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RECLAMATION REPORT BASALT WASTE ISOLATION PROJECT BOREHOLES 1990

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SUMMARY

In 1968, a program was started to assess the feasibility of storing Hanford Site defense waste in deep caverns constructed in basalt. This program was expanded in 1976 to include investigations of the Hanford Site as a potential location for a mined commercial nuclear waste repository. Some 98 boreholes were drilled, deepened, or modified to study the geology and hydrology of the Hanford basalts. These boreholes were sited on 71 drill pads ranging in size from 0.1 to over 2.6 ha. Reclamation of these sites was begun in 1988 as a consequence of termination of the Basalt Waste Isolation Project site characterization program.

The objective of the reclamation program was to return sites as nearly as practicable to conditions existing before the disturbance. Vegetation established on the sites must be native and self-sustaining. Reclamation was begun in 1988 as a two-phase program in which sites were cleared of added materials and seeded and planted in 1988 and 1989. This report examines the success of that effort.

Sandberg's bluegrass was the most common grass found at all sites where it was seeded. The greatest abundance of bluegrass was found on sites Benson Ranch, DC-15, DC-32, DC-33, DH-27, DH-28, and DH-34. Sites without bluegrass where such was planted were DB-1, DB-2, DB-15, DC-12, RRL-4, RRL-5, RRL-7, and RRL-16. Bottlebrush squirreltail appeared at low densities. Ricegrass density was significantly higher on DC-15 and DC-25 than on other sites. Needle-and-thread grass density was sparse but relatively uniform across sites. Downy wheatgrass and ricegrass performed exceptionally well. Shrub mortality rates were higher than expected, averaging just under 45%. Hopsage suffered the greatest mortality (62%) as a consequence of predation by jackrabbits. The lowest mortality was experienced by grey rabbitbrush (41%).

Differences in grass growth were primarily a result of the failure of the winter rains during 1989-1990. Plants growing in different soil types responded differently to this stress. Furrow orientation had no effects on performance, and differing nutrient levels had no noticeable effects except in markedly poor or unstable soils (sands and pit-run material) where additional nutrients enhanced bluegrass growth. Deep-rooted grasses fared better during the drought than did the more shallow-rooted bluegrass. The main source of mortality for the shrubs other than hopsage was probably related to exposure to drying winds. Plants at the edge of the revegetated areas were somewhat sheltered from winds by the neighboring adult shrubs. Overall, the extreme mortality can probably be attributed to the drought during the critical period before the shrubs planted in fall of 1989 were able to establish a strong root system.

A number of sites currently meet revegetation goals for grass and shrub cover, though most do not. A number of sites are without any cover at all. Although many sites currently meet the reclamation standards in terms of grass cover, there is no evidence to suggest that they will continue to do so. Bluegrass density in spring of 1989 averaged 15.6 plants/m of seeded row. By spring 1990, the average density at these same locations was 2.5 plants/m This rate of mortality would leave sites without bluegrass cover in a few years. Longer-term monitoring is necessary to determine whether the native grasses established during revegetation can be self-sustaining, which is a key requirement for reclamation of lands disturbed by the BWIP.

ACKNOWLEDGMENTS

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CONTENTS

FIGURES

TABLES

1.0 INTRODUCTION

The restoration of areas disturbed by activities of the Basalt Waste Isolation Project (BWIP) has been undertaken by the U.S. Department of Energy (DOE) in fulfillment of obligations and commitments made under the National Environmental Policy Act and the Nuclear Waste Policy Act. This restoration program comprises three separate projects: borehole reclamation, Near Surface Test Facility reclamation, and Exploratory Shaft Facility reclamation. Detailed descriptions of these reclamation projects may be found in a number of previous reports (Brandt et al. 1990a, 1990b; Brandt and Rickard 1990). This report describes the second phase of the reclamation program for the BWIP boreholes and analyzes its success relative to the reclamation objective.

1.1 RECLAMATION PROGRAM

In 1968, a program was started to assess the possibility of storing Hanford Site defense waste in deep caverns constructed in basalt. This program was expanded in 1976 by the DOE to investigate the potential for a national commercial nuclear waste repository at Hanford. The Nuclear Waste Policy Act of 1982 required DOE to conduct an extensive site characterization program to determine the feasibility of using the basalts beneath the Hanford Site for the repository. Site research focused primarily on determining the direction and speed of ground-water movement, the uniformity of basalt layers, and tectonic stability. During this research, 98 boreholes were sited, drilled, deepened, or modified by BWIP between 1977 and 1988

On December 22, 1987, the Nuclear Waste Policy Amendments Act was signed into law. This law mandated, among other things, that DOE must proceed with the orderly phase out of all repository-related activities other than reclamation at all candidate sites except Yucca Mountain. No specific standards or criteria were spelled out in the Amendments Act governing reclamation; therefore, other guidelines and commitments were applied. Primary among these is the Nuclear Waste Policy Act, which requires DOE to reclaim sites disturbed during civilian radioactive waste management activities. The Mission Plan for the Civilian Radioactive Waste Management Program (DOE 1985) requires that disturbed sites be returned as nearly as practicable to their original condition. This was applied as the objective of the BWIP reclamation program.

Primary goals were to establish self-sustaining vegetation and to produce cover conditions comparable to those existing before the disturbance. Restoration focused on re-establishment of native plant species and suppression of invading exotic species. Disturbed sites located entirely within plant communities dominated by exotic species were not required to be reclaimed with native species. Restoration success will be evaluated 1 year after completion of the reclamation activities, when a determination will be made regarding success and the need for additional remediation work. Success will be based on how well the planted stands resemble nearby undisturbed plant communities.

1.2 BOREHOLE DESCRIPTIONS

The BWIP boreholes comprised a number of wells drilled, deepened, or modified for the purposes of seismic monitoring, geohydrologic investigation, tectonic and hydrochemical investigations, and piezometric monitoring. The 98 boreholes were located on 71 separate sites around the Hanford Site (Figure 1). Boreholes were constructed on areas cleared of existing cover and leveled. Sizes of individual clearings range from 0.1 ha to over 2.6 ha. Most sites included from several centimeters to several meters of compacted pit-run gravels that served as a stable base supporting drilling operations. Most sites included a mud pit where drilling muds and rock waste were pooled. Various pilings and tie-downs were buried at a number of locations. Electric utility lines were also laid to several sites.

