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TERRESTRIAL PLANT AND WILDLIFE COMMUNITIES ON PHOSPHATE-MINED LANDS IN CENTRAL FLORIDA

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TERRESTRIAL PLANT AND WILDLIFE COMMUNITIES ON PHOSPHATE-MINED LANDS IN CENTRAL FLORIDA

ROGER S. SCHNOES AND STEPHEN R. HUMPHREY[1]

ABSTRACT: A study of plant and animal communities documented the recovery of phosphate-mined land in central Florida. Hypotheses about community structure were tested in two sets of treatments. One set consisted of the relatively stable end results of post-mining land use. These treatments were: consolidated waste clay soil; late successional forest on unreclaimed overburden spoil piles with and without interspersed lakes; and grazed and ungrazed pastures on reclaimed overburden soil. The other set of treatments tested for differences in community structure among several seral stages on unreclaimed overburden spoil piles with interspersed lakes. The responses of biological communities were measured as the identity, diversity, and abundance of plants, mammals, birds, reptiles and amphibians, and insects. Major findings include:

1) Succession on clay waste areas was slow, resulting in senescent forest and a depauperate animal community.

2) Unreclaimed spoil piles underwent a rapid primary succession culminating in xeric or mesic oak forest with rich animal communities. The faunas were different on treatments with and without lakes, but both had moderate-to-high wildlife value, high aesthetic quality, and much potential for enhancing animal populations.

3) Succession on reclaimed sites was arrested by grazing or mowing. Both treatments provided relatively poor wildlife habitat, though animal diversity and abundance generally were higher on ungrazed sites. However, stocking with cows resulted in high livestock biomass and slightly more diverse vegetation.

4) Aboveground lenses of hardening clay appear to be properly characterized as wastelands, so implementing optimal reclamation procedures for clay wastes should be a top priority.

5) By contrast, both unreclaimed sites and the type of reclaimed sites examined here are valuable land with a variety of potential uses. The advantage these have in common is the presence of overburden soil.

6) The biological factors underlying the value of reclaimed land are the abundant, balanced nutrients in overburden soil and the free services provided by colonizing biota, notably creation of topsoil through symbiotic nitrogen-fixation by *Frankia* and *Myrica*, seed dispersal by wind and later by migratory birds, and possibly by introduction of mycorrhizal fungi spores by rodents. Operation of these processes should be built into plans for managing reclamation.

7) Succession on overburden soil was to mesic oak forest. Because its soil hardpan is destroyed during mining, restoration of pine flatwoods is not possible without new engineering designs for soil reclamation.

8) The study supports reclamation to rangeland as a legitimate post-mining land use, even though its wildlife value is low. However, the current trend of maintaining improved

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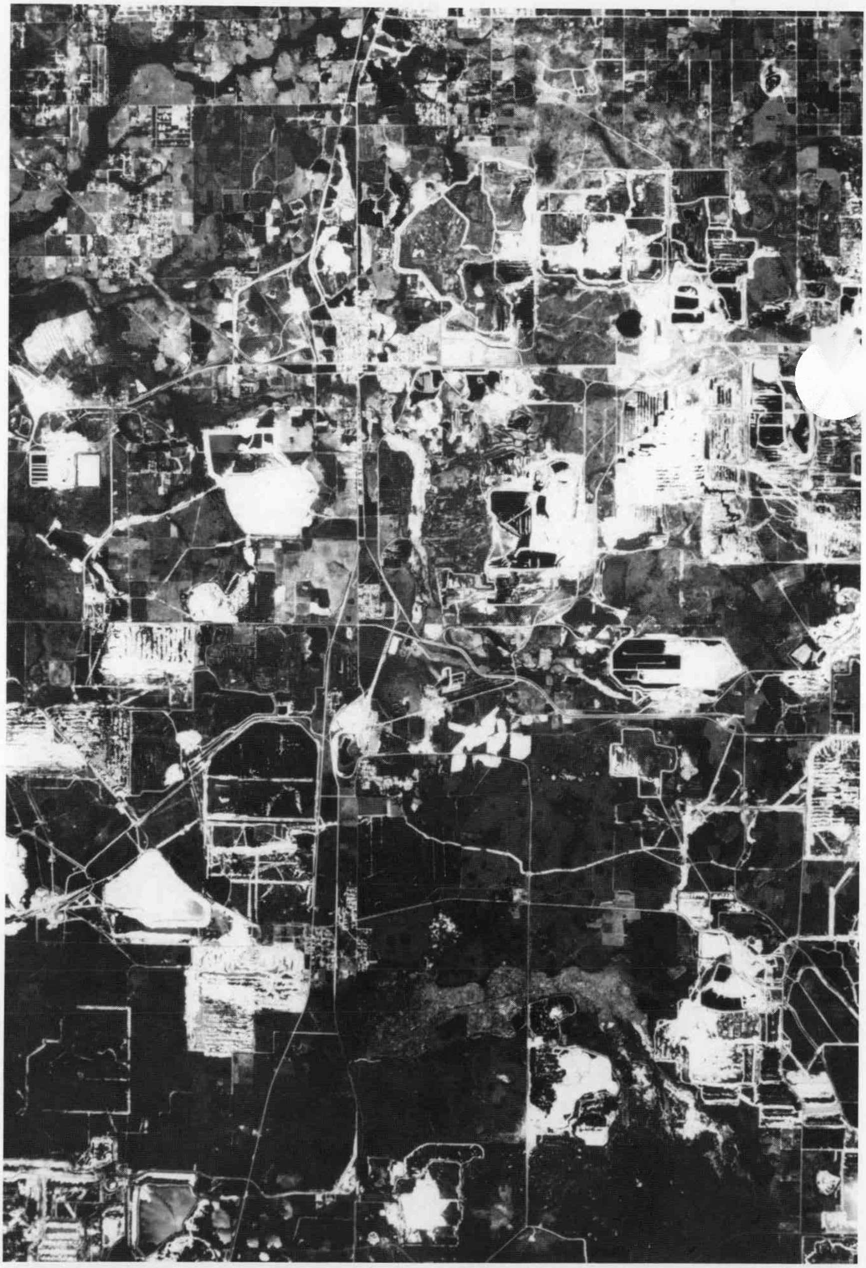

FRONTISPIECE: Part of the central Florida mining district photographed from a U–2 airplane in 1973. Active or recent mines show parallel lines of pits and spoil piles. Dark water bodies are active clay settling ponds. Floodplain forest of the Alafia River is in upper left, the town of Mulberry is at the major crossroads in top center, and Hooker's Prairie is in bottom center. Scale: 1 cm = 1.5 km, 1 inch = 2.9 miles.

pasture on nearly all reclaimed land will result in a region-wide decline of wildlife resources in comparison to both pre-mining conditions and the present transitional habitats. The impending losses could be reduced by including modifications in reclamation plans that will provide wildlife habitat or by directing some reclamation projects specifically at wildlife values.

9) A second trend, toward the use of sand tailings as the major surface soil in reclamation, has the potential to diminish post-mining land quality on a large scale. Because the nature of reclaimed soil is a key variable, regulations should address soil quality and depth.

10) Evaluating the productivity of mined lands would be enhanced by closing information gaps including succession on sand tailings, wildlife communities in pre-mining habitats, socioeconomic value of the wildlife resources lost, field trials of game and vegetation management techniques, habitats restorable on soils that combine sand tailings with consolidated clay, and agronomic and forestry potential of reclaimed soils.

RESUMEN: El presente estudio documenta la recuperación de tierras para extracción de fosfatos en el centro de Florida. Varias hipótesis sobre estructura de comunidad fueron examinadas en dos grupos de tratamientos. Un grupo consistió de las consecuencias, relativemente estables, de usos de la tierra después de actividades de extracción minera. Estos tratamientos fueron: suelo de residuos consolidados de arcilla; bosques sucesionales tardíos en montículos de suelo removido en áreas mineras sobrecargadas y no recuperadas, con y sin lagos interdispersos; y pastizales expuestos y no expuestos a ramoneo en suelos sobrecargados, no recuperados. El otro grupo de tratamientos incluyó varios estadíos serales en montículos de suelo removido y sobrecargado, interdisperso con lagos. Las respuestas de las comunidades biológicas fueron medidas con respecto a la identidad, diversidad y abundancia de plantas, mamíferos, aves, reptiles, anfibios e insectos.
Los resultados mas importantes incluyen:

1) La sucesión en áreas de residuos de arcilla fue lenta, dando como resultado un bosque senescente y una comunidad animal empobrecida.

2) Montículos de suelo removido, no recuperado experimentaron una rápida sucesión, terminando en bosques mésicos o xéricos de roble con ricas comunidades animales. La fauna fue diferente en los tratamientos con y sin lagos, pero ambos tuvieron un moderado a alto valor de fauna silvestre, gran calidad estética y mucho potencial para promover poblaciones animales.

3) La sucesión en tierras no recuperadas fue impedida por pastoreo y corte. Ambos tratamientos indican hábitats relativamente pobres en fauna; si bien la abundancia y diversidad animal fueron, generalmente, mayores en sitios no expuestos al pastoreo. Sin embargo, pasturas para vacunos resultaron en una gran biomasa de ganado y una diversidad de vegetación ligeramente mayor.

4) Capas superficiales de arcilla endurecida parecen estar caracterizadas como tierras improductivas. Por ello, se debe dar primera prioridad a procedimientos que permitan la recuperación adecuada de los deshechos de arcilla.

5) En contraste, tanto los sitios recuperados como los no recuperados examinados en el presente estudio, están tierras valiosas gracias a la variedad de sus usos potenciales. La ventaja que estos tienen en común es la presencia de suelo sobrecargado.

6) Los factores biológicos que contribuyen al alto valor de las tierras recuperadas son: la abundancia de nutrientes balanceados en suelo sobrecargados y los servicios gratuitos proporcionados por la biota colonizadora, especialmente la formación de suelo a través de la fijación simbiótica de nitrógeno por *Frankia* y *Myrica*; dispersión de semillas por el viento y posteriormente por aves; y posiblemente la introducción de esporas de hongos formadores de micorrizas por roedores. El funcionamiento de estos procesos debería ser incorporado en cualquier plan de manejo para recuperación de tierras.

7) La sucesión de suelos sobrecargados fue hacia bosques mésicos de roble. Debido a que la cubierta endurecida de suelo en bosques planos de pinos es destruída durante las operaciones mineras, la restauración de estos bosques no es posible sin nuevos diseños de ingeniería para reclamación de suelos.

8) Este estudio respalda la recuperación de tierras como una alternativa legítima de uso después de actividades mineras, aun en cuando su valor para fines de fauna silvestre sea bajo. Mas aun, la tendencia actual de mantener pasturas mejoradas en casi todas las tierras recuperadas resultará en una disminución regional de recursos de fauna en comparación a las condiciones previas a las actividades mineras y a las condiciones presentes de hábitats transicionales. Las pérdidas inminentes podrían ser reducidas si se modifica los planes de recuperación, de tal manera que se provea a la fauna silvestre de hábitat, o si se orienta algunos de estos proyectos de recuperación de tierras específicamente hacia la explotación de los valores de la fauna.

9) Una segunda tendencia que propugna el uso de tierras arenosas como la principal superficie en recuperación, tiene el riesgo potencial de disminuir la calidad de la tierra, a gran escala, después de la extracción minera. Debido a que la naturaleza del suelo a ser recuperado es una variable clave, se debería dar regulaciones acerca de la calidad y profundidad del suelo en cuestión.

10) La evaluación de la productividad de tierras con aptitud minera se vería beneficiada si se obtiene mas información detallada acerca de sucesión en tierras arenosas, comunidades animales en hábitats aun no expuestos a minería, valor socio-económico de los recursos faunísticos a perder, experimentos de campo sobre técnicas de manejo de fauna y flora, hábitats recuperables en suelos que combinan arena y arcilla consolidada, y potencial agronómico y forestal de los suelos recuperados.

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INTRODUCTION

About 5180 square kilometers in central Florida have large phosphate resources accessible by surface mines. Beginning in the 1880s, mining has concentrated in the northern portion of the district, and about 750 square kilometers have been mined. These northern reserves will be depleted in the next 10 to 30 years, and mining operations will shift to the southern part of the district.

Loss of valuable environments and wildlife because of surface mining for phosphate has become a major conflict in Florida's land use planning. Mining of a non-renewable resource is a temporary but total use of the land, and its destructiveness makes mining unpopular among citizens whose individual benefits from the activity are small. However, demand for fertilizer to grow human food is increasing, and mining is expected to occur throughout the phosphate district. Government's challenge is to permit the extraction of necessary resources while minimizing losses over the long term. Consequently regulatory agencies need to focus on mining and reclamation practices that return land to attractive and useful conditions. At present, neither the preferred conditions nor appropriate reclamation practices have been determined or agreed upon by mining companies and regulatory agencies. Carefully considered criteria for quality need to be established, and future land use options (residential/industrial development, agriculture/silviculture, water storage, wildlife areas) need to be retained.

Because mineral extraction technology has become more efficient and because pumping rights for water (a limiting factor for mine operation) have been regulated as a per-acre water crop, mining companies have tried to hold their lands as cheaply as possible for eventual re-mining and to qualify for consumptive water-use permits. Consequently no interest has operated to return the land to any other use, and no intrinsic incentive for reclamation has existed. Lands that have escaped re-mining have undergone natural recovery without prescribed manipulation of soil, topography, or pioneer biota.

Reclamation of newly mined lands became required by a 1975 state severance-tax law. A revision of the law in 1978 provided a mechanism to use tax money to reclaim pre–1975 mined lands and required mining companies to reclaim future mined lands as an internal feature of their operating economies. During the past decade, county governments have imposed reclamation requirements with specific regulations designed to protect the future contribution of mined lands to the property tax base. County and state regulations often conflict, and they have poorly understood implications for biological recovery.

The shift of new mining southward and the areawide practice of reclamation are major developments in determining land use. Results to be expected in the northern part of the district are nearly ubiquitous reclamation with unknown impacts, followed by either conversion of the land to productive non-mining uses by the companies or release of large tracts for sale. In the southern part of the district, the entire cycle of mining-related land use will occur, from destruction of existing uses, through temporary types, to subsequent reclamation for unknown purposes.

Now that the decision to reclaim mined land has been made, the results of reclamation practices need to be evaluated. The quality of reclaimed land is reflected by biological responses to site treatments. Plant growth and wildlife use are meaningful criteria of quality because they show the ability of the land to support natural communities, agriculture, or silviculture, and they are major components of the aesthetic character of the land. The purpose of this study was to document plant succession and wildlife use on the abandoned and reclaimed sites in the central Florida phosphate district.

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METHODS

Research Design

This research was designed to evaluate the terrestrial habitats that have been created after mining in central Florida. Included were both reclaimed sites and those that were left to recover without manipulation. Successional changes were detected by studying sites of different ages. Major components of the biological community were documented in terms of their identity, abundance, and diversity, and these were evaluated as responses to site treatment. These groups of organisms included plants, insects, reptiles and amphibians, birds, and mammals. Measurements were done with systematic, standardized sampling methods that enabled comparison of all habitats and sites. Three separate sites were studied for each post-mining treatment, with the replicates selected to represent the full range of site variation evident from visual examination of soil, topography, and vegetation. Plants were measured once during the study, whereas animals were measured quarterly to enable detection of seasonal changes while producing realistic average values for the year.

STUDY AREAS

The 24 study areas were located in Polk County, Florida, and comprised three replicates each of eight post-mining treatments (Table 1). The first category, consolidated clay settling ponds, is the terrestrial habitat resulting from consolidation of clay waste stored in large ponds. After slime ponds are filled with colloidal clay, they slowly dry out by evaporation and transpiration. When the surface clay of a site compacts into a thick crust with deep cracks, it has made the transition from aquatic to terrestrial habitat, and the dewatered pond is no longer subject to regulations of the Environmental Protection Agency. Data from these sites can be compared with data from the younger artificial marshes (see Gilbert et al. 1981). Subsequent successional stages seldom occur because these areas become subject either to re-mining or to reclamation by capping with sand tailings. Because the latter practice is a recent development, fully reclaimed sites were unavailable

Table 1. Study sites, showing eight treatments with three replicates of each.

	Replicates		
Treatments	1	2	3
Consolidated Clay Settling Ponds	Swift	N-2	A-3
Unreclaimed Pits and Spoil Piles			
0–5 years with lakes	Big Teeth	Shark Tooth	Young Tiger
5–15 years with lakes	Orange Grove Pits	Tiger Tail	Tiger Bay South
15–30 years with lakes	Homeland Cemetery	Gator Lake	Achan-4
>30 years with lakes	Bartow South	Saddle Creek Park	Sanlan Ranch
>30 years without lakes	Old Spoil Piles	Christina	Old Clarke James
Reclaimed Pastures			
Ungrazed	Parcel B	Noralyn	Kibler
Grazed	6-D	Marina East	H-4

for study. However, current trends indicate that a major area of land will be formed by this process.

Mining activities leave a series of roughly parallel spoil piles and pits. In flat regions the pits fill with groundwater, leaving steep emergent hills interspersed with lakes whose size depends on whether water levels are high enough to connect many pits. Along topographic ridges and in the upland slopes around freshwater marshes, the spoil piles are sufficiently drained that no lakes develop. With or without lakes, these spoil areas normally were abandoned without modification prior to the reclamation required by 1975 Florida law, and such lands are viewed by the public as "moonscapes." Spoil piles are steep and easily eroded but become stabilized by vegetation. The soil of spoil piles consists of the mixed sand and clay of the overburden that is set aside to gain access to the phosphate ore. The steep underwater slopes do not support littoral vegetation, which is limited to areas where erosion has created gentler gradients.

Because of the long history of mining in central Florida, unreclaimed spoil piles and pits have become a dominant landform in the region, with different tracts available in a continuous age sequence up to about 50 years old. The research design included four successional stages of this sequence, to determine what communities result from natural recovery after mining. Successional categories were established as 0–5, 5–15, 15–30, and >30 years after mining, based on historical records of the mining companies. A fifth treatment included was the most mature category without the aquatic habitat of interspersed lakes. This more homogeneous site treatment was expected to support a community distinct from that with lakes, to be more directly comparable to unmined native forests, and to provide insight to reclamation planners in comparison with the type including lakes.

