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Evaluating Habitat Manipulations and Rodenticides to Protect Seedlings from Rodent Damage at Restored Landfills in New York

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RESEARCH ARTICLE

Evaluating Habitat Manipulations and Rodenticides to Protect Seedlings from Rodent Damage at Restored Landfills in New York

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Abstract

Solid waste landfills have become rather commonplace in urbanized and industrialized regions of the world. If designed, managed, and restored properly, they can be converted to useful land uses. However, restoration of woody vegetation can be difficult when animal damage occurs. Numerous species of voles occur throughout the northern hemisphere and several may become serious pests of restoration plantings at high population density, increasing the expense and difficulty of establishing targeted plant communities. We anticipated that meadow voles (*Microtus pennsylvanicus*) were responsible for causing the majority of damage to seedlings planted on restored landfill sites in Brooklyn, New York. We evaluated the ability of two habitat manipulations (e.g. mowing, pea gravel barrier) and rodenticides to protect seedlings. We documented substantial damage and deaths of seedlings caused by rodents in the study plots with losses (damaged or dead seedlings combined) ranging from 40 to 73%. These losses occurred regardless of seedling species. Because of the preponderance of voles (71% of all first-time captures), we suspect that voles are the main species causing seedling damage. Substantial losses of seedlings occurred across treatments, although there were fewest losses with a pea gravel barrier treatment. While the pea gravel treatment reduced seedling losses about 55% compared to control plots, it is clear that additional research is needed to identify more efficient ways to reduce seedling losses to rodents in restoration plantings.

Key words: **management, mice, *Microtus*, restoration, vegetation damage, vole.**

Introduction

Solid waste landfills have become commonplace in industrialized countries, especially in urbanized areas where much waste is generated. It has been estimated that 95% of the waste generated worldwide is placed in landfills (El-Fadel et al. 1997; Scott et al. 2005). In the United States alone, the U.S. Environmental Protection Agency estimated that there were 3,536 landfills in 1996 (www.epa.gov/waste/nonhaz/munical/landfill.htm). However, landfills can degrade habitat and result in environmental degradation and reduced water quality, especially if they are not designed, managed, and restored adequately (e.g. El-Fadel et al. 1997; Scott et al. 2005). To reduce the likelihood of environmental harm, regulations on the design, management, and restoration of landfills have been put in place in a number of countries (e.g. The 1976 Resource Conservation and Recovery Act of the United States, and the European Union's Council Directive 1999/31/EC in Europe). Additionally, pest animals often thrive at active landfills because of the cover and food available; this situation can result in disease hazards from rodents and bird-aircraft strike hazards if airports are located nearby (Schroder & Hulse 1979; Baxter & Robinson 2007; Duarte et al. 2011). If landfills are effectively restored, they can provide habitat for native wildlife species, outdoor parks, or sites for other land uses (El-Fadel et al. 1997; Carballido et al. 2011; Rahman et al. 2011). Achieving these goals, however, often requires the successful restoration of woody plants such as trees and shrubs (Robinson et al. 1992; Hutchings et al. 2006).

Numerous species of microtines (Subfamily Microtinae) occur throughout the northern hemisphere and, at high population density, several may become serious pests affecting restoration plantings and agricultural production (Nowak 1991; Witmer & Proulx 2010). In North America, many of the pest species belong to the genus *Microtus*, commonly called voles or meadow mice (Clark 1984; O'Brien 1994). The biology, ecology, management, and distribution of voles, along with the types of damage they may cause, are summarized by Pugh et al. (2003) and O'Brien (1994).

Because it has been well established that voles damage seedlings (above citations), we anticipated that meadow voles

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(*Microtus pennsylvanicus*) were responsible for causing the majority of damage to planted seedlings observed on restored landfill sites in Brooklyn, New York, although other rodent species (deer mice, *Peromyscus* spp., and house mice, *Mus musculus*) were present. Most research on the management of vole damage to trees in the Northeastern United States has focused on orchard tree damage (e.g. Byers & Young 1974; Tobin and Richmond 1993). In these settings, rodenticides are used for vole population control, but habitat manipulation is also employed (i.e. herbicides, mowing, mulching, roto-tilling, and burning; Clark 1984; Byers 1985; Sullivan & Hogue 1987; O'Brien 1994; Edge et al. 1995; Witmer & VerCauteren 2001; Pugh et al. 2003). However, most of these habitat manipulation methods are not viable options for the restored landfill sites in Brooklyn because state agencies want to create a park-like setting using only native species of vegetation. Native grasses and forbs were first planted to reduce soil erosion; this cover was thick and up to 0.5 m tall in many areas. However, restoration ecologists attempting to plant native species of trees and shrubs, sometimes lose greater than 60% of nursery seedlings to clipping, bark gnawing, and belowground root feeding. While these are signs of damage by voles, other small rodents also may be causing some damage. USDA Wildlife Services personnel in New York are assisting the state agencies by providing rodent control at the sites, using various rodenticide baits applied in a grid of bait stations. However, seedling damage still occurs at these sites.

