WILDFLOWER ESTABLISHMENT ON LANDFILLS IN CENTRAL AND SOUTHWESTERN VIRGINIA

by

Mara Sabre

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APPROVED:

John Cairns, Jr., Chair

M. Rupert Cutler

Robert E. Lyons

Eric Smith

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Prof. John Cairns, Jr., Chair

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ABSTRACT

Municipal solid waste landfills are convenient means of disposing of society's waste; once closed, they become a liability to the community due to attributes which contribute to soil and water contamination. Regulations state that adequate vegetation be used to maintain the integrity of the soil trash cover. Alternatives to leaving a landfill derelict include establishing meadow-type communities that enrich floristic diversity while providing adequate cover to protect the soil cap over the trash.

In 1993, an experimental study was conducted at the Roanoke Regional Landfill where a mixture of native wildflowers and grasses and the standard revegetation mixture were sown on plots on varying aspects at the landfill. In 1993, the plots sown with the native mixture had a higher average species richness than the plots planted with the native mixture. Plots with the standard revegetation mixture had higher cover than plots planted with the native mixture.

In 1993 and 1994, an observational study was conducted at the Chancellorsville landfill in Spotsylvania county. Willdflowers had been seeded on part of the landfill in 1992. It was observed that the wildflower mixture decreased in species richness. The areas revegetated with the standard revegetation mixture had high richness due to the presence of invasive plants. Average cover over time was higher in areas planted with the standard revegetation mixture. Without regulations quantifying standards for aboveground cover, other methods should be implemented to determine to what extent revegetation mixtures are maintaining the integrity of a soil cap.

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GENERAL INTRODUCTION

In applied ecological projects there are always numerous issues and observations that could be addressed but for one reason or another cannot because of limited time, resources, information, or a combination of all three. The question of whether certain communities of species can thrive given the ecological constraints existing at a landfill is one strongly recommended as a project for restoration ecologists (Jordan, 1987). However, even given the amount of verified data and supporting evidence that different floral communities can persist on municipal landfills, there is an astonishingly limited number of communities interested in pursuing the opportunity to enhance the view of a closed landfill. The most challenging aspect for this project was not that the adverse conditions might prevent any native wildflower species from establishing, but rather that the community might not "take" or accept the idea of the experiment. Without the support of the community, the project would not be maintained.

As the project began, the nagging question of the time frame caught us with us. In 1992, new regulations regarding the structure of the soil cap which covers the trash were to be implemented, though no one, including the operator at the Roanoke landfill, knew when. After the plots were established in 1993, we learned that in all likelihood the plots at the Roanoke landfill would be lost some time in 1994. As it turned out, we lost them in early June 1994. For any project endeavoring to characterize the communities over time of different species mixtures, the loss of the plots in 1994 was a severe blow.

Because of safety concerns, we were also limited at the Roanoke landfill to the size and numbers of the plots. Again we learned a very important lesson: non-academic concerns may govern all or part of an experimental design. On the other hand, the process of negotiating plot size, location, and number can often draw in and include some of the most reluctant and pessimistic stakeholders, making them feel as though they were part of a project, rather than merely an observer.

Finally, the question of whether the project would be acceptable from a community's standpoint arose. In 1993, I encountered a doctoral student in science education who was looking for a topic for her dissertation. In the year and a half that followed, a collaboration was built between science, education, and teaching. This process taught students and collaborators how to resolve issues of landfill closure and post closure use, defined who were the important players, and illustrated through experiments what were the limits for restoration of the Roanoke landfill. This experience demonstrated an important lesson for people working in the scientific discipline of restoration ecology: that we will have to venture outside the realm of academic science, again and again, to resolve scientific problems.

Chapter 1

LANDFILLS, REVEGETATION, AND THE ASSOCIATED REGULATIONS

In the United States, increasing amounts of labor saving technology and products are available to the population. The unusable portions of technology and products are deposited in landfills, the most common receptacles for waste. Waste is composed of many different materials and compounds and many of these components are not found naturally in large concentrations in natural areas. In landfills, some of these materials accumulate to high concentrations dangerous to human health. Such materials include mercuric compounds, radiation chemicals, pesticide residues, and fingernail polish. Because not all wastes are dangerous to human or environment, federal regulations were created to define how to separate wastes into hazardous and nonhazardous waste sites. A statute governing landfill management including waste separation was passed in 1978, but it was not fully enforced until new, more stringent regulations appeared in 1984[1]. Hazardous compounds also can be produced from nonhazardous waste within landfills as a result of microbial activity on the putrescible matter (organic matter). New regulations have been passed prohibiting escape of these byproducts, and states now have guidelines to contain these compounds in landfills. These regulations are in place to protect the public from the effects of wastes.

LANDFILLS AND BIOTIC ACTIVITIES

Over the last thirty years, biologists have investigated two attributes of landfills: 1) microbial decomposition of the landfill contents, and 2) plant community ecology on landfill surfaces. Researchers investigating the source and contents of leachate, a liquid

[1] For more information about the shaping of the chief regulations concerning landfills, see the handbook Hazardous Waste Regulation: The New Era ; An Analysis and Guide to RCRA and the 1984 Amendments, by Richard C. Fortuna and David J. Lennett (1987), McGraw-Hill Publishers.

produced in the landfill, discovered a two-tiered system of bacterial activity. The liquid produced by anaerobic decomposition percolates through the landfill, chelating and collecting any soluble substance (and insoluble ones also). When the liquid reaches the bottom of the refuse pile or is forced to the surface, it follows the concentration or pressure gradients and is transported away from the landfill. In the past, before waste was separated into hazardous and nonhazardous, leachate contained high levels of heavy metals, organics, and pesticides. Today, leachates contain these materials in lesser quantities which can still bioaccumulate offsite. Because of research done on the production of leachate and gases due to decomposition within landfills, regulations now require the soil cap be stabilized in order to prevent exposure of the contents to oxygen and water. Through research on various types of waste sites including nonhazardous community fills and uranium mine tailing sites, it came to the federal government's attention that soil tended to stay in place as effectively with carefully planted vegetation as with rip rap or gravel and stone covers. This research on hazardous waste sites was applied to conditions affecting the surface of nonhazardous waste sites. Today, in Virginia, there are requirements for capping a landfill with a vegetative cover appropriate for erosion control.

Researchers found that plant community survival was dependent on several factors including: soil depth and type, soil gas contents, canopy structure, aspect, degree of slope, and precipitation. These constraints defined which species would survive and the extent of cover the species would effect. Researchers were especially interested in the effects of landfill gases on various species of plants. Wong (1988), Duell (1982), Gilman, et al (1985) Ettala (1987), Emberton (1990), and others investigated the relationship of the gases carbon dioxide and methane, two of the principle gases of anaerobic decomposition, on plant roots. They found that plants died in soil environments where gas with carbon dioxide concentrations of 20 percent or more migrated to the surface. Methane, while not found to be directly toxic to root growth, replaces oxygen in soil root interactions, thus increasing the overall concentration of

CO_2, which is toxic to plant roots (Duell, 1982, Wong, 1988). This research was being conducted at the same time as reports about methane fires were being considered by lawmakers. In 1992 regulations finally appeared requiring that gas from landfills be monitored and vented from passive or active venting systems. While the regulation was not made in reference to the effects of gas on plant growth and survival, plant communities that are otherwise adapted to the constraints will have an increased chance at survival on sites where such venting is in place (see Gilman, 1985).

Researchers were also interested in soil depth and cover. In the United States, regulations require a soil stabilizing vegetative cover layer six months after germination. With regulations prior to 1992, plants had to survive on whatever soil was used as a capping layer, and this soil was usually of a dense high clay content and compacted to prevent cracks. The new requirement of a topsoil layer for the vegetative cover ameliorates this situation.

Reports as far back as 1980 explain how landfills can be revegetated successfully, with protection from soil cover rupture, long before regulations were enforced concerning landfill capping. As stated in Gilman et.al (1985), landfill revegetation can prevent erosion, conform with the surrounding environment, and be cost effective if certain procedures are followed. The following guidelines are from the 1985 article published by the U.S. Environmental Protection Agency (EPA).

1. Landfill gases must be diverted from the vegetative layer either through active or passive venting systems.
2. Prior to landfill closure, soil analyses must be done of the topsoil designated for the vegetative cover.
3. Species for the community must be chosen according to cover requirements and be as close as possible to local plant communities.
4. Species must be tested onsite prior to final closure and monitored seasonally for cover.
5. After herbaceous cover has been established, tree seedlings acclimated to the local

climate and topsoil can be transplanted to increase cover and improve surface evapotranspiration (see also Handel and Robinson, 1994).

These guidelines represent simple to follow techniques and produce reliable results because they are based on surveys done at each landfill. These guidelines were published seven years before new regulations appeared at the state level requiring gas venting systems and topsoil. Clearly, although the need for revegetating the surface of landfills was demonstrated, the amount of information in state handbooks is limited.

LANDFILL REVEGETATION, RESTORATION ECOLOGY, REGULATIONS, AND HUMAN NEEDS

One of the reasons that landfills present interesting questions for restoration ecologists is that state and federal regulations do not mention what kinds of vegetation can be used. As a result of this omission, landfills either contain species not wholly adapted to the altered environment, or plants nonnative to the system that are highly aggressive and which do not preserve the landscape visually or return it ecologically to the preexisting system. Even though many landfills in Virginia are located in areas once dominated by forests, few landfills have trees on them, not because regulations prohibit trees, but because local lore has developed implicating trees with disruption of the integrity of the cap liner. Researchers at the Fresh Kills landfill in New York City have studied tree growth over time and have not observed disruption in liner systems (Handel , pers. comm.). The relationship between highly compacted soil, low oxygen environments, and plant rooting patterns is well documented, but none of this research has been reflected in any amendment to any regulation because there are no regulations specifically prohibiting tree growth. Thus, at a local level, money and effort have been spent to produce a plant community the purpose of which, second to erosion control, is to prevent the successful invasion and growth of woody plants.

CASE STUDIES: ROANOKE REGIONAL AND CHANCELLORSVILLE LANDFILLS

The questions for many ecologists are then, why not trees, and if not trees, why not something else? Any project exploring other options for stabilizing the landfill cap liner must first consider each option available to the community at large, the degree to which each option satisfies community and environmental needs, and which regulations govern each activity. Researchers must either consign themselves to investigating hybrid grasses and dicots or risk exploring other avenues of plant communities. Then at the same time, they must convince the community, the landfill operator, and the state that the alternative is viable, more attractive, and most of all, economical.

At two landfills in southwestern Virginia, studies were conducted to explore the use of native wildflower and grass mixtures as an alternative to the standard revegetation mixtures used at those sites. However, there was no baseline information or regulatory tables defining what was adequate cover; in other words, there was no legal limit defined for satisfactory vegetative cover. Therefore, the investigators examined the progress of the standard revegetation mixture and the alternative wildflower mixture on plots over time to generate some data on the green cover and species composition of the area. The experimental study at the Roanoke landfill and the observational survey established at the Chancellorsville landfill could only study two attributes of plant communities because, as with most projects established in the field, the researcher was constrained not only by the unique ecological conditions but also regulatory, societal, financial, and temporal factors. Each landfill had a different set of conditions which had to be taken into consideration before beginning the studies. The Roanoke Regional was very large, and it had, in 1992, not been required to follow new regulatory guidelines for soil covers or gas venting pipes. Spotsylvania county, on the other hand, had recently closed in the fall of 1991, and its soil cap was far more complex, complete with geotextile membrane liner, topsoil, and venting devices (see Figure 3.1, p. 59).

RELATING HUMAN AND ECOLOGICAL VALUES

In 1992, the National Research Council (NRC) included a matrix diagram of community/ecological needs for assessing restoration projects (see figure 1, p.15). Researchers can use this matrix to outline the possibilities and limitations of a landfill restoration project based on the current information and resources. In this section, each of the major components of the matrix is described in terms of landfill revegetation projects undertaken at the Roanoke and Chancellorsville landfill.

AO= zones of anoxia created by inadequate soil cover on landfills; plant death; leachate in surface and groundwater supplies; methane fires; closed without regulatory changes

A1-A2= increasing amounts of capping and venting with regulations. This increases the level of human acceptability, because the landfill contents are prevented from contaminating needed resources. However, the use of nonnative, aggressive vegetation as prescribed by the same regulations keeps the matrix coordinated below the threshold of ecological acceptability.

BO= letting the area revegetate itself, minimal cover as before 1992 changes, no venting. This option is unacceptable for society over the short term. While allowing native invasive annuals and perennials to invade this system, the protrusion of gases and leachate will kill all but the most aggressive plants, contaminate surface and groundwater supplies. Without further intervention the erosion of the cap liner will move the entire area down to AO by altering the native ecosystem negatively.

B1= nonnative vegetation with old regulations. This scenario is the one that persisted at the landfill until final closure in 1992. While a soil cap was placed on the landfill and the standard revegetation mixture applied, several factors made the cover unacceptable to society and the ecosystem. Because soil was placed on slopes of 25% and greater, the soil gases were not vented, large bare areas of anoxia appeared on the landfill, increasing the potential for erosion. When the landfill was closed in 1994, areas thought to be under adequate cover were subjected to new capping laws because the cover depth was inadequate to ensure long term stabilization of key portions of the slope. Different areas had sufficient native establishment of woody species (including Tulip poplar and blackberry) because of inadequate standard mix establishment, but no species appeared to be able to persist for very long. In addition, some small trees had grown and persisted on the periphery of the landfill. Leachate was apparent both on the landfill and offsite, and some streams immediately below the landfill were devoid of invertebrates except for oligocheates (unpublished data).