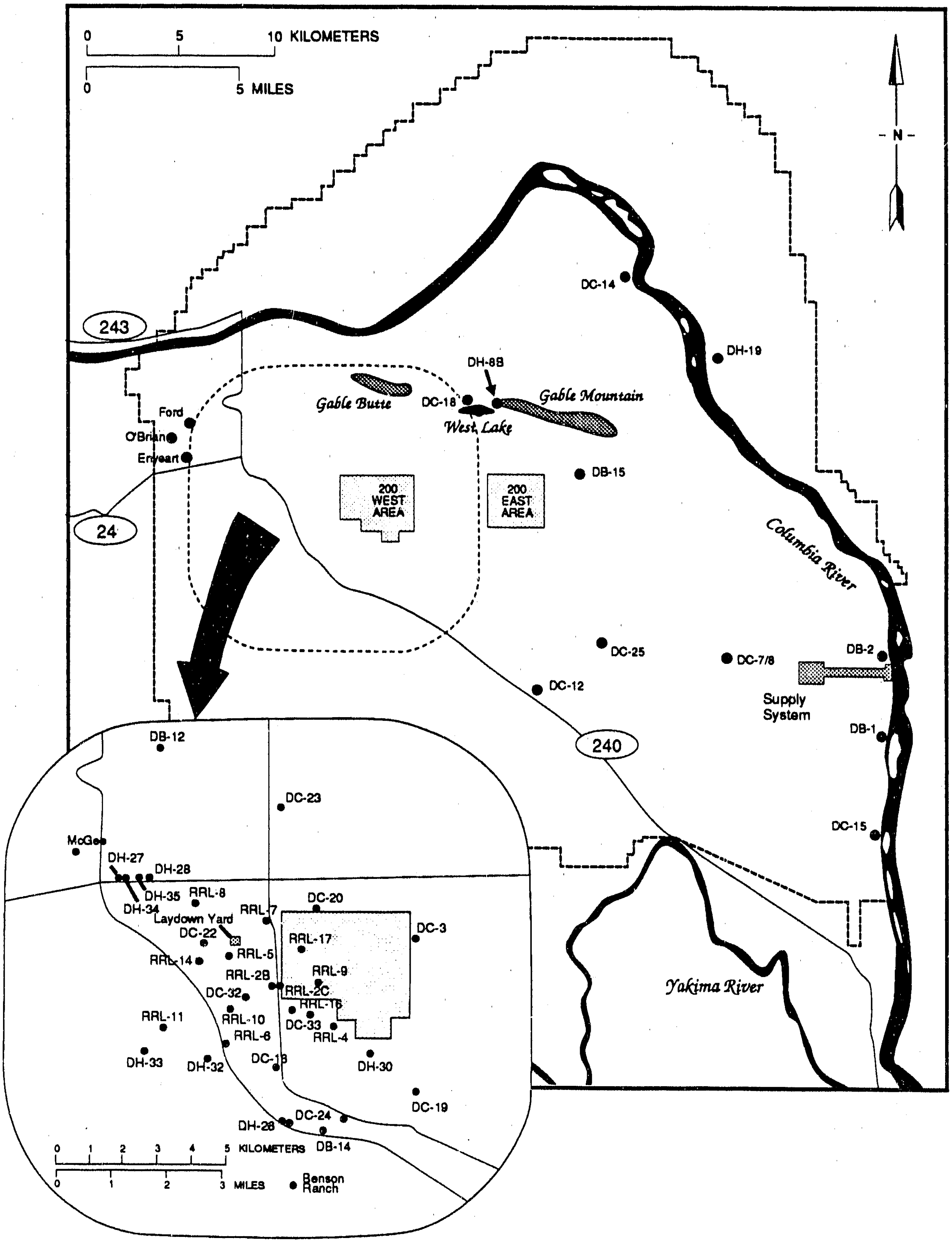

Figure 1. Locations of BWIP Borehole Sites Scheduled for Reclamation

2.0 RECLAMATION METHODOLOGY

Reclamation was approached in a series of steps. Sites were grouped according to eventual uses and a determination made regarding whether sites currently met the reclamation objective or needed further treatment. Sites to be reclaimed were then grouped by shared habitat features and seeding methods and mixes determined on that basis.

2.1 SITE CLASSIFICATION

Borehole sites were visited by PNL reclamation staff before any reclamation to determine the nature of the disturbance and the characteristics of the surrounding habitat, and to compare soil parameters in disturbed and undisturbed areas. Primary reclamation categories were defined for the 98 boreholes based on their locations and expected final uses (Table 1).

Habitat types of the sites identified for reclamation were attributed to the least disturbed habitat in the vicinity of each site. These habitats were sampled using a randomizing scheme to quantify their salient vegetation characteristics (Brandt et al. 1990a). Permanent plots were established in these habitats for two purposes: to indicate the appropriate species mixes and densities to be included in revegetation, and to serve as a yardstick by which revegetation success at any site will be measured.

Sampling locations consisted of 10-by-10-m plots located at least 10 m distant from the edge of the reclamation site. Plots were marked with wooden stakes bearing the site and location designations. Canopy cover of grasses and shrubs was measured along the side of the plot nearest the disturbed area. Plant cover was measured using the point-interception method (Goodall 1953) by means of an optical point bar. The bar consists of 10 ocular scopes with cross hairs. Species were recorded whenever they intersected the view beyond the cross hairs. Sampling using the optical point bar was repeated at 1-m intervals starting 1 m from one corner of the plot. Percentage cover for any species at any sampling location was, therefore, simply the sum of the point interceptions for that species at that location. Shrub density was determined by counting all shrubs by species within the plot.

Eleven habitat types were identified, based on 10 shrub groupings and 10 grass groupings (Figure 2). No shrubs or grasses were present in the riparian habitat at DC-14. Shrubs were also absent in the burned cheatgrass/bluebunch wheatgrass habitat. Sandberg's bluegrass was found in all but four habitat types; big sage was found in all but five. Cheatgrass was present in all habitats except riparian. The big sage/cheatgrass habitat was the most widespread type. Although the spiny hopsage/Sandberg's bluegrass type was represented by but one site (RRL-10), hopsage was a minor component of both the big sage habitat types.

2.2 DECONSTRUCTION

The first phase of reclamation was to remove artificial facilities and compacted pit-run materials from the sites and to restore the original grades. Above-ground facilities such as trailers and portable equipment were removed and salvaged. Above-ground utilities were removed and disposed of according to pertinent regulations. Two wooden poles carrying power to RRL-6 were purchased by PNL from General Telephone and Electric and converted in-place into raptor nesting platforms.

Where required, wells were decommissioned or converted to alternative uses. Decommissioned wells were capped with a welded steel plate. Decommissioning was completed in July 1989.

Pit-run surface materials were removed from the reclamation sites and trucked to Hanford Pit 25. Where present, mud pit contents were pumped and disposed of according to pertinent regulations. Mud pits were filled, and excess material was graded and blended to approximate surrounding contours. Access roads scheduled for reclamation were also graded to match surrounding contours.

Table 1. Recommendations for Reclamation of BWIP Boreholes

Location	Recommendation
BH-17	Abandon site as is.
CH-1-6	Remove casing and abandon.
DB-1	Partially remove gravel, recontour, prepare seedbed, and revegetate.
DB-2	Relieve compaction and reseed.
DB-4	Abandon after removal of anchors. Site predates BWIP.
DB-5	Rremove of anchors and abandon. Site predates BWIP.
DB-11	Abandon as is (too close to Yakima Barricade).
DB-12	Prepare seedbed and revegetate. Part of site to remain as monitoring well.
DB-14	Prepare seedbed and revegetate.
DB-15	Remove gravel, recontour, prepare seedbed, and revegetate.
DC-3	Remove gravel, recontour, prepare seedbed, and revegetate. (Site later identified for other WHC uses, so was removed from revegetation requirement.)
DC-4/5	Abandon. Site has no wildlife habitat potential.
DC-6	Recontour mudpit and abandon site. Site is on preexisting pad.
DC-7/8	Remove gravel, recontour, prepare seedbed, and revegetate.
DC-10	Site not located.
DC-11	Site not located.
DC-12	Remove gravel, recontour, prepare seedbed, and revegetate.
DC-14	Remove gravel, recontour, and plant 5 white poplar trees.
DC-15	Remove gravel, recontour, prepare seedbed, and revegetate.
DC-16	Remove gravel, recontour, prepare seedbed, and revegetate.
DC-18	Remove gravel, recontour, prepare seedbed, and revegetate.
DC-19	Remove gravel, recontour, prepare seedbed, and revegetate.
DC-20	Remove gravel, recontour, prepare seedbed, and revegetate.
DC-22	Remove gravel, recontour, prepare seedbed, and revegetate.
DC-23	Remove gravel, recontour, prepare seedbed, and revegetate.
DC-24	Remove gravel, recontour, prepare seedbed, and revegetate.
DC-25	Remove gravel, fill mud pit, prepare seedbed and revegetate.
DC-32	Remove gravel, fill mud pit, prepare seedbed, and revegetate.
DC-33	Remove gravel, fill mud pit, prepare seedbed, and revegetate.
DH-8B	Remove gravel, recontour, prepare seedbed, and revegetate.
DH-18	Fill mud pit and abandon. Pad plant cover consistent with surrounding vegetation.
DH-19	Recontour trench, prepare seedbed, and revegetate.
DH-20	Abandon site. Vegetation on pad consistent with surrounding vegetation.
DH-21	Abandon site. Vegetation on pad consistent with surrounding vegetation.
DH-22	Abandon. Pad vegetation consistent with offpad.
DH-23	Abandon site. Present cover adequate.
DH-24	Abandon site. Pad vegetation consistent with surrounding vegetation.
DH-25	Abandon as is. Vegetation on pad consistent with off pad.
DH-26	Prepare seedbed and revegetate.
DH-27	Recontour, prepare seedbed, and revegetate.
DH-28	Recontour, prepare seedbed, and revegetate.
DH-29	Abandon. Vegetation on pad is consistent with burned surroundings.
DH-30	Remove gravel, recontour, prepare seedbed, and revegetate.
DH-31	Remove gravel, recontour, prepare seedbed, and revegetate.
DH-32	Remove gravel, recontour, prepare seedbed, and revegetate.
DH-33	Remove gravel, recontour, prepare seedbed, and revegetate.
DH-34	Remove gravel, recontour, prepare seedbed, and revegetate.

Table 1. (Cont.)

Location	Recommendation
DH-35	Remove gravel, recontour, prepare seedbed, and revegetate.
Benson Ranch	Remove gravel around well head, recontour, prepare seedbed, and revegetate.
Enyeart	Partially remove gravel, recontour, prepare seedbed, and revegetate.
Ford	Partially remove gravel, recontour, prepare seedbed, and revegetate.
Laydown Yard	Remove gravel, recontour, prepare seedbed, and revegetate.
McGee	Remove gravel around well house, recontour, prepare seedbed, and revegetate.
Obrian	Prepare seedbed and revegetate.
RRL-1	Abandon. Vegetation consistent with surroundings.
RRL-2B	Remove gravel, fill mud pit, recontour pump test pit, prepare seedbed, and revegetate (done under Exploratory Shaft reclamation).
RRL-2C	Remove gravel, fill mud pit, prepare seedbed, and revegetate (done under Eexploratory Shaft reclamation).
RRL-3	Abandon as is. Site is in waste management area.
RRL-4	Prepare seedbed and revegetate.
RRL-5	Recontour, prepare seedbed, and revegetate.
RRL-6	Remove gravel, recontour, prepare seedbed, and revegetate.
RRL-7	Recontour, prepare seedbed, and revegetate.
RRL-8	Prepare seedbed and revegetate.
RRL-9	Prepare seedbed and revegetate.
RRL-10	Remove gravel, recontour, prepare seedbed, and revegetate.
RRL-11	Recontour and abandon. Will be recolonized with appropriate vegetation.
RRL-12	Abandon as is. Vegetation cover on pad is consistent with surrounding vegetation.
RRL-14	Remove gravel pad, close mud pit, prepare seedbed, and revegetate.
RRL-16	Remove gravel, recontour, prepare seedbed, and revegetate.
RRL-17	Remove gravel, recontour, prepare seedbed, and revegetate.
UC-1	Abandon site. Vegetation consistent with surrounding habitat.