Reclamation began on a significant scale on these mined lands in 1975. Consequently reclaimed sites are young and few alternative types of treatment are fully accomplished. The most widely practiced reclamation treatment has been to fill old mine pits with sand tailings and cap the area with overburden. The sand and clay soil is contoured to a flat or gently rolling surface and planted with exotic legumes and grass to stabilize the soil. These reclaimed pastures are either ungrazed or leased to private individuals who fence the areas, fertilize as needed, and stock them with cattle. Reclaimed areas that are not grazed are mowed twice annually to maintain the potential of these areas as pastures. The mowing arrests succession at a stage of non-native pasture. Both ungrazed and grazed pastures were included in the research design to document wildlife use on reclaimed land and to indicate cattle stocking levels achieved in practice. Other types of reclamation that are beginning to be practiced will be considered in the Discussion.

FIELD WORK

Field work was conducted from 17 October 1978 trough 3 July 1979 and was split into four quarters to measure seasonal variation in wildlife communities and habitat use. The quarterly field periods were: Autumn, 17 October–3 December 1978; Winter, 8 January–2 March 1979; Spring, 13 March–6 May 1979; and Summer, 1 June–3 July 1979.

Bird, small mammal, and insect communities were systematically sampled on each site during each of the four quarters. Plant communities were sampled in May and June. Evidence and observations of larger mammals and herpetofauna were recorded throughout the field work. Not all sites were selected in time to be sampled during the autumn quarter. These sites are indicated in Tables 3, 7, and 11, and missing data are identified where appropriate in the Results. The full complement of study sites was available for sampling during the other three quarters.

SAMPLING TECHNIQUES

VEGETATION.—Plant community sampling was conducted along a 100 m transect in each study site. Percent cover of shrubs, woody vines, and tree seedlings <5 cm dbh was measured along the transect with a line-intercept method. Herbaceous vegetation was sampled using ten 20 cm x 50 cm plots, located at 10 m intervals along the transect. Plants were identified to species level, and percent cover in each plot was visually estimated. Plant names agree with those used by Radford et al. (1964) and Long and Lakela (1976).

Tree species were sampled using 20 of 40 cells, each 10 m long and 5 m wide, by selecting every other cell on each side of the 100 m transect. In each cell, trees (>5 cm dbh) were identified and counted. Height was measured with an optical clinometer, and diameter at breast height (dbh) was measured with a tape measure. Basal area (BA) was computed for each species using the formula

$$BA = \frac{D^2}{4}$$

where D = dbh. Frequency of occurrence for each species was obtained for the 20 cells. Relative frequency (RF), relative abundance (RA), and relative dominance (RD) for each species were calculated using the frequency of occurrence, number of stems, and basal area respectively compared with the totals for each transect. An importance value (I) was then assigned to each species such that I = RF + RD + RA.

SMALL MAMMALS.—Small mammal communities were sampled once each quarter using both Sherman live traps and museum special snap traps. A removal technique was employed and all animals caught were identified, weighed, and measured, and age class and reproductive status were noted. Each site was trapped for three consecutive nights using 64 stations consisting of one live trap and one snap trap baited with peanut butter and oatmeal. These stations were arrayed in two 4 x 8 grids, with trap stations 8 m apart. Traps were checked each morning and rebaited as necessary.

BIRDS.—Avian communities were sampled using a variable-width transect method (Emlen 1971). Transects were walked through study sites during the first 2.5 hours after sunrise, and all birds seen or heard were tallied, along with the distance from the transect when first detected. Birds were excluded if they occurred beyond 100 m of the transect line. Transect counts were standardized by extrapolating to the equivalent of a 1 km transect. In all but the first quarter, time permitted transects to be run twice on different days on each site. During autumn quarter, only one run was conducted.

Following Emlen's method, a coefficient of detectability (CD) was calculated for each species, each type of habitat, and each quarter. These coefficients were then used to correct the original count data to provide a more reliable estimate of the number of birds present within the transect boundaries. A separate set of CDs was computed for each of the 8 treatment classes, except that the two types of reclaimed pastures were considered as one group.

Biomass estimates were made from several sources, including the University of Florida bird collection, Clench and Leberman (1978), Greenewalt (1975), and incidental weight measurements made on birds during field work.

INSECTS.—Insects were sampled using light traps with 8 watt blacklight bulbs (BioQuip Inc., 1320 E. Franklin Ave., El Segundo CA 90245). Light traps were set 1–2 m above the ground in the evening and retrieved early the next morning. The samples were oven-dried for 48 hours at 70°C and then were weighed to yield biomass data. Time permitted only 1 set of samples (those from winter quarter) to be sorted to Order. The diversity values used in this report are from that quarter.

Only three light traps were available for use, and technical problems at times reduced that number to two or even one. This caused the sampling of all sites to be spread out over at least ten days and at times much longer. This factor added to the high variance in the data expected from the nature of insect hatches and insect responses to weather variation.

HERPETOFAUNA.—Original plans called for pitfall-with-drift-fence trap arrays to be constructed on each site, but this proved to be impractical due to the time required in maintenance of the traps, as well as the destruction of traps by humans and cows. Consequently, reptiles and amphibians were simply noted when observed in the course of other field work. The result was a list of species without quantification of relative abundance.

LARGE MAMMALS.—Much the same situation existed with this class of wildlife as with the herpetofauna. A systematic, quantified method of counting tracks along dirt roads was applied but proved unfeasible because of the clay substrate and heavy vehicular travel. Tracks, scats, and sightings were recorded when encountered during other activities on the sites.

DATA ANALYSIS

The simplest method of characterizing post-mining treatments was by comparing lists of the kinds of plants and animals that were present after recovery. However, more rigorous comparisons involved indices of abundance and diversity that reflected differences among the communities supported by the post-mining treatments. The number of individuals and biomass provided measures of relative abundance. These two variables normally show similar trends for animal communities, but not for plants. The Shannon-Wiener index (Shannon and Weaver 1949) was used to measure species diversity, defined as $H' = -\Sigma p_i \ln p_i/p_i$, where p_i is the proportion of individuals in species i. This diversity index has two major components. The first is the number of species, or species richness, which is the fourth type of variable used in our comparisons. The second component is equitability, or the evenness of distribution of the species, and is defined as $E = H'/H_{max}$ (Sheldon 1969), where H_{max} is the natural log of the number of species. Equitability was not extensively used in this report. Like the measures of abundance, H' and the species number usually show similar trends of diversity (for both plants and animals). Generally all four quantitative evaluations are presented together to provide a thorough view of community structure and to emphasize the differences and similarities between treatments.

STATISTICAL ANALYSIS

Statistical analyses of these data were performed by version 79.2B of the Statistical Analysis System, using the computational facilities of the Northeast Regional Data Center at the University of Florida.

For statistical analysis the results were separated into two data sets—the annual or aseasonal measurements of 12 variables involving plants, herpetofauna, and large mammals, and the seasonal (quarterly) measurements of 9 variables involving small mammals, birds, and insects. Two sets of hypotheses were posed for each data set. One tested for differences among the relatively stable end results of post-mining land use, including five treatments (consolidated clay settling areas, unreclaimed pits and spoil piles) > 30 years with lakes and without lakes, and both ungrazed and grazed pastures). The other tested for trends over the years of the successional sequence on unreclaimed pits and spoil piles with lakes. Rather than evaluating seral sites simply as replicated sites within treatments, each was considered as an observation with a specific age in years. Throughout the analysis, some data were transformed to ensure constant variances (Steel and Torrie 1960). Small value counts and measurements of area were transformed by $(y + 0.5)^{1/2}$. Large value counts were transformed by $\log(y + 1)$. And weights were transformed by $y^{1/3}$. F-tests were made with alpha = 0.05 using multivariate analysis of variance. Because of sites and variables missed during autumn sampling, the autumn data were deleted from the seasonal data set. For both site age and final land uses, analysis of variance was begun by testing for interaction between season and age or treatment. No significant interaction occurred, though for most variables there was a strong seasonal effect. Therefore the analyses of seasonal and aseasonal data were identical. Distinctness of final land uses was first tested by applying Duncan's multiple range test to treatment means. Natural contrasts anticipated in the experimental design were confirmed as groups by the Duncan's test, so the more powerful analysis of variance specifying these contrasts was conducted (combined over seasons for seasonal data) to look for more subtle distinctions between contrasted treatments. Contrasts were as follows: mature unreclaimed sites with vs. without lakes, ungrazed vs. grazed pastures, clay vs. mature unreclaimed sites, and clay vs. reclaimed pastures. Significance of hypothesized age effects was established by pooling sums of squares of non-significant responses in with the error sum of squares until only significant effects remained. The effect of site age was modelled by computing equations of significant variable responses to site age, using linear regression of the transformed data. Finally, simple relationships between animal and plant variables were sought by stepwise multiple regression.

RESULTS

VEGETATION

CONSOLIDATED CLAY SETTLING PONDS.—The three sites were chosen to exhibit a successional sequence within the treatment—the Swift site supporting the youngest community (Fig. 1) and A–3 having the oldest (Fig. 2). This sequence was reflected in the vegetation analysis (Table 2). The Swift site was dominated by a dense, young stand of willow (*Salix caroliniana*) and a few *Baccharis*, with a well-developed understory of grasses. This site was wet enough that cattails (*Typha* sp.) and rushes (*Juncus* sp.) also were established in places. Most willows in this situation were too small to be considered trees (dbh <5 cm) and thus were measured as shrubs.

The intermediate-age settling area, N–2, also was dominated by willow, but these were much larger than in the Swift site. Willows of tree size in N–2 had a mean dbh of 6.3 cm and a mean height of 4.4 m. Herb cover, shrub cover, and shrub diversity were somewhat higher than at the Swift site. However, willows still heavily dominated the shrub layer.

Tree-size wax myrtle (*Myrica cerifera*) dominated A–3, the oldest settling area, but willows were still well established. These willow trees were generally larger than the wax myrtles and occurred in wet depressions. In addition, numerous dead trees all were found to be willows. Vines dominated the shrub and herbaceous cover, but this may be misleading because the crowns of the abundant, young wax myrtles were intermixed with the crowns of the mature trees, and it was impossible to determine what percent of the cover was contributed by the younger trees. In this case only shrubs less than 3 m in height were measured. No herbaceous vegetation was present. This late successional community on clay settling ponds is unlike undisturbed mature vegetation found in

Figure 1.—Thicket on a Consolidated Clay Settling Pond, the Swift site. Willows are in the Foreground, light seed heads of *Andropogon* are in the center, and dark wax myrtle and *Baccharis* shrubs are scattered in the background.

the region. The single black cherry (*Prunus serotina*) found in A–3 is considered to be an artifact, because this individual was located near a spoil pile island, and it may have been rooted in that substrate rather than in the clay itself.

Combined as a class, the consolidated clay settling ponds showed moderate abundance values for herbaceous and shrub vegetation, and diversities were generally quite low (Figs. 3–5). Both abundance and diversity values for trees were very low, except that the number of individuals was higher than in any other site category (Table 2).

It appears that clay settling ponds tended to progress toward a monotype of wax myrtle, an unnatural successional pattern. However, effects and interactions of the clay crust, the underlying colloidal clays, distance from native seed sources, and the allelopathic effects of wax myrtle (Dunevitz and Ewel 1981) are not fully understood. Further research is necessary on these factors, but it will require study of older and more isolated settling areas.

UNRECLAIMED PITS AND SPOIL PILES.—Beginning the successional sequence of unreclaimed treatments, vigorous oldfield succession occurred in the 0–5 year age class (Figs. 6–7). The three measures of her-

Figure 2.—Interior of the A–3 clay waste site. The ground is devoid of herbaceous plants, and a dense forest canopy is formed by wax myrtle (left) and willow (leaning from right).

baceous growth began at low to moderate levels soon after mining, as ragweed (*Ambrosia artemisiifolia*), dog fennel (*Eupatorium album*), and natal grass (*Rynchelytrum repens*) began to colonize the bare spoil piles. Only a few shrubs (*Baccharis*) were present, and trees were absent.

Herbaceous communities reached peak levels of abundance and diversity in the 5–15 year age class (Figs. 8–9), as Caesar weed (*Urena lobata*), cogongrass (*Imperata cylindrica*), and *Andropogon* sp. became established and dog fennel disappeared. Shrubs, vines, and saplings increased markedly in this period, the major species being *Baccharis*, *Lantana camara*, grape (*Vitis rotundifolia*), blackberry (*Rubus* spp.), and several kinds of saplings. Trees also became established in this interval, primarily pioneer species like willow, wax myrtle, and *Baccharis*, along with the exotic Brazilian pepper (*Schinus terebinthifolius*).

Shrubs dominated the vegetation in the 15–30 year age class (Figs. 10–11), as herbaceous growth became less prominent and trees continued their invasion of the sites. Cogongrass was no longer present, and panic grass (*Panicum dichotomiflorum*) and shade-tolerant ferns (*Polystichum acrostichoides* and *Thelypteris normalis*) joined the association. Shrub composition was similar to the previous age class, with significant

Table 2. Summary of plant diversity and abundance.

Treatments Sites	Herbaceous Vegetation			Shrubs			Trees			
	Diversity		Abundance	Diversity		Abundance	Diversity		Abundance	
	Number of species	H'	% cover	Number of species	H'	% cover	Number of species	H'	Number of individuals	Total basal area
Consolidated Clay Settling Ponds										
Swift	4	0.71	17.7	4	0.46	47.9	1	0	7	191
N-2	2	0.67	28.8	5	0.79	77.9	1	0	134	4,244
A-3	0	0	0	9	1.11	33.3	2	0.66	331	14,879
Mean ± standard deviation	2.0 ±2.0	0.46 ±0.39	15.5 ±14.5	6.0 ±2.6	0.78 ±0.32	53.0 ±22.7	1.3 ±0.6	0.22 ±0.38	157.3 ±163.2	6,438 ±7,586
Unreclaimed Pits and Spoil Piles										
0–5 Years With Lakes										
Big Teeth	3	1.03	5.0	1	0	4.0	0	--	0	--
Shark Tooth	5	1.33	3.0	1	0	1.7	0	--	0	--
Young Tiger	7	0.84	39.5	3	0.82	11.3	0	--	0	--
Mean ± standard deviation	5.0 ±2.0	1.06 ±0.24	15.8 ±20.5	1.7 ±1.2	0.27 ±0.47	5.7 ±5.0	0	--	0	--
5–15 Years With Lakes										
Orange Grove Pits	13	1.49	43.7	10	1.46	71.9	4	1.30	17	1,183
Tiger Tail	11	1.54	39.3	12	1.88	122.4	2	0.40	36	1,559
Tiger Bay South	6	1.54	51.8	10	1.62	53.4	3	0.76	11	487
Mean ± standard deviation	10.0 ±3.6	1.52 ±0.02	44.9 ±6.3	10.7 ±1.2	1.65 ±0.21	82.6 ±35.7	3.0 ±1.0	0.82 ±0.45	21.3 ±13.0	1,076 ±544

15–30 Years With Lakes										
Homeland Cemetery	6	0.86	29.7	12	1.76	23.5	8	0.82	200	19,655
Gator Lake	7	1.54	33.1	13	1.96	27.1	3	0.33	69	8,364
Achan-4	6	1.21	36.0	6	0.88	78.1	3	0.41	60	3,061
Mean ± standard deviation	6.3 ±0.6	1.20 ±0.34	32.9 ±3.2	10.3 ±3.8	1.53 ±0.57	42.9 ±30.5	4.7 ±2.9	0.52 ±0.26	109.7 ±78.4	10,360 ±8,475
>30 Years With Lakes										
Bartow South	7	1.61	17.8	18	2.29	63.0	8	1.64	113	18,672
Saddle Creek Park	6	1.30	15.0	19	1.78	125.5	10	1.76	93	19,084
Sanlan Ranch	4	0.72	11.8	15	2.12	23.5	10	1.69	68	20,797
Mean ± standard deviation	5.7 ±1.5	1.21 ±0.45	14.9 ±0.30	17.3 ±2.1	2.06 ±0.20	70.7 ±51.4	9.3 ±1.2	1.69 ±0.06	91.3 ±22.5	19,518 ±1,127
>30 Years Without Lakes										
Old Spoil Piles	4	1.00	23.4	17	2.09	31.7	4	0.76	31	23,994
Christina	9	1.55	26.5	18	2.06	35.4	4	1.23	18	21,968
Old Clarke James	0	0	0	17	1.56	82.9	4	0.81	44	25,671
Mean ± standard deviation	4.3 ±4.5	0.85 ±0.78	16.6 ±14.5	17.3 ±0.6	1.90 ±0.29	50.0 ±28.6	4.0 ±0.0	0.93 ±0.25	31.0 ±13.0	23,877 ±1,854
Reclaimed Pastures										
Ungrazed										
Parcel B	3	0.12	51.3	1	0	0.0	0	--	0	--
Noralyn	6	0.72	47.5	1	0	0.2	0	--	0	--
Kibler	5	0.42	69.6	1	0	0.1	0	--	0	--
Mean ± standard deviation	4.7 ±1.5	0.42 ±0.30	56.1 ±11.8	1.0 ±0.0	0 ±0.1	0.1	0	--	0	--
Grazed										
6-D	2	0.11	43.5	0	--	0	0	--	0	--
Marina East	6	0.61	63.4	1	0	0.4	0	--	0	--
H-4	9	1.52	62.3	3	0.46	4.4	0	--	0	--
Mean ± standard deviation	5.7 ±3.5	0.74 ±0.71	56.4 ±1.5	1.3 ±0.32	0.23 ±2.4	1.6	0	--	0	--

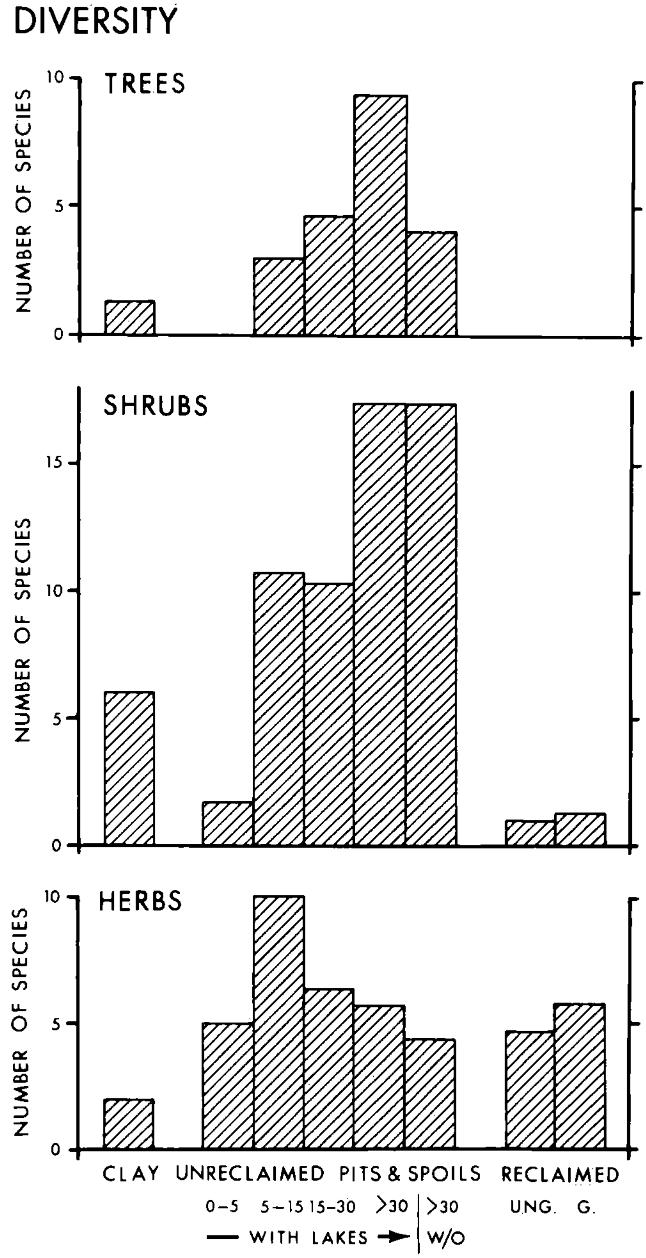

Figure 3.—Summary of plant diversity (as measured by species number) on Consolidated Clay Settling Ponds, Unreclaimed Pits and Spoil Piles, and Reclaimed Pastures. Abbreviations refer to whether pastures are grazed or ungrazed and to the age and presence or absence of lakes on unreclaimed sites.