CO=revegetation at below cover levels with native vegetation, noncompetitive; old regulations. This position of the matrix is reflected by the efforts of the Montgomery County authorities to plant trees on an old landfill- The result was large quantities of leachate percolating from the landfill.

C1=revegetation with native vegetation at appropriate cover levels. With regulations in place, the level of human acceptability is met, and a meadow-like system provides some equilibration or imitation of the surrounding floristic diversity without adding trees.

C2=revegetation with native vegetation, study of lower communities, biomass with new regulations, including native trees? Here all new regulations are met and monitored, gas venting, proper liners, and the community has invested in research that studies which type of native landscape will most serve the surrounding ecosystem in terms of restoration of floristic and faunal diversity, net primary productivity (NPP), and at the same time ensure erosion control.

The matrix shows that at different stages of community and scientific cooperation there are different levels of needs met. For instance, landfills prior to the 1970s and scientific awareness of the potential of water contamination stayed at an AO or at best BO level, unacceptable to human needs because of contamination of soil and water supplies (see Booth, 1990). With the introduction of legislation and research about capping landfills and moving landfills away from high water table areas and marshes, the position on the matrix changes to a level of A1; with gas venting, to A2 or B1. With increasing research, the level of human acceptability has reached its limit so long as humans acknowledge the continued need for landfills. However, with regulations as they are, there will not be much done to move the position of the matrix to the C level. With work on highly aggressive cultivars of grasses and legumes for cover, the reuse of the same mixture with little variation creates a frozen community of 1-3 species within ten years, leaving the question of where and whether ecosystem needs are being met.

A level of B2, the only level not yet discussed, where all the necessary new regulations concerning capping, underground well monitoring, and gas venting are implemented, the level of human desirability is reached. At the same position, a native herbaceous vegetation cover will improve floristic diversity, but because it will have to monitored through time to replace showy annuals, remove tree seedlings, and be composed of plants introduced to the bioregion (even if the origin is on the same continent), the level must stay within the confines of ecological acceptability rather than desirability (the C level). A restoration ecologist tries to move the level of the matrix up without losing the human desirabilities portion (i.e., within the regulatory and known scientific constraints). But researchers and natural resource mangers can move the position in the matrix no more swiftly than the time it takes society to learn about intrinsic ecological values. For the landfill project and many others, movement of the position of the matrix is governed first by regulations (which in turn are driven by societal needs), and then by the society itself, and then by inactivity on the part of either the regulations or society, and almost never by the needs of the ecosystem affected. Many people in society are only beginning to understand what it means to lose species native to an area, to lose land to waste, and to lose diversity as though it were not an essential part of life on earth. So the ecologist's job becomes confounded when it is realized that replacing something cheap and "effective" with an unknown meadow seed mix is being done for reasons that will affect ecosystem health over the long term, but for which the public still has only a little interest. Without regulatory assistance declaring that native biodiversity is a requirement for revegetation, efforts to improve the floristic diversity of an area is basic research at the landscape scale and must always justify all costs even when true costs of ecosystem attributes are not known. However, there may be no other way to explain the interconnectedness of plants, insects, birds, and ecosystems in general without prodding the community to look at alternatives, all the while assuring them that the law is being followed to the letter.

CONCLUSION

James Luken, in his book Managing Directed Succession (1990), wrote that the recovery of a system from severe disturbances is facilitated if the original environment and organisms are considered essential to the recovery process. For landfills, if it could be shown that native plant species can survive and reproduce on a landfill with venting systems and proper soil caps, then studies could be made to determine if the plants can compare with the non-natives already in use in terms of overall cover. Such research necessitates involving people at all levels of the project. There are two difficulties that the researcher must confront in beginning a restoration project:

1. There may be insufficient information to determine the prior level of existing ecosystem services when the landfill was constructed, and
2. Once incorporating human interests in a project, control of experimental design will have to be negotiated at many different stages of the experiment.

For example, there is an acknowledged lack of information at the Roanoke landfill concerning soil structure, microbial communities, water evapotranspiration rates, NPP, gas exchange, diversity and interactions. Topography and drainage patterns have been changed due to construction, and sediment collection basins have been formed where none existed before. Around the landfill, the best areas to serve as reference sites may no longer exist. The question of reflecting all predisturbance conditions was quickly reduced to recovering some predisturbance conditions, especially because the soil structure had become permanently modified.

In the second case, all sorts of confounding factors can arise during the course of an experiment when non-scientists are permitted input. These have included modification of the plot size, number, and location to avoid moving machinery and to reduce the perceived risk of working on marginally stabilized caps. At the Roanoke landfill, the greatest obstacle to moving the matrix position to a level of ecological desirability has been a strong reluctance to even the remotest possibility of tree establishment. Engineering firms, public works officers, and members of solid waste management boards all expressed great reluctance at all stages of the project to the idea of trees even accidentally appearing on a landfill site, even though there is not a single word mentioned about trees in any regulation. Some research could be motivated offsite to show that soil depth, compaction, and the proper choice of shallow rooted trees native to the area, tree root systems do not penetrate any deeper than most grasses, and often less. Onsite research, however, would be long term, ten to thirty years at least, to assure the landfill owners that trees would not tap into the landfill at any point in time during the monitoring period, and this has only been done in a few areas with a history of collaboration and trust between researcher and community (Handel and Robinson, 1994).

A recent article in American City and County (September 1994 issue) illustrated a trend in governments towards dialogue rather than conflict in resolving issues of land development and planning. If such an interest is already in the minds of local government agencies, then researchers have an avenue for discussing alternative measures for landfill revegetation without having to come in entirely as an outside, unaffiliated interest (see Appendix). Incorporating community members in a project is beneficial in unanticipated ways, and the process will provide knowledge about how human systems can respond to natural crises caused by human activities.

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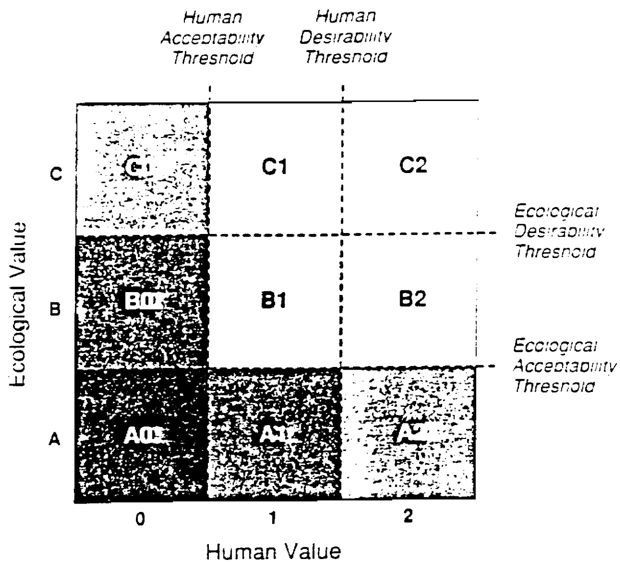

Cell	Ecological Value	Human Value
A0	Unacceptable	Unacceptable
A1	Unacceptable	Acceptable
A2	Unacceptable	Desirable
B0	Acceptable	Unacceptable
B1	Acceptable	Acceptable
B2	Acceptable	Desirable
C0	Desirable	Unacceptable
C1	Desirable	Acceptable
C2	Desirable	Desirable

Figure 1.1 Matrix of ecological and community needs. Courtesy of the National Research Council.

Chapter 2

THE ROANOKE REGIONAL LANDFILL: VEGETATION ESTABLISHMENT AND ANALYSIS

INTRODUCTION

Landfills are the most widely accepted means of nonhazardous solid waste management disposal today. In the United States there are over 6,000 landfills in operation. With urban expansion into rural areas, active landfills are now found side by side with new human residential and commercial developments. Society is confronted directly with the visible signs of trash on the road and odors from the organosulfurous compounds produced by microorganisms in the landfill's interior. Landfills produce liquid as well as gaseous products of internal anaerobic decomposition processes, and these products have been shown to present human and environmental health hazards. Ensuring the integrity of landfills so that none of the contents escape into the environment is the chief reason for new design criteria pertaining to landfill construction and closure. New regulations in the state of Virginia require trash to be covered with either a lining of 60 cm of clay compacted to 10^{-7} cm/sec or a geotextile membrane liner to cover the trash (see figure 1). An important component of maintaining the cover material during and after closure of a landfill is establishing a vegetative community to (1) hold the soil cover using an extensive, shallow vegetative rooting system, (2) buffer the soil cover from rainfall with a dense foliage, and (3) assist in the reduction of water penetration via evapotranspiration.

Difficulties, however, exist in revegetating capped landfill surfaces because landfill gases migrate to the soil surface layers, creating highly reduced and anoxic areas (Chan, 1991; Duell, 1986; Wong, 1988). The high carbon dioxide contents of the soils may exclude plants whose rooting systems are intolerant of such levels (Chan, 1991; Duell, 1986). Similarly, methane, another constituent of landfill gas, may indirectly affect the rooting pattern of plants by replacing oxygen in the soil air matrix; a situation unsuitable for most plants (Chan, 1991). Difficulties in stabilizing the trash pile also arise when selecting an appropriate soil for the vegetative cover. Traditionally, soils used in capping liners at landfills have a high clay content. If resources are insufficient to install high quality, loamy topsoil over the cap, plants used for revegetation are excluded if they cannot grow in compacted clay with its properties of low drainage and low soil air space. Of concern also is the potential rooting depth of plants, especially woody species, because if the rooting systems penetrate the capping soil all the way down to the refuse layers, air and water lines would be opened, and leachate, the liquid byproduct of anaerobic decomposition within the landfill, will have a direct exit route.

The species in the revegetation mixture used at the Roanoke Regional Landfill were chosen because of their known ability to colonize waste and droughty areas; and also for their low cost as seeds and minimal maintenance requirements following germination (see Table 2.1).

Table 2.1 Standard species mixture seeded on experimental plots at the Roanoke Regional landfill, 1993

Agrostis alba
Festuca arundinacea
Lolium multiflorum
Lolium perenne
Secale cereale
Setaria italica
Coronilla varia
Lespedeza cuneata
Trifolium pratense

All species are members of the Poaceae (the grass) or Fabaceae (the legume) families. In the standard revegetation mixture, one to three legumes are chosen to provide longer term perennial cover, often crowding out even the perennial grasses within a few years, and also enhance soil nitrogen, alleviating the neceesity for fertilization().

Legumes are expensive, almost three times the cost per kilogram of grasses; however, the seeding rates for legumes are much lower because the plants are quite aggressive and will colonize large areas over time. Grasses and legumes have also been used on road cuts and along highways because they appear to reduce erosion and inhibit the succession of woody plants; both are qualities that preserve safe, clear rights of way close to the road. While it appears that the species used on road cuts would be ideal for landfill use as well, concerns have arisen in both the scientific and the general communities that this inexpensive solution may not be realistic for providing adequate erosion control and capping liner stabilization. Furthermore, this revegetation mixture may be contributing to the reduction in plant diversity at the landfill because of the aggressive nature of the plants. In addition, none of the species listed in table one is native to the United States. Regulatory considerations mandate only that the plants used for landfill revegetation control erosion; however, no stipulations appear with regard to origin or nativity of plants, nor are they anywhere in the 1993 regulations which discuss "adequate cover" (VA Solid Waste Management Guidelines, 1993). Most recently, questions concerning the impact of introduced exotics have arisen. Specifically, can they inhibit natural succession and reduce native plant diversity?

Alternatives to standard revegetation mixtures used at landfills along the east coast of the United States have been investigated. Gilman et. al (1985) developed sound methodologies for revegetation techniques with tree species on landfill sites. These authors also recommended establishment of a short term herbaceous cover while the trees are growing. However, as these guidelines and the majority of the literature on landfills have as the end purpose a stand of native trees, other types of plant communities including wildflower meadows or tall grass prairies have received lesser attention. If regulations, finances, or social stigmas prevent revegetation with trees directly on landfills, alternatives to the standard revegetation mixture should be made available as there is no published evidence at each landfill site that this mixture satisfies local regulations, or that it enhances property values, or is responsive to a growing societal interest in protecting native plant diversity.

The impetus for using an alternative revegetation mixture at the Roanoke Regional landfill in eastern Roanoke County, Virginia, came from one of the landholders immediately adjacent to the landfill. Virginia's Explore Wilderness Heritage Park, a 1,300 acre "living history" museum and wilderness park, located immediately east of the 250 acre landfill, was concerned about the view that the landfill would offer visitors to Explore. This is because the main access road to Explore Park will be a National Park Service-administered spur across the landfill connecting Explore Park and the Blue Ridge Parkway, a popular corridor for people traveling along the Appalachian mountains. Explore Park will administer the closed landfill surface as part of the park's recreation area, and it desired a native species prairie-like landscape. Explore proposed an ecological restoration project to Virginia Tech to investigate an alternative native revegetation mixture that would enhance local plant diversity and increase the aesthetic value of the area while satisfying state regulations for adequate erosion control.