Zinc phosphide coating on grain or first-generation anticoagulant baits can effectively control vole populations in many situations (e.g. orchards, reforestation sites, grasslands, airports; O'Brien 1994; Witmer & Fantinato 2003; Witmer et al. 2007). Studies indicate that some repellents and physical barriers may also reduce feeding, or access to food, by voles (Johnson et al. 1985; Merkens et al. 1991; O'Brien 1994; Witmer et al. 2000); however, voles can readily burrow under tree wraps (Askham 1992). Fortier et al. (2000) demonstrated that a planted monoculture of endophytic grasses (containing alkaloids to reduce herbivory) may reduce rodent population carrying capacity and damage to seedlings. Also, supplemental feeding of voles with more preferred foods may reduce seedling damage in some cases (Sullivan & Sullivan 1988). However, no clear pattern of appropriate management response to rodent damage in restoration plantings has emerged despite the frequency and severity of this damage.

While several commercial rodenticide baits are available on the market for control of voles (Jacobs 1994; O'Brien 1994), each situation is unique with its set of environmental characteristics, potential nontarget hazards, environmental regulations, and social-political concerns. In some situations, regulations or other constraints prevent rodenticides from being used. In these cases, it is essential to have nonlethal methods of protecting seedlings (O'Brien 1994) and such methods are more practical for use by private landowners and the general public. Preliminary trials (Witmer et al. 2000) with captive voles revealed that several repellents showed potential to reduce vole feeding on seedlings, but only at high concentrations. The study also showed that tall barriers could be effective, but only if voles are prevented from burrowing under them.

We evaluated the ability of two types of habitat manipulation (e.g. mowing, pea gravel barriers) as well as rodenticides to protect seedlings from vole damage at restored landfill sites in Brooklyn, New York. We hypothesized that some of the treatments would be highly effective (i.e. defined as ≤20% of seedlings damaged) in protecting seedlings from small rodents. The study was conducted with the cooperation of USDA Wildlife Services in New York and the New York Department of Environmental Protection.

Methods

We conducted this study at the Pennsylvania Avenue restored landfill (Penn) and the Fountain Avenue restored landfill (Fountain). Both landfills are on small peninsulas that extend into Jamaica Bay on the southwest end of Long Island, New York. The Penn landfill is 40 ha and 29 m above msl, while the Fountain landfill is 120 ha and 38 m above msl. After capping the sites with a 45-cm clay layer and a geo-membrane, the two landfills were covered with 6 cm of coarse soil and topped with 15 cm of topsoil to support root establishment. To reduce erosion into Jamaica Bay, a mixture of grass and forb seed was spread over the landfills, generally resulting in a tall (about 0.5 m) ground cover. Tree and shrub seedlings were planted after the ground cover was well established.

We evaluated potential rodent control measures by using two habitat manipulations along with zinc phosphide-treated grain in a grid of bait stations. The treatments were: (1) grass mowed short (≤10 cm) plots, (2) grass mowed short plots with a grid of rodenticide bait stations (10 × 10 grid with 10 m spacing between bait stations) containing zinc phosphide-treated grain, (3) grid of rodenticide bait stations alone containing zinc phosphide-treated grain plots, (4) a ring of pea gravel about 7.5 cm deep around the seedlings in the plot and extending out about 0.5 m from the seedling, and (5) control plots (no treatment). Treatments were applied to 0.4-ha circular plots and there were three plots per treatment for replication. Treatments were randomly assigned to the plots. All perimeters of all plots were at least 50 m from each other to avoid a treatment having an effect on another plot. Nine plots were placed on the larger Fountain landfill and six were placed on the smaller Penn landfill (see Table 2 for plot location by landfill). On casual observation, the two sites appeared very uniform and similar, probably because the same restoration methods and the same grass-forb seed mix for ground cover establishment were used at both sites. However, we wanted our study plots widely distributed across the two sites so as to get a better indication of the extent of the seedling damage problem and whether or not the tested treatments would reduce seedling damage at widely dispersed parts of the two landfills. All healthy, undamaged seedlings within the inner 0.2-ha circular central area of the plot were tagged and given an individual number for condition monitoring throughout the course of the study. The treatments were maintained for about