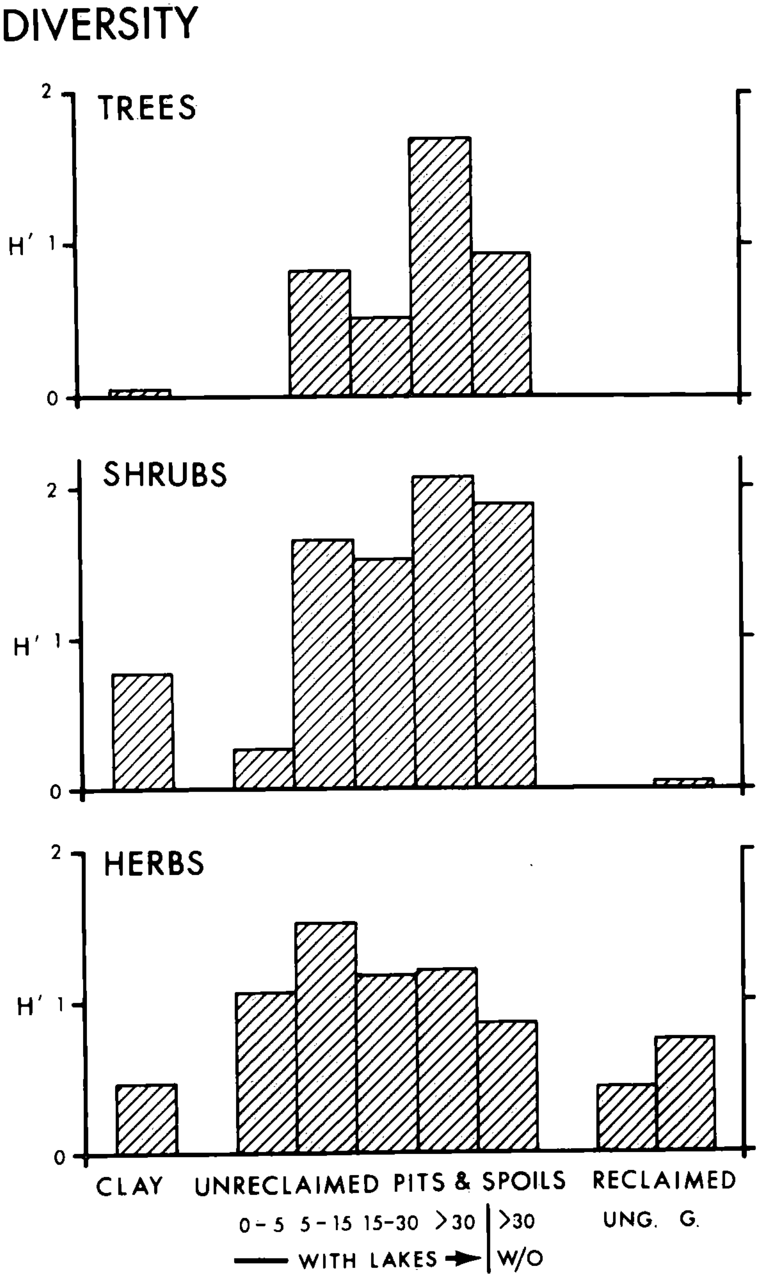

Figure 4.—Summary of plant diversity, as measured by the diversity index H'. Treatments and abbreviations are as in Figure 3.

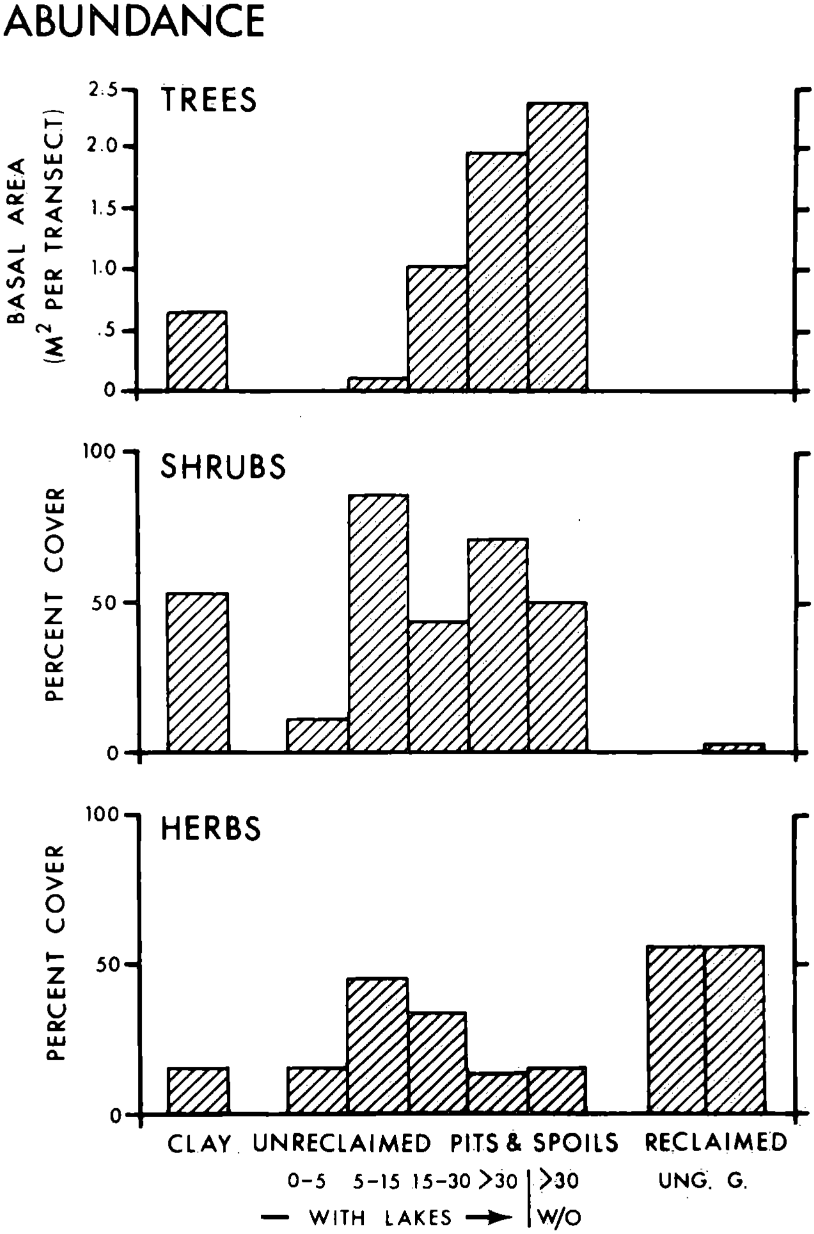

Figure 5.—Summary of plant abundance on Consolidated Clay Settling Ponds, Unreclaimed Pits and Spoil Piles, and Reclaimed Pastures. Abbreviations are as in Figure 3.

Figure 6.—The Shark Tooth site, Unreclaimed Pits and Spoil Piles, 0–5 years with lakes. Near the beginning of the time range, the mine is being enlarged by a dragline in the background. The low water level in pit bottoms is maintained by pumping while mining continues.

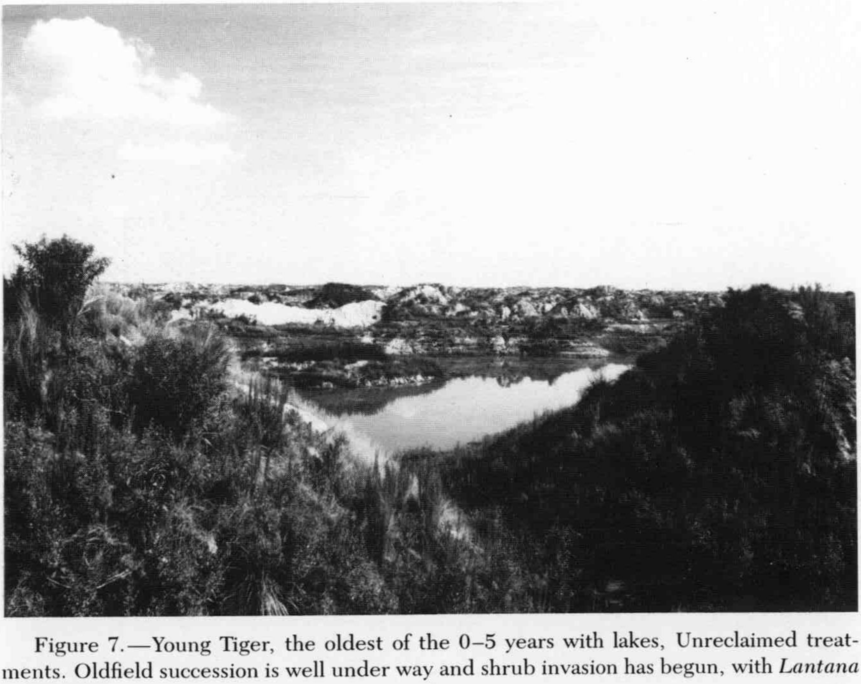

Figure 7.—Young Tiger, the oldest of the 0–5 years with lakes, Unreclaimed treatments. Oldfield succession is well under way and shrub invasion has begun, with *Lantana* on the left.

Figure 8.—Tiger Tail, 5–15 years old with lakes, Unreclaimed Pits and Spoil Piles, showing advanced oldfield growth and shrub invasion. Foreground has *Baccharis* high on the left, dog fennel downslope, and willow near the lake edge.

Figure 9.—Tiger Bay South, Unreclaimed Pits and Spoil Piles, 5–15 years with lakes, showing extensive shrub growth.

Figure 10.—Gator Lake, 15–30 years old with lakes, Unreclaimed Pits and Spoil Piles, showing extensive shrub and tree growth. In the foreground are wax myrtle, and the background trees include a volunteer slash pine near the right.

Figure 11.—Achan–4, Unreclaimed Pits and Spoil Piles, 15–30 years with lakes. Two patches of cattail remain along the bank at center and left.

addition of sapling wax myrtle and Brazilian pepper and reduction of blackberry. Small wax myrtle trees became very abundant, and many pioneer and shade-tolerant species entered the community.

Trees were the most abundant plants in the >30 year age class with lakes (Figs. 12–13), though shrubs remained more diverse than trees. Herbaceous vegetation continued to decline in prominence, with ferns and panic grass becoming more important components. Changes in shrubs included a reduced *Baccharis* contribution, appearance of new shade-tolerant species, prominence of Brazilian pepper at one site, and continued diversification of vines. Trees increased strikingly in diversity and abundance. Wax myrtle and other pioneer species diminished in importance as exotic Brazilian pepper and camphor tree (*Cinnamomum camphora*) and native forest species like sweetgum (*Liquidambar styraciflua*), water oak (*Quercus nigra*), live oak (*Q. virginiana*), and American elm (*Ulmus americana*) dominated the canopy.

Vegetation on the >30 year age class without lakes (Figs. 14–15) differed in several respects from that on the sites with lakes, though it was similar in high tree abundance. Herbaceous associations were similar,

Figure 12.—Bartow South, >30 years with lakes, Unreclaimed Pits and Spoil Piles. Most of the trees are water oaks. Grass in the foreground is the edge of a road used frequently by recreational visitors. With spoil piles partly leveled, this habitat was called "land and lakes" prior to the uniform reclamation regulations implemented in 1975.

Figure 13.—Saddle Creek Park, >30 years with lakes, Unreclaimed Pits and Spoil Piles, with an elm and several red maples on the left. The forest canopy completely shades the water's edge.

characterized by Caesar weed, ferns, and panic grass. One site had little herbaceous growth but an unusual abundance of grape vines. Shrubs were similar in identity on the two treatments, but grape vines were dominant, and young trees and shrubs were few on all of the sites without lakes, giving the shrub layer an open appearance. The abundance of vines may be underestimated, because much vine growth was high in the forest canopy where our sampling technique was relatively ineffective. Unlike the with-lakes treatment, all sites without lakes were dominated by a closed canopy of live and water oaks, with more biomass but much less diversity. Relictual pioneers from earlier seral stages were scarce.

To summarize the response of vegetation on unreclaimed pits and spoil piles, we documented a primary successional process, with an oldfield community developing in 0–5 years and peaking in 5–15 years, a shrub-dominated community in 15–30 years, and a maturing, closed-canopy hardwood forest at >30 years. Mean total basal area of trees steadily increased with the age of the spoil piles (Fig. 5), as biomass accumulated in the growing trees. Forest composition differed in old sites with and without lakes. Presumably the more diverse forests on with-lakes sites resulted from the gradients of groundwater and sunlight along lake edges,

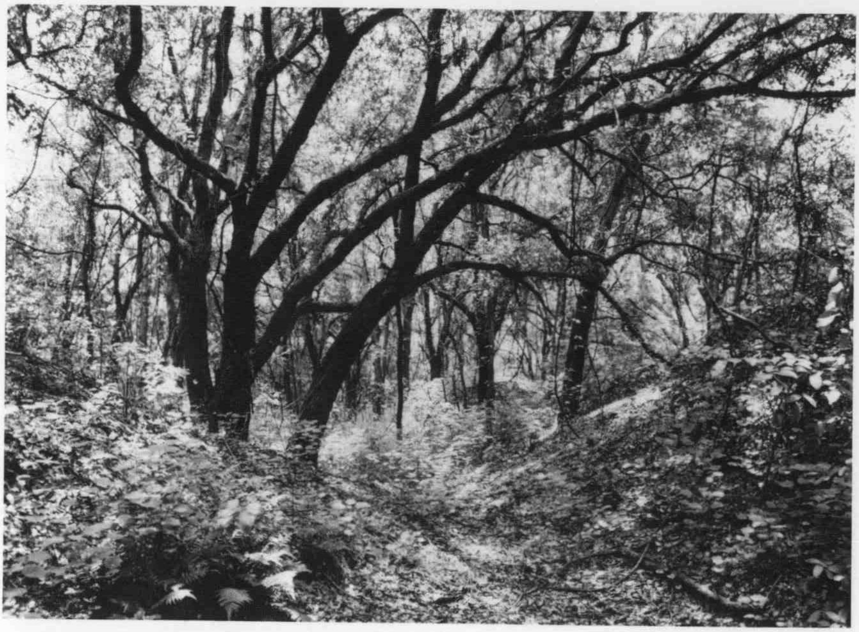

Figure 14.—Old Spoil Piles, Unreclaimed >30 years without lakes. The forest canopy is dominated by live oaks and grape vines. Caesar weed and ferns are in the foreground. Four piles of overburden are visible. The terrain slopes to Hooker's Prairie toward the rear.

whereas the more uniform live oak/water oak forests resulted from more uniform physical characteristics of environments lacking lake edges. Compared with communities maintained on consolidated clay settling ponds and reclaimed areas (Figs. 3–5), the maturing forests on unreclaimed pits and spoil piles were far higher in diversity and abundance of plant life.

RECLAIMED PASTURES.—The reclaimed sites were grassy fields, either ungrazed (periodically mowed, Fig. 16) or grazed (Fig. 17). Both treatments were dominated by exotic bahia grass (*Paspalum notatum*), hairy indigo (*Indigofera hirsuta*), and native partridge pea (*Cassia fasciculata*). Both treatments had a few colonizing shrubs, mainly *Baccharis*.