Ecological restoration projects imply efforts to return an area to predisturbance conditions or to mirror the surrounding unaffected landscape (Cairns, 1988, Jordan, 1987). However, proposing to establish and maintain a wildflower and grass meadow indefinitely in the Valley and Ridge region of Southwestern Virginia is not a restoration project by the definition given. A wildflower meadow is usually an intermediate step in a successional event for abandoned agricultural or logged lands in piedmont areas of the southeastern United States, but this transitional meadow is eventually colonized and shaded out by woody species unless regularly burned or heavily grazed. On the other hand, if resources or current regulations prohibit, as they did in this case, the deliberate establishment of the community most closely reflecting the surrounding ecosystem, then another system can be created to emulate some of that ecosystem's important attributes, even if this system, a wildflower meadow, puts the area into a permanent or frozen state of transition. In this study, floral diversity, an important ecosystem attribute serving both the ecosystem and humans with valuable services, was selected as a factor in determining the selection of a wildflower grass meadow (Kendle, 1994; Cairns, 1990; Jordan, 1987). If the diversity of trees and other plant species could not be encouraged, then perhaps comparable species attractive to local fauna and humans alike would serve. In addition, this community would have to provide adequate erosion control cover, at least comparable to that found in the standard revegetation mixture. Erosion control is also an important ecosystem attribute (Cairns, 1990). Plants (especially trees) hold the soil, keeping rivers from becoming silted, and also alter soil environments, facilitating their use by macro and micro fauna.

This project proposed to examine the ecosystem attributes of floral diversity and erosion control by using indirect measurements of these criteria through data on species richness and cover estimates on experimental plots established at the Roanoke Regional landfill. The scientific component of the ecological restoration project at the landfill included laboratory and field components. The laboratory components examined the germination rates of all seed species, surface soil nutrients, and soil particle size distribution analyses. Germination studies in a uniform setting aided in identification of field species in field as well as inferring maximum germination rates in field for all species. Soil nutrient analyses provide an idea of the nutrient availability or limitation of essential elements. Soil particle size distribution is an indirect indicator of the erodibility of the soil. It also provides information about the drainage and potential air space in the soil for plant rooting systems. The field component of the study was designed to investigate three factors: 1) whether the native or the standard species mixture maintained a higher species richness; 2) whether the native species mixture used was comparable in terms of green cover to the standard revegetation mixture at equivalent seeding rates; and, 3) whether variables such as soil nutrient content or aspect affected either the cover or the richness of one or both species mixtures.

METHODS AND MATERIALS

SITE DESCRIPTION

The old Roanoke Regional landfill is located in Roanoke county. The landscape surrounding the landfill is the Valley and Ridge region of the Blue Ridge Mountains. The Roanoke River is one kilometer north of the landfill, and the Blue Ridge Parkway has several overlooks less than a half kilometer distance from the site. The community near the landfill is called Mount Pleasant, a rural population of 3,000 people. The landfill was divided into three sections according to use. Section A was not used for landfill operation. Section B was filled to capacity in the early 1980s and closed in 1983. Section C was still in operation during the course of the study. The landfill was built up in layers as each mound of trash was contoured, and slopes with bench terraces were created to aid in the cap construction. These slopes range in age on section C from the oldest being at the bottom, at about 7-10 years of age, to the most recent, which were only contoured in May 1994.

SITE PREPARATION

In March 1993, five aspects were selected for study on section C, the active section of the landfill. Two plots 10 X 5 m were staked per aspect. One plot was located on an upper, more recently vegetated slope, and the other was located on a lower slope with vegetation estimated at four to eight years of age. Two 3 m^2 sub-plots were staked in each of the plots, with a space of 0.5 m separating the two sub-plots. One m^2 permanent plots were staked at the center of each 3 m^2 plot for cover surveys. Preexisting vegetation was not identified on each block before the initiation of the study.

The preseeded and preexisting vegetation began to emerge in April. Each of the plots was sprayed with a broad spectrum herbicide, glyphosate, commercially known as Roundup (Monsanto), to eradicate the preexisting vegetation. Roundup is a topically applied systemic, general herbicide that kills nonwoody plants; however, it does not affect seed viability. A 0.5 percent solution of concentrate was mixed with water onsite, and the plots were sprayed using a backpack sprayer. Each block was sprayed twice, with an interval of 7-10 days between sprayings. Much of the growing vegetation soon displayed symptoms of chlorosis and died within 14 days of spraying. The areas were raked lightly to remove plant debris.

In May, after observing that 99 percent of the vegetation on the plots had been killed, each 3 m^2 plot was seeded with one of two species mixtures. The seed mixtures were preweighed for each plot, and then were mixed with 500 g of coarse construction sand and spread by hand broadcasting the seeds so that the entire plot had an even distribution of the sand and seed. The plots were not prepared with fertilizers nor were the plots irrigated. Trenches 15-30 cm deep were dug above and below each experimental block to slow erosion and to deter rill formation, a possible consequence of the site preparation.[1]

The plots were monitored weekly for 12 weeks. Identification of the germinating seedlings was aided by greenhouse germination studies, which permitted rapid identification after the cotyledons had unfurled. Within the 1 m^2 plots, the number of individuals of each species surviving from each seeded mixture, the percent of total green cover for each species seeded, and the cover of nonseeded species (coming from preexisting vegetative growth, the soil seed bank, and/or from wind dispersed seeds), were recorded. The breakdown of cover in percent for each plot was divided into green vegetation, bare ground (including rocks) and dead/killed vegetation. Species composition data were also collected using the entire 3 m^2 area.

STATISTICAL ANALYSIS

The experimental design for the study was a split split plot design (Lentner and Bishop, 1986). Slope position of the plots with upper and lower levels was considered

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[1]Immediately following the first seeding, a thunderstorm came through the area, creating flash flooding. To ensure an adequate stand of vegetation for the landfill operator at all plots, every plot was reseeded one month later with proportions of seed reflecting germination quantities found in greenhouse studies.

the whole plot treatment. The first split considered types of seed mixtures (two levels). The second split was time, and it was used for repeated measures analysis of variance to look at trends among groups. Aspect was thought to be an important factor in determining plant species composition and was used as a blocking factor. Two subplots at each plot were established to test the effects of mixture type on species composition and green cover for a total of 20 subplots. Response variables were the number of species appearing per plot and the total green cover per plot. Data were analyzed using the Statistical Analysis System package (SAS Institutes 1991). All populations in the experimental blocks were assumed to have a normal distribution. Significance was determined at a p-value of 0.05 or less. A univariate test for repeated measures analysis of variance was used to describe the behavior of aspect and slope and seed mixture type in terms of the response variables of species richness and green cover over four different points in time over the summer. Between subject and within subject effects of the plots were analyzed using seed mixture type, slope position, time, and their related interactions as error terms (Meredith and Stehman, 1993). Trends were tested by orthogonal contrasts, and simple linear regression analysis (Sokal and Rohlf, 1981) was performed to determine the relevance of soil nutrients to green cover and species richness of each species mixture.

SEED SELECTION AND PREPARATION

The selection of seeds for the standard mixture was made from the most recent invoice of seeds ordered by the Roanoke Regional Landfill. References for native and naturalized seeds for the Ridge and Valley region of Virginia included: <u>Guide to the Vascular Flora of the Blue Ridge</u> (Wofford, 1993), <u>Atlas of Virginia Flora</u>, 3rd Edition (Harvill, et al. 1992), and <u>Manual of the Vascular Flora of the Carolinas</u> (Radford, 1968). The preliminary species list was reduced to seeds available from several wildflower seed companies in the United States. Seeding amounts for the native mixture were determined using the base that each square foot should be covered with 100-120 seeds assuming 100 percent germination. Each wildflower species had the same number of seeds per plot, so the total number of seeds was divided by the number of species and the resulting number of seeds per species was weighed out according to the number of seeds per kilogram of each species (Lyons, pers. comm.). Grasses were seeded at a density of 132 grams per acre per species. The species used, their commercial sources, their origins, and whether they were found in Virginia, are listed in Table 2.2.

Table 2.2 Wildflowers and grasses seeded in the native mix at the Roanoke Regional landfill.

SPECIES RICHNESS	COMMON NAME	ORIGIN[1]	FROM VA[2]
Centaurea cyanus	Cornflower	Europe	I
Coreopsis lanceolata	Lance-leaved coreopsis	Mid-west U.S.	I
Coreopsis tinctoria	Plains coreopsis	Mid-west U.S.	I
Echinacea purpurea	Purple coneflower	Middle U.S.	I
Helianthus annuus	Annual sunflower	Middle U.S.	I
Hesperis matronalis	Dame's rocket	Pakistan	I
Liatris spicata	Dense blazing star		I
Lupinis perennis	Perennial lupine	NE U.S.	I
Oenothera speciosa	Showy evening primrose	Middle U.S.	I
Rudbeckia hirta	Black-eyed susan	SE U.S.	Y
Silene armeria	Catchfly	NE U.S.	I
Solidago rigida	Stiff goldenrod	MW U.S.	I
Andropogon gerardii	Big bluestem	MW U.S.	I
Schizachrium scoparius	Little bluestem	MW U.S.	I

[1] MW=mid western states; NE= northeastern states; SE=southeastern states; additional note: *Centaurea* is reported to have been introduced to Sweden in 100 A.D.
[2] I= introduced through cultivation or escape; Y=native to Virginia

Seed amounts in the standard mixture were determined differently because the donated seeds had arrived premixed. An estimation of the number of seeds was made based on the number of seeds commonly found per gram of each species and then multiplied by the number of seeds needed to complement the number of seeds being seeded in the native species mixture.

GERMINATION STUDIES

In March 1993, seeds received from various seed sources underwent germination tests to determine the best possible seed germination rates. One hundred seeds of each species from both the native and standard species mixtures were sown in two soil types in 1 ft^2 flats in the greenhouses at Virginia Tech. The two soil types used were a control potting soil, a commercial mix called "Sunshine", and soil from the Roanoke Regional Landfill[2]. The landfill soil was taken from the same cut as the capping material. Over a period averaging 30 days per experiment, the seeds in each flat were watered daily and germinating seeds and survival rates were counted every three to four days. The results from pilot experiments comparing all species from all companies to the distributor's specifications are published elsewhere (Hyer, et. al 1994). Secondary experiments were established for those species exhibiting high germination rates in the landfill soil and the sources of these seeds were used for the field plantings.

SOIL ANALYSES

Fifty gram samples of soil were removed from each experimental block after spraying and before planting for nutrient analysis. Transects within each experimental block formed a grid of 5 m^2 blocks. Randomly, the top 5 cm of an area in each transect were scraped off, mixed with the soil scraped off of all the other soil from the other transects within the block, and the contents mixed together in an airtight bag. Fifty grams of soil were sent to the Virginia Tech Soil Testing laboratories for analysis of macronutrients, micronutrients (including aluminum, sulfur and boron, and soluble salts) and organic matter content. Fifty grams of the soil from the bag were removed an dried in a 105 C oven for 24 hours to determine mass moisture content of the soil. Fifty more grams of bagged soil were air dried, shaken overnight in a solution of 5

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[2]Sunshine mix is a 3:1:1 mixture of peat, perlite, and vermiculite. It is produced by Fisons Horticulture, Vancouver, B.C., Canada.

percent sodium hexametaphosphate (Calgon), and suspended in graduated cylinder filled with distilled water. Particle size distribution of the sand silt and clay constituents of the soil was determined by floating a soil hydrometer which measures changes in density of the liquid, at two intervals in time.

RESULTS

FIELD STUDY

SPECIES RICHNESS

Lists of all species and the plots in which they occurred are found in Tables 2.3 and 2.4.

Table 2.3 Location of species found on plots planted with the native species mixture

SPECIES NAME	FAMILY	NUMBER OF PLOTS OCCURRING
Ambrosia artemissifolia	Asteraceae	2
Andropogon gerardii	Poaceae	2
Centaurea cyanus	Asteraceae	8
Coreopsis lanceolata	Asteraceae	8
Coreopsis tinctoria	Asteraceae	9
Coronilla varia	Fabaceae	4
Digitaria sp. (or *Cynodon dactylon)*	Poaceae	6
Echinacea purpurea	Asteraceae	8
Helianthus annuus	Asteraceae	6
Hesperis matronalis	Brassicaceae	5
Lathyrus sylvestris	Fabaceae	2
Liriodendron tulipifera	Magnoliaceae	5
Lespedeza cuneata	Fabaceae	10
Lupinis perennis	Fabaceae	2
Oenothera speciosa	Onagraceae	6
Rudbeckia hirta	Asteraceae	8
Rumex sp.	Polygonaceae	2
Silene armeria	Caryophyllaceae	7
Setaria italica	Poaceae	3
Solidago rigida	Asteraceae	3
Trifolium sp.	Fabaceae	2

Polygynum pensylvanicum	Polygonaceae	4
standing aster, whorled leaves daisy flower (*Chrysanthemum* or *Erigeron*)	Asteraceae	2

Table 2.4 Species found on the plots planted with the standard mixture

SPECIES NAME	FAMILY	NUMBERS OF PLOTS OCCURRING
Agrostis alba	Poaceae	2
Ambrosia artemissifolia	Asteraceae	2
Coronilla varia	Fabaceae	6
Digitaria sp. (or *Cynodon dactylon)*	Poaceae	8
Festuca arundinacea	Poaceae	1
Festuca rubra	Poaceae	
Lathyrus sylvestris	Fabaceae	2
Liriodendron tulipifera	Magnoliaceae	1
Lespedeza cuneata	Fabaceae	10
Lolium multiflorum	Poaceae	4
Rumex sp.	Polygonaceae	2
Secale cereale	Poaceae	2
Setaria italica	Poaceae	9
Toxidendron radicans	Anacardiaceae	1
viny aster, white flowers (reduced)	Asteraceae	4
standing aster, whorled leaves daisy flower (*Erigeron*)	Asteraceae	2

The average number of species found on each 3 m^2 plot was 10.6 ($\pm$ 3.09 sd) species for the native mixture plots and 4.31 ($\pm$ 2.01 sd) for the standard mixture plots. In the 1 m^2 plots where actual stem counts were made and green cover was estimated, the total number of species in each treatment was considerably less, 5.62 ($\pm$ 3.01sd) for the native plots and 2.80 ($\pm$1.18) for the standard plots. Data from May and June 1993 were not used because of mistaking several wildflower species during identification and because identification of monocots in the first 6 weeks of growth was not accurate.

