PRACTICE AND PERSPECTIVE

Roots of Chaparral Shrubs Fail to Penetrate a Geosynthetic Landfill Liner

by Karen D. Holl

Study shows that managers could safely revegate landfills in California with chaparral shurbs.

Legislation in the United States (USEPA 1989) and most of Europe (Forster 1993) restricts the planting of woody shrubs and trees on landfills, largely because regulators fear that roots of woody plants will penetrate the landfill liner (Dobson and Moffat 1995). This limitation precludes revegetating landfills with pre-disturbance ecosystems, such as chaparral, in which woody species are an important part of the vegetation. Moreover, it requires landfill managers to engage in the costly and ongoing practice of removing woody plants that occur naturally on landfills.

Previous studies in Great Britain and the eastern United States suggest that tree roots do not penetrate landfill liners (Gillman 1989, Dobson and Moffat 1995, Robinson and Handel 1995, Handel and others 1997). For example, Robinson and Handel (1995) excavated 12 species of shrubs and trees that ranged from 3- to 7-years-old on a landfill with only 4-12 inches (10-30 cm) of soil in the eastern United States, and they found no penetration of the liner. While the results of this research are noteworthy, one cannot assume that similar findings would be the case in the arid western United States. Not only is the physical environment quite different in the West, but most previous research has been done on clay liners rather than the geosynthetic liners that are increasingly used in arid areas. This article is the first published research report about the growth of woody plants on a landfill in the western United States. The goal of my work was to determine whether roots of a number of northern California chaparral shrub species would penetrate a geosynthetic landfill liner. Ultimately, the results should provide guidance on whether to use such species in planting efforts on western landfills.

Materials and Methods

I conducted the study in maritime chaparral at the former Fort Ord Army Base in the city of Marina, Monterey County, California. Maritime chaparral in this region is dominated by shrubs, including several species of manzanita (*Arctostaphylos*) and ceanothus (*Ceanothus*), and a high diversity of annual herbs (Griffin 1978). The soils are medium-grained sands (92-96 percent sand) that are well-drained, and have low organic matter content and fertility. Mean rainfall is 19 inches (475 mm) per year with high interannual variability (11 to 38 inches/275 to 957 mm; National Climate Data Center, Asheville, NC).

I established the study area in January 1997. Two adjacent square areas, each approximately 35 m on a side, were covered with soil from the same sources as that used to cover a nearby landfill that was in the process of being closed. The two experimental areas were graded to create a ridge in the center and sides that sloped 3 percent to the north and south, in order to provide drainage. On the test cap area, a 40-mil polyethylene geomembrane liner

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Figure 1. A view of the control site, August 2001. A coyote brush (*Baccharis pilularis*) is in the foreground. *Photos by Karen Holl*

(Poly-Flex Construction, Inc., Grand Prairie, Texas) was placed on top of the fill material. The liner was covered with approximately 26 inches (65 cm) of soil in order to match current regulations. The adjacent control area was identical except that no liner was installed. I could not plant shrubs on the actual landfill because of liability issues, but some species—primarily coyote brush (*Baccharis pilularis*), deerweed (*Lotus scoparius*), bush lupine (*Lupinus arboreus*)—colonized the landfill naturally.

In January 1997, my research assistants and I planted a total of 370 native shrub seedlings of nine species on the control and test cap areas. We planted the seedlings in square grids with 5 feet (1.5 m) between the plants (Figure 1). Due to low shrub survival during spring and summer 1997, we planted additional seedlings in November 1997. Seedlings planted in January 1997 were watered three times in the first year, while seedlings planted in November 1997 were only watered at the time of outplanting. We fenced all plants with chicken wire cages at the time of planting. We removed these cages when they began to constrain the growth of the seedlings. In February 1999, 2000, and 2001, we fertilized all surviving seedlings with 10 g of 17:6:12 (N:P:K) slow-release fertilizer with micronutrients because data from the first two years showed that the plants were growing extremely slowly. We measured the survival and cover of seedlings annually, although in this article I am using the final measurements from August 2001.

In August 1998 and 2001, my research assistants and I excavated the root systems of five plants of most species on both the root test cap and control areas (Table 1). In 2001, we also excavated the roots of five plant species that had naturally invaded the landfill (Table 1). The landfill was closed in 1997 so the largest plants were likely 3-4 years old at the time of our excavations. Only two species—deerweed and bush lupine—had well-developed root systems in 1998and results of 2001 excavations gave similar results for these species, so I report 2001 results only.