The most heterogeneous sites (H–4 and Kibler) were inadequately represented by our samples. In each reclaimed treatment, sites were chosen to span the range from homogeneous bahia grass pasture (as in Fig. 17 for the grazed treatment) to patchy habitat that included pasture and mesic swales, ditches, and ponds that were subject to less grazing or mowing pressure (as in Fig. 16 for the ungrazed treatment). The full range of plant diversity among sites was underestimated because of un-

Figure 15.—Old Clarke James, Unreclaimed >30 years without lakes. This site had the spoil piles partly leveled, and the forest was more mesic than at Old Spoil Piles, with more water oaks (background) mixed with the live oaks (foreground and left).

sampled patches of various habitats on H–4 and Kibler. We avoided the non-pasture patches of habitat in sampling both plants and animals, but these areas nonetheless affected the data for mobile animals.

Though the two treatments were similar in amount of plant cover, the grazed sites were consistently more diverse than the ungrazed sites (Figs. 3–5), resulting from selective cropping by grazers and non-selective harvest by mowing machines. The herbaceous cover was more abundant than for any of the other treatments, as is expected in the absence of competition from shrubs and trees. Herbaceous diversity, however, was comparable to that on both consolidated clay settling areas and mature unreclaimed pits and spoil piles.

SMALL MAMMALS

The results of sampling for small mammals are summarized in Tables 3–6. A total of nine species was sampled during the study.

CONSOLIDATED CLAY SETTLING PONDS.—The clay areas supported populations of cotton mice (*Peromyscus gossypinus*) and some rice rats (*Oryzomys palustris*), cotton rats (*Sigmodon hispidus*), house mice (*Mus*

Figure 16.—Kibler, the most heterogeneous Reclaimed, Ungrazed site. Reclamation consisted of leveling the overburden piles, leaving scattered ponds (right background) and marshes. Oldfield succession is arrested by mowing twice a year. Since the implementation of reclamation regulations in 1975, a combination of mowed grassland with ponds or lakes is referred to as "land and lakes reclamation."

musculus), and two species of shrews (*Blarina carolinensis* and *Cryptotis parva*). As the willow thicket developed and later the wax myrtle canopy closed, the semi-arboreal *P. gossypinus* became very abundant, *Sigmodon* populations remained unchanged, and the *Mus* and shrews became less abundant. The result was that diversity values generally decreased from the youngest stage (Swift) to the oldest (A–3), whereas abundance measures increased during the sequence. In comparison with other treatments (Fig. 18), the diversity and abundance of small mammals on clay wastes were moderate.

UNRECLAIMED PITS AND SPOIL PILES.—Beginning the successional sequence, moderately high small mammal diversity and abundance values were found in the 0–5 year old treatment (Fig. 16), indicating a strong colonization of the young herbaceous vegetation. Colonization of the unreclaimed land was by *Mus*, *Sigmodon*, *Oryzomys*, and some *P. gossypinus*. Single oldfield mice (*Peromyscus polionotus*) were captured at two of the youngest sites, Big Teeth and Shark Tooth (Fig. 6), but none occurred on older sites.

Figure 17.—6-D, the pasture with the least plant cover among Reclaimed, Grazed sites. Reclamation here involved filling in old mine cuts with fine sand tailings (resulting from recent flotation treatment of ore) and then flattening emerged spoil pile tops as a shallow overburden cap. Vegetation is bahia grass with some hairy indigo and rattlesnake weed in the foreground.

Additional species of small mammals established populations in the 5–15 year old treatment (Fig. 18), resulting in very high values. The population of *Mus* declined somewhat between the 0–5 and 5–15 year classes, but the major change was a substantial increase in the abundance of *Sigmodon*, *P. gossypinus*, and *Oryzomys*. Both events were normal responses to the increase in plant cover, particularly herbaceous species and vines. The pattern of increasing abundance was accompanied by similar increases in diversity, because most populations continued to grow and a new species (the eastern woodrat, *Neotoma floridana*) invaded.

In later seral stages, the small mammal community became less prominent, with moderate diversity and abundance levels. *Mus* became very uncommon and population levels of *Sigmodon* and *Oryzomys* fell. *P. gossypinus* populations remained fairly constant, whereas *Neotoma* became slightly more common. The reduction of *Mus* populations probably was caused by changing habitat characteristics, resulting from development of shrub and tree vegetation, and possibly by increased competition from other small mammal species. The drop in *Oryzomys* numbers may have

Table 3. Summary of small mammal diversity and abundance during autumn quarter. Asterisks denote sites not sampled during this quarter.

	Diversity		Abundance	
Treatments Sites	Number of species	H'	Number of individuals	Biomass (g)
Consolidated Clay Settling Ponds				
*Swift	--	--	--	--
N-2	1	0.00	5	156.0
A-3	3	0.74	32	1374.0
Mean ± standard deviation	2.0±1.4	0.37±0.52	18.0±19.1	765.0±861.2
Unreclaimed Pits and Spoil Piles				
0–5 Years With Lakes				
*Big Teeth	--	--	--	--
*Shark Tooth	--	--	--	--
*Young Tiger	--	--	--	--
Mean ± standard deviation				
5–15 Years With Lakes				
Orange Grove Pits	5	1.36	48	3305.3
Tiger Tail	7	1.69	38	2193.0
Tiger Bay South	4	1.15	62	3636.0
Mean ± standard deviation	5.3±1.5	1.40±0.27	49.3±12.0	3044.8±756.0
15–30 Years With Lakes				
*Homeland Cemetery	--	--	--	--
*Gator Lake	--	--	--	--
*Achan-4	--	--	--	--
Mean ± standard deviation				
>30 Years With Lakes				
Bartow South	2	0.19	21	1712.2
*Saddle Creek Park	--	--	--	--
*Sanlan Ranch	--	--	--	--
Mean ± standard deviation	2	0.19	21	1712.2
>30 Years Without Lakes				
Old Spoil Piles	1	0.00	6	188.0
Christina	3	0.86	13	380.0
Old Clarke James	2	0.24	15	490.6
Mean ± standard deviation	2.0±1.0	0.36±0.44	11.3±4.7	352.9±153.1
Reclaimed Pasture				
Ungrazed				
Parcel B	1	0.00	4	39.5
Noralyn	1	0.00	5	58.5
Kibler	3	0.64	89	5197.0
Mean ± standard deviation	1.7±1.2	0.22±0.36	32.7±48.8	1765.0±2972.2
Grazed				
6-D	0	0.00	0	0
Marina East	2	0.69	2	62.5
*H-4	--	--	--	--
Mean ± standard deviation	1.0±1.4	0.34±0.48	1.0±1.4	31.2±44.2

Table 4. Summary of small mammal diversity and abundance during winter quarter.

	Diversity		Abundance	
Treatments Sites	Number of species	H′	Number of individuals	Biomass (g)
Consolidated Clay Settling Ponds				
Swift	4	1.47	22	473.4
N-2	3	0.71	17	654.0
A-3	3	0.48	29	992.1
Mean ± standard deviation	3.3±0.6	0.88±0.51	22.7±6.0	706.5±263.3
Unreclaimed Pits and Spoil Piles				
0–5 Years With Lakes				
Big Teeth	4	0.90	14	262.5
Shark Tooth	3	0.34	25	301.5
Young Tiger	5	1.11	65	1952.0
Mean ± standard deviation	4.0±1.0	0.78±0.40	34.7±26.8	838.7±964.4
5–15 Years With Lakes				
Orange Grove Pits	4	0.89	67	4212.0
Tiger Tail	6	1.38	46	2699.4
Tiger Bay South	6	1.52	56	3808.7
Mean ± standard deviation	5.3±1.2	1.26±0.33	56.3±10.5	3570.0±788.9
15–30 Years With Lakes				
Homeland Cemetery	3	0.74	8	334.0
Gator Lake	4	1.23	34	2840.8
Achan-4	4	1.12	11	525.0
Mean ± standard deviation	3.7±0.6	1.03±0.26	17.7±14.2	1233.3±1395.4
>30 Years With Lakes				
Bartow South	1	0	4	457.0
Saddle Creek Park	3	1.06	5	574.0
Sanlan Ranch	3	1.06	5	519.5
Mean ± standard deviation	2.3±1.2	0.70±0.61	4.7±0.6	516.8±58.5
>30 Years Without Lakes				
Old Spoil Piles	1	0	11	296.5
Christina	5	1.33	14	321.0
Old Clarke James	3	0.80	7	291.5
Mean ± standard deviation	3.0±2.0	0.71±0.66	10.7±3.5	303.0±15.8
Reclaimed Pasture				
Ungrazed				
Parcel B	1	0	8	98.5
Noralyn	1	0	1	16.5
Kibler	3	0.40	37	2458.0
Mean ± standard deviation	1.7±1.2	0.13±0.23	15.3±19.1	857.7±1386.5
Grazed				
6-D	0	0	0	0
Marina East	4	0.25	12	169.0
H-4	4	1.19	22	1184.0
Mean ± standard deviation	2.7±2.3	0.48±0.62	11.3±11.0	451.0±640.4

Table 5. Summary of small mammal diversity and abundance during spring quarter.

	Diversity		Abundance	
Treatments Sites	Number of species	H′	Number of individuals	Biomass (g)
Consolidated Clay Settling Ponds				
Swift	2	0.66	8	683.3
N-2	3	0.83	16	706.5
A-3	2	0.17	25	761.0
Mean ± standard deviation	2.3±0.6	0.55±0.34	16.3±8.5	716.9±39.9
Unreclaimed Pits and Spoil Piles				
0–5 Years With Lakes				
Big Teeth	2	0.50	10	147.0
Shark Tooth	3	0.86	11	139.0
Young Tiger	3	0.83	26	710.5
Mean ± standard deviation	2.7±0.6	0.73±0.19	15.7±9.0	332.2±327.7
5–15 Years With Lakes				
Orange Grove Pits	4	1.21	27	1708.0
Tiger Tail	5	1.39	36	1817.7
Tiger Bay South	4	1.25	27	1264.4
Mean ± standard deviation	4.3±0.6	1.28±0.09	30.0±5.2	1596.7±293.0
15–30 Years With Lakes				
Homeland Cemetery	2	0.47	11	355.0
Gator Lake	3	1.08	15	957.5
Achan-4	4	1.12	11	1288.5
Mean ± standard deviation	3.0±1.0	0.89±0.36	12.3±2.3	867.0±473.3
>30 Years With Lakes				
Bartow South	2	0.68	12	1081.5
Saddle Creek Park	2	0.64	3	249.5
Sanlan Ranch	1	0.00	1	22.0
Mean ± standard deviation	1.7±0.57	0.44±0.38	5.3±3.8	451.0±557.8
>30 Years Without Lakes				
Old Spoil Piles	2	0.24	15	280.0
Christina	3	1.04	4	198.3
Old Clarke James	1	0.00	3	77.5
Mean ± standard deviation	2.0±1.0	0.42±0.54	7.3±6.6	185.3±101.9
Reclaimed Pasture				
Ungrazed				
Parcel B	2	0.69	2	61.0
Noralyn	0	0.00	0	0.0
Kibler	4	1.06	50	3830.1
Mean ± standard deviation	2.0±2.0	0.59±0.54	17.3±28.3	1297.0±2193.8
Grazed				
6-D	1	0.00	1	12.5
Marina East	0	0.00	0	0.0
H-4	4	0.89	21	1767.5
Mean ± standard deviation	1.6±2.0	0.29±0.51	7.3±11.8	593.3±1767.5

Table 6. Summary of small mammal diversity and abundance during summer quarter.

Treatments Sites	Diversity		Abundance	
	Number of species	H′	Number of individuals	Biomass (g)
Consolidated Clay Settling Ponds				
Swift	3	0.99	11	419.0
N-2	3	0.85	13	783.5
A-3	1	0.00	14	376.0
Mean ± standard deviation	2.4±1.2	0.61±0.53	12.7±1.5	523.8±225.6
Unreclaimed Pits and Spoil Piles				
0–5 Years With Lakes				
Big Teeth	3	0.79	13	397.9
Shark Tooth	2	0.38	8	101.1
Young Tiger	2	0.65	14	409.5
Mean ± standard deviation	2.3±0.6	0.60±0.20	11.7±3.2	302.8±174.8
5–15 Years With Lakes				
Orange Grove Pits	5	1.14	28	2275.0
Tiger Tail	3	0.97	42	3019.0
Tiger Bay South	5	0.99	55	4829.1
Mean ± standard deviation	4.3±1.2	1.03±0.09	41.7±13.5	3374.3±1313.6
15–30 Years With Lakes				
Homeland Cemetery	2	0.66	8	343.5
Gator Lake	4	1.00	20	1443.8
Achan-4	4	1.24	6	494.0
Mean ± standard deviation	2.9±1.0	0.96±0.29	11.3±7.6	760.4±596.6
>30 Years With Lakes				
Bartow South	3	0.74	8	704.0
Saddle Creek Park	3	0.84	9	763.1
Sanlan Ranch	2	0.64	3	487.0
Mean ± standard deviation	2.7±0.6	0.64±0.10	6.7±3.2	651.3±145.3
>30 Years Without Lakes				
Old Spoil Piles	1	0.00	18	471.3
Christina	3	1.05	5	393.0
Old Clarke James	2	0.27	13	410.0
Mean ± standard deviation	2.0±1.0	0.44±0.54	12.0±6.6	424.8±41.2
Reclaimed Pasture				
Ungrazed				
Parcel B	0	0.00	0	0.0
Noralyn	1	0.00	1	4.5
Kibler	3	0.25	25	2129.4
Mean ± standard deviation	1.3±1.5	0.08±0.14	8.7±14.2	711.3±1228.1
Grazed				
6-D	2	0.68	5	72.0
Marina East	1	0.00	1	13.0
H-4	4	0.85	18	1623.7
Mean ± standard deviation	2.3±1.5	0.51±0.44	8.0±8.9	569.6±913.4

MAMMALS

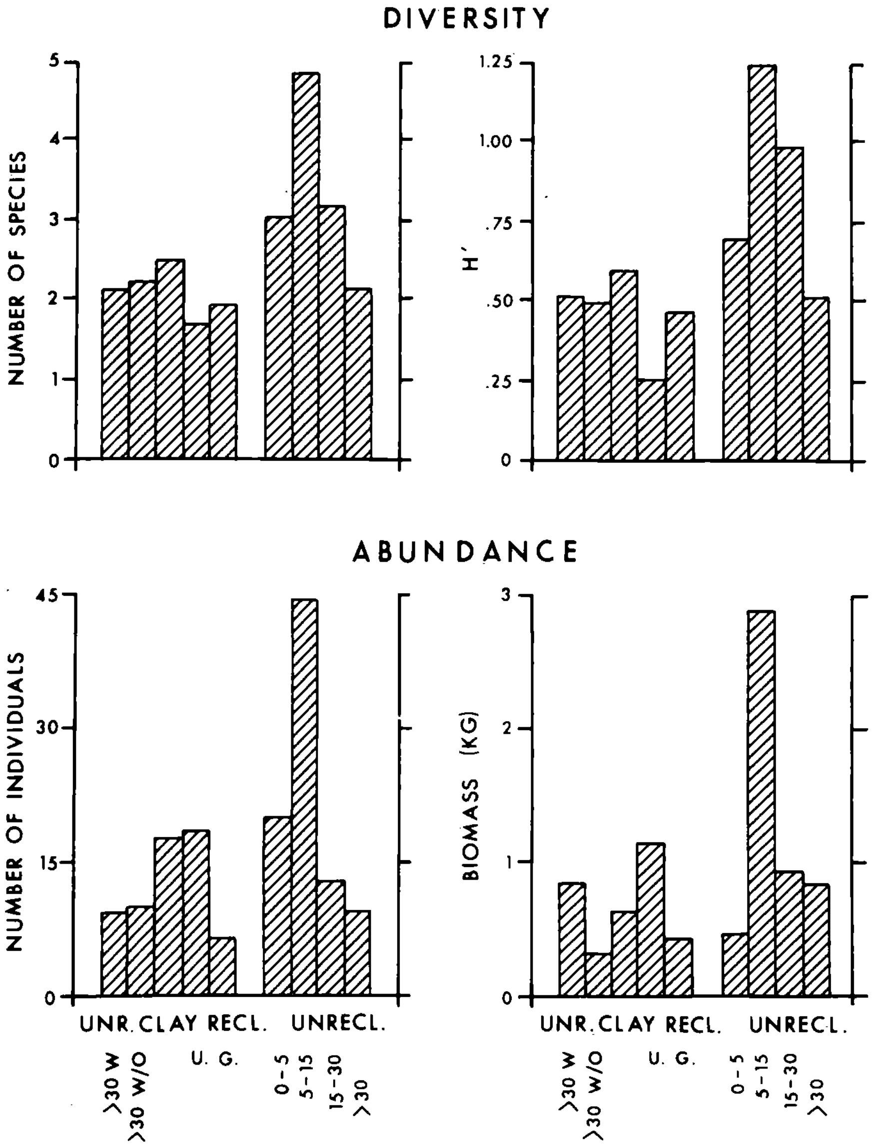

Figure 18.—Small mammal diversity and abundance, annual mean of quarterly means (n = 4). Abbreviations are as in Figure 3.

resulted from several factors. When pits were first abandoned, broad areas were available for marsh development because water levels were kept low by pumping. Over time water rose on the steep sides of the pits, narrowing the zone for littoral vegetation. When shrubs and trees grew on the bank, shading of cattails and other interactions may have become important. Whatever the mechanism, older sites characteristically had very little emergent marsh vegetation.

Lowest abundance occurred in the >30 year old class without lakes. However, the difference between the unreclaimed areas with lakes and those without was more evident in the species composition than in the diversity and abundance measures shown in Figure 18. The strictly terrestrial sites were heavily dominated by *P. gossypinus*, and other species were uncommon. The Christina site contributed much to the diversity of the treatment because both species of shrews (*Blarina carolinensis* and *Cryptotis parva*) and *Mus* occurred there. But these animals may have immigrated from adjacent habitats—a residential community and a grassy field. Woodrats were absent from these sites, except for one immature individual caught at Christina during the summer quarter. This animal also may have dispersed from neighboring locations.

In contrast, the mature sites with lakes had considerably fewer *Peromyscus*, while moderate populations of *Neotoma* and *Sigmodon* were found on most areas. This caused the difference in biomass between the two treatments, because these species are much larger than the *Peromyscus* that dominated the without-lakes community. *Sigmodon* probably was favored by the retention of herbaceous cover (Fig. 12) along recreational roads. *Neotoma* may have benefitted from the combination of mature forest and the structurally diverse vegetation along water edges.