Seed mixture type had a linear trend for species richness across all plots ($p < 0.0329$, 1df, F value = 16.000). The repeated measures analysis of the main effects of seed mixture type, slope position revealed that only seed mixture type had a significant effect on species richness when the interaction of aspect and slope position was used as the error term for between plot effects ($p < 0.0002$, 1 df, F value = 44.77). None of the other tests showed slope position individually or in an interaction with the other main effect to be significant in determining species richness.

COVER ESTIMATES

The average green cover over the summer was 18.26 percent (s.d. = 19.51 percent) for plots planted with the native mixture. The average cover for the plots planted with the standard revegetation mixture was 27.34 percent (s.d.= 25.43 percent). Aspect showed a cubic trend in relation to total cover, but it was used as a blocking factor and the p-value of 0.0325 (1 df, F value = 4.51) may not be large enough a difference to be relevant. Between plots, the different seed mixture types, slope positions and their interactions had no effects on the dependent variable of total cover at any time. In the analysis of within subject effects, none of the main effects or their interactions with time affected the total cover at any treatment plot.

LABORATORY STUDY

The results of germination studies for each of the species used in the native and standard species mixtures are listed in tables 2.5 and 2.6. Approximately twice as many seeds germinated in the control soil as in the soil taken from the Roanoke landfill. Seedlings in the control potting soil were taller and had more leaves at the end of the testing period than those in the landfill soil (data not shown). However, the seeds grown in the landfill soil, while stunted, showed no signs of chlorosis and only one species, *Liatris spicata*, wilted during the testing period. *Centaurea cyanus* was the first to germinate in all tests, appearing within three days after seeding. *Andropogon scoparius* was the last species to produce a cotyledon, taking 10 or 15 days before the first seed leaves appeared.

Table 2.5. Native species mixture seeded on experimental plots at the Roanoke Regional landfill 1993.

WILDFLOWER SPECIES	SEED SOURCE	SOIL A[1]	SOIL B[2]
		# germinated	
Centaurea cyanus	Lofts	33	70
Coreopsis lanceolata	Lofts	23	51
Coreopsis tinctoria	Applewood	47	71
Echinacea purpurea	Applewood	47	56
Helianthus annus	Applewood	2	4
Hesperis matronalis	Lofts	58	60
Liatris spicata	Applewood	78	67
Lupinis perennis	Lofts	28	37
Oenothera speciosa	S&S	53	53
Rudbeckia hirta	Lofts	9	57
Silene armeria	Applewood	55	78
Solidago rigida	S&S	2	57
Trifolium pratense	Landscape Supply	62	54
Andropogon gerardii [3]	Prairie Nursery	24	29
Schizachrium scoparius[3]	Prairie Nursery	18	14

[1] Soil from the Roanoke Regional landfill
[2] Soil from a commercial potting mix
[3] These two species are grasses native to midwestern United States.

Table 2.6. Standard species mixture seeded on experimental plots at the Roanoke Regional landfill 1993

SPECIES	SEED SOURCE	SOIL A[1]	SOIL B[2]

		# germinated	
Agrostis alba	Landscape Supply	67	57
Coronilla varia	Landscape Supply	53	46
Lespedeza cuneata	Landscape Supply	49	1
Lolium multiflorum	Landscape Supply	71	79
Secale cereale	Landscape Supply	31	61
Setaria italica	Landscape Supply	84	50

[1] Soil from the Roanoke Regional landfill
[2] Soil from a commercial potting mix

NUTRIENTS

Results from soil nutrient analyses run in May 1993 are listed in table 2.7.

Table 2.7. Soil nutrient analysis for experimental plots, May 1993.

BLOCK #	pH	OM[1]	SS[2]	NO_3-N	P	K	Ca	Mg	Zn	Fe	Cu
1	6.2	0.8	1	3	17	83	384	189	1.6	15.2	0.4
2	5.6	0.8	1	3	17	80	492	209	3.1	49.2	0.7
3	7.1	1.0	1	3	60	143	804	365	3.0	32.2	0.5
4	5.7	1.0	1	3	12	69	456	229	2.7	79.4	0.7
5	7.4	1.6	166	28	32	138	864	310	3.2	37.9	0.6
6	6.7	1.4	128	23	20	93	672	244	2.7	35.0	0.6
7	5.4	0.6	1	3	21	117	372	176	2.0	37.9	0.4
8	6.1	0.6	1	3	24	74	660	256	3.2	43.6	0.4
9	7.1	2.0	1	3	29	83	816	296	4.4	64.0	1.4
10	6.6	0.9	1	5	8	51	420	228	1.7	76.0	0.5

[1] OM= organic matter content, reported as percent of total soil
[2] SS= soluble salts. Soluble salts, nitrate nitrogen, and all elemental data are reported in parts per million.

The pH did not vary widely among all plots, although within aspect three there was a 1.4 fold difference in pH. Organic matter contents are low for areas where the soil horizon was composed of disturbed B and upper C horizons (Brady, 1990). Organic matter accounted for less than 1percent of the upper four inches of soil collected at each plot. The area of plot nine had been mulched with a dry chip mulch in 1988 or 1989, which may have accounted for the relatively high level of organic matter in the sample. Nitrate nitrogen levels were consistent in all but plots five and six on aspect number four. Phosphorous, calcium, magnesium and potassium levels were about average for soils, although among all aspects the levels varied widely (Brady, 1990).

The results of simple linear regression analysis of species richness and cover, each as a function of nitrogen, phosphorous, potassium, and calcium (the 4 principal nutrients added as amendments to hydroseed slurries) are listed in Table 2.8.

Table 2.8 Results of regression analysis of species richness and cover for each of the experimental mixtures as possibly affected by four soil macronutrients

VARIABLE	NATIVE MIX SPECIES RICHNESS	NATIVE MIX COVER	STANDARD MIX SPECIES RICHNESS	STANDARD MIX COVER
CALCIUM	0.0506*	0.1199	0.8872	0.9115
NITROGEN	0.0275*	0.0650	0.5882	0.9405
PHOSPHOROUS	0.4737	0.1178	0.1796	0.7340
POTASSIUM	0.0658	0.3527	0.0638	0.9886

* Significant at the 0.05 level

Results for a multiple regression analysis of species richness and cover each for the above nutrients together is listed in table 2.9.

Table 2.9 Results of multiple regression analysis of four nutrients for plots at the roanoke regional landfill; reported as p values

VARIABLE	NATIVE MIX SPECIES	NATIVE MIX COVER	STANDARD MIX SPECIES	STANDARD MIX COVER

	RICHNESS		RICHNESS	
CALCIUM	0.0239*	0.1580	0.3511	0.3300
NITROGEN	0.0119*	0.7900	0.0793	0.3076
PHOSPHOROUS	0.0850	0.1557	0.1922	0.2453
POTASSIUM	0.3843	0.4141	0.0362*	0.2718

* Significant at the 0.05 level

The individual effects of nitrogen on species richness in the native plots were significant ($p<0.025$), but it was not significant for species richness of the standard revegetation plots nor for cover in either of the sets of plots. The individual effect of calcium was not significant for species richness of the native plots; however, in combination with other nutrients its effects were significant ($p<.0211$).

SOIL ANALYSES

Results from a particle size distribution analysis are listed in table 2.10. Plots on lower slopes had a slightly higher proportion of the larger sand particles and upper slopes had a higher proportion of the smaller (< 0.5mm) clay particles. These proportions place the soil texture into the clay category, but with many variations in texture independent of location.

Table 2.10 Particle size distribution of soils from experimental blocks at the Roanoke Regional landfill[1]

BLOCK #	SAND	SILT	CLAY	TEXTURAL CLASS[2]
1	45.2	13.9	40.9	Sandy clay
2	51.2	11.9	36.9	Sandy clay-sandy clay loam
3	41.9	22.8	35.3	Clay loam
4	48.8	17.5	33.7	Sandy clay-sandy clay loam
5	32.4	23.4	45.2	Clay
6	41.2	17.5	41.3	Clay-sandy clay
7	39.1	19.1	41.8	Clay
8	40.8	18.6	40.6	Sandy clay-clay
9	45.7	17.6	36.7	Sandy clay loam

10	49.3	24.2	23.2	Sandy clay loam

[1] Data are given as percent total soil. [2] After Brady (1990).

DISCUSSION

This study has demonstrated that, even at low seeding quantities by standard reclamation methods (about 25-30 pounds seed per acre), 70 percent of the wildflower species became established on plots on an active portion of a landfill, regardless of aspect or slope position, and under varying nutrient conditions (see Torbert and Burger, 1991, Jeff Crommer, pers. comm.). The plots with the greatest number of species planted using either mixture were the native sub-plots five, six and seven.. The plots with the greatest number of species including invasive plants were sub-plots planted with the native mixture on plots five and six. The plots with the highest cover and species richness were plots five and six. Age of the plot and the preexisting vegetation type probably contributed to the high levels of species richness on plots five and six. However, the high level of species richness in the native mixture sub-plot 7 cannot be explained by the same variables since the area around the plot indicates that the plot area was the most recently seeded at the landfill and cover estimates were some of the lowest.

A possible reason for the responses seen in cover and richness and the greatest challenge to this project were preexisting ground cover which may have on the one hand enriched soil material in some areas and reduced establishment potential for wildflowers by competition in others. Soil nitrogen provided by the dead legumes may explain some of the variation in cover across all plots.

Tests showed species richness and cover to be significantly different between the two revegetation mixtures. The effect of slope position was not significant for contributing to species richness or green cover except at certain time points during the summer. This is an important conclusion because it indicates that widflower establishment at the Roanoke landfill may not be affected by a differential soil moisture content. Future studies testing soil water potential at each plot would confirm this hypothesis. Performing a repeated measures analysis of variance indicated that trends over time did not show slope position to be a significant factor in determining species richness. Neither the standard nor the native species mix had more than 10 percent cover after the first year at the Roanoke Regional Landfill. Higher rates of seeding and/or nutrient amendments may induce higher cover at the outset, but this also increases the cost to the landfill operator. Species richness was found to be higher for the native species mixture than for the standard mixture, but there were also more species in the native mix. Caution must be taken, however, in extrapolating these results because seeding densities for the first seeding were not identical in the two mixtures and reemerging *Lespedeza* may have skewed the total cover data.

Using previously revegetated areas for the study introduced the problems of *Lespedeza cuneata* and potentially of *Coronilla varia.* In order to construct plots at the landfill while the landfill was still in operation, the researcher had to keep plot numbers and sizes to a minimum and had to establish the plots deemed out of the way of the landfill operator. This created crucial problems in design including loss of statistical power because of low replicate size in addition to the factor of preexisting vegetation altering soil conditions. Figure 2.1 is a graph of the breakdown of total cover in terms of *Lespedeza,* planted species, and invasive plants. *Lespedeza* was weeded regularly from the plots planted with the native mixture and surrounding the plots planted with the standard mixture, but it was not removed from within the standard plots, because we could not distinguish which *Lespedeza* had been planted for the study and which was reemerging from preexisting vegetation. Other species on the standard plots listed as planted are also suspect for the same reason. The landfill operator had not recorded the species planted at each particular site (and the species planted varied from year to year). The level of invasive plants remained the same across both plots, indicating that at least during the first year, merely by eliminating the dominant vegetation types other dicots and grasses that can invade naturally. It is recommended that future studies of this nature be located on newly capped areas free of vegetation to avoid the confounding factors of reemerging vegetation and to distinguish vegetation sources.

It has been argued that cover estimates alone are not an accurate reflection of erosion control. Several authors including Torbert and Burger (1991) have developed methods of measuring soil movement independent of cover estimates on steep slopes. In addition, below-ground biomass, while as variable in morphology, mass and length seasonally, also contributes to soil structure and integrity (Brady, 1990). These two variables should also be tested in studies to determine the efficiency of any species mixture to maintain soil capping layers in the future. The soil used for the capping liner varies in texture and particle size distribution, but it is not the optimal soil for preventing water penetration. With sand particle proportions in excess of 30 percent, the degree of soil stability will decrease and the percolation of water will increase, even if the soil is heavily compacted (Brady, 1990).

Across all plots planted either with the native or the standard revegetation mixtures there is a highly varying soil nutrient environment for plant growth. In areas of increasing nitrogen and calcium contents there is an increase in plant species richness, especially, if not exclusively, on plots five and six. Future studies investigating nutrient cycling in plant soil-interactions could focus on the advantages or disadvantages to high levels of these two nutrients in restoration os disturbed sites. *Lespedeza* was the dominant species on all but plots five, six and seven. *Coronilla varia* was the dominant species on plots five and six prior to spraying. The absence of any legume on plot seven was another indicator that it had only been recently seeded prior to the commencement of the study, and so low values for most of the nutrients was anticipated.