7 months (October 2009 to April 2010). Seedling species and condition were monitored and recorded twice during the fall (October and December 2009) and twice in the late winter-early spring (March and April 2010). Damage classifications included: (1) no damage, (2) partially girdled stem, (3) totally girdled stem, (4) clipped terminal stem, (5) clipped lateral branch, (6) root damage, (7) dead, and (8) missing. Damage was also recorded as fresh or old. We also recorded animal sign (fecal pellets, tracks, burrows, and runways) so that the damaging agent (rodent, rabbit [*Sylvilagus floridanus*], other, or unknown) could be assigned.

The percentage of damaged seedlings was compared across treatments with Welch's analysis of variance (ANOVA) tests. We also compared the percentage of damaged seedlings in the treatment with the least amount of seedling damage against the damage levels of the control plots with a T test. We considered a p value of ≤ 0.05 to represent a significant difference. These tests were run at three levels: (1) using only the percent dead seedlings, (2) using only the percent damaged seedlings (but not dead), and (3) the percent damaged seedlings combined with the percent dead seedlings for each plot. We used percentages because the number of seedlings varied by plot. Finally, we qualitatively assessed the levels of damage across seedling species to see if some species were less susceptible to rodent damage.

We monitored rodent populations in the treatment and control plots using Sherman live traps (H. B. Sherman Traps, Tallahassee, FL, U.S.A.). We placed 25 traps in each plot in a 5×5 grid with 10 m spacing between traps. Traps were baited with peanut butter and oatmeal balls, a small piece of apple, and a few cotton balls for bedding material. The traps were operated for seven consecutive nights. Trapping sessions occurred in September and December 2009 and in February and April 2010. These trapping sessions provided a measure of the relative abundance of rodents in the various treatment and control plots and the frequency of occurrence by species. All captured rodents were given an ear tag with a unique number, and the species, ear tag number, capture date, and locations were recorded prior to release. We recorded recaptures as well; however, in this paper, we only present results from the first-time capture numbers.

Results

Seedling Species and Numbers per Plot

The species composition and number of individual seedlings varied widely among plots (Table 1). The average number of seedling species per plot was 7.3 (SD = 1.4; range 4–10). The number of seedling species, however, did not vary significantly ($F = 2.31$, $df = 14$, $p = 0.1291$) across treatments. The average number of seedlings per plot was 36.3 (SD = 12.6; range 18–51). Despite the range in seedling numbers, the number of seedlings did not vary significantly across treatments ($F = 3.00$, $df = 14$, $p = 0.0724$). One reason for the variable number of seedlings per plot was that some seedlings had already been damaged or killed in some plots and we chose only healthy seedlings to monitor once the study began.

Table 1. Number of seedlings by species and plot at restored landfills, Long Island, New York, in 2009–2010.

	Plot Number															
Species	*1*	*2*	*4*	*5*	*6*	*8*	*9*	*10*	*11*	*12*	*14*	*15*	*16*	*17*	*18*	*Total*
Amelanchier arborea (Common serviceberry)			1						2	1					1	5
Amelanchier canadensis (Canadian serviceberry)		3	1	1											6	11
Amelanchier laevis (Allegheny serviceberry)		3	1												3	7
Amelanchier species (serviceberry)				1											8	9
Betula populifolia (Gray birch)														1		1
Carya species (Hickory)														1		1
Carya tomentosa (Mockenut hickory)								1								1
Celtis occidentalis (Common hackberry)								1								1
Diospyros virginiana (Common persimmon)							1				1		1			3
Ilex opaca (American holly)		12	3	8		15			7	10					10	65
Nyssa sylvatica (Blackgum)		1	3	3		2										9
Quercus alba (White oak)	12			1	15		6	4			2	8	13	10		71
Quercus coccinea (Scarlet oak)	15				6		23	23			1	3	3	8		82
Quercus ilicifolia (Bear oak)	3				8			2				3				16
Quercus marilandica (Blackjack oak)	7				5		6	3	4	9	2	4	7	9	4	60
Quercus montana (Chestnut oak)					4			5			1	3				13
Quercus rubra (Northern red oak)	4				2		4	4			1		3	1		19
Quercus species (Oak)	2				2		2	2			8	9	17	15	2	59
Quercus stellata (Post oak)	3	1	3		1											8
Quercus velutina (Black oak)	4	9	5	2	7	14	8	4	4	1	2		7	5		72
Rhus copallinum (Winged sumac)									1	1						2
Rhus typhina (Staghorn sumac)		1							1							2
Sassafras albidum (Sassafras)			1	17		4			3	3						28
Total	50	30	18	33	50	35	50	49	22	25	18	30	51	50	34	**545**