Reclaimed Pastures.—In general the reclaimed pasture sites showed low to intermediate small mammal community measures compared with the other treatments (Fig. 18). These summary values are probably somewhat higher than the "typical" case for reclaimed sites in the region, because two sites, Kibler and H–4, accounted for 87% of the individuals and 97% of the biomass on both reclaimed treatments (Tables 3–6). This high concentration resulted from the dense populations of *Sigmodon* found in the tall stands of grass that escaped mowing or intensive grazing. Most of the modern reclamation treatments in the area more closely resemble the other sites, but the Kibler and H–4 sites may indicate the potential for succession if mowing and intensive grazing were to be reduced.

The difference between grazed and ungrazed reclaimed sites was affected by these two sites. The extraordinarily high numbers of *Sigmodon* at the Kibler site resulted in very high abundance values, whereas H–4 consistently had four species present in more even proportions, resulting in higher diversity for the grazed category.

BIRDS

The results of bird transects are summarized in Tables 7–10. A total of 150 species was observed in the mining region during the study, and 114 were recorded from the 24 discrete study sites.

CONSOLIDATED CLAY SETTLING PONDS.—In this treatment, both abundance and diversity values were low compared with the other seven treatments (Fig. 19). Most of the avifauna on these sites consisted of resident passerines that usually were associated with brushy habitats, including gray catbird, white-eyed vireo, common yellowthroat, red-winged blackbird, cardinal, and rufous-sided towhee. Only six non-passerine species were recorded from the treatment, and wading and water birds generally were absent. Two wetland species, common moorhen and common snipe, were seen in the Swift site, which was the wettest and least consolidated of the three. The low bird diversity and abundance of clay waste sites probably was related to the uniform and simple structure of the vegetation.

Most of the species in this treatment were permanent residents, and the bird community showed very little seasonal variation in either diversity or abundance (Tables 7–10). The abundance values in particular were low and remained low through the winter, when other categories of sites were used by flocks of either warblers (unreclaimed pits) or sparrows (reclaimed sites). Though non-resident wintering birds heavily used wax myrtle on unreclaimed sites, wintering birds were scarce on consolidated clay settling ponds despite abundant wax myrtle. Evidently an important component was lacking. Low amounts of insect biomass (Table 11) may have resulted in a short supply of protein for insectivorous or seasonally omnivorous birds.

UNRECLAIMED PITS AND SPOIL PILES.—In the successional sequence, the diversity and abundance measures increased with increasing age of the site but, unlike the small mammal data, reached their peak at a much later stage—either the 15–30 year class or the >30 year old class with lakes (Fig. 19).

The youngest class, 0–5 years old, was distinctly different from the older stages, with lower diversity and abundance measures as well as different species composition. This undoubtedly resulted from the early stage of oldfield succession on these sites. In some respects the avifauna on these young sites resembled that found on reclaimed pastures, with savannah sparrows, palm warblers, killdeer, and other shorebirds being common in both categories. In addition the lakes on these sites attracted the largest diversity of waterfowl of the eight categories. Nine species were observed there, compared with only three in the 5–15 year old pits. The reason for the high use by ducks is unclear. One possible expla-

Table 7. Summary of bird diversity and abundance during autumn quarter based on one-kilometer transects. Asterisks denote those areas that were not sampled this quarter.

	Diversity		Abundance	
Treatments Sites	Number of species	H'	Number of individuals	Biomass (kg)
Consolidated Clay Settling Ponds				
*Swift	--	--	--	--
N-2	8	1.80	247.7	6.51
A-3	4	1.04	269.6	7.59
Mean ± standard deviation	6.0±2.8	1.42±0.53	258.6±15.5	7.05±0.76
Unreclaimed Pits and Spoil Piles				
0–5 Years With Lakes				
*Big Teeth	--	--	--	--
*Shark Tooth	--	--	--	--
*Young Tiger	--	--	--	--
Mean ± standard deviation				
5–15 Years With Lakes				
Orange Grove Pits	15	2.32	829.5	224.98
Tiger Tail	14	2.18	1228.9	91.21
*Tiger Bay South	--	--	--	--
Mean ± standard deviation	14.5±0.7	2.25±0.9	1029.2±282.4	158.09±94.58
15–30 Years With Lakes				
*Homeland Cemetery	--	--	--	--
*Gator Lake	--	--	--	--
*Achan-4	--	--	--	--
Mean ± standard deviation				
>30 Years With Lakes				
Bartow South	22	1.45	2071.2	114.35
*Saddle Creek Park	--	--	--	--
*Sanlan Ranch	--	--	--	--
Mean ± standard deviation	22	1.45	2071.2	114.35
>30 Years Without Lakes				
Old Spoil Piles	3	0.84	62.2	0.66
Christina	4	1.19	118.1	7.00
Old Clarke James	6	1.57	228.6	17.02
Mean ± standard deviation	4.3±1.5	1.20±0.36	136.1±84.4	8.22±8.24
Reclaimed Pasture				
Ungrazed				
*Parcel B	--	--	--	--
Noralyn	10	1.70	869.6	94.03
Kibler	8	1.20	181.3	22.77
Mean ± standard deviation	9±1.41	1.45±1.35	844.0±36.3	58.40±50.38
Grazed				
*6-D	--	--	--	--
*Marina East	--	--	--	--
*H-4	--	--	--	--
Mean ± standard deviation				

Table 8. Summary of bird diversity and abundance during winter quarter based on one-kilometer transects.

Treatments Sites	Diversity Number of species	 H′	Abundance Number of individuals	 Biomass (kg)
Consolidated Clay Settling Ponds				
Swift	8	1.87	108.8	3.41
N-2	12	2.23	309.2	10.50
A-3	7	0.70	305.1	5.54
Mean ± standard deviation	9.0±2.6	1.60±0.80	241.0±114.5	6.48±3.64
Unreclaimed Pits and Spoil Piles				
0–5 Years With Lakes				
Big Teeth	9	1.38	117.0	12.56
Shark Tooth	15	1.87	47.4	6.28
Young Tiger	26	2.18	297.9	75.40
Mean ± standard deviation	16.7±8.6	1.81±0.40	154.1±129.3	31.41±38.22
5–15 Years With Lakes				
Orange Grove Pits	18	2.12	731.5	77.32
Tiger Tail	24	1.46	992.8	58.87
Tiger Bay South	25	1.94	1208.1	76.66
Mean ± standard deviation	22.3±3.71	1.84±0.34	977.5±238.7	70.95±10.47
15–30 Years With Lakes				
Homeland Cemetery	24	1.89	1474.6	45.42
Gator Lake	19	1.34	1672.9	124.97
Achan-4	26	2.38	1051.9	126.48
Mean ± standard deviation	23.0±3.6	1.87±0.52	1399.8±317.2	98.96±46.37
>30 Years With Lakes				
Bartow South	30	1.67	2280.2	184.75
Saddle Creek Park	24	1.44	383.5	22.89
Sanlan Ranch	22	2.38	366.1	136.43
Mean ± standard deviation	25.3±4.2	1.83±0.49	1009.9±1100.2	114.69±83.09
>30 Years Without Lakes				
Old Spoil Piles	8	1.18	196.5	2.53
Christina	12	2.12	127.5	4.17
Old Clarke James	16	2.26	389.8	11.37
Mean ± standard deviation	12.0±4.0	1.85±0.59	237.9±136.0	6.02±4.70
Reclaimed Pasture				
Ungrazed				
Parcel B	7	0.58	124.6	10.75
Noralyn	9	1.56	130.0	6.50
Kibler	16	1.96	239.6	17.32
Mean ± standard deviation	10.7±4.7	1.37±0.71	164.7±64.9	11.52±5.45
Grazed				
6-D	4	0.75	218.8	50.06
Marina East	7	0.43	97.0	5.18
H-4	12	1.37	640.1	44.29
Mean ± standard deviation	7.7±4.0	0.85±0.48	318.6±285.0	33.18±24.42

Table 9. Summary of bird diversity and abundance during spring quarter based on one-kilometer transects.

	Diversity		Abundance	
Treatments Sites	Number of species	H′	Number of individuals	Biomass (kg)
Consolidated Clay Settling Ponds				
Swift	7	1.75	78.5	2.85
N-2	5	1.44	50.9	1.85
A-3	8	1.82	60.4	1.72
Mean ± standard deviation	6.7±1.5	1.67±0.20	63.3±14.0	2.14±0.62
Unreclaimed Pits and Spoil Piles				
0–5 Years With Lakes				
Big Teeth	9	1.70	74.6	3.16
Shark Tooth	13	2.19	44.6	4.28
Young Tiger	18	1.83	202.5	84.64
Mean ± standard deviation	13.3±4.5	1.91±0.25	107.2±83.9	30.69±46.72
5–15 Years With Lakes				
Orange Grove Pits	19	2.33	291.9	32.15
Tiger Tail	25	2.64	222.2	18.18
Tiger Bay South	25	2.36	453.1	37.21
Mean ± standard deviation	23.0±3.5	2.44±0.17	322.4±118.4	29.18±9.86
15–30 Years With Lakes				
Homeland Cemetery	18	2.34	238.1	27.10
Gator Lake	24	2.57	350.3	63.11
Achan-4	21	2.64	330.4	248.86
Mean ± standard deviation	21.0±3.0	2.52±0.16	306.3±59.9	113.02±119.01
>30 Years With Lakes				
Bartow South	30	2.72	880.0	108.26
Saddle Creek Park	17	2.19	148.8	9.69
Sanlan Ranch	13	2.28	77.3	16.88
Mean ± standard deviation	20.0±0.89	2.40±0.28	368.7±444.2	44.94±54.95
>30 Years Without Lakes				
Old Spoil Piles	10	2.08	101.0	5.24
Christina	11	2.17	89.8	4.93
Old Clarke James	14	1.96	287.6	8.21
Mean ± standard deviation	11.7±2.08	2.07±0.10	159.5±111.1	6.13±1.81
Reclaimed Pasture				
Ungrazed				
Parcel B	9	2.02	20.6	6.31
Noralyn	7	1.38	55.1	6.04
Kibler	15	2.20	132.3	11.04
Mean ± standard deviation	10.3±4.2	1.87±0.43	69.3±57.2	7.80±2.81
Grazed				
6-D	3	0.94	13.4	1.30
Marina East	3	1.10	3.0	0.22
H-4	7	1.79	82.0	2.26
Mean ± standard deviation	4.3±2.3	1.28±0.45	32.8±42.9	1.26±1.02

Table 10. Summary of bird diversity and abundance during summer quarter based on one-kilometer transects.

	Diversity		Abundance	
Treatments Sites	Number of species	H′	Numberof individuals	Biomass (kg)
Consolidated Clay Settling Ponds				
Swift	10	1.74	75.5	4.66
N-2	8	1.83	131.1	5.19
A-3	6	1.29	55.5	1.41
Mean ± standard deviation	8.0±2.0	1.62±0.28	87.40±39.2	3.75±2.04
Unreclaimed Pits and Spoil Piles				
0–5 Years With Lakes				
Big Teeth	3	0.81	31.2	3.45
Shark Tooth	5	1.21	22.3	1.99
Young Tiger	12	1.58	107.9	33.38
Mean ± standard deviation	6.7±4.7	1.20±0.38	53.8±47.1	12.94±17.72
5–15 Years With Lakes				
Orange Grove Pits	13	1.50	190.5	35.76
Tiger Tail	21	2.57	163.2	17.33
Tiger Bay South	13	1.04	365.1	39.85
Mean ± standard deviation	15.7±4.6	1.70±0.78	239.6±109.5	30.98±12.00
15–30 Years With Lakes				
Homeland Cemetery	15	2.22	139.9	29.90
Gator Lake	13	2.10	153.2	66.37
Achan-4	15	2.30	202.9	101.84
Mean ± standard deviation	14.3±1.2	2.21±0.10	165.3±33.2	66.04±35.97
>30 Years With Lakes				
Bartow South	21	2.34	238.5	58.80
Saddle Creek Park	20	2.69	62.0	22.61
Sanlan Ranch	15	2.09	88.4	21.01
Mean ± standard deviation	18.7±3.2	2.37±0.30	129.6±95.2	34.14±21.37
>30 Years Without Lakes				
Old Spoil Piles	9	1.93	42.2	3.59
Christina	9	1.86	66.7	8.44
Old Clarke James	13	2.04	120.8	8.37
Mean ± standard deviation	10.3±2.3	1.94±0.09	76.6±40.2	6.80±2.78
Reclaimed Pasture				
Ungrazed				
Parcel B	6	1.68	25.5	5.85
Noralyn	5	1.84	37.2	4.20
Kibler	10	1.70	77.9	12.13
Mean ± standard deviation	7.0±2.6	1.74±0.09	46.9±27.5	7.39±4.18
Grazed				
6-D	1	0.00	1.0	0.10
Marina East	4	1.27	26.7	8.07
H-4	6	1.49	91.3	23.86
Mean ± standard deviation	3.7±2.5	0.92±0.80	29.7±30.3	10.68±12.09

BIRDS

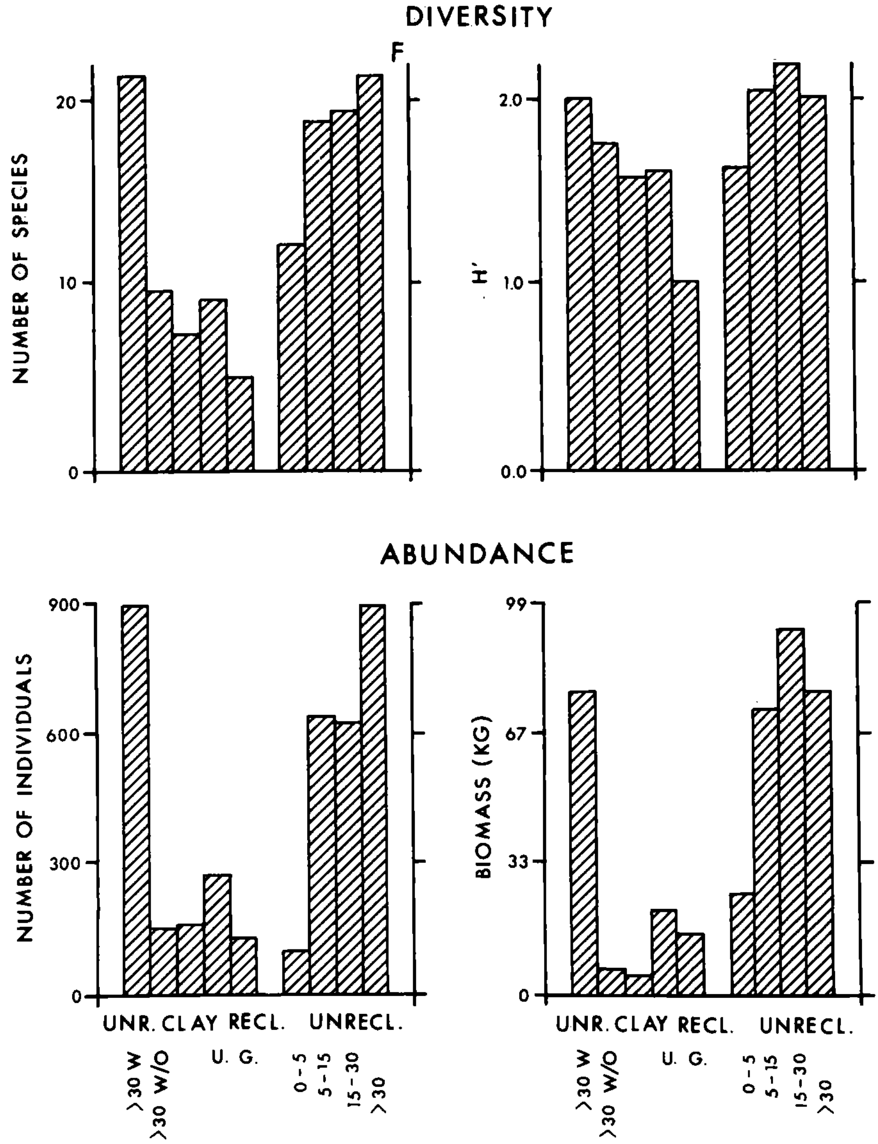

Figure 19.—Bird diversity and abundance, annual mean of quarterly means (n = 4). Abbreviations are as in Figure 3.

Table 11. Insect biomass (g) in light trap samples through the year. Sample sizes are given in parentheses.