We excavated the largest plants of each species, presuming that they would have the most developed root systems. For each plant, we excavated the entire woody root system using shovels and hand trowels. We wetted the sand with a watering truck to facilitate excavation. We followed all major roots of each plant until they became very fine (less than 0.07-0.11 inches {2-3 mm} diameter). For each plant we excavated, we measured the maximum root depth and the maximum lateral root extension, and described the root morphology. I excavated roots up to a depth of 40 inches (100 cm) in the control area.

Results and Discussion

Survival and Growth

Overall, the liner appeared to have little effect on survival (Figure 2). Most plants

Table 1. Results of excavations of 4- to 5-year-old chaparral shrubs.

Species	Number excavated	Location excavated	Max. root[a] depth (m)	Max. lateral[a] root spread (m)
Adenostema fasciculatum—chamise	10	CO, TC	0.2-liner	0.4-3.0
Arctostaphylos pumila—sandmat manzanita	10	CO, TC	0.2-0.6	1.0-2.0
Arctostaphylos tomentosa—shaggy bark manzanita	4	LF	0.2-0.3	0.6-1.8
Artemisia californica—California sagebrush	5	LF	0.3-liner	0.9-1.3
Baccharis pilularis—coyote brush	14	CO, TC, LF	0.2-liner[b]	0.2-4.5
Ceanothus cuneatus var. rigidus—Monterey ceanothus	10	CO, TC	0.3-liner[b]	1.0-4.0
Ericameria fasciculata—golden fleece	10	CO, TC	0.2-liner	0.4-1.5
Lotus scoparius—deerweed	6	LA, TC	0.2-liner	1.0-4.0
Lupinus arboreus—bush lupine	5	LA	liner	2.0-3.0
Quercus agrifolia—coast live oak	5	CO, TC	0.2-0.4	0.1-1.3
Rhamnus californicus—gooseberry	6	CO, TC	0.2-0.6	0.2-2.0

Values are lumped for different locations. Locations: CO – control, TC – test cap, LF – landfill.
[a] Range of values for excavated plants. The liner was at 65-70 cm depth on the test cap and 90-100 cm on the landfill.
[b] Roots of these species went deeper than 1 m on the control area.

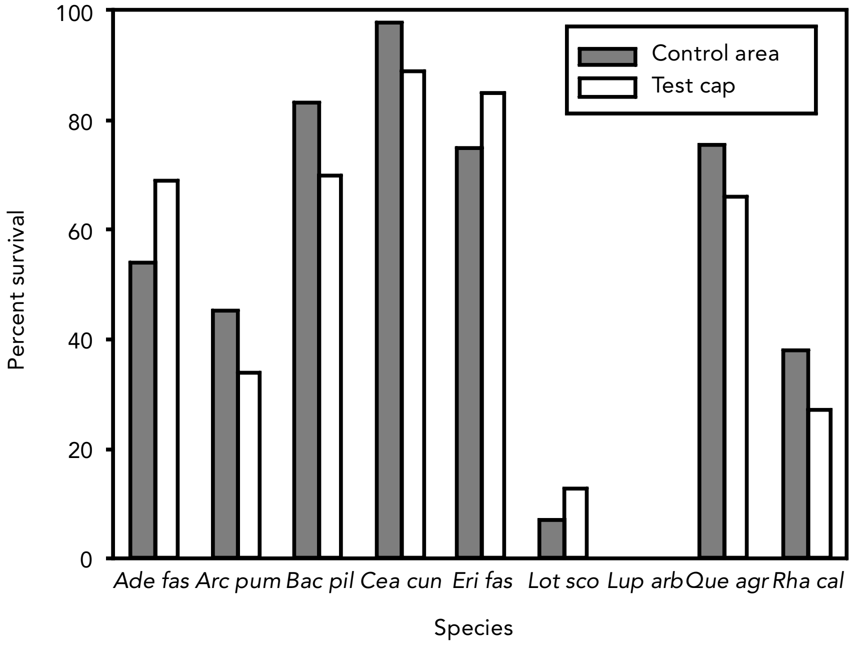

Figure 2. Percent survival of chaparral shrubs on the control area and test cap, August 2001. *Ade fas* **= chamise,** *Arc pum* **= sandmat manzanita,** *Bac pil* **= coyote brush,** *Cea cun* **= Monterey ceanothus,** *Eri fas* **= golden fleece,** *Lot sco* **= deerweed,** *Lup arb* **= bush lupine,** *Que agr* **= coast live oak, and** *Rha cal* **= gooseberry.**