Lespedeza is an earlier successional species than *Coronilla* and so the buildup of nitrogen in the soil may not have been as great on younger plots. There have been numerous studies investigating the use of perennial legumes to enhance annual crops and reforestation projects; most of the research has concluded that *Coronilla varia* and *Lespedeza cuneata* offer approximately the same benefits in terms of soil nitrogen enrichment (Barnard and Folscher, 1988; Elias and Chadwick, 1979; Luken, 1987; McGuinnies and Townsend, 1983). The degree of success as live or dead mulches of these and other perennial legumes like *Lotus corniculatus* and *Medicago sativa* depends upon the concentration of other soil nutrients, the type of crop or tree seeded in conjunction with the legume, and the geographic location of the experiment (e. g., *Coronilla varia* failed to establish in several studies conducted in areas west of the Appalachian Mountains). No study has been found that examines the enrichment of soil nitrogen through successional monocultures or mixed cultures of legumes. This type of study is probably site- specific in terms of the desired species responses and is necessary if certain desired species require a particular nitrogen-enriched environment but are not amenable to artificial fertilizers (see Larson and Schwartz, 1980).

Second year soil data taken shortly before the landfill closed showed a drop in the levels of nitrogen in the soils at plots five and six from 28 ppm in the first year to 5 and 3 ppm the second year (data not shown). This change has been attributed to the change from a nearly pure stand of *Coronilla varia* in 1993 to a non-legume dominated community in 1994. Total cover for the second year at these plots was as high as the first year; however, *Lespedeza* rather than *Coronilla*, is now present.

In agriculture and in natural systems nitrogen is a principal nutrient and often a limiting factor for growth (Mengel and Kirkby, 1976). However, researchers in the United Kingdom have found in studies of restoring species rich grasslands to abandoned agricultural lands that nutrient amendments including nitrogen and phosphorous already present in the soil have helped invasive species to colonize and grow before desired species can have a fair shot (Kendle, 1994; Grimes, 1973; Grignon, 1972). Comparing intensely cultivated areas with nutrient poor abandoned commercial land for species rich grassland establishment, the investigators found that the revegetation communities on the agricultural lands were dominated by undesirable species. On unamended soils native, desired species more often establish and persist (Kendle, 1994; Grimes, 1973).

Kendle and others in the United Kingdom have suggested that higher degrees of heterogeneity in habitat development will produce higher species richness as a direct result of patchiness of microenvironments, encouraging different species to thrive in different areas within one managed area. They also recommend non-homogeneous soil nutrient environments for the same reason, to increase the potential for soil microhabitat diversity as well as for macrohabitats. If habitat heterogeneity produces a few plants that only appear in small areas, as did the native grasses on plots five and six at the landfill, then plants should not be excluded from large scale habitat recreation merely because of low occurrence. The environments where the plants thrive may be able to be reconditioned, at a later time and at a smaller scale within the larger rehabilitation project, allowing the successful establishment of these species and a higher overall species richness and cover in these areas.

Data from second year plots on other sites have indicated that numerous plants will appear even without nutrient amendments (unpublished data). *Coreopsis lanceolata*, and the annuals *Centaurea cyanus*, *Coreopsis tinctoria*, and *Silene armeria*, have exhibited extensive branching, increased cover per plant per plot, and larger and more numerous flower heads in 1994 than 1993. In 1994, *Lupinis perennis* reappeared in plots where the year before the seedlings had appeared to wither away.

At these sites and at the landfill there is a clear advantage to sowing annuals into a perennial mixture. Annual plants including *Centaurea cyanus* and *Coreopsis tinctoria* establish shallow rooted systems quickly on the tractor compacted terrain of the landfill. In addition, the color of annuals is often greater than that of subsequent perennials. If annuals can coexist with grasses traditionally used for short term cover, e.g., *Setaria italica* or *Lolium multiflorum*, then the potential of achieving short term cover which is aesthetically pleasing at reasonable cost would be achieved.

Annual grasses and wildlfowers should be able to contribute significantly to soil stability if sufficient attention has been paid in the first year to providing an adequate dry mulch cover or other mechanical means of soil stabilization (i. e., matting or netted straw). Costs for such methods may be higher than the allocated by the current budget at the Roanoke landfill; however, observations of overall soil loss on the active portions of the landfill indicate that standard revegetation methods have been insufficient to deter significant soil runoff.

Guidelines for wildflower and grass seeding in Maryland, Pennsylvania, and New Jersey, recommend seeding seeds first, then mulching with fertilizer as necessary, and finally spreading sterile straw for cover. This sequence of events allows seed to soil contact before mulch application. Drill seeding, a standard revegetation method in reclamation/restoration projects, is not a viable option for the 25 percent slopes at the Roanoke landfill. Standard hydroseeding equipment can be used, although the cost increases because three passes with machinery are required over an area instead of one or two. However, the high cost of wildflower seeds necessitates careful seeding procedures with attention paid to time of seeding and documentation of areas that do not show germination within six weeks to two months after seeding. Soils analyses of nutrients prior to seeding combined with germination studies of seeds scheduled for seeding will provide invaluable information on potential problems areas on site and potential seeding quantity changes before seeding (and see Gilman, et.al, 1985).

While cost of the project has been a major concern for the Roanoke Valley Resource Authority (RVRA), the Authority has recognized that reseeding portions of the landfill with wildflowers and native grasses is an environmentally responsible gesture. The RVRA is taking a risk in following recommendations based upon one year of data. However, the RVRA also understands well the high-profile nature of this site. As waste managers have come under increasing public scrutiny because landfill tipping fees are increasing to $65.00/ton, landfill operators have to make greater investment in the endpoint of landfill operation, post closure use. With highway wildflower projects being required to include a percentage of money spent for research on wildlfowers, and with wildlfower roadways receiving favorable comments from tourists and local citizens, landfills may be next on the list for requiring sowing aesthetically pleasing vegetation. For optimal results, research can be conducted in each region where soil type for the cap, temperature, slope degree, and soil constituency varies to answer the question whether state money could be spent on landfill wildflower establishment, using native or naturalized non-competitive wildflowers and legumes and high forage and habitat value grasses. In New York, the Fresh Kills landfill, the largest of its kind in the world at 3,000 acres, the city has spent thousands annually investigating how best the landfill might serve the community when it closes 20-30 years from now (Handel and Robinson, 1994). Proper planning and investment in a landfill restoration option will occur at least 3-10 years before closure to reduce costs of soil amendments, to locate appropriate vegetation types, and to reduce the risk of erosion as a result of inadequate seeding densities or dead seed at closure.

It is difficult to design projects that are not permitted, by changing regulations or unchanging attitudes, to continue after their first year. However, with the possible future intervention of concerned landholders, especially Explore Park, research at the Roanoke landfill may continue. One of the recommendations made for future research at this site includes incorporating volunteers at Explore to search for and collect seed stocks of local origin for future work at the landfill. This type of continued collaboration must be reinforced by community approval at all stages of the project; if so, regulations will sway to allow continued research benefitting both the environment and society.

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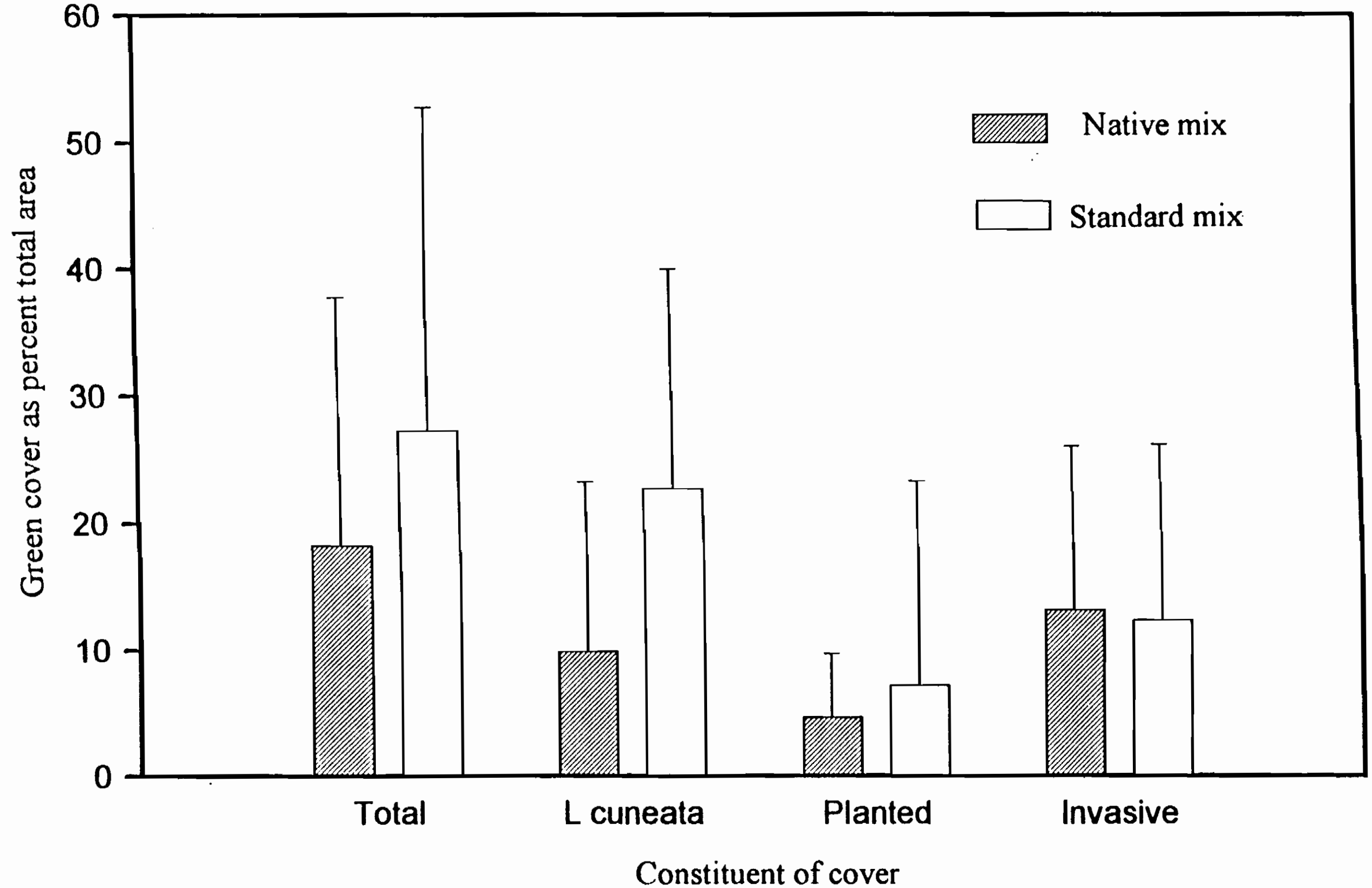

Figure 2.1 Breakdown of mean cover across all experimental plots

Chapter 3

VEGETATION SURVEY AT CHANCELLORSVILLE LANDFILL, SPOTSYLVANIA COUNTY, VA

INTRODUCTION

Landfilling is a common means of disposing household nonhazardous waste. Growth in community populations has resulted in increasing amounts of solid waste being generated. Reducing solid waste does not seem popular with the general public. This waste is filling existing landfills to capacity earlier than anticipated and has necessitated opening larger landfills. City and local governments often are confronted with the escalating costs of landfill construction, operation, and closure. It has become more difficult to site landfills in areas of appropriate geological and hydrological parameters that are not also in immediate public view. Landfill equipment, labor, and maintenance increase in cost as the size of the landfill increases. Landfills emit offensive odors during their years in operation and afterwards, and trash from the landfill may blow off trucks onsite despite efforts to keep the material in place. During landfill closure, sealing is essential because of to concerns about environmental contamination resulting from anaerobic decomposition within the landfill.

With these constraints pressing upon communities, landfill managers often have to locate their facilities in areas slated for development, and, once a landfill is closed, to ensure that the landfill is an asset rather than a visual or environmental liability. In the 1970s and early 1980s, communities invested large sums of money to create parks, sports areas, and even parking lots on closed landfill surfaces. However, problems emerged that were consequences of the unique properties of landfills. Booth (1990) described an area where a recreational park and swimming pond had been created where the swimming pond had been contaminated with numerous organic compounds and metals leaching from the closed landfill. The researchers demonstrated that a porous soil cap on the landfill, a clayey, permeable base, and placement of the landfill below the local water table contributed to the contamination of the pond and the closure of the pond for swimming. Work by Emberton and Chavis (1993) documents the hazards of building on closed landfills because of the nature of settling as the contents of the landfill interior are diminished by anaerobic activity. Even tree plantations as a form of cover over the landfill have been implicated in evidence of escaping leachate, which has the potential of contaminating surface water supplies. As with other facets of landfill operation, the degree of post closure landfill use is closely tied to the amount of money available for the most advanced forms of landfill closure (see Gilman , et. al., 1985).