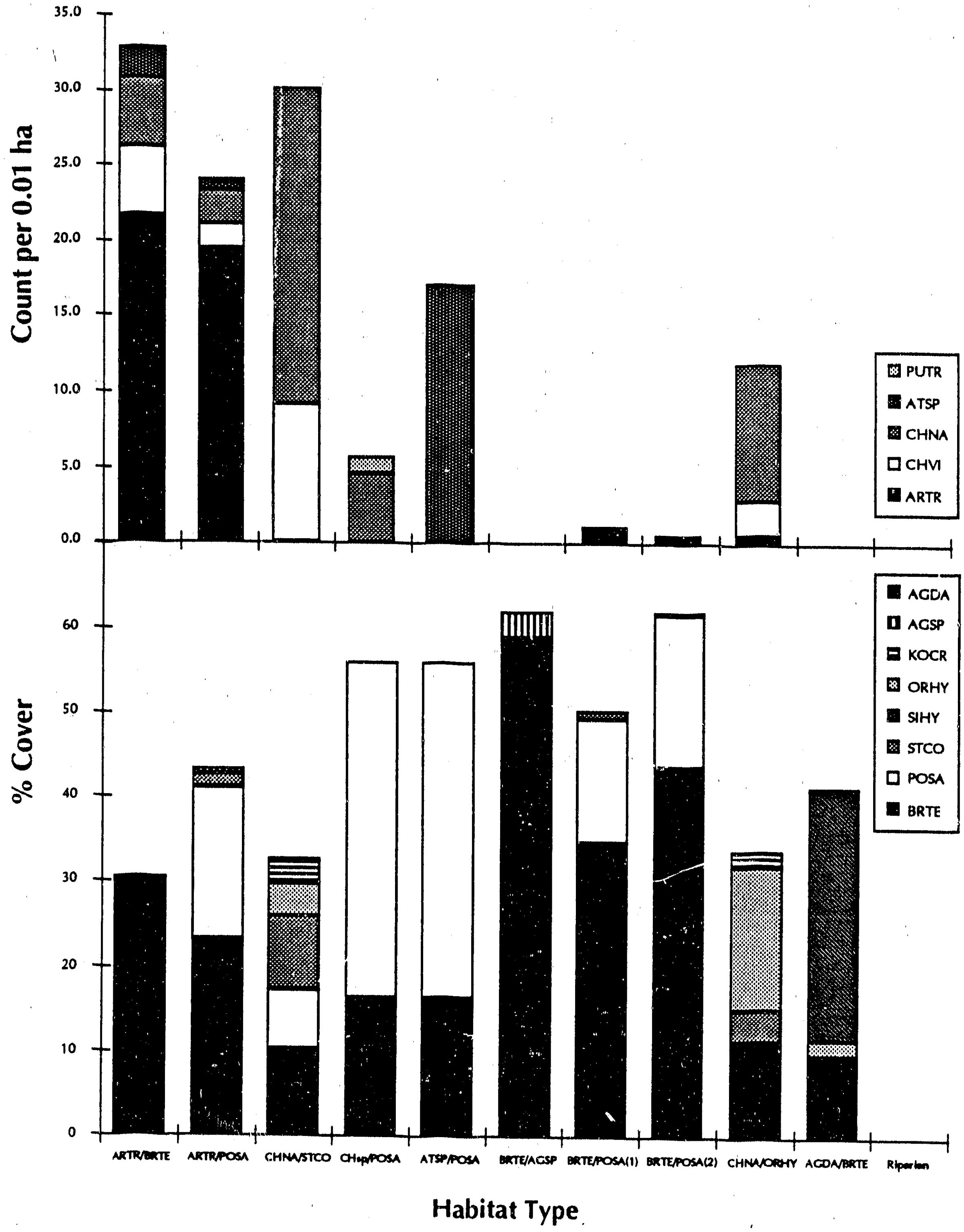

Figure 2. Species Composition in Undisturbed Habitat at Selected Borehole Sites, 1988 (AGDA = downy wheatgrass (*Agropyron dasystachium*), AGSP = bluebunch wheatgrass (*Agropyron spicatum*), ARTR = big sagebrush (*Artemisia tridentata*), ATSP = hopsage (*Atriplex spinosa*), BRTE = cheatgrass (*Bromus tectorum*), CHNA = grey rabbitbrush (*Chrysothamnus nauseosus*), CHVI = green rabbitbrush (*C. viscidiflorus*), KOCR = prairie junegrass (*Koelaria cristata*), ORHY = Indian ricegrass (*Oryzopsis hymenoides*), POSA = Sandberg's bluegrass (*Poa sandbergii*), PUTR = bitterbrush (*Purshia tridentata*), SIHY = bottlebrush squirreltail (*Sitanion hystrix*), STCO = needle-and-thread grass (*Stipa comata*)

2.3 REVEGETATION METHODS

Reproduction of arid-land plants native to the Hanford Site is limited primarily to the relatively infrequent years when adequate soil moisture is maintained during the November-to-March growing season. Although moisture requirements vary among different species, no species is expected to successfully reproduce from seed every year. Consequently, the revegetation methodology chosen was designed to limit the adverse effects of low moisture regimes by emphasizing robust species where possible, avoiding exposure of plants during sensitive growth phases, and including water harvesting features in the plant introduction phase. The more robust native grasses were introduced from seed, using a furrowing drill to enhance moisture harvesting and stabilize soil moisture at the seed. The less-hardy shrub species were grown in nurseries from seeds obtained from plants on the Hanford Site. These tubeling shrubs were then planted in a configuration likely to enhance mutual water harvesting. Revegetation thus consisted of four steps: preparing the seedbed, mulching the seedbed with straw, seeding of grasses using a furrowing drill, and planting shrubs using tubelings.

Revegetation of boreholes was divided into two phases. Phase I comprised revegetation of boreholes where construction and well modifications had been completed before October 1, 1988. Sites at which construction work was completed after October 1 were prepared and fallowed. Phase I revegetation sites are listed in Table 2. Phase II consisted of seeding the remaining borehole sites with native grasses and planting all sites with native shrubs. Phase II sites are listed in Table 3. Several Phase I sites were remediated in Phase II as a consequence of failures identified during their first season of growth (Brandt et al. 1990a). Remedial sites received an additional incorporation of 7% (by weight) composted municipal sludge into the seedbed. The various steps for revegetating the boreholes sites are described below.

Table 2. Boreholes Revegetated under Phase I

Location	Habitat	Soil Type	Area (ha)	Seed Mix[a]	Plant Mix[b]	Seedbed Prep. Date	Seeding Date
Benson	ARTR/BRTE	Esquatzel Silt Loam	0.2	1	1	9/28/88	10/19/88
DB-12	ARTR/POSA	Burbank Loamy Sand	0.2	2	2	10/13/88	10/21/88
DB-14	ARTR/POSA	Koehler Sand	0.3	2	2	10/14/88	10/17/88
DC-7/8	ARTR/POSA	Burbank Loamy Sand	0.5	2	2	10/25/88	10/26/88
DC-15	PUTR/POSA	Rupert Sand	0.8	4	4	10/6/88	10/27/88
DC-22	ARTR/BRTE	Rupert Sand	1.8	1	1	10/17/88	10/31/88
DC-23	BRTE/POSA(1)	Burbank Loamy Sand	1.4	6	6	10/27/88	10/21/88
DC-24	ARTR/BRTE	Hezel Sand	2.7	1	1	10/11/88	10/18/88
DC-32	ARTR/BRTE	Hezel Sand	2.6	1	1	9/9/88	10/18/88
DC-33	ARTR/BRTE	Rupert Sand	2.6	1	1	9/1/88	10/19/88
DH-19	ARTR/POSA	Kiona Silt Loam	0.2	2	2	9/29/88	10/24/88
DH-26	ARTR/BRTE	Hezel Sand	0.1	1	1	9/16/88	10/18/88
DH-27	BRTE/POSA(2)	Warden Silt Loam	0.2	7	7	9/22/88	10/20/88
DH-28	BRTE/POSA(2)	Burbank Loamy Sand	0.1	7	7	9/23/88	10/20/88
DH-30	CHNA/STCO	Rupert Sand	0.6	3	3	9/16/88	10/17/88
DH-31	CHNA/STCO	Rupert Sand	0.6	3	3	9/19/88	10/17/88
DH-32	BRTE/POSA(1)	Hezel Sand	0.7	6	6	9/27/88	10/19/88
DH-33	BRTE/POSA(2)	Warden Silt Loam	0.4	7	7	9/27/88	10/20/88
DH-34	ARTR/POSA	Burbank Loamy Sand	0.5	2	2	9/20/88	10/20/88
DH-35	ARTR/BRTE	Burbank Loamy Sand	0.5	1	1	9/26/88	10/20/88
Enyeart	ARTR/BRTE	Warden Silt Loam	0.6	1	1	10/5/88	10/20/88
Ford	ARTR/BRTE	Warden Silt Loam	0.4	1	1	9/30/88	10/21/88
Obrian	ARTR/BRTE	Ritzville Silt Loam	0.4	1	1	10/4/88	10/21/88

(a) See Table 5 for seeding mix codes.