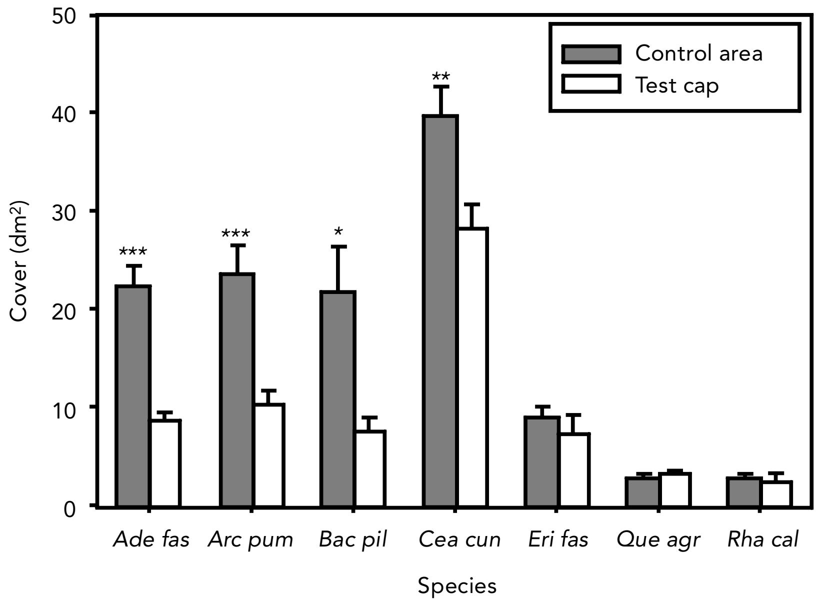

Figure 3. Cover of chaparral shrubs on the control area and test cap, August 2001. *Ade fas* **= chamise,** *Arc pum* **= sandmat manzanita,** *Bac pil* **= coyote brush,** *Cea cun* **= Monterey ceanothus,** *Eri fas* **= golden fleece,** *Que agr* **= coast live oak, and** *Rha cal* **= gooseberry. *= p < 0.05, **= p < 0.01, ***= p < 0.001 using a t-test to compare growth.**

that died did so in the first year, and there was little mortality thereafter. A number of species—coyote brush, Monterey ceanothus (*Ceanothus rigidus*), golden fleece (*Ericameria fasciculata*), and coast live oak (*Quercus agrifolia*)—had greater than 70 percent survival, which is high for this arid ecosystem (Figure 2). Survival of sandmat manzanita (*Arctostaphylos pumila*) and gooseberry (*Rhamnus californicus*) was lower, but many sandmat manzanita and all gooseberry were planted out as small plants in January 1997, after which rains ceased. On the control area and test cap, all bush lupine died between 1998 and 1999, most likely due to extensive insect herbivory. Almost all deerweed had died by 2001.

Most species grew slowly in the first couple years after planting and then showed substantial increases in cover in 2000 and 2001, although the cover of gooseberry and coast live oak remained low even at the end of the study (Figure 3). My excavations indicated that the roots of many of the coast live oak seedlings were rootbound at the time of outplanting and never developed fully thereafter, which could explain their slow growth.

For four of the seven species, growth was higher on the control area than the test cap (Figure 3). These differences in growth rates are likely due to significantly higher total nitrogen and organic matter on the control site compared to the test cap (percent total nitrogen—control: 0.02 ±0.01, test cap: 0.01 ± 0.00; percent organic matter-control: 0.21 ± 0.03, test cap: 0.10 ± 0.01). Another possible explanation for difference in growth of a couple of the larger species is differences in root morphology on the test cap and control area (discussed below). A final, less likely explanation is differences in soil moisture. Surface soil moisture (2 inches {5 cm} depth) was slightly higher on the test cap during the dry season, and soil moisture was similar at 2- and 3-foot (30 and 60 cm) depths on the two sites (data not shown). The drier conditions on the control site would seem to be less favorable for growth in this arid system. But most chaparral plants are adapted to well-drained soils and there may have been some negative effects of slower drainage on the test cap, such as anoxic conditions or altered microbial communities (Parsons and others 1998), that influenced plant growth.