By law when a landfill is closed, it must be capped with an appropriate soil or geotextile membrane liner and seeded with fast growing vegetation to keep the liner in place (Figure 3.1, p.59). Most of the literature concerning landfill revegetation suggests that a mixture of quick growing annual and perennial grasses and perennial legumes be used to effect soil stabilization (Gilman, et. al, 1985). The standard roadside revegetation mixture of Virginia (created by the Virginia Department of transportation in the 1970s), is the mixture most commonly used for landfill revegetation in Virginia (see Table 2.1 of chapter 2, p.17). These plants are all hybrid non-native species which have been particularly effective in suppressing the invasion of woody species, an important factor for landfill operators. Normally, as discussed in chapter two, the standard revegetation mixture succeeds within three to four years to a monoculture of *Coronilla varia* or *Lespedeza cuneata.*

The aesthetic value of this mixture during various states of succession has not been shown be as attractive as a wildflower stand for most motorists, though studies are lacking which compare the appearance of annual rye or crown vetch blooms to those of black-eyed susans and purple coneflowers.

In Spotsylvania county in central Virginia the director of public works was confronted with the task of creating a reasonably acceptable landscape from a nine acre landfill located near Fredricksburg. The landfill had been in operation since the mid 1970s and closed in 1992. Secondary roads now encircle the landfill, and the northern and western portion of the landfill site is less than a kilometer from residential housing. In addition, old railroad tracks ran alongside the landfill and the tracks had been designated as part of the statewide trail building "Rails to Trails" project. In an effort to create a more aesthetically pleasing landscape, the Board of Supervisors for Spotsylvania county approved a sum of money to sow a bed of wildflowers over part of the Chancellorsville landfill.

The operator was concerned about the feasibility of using wildflowers as sufficient cover to retain the soil and maintain the integrity of the cap liner. As a result, The director of public works chose to seed a 4:1 slope of the landfill as a trial study. The other, steeper 3:1 slopes were seeded with a standard revegetation mixture. In December of 1992, contact was established between Virginia Tech and the director of public works to set up surveys investigating the progress of the two seed mixtures at the landfill. The objectives of the study were to determine which species survived from each mixture type and the degree of total cover each mixture offered over time. In combination with a cost analysis, these analyses would determine if the seed mixture used or some part of it could be used in future seedings as an alternative to the standard revegetation mixture.

MATERIALS AND METHODS

SITE DESCRIPTION

The old Chancellorsville landfill is a 9.4 acre nonhazardous solid waste disposal area that closed in April, 1992. It is located at coordinates Lat. N38° 16.3" and Long. E77° 32.7" near Fredricksburg, Virginia, in the piedmont region. The annual precipitation for both years of the study is listed in appendix 1. The capping and gas venting design for the landfill is shown on figures 1 and 2. The capping soil is from cuts made from soil excavated when the landfill was constructed.

Seeding of the capped landfill was completed in July 1992. Aspects with 3:1 (33%) slopes were seeded with a standard revegetation mixture (see Table 3.1).

Table 3.1 Standard revegetation mixture used at the Chancellorsville landfill

SPECIES	COMMON NAME	FAMILY
Agrostis alba	Red top	Poaceae
Coronilla varia	Crown vetch-penngift	Fabaceae
Festuca arundinacea	Kentucky-31 tall fescue	Poaceae
Lespedeza cuneata	Sericea lespedeza	Fabaceae
Lespedeza	Korean lespedeza	Fabaceae
Lolium multiflorum	Annual rye	Poaceae
Lolium perenne	Perennial rye	Poaceae
Secale cereale	Abruzzi rye	Poaceae
Setaria italica	German foxtail millet	Poaceae

using a hydroseeder mulch slurry. The southwestern aspect with a 4:1 (25%) slope was seeded with a "Northeastern" mixture of seeds prepared by Applewood Seed Company (see Table 3.2), using the same procedure.

Table 3.2 Northeastern wildflower mixture used at Chancellorsville landfill

SPECIES	COMMON NAME	FAMILY
Aquilegia canadensis	Eastern columbine	Ranunculaceae
Aster novae-angliae	New England Aster	Asteraceae
Centaurea cyanus	Cornflower/Bachelor's button	Asteraceae
Cheiranthus alonii	Wallflower	Brassicaceae
Chrysanthemum suberbum	Shasta daisy	Asteraceae
Coreopsis lanceolata	Lance-leaved coreopsis	Asteraceae
Dianthus barbatus	Sweet William pinks	Caryophyllaceae
Digitalis purpurea	Foxglove	Scrophulariaceae
Echinacea purpurea	Purple coneflower	Asteraceae
Gysophila elegans	Baby's Breath	Caryophyllaceae
Hesperis matronalis	Dame's rocket	Brassicaceae
Linaria maroccana	Spurred Snapdragon	Scrophulariaceae
Linum grandiflorum rubrum	Scarlet flax	Linaceae
Lupinis perennis	Perennial lupine	Fabaceae
Oenethora missourensis	Dwarf evening primrose	Onagraceae
Papaver rhoeas	corn poppy	Papaveraceae
Rudbeckia hirta	Black-eyed susan	Asteraceae
Silene armeria	Catchfly	Caryophyllaceae

The hydroseed tank was not rinsed before the wildflower mixture was added, and parts of the aspect sprayed with the wildflower mix included residual seeds from the standard revegetation mixture. The southwestern aspect was targeted for the study.

METHODS AND MATERIALS

SITE PREPARATION

The area for the survey was chosen according to the seed mixture type used and the proximity in aspect. In July 1992, eighty percent of the landfill was seeded with the standard revegetation mixture. The southwestern aspect, being of a lesser degree in slope (4:1), was seeded in July 1992 with the "Norteastern"widflower mixture. The standard revegetation mixture was seeded at a density of 25 pounds per acre, and the Northeastern mixture at a density of 20 pounds per acre. Both mixtures were hydroseeded using a mix of seeds, paper mulch, nutrients, and water. No strw cover or additional irrigation was provided. The southwestern aspect was chosen for study because it had both mixtures represented on its hillface. Four transects, 10 meters in distance between each, were established along the length of the same hillface. Two transects were located in an area represented by the wildflower mix, and two more were located in an area representing the standard mix. Each transect was 80 meters long. Permanent flagging was placed at 10 meter intervals along each transect for surveys. Data including species composition and total cover per one m^2 transect were collected at every permanent stake at three dates in 1993 and four dates in 1994. Samples of plants not identified in field were verified at the Virginia Tech Herbarium.

STATISTICAL ANALYSIS

The paired transects for each seed mixture were analyzed by averaging the replicate adjacent plots. All analyses were run using the Statistical Analysis Software package (SAS Institutes, 1992). T-tests were run to determine differences ($p=0.05$ level of significance) in species composition and cover between the seed mixtures at each plot (Sokal and Rohlf, 1981). A repeated measures analysis of variance was run to determine if seed mixture type, time, or the related interaction was significant across both pairs of transects, as well as along each transect (see Meredith and Stehman, 1993). Orthogonal contrasts were established to determine whether the effects of seed mixture type and time were linear or quadratic for species composition or cover (Lentner, 1984).

RESULTS

SPECIES RICHNESS

The dominant species from each mixture in 1993 and 1994 are listed in Tables 3.3 and 3.4.

Table 3.3 Plant species inventory from transects 1 and 2 at the Chancellorsville landfill in 1993 and 1994.

SPECIES	1993	1994
Agrostis alba	------	LF
Coronilla varia	LF	LF
Festuca arundinacea	HF	HF
Lespedeza cuneata	LF	LF
Lespedeza sp.	HF	HF
Lolium mulitflorum	LF	LF
Lolium perenne	HF	HF
Secale cereale	LF	------
Setaria italica	LF	------
INVASIVES		
Ambrosia artemissifolia	HF	HF
Bidens polylepis	LF	LF
Cassia nictitans	LF	MF
Holcus lanatus	LF	LF
Hypericum perforatum	LF	MF
Medicago sativa	MF	MF
Rosa multiflora	LF	LF
Phleum pratense	LF	LF
Rumex acetosella	LF	LF
Rumex obtussifolia	LF	LF
Solidago spp.	-----	LF

Trifolium arvense	MF	MF

LF = Low Frequency; MF = Moderate Frequency; HF = High Frequency;

----- = absent; (1) = 1 stem was found on the entire slope

Table 3.4 Plant species inventory from transects 3 and 4 at Chancellorsville landfill 1993 and 1994.

SPECIES	COMMON NAME	1993	1994
Aster novae-angliae	New England Aster	LF	LF
Centaurea cyanus	Cornflower	LF*	LF
Cheiranthus allonii	Wallflower	HF	------
Chrysanthemum maximum	Shasta daisy	LF	------
Coreopsis lanceolata	Lance-leaved coreopsis	HF	HF
Dianthus barbatus	Sweet William pinks	HF	HF
Digitalis purpurea	Foxglove	1	------
Echinacea purpurea	Purple coneflower	1	1
Gysophila elegans	Baby's Breath	LF	------
Hesperis matronalis	Dame's rocket	------	LF
Lupinis perennis	Perennial lupine	1	------
Oenethora missourensis	Dwarf evening primrose	1	1
Rudbeckia hirta	Black-eyed susan	HF	MF
Silene armeria	Catchfly	LF*	LF
Bouteluoua gracilis	grama grass	LF	HF
INVASIVES			
Ambrosia artemissifolia	ragweed	HF	HF
Bidens polylepis	beggars ticks	LF	LF
Cassia nictitans		LF	MF
Holcus lanatus	velvet grass	LF	LF
Hypericum perforatum	St. John's wort	LF	MF
Medicago sativa	alfalfa	MF	MF
Phleum pratense	Timothy	LF	LF
Rumex acetosella	dock	LF	LF
Rumex obtussifolia	curly dock	LF	LF
Solidago spp.	goldenrod	-----	LF
Trifolium arvense	rabbit's foot clover	MF	MF

*Indicates species that may have had significant flower displays in the spring of 1993, April or May. These species are annuals and flower in early spring.

Two species, *Coreopsis lanceolata* and *Dianthus barbatus*, appeared with high frequency both years, 5 more appeared at variable frequencies over the two years (e.g., *Rudbeckia hirta, Silene armeria*), four species appeared with only one plant visible on the whole landfill in either or both years (e.g., *Echinacea purpurea, Lupinis perennis*), three species appeared in one year only, and the flowers and vegetative structures of three species were not found anywhere during the two summers the surveys were taken (e.g., *Papaver rhoeas, Linaria maroccans*).

Average numbers of species found on the area planted with the Northeastern mix were 15.5 (s.d $\pm$4.2) in 1993 and 10.7 (s.d.$\pm$4.3) in 1994 (see figure 3.2, page 60). Average numbers of species surveyed in the area planted with the standard revegetation mixture were 10.0 (s.d $\pm$3.7) in 1993 and 11.3 (s.d. $\pm$3.7) in 1994. Averaged species numbers were highest in June 1993 and declined in July through September (see figure 3-3?). In 1994, the average richness in the areas planted with the wildflower mixture increased, but never recovered to the same level as recorded in June 1993. The number of species in plots planted with the standard revegetation mixture increased after an initial drop between June and July 1993. Average species richness for the standard revegetation areas was nearly the same at the end of the survey as in the areas planted with the wildflower mixture.

Paired t-tests within each transect pair of each mixture type revealed no significant differences in species composition except in four instances. In June and July 1993, there were significant differences in species richness between transects 1 and 2 ($p < 0.0001$). In July 1993 and April 1994 there were significant differences in species richness between transects three and four ($p < 0.0282$, $p < 0.0121$, respectively).

Repeated measures analysis of variance whole unit analysis of data showed that in 1993 and 1994, plot (an alternative) the blocking factor, was significant for between subject effects for species richness ($p < 0.0001$). In 1993, neither the main effect for mixture type nor the interaction of mixture type and plot was significant ($p = 0.0877$, $p = 0.4042$, respectively); but in 1994 the main effect of mixture type was significant between plots ($p < 0.001$). A test of the hypothesis that mixture type was not significant when the interaction of mixture type and plot was used as the error term was not rejected in favor of the alternative ($p= 0.1353$). Analysis of within subject effects (within plot effects) showed that within each plot over time mixture type, plot, and the related interaction contributed to significant differences in species richness. In 1993 and 1994 the trends were both linear and quadratic ($p < 0.0021$, $p < 0.0001$, respectively). The main effect of mixture type and the interaction of mixture type and plot exhibited quadratic trends in 1993 ($p < 0.0004$); but mixture type exhibited both linear and quadratic trends in 1994 ($p < 0.0001$, $p < 0.0001$). The interaction of mixture type and plot was quadratic in 1994 ($p < 0.0001$). The main effect of plot over time was still a blocking factor, and was marginally quadratic in response in 1993 ($p < 0.0198$), but, like the other effects, showed linear and quadratic trends in 1994 ($p < 0.0001$, $p < 0.0001$).

COVER

In 1993, average cover in percent of total area for the areas surveyed with the Northeastern mixture was 55.39% (s.s.d. $\pm$ 0.9475) per one m^2, and for the standard revegetation mixture areas the average cover was 62.3% (s.s.d. $\pm$ 14.71) (see figure 3.3, p.61). In 1994, average cover for areas surveyed with the Northeastern mixture was 57.65% (s.s.d. $\pm$ 5.738) of the total plot area, and for the standard revegetation areas the average cover was 71.4% (s.s.d. $\pm$ 5.645). Average cover for the areas seeded with the Northeastern mixture remained at approximately the same level, rising slightly by July 1994. The average cover on the areas seeded with the Northeastern mixture fluctuated much more within each year, lowest earlier in the year and highest by the end of the survey. The average cover was always higher for the standard revegetation mixture, although cover of individual plots was often the same or lower than that of the northeastern mixture plots. Paired t-tests did not reveal any significant difference within paired transects at any time during the two years of survey.