The most common seedling species were oaks (*Quercus* spp.), followed by American holly (*Ilex opaca*), serviceberry (*Amelanchier* spp.), and sassafras (*Sassafras albidum*) (Table 1).

Seedling Damage

We monitored the fate of 545 tree and shrub seedlings across 15 treatment plots. Considerable seedling damage occurred in almost all plots (Table 2) and almost all of the damage was attributed to rodents, with less than 5% attributed to rabbits. The percentage of damaged seedlings did not vary significantly across treatments ($F = 0.61$, $df = 14$, $p = 0.6630$). Seedling damage levels ranged from 19.6 to 78.8%. The lowest levels of damage were observed in pea gravel plots (mean = 38.7%). The means for the other treatments ranged from 56.4 to 57.9% (Table 2).

The percentage of dead seedlings per plot varied significantly ($F = 4.11$, $df = 14$, $p = 0.0318$) across treatments. The smallest percentages of dead seedlings were in the mowed (mean = 0.0%) and pea gravel (1.3%) treatment plots. Both of these treatments had significantly lower ($T = 3.41$, $df = 8$, $p = 0.0270$) percentages of dead seedlings than the control plots (mean of 9.7%). The percentages of dead seedlings in the other three treatments varied from 9.7 to 15.3% (Table 2).

When we combined percentages of damaged and dead seedlings per plot the pattern was similar to the results of the damaged-alone analysis. No significant difference ($F = 0.86$, $df = 14$, $p = 0.5191$) occurred in percentages of damaged + dead seedlings across treatments. Once again, the pea gravel plots had the lowest percentage of damaged + dead seedlings (Fig. 1). All species of seedlings seemed prone to damage by rodents (Fig. 2). The percentages of dead + damaged seedlings by species averaged 68.9% (SD = 20.1) (Table 2). The species with the lowest percentages of damaged + dead seedlings were common persimmon (*Diospyros virginianus*; 33.3%), winged sumac (*Rhus copallinum*; 50%), and staghorn sumac (*Rhus typhina*; 50%). This result may be an artifact of sample size, however, because only a total of 2–3 seedlings of each of these species occurred on treatment plots.

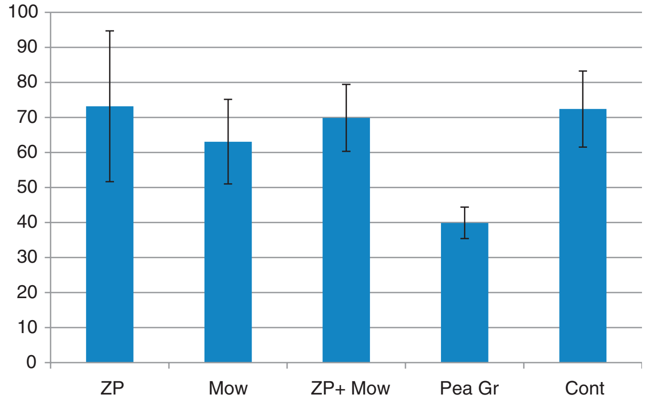

Figure 1. The average percentage of damaged + dead seedlings by treatment (with standard deviation bars) at restored landfills, Long Island, New York, in 2009–2010. ZP, zinc phosphide rodenticide; Mow, mowed area; ZP + Mow, zinc phosphide rodenticide plus mowed area; Pea Gr, ring of pea gravel; Cont, control (no treatment).

Rodent Captures and Species Composition

We recorded 441 first-time captures of rodents in live traps at the 15 treatment plots at the two restored landfill sites (147 Fountain site; 294 Pennsylvania site) (Table 3). The majority

Table 2. Fate of seedlings by treatment and plot at restored landfills, Long Island, New York, in 2009–2010.