Treatments Sites	Autumn	Winter	Spring	Summer	Mean of Quarterly Values
Consolidated Clay Settling Ponds					
Swift	--	1.54(1)	1.80(1)	3.41±0.24(2)	2.25(3)
N-2	9.95±0.44(2)	0.64(1)	8.34(1)	2.49±0.01(2)	5.36(4)
A-3	0.80(1)	0.48(1)	3.58(1)	4.11±0.70(2)	2.24(4)
Mean ± standard deviation	5.38±6.47(2)	0.89±0.57(3)	4.57±3.38(3)	3.34±0.80(6)	3.54(4)
Unreclaimed Pits and Spoil Piles					
0-5 Years With Lakes					
Big Teeth	--	0.00(1)	2.00± 1.80(2)	5.89±0.17(2)	2.63(3)
Shark Tooth	--	0.42(1)	2.99± 0.85(2)	13.09±7.07(2)	5.50(3)
Young Tiger	--	0.15(1)	18.81±17.60(2)	16.01±5.89(2)	11.66(3)
Mean ± standard deviation	--	0.19±0.21(3)	7.93±11.57(6)	11.66±6.21(6)	6.59(3)
5–15 Years With Lakes					
Orange Grove Pits	36.44(1)	0.94(1)	17.07±11.64(2)	6.76± 4.60(2)	15.30(4)
Tiger Tail	5.48(1)	0.48(1)	1.50± 1.87(2)	4.63± 3.13(2)	3.02(4)
Tiger Bay South	26.02(1)	2.59(1)	7.84± 4.14(2)	25.58± 3.11(2)	15.91(4)
Mean ± standard deviation	22.65±15.76(3)	1.34±1.11(3)	8.80± 8.96(6)	12.32±10.70(6)	11.28(4)
15–30 Years With Lakes					
Homeland Cemetery	--	1.60(1)	3.71±1.77(2)	17.99±0.77(2)	7.77(3)
Gator Lake	--	0.17(1)	7.31±2.31(2)	2.49±0.98(2)	3.32(3)
Achan-4	--	0.30(1)	6.31±6.29(2)	10.28±4.64(2)	5.63(3)
Mean ± standard deviation	--	0.69(3)	5.78±3.52(6)	10.25±7.26(6)	5.57(3)

>30 Years With Lakes					
Bartow South	0.48(1)	0.18(1)	7.56± 6.96(2)	14.69±0.04(2)	5.73(4)
Saddle Creek Park	--	5.68(1)	2.99± 3.45(2)	8.64±0.77(2)	5.77(3)
Sanlan Ranch	--	0.29(1)	9.58±13.26(2)	8.25±2.23(2)	6.04(3)
Mean ± standard deviation	0.48(1)	2.05±3.14(3)	6.71± 7.51(6)	10.53±3.40(6)	4.94(4)
>30 Years Without Lakes					
Old Spoil Piles	2.80(1)	0.04(1)	68.11±75.75(2)	14.87±3.25(2)	21.46(4)
Christina	7.68(1)	0.76(1)	7.93± 8.98(2)	14.60±0.24(2)	7.74(4)
Old Clarke James	6.21(1)	0.19(1)	13.28±11.16(2)	15.48±3.82(2)	8.79(4)
Mean ± standard deviation	5.56±2.50(3)	0.33±0.38(3)	29.77±45.57(6)	14.98±2.28(6)	12.66(4)
Reclaimed Pasture					
Ungrazed					
Parcel B	46.17(1)	0.01(1)	18.83±11.82(2)	21.12±5.81(2)	21.53(4)
Noralyn	12.92(1)	0.00(1)	15.66±14.19(2)	2.24±2.04(2)	7.70(4)
Kibler	5.72(1)	0.64(1)	65.51 (1)	8.38±4.06(2)	20.06(4)
Mean ± standard deviation	21.60±21.58(3)	0.22±0.36(3)	33.33±27.91(3)	10.58±9.22(6)	16.43(4)
Grazed					
6-D	2.39(1)	0.00(1)	10.05±11.47(2)	10.20± 2.27(2)	5.66(4)
Marina East	1.19(1)	0.02(1)	9.73± 6.57(2)	12.66± 9.98(2)	5.90(4)
H-4	--	0.26(1)	4.82± 5.04(2)	25.77±30.88(2)	10.28(3)
Mean ± standard deviation	1.79±0.85(2)	0.09±0.14(3)	8.20± 6.85(6)	16.21±16.36(6)	6.57(4)

nation may be that these young sites usually were adjacent to active mining operations. Consequently the areas were not open to the public and were completely closed to waterfowl hunting, resulting in little human disturbance to the birds. Another possible reason may involve a more dense or higher quality food source than in older pits.

In a parallel with the distribution of oldfield mice, there appeared to be a distinct bird community on Young Tiger compared with birds on the two younger sites in this class, Shark Tooth and Big Teeth. Young Tiger had 42 species present during the year, compared with 27 and 24 respectively for the other two. In addition, the other diversity and abundance figures showed comparable differences (Tables 7–10). The higher bird community measures may be explained by the more advanced stage of plant succession supported by Young Tiger. Indeed, certain passerine species, such as palm warblers, savannah sparrows, boat-tailed grackles, and red-winged blackbirds, were consistently more abundant on the Young Tiger site than on the other two. However, much of the difference in species composition resulted from the high number of wading and water birds found at Young Tiger. This is more likely tied to some difference in food supply, water quality, or water levels than to terrestrial plant succession on the exposed spoil piles. We lack the data to evaluate the importance of these or other factors. In any case, it appears that in terms of bird communities the arbitrary age category of 0–5 years may be misleading in that the first major increase of bird diversity and abundance may occur in 3 years after mining. This statement is based on the data from only one site; however, qualitative observations on other young pits in the area tended to support that view.

The 5–15 year old treatment was similar in species composition to Young Tiger, but with the increase in vine and shrub cover we found additional species of resident passerines, including white-eyed vireos, cardinals, and blue jays. In addition, several species of winter residents, such as yellow-rumped warblers and house wrens, were rare in the 0–5 year class but abundant in the 5–15 year sites. Undoubtedly the shrubs and vines provided good cover for both wintering and nesting species, but perhaps even more important was the use of wax myrtle berries for food during the winter months. This became more apparent in the older sites but was readily observed here.

Wading birds were still quite common in this class, and increased shoreline and littoral vegetation provided habitat for king rails and soras. However the only ducks using these sites consistently were blue-winged teal.

The 15–30 year old pits and those >30 years old with lakes showed quite similar species composition and diversity measures (Fig. 19). Perhaps the most significant difference was with the woodpeckers. Four species (red-bellied and pileated woodpeckers, yellow-bellied sapsucker, and common flicker) were found in the older category, whereas only the common flicker was found in the 15–30 year class. This reflects the increased availability of larger trees and dead snags for both nesting and foraging.

Another interesting difference was that wood ducks were found in all three of the older sites, but in none of the 15–30 year old sites. Again, this could be due to the presence of trees large enough to contain cavities. The hypothesis that nesting sites limit wood ducks to use of the forested sites could be tested by erecting artificial nesting boxes in younger areas and observing subsequent use of the sites.

Palm warblers, typically occurring in open ground and brushy habitats, declined in importance with increasing age of the sites after reaching their peak numbers in the 5–15 or 15–30 year old category. The fairly large number of palm warblers on the older Bartow South site may have been in response to the surrounding areas that were dominated by oldfields.

Unlike the diversity measures, the abundance figures for the 15–30 year class and the >30 year class with lakes were quite different (Fig. 19). This pattern is misleading because the younger treatment was not sampled during the fall quarter and, among the older sites, only Bartow South was sampled. A great many small birds (2071) were recorded; over half of these were wintering yellow-rumped warblers in large flocks. This extraordinarily high count affected the four-quarter mean for this treatment. It may have been representative of the site (the winter count was even higher), but it was not balanced by the other two sites, which generally were lower. In fact, using the three quarters for which complete data are available, the mean number of individuals is higher for the 15–30 year class than for the >30 year class (623 vs. 502). Domination of the younger site by wax myrtle created a very concentrated, high energy food source for wintering birds. Because the large flocks of wintering warblers have such a major effect on the total autumn and winter quarter counts, their habitat use is directly related to the total year counts. This is supported by the fact that Bartow South had far more yellow-rumped and palm warblers than Saddle Creek Park and Sanlan Ranch, where the importance of wax myrtle was much less.

The larger differences between old sites with lakes and those without (Fig. 19) resulted from the absence of water and the small wintertime berry crop in the latter category. Obviously all wading and water birds were absent from the bird community, which greatly reduced the diversity and biomass of birds found on these sites. Though the passerine species composition was very similar, abundance values were much lower in the without-lakes category, because large flocks of wintering warblers did not use these habitats. This again suggests the importance of wax myrtle to the winter ecology of these birds. The most common species were cardinals, rufous-sided towhees, and Carolina wrens—typical resident forest species.

As expected, maturing forest without lakes was heavily occupied by woodpeckers, with six species recorded for the category. The wealth of large trees and a good supply of dead stubs provided excellent foraging and nesting habitat.

Reclaimed Pasture.—Fairly low diversity and abundance figures were obtained for both categories of reclaimed pastures (Fig. 19). These values were most comparable to those for the consolidated clay settling ponds and the >30 year class without lakes, although because of the vastly differing plant structure the avian community was composed of different species. Typical species found on reclaimed sites included cattle egrets, red-winged blackbirds, and American kestrels. As on the 0–5 year unreclaimed pits and spoil piles treatment, some shorebirds and wintering savannah sparrows occurred on reclaimed pastures.

The two reclaimed sites with the most advanced and heterogeneous plant communities, Kibler and H–4, also supported the most diverse avian communities. In addition to the species mentioned, swamp sparrows, common yellowthroats, northern harriers, and a few cardinals were observed on these two sites and not on the other four. As with the small mammal data, Kibler and H–4 contributed heavily to the mean diversity and abundance values for their respective classes of reclaimed pastures.

The diversity and abundance values for ungrazed sites usually were much higher than those for grazed sites. This was the case during spring and summer, but the situation was reversed during winter because large flocks of birds occurred on grazed sites (American robins on H–4 and boat-tailed grackles on 6-D). The higher values on ungrazed sites did not result directly as a response to vegetation, which was somewhat more diverse and abundant on grazed sites (Figs. 3–5). They may have been related to the very large insect biomass found on the ungrazed pastures (Table 11), because many of the bird species are at least partially insectivorous.

From a regional perspective, the open grassland provided habitat for some species that were not found in other types of sites. Eight species were found only on reclaimed sites: cattle egrets, black vultures, bald eagles, short-billed marsh wrens, starlings, bobolinks, eastern meadowlarks (with one exception), and song sparrows. While some of these may be sampling artifacts (i.e. bald eagle), it is clear that the presence of these pastures serves to increase the avian diversity of the region as a whole.

INSECTS

Insect responses to post-mining treatments were presented as an overview of abundance (Fig. 20), because detailed sample analysis was completed only for winter quarter. Seasonal levels of abundance are given in Table 11. The lowest insect abundance occurred on consolidated clay settling ponds, with consistently low values in all quarters. During winter, the insect fauna on these sites was dominated by flies and beetles. In the successional range of sites, insects were most abundant in the young willow seral stage (Swift) and least abundant in the mature wax myrtle forest (A–3).

In the successional sequence of unreclaimed pits and spoil piles with lakes, insect abundance peaked in the 5–15 year age class and declined

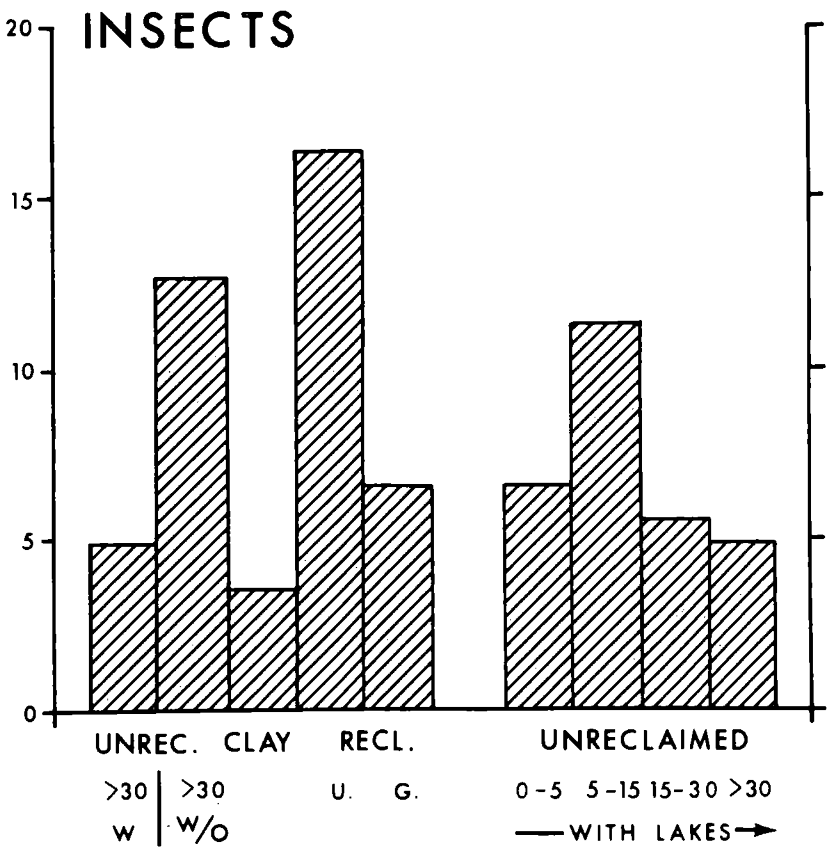

Figure 20.—Nightly insect biomass in light trap samples through the year, annual mean of quarterly means (n = 4). Abbreviations are as in Figure 3.

thereafter. All these communities were characterized by high levels during the summer, and the prominence of the 5–15 year treatment was a result of high levels in autumn. However, the >30 year treatments lacked this large contribution in the autumn. The two mature forest insect communities resembled each other in having high summer and low autumn levels, but the without-lakes community was distinctive in having very high numbers of large beetles and moths during the spring quarter. As a result, this treatment had the highest insect abundance of any unreclaimed treatment.

Both ungrazed and grazed reclaimed treatments had insect faunas dominated by caddisflies (Trichoptera) and small beetles. Ungrazed sites had the most abundant insects of any treatment, with high numbers in spring, summer, and autumn. Seasonal abundance was much different on grazed sites, which had moderate numbers in spring, high numbers in summer and low numbers the rest of the year.

HERPETOFAUNA

Observations of the 9 species of amphibians and 23 species of reptiles found on study sites are presented in Table 12. Perhaps the most striking figure was the low number of species (total = 5, mean = 2) observed in the consolidated clay settling ponds. Only one frog species, the greenhouse frog (*Eleutherodactylus planirostris*), was observed in this category even though the moist substrate, deep cracks in the clay crust, and shady aspect of the sites seemed to provide suitable habitat for more species.

Only six species were observed on each of the two early unreclaimed treatments. In contrast, high numbers of species were found in older stages of unreclaimed pits and spoil piles, because these sites provided both aquatic habitat for frogs, turtles, and water snakes and shaded terrestrial habitat for snakes and skinks. The 15–30 year old class had the highest number of species (16). The highest mean number of species (7.7) occurred in the >30 year old pits without lakes, despite the lack of aquatic habitat on these sites. The well-developed forest there supported a consistently large number of snake, lizard, and arboreal frog species. Additionally, all three sites contained active and inactive burrows of the gopher tortoise (*Gopherus polyphemus*), which provide cover and nest sites for numerous vertebrates (Auffenberg 1978).

As expected, few reptiles (3 species of snakes) and no amphibians were found on reclaimed sites because the very open, sunny aspect created severe conditions that most species find intolerable. In addition, no burrows were available to provide protection from the sun.

LARGE MAMMALS

Observations of large mammals and their signs recorded throughout the study are presented in Table 12. Thirteen species were found, but no relative abundance values could be attached to the presence/absence data. The most ubiquitous of the species was the bobcat (*Lynx rufus*), which was found in 14 sites—in all 8 treatments. Other species were nearly as widespread, including raccoons (*Procyon lotor*, 13 sites), armadillos (*Dasypus novemcinctus*, 11 sites), and opossums (*Didelphis virginiana*, 10 sites). River otters (*Lutra canadensis*) were observed in all age classes of unreclaimed pits and spoil piles where lakes were present. In addition, otters were commonly seen in ditches, pools, and active clay settling ponds in the area. Gray squirrels (*Sciurus carolinensis*) were confined to both categories of old unreclaimed pits where oaks were abundant. No sign of white-tailed deer was noted, however, and their absence from the mined region was confirmed by mining company employees.

The highest mean numbers of species (Table 12) occurred in the 5–15 and 15–30 year classes of unreclaimed pits, with 6.3 and 6.0 species respectively. The high figures probably resulted from two factors: the habitats had developed sufficiently to allow many species to use the sites, and most of the sites had little human disturbance because they were partially closed to the public. The sites in the >30 year old pits-with-lakes category were generally more accessible to the public and were heavily used for fishing, picnicking, and other activities that may have reduced the mean number of large mammals (3.7) using those sites. Old sites without lakes had a mean of 5.3 species per site, and these sites were seldom used by the public.

Reclaimed sites showed consistently low numbers of species, although some of the wide-ranging animals such as bobcats, raccoons, and red foxes (*Vulpes vulpes*) were found to either use or travel through some of the sites.

The most conspicuous large mammal on the grazed treatment was domestic cattle. Data provided by the landowner, International Minerals and Chemical Corporation, showed the sites to be stocked at an average of 0.90 head per ha (0.68 on 6-D, 1.25 on Marina East, and 0.77 on H-4). With biomass approximated as 205 kg per head, an average of 184 kg of cattle biomass per ha is indicated. Higher stocking rates may be possible, but company policy of assuring that grassland cover is maintained on reclaimed pastures is implemented by lease agreements that prohibit overglazing.

Table 12. Number of species of amphibians, reptiles, and large mammals observed during all four quarters of field work.

Treatments Sites	Number of Species Amphibians	 Reptiles	 Large mammals
Consolidated Clay Settling Ponds			
Swift	0	1	3
N-2	1	1	4
A-3	1	1	1
Unreclaimed Pits and Spoil Piles			
0-5 Years With Lakes			
Big Teeth	2	0	4
Shark Tooth	2	0	3
Young Tiger	3	1	7
5–15 Years With Lakes			
Orange Grove Pits	0	1	6
Tiger Tail	1	1	7
Tiger Bay South	0	2	6
15–30 Years With Lakes			
Homeland Cemetery	2	5	9
Gator Lake	2	5	6
Achan-4	3	2	3
>30 Years With Lakes			
Bartow South	3	4	4
Saddle Creek Park	5	0	3
Sanlan Ranch	1	4	4
>30 Years Without Lakes			
Old Spoil Piles	3	5	4
Christina	1	5	3
Old Clarke James	2	4	9
Reclaimed Pasture			
Ungrazed			
Parcel B	0	0	1
Noralyn	0	1	3
Kibler	0	2	1
Grazed			
6-D	0	0	0
Marina East	0	0	3
H-4	0	2	0

STATISTICAL ANALYSIS

The results of tests of hypotheses on contrasted final land uses are presented in Table 13. Considering annual data, the shrub and tree variables showed significant differences among end results of treatments, whereas herb, herpetofaunal, and large mammal variables did not. Duncan's multiple range tests of end results of reclamation showed two significantly different groups—>30 year old unreclaimed sites with and without lakes had high mean values, and ungrazed and grazed reclaimed pastures had low values. The clay waste treatment fell between these groups with intermediate values but was not clearly assignable to either. The two reclaimed treatments were never significantly different. In cases where the clay treatment moved up in mean value to second or first place, it was never significantly different from the third place treatment. When the two unreclaimed treatments were significantly different, the treatment with lakes had the higher mean value. For variables with this relation reversed, the differences were not significant. The contrasts reinforced these observations without showing additional distinctions.