Root Excavations

Results of excavations are shown in Table 1. Results are lumped for the control, test cap, and landfill areas as root morphology was similar on all sites unless otherwise noted. My results show that roots of most

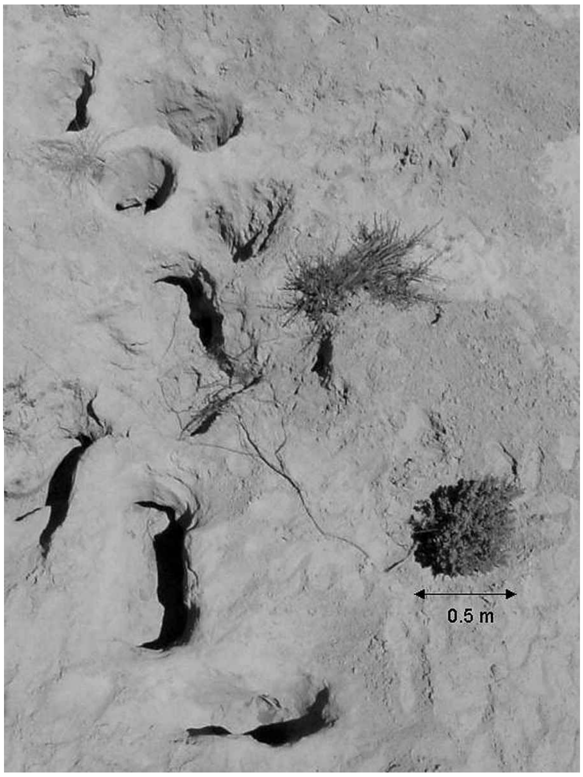

Figure 4. The 1.7-ft (0.5-m) wide coyote brush (*Baccharis pilularis*) shrub in the lower right corner of the photo has roots that extend through all the holes researchers dug to the left of the plant.

species studied often reached the liner, but that no roots penetrated the liner. The liner was generally at 24-28 inches (60-70 cm) on the test cap and 35-39 inches (90-100 cm) on the landfill.

The roots of most species—chamise (*Adenostema fasciculatum*), both species of manzanita, California sagebrush (*Artemisia californica*), coyote brush, Monterey ceanothus, and deerweed—had similar morphologies. These species usually had a taproot that split into 2-5 medium-sized (less than 2 cm diameter) roots that mostly spread laterally in the top 12 inches (30 cm) of soil. Occasionally, the roots would grow deeper and reach the liner where they would run along the liner for sometimes long distances (greater than 13 feet {4 m}). For example, Figure 4 shows the lateral extent of a root system of a coyote brush. Aboveground cover for the plant is approximately 0.25 m^2, whereas the roots extend up to 16 feet (5 m) in different directions. For these species, the roots were generally less than 0.5 cm diameter when they reached the liner (Figure 5). Individuals of single species varied greatly in their root depth and lateral extent.

The remaining species showed different root morphologies. Bush lupine had the thickest root system. (We only excavated bush lupine that had naturally colonized the landfill, so their exact age was unknown.) The roots were up to 2 inches (5 cm) in diameter at the base of the plant, and some roots were as large as 0.4-0.8 inches (1-2 cm) diameter when they touched the liner. Many bush lupine roots ended abruptly upon touching the liner, apparently rotted. Golden fleece had a finer, more fibrous root system. Gooseberry plants were still small and roots did not extend past 12 inches (30 cm) deep on the test cap. The main roots branched into a fibrous system at about 8 inches (20 cm). Coast live oak had one main tap root, but it was impossible to make conclusions about the effect of coast live oak roots on the landfill liner because many of the plants were rootbound at the time of planting. Even after four years the tap roots were curled and had extended little beyond the original bounds of the pots.