Treatment	*Plot*	*Landfill*	*Total Seedlings*	*Undamaged*	*% Undamaged*	*Damaged*	*% Damaged*	*Dead*	*% Dead*	*% Damaged plus % Dead*
Zinc phosphide	1	P	50	0	0.0	39	78.0	11	22.0	100.0
	12	F	25	1	4.0	19	76.0	5	20.0	96.0
	16	P	51	39	76.5	10	19.6	2	3.9	23.5
					$\mu = 26.8$		$\mu = 57.9$		$\mu = 15.3$	$\mu = 73.2$
Mowing	4	F	18	2	11.1	16	88.9	0	0.0	88.9
	11	F	22	9	40.9	13	59.1	0	0.0	59.1
	18	P	34	20	58.8	14	41.2	0	0.0	41.2
					$\mu = 36.9$		$\mu = 63.1$		$\mu = 0.0$	$\mu = 63.1$
Zinc phosphide + Mowing	6	F	50	11	22.0	34	68.0	5	10.0	78.0
	10	F	49	8	16.3	30	61.2	11	22.4	83.6
	17	P	50	26	52.0	20	40.0	4	8.0	48.0
					$\mu = 30.1$		$\mu = 56.4$		$\mu = 13.5$	$\mu = 69.9$
Pea gravel	2	F	30	19	63.3	11	36.7	0	0.0	36.7
	9	F	50	25	50.0	23	46.0	2	4.0	50.0
	15	P	30	20	66.7	10	33.3	0	0.0	33.0
					$\mu = 60.0$		$\mu = 38.7$		$\mu = 1.3$	$\mu = 39.9$
Control	5	F	33	3	9.1	26	78.8	4	12.1	90.9
	8	F	35	18	51.4	13	37.1	4	11.4	48.5
	14	P	18	4	22.2	13	72.2	1	5.6	77.8
					$\mu = 27.6$		$\mu = 62.7$		$\mu = 9.7$	$\mu = 72.4$

F, Fountain Landfill; P, Pennsylvania Landfill.

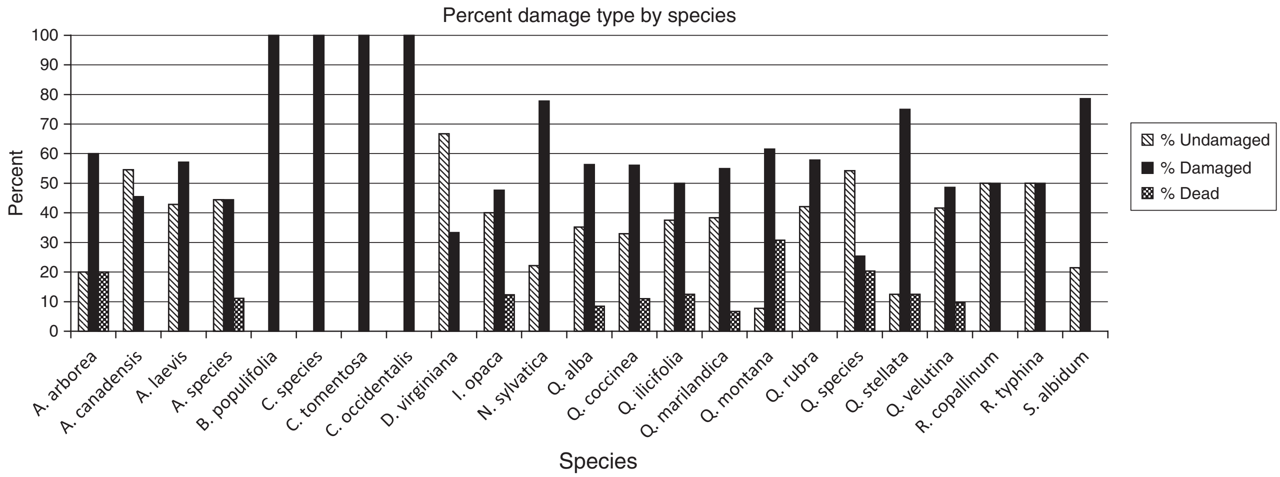

Figure 2. Fate of seedlings by species (see Table 1 for full species names) at restored landfills, Long Island, New York, in 2009–2010.

Table 3. Rodent first-time captures at the 15 treatment plots by species and restored landfill site, Long Island, New York, in 2009–2010.