Considering seasonal data (Table 13), only bird variables showed significant differences among final land uses; insect and small mammal variables did not. Response of seasonal variables to treatment end results was weaker than their successional responses, for distinct reasons in each group of animals. For small mammal data, no seasonal effect appeared in the analysis of variance, but the effect of sites within treatments was stronger than the overall treatment effect. Hence high site variance prevented distinction of post-mining treatments (Table 13) with small mammal data. By comparison, the strongest effect on bird variables was the season effect. The Duncan's grouping of final land uses and the contrasts showed patterns similar to those for annual data, with two different features. The clay waste treatment was never significantly different from the reclaimed pastures. Ungrazed pastures were significantly higher than grazed pastures in bird H'.

The results of hypotheses on response to site age also are presented in Table 13. Considering annual data, the shrub and tree variables showed significant responses to age, whereas herpetofaunal and large mammal variables did not. Considering seasonal data, small mammal and bird variables showed significant responses to age over the interval 0–36 years, and insect variables did not. Tests showed no simple pattern of X^2, X^3, or X^4 functions for all variables.

Models of plant and animal response to age, based on statistically significant age effects (Table 13), yield predictions of community succession on unreclaimed overburden soil (Fig. 21). Shrub species colonized for the first 9 years after mining (Fig. 21A); then the number of species

Table 13. *F*-tests of hypotheses showing significance levels of contrasts between end results of post-mining treatments and of response to site age. Because of the large number of tests, an elevated alpha is appropriate, and significance is judged at $P<0.01$.

Variables	with vs. without	ungrazed vs. grazed	clay vs. with/without	clay vs. pastures	response to site age
Annual data					
T. herb species	ns	ns	ns	ns	ns
Herb H′	ns	ns	ns	ns	ns
T. herb cover	ns	ns	ns	ns	ns
T. shrub species	ns	ns	***	***	**
Shrub H′	ns	ns	***	**	**
T. shrub cover	ns	ns	ns	***	**
T. tree species	***	ns	***	***	***
Tree H′	**	ns	***	ns	**
T. tree individuals	ns	ns	ns	**	***
T. tree basal area	ns	ns	*	***	**
T. herpetofauna species	ns	ns	*	ns	ns
T. large mammal species	ns	ns	ns	ns	ns
Seasonal data					
T. small mammal species	ns	ns	ns	ns	*
Small mammal H′	ns	ns	ns	ns	***
T. small mammal individuals	ns	ns	ns	ns	**
T. small mammal biomass	ns	ns	ns	ns	***
T. bird species	*	ns	**	ns	*
Bird H′	ns	*	ns	ns	*
T. bird individuals	ns	ns	ns	ns	***
T. bird biomass	**	ns	*	ns	**
T. insect biomass	ns	ns	*	ns	ns

T = transformed
ns = not significant
* = $P<0.05$
** = $P<0.01$
*** = $P<0.001$

lized as shrub cover and H' continued to increase (the latter because of increased evenness of species' abundances). Beginning in year 17, a cycle of colonization and decline occurred, with a peak at 30–31 years. Concurrently, shrub cover and H' decline as trees became more dominant. Tree species, H', and individuals (Fig. 21B) all showed steady increases during succession. However, tree basal area reaches its peak in year 26–27 and decreased thereafter. Transformed values for small mammal species and H' (Fig. 21D) changed very little over time. However, the pattern for small mammal individuals and biomass roughly corresponded

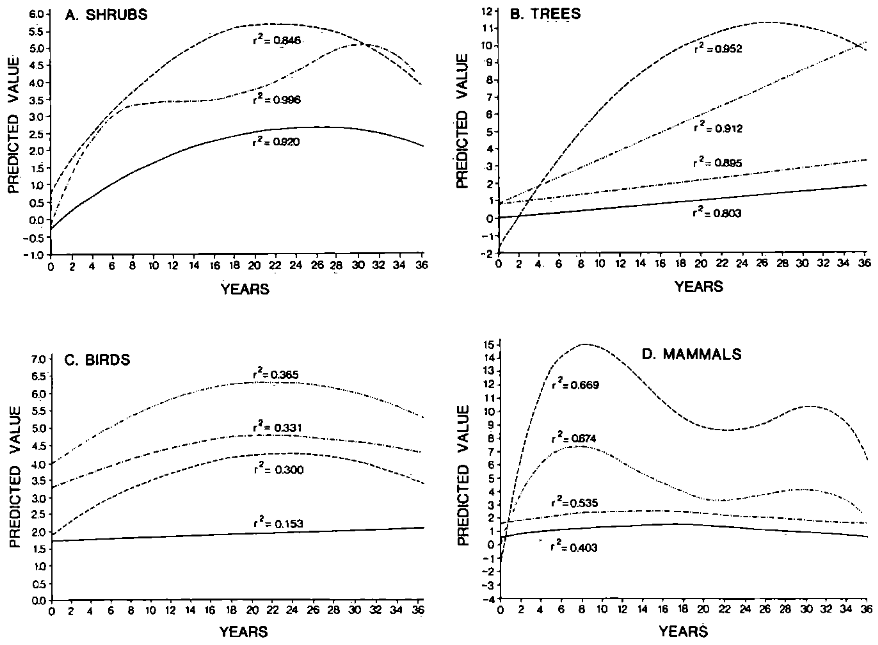

Figure 21.—Models of plant and animal response to seral age of unreclaimed overburden piles, based on the age effects shown in Table 13.

with that for shrub species, with two cycles of colonization and decline showing peaks at 8–9 and 30–31 years and a low at 23 years. The first peak was higher, and abundance levels were very low by year 36. Bird species, individuals, and biomass increased until 22–25 years and then decreased through year 36 (Fig. 21C). Bird H' increased slowly throughout the sere.

Stepwise multiple regression generated a large number of significant relationships between bird and plant variables. The most consistent relationships can be used to estimate wildlife potential of field sites. Equations selected for this purpose were limited to those that were based on annual (not quarterly) data, were mathematically simple, had very high probability values, and had their dependent variables already shown to change predictably during succession (Fig. 21A, B). Two equations met these criteria. For end treatments,

$$\text{TBS} = 2.0777 + 0.7411\ \text{TTS}\ (F = 22.1,)\ P<0.001, r^2 = 0.630),$$

and for successful sites,

$$\text{TBS} = 2.7161 + 0.4489\ \text{TSC}\ (F = 19.4,\ P<0.001,\ r^2 = 0.661),$$

where TBS is transformed bird species, TTS is transformed tree species, and TSC is transformed shrub cover.

DISCUSSION

SYNTHESIS OF RESULTS

The approach of this study solved a commonly recognized problem in evaluating ecosystems: "Comparisons of the quality of biomass before and after mining are . . . difficult because the wildlife composition is of different species" (Phosphate Land Reclamation Study Commission 1978). Measuring both diversity and abundance of several components of the biota on each study site enabled use of features common to all biological communities in evaluating the quality of post-mining habitats. A wildlife community normally is considered valuable if it contains a great diversity of species, a high abundance of one desirable species, or a balance of moderate levels of diversity and abundance. For example, valuable communities may include a tropical forest (with many species but low abundance), hoofed animals of the Great Plains (with many bison but low species diversity), and hoofed animals of East African grassland (with substantial numbers of both species and individuals). Using this rationale we have compared the quality of very different communities that develop on post-mining treatments.

Table 14 summarizes the relative diversity and abundance of the five categories of wildlife over the range of treatments. The values are presented as a percentage of the maximum value obtained for each variable. No attempt was made to derive a numerical rating of the treatments from this table, because we chose not to equate the importance of different types of animals. Instead we compared wildlife values by dividing the relative figures into three arbitrary ranges and counting the number of scores in each range for each site class.

This summary shows that the clay settling ponds consistently had low to moderate values, with only one measure in the high range (Table 14). It was apparent from general observations in the area that active and recently deactivated settling ponds provided excellent wetland habitats with much higher wildlife values, but once a crust formed and willows dominated the site much of the attractiveness to wildlife was lost. Values continued to decline as the clay dried further.

The series of unreclaimed treatments showed a primary succession that included high-quality wildlife communities (Table 14). Colonization of mined areas began soon after the disturbance and, without management, fairly diverse and abundant communities became established within 5–7 years. The 5–15 and 15–30 year old age classes in particular supported large communities. The two mature classes had slightly lower values, especially in abundance, but diversities often remained high.

Natural succession of unreclaimed overburden soil led to maturing

Table 14. Summary of relative importance for mean diversity and abundance. Values are expressed as percentage of the maximum value obtained for each parameter, and placed in arbitrary ranges (low = 0–33 percent, medium = 34–66 percent, high = 67–100 percent). Values considered high are in italics. Low values are in parentheses.

	Small Mammals				Birds				Insects	Herpetofauna	Large Mammals
Treatments	Number of Species	H′	Number of Individuals	Biomass	Number of Species	H′	Number of Individuals	Biomass	Biomass	Number of Species	Number of Species
Consolidated Clay Settling Ponds	52	48	39	(23)	34	72	(18)	(5)	(22)	(30)	43
Unreclaimed Pits and Spoil Piles											
0–5 Years With Lakes	62	56	47	(17)	57	*74*	(12)	(27)	40	35	*75*
5–15 Years With Lakes	*100*	*100*	*100*	*100*	*88*	*94*	*72*	*78*	*69*	(30)	*100*
15–30 Years Without Lakes	*67*	*77*	(31)	(33)	*90*	*100*	*70*	*100*	34	*87*	*95*
>30 Years Without Lakes	46	42	(21)	(29)	*100*	*91*	*100*	*83*	(30)	*78*	59
>30 Years Without Lakes	47	39	(23)	(11)	45	*80*	(17)	(7)	*77*	*100*	*84*
Reclaimed Pasture											
Ungrazed	35	(21)	42	40	43	73	(31)	(23)	*100*	(17)	(27)
Grazed	40	(32)	(14)	(14)	(24)	46	(14)	(16)	40	(9)	(16)

forest, shown by models (Fig. 21B) to be at a late successional stage at 36 years after mining. The late successional stage had an enormous amount of biomass stored as living wood and had more diverse and more abundant wildlife than endpoints of other treatments—clay waste areas and reclaimed pastures. In addition, these old sites had considerable aesthetic value that is difficult to quantify. As anticipated, community structure on late successional sites was strongly affected by the presence of lakes. The kinds of wildlife occupying these two treatments were very different, and the numbers of tree and bird species, tree H', and amount of bird biomass were significantly different (Table 13).

Reclaimed pastures had consistently low wildlife values (Table 14). In almost all categories the animal community on ungrazed sites was more diverse and abundant than on grazed sites, with a significant difference apparent for bird H' (Table 13). However, the selective harvest of grazing resulted in a somewhat more diverse pasture vegetation. Stocking of pastures with cattle, by adding a large amount of mammal biomass, showed that reclaimed sites have integrity as good life-support systems. Hence, reclaimed pastures are valuable because they support an abundant food source for humans. Though wildlife value of this treatment is low, the viability of reclaimed pastures suggests that high wildlife potential could be realized on these sites if a wildlife-oriented land use decision was made.

Four distinct seral stages are apparent (Fig. 21). First is the oldfield stage of grasses and forbs, reaching its fullest development at 5–7 years. Second is the pioneer shrub stage, characterized by *Lantana*, *Baccharis*, vines, and forbs, between 8 and 14 years after mining. Third is the wax myrtle stage, dominated by wax myrtle and invading forest trees from about 15 to 30 years. Fourth is the oak forest stage, dominated by water oak, live oak, and several other species. Later forest types that might occur were not available for study. The decline of herbs occurred as woody plants increasingly intercepted the sunlight on which the herbs depended for energy. Minimum values for shrub species and tree H' coincided in time and correlated with dominance of wax myrtle in the tree and/or shrub data. Apparently the allelopathic wax myrtle forced the decline of the pioneer shrub community, dominated the next community of young trees, and declined as the forest community emerged into the full sunlight. Two distinctive small mammal communities occurred with peak abundances in the pioneer shrub and forest stages. Mammal abundance correlated with the number of shrub species (and no other plant variable) and may have responded directly to shrubs for food or shelter. However, shrub H' and cover cannot be eliminated as causes of the mammal pattern, because significance levels did not permit modelling of possible effects. The reason for low mammal abundance in the wax myrtle stage is unknown. Bird species number and abundance stabilized and began to decrease during the wax myrtle stage, and the decline continued as the forest developed. The final stabilization of variables to be expected in a climax community did not appear by year 36.

COMPARISON WITH OTHER STUDIES

Based on a compilation of pre-existing knowledge of the fish and wildlife of the central Florida phosphate district, Layne et al. (1977) predicted general faunal changes likely to result from mining and reclamation. They concluded that impacts of mining on important "species are likely to be adverse . . . the overall effect will be a serious reduction in both diversity and abundance of wildlife resources of the seven-county area. Some of the deleterious impacts of mining could be reduced by modification of current reclamation practices and priorities; however, the net loss of fish and wildlife habitat and populations will still be of major proportion." Our study suggests the same conclusions, but our interpretation differs in one respect. How large a net loss of habitats and populations occurs depends strongly upon decisions about both reclamation practices and subsequent land use. Our data indicate that the adverse effects of mining can be temporary and that at least some fish and wildlife resources can be restored after mining. Consequently our conclusions emphasize the potential for restoration as determined by the new soils and landforms and the actual restoration accomplished as determined by post-mining land use decisions.

Recent work by Frohlich (1981) balances our results and those of Layne et al. (1977). He showed that although small mammals were more abundant in unreclaimed mines than in unmined flatwoods, some species were lost in the conversion. As in our study, small mammals were more abundant on unreclaimed sites than on reclaimed ones, and reclaimed and sand tailings treatments were similar in supporting few small mammals.

In a baseline study on endangered species that might be impacted by the proposed mining of the Osceola National Forest, the National Fish and Wildlife Laboratory (1978: 272,274) concluded that "Phosphate extraction by surface mining techniques will effectively extirpate all of the local flora and fauna in the mined area. This impact will be total but, for some species, need not be permanent if wildlife habitats are considered in reclamation plans. Osceola National Forest could be mined for phosphate and returned to a system of wildlife habitats that, for many species, would be equal to or improved over habitats now available." In the final supplement to the final environmental statement on whether Osceola mining leases should be approved, the basic scenario gave the reclamation goal as "the restoration of the existing resource and reestablishment of its multiple use, sustained-yield capabilities including sustained timber and forage production, wildlife and watershed management, and recreation. Reclamation would . . . be aimed at reestablishing . . . the same type of plant and aquatic communities with the same interspersion of community types, i.e. the pine flatwoods, cypress swamps, creek swamps and lakes . . . " (U.S. Bureau of Land Management 1979: I–6). Though the original statement emphasized as workable many specific reclamation practices, the supplement stated (p. I–8) that "the present primitive state-of-the-art of phosphate mine reclamation precludes the evaluation of the potential impact of future mining and reclamation of the Osceola by merely extrapolating present technology to future conditions. Research is needed to provide the technological base required to restore to [sic] the 'natural' system of the Osceola." Our study shows that establishing some kind of forested wildlife habitat is certainly possible, but achieving specifically targeted habitats that have never before been recreated will require experimental engineering of soil structure and quality and of hydrologic regime. Some habitats, such as pine flatwoods over soil hardpan, may not be restorable in a reasonable framework of time or money.

BIOLOGICAL FACTORS AFFECTING VALUES AND USES OF MINE-CREATED LANDS

Of the three distinct groups of treatments in this study (clay waste areas, unreclaimed overburden, and reclamation with an overburden cap), the latter two support valuable biological communities and have high potential for natural or self-restoration. The clay waste areas appear to form ecosystems with limited value for wildlife and for future land uses.

We have documented the successful, unsubsidized development of hardwood forest on overburden spoil piles. The primary attribute of this treatment is the soil itself. Overburden consists of about 80 percent sand and 20 percent clay; it exceeds native soil in values for CaO, MgO, and P_2O_5 but is deficient in K_2O (Hawkins 1979). Importantly, very little nitrogen is present. The invading biota invests free services that enhance succession, with plants rebuilding topsoil and wildlife dispersing seeds to reintroduce and diversify the plants. The earliest plant colonization is mainly of species with seeds strongly dispersed by autumn winds—dog fennel, grasses, and *Baccharis*. Significantly, most invading woody species have animal-dispersed seeds, whereas few species with water-dispersed or weakly wind-dispersed seeds become reestablished. An early invader, wax myrtle, plays a special role by hosting a symbiotic root bacterium (*Frankia*) responsible for nitrogen fixation. This actinomycete catalyzes the fixation of dinitrogen from the atmosphere and converts it to ammonia (Torrey 1978). The nitrogen gives a great advantage to the pioneering wax myrtle, because the nitrogen fixed in root nodules is rapidly transported for use in the aboveground portion of the plant. An annual increment of nitrogen is returned to the soil as leaf litter, but nitrogen stored in the wood is unavailable to other plants until the pioneer dies. Aside from having its own supply of a scarce nutrient, wax myrtle inhibits the success of competing plants through an allelopathic effect, shown against the exotic Brazilian pepper and likely against other species as well (Dunevitz and Ewel 1981). Wide and rapid dispersal is assured because wax myrtle provides an abundant supply of berries to migrant and resident birds in autumn and winter. Perhaps the most spectacular example is the tree swallow, with millions of individuals wintering in Florida. Tree swallows are regular users of unreclaimed sites with lakes, where flocks of hundreds or thousands alternate their feeding between wax myrtle berries and flying insects (over both water and land). Use of actinomycete-nodulated plants in land reclamation has been recommended by Silvester (1976). Another process possibly enhancing succession is the introduction of spores of mycorrhizal fungi by colonizing rodents that include fungi in their diets (Maser et al. 1978).