Most species showed little difference in root morphology on the test cap compared to the control area, probably because even on the control area, most of their root system was less than 2 feet (60 cm) deep. Two of the species with more extensive root systems—coyote brush and Monterey ceanothus—had roots that extended deeper on the control sites, beyond 3 feet (1 m) deep. This difference

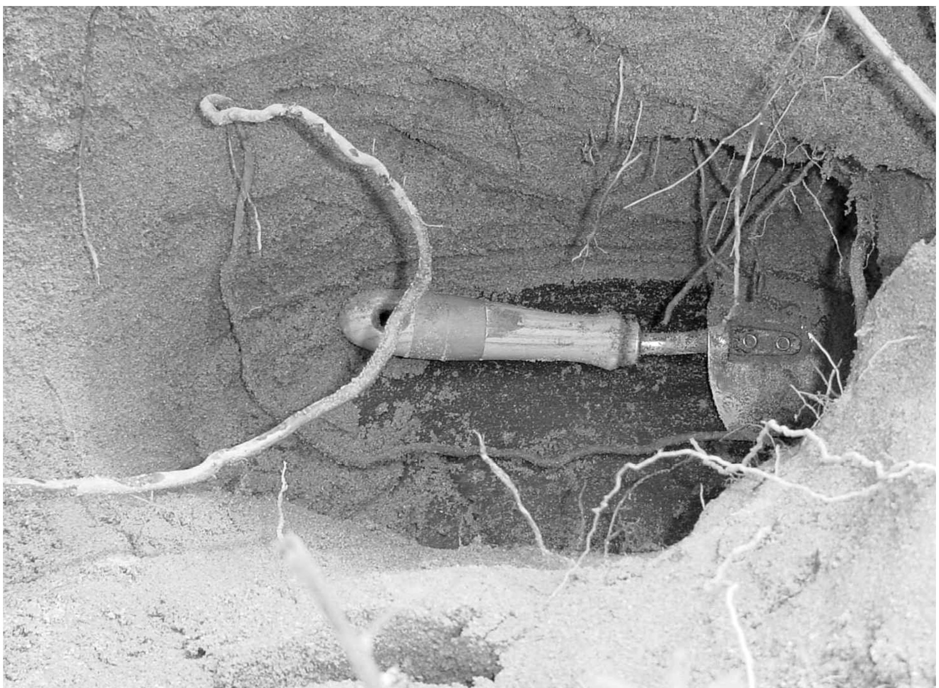

Figure 5. Example of shrub roots growing along the top of the geosynthetic landfill liner. No roots in this study penetrated the liner.

may help to explain the difference in growth for these two species on the control site and test cap in the past couple years. With time, growth on the test cap may be increasingly stunted, but more data are needed to test this hypothesis.

This and a previous study indicate that most chaparral shrub roots grow at less than 2 foot (60 cm) depths (Kummerow and Mangan 1981), which is one of the reasons for minimal differences in root morphology between the cap site and the control. Kummerow (1980) states "Rooting depths are highly variable and apparently are more dependent on soil conditions than on the plant's genetic makeup." Indeed, results of this study suggest that root morphology varies with condition and, furthermore, that chaparral plant roots do not fit neatly into the binary categorization of coarse woody shrubs with roots either growing downward or growing laterally (Hellmers and others 1955).

Management Recommendations and Future Research

This research indicates that a number of species of chaparral shrubs are able to survive and grow on landfills that conform to current legislative standards. It also suggests that the roots of the ~4.5-year-old plants of the species studied do not constitute a threat to the integrity of a 40-mil geosynthetic landfill liner and, therefore, do not need to be excluded from landfill revegetation efforts. This result agrees with much previous research on landfills suggesting that woody plant roots do not penetrate liners and that woody plant roots have fairly plastic morphology allowing them to adjust to their immediate microenvironment (Handel and others 1997, Parsons and others 1998). Most roots were fairly thin when they reached the liner and readily grew laterally along the liner. The one species that had thick roots at the liner, bush lupine, regularly dies after a few years and, therefore, efforts to remove it from the landfill seem unwarranted.

A few caveats are necessary. First, the growth rates of shrubs in the soils studied is clearly nutrient limited. Therefore, development of roots on actual landfills may be faster than those observed on the nutrient-poor test cap soils. Second, it is impossible from the results of this study to conclude anything about the effect of oak roots on a landfill liner because the container-grown oaks did not have the same morphology as naturally established oaks. Coast live oak is a long-lived tree with a single tap root that could potentially become quite thick. Third, many chaparral shrubs live for years and it is impossible to predict what their roots will do as they increase in size. Therefore, I plan to repeat excavations after an additional five years.

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