Site	*Voles*	*Deer Mice*	*House Mice*	*Total Rodents*
Fountain site	87 (59.2%)	26 (17.7%)	34 (23.1%)	147
Pennsylvania site	226 (79.9%)	0 (0%)	68 (23.1%)	294
Both sites combined	313 (71.0%)	26 (6.0%)	102 (23.0%)	441

Numbers in parentheses are percentages of rodent captures by species.

of captures were voles (71%), followed by house mice (23%) and deer mice (6%). Only one Norway rat (*Rattus norvegicus*) was captured in a live trap.

The average number of first-time rodent captures per plot varied from 18.0 to 45.7 ($F = 3.25$, $df = 14$, $p = 0.0596$). The fewest captures per plot were in the mowed plots (18.0), followed by the zinc phosphide + mowed plots (20.0) and the zinc phosphide plots (26.7). The most first-time captures were in the pea gravel plots (45.7), followed by the control plots (32.7). For exploratory purposes, we generated a post hoc contrast by combining the first-time captures for the two treatment types with the most captures (pea gravel plots and control plots) and compared the number of captures per plot with the other three treatments, which illustrated a significant difference ($T = 3.08$, $df = 13$, $p = 0.0087$) in first-time captures.

We also observed a significant ($F = 3.61$, $df = 59$, $p = 0.0186$) decline in first-time captures over the span of the study. There were 153 first-time captures in September 2009, which declined to 134 in December 2009, to 96 in February 2010, and to 59 in April 2010.

Discussion

We observed substantial damage and deaths (i.e. losses) of seedlings in restored landfill sites caused by rodents, with losses (damaged and dead seedlings combined) ranging from 40 to 73% of shrub and tree seedlings. The losses occurred regardless of seedling species. We also noted substantial losses of seedlings across treatments, although there were fewest losses with the pea gravel treatment. Previous studies have noted substantial losses of seedlings, and even mature trees, from rodents, but these studies focused on losses of commercial conifers (e.g., Askham 1992) and deciduous orchard trees such as apples (e.g., Byers & Young 1974). While the primary damaging rodent species generally has been considered to be voles in these situations, Witmer et al. (2012) recently demonstrated that house mice and deer mice also may cause damage to seedlings, especially among deciduous species. However, because of the preponderance of voles (71% of all first-time captures) at the restored landfill sites, we suspect that voles are the main damaging species.

It is interesting to note that the treatments with the highest numbers of rodent captures (i.e. pea gravel plots) had the lowest levels of seedling damage. This treatment, like the control plots, was least invasive in terms of habitat modification. The control plots were second in total rodent captures. Conversely, the other three treatments had fewer rodent captures. These latter treatments had the highest level of habitat manipulation (mowed) and rodent population reduction (zinc phosphide-treated plots), but nonetheless, had high levels of seedling damage and deaths. This result suggests that substantial losses of seedlings can occur even with lower densities of rodents. This pattern of herbivory may occur because woody vegetation (stems and root systems) is an important food source for rodents, especially voles, during the late fall through early spring portions of the year when the availability of other vegetation is limited in temperate regions (Askham 1992; O'Brien 1994; Witmer & VerCauteren 2001).

While the pea gravel treatment reduced seedling losses by about 55% over control plots, it is clear that additional research is needed to identify better and more efficient ways to reduce seedling losses to rodents. Until such methods are identified, one approach would be to greatly reduce rodent

numbers until tree and shrub seedlings are well established at restoration sites. Such control is generally done by widespread use of rodenticides and, to a much lesser extent, with traps. In many situations, however, nontarget animal concerns or environmental regulations may prevent use of this approach. Another approach would be to establish seedlings before large-scale establishment of grasses and forbs, which provide high quality habitat for rodents, both in terms of cover and food. However, the need to quickly stabilize newly placed soils at landfill restoration sites may generally require that grasses and forbs are planted soon after soil placement. It appears that rodents will continue to pose serious logistical and economic challenges, not just to food and fiber production for humans, but for natural resource managers and practitioners of ecological restoration as well (Witmer & Singleton 2010).

Implications for Practice

- Restoration managers need to be mindful of the potentially high levels of damage to seedlings by rodents when restoring woody vegetation at reclaimed landfill sites.
- Restoration managers may need to control rodent populations to reduce seedlings damage by using a proven effective rodenticide, all while minimizing nontarget animal hazards (e.g. using rodenticide bait stations).
- Habitat manipulations such as pea gravel around seedlings and regular mowing to reduce ground vegetation height may reduce rodent damage to seedlings, but should be tested on a site-specific basis.

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