Repeated measures analysis of variance whole unit analysis of data showed that in 1993 and 1994, the main effects of mixture type and plot, the blocking factor, were significant for between subject effects for cover ($p < 0.0001$). In 1993, the interaction of mixture and plot was not significant in determining cover ($p = 0.2076$); in 1994, the interaction was significant ($p < 0.0001$). Tests of no time relation with the main effects, or time and the interactions, showed that mixture type, and the interaction were significantly different over time in influencing species richness. Plot interacting with time was not significant in 1993 for affecting cover ($p = 0.0623$), but it was in 1994 ($p < 0.0001$). Tests for within-subject effects showed again that there was significant within plot variation due to mixture type over time, time, and the interaction with mixture type and plot over time ($p < 0.0001$) in 1993 and 1994. However, as in the tests for between subject effects, plot ionteracting with time was only significant in 1994 ($p < 0.0001$). Trends for polynomial contrasts over time were only completed for 1994 as 1993 only had two survey dates recorded for cover estimates. The average trend over time for cover was both linear and quadratic. Liewise, the main effects of mixture type, plot, and the related interaction were also quadratic and linear in trends on cover over time ($p < 0.0001$). The trend for the test of mixture type using the interaction term of mixture type and plot as a source of error showed no trends for the main effect over time on cover ($p = 0.8537$, $p = 0.4312$, respectively).

COST ANALYSIS - The total cost of the perennials was \$265.44, and the cost of the annuals was \$125.56. The species with the least occurrence were *Linaria maroccana*, *Linum grandiflorum rubrum*, and *Papaver rhoeas*. Other species that appeared nowhere on the plots but which were sited offsite with one stem included *Echinacea purpurea*, *Digitalis purpurea*, *Lupinis perennis*, and *Oenethora missouriensis*.

The cost of the four species with the lowest occurrence was $100.04. Four species, 22% of the mixture, cost 25% of the total mixture in covering one acre of land. If uniform distribution is assumed, then at least 929 cm^2 (one meter sqaured plot) would have 4 seeds and from them, two should have germinated.

NUTRIENTS

Table 3.5 lists averages and standard errors of nutrients taken from each transect.

TRANSECT	PH	P	K	N	Ca	Mg	SS
STANDARD (1)	6.8	6	63	3.7	592	77.3	55.3
STANDARD (2)	6.4	3.7	55.7	3.7	492	70.3	46.7
NORTHEASTERN (3)	6.9	13.3	55.7	3.7	1036	98.3	93.7
NORTHEASTERN (4)	6.6	6.3	56.7	4.3	788	86	64

T-tests showed no significant differences within each transect pair nor between mixture type for each nutrient ($p = 0.213$). The values for pH are more nearly neutral than reported on other landfill sites (see chapter two, p., and see Booth, 1990). The values for all nutrients are within ranges acceptable for growth, although the level of nitrate nitrogen remained low (3-5 parts per million). Soluble salts showed the widest variation in concentration, and the values follow the Ca^{++} curve closely.

DISCUSSION

In 1993, species richness was higher overall in the areas planted with the Northeastern mixture than in areas planted with the standard revegetation mixture. In 1994, the numbers of species were about the same between the two groups. Mixing of standard revegetation seeds in the hydroseeder with the Northeastern mix seeds complicates determining absolute numbers of species successfully establishing in each area, as does the absence of demarcation of areas hydroseeded with each mixture. By the low proportion of occurrences of the standard revegetation species along the two transects used to determine Northeastern mix numbers, we feel confident that the areas surveyed were an accurate reflection of the site sown with the Northeastern mix.

The dominant species in the Northeastern mix during the two year study were *Coreopsis lanceolata*, *Dianthus*, and to a lesser extent, *Rudbeckia hirta*. *Coreopsis lanceolata* is recognized as a highly aggressive plant producing large and dense leaves and persisting throughout the growing season. *Centaurea cyanus*, *Silene armeria*, and *Hesperis matronalis*, all naturalized from Europe, have been very successful establishing on other types of disturbed sites. Their low occurrence at this particular area may be due to the confounding factors of time of seeding and variable germination densities in seed stock. For the species not appearing at all, or with a frequency of one, the same confounding factor of time of seeding and variable germination rates may have contributed to the absence. *Lupinis perennis, Linaria maroccana*, *Linum grandiflorum rubrum* and *Papaver rhoeas* were chosen for the mix primarily because of the high color and interesting sizes even at low densities (Lyons, pers. comm.). *Papaver rhoeas* in particular, an annual , is a popular species used along roadside widlflower plantings throughout Virginia and the United States. If this species can thrive with care on disturbed roadbank conditions then the hypothesis that the absence of this and other species at the landfill may be at least in part due to time of seeding appears more credible. All of the species may have suffered lower germination densities being sown in midsummer. With a protective mulch cover of straw and hay, seedlings can be protected from desiccation, and using netted mulch covers, slopes can be protected from losing seeds during summer thunderstorms. From repeated measures anlaysis of variance data using plot as a blocking factor, ...

In the standard mixture, nearly all the eight species used were present at same time during the two year study. *Lespedeza cuneata* on the southwestern slope was slower to establish than usual, but *Coronilla varia* will probably not be a significant species on the landfill until 1995, since it colonizes slowly. *Festuca arundinacea* and *Lolium perenne* were the dominant species. Since this mixture has been tested for many years on many different types of disturbed areas, soils, and slopes, the results for richness are consistent for this species.

In both mixes, approximately the same number and type of invasive plants appeared. One of the long term properties of the standard mixture is the deterrence of invasive of woody plants and other species, but in the first few years of establishment herbaceous species such as *Bidens* and *Solidago* with wind-borne seeds would take advantage of the bare area and available nutrients to establish.

Both mixes had, by 1994, the equivalent species numbers, although this may be due to variable germination rates, time of seeding, and hydroseeder concentration of seeds.

The standard mixture resulted in a higher overall cover during both years of the study. The Northeastern mixture area, however, offered at least 50% cover both years, with cover on individual plots ranging from 30-98% cover (data not shown). As noted previously, variable germination densities by virtue of the time of year of seeding may have impacted the stand survival of the northeastern mix species. A fall or spring planting of the same mix may alter the cover results by permitting seedling establishment during periods of plentiful rain and cooler temperatures; similarly, an initial application of mulch or netted hay covering might reduce soil temperature and permit faster growth and increased numbers.

COST ANALYSIS

The ratio of perennial to annual cost was 2:1. There were 11 perennial species and 7 annuals, so amount spent was equivalent to the ratio of perennials to annuals. However, if low occurrences are recorded of even the vegetative presence of the perennials in the first couple of years, care should be taken to choose ones of greater establishment histories. *Oenethora mississourensis* was spotted off the plots, but with the investment made and the proportion of the mixture used the species would have been expected to appear on at least 50% of the transect plots. If germination tests are the same as conducted in house, then no less than 40% of any species should have germinated, with plot occurrences for annuals and perennials ranging from 40% (4-6 plots) to 65% (10-11 plots). As it was, a low occurrence was counted as one plot, a moderate occurrence from 3-8 plots, and a high occurrence from 9-16 plots. This is all assuming uniform distribution of seeds, which even if there was, the proportion of seeds must be taken into account.

Removing species that do not appear in germination tests and replacing them with native grasses, other nonaggressive legumes like *Melilotus* or *Trifolium pratense* or other wildflowers, could have reduced the cost of the mixture. The landfill operator was notified of the species absent, and he decided to call the seed company to remove those species from the NE mixture he was planning to use at other areas and increase the densities of the other species in the mix. He was also advised on placing a mulch cover if the seeds were going to be sown in midsummer.

While the data for soil nutrients are incomplete, having been taken at only one date, results indicate that the soil is homogeneous across the aspect for all plots involved in the study. Nutrient data had also been subjected for tests of variation from the top to the bottom of the slope and the results were not significantly different (data not shown). These results indicates that at after two years of plant growth, the soil mineral environment has not significantly changed to offer any plants a conspicuous advantage or disadvantage for growth. Uniformity in soil conditions may also explain the fairly uniform distribution of invasive plants across the area surveyed.

As discussed in chapter 2, it is doubtful that cover alone is an accurate indicator of soil retention on slopes. Tests of soil depth at intervals over time along a transect (as described by Torbert and Burger, 1992), as well as determining below ground root biomass, would aid in creating a more complete picture of the vegetative cover profile.

The color display was dominated by the yellows of *Coreopsis lanceolata* and *Rudbeckia hirta* and the beggar tick *Bidens*, and for the operator it contrasted favorably against the standard mix areas and the surrounding meadow. The operator was satisfied with the color display he has seen thus far, and although he understands the implications of mixing the species standard with the Northeastern mixes, he has proceeded with a regimen of mowing beneficial to the NE mix and plans to reseed with more wildflowers in the next three years.

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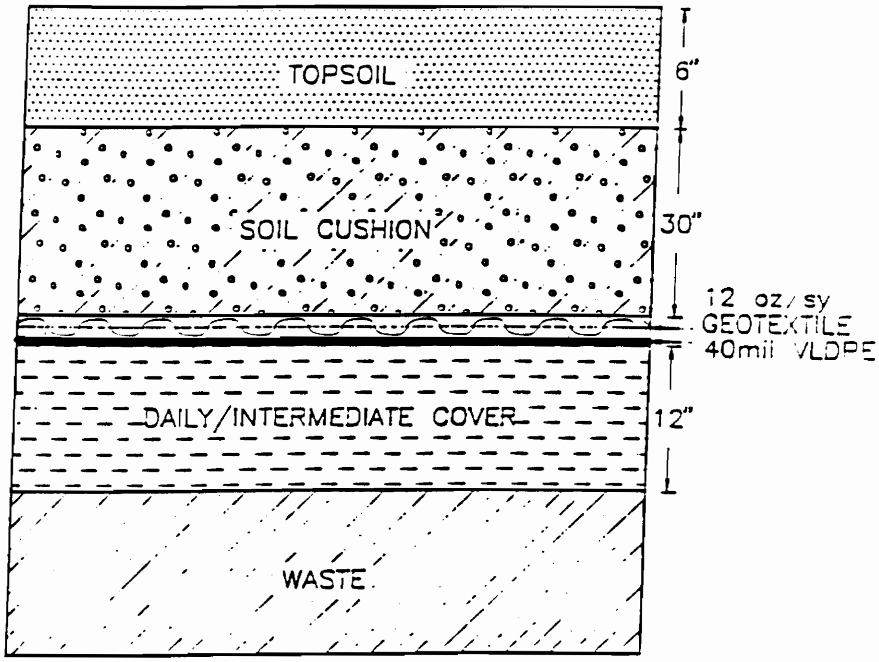

Figure 3.1 Soil cap design used at the Chancellorsville landfill. Courtesy of Draper Adden and Associates.