The forest community resulting on unreclaimed overburden is aesthetically attractive and supports a number of game species. The soil is likely to be useful for many forms of profitable land use, including agriculture and silviculture. The number of uses of this mined land would be increased by rounding off the spoil piles to produce gently rolling terrain, and also succession would be speeded by reduced erosion. Surfacing the land with topsoil set aside at the beginning of mining probably would speed the recovery process by supplying nitrogen and seeds, but providing topsoil appears to be unnecessary if ample time is allotted for natural recovery on overburden soil. The current regulatory criterion of 80 percent plant cover was exceeded on unreclaimed sites in about 10 years, as compared with the regulatory limit of 5 1/2 years after the cessation of mining. If the piles were rounded to reduce slope erosion, probably this level of plant cover could be achieved in 6–8 years without investing in improved pasture.

Our documentation has shown that the reclaimed pastures are relatively poor wildlife habitat. Nonetheless they are valuable as a prairie-like monoculture, supporting abundant grass, insects, cotton rats, and cows. Subsidies involved are leveling of spoil pile tops to form the surface soil, establishing improved pasture, fencing, and animal husbandry, plus periodic rehabilitative fertilizing and mowing. We have no data to show whether ranching on this soil is competitive in terms of pasture maintenance and livestock production on non-mined land, but the overburden cap appears to be a justifiable reclamation treatment with a valuable post-mining use. Furthermore, the overburden cap, if of sufficient depth, should resemble unreclaimed spoils in supporting other agricultural and silvicultural uses and native hardwoods. Hence the Kibler site (Fig. 16), if not mowed, probably would develop a plant and wildlife community like that on Bartow South (Fig. 12) or Old Clarke James (Fig. 15), differing only in the amount of lake area. Presumably the depth of the overburden cap and, if shallow, whether underlain by clay waste or sand, would be important determinants of whether pine plantations or particular forest types would thrive. Presumably the overburden should be about 1 m deep to support mesic-adapted trees with diffuse root systems, like slash pines and water oaks, and deeper for xeric-adapted trees with taproots, like longleaf pines and live oaks. A subsoil of clay wastes probably would result in a perched water table, which would affect the surficial plant community on a relatively shallow cap.

Our study indicated that dewatered clay waste has only moderate wildlife value and moderate potential for natural recovery. As active clay settling ponds, these areas have very high wildlife value as marshes, and they could be maintained as marshes by proper water level manipulation. However, absorption of water by the clay creates a volume of waste to be stored that can exceed the volume of mined pits, so at some mines clay must be stored aboveground, behind dikes. Concern over polluting clay spills from above-grade ponds prompts efforts to dewater the clay. Invasion of consolidated clay by willows helps the process, because willows are phreatophytes with high rates of evapotranspiration. Willows and the wax myrtles that replace them should enhance soil development with surface litter and root material, but further succession is not apparent. We found a very old clay waste area on Sanlan Ranch, with native tree seed sources nearby, that had an open, senescent stand of large red maple trees scattered in a vine-covered space. Probably the clay waste areas begin to develop into swamp forests but eventually become too dry and hard to survive.

The colloid under the clay crust will not support heavy buildings, so settling areas cannot be used for residential or industrial development. The soil is fertile, even in potassium (Hawkins 1979), and has proven capable of growing pasture grass and row crops. The feasibility of cultivating consolidated clay has been demonstrated, but low ground-pressure vehicles must be used. More typically, the clay is capped with sand tailings and improved pasture is established on the cap soil. Because few options exist for use of these aboveground lenses of hardening clay, top priority should be placed on identifying and mandating optimal reclamation techniques. With a sand or overburden cap, clay lenses may develop perched water tables and probably would favor the growth of swamp-adapted trees like slash pines. From the standpoint of wildlife habitat, a preferable way to use the clay and sand wastes might be to replace relatively deep sand around the edge of the central clay-surfaced depression. This linkage of an aquiclude and a body of water-storing soil should extend the hydroperiod from winter and summer rains to enhance the central wetland while diversifying it with fringing uplands. A major improvement of the soil may be achieved if the logistic problems of mixing sand tailings with clay waste during deposition can be solved.

FUTURE LANDSCAPES OF THE MINING REGION

Past landscapes of the region—dominated by extensive pine flatwoods and high sand ridges or terraces—have been destroyed by mining and will not be replaced. The ridges have been leveled and dispersed as overburden. Low ground has lost the soil hardpan that had maintained seasonally flooded forests. Though the former habitats and biota (Davis 1967, Layne et al. 1977) will not be replaced, our results show that other forests and wildlife can be established on mine overburden. Our results are relevant to the 46,868 ha in Florida mined for phosphate prior to 1975 (Phosphate Land Reclamation Study Commission 1978), but if reclamation practices and subsequent land use decisions change, then there is no assurance that the natural resource values we have documented will pertain.

Indeed, new post-mining treatments have been established by a 1978 land reclamation law (Florida Statutes, Chapter 378) and current reclamation rules (Florida Administrative Code, Chapter 16C–16). Post–1975 spoil pile areas that do not include settling ponds or recirculating water systems must be reclaimed, beginning within 18 months after mining ceases and completed within 4 years thereafter. Consequently, spoil piles will undergo little more succession than is documented for our Shark Tooth site (Fig. 6). Clay settling ponds must be reclaimed, beginning within 10 years after semi-liquids are no longer added to the area and completed within 4 years thereafter. Consequently, consolidated clay will be reclaimed at the stage of our Swift or N–2 sites (Fig. 1). Active clay settling ponds thus will become the dominant transitional mining land use because of their long periods of filling and dewatering—up to about 20 years, including the 10-year rule for reclamation. If spoil piles are left in the active settling areas, terrestrial succession will result in islands of habitat intermediate in maturity between our 5–15 year old (Figs. 8–9) and 15–30 year old (Figs. 10–11) spoil pile sites, but presumably these islands will be destroyed when the tops of the overburden piles are levelled during reclamation. Because the trend of post-reclamation land-use decisions is overwhelmingly toward ranching and agriculture, very little of the good wildlife habitat lost to mining is being restored. The result of these trends is that future wildlife values will be sharply truncated, occurring mainly in the artificial freshwater marsh habitat of active and inactive clay settling ponds. Wildlife use of this habitat is documented by Wenner and Marion (1981), Maehr (1980), and Gilbert et al. (1981).

An even greater threat to both productivity and wildlife potential of post-reclamation soils is suggested by long-term trends in the nature of surface soils resulting from mining. Table 15 shows that in 20 years most reclaimed surface may be sand instead of overburden, resulting in a loss of both wildlife potential and productive agricultural uses. During the 1970s, the desirable overburden has been the dominant surface soil, averaging 72.4 percent (with 1977 data missing). Moreover, the vast majority of this reclaimed overburden has been deep soil. In the 1980's overburden surface soil is projected to continue to dominate reclaimed lands, but most of it will be in the form of a relatively shallow cap over sand tailings and/or clay. In the following two decades overburden will diminish to a small minority of the reclaimed surface. Contributing factors to this pattern are the use of large amounts of overburden to construct settling pond dikes and the lesser depth of overburden in new mines in the southern part of the district. The change complementary to the decline of overburden is the projected increase in sand tailings surface soil from 11.5 percent in the 1970s to 68.1 percent during 2000–09. If that soil is a sand-clay mix, as proposed, the value of the reclaimed soil may be quite high. However, if the mixing process continues to be unfeasible or uneconomical, most reclaimed lands will be dewatered clay surfaced with low-quality sand tailings.

The ability of sand tailings to support wildlife habitat, grazing, agriculture, and silviculture needs to be investigated. Small mammal communities on early seral tailings are low in diversity and abundance (Marion et al. 1981). Fertility of sand tailings is relatively low. This soil consists of about 99 percent sand and 1 percent clay; it is high in CaO and P_2O_5 but deficient in MgO and K_20 (Hawkins 1979). Like other post-mining soils, sand tailings also is very low in nitrogen. We have examined both patchy and complete-cover pastures on sand tailings but do not know whether pasture is difficult to establish or whether cattle stocking levels need to be low to prevent overgrazing. A citrus planting on sand tailings between Bartow and Winter Haven failed to survive (Hawkins 1979). Successional patterns on sand tailings are unknown but are likely to lead to a xeric plant association, like native longleaf pine savanna, sand pine forest, or rosemary (*Ceratiola*) desert, or else to a scrub oak forest in the absence of fire (Veno 1976).

INFORMATION GAPS

A substantial number of information gaps prevent a complete evaluation of the capability of mined land to support wildlife populations and

Table 15. Type of reclamation recently completed or approved for implementation in the central Florida phosphate district (as of November 1979). The sequence of soil strata is shown from top to bottom. Mixed soil types are indicated by hyphens.

Reclamation sequence (top/bottom)	Relative area of reclamation types (percent and total hectares)							
	1971–4[a]	1975[a]	1976[a]	1978[b]	1979[b,c]	1980–89[c]	1990–99[c]	2000–09[c]
Overburden (area includes some lake surface)	63.8	51.1	53.1	--	65.9	31.7	8.1	--
Overburden/sand tailings	1.4	4.0	8.2	28.7	--	16.7	--	--
Overburden/sand tailings/clay	--	--	--	--	1.8	16.9	--	--
Overburden/sand tailings-clay	--	--	--	--	27.5	9.8	--	--
Overburden/clay	--	--	--	--	4.9	1.2	4.7	--
Overburden-sand tailings	--	--	--	--	--	--	3.7	--
Overburden-sand tailings/natural ground	--	--	--	--	--	--	--	--
Overburden-sand tailings/clay	9.5	5.5	6.4	--	--	--	--	7.5
Subtotal	74.7	60.6	67.7	28.7	100.1	76.3	16.5	7.5
Clay	9.7	17.9	15.8	--	--	4.9	45.6	24.4
Clay/natural ground	--	--	--	--	--	2.5	--	--
Clay/sand tailings	2.8	15.3	--	5.5	--	--	--	--
Subtotal	12.5	33.2	15.8	5.5	0.0	7.4	45.6	24.4
Sand tailings	12.9	6.3	12.6	--	--	0.4	--	--
Sand tailings/clay	--	--	--	65.8	--	11.8	--	--
Sand tailings/clay/natural ground	--	--	--	--	--	--	--	--
Sand tailings-clay	--	--	--	--	--	1.8	--	--
Sand tailings-clay/overburden	--	--	--	--	--	--	37.9	68.1
Sand tailings-clay/natural ground	--	--	--	--	--	1.5	--	--
Subtotal	12.9	6.3	12.6	65.8	0.0	15.5	37.9	68.1
Peat/sand/tailings/clay	--	--	--	--	--	0.7	--	--
Total hectares	1565	1037	1742	229	982	4408	3704	2080

[a] Phosphate Land Reclamation Study Commission 1978.

[b] Based on release dates in records of the Bureau of Geology.

[c] Based on scheduled completion dates in records of the Bureau of Geology.

other productive uses in the future. Research begun on the successional sequence of sand tailings and to relict native habitats (Marion et al. 1981) should be continued. This would complete coverage of the array of existing post-mining treatments and would use natural areas both as controls for gauging the success of natural reclamation and as indicators of what wildlife resources have been lost in the mining/reclamation process. Another approach to evaluating the fish and wildlife to be lost in a proposed mining area is to estimate the socioeconomic value of the resource from a survey of recreational fish and wildlife activities; such a study has been conducted by the Alberta Oil Sands Environmental Research Program (1978). Management techniques for enhancing target game populations on transitional clay settling ponds, unreclaimed land, and reclaimed areas should be evaluated with field trials. Field trials also could be used to test the role of fire in altering succession on consolidated clay, as suggested by Breedlove and Adams (1977). Tests should be conducted to combine consolidated clay settling areas with a complete or fringing sand cap to create flatwoods or upland/wetland. Continued work is needed to evaluate the amount and regional diversity of the fish and wildlife resource to be restored after mining.

Agronomic studies of reclaimed pastures with both overburden and sand tailings soils should be conducted to learn what subsidies are needed to support ranching and whether such ranchland is competitive with nonmined rangeland. Forestry studies of both native tree communities and commercial plantations should be done to evaluate the effect of reclaimed soil composition, depth, and substrate on tree growth. The potential for establishing longleaf pine savanna or sand pine forest on deep sand tailings should be investigated.

LITERATURE CITED

Alberta Oil Sands Environmental Research Program. 1978. A socioeconomic evaluation of the recreational use of fish and wildlife resources in Alberta, with particular reference to the AOSERP study area. Vol. 1: Summary and conclusions. AOSERP Report 43:1–116. (Available from 15th Floor, Oxbridge Place, 9820–106 St., Edmonton, Alberta, Canada T5K 2J6).

Auffenberg, W. 1978. Gopher tortoise. Pp. 33–35 *in* R. W. McDiarmid (ed.). Rare and Endangered Biota Florida. Vol. 3. Amphibians and Reptiles. Univ. Presses of Florida, Gainesville, 74 p.

Breedlove, B.W., and S.R. Adams. 1977. Natural systems occurring on mined lands of the central Florida phosphate district. Pp. 15–29 *in* Environments of the Central Florida Phosphate District. Southeast. Geol. Soc. Guidebook No. 19, 76 p.

Clench, M.H., and R.C. Leberman. 1978. Weights of 151 species of Pennsylvania birds analyzed by month, age, and sex. Bull. Carnegie Mus. Nat. Hist. No. 5, 87 p.

Davis, J.H. 1967. General map of natural vegetation of Florida. Univ. Florida, Inst. Food Agric. Sci., Agric. Exper. Stat. Circ. S–178.

Dunevitz, V., and J. Ewel. 1981. Allelopathy of wax myrtle (*Myrica cerifera*) on *Schinus terebinthifolius*. Florida Sci. 44:13–20.

Emlen, J.T. 1971. Population densities of birds derived from transect counts. Auk 88:323–342.

Florida Game and Fresh Water Fish Commission. 1977. Florida phosphate mine site reclamation and wildlife: An overview. Preliminary findings. Mimeo, 81 p.

Frohlich, R.K. 1981. Effects of Phosphate Mining on Mammal populations in North Florida. M.S. Thesis, Univ. Florida, Gainesville, 63 p.

Gilbert, T., T. King, and B. Barnett. 1981. An assessment of wetland habitat establishment at a central Florida phosphate mine site. FWS/OBS–81/38, U.S. Dept. Interior, 96 p.

Greenewalt, C.H. 1975. The flight of birds. Trans. Amer. Phil. Soc. 65(4):1–67.

Hawkins, W.H. 1979. Reclamation of disturbed phosphate land in central Florida—past, present, and future. Paper presented at Workshop on Reclamation of Surface-Mined Lands in the Southeastern Coastal Plain. Univ. Florida, Gainesville, September 10–11.

Layne, J.N., J.E. Stallcup, G.E. Woolfenden, M.N. McCauley, and D.J. Worley. 1977. Fish and wildlife inventory of the seven-county region included in the central Florida phosphate industry areawide environmental impact study. U.S. Fish Wildl. Serv., Natl. Tech. Info. Serv. PB–278456, 1279 p.

Long, R.W., and O. Lakela. 1976. A Flora of Tropical Florida. Banyan Books, Miami, 962 p.

Maehr, D.S. 1980. Avian Abundance and Habitat Preference on New Habitats Created by Phosphate Mining. M.S. Thesis, Univ. Florida, Gainesville, 122 p.

Marion, W.R., D.S. Maehr, and R.K. Frolich. 1981. Phosphate mine reclamation and habitats for wildlife. Pp. 501–506 *in* D.H. Graves (ed.). Symposium on Surface Mining Hydrology, Sedimentology, and Reclamation. Univ. Kentucky, Lexington, 558 p.

Maser, C., J.M. Trappe, and R.A. Nussbaum. 1978. Fungal-small mammal interrelationships with emphasis on Oregon coniferous forests. Ecology 59:799–809.

National Fish and Wildlife Laboratory. 1978. Osceola National Forest phosphate extraction and processing: Impacts on federally listed threatened or endangered and other species of concern. U.S. Fish Wildl. Serv., Gainesville, Florida. Mimeo, 414 p.

Phosphate Land Reclamation Study Commission. 1978. Report on phosphate mining and reclamation. Bur. Geol., Florida Dept. Nat. Res., Photo offset, 31 p. ; 21 maps.

Radford, A.E., H.E. Ahles, and C.R. Bell. 1964. Manual of the Vascular Flora of the Carolinas. Univ. North Carolina Press, Chapel Hill, 1183 p.

Shannon, C.E., and W. Weaver. 1949. The Mathematical Theory of communication. Univ. Illinois Press, Urbana, 117 p.

Sheldon, A.L. 1969. Equitability indices: dependence on the species count. Ecology 50:466–467.

Silvester, W.B. 1976. Ecological and economic significance of the non-legume symbioses. Pp. 489–506 *in* W.E. Nerton and C.J. Nyman (eds.). Proceedings of the 1st International Symposium of Nitrogen Fixation. Washington State Univ. Press, Pullman.

Steel, R.G.D., and J.H. Torrie. 1960. Principles and Procedures of Statistics. McGraw-Hill, New York, 481 p.

Torrey, J.G. 1978. Nitrogen fixation by actinomycete-nodulated angiosperms. BioScience 28:586–592.

U.S. Bureau of Land Management. 1979. Final supplement to the final environmental statement: Phosphate leasing on the Osceola National Forest, Florida. Alexandria, Virginia.

U.S. Environmental Protection Agency. 1978. Final areawide environmental impact statement, central Florida phosphate industry. Region IV, Atlanta, Georgia, Vol. 2.

U.S. Fish and Wildlife Service. 1979. Habitat evaluation procedures. Mimeo, 66 p. (Available from Project Impact Evaluation Team, Division of Ecological Services, 2625 Redwing Road, Fort Collins, CO 80526).

Veno, P.A. 1976. Successional relationships of five Florida plant communities. Ecology 57:498–508.

Wenner, K.C., and W.R. Marion. 1981. Wood duck production on a northern Florida phosphate mine. J. Wildl. Manage. 45:1037–1042.

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