(b) See Table 6 for planting mix codes.

Table 3. Boreholes Revegetated under Phase II

Location	Habitat	Soil Type	Area (ha)	Seed Mix[(a)]	Plant Mix[(b)]	Seedbed Prep. Date	Seeding Date
DB-1	CHNA/STCO	Rupert Sand	0.3	3	3	10/25/88	9/15/89
DB-2	BRTE/POSA(1)	Rupert sand	0.2	6	6	9/11/89	9/15/89
DB-12	ARTR/POSA	Burbank Loamy Sand	0.2	2	2	10/13/88	10/21/88
DB-14	ARTR/POSA	Koehler Sand	0.3	2	2	10/14/88	10/17/88
DB-15	ARTR/POSA	Burbank Loamy Sand	0.2	2	2	10/2/89	10/3/89
DC-7/8	ARTR/POSA	Burbank Loamy Sand	0.5	2	2	10/25/88	10/26/88
DC-12	ARTR/BRTE	Hezel Sand	0.3	1	1	9/26/89	10/10/89
DC-15	PUTR/POSA	Rupert Sand	0.8	4	4	10/6/88	10/27/88
DC-16	ARTR/BRTE	Hezel Sand	1.5	1	1	9/18/89	10/13/89
DC-18	ARTR/POSA	Burbank Sandy Loam	1.0	2	2	9/29/89	10/15/89
DC-19	CHNA/ORHY	Rupert Sand	1.4	8	8	10/27/88	9/29/89
DC-20	ARTR/POSA	Rupert Sand	1.5	1	1	9/28/89	10/3/89
DC-23	BRTE/POSA(1)	Burbank Loamy Sand	1.4	6	6	10/27/88	10/21/88
DC-25	AGDA/BRTE	Rupert Sand	2.1	9	0	10/26/88	10/12/89
DH-26	ARTR/BRTE	Hezel Sand	0.1	1	1	9/16/88	10/18/88
Laydown Yd	BRTE/POSA(1)	Esquatzel Silt Loam	2.0	6	6	9/22/89	10/11/89
Mcgee	ARTR/POSA	Warden Silt Loam	0.4	2	2	9/27/89	10/5/89
RRL-4	CHNA/STCO	Rupert Sand	0.2	3	3	10/31/88	9/15/89
RRL-5	BRTE/POSA(1)	Equatzel Silt Loam	0.1	6	6	11/2/88	9/15/89
RRL-6	ARTR/BRTE	Esquatzel Silt Loam	0.9	1	1	9/20/89	10/7/89
RRL-7	ARTR/BRTE	Burbank Loamy Sand	0.3	1	1	11/3/88	9/15/89
RRL-8	ARTR/BRTE	Rupert Sand	0.8	1	1	9/26/89	10/15/89
RRL-9	ARTR/BRTE	Rupert Sand	0.2	1	1	10/21/88	9/15/89
RRL-10	ATSP/POSA	Esquatzel Silt Loam	0.2	4	5	9/21/89	10/15/89
RRL-14	BRTE/AGSP	Hezel Sand	1.3	5	0	9/25/89	10/15/89
RRL-16	ARTR/BRTE	Rupert Sand	0.3	1	1	9/21/89	10/15/89
RRL-17	ARTR/BRTE	Rupert Sand	2.5	1	1	10/24/88	10/5/89

(a)See Table 5 for seeding mix codes.

(b)See Table 6 for planting mix codes.

All sites to be reseeded were machine ripped to a minimum depth of 30 cm and disked to a minimum depth of 15 cm to relieve deep compaction. Following disking, the seedbed was surface-compacted using a cultipacker. Certified weed-free chopped straw was mechanically blown over the seedbed at a rate of 4500 kg/ha and was crimped into the soil by a rotary hoe run in reverse. Chopped straw was used before drilling seed instead of after to increase the incorporation of soil with the straw. The resulting mixture greatly enhanced the stability of the furrows and increased the decomposition rate of the introduced organic matter.

Where delays of more than 1 month were anticipated between completion of seedbed preparation and seeding a given site, an organic erosion protection agent (Terra Tack AR) was applied within 1 week after cultivation at a rate of 90 kg/ha. Fallowed sites receiving this treatment are listed in Table 4. Fallowed areas were sprayed in May 1989 with a nonselective contact herbicide (glyphosate) to kill broad-leafed weeds and cheatgrass.

Table 5 lists the specific seeding mixes recommended for each borehole site to be revegetated (see seeding codes listed in Tables 2 and 3). Rates are given in terms of kilograms Pure Live Seed (PLS) per hectare. The percent PLS of a given batch of seed is the product of percent purity and percent germination of a batch of seed divided by 100. Seeds of bluegrass, bottlebrush squirreltail, needle-and-thread grass, and prairie junegrass were to be introduced at a depth of 6 to 12.5 mm. Indian ricegrass was to be seeded at a depth of 5 to 10 cm, and the two wheatgrasses were to be seeded at 12.5 to 20 mm.

Table 4. Boreholes Fallowed Before Seeding in 1989

DB-1	DC-19	DC-25
RRL-4	RRL-5	RRL-7
RRL-8	RRL-9	RRL-17

Seed was placed with a John Deere/Van Brunt drill equipped with a furrowing device mounted ahead of the disk openers such that seeds were emplaced only in the bottom of the furrows. The furrowing device was set to provide a furrow no shallower than 7.5 cm and no deeper than 12.5 cm. Openers were spaced 35 cm apart. Where two species were recommended, species were loaded into separate seed-hoppers on the drill, and seeding ports were covered with duct tape such that each species was seeded into alternate drill furrows. Where more than two species of grass were recommended, Sandberg's bluegrass seeds were loaded into one hopper, and the remaining species were mixed in the other hopper. In seed mixes 3 and 9, Indian ricegrass was seeded first at the specified depth without using the furrowing attachment. The remaining grass species were seeded as per the above procedure; however, the drill was operated such that the seeding row was at 90° to the ricegrass rows whenever possible.

Table 5. Seeding Mixes used on Borehole Reclamation Sites

Code	Species	Seeding Rate, kg PLS/ha
0	None	0.0
1	Sandberg's bluegrass	3.3
	bottlebrush squirreltail	2.2
2	Sandberg's bluegrass	3.3
	bottlebrush squirreltail	1.1
	needle-and-thread grass	1.1
3	Prairie junegrass	0.6
	Indian ricegrass	2.2
	Sandberg's bluegrass	2.2
	needle-and-thread grass	2.2
4	Sandberg's bluegrass	4.5
5	bluebunch wheatgrass	4.5
6	Sandberg's bluegrass	3.3
7	Sandberg's bluegrass	3.3
	bottlebrush squirreltail	1.1
8	Indian ricegrass	9.0
9	downy wheatgrass	6.7
	Indian ricegrass	2.2

Seeding of sites included in Phase I revegetation began October 11, 1988 and was completed October 31, 1988. Seeding of sites under Phase II began on October 10, 1989 and was completed by October 21.

Shrubs were planted after seeding was completed at the rates and densities given in Table 6 (see also Tables 2 and 3). These densities were selected based on an expected mortality rate of 30% (Brandt et al. 1990a). Big sagebrush was planted on three sites (DC-22, DC-24, and DC-32) in Phase I between March 1 and March 29, 1989. The remainder of the sites were planted during Phase II between November 1 and December 8, 1989.

Shrubs were planted in clumps of three at 2.5 cm below grade. Clumps consisted of three tubelings of the same species planted in a triangular configuration with approximately 35 cm between plants. Most holes in Phase II were drilled by a hydraulic auger carried on a low-ground-pressure tracked vehicle. After each clump was planted, each tubeling was surrounded with a handmade soil berm between 2.5 and 5.0 cm high with a radius of approximately 17 cm. Approximately 2 l of water were applied to each tubeling within 1 hour of planting. Clumps were distributed over each site in a spatially random pattern.

