\$10.00	\$.33
Report writing	4 hr. x \$10.00/hr.	\$40.00	\$1.33
Subtotal	10 hr. x \$10.00/hr.	\$100.00	\$3.32
b. Supplies			
Computer tapes, paper, filters		\$15.00	\$.50
c. Aerial Photographs-Procurement of			
9 x 9 in Color infrared transparencies		\$100.00-	\$3.33-
1:12,000 scale		\$400.00	\$13.33
d. Computer time			
Digital image analysis and			
data display	4 hr. x \$8.00/hr.	\$32.00	\$1.07
	Total	\$247.00-	\$8.22-
		\$547.00	\$18.22

5. COMPLIANCE WITH THE CONTRACT

To our knowledge, we have fully complied with the letter and the spirit of the contract.

6. EFFORT OF SCIENTIFIC PERSONNEL

The principal investigator (PI) devoted at least 25% of his time during the academic year and 50% during 4 summer and fall months to this project. During the remainder of the contract period, from January to March, 1979, the PI expects to spend 50% of his effort on the project.

All other scientific personnel have complied with the effort description in the original proposal.

7. BIBLIOGRAPHY

- 7.1. R. K. Wieder and J. E. Carrel. 1979. Radioactive Carbon-14 as an Indicator of Energy Flow in Litter Decomposition Studies. Oecologia. (In press).
- 7.2. C. J. Johannsen, T. W. Barney, A. D. Coble, J. E. Carrel, W. McFarland, and D. J. Barr. 1979. Characterization of Vegetation and Drainage in Strip Mined Land Utilizing Remote Sensing Techniques. U.S. E.P.A. Report No. 600/7-79-194.
- 7.3. J. E. Carrel, C. J. Johannsen, T. W. Barney, A. D. Coble, S. Weems, and W. McFarland. 1979. Remote Sensing Techniques Measure Revegetation Success in Strip Mines. Abstracts of Papers of the 145th National Meeting, American Association for the Advancement of Science. (In press).
- 7.4. S. R. Weems. 1979. Floristics of Central Missouri Surface Mines. Unpublished A.M. thesis, University of Missouri, Columbia. 104p.
- 7.5. T. W. Barney (ed.). 1980. Users' Guide to Remote Sensing Activities in Missouri. University of Missouri Extension Publication. (In press).
- 7.6. J. E. Carrel and J. E. DeMott. 1980. Rates of Natural Revegetation in Missouri Surface Coal Mines. (In preparation).
- 7.7. M. Game, J. E. Carrel, and T. Hotrabhavanda. 1980. Patch Dynamics in Missouri Strip Mines Undergoing Natural Revegetation. (In preparation for the Journal of Applied Ecology).
- 7.8. J. E. Carrel. 1980. Recovery of Abandoned Strip Mines: Time Heals Most Wounds. Missouri Conservationist. (In preparation).
- 7.9. J. E. Carrel. 1980. Space Age Techniques Measure Success of Revegetation in Strip Mines. Missouri Conservationist. (In preparation).
- 7.10. J. E. Carrel, J. R. Rapp, C. L. Kucera, and S. R. Weems. 1980. Plant Biomass Production in Mineland Ecosystems. Reclamation Reviews. (In preparation).