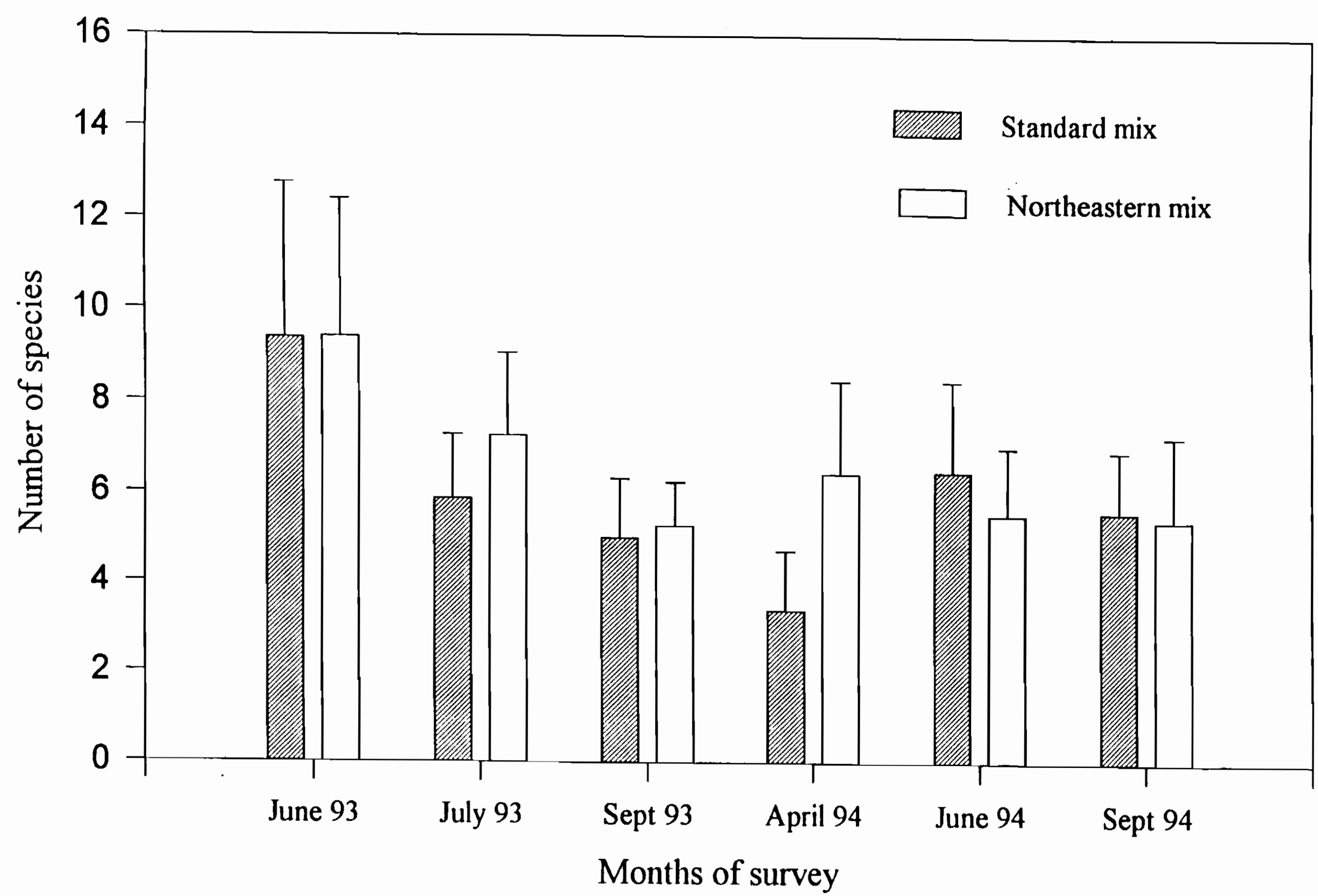

Figure 3.2 Average species richness for transects surveyed over time

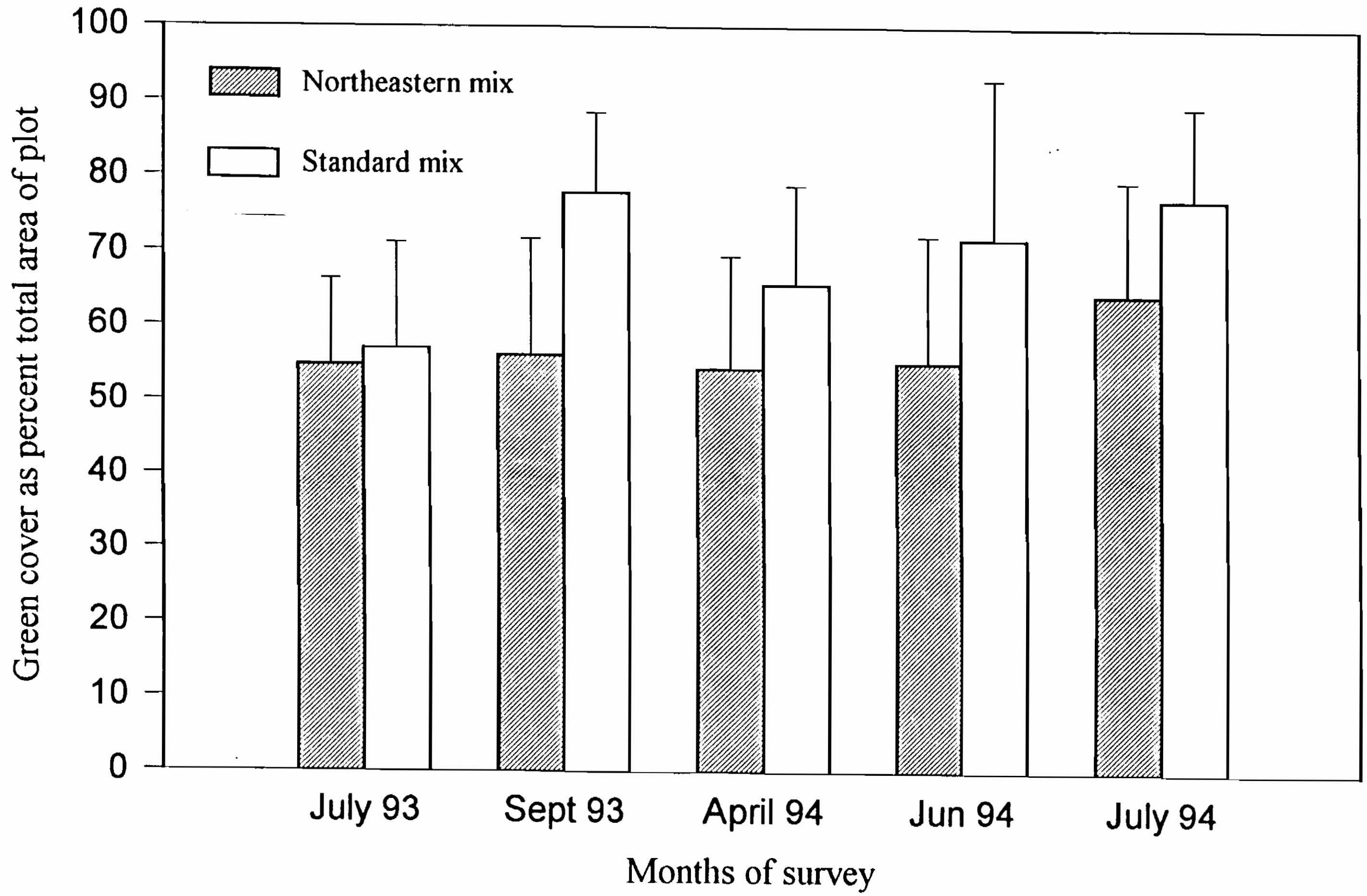

Figure 3.3 Average cover across transects for areas seeded with the two mixtures

GENERAL CONCLUSIONS

The results from the studies undertaken at the Roanoke Regional and Chancellorsville landfills have several implications for restoration. The most crucial is that there is insufficient information available to determine whether any vegetative community currently established on municipal landfills is completing the task that it was intended to do. The absence of quantified tables with references to cover on a specific slope as providing x degree of soil stabilization brings into question whether any vegetative cover, even 100% green cover at a site, should be used as a blanket guarantee that the soil cap is not losing the top layers. Because this issue has not been resolved in the regulations, the question of whether the cover is "adequate" for any experimental alternative mixture type, whether it is a mix of native grasses and legumes such as the one used at the Roanoke landfill, or a widlflower mix prepared be a national seed company seems almost pointless without a standard with which to compare.

The regulations also do not stipulate how many species need to be used, what type or from what source. Results from Chancellorsville landfill in Spotsylvania county indicate that time of seeding and choice of seeds probably contributed to less than 50% of the species initially seeded surviving to the end of the second year. Without any control plots seeded at a more suitable time of the year with the same stock of Northeastern mix, the principal cause of species failure to establish cannot be determined. At the Roanoke landfill, care was taken to choose drought tolerant seeds and the seeds were planted in a suitable season; however, the reemergence of preexisting vegetation, the low quality and thin soil cap layer over the trash, and the stoppage of the project after one growing season probably contributed to masking the potential richness of the native mixture.

As noted in chapter 2, there are various ecological constraints restricting plant growth on landfills. With new regulations coming into play every year, species mixtures may become subjected to variations in those constraints (less direct contact between the roots and the soil gas contents, more intact, compacted clay encountered below a few centimeters of topsoil). Wildflowers such as the ones used in this study are well adapted to various conditions, but they must be tested at each site before use. Reduction in overall cost to the landfill operator by using only species that flourish will also build confidence in the sponsors that using more attractive species is an option.

The question remaining is whether biodiversity, or at least floristic diversity, is enhanced by having a wildflower mixture. Research in the future will also determine the faunal species frequenting different species, the soil faunal and bacterial interactions with the root systems of each species, the allelopathic responses given off by each species, the net primary production and the sequestering of carbon dioxide, and the competitive interactions with other species in the mix and with the species invading. These attributes may also contribute to determining which species are used on landfill restoration projects; therefore, they will provide a more accurate measure of the biodiversity of an area being restored. With decreasing area given for wilderness areas and larger areas dedicated for long term landfill use and operation, consumer money will be well spent if investigations can be made of how to merge and recoup the losses of wilderness areas with the large landscapes created at landfill closure.

APPENDIX

PERSPECTIVES ON THE EDUCATION COMPONENT

The following is a synopsis of the work done with the Roanoke Valley Governor's School. For a complete description of the STS project, please see the dissertation by Beatrice L. Taylor (1994), Virginia Tech, Blacksburg, Virginia.

In spring of 1993, a doctoral student in science education proposed to use the landfill as a Science and Technology in Society (STS) project for students in the Roanoke City School System. STS projects are an alternative method proposed by educators to teach concepts to students. Students learn what scientific, technological, and societal concepts that are relevant to the topic at hand. By acquiring information and knowledge leading to the resolution of a relevant problem, the information may have greater staying power as well as the acquired ability to go through the steps to problem solving.

The idea of using the impending closure of the Roanoke Landfill would include students investigating the technological processes of construction, maintenance, and closure of the fill the scientific, specifically ecological, processes and constraints regulating growth of revegetation covers, and the societal regulations and constraints overseeing the technological and scientific processes as well as the human influences.

The researcher, Bea Taylor, visited primary and secondary schools to solicit support for an STS-landfill project. Two high schools biology teachers from Patrick Henry High and Roanoke Valley Governor's School (RVGS), accepted the offer. In the spring, students set up a database of information about landfills in general. This database helped Bea, the researcher, and the teacher at RVGS, John Kowalski, note a sequence of activities during the summer to begin in the fall 1993 quarter.

As part of an STS format, the students were given a lecture on the ecological, societal, and regulatory constraints for revegetation of capped landfills. The students were asked to choose one or more of the variables of soil compaction, slope, gas emissions, plant competition, and temperature, and use species from the standard revegetation mixture and the proposed alternate native wildflower mixture to investigate plant responses to these variables. Students chose which variables to use, the general design, number of replicates, controls or references, the number of seeds, and monitoring. The scientist provided suggestions only.

The students first sieved landfill soil through a one quarter inch sieve to remove rocks and trash. Seeds were counted, and the experiment data collection began in mid-November. Winter holidays and a month long interim session in January 1994 interrupted the data collections. Data collection resumed in February and the experiments were taken down and the roots and shoots weighed and measured in March. The activity culminated in April with students presenting their findings, comments, and problems to representatives from the Roanoke Board of Supervisors, the Roanoke Valley Resource Authority, Explore Park, Virginia Tech, and the principal of RVGS. The community leaders were impressed by the students' efforts. The students reflected afterward that they had learned what it was like to do real scientific research including all the frustrations and problems with design and time constraints. In addition, the students commented that they were able to see how their work could influence people in the position to affect landfill restoration, and so the students finished the project believing they were part of a process demonstrating the important issue of post closure landfill revegetation to the Roanoke community..

CURRICULUM VITAE

MARA SABRE

Mailing Address

University Center for Environmental and Hazardous Materials Studies
1020 Derring Hall
Virginia Polytechnic Institute and State University
Blacksburg, Virginia 24061
Telephone (703) 231-6057

Personal Data

Date of Birth: 07 November 1966
Place of Birth: Durham, North Carolina

Education

M.S.	Biology, (in progress) December 1994 Virginia Polytechnic Institute and State University Thesis topic: Restoration of a Sanitary Landfill Major Professor: Dr. John Cairns, Jr.
B.S.	Biology, magna cum laude, 1989 North Carolina State University
B.S.	History, summa cum laude, 1989 North Carolina State University
1987-1988	Biology, certificate, nondegree year of exchange University of Strathclyde, Glasgow, United Kingdom

Professional Experience

1992	Graduate teaching assistant, Virginia Polytechnic Institute and State University Taught General Biology laboratory to first and second year undergraduates

1992	Plant Molecular Physiology Research Assistant, USDA Agricultural Research Service, Oxford, N.C. Characterization of nitrate reductase in the leaf and root RNA of Zea mays
1989-91	United States Peace Corps Volunteer, Honduras Created and supervised projects in watershed management and environmental education Served as advisor and coauthor of a management plan for a municipality Participated in inventories of the water systems, flora and fauna, and land tenure Trained teachers on topics of endangered species, pesticides, and natural areas in Honduras Developed environmental education programs in rural and city schools including tree nurseries, organic gardening, and interschool information sharing
1987-89	Developmental Biology research assistant/technician, NCSU Department of Genetics, Raleigh, N.C. Developed gene specific probes to characterize maize catalase isozyme activity, with emphasis on the temporal and tissue variation and circadian rhythm at the RNA level

Publications

M. Redinbaugh, M. Sabre, and J.G. Scandalios (1990) The Description of Catalase Activity, Isozyme Protein, and Transcript in the Tissues of the Developing Maize Seedling. Plant Physiology 92:375-380.

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D. Jones and M. Sabre (1992) Poster presentation for the 2nd Annual Environmental Day. Radford Arsenal, Radford, Virginia.

Grants

1993 Virginia Tech GRDP grant, $200.00 with matching funds from the Department of Biology. Studies of subsurface soil nutrients for vegetation on a landfill

1990 USAID Small Projects Assistance Grant, $1,000. Lodging and food for student participants in the first annual Danlí Musical Festival for the Environment

Professional Memberships

Phi Alpha Theta, National History Society
Phi Kappa Phi, National Honor Society
Phi Sigma, Honors Biology Society
Virginia Academy of Science

Public Service

1992-94 Member of ECOCYCLE, Virginia Tech's student conservation organization

1992 Acolyte head and trainer, St. Timothy's Episcopal Church, Raleigh, N.C.

1991 New Generation Leader for the United Nations Global Assembly for Women and the Environment, Miami, Florida

1990 Founding member of the Danlí Comité para la Protección Ambiental (CORPA), Danlí, El Paraiso, Honduras

Languages

English, Spanish

Interests

Hiking, camping, canoeing, dancing, world history