DC-14 was not revegetated during Phase II, but will be revegetated by PNL at conclusion of testing.

Table 6. Shrub Planting Rates for Borehole Revegetation

Code	Species	Plants/ha
0	None	0
1	big sagebrush	2817
	grey rabbitbrush	594
	green rabbitbrush	594
	hopsage	267
2	big sagebrush	2520
	grey rabbitbrush	297
	green rabbitbrush	222
	hopsage	90
3	grey rabbitbrush	2742
	green rabbitbrush	1185
4	grey rabbitbrush	594
	bitterbrush (*Purshia tridentata*)	147
5	hopsage	2223
6	big sagebrush	147
7	big sagebrush	75
8	big sagebrush	75
	grey rabbitbrush	1185
	green rabbitbrush	297

3.0 RECLAMATION SUCCESS

Reclamation progress was tracked by periodic checks during deconstruction, revegetation, and plant development after seeding and planting. Plant germination and growth was quantified during surveys carried out in the spring and fall of 1989 and the spring and early summer of 1990. Control plots established near borehole sites were surveyed during the same periods to provide a basis for estimating revegetation success and identifying community trends. Deconstruction performance was reported in Brandt et al. (1990a).

3.1 SEEDING AND PLANTING

The performance of the Phase I seeding program was reported in Brandt et al. (1990a). Pertinent findings from that review that were applied to Phase II seeding included the use of depth bands to better control placement of bluegrass seeds. Setting close tolerances on seeding rates was not found to be worthwhile as different seeding rates had no significant effects on grass emergence rates. Finally, seed flow through the drill was enhanced during Phase II by incorporating pearlized nitrogen fertilizer with the seed at a rate of three parts seed to two parts fertilizer by volume. The fertilizer used was 27% total N, 12% available phosphoric acid, and 4% soluble potash. Seed for most grass species was collected from wild and commercial fields in the Columbia Basin.

Some modifications to the overall seeding program were made as Phase II progressed. Of the sites to be reseeded, additional straw was added to DC-7/8, DC-15, and DC-23 because no mulch remained on these sites from Phase I. The remaining remediation sites (DB-12, DB-14, and DH-26) received no second application of mulch. DC-12 was exempted from the seedbed preparation requirement because of its location in a heavily wind-eroded area. DC-12 was substantially compacted, however, and the reseeding crews found it difficult to introduce a furrow into the substrate.

Few of the sites seeded in Phase II were occupied by cheatgrass at the time of seeding, although large Russian thistle (*Salsola kali*) plants were present on many locations. These were removed by hand as seeding progressed. Two of the Phase I sites (DH-32 and DH-33) were mowed during the summer to prevent the Russian thistle from interfering with shrub planting.

Seeding depths were periodically checked by PNL staff during Phase II. Ricegrass proved difficult to seed at the extreme depths required in the specifications; actual seeding depths were seldom over 5 cm, with average depth in the range of 3 cm. Bluegrass seeding depth averaged between 6 and 15 mm.

3.2 CONTROL HABITATS

To track the development of vegetation in the target habitats, data on percentage cover and plant density were obtained from 18 control plots representing the 10 revegetated habitat types. Because DC-14 was not scheduled for any treatment other than the planting of trees, no control plots were established in the riparian habitat. Vegetative cover and density in the control plots were assessed using the methods described previously (Section 2.1). Plant cover, density, and occurrence data were collected in April, June, and October 1989, and in April, May, and June 1990.

The alien annual cheatgrass occurred in all habitat types and was the dominant species in terms of cover in all habitats except the hopsage-bluegrass and bitterbrush-bluegrass habitats (Figure 3). Cheatgrass cover was highest in the burned habitats (cheatgrass-bluebunch wheatgrass, and cheatgrass-bluegrass). Although bottlebrush squirreltail was not found in the cover samples of most of the habitat types, it did occur in most of the species lists, which were based on complete rather than point sampling of 100-m^2 plots. It is thus a common but not abundant grass. Downy wheatgrass and Indian ricegrass were the dominant native grasses on extremely sandy sites where active dunes were present.

The most abundant shrub on the control plots was big sagebrush, which occurred at just over 22 plants/100 m^2 in the big sagebrush-cheatgrass habitat (Figure 4). Hopsage was the only shrub species in the hopsage-bluegrass habitat. Burned cheatgrass-bluegrass habitats supported sparse stands of big sage, but no shrubs were identified in the plots on the wheatgrass/cheatgrass habitats.

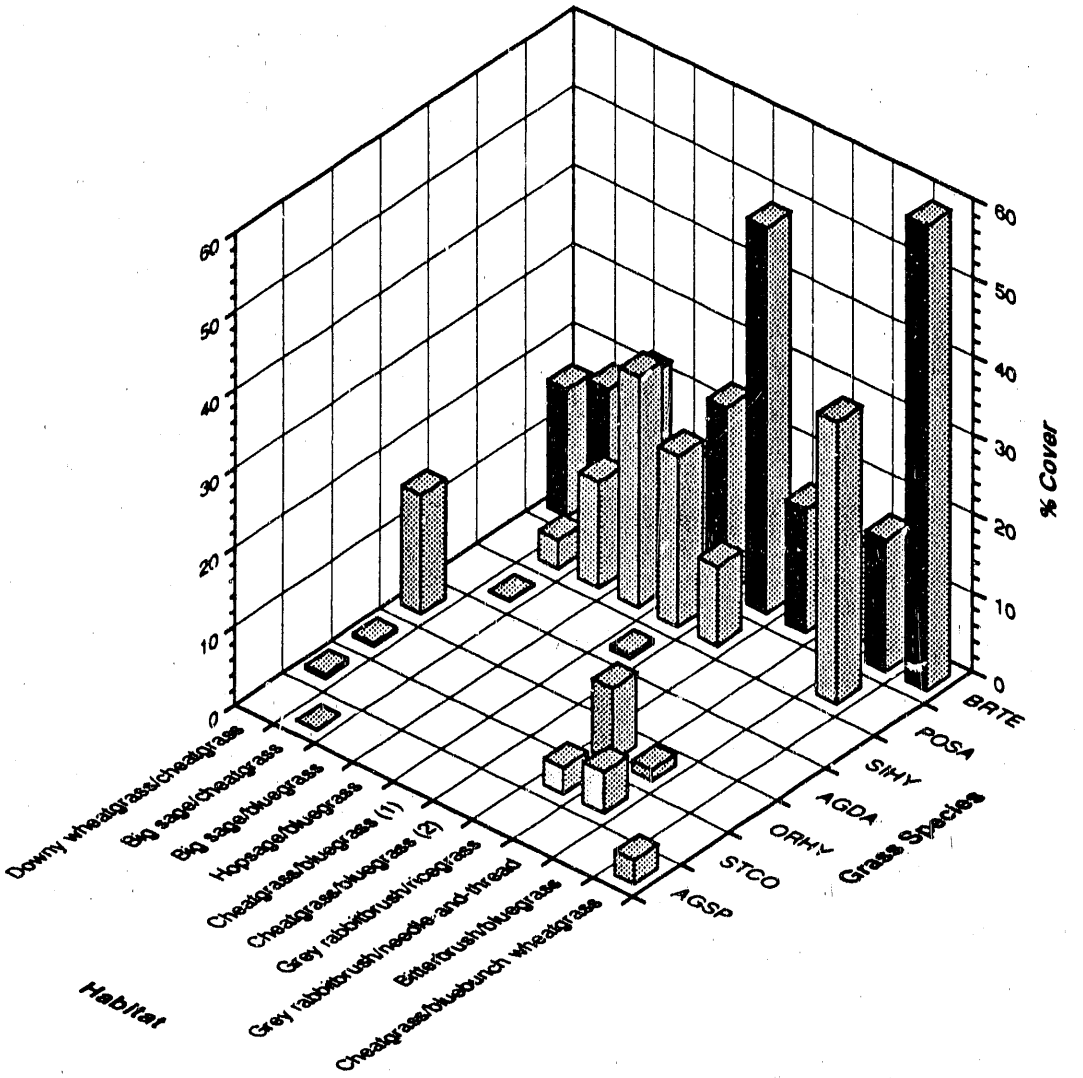

Figure 3. Grass Cover in Undisturbed Habitats

Native forbs were not abundant compared to grasses and shrubs, although they were common in all habitats. Common native forbs included hoary aster (*Machaeranthera canescens*), winged cryptantha (*Cryptantha pterocarya*), various species of buckwheat (*Eriogonum* spp.), white-stemmed globe-mallow (*Sphaeralcea munroana*), pale evening primrose (*Oenothera pallida*), threadleaf phacelia (*Phacelia linearis*), lance-leaf scurf pea (*Psoralea lanceolata*), large-flowered desert parsley (*Lomatium macrocarpum*), turpentine cymopterus (*Cymopterus terebinthinus*), Carey's balsamroot (*Balsamorhiza careyana*), yarrow (*Achillea millefolium*), and yellow salsify (*Tragopogon dubius*).

The predominant alien annual species aside from cheatgrass were bur ragweed (*Ambrosia acanthicarpa*), Russian thistle, and spring whitlow-grass (*Draba verna*). All are early succession colonizers and so are expected to invade the revegetated areas at some time. During the first years of succession, ragweed and Russian thistle invade disturbed areas earlier and in greater number than do the other alien species. Because of the large amount of cheatgrass in the surrounding habitat, however, cheatgrass is expected to overtake the other annuals on the revegetated site within several years.

3.3 REVEGETATED SITES

Growth of grasses on the revegetated areas was assessed during March, May, and December 1989 and in

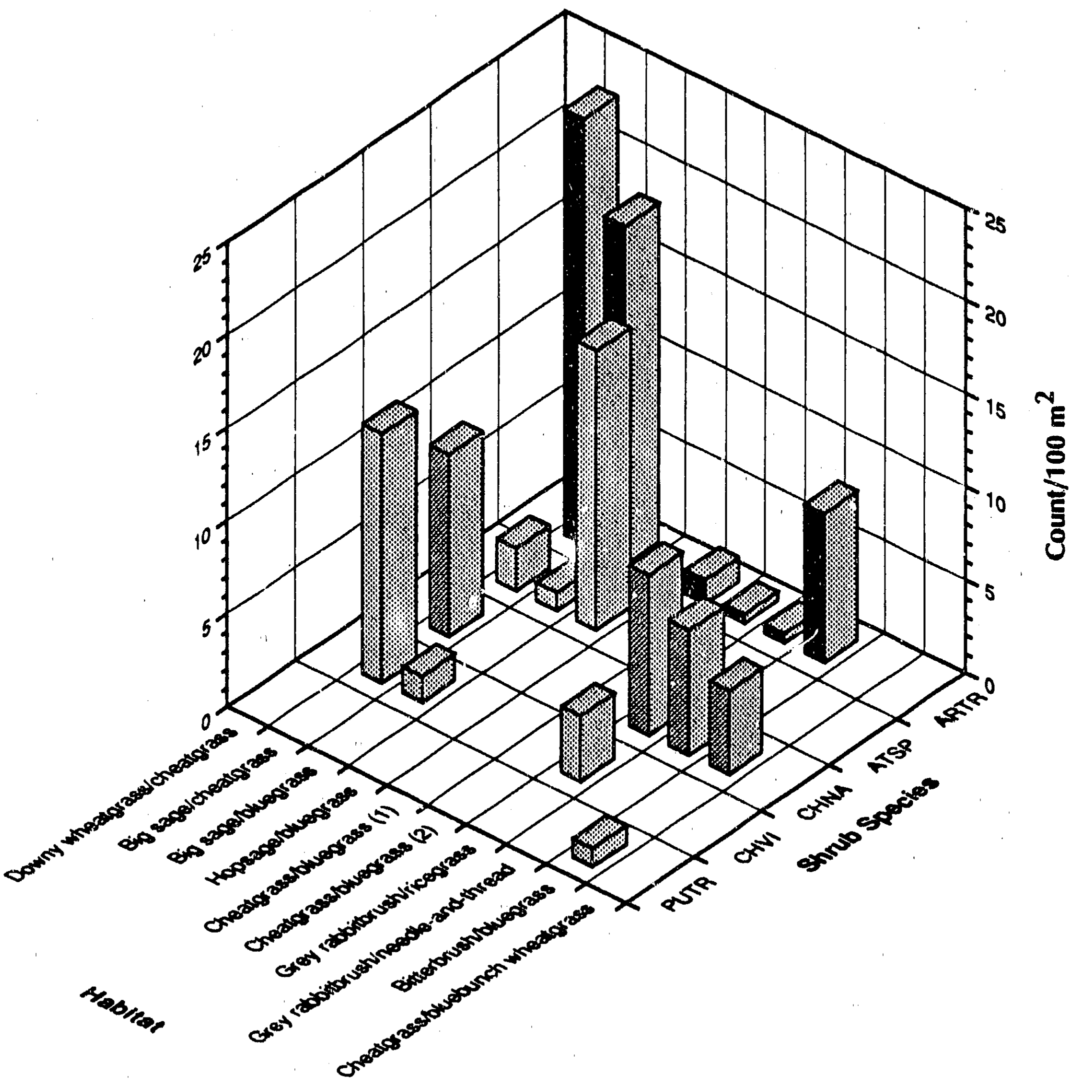

Figure 4. Shrub Density in Undisturbed Habitats

March through June 1990. Revegetated sites were sampled using a stratified random technique. Strata were distributed evenly over each site at the rate of 1 per 0.1 ha, with one 1-by-0.35-m plots located randomly within each stratum. Plots were aligned parallel with the drill furrow and were located by tossing a stake within a stratum. The corner of the plot frame was then aligned with the point of the stake. All plants growing within the plot frame were counted by species and by the number of leaves, and average height was recorded. On revegetated sites where species were seeded in alternate rows, the plot frame was also moved over one furrow and recounted after the first counting. Because the plants were immature, it was seldom possible to differentiate bottlebrush squirreltail, prairie junegrass, and needle-and-thread grass, so observations of these species were lumped into a single category.

Comparisons of immature grasses to their mature counterparts in target habitats is difficult without a common standard of measurement. For the purposes of this report, that standard is taken to be plant density, although percentage cover is the standard accepted by most state land reclamation agencies. Cover is not a practical standard for immature species, because cover by mature plants is much greater than that of immature plants. Based on field assessments, mature Sandberg's bluegrass was assumed to cover 0.01 m^2, bottlebrush 0.02 m^2, and wheatgrasses, needle-and-thread grass, and ricegrass 0.04 m^2each. These values were used to convert percentage cover in control plots to density/100 m^2. Densities of immature plants, measured on a 0.35-m^2 basis (or 0.7-m^2 where species were seeded in alternate rows), were appropriately factored to give densities/100 m^2 when compared to control areas.

Statistical comparisons were made using parametric analysis of variance. Data are transformed as $Y' = \log(Y+1)$ to normalize distributions. Normality assumptions were checked using normality plots. Significance was attributed to differences whose probability of occurrence resulting from chance alone was greater than 1 in 20.

Sandberg's bluegrass was the most common grass found at all sites where it was seeded (Figure 5). Downy wheatgrass and ricegrass performed exceptionally well. Ricegrass appeared in relatively high density on DC-15, although seeding specifications did not call for its use on this site. It is likely that the appearance of ricegrass on this site was due to its inadvertant seeding rather than to germination of native seeds preserved in the soil or introduced from neighboring plants. All species exhibited a great deal of spatial variability in density; standard deviations for densities of all revegetated grasses were much larger than the mean values. The least variable grass was downy wheatgrass.

Sites exhibited significant differences in bluegrass density ($F_{38,496}$= 5.712, $P < 0.0001$). The greatest abundance of bluegrass was found on Benson Ranch, DC-15, DC-32 , DC-33, DH-27, DH-28, and DH-34. Sites without bluegrass where such was planted were DB-1, DB-2, DB-15, DC-12, RRL-4, RRL-5, RRL-7, and RRL-16. Bottlebrush squirreltail appeared at such low densities that differences among sites were not statistically significant ($F_{28,379}$ = 1.404, $P = 0.0865$). Ricegrass density was significantly higher on DC-15 and DC-25 than on other sites where it was seeded ($F_{6,73}$= 13.966, $P = 0.0001$). There were no significant differences among sites in terms of needle-and-thread grass density ($F_{11,98}$ = 1.289, $P = 0.2421$). Wheatgrasses were planted on one site each.

Shrub performance was determined by walking transects crossing each site. Transects were walked in June 1989 and June and July 1990, tallying shrubs within 10 m of each transect according to species and whether the shrub appeared alive or dead. Sites were sampled at a minimum rate of 50% by area. Tallies were subdivided according to whether the observation was in the central third of the site, middle third, or the outer third. Observations on small sites were divided into central and edge halves only. Mortality rates were calculated from these data for each species planted on each site. Densities of remaining live shrubs were then calculated based on decrementing the specified planting densities. Mortality data were transformed to arcsine square roots to normalize distributions before parametric analyses.

Mortality rates were higher than expected, averaging just under 45% overall. Not all species fared alike: hopsage mortality (62%) was significantly higher than that among the other species ($F_{5,712}$ = 220.977, $P < 0.0001$). Hopsage was heavily preyed on by jackrabbits (*Lepus californicus*). The lowest mortality was experienced by grey rabbitbrush (41%).

No species experienced the same mortality rate at all sites (analysis of variance, $P < 0.0001$). Mortality of big sagebrush was lowest on DC-15, DC-33, DH-32, DH-33, DH-34, and RRL-17. Mortality rates on these sites was less than 10%. In contrast, mortality for this species was approximately 100% on DH-28, RRL-7, and RRL-9. Overall mortality for this species was 43.9%. Hopsage mortality ranged from 33% on DC-24 to 82% on RRL-6. Grey rabbitbrush mortality ranged from 0% on DB-14 to 100% on RRL-9; green rabbitbrush mortality had a similar range, from 0% at McGee to 100% at RRL-7. Bitterbrush was planted only on DC-15, where mortality was 51%. Current shrub densities on the revegetated sites consequently vary considerably from site to site (Figure 6).

The raptor nesting platforms erected on the two power poles at RRL-6 were not used as nesting sites during the year, but did serve as temporary roosts for magpies (*Pica pica*) and Swainson's hawks (*Buteo swainsoni*).

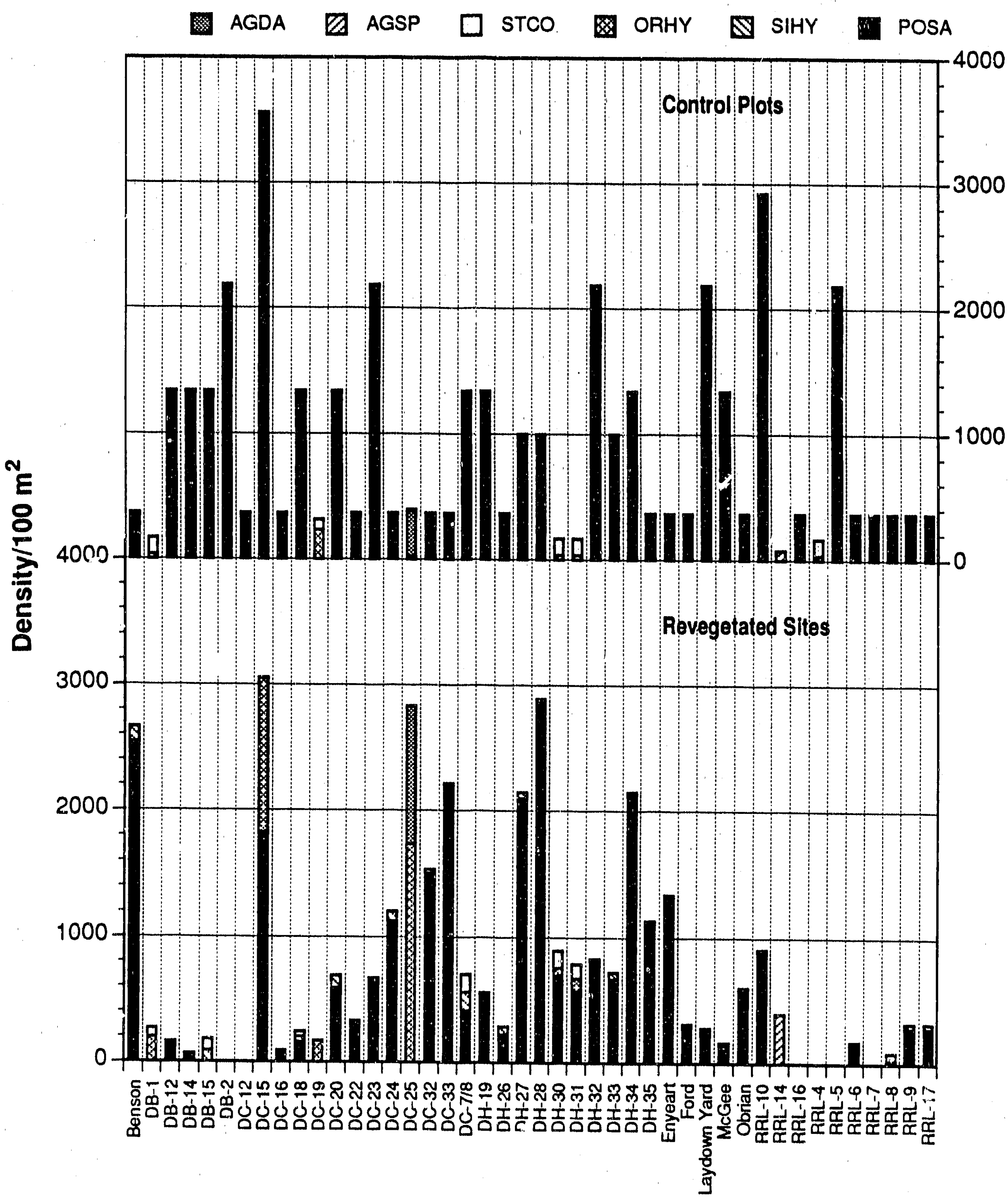

Figure 5. Grass Density on Control Sites Versus Revegetated Boreholes

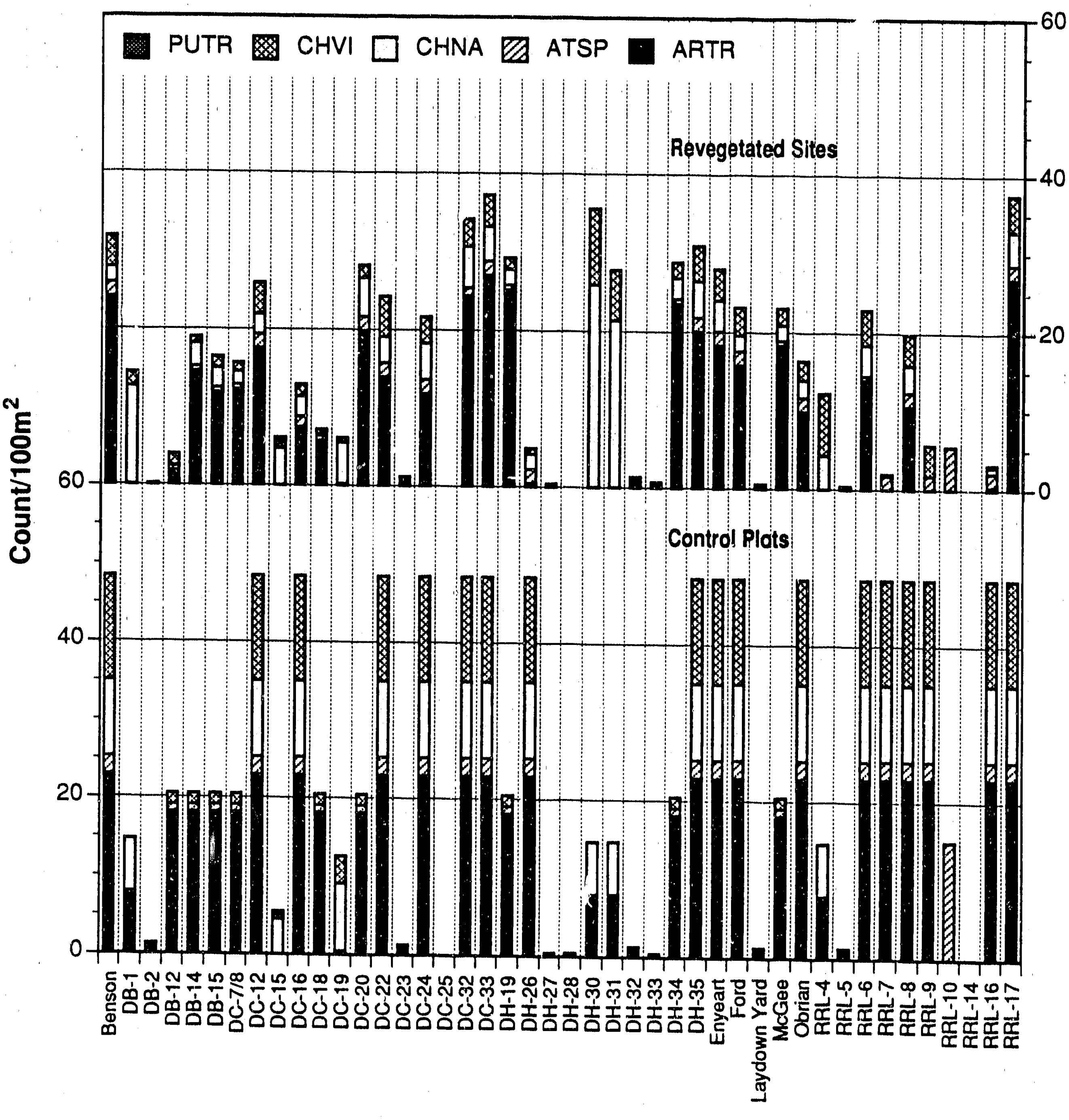

Figure 6. Shrub Density on Control Sites Versus Revegetated Boreholes

4.0 POTENTIAL CAUSES OF PERFORMANCE DIFFERENCES

Differences in density and vigor among the seeded and planted species and among locations were marked. Potential causes of differences include weather trends and events over the 2-year period, soil type, addition of composted sludge to the seedbed on remediation sites, seeding rates, fertilizer additions, furrow orientation, proximity to the edge of the disturbance, and effects of density on vigor of seeded species. The significance of these causes are examined below for grasses and shrubs.

4.1 GRASSES

During the first phase of the borehole reclamation program, it was found that seeding rate differences bore little statistical relationship to bluegrass density at least during the first 6 months of growth (Brandt et al. 1990a). This lack of relationship was attributed to the extremely wide range of emergence rates observed for each seeding rate. However, plants that were growing at higher densities tended to be larger in stature than plants growing in less dense conditions. Plants growing at higher densities also put on more leaves than did less-crowded plants, so total leaf area and vigor were probably greater as density increased (Brandt et al. 1990a).

These relationships remained true in part for plants measured after Phase II. The regression of bluegrass density (log transformed) on height (log transformed) was positive and significantly different from zero (log height = 0.05*log density + 0.434, R^2 = 0.033, P = 0.001). Similar results were found for ricegrass (log height = 0.271*log density + 0.731, R^2 = 0.270, P = 0.001). Regressions for other species were not significantly different from zero. In contrast to Phase I, however, the mean number of leaves per plant was significantly lower for bluegrass plants growing at higher densities (log leaf no. = -0.065*log count + 0.667, R^2 = 0.034, P = 0.0008). Similar trends were observed for the other species seeded, but regressions were not significantly different from zero. All the primary grass species exhibited a positive relationship between plant height and leaf number, indicating that taller plants were generally more vigorous (rather than more spindly) than smaller plants (log bluegrass leaf no. = 0.661*log height + 0.266, R^2 = 0.271, P < 0.0001; log bottlebrush leaf no. = 0.631*log height + 0.136, R^2 = 0.410, P < 0.0001; log needle-and-thread leaf no. = 0.576*log height + 0.155, R^2 = 0.466, P < 0.0001; log ricegrass leaf no. = 0.311*log height + 0.132, R^2 = 0.338, P < 0.0002).

These relationships indicate that tall plants of all species were generally in better health than shorter plants. However, bluegrass plants growing at high densities were adversely affected by crowding: plants were tall, but spindly, with fewer leaves than expected for their height.

Effects of seeding date, sampling date, and seed mix on plant density were examined simultaneously using analysis of variance. The dependent variable in each case was count/m of seeded row log transformed to produce a normal distribution.

Significant effects of seeding date, sampling date, and seed mix were found for bluegrass, but not for bottlebrush squirreltail or needle-and-thread grass (Table 7). Bluegrass density was much lower for plants seeded in 1989 versus 1988 over all seeding mixes (Figure 7). Consequently, each successive sampling of plant height turned up smaller plants on average than did the previous sampling. Overall density of grasses planted in 1988 was 6.3 plants/m of seeded row, versus 0.7 plants per row seeded in 1989. The highest bluegrass seeding rates per row (755 seed/m) were for mixes 1, 2, and 7; mix 7 produced the highest density of plants, but mix 2 produced the second lowest density. Pure seedings of bluegrass (mixes 4 and 6 at 503 seeds/m and 377 seeds/m, respectively) did no better than mixtures. Consequently, although differences in seed mix were significant, it is likely that the effects were a consequence of other factors correlated with mix, such as soil type (examined below). Weather patterns experienced by plants during their first growing season were, however, a significant factor in determining bluegrass growth.

No significant differences were noted among bottlebrush squirreltail or needle-and-thread grass seeding mixes, planting dates, or sampling dates (Table 7). This is surprising given the fact that few plants of either species had emerged during the first growing season (Brandt et al. 1990a). Needle-and-thread grass

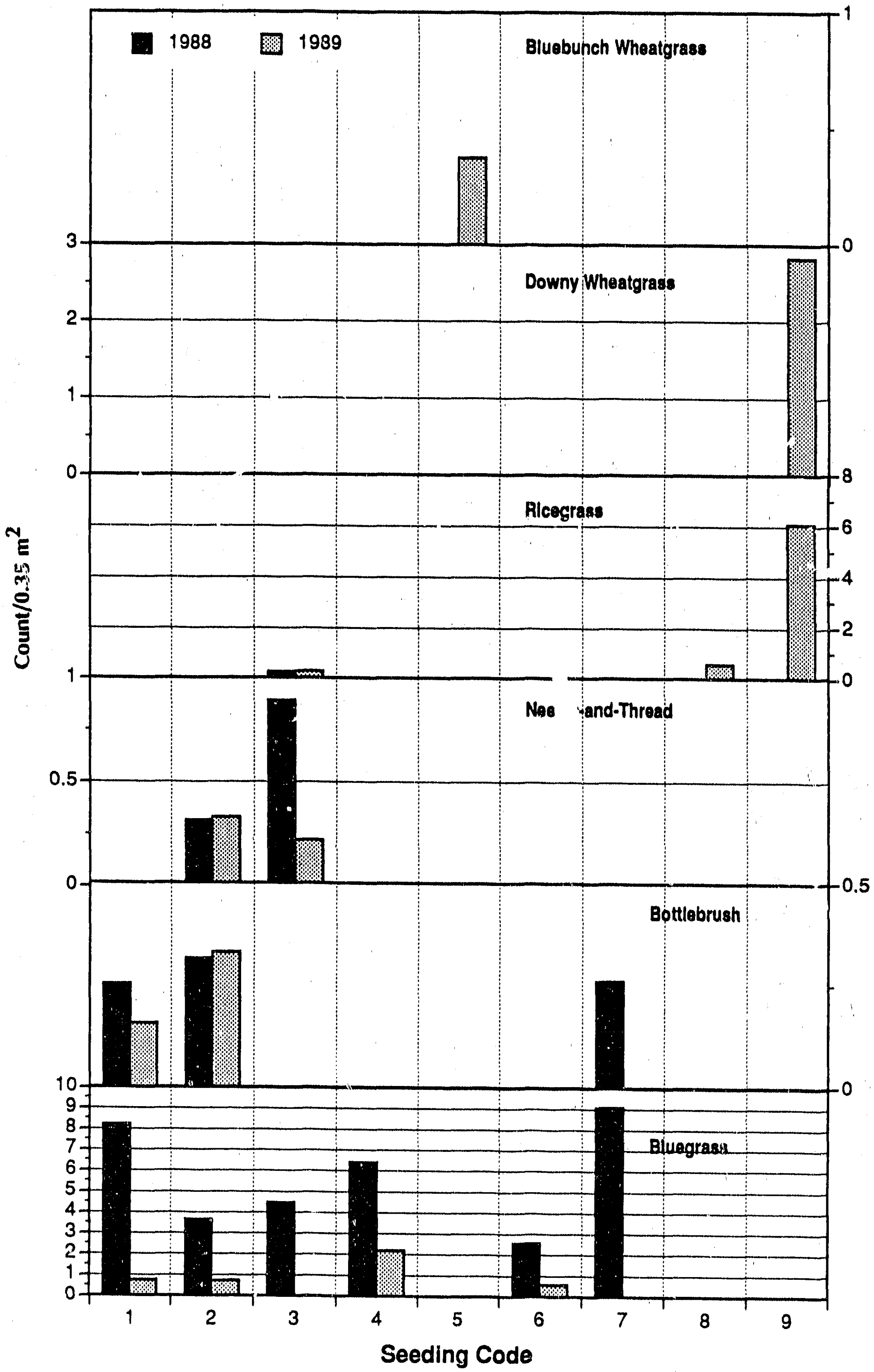

Figure 7. Grass Density Versus Seeding Code and Seeding Date

Table 7. Analyses of Variance for Date and Seed Mix Effects on Grass Count/m Seeded Row (log transformation)

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Bluegrass					
Seed Date	1	3.843	3.843	11.807	0.0006
Sample Date	2	29.548	14.774	45.395	0.0001
Seeding Mix	5	5.761	1.152	3.540	0.0037
Residual	526	171.188	0.325		
Bottlebrush					
Seed Date	1	0.013	0.013	0.183	0.6687
Sample Date	2	0.00001	0.000006	0.00009	0.9999
Seeding Mix	3	0.110	0.037	0.521	0.6681
Residual	401	28.103	0.070		
Needle-and-thread					
Seed Date	1	0.025	0.025	0.199	0.6563
Sample Date	2	0.248	0.124	0.986	0.3763
Seeding Mix	1	0.129	0.129	1.024	0.3140
Residual	105	13.213	0.126		

density from seeding mix 3 was twice that of seeding mix 2, as was the seeding rate, but, due to the wide variation in realized density, the difference was not statistically significant.

Ricegrass was planted in 1988 in seeding mix 3 only; consequently it is not valid to analyze effects in the same manner as for the other species. However, seed mixes 3 and 9 included ricegrass at the same rate per meter of seeded row. There were no performance differences between years for mix 3, but mix 9 produced significantly greater numbers of plants than did mix 3 in 1989. Thus differences in ricegrass density cannot be attributed to seed density, but must be caused by other factors. Wheatgrasses were planted only in single mixes in 1989.

Plants seeded in 1988 received normal moisture input during November, but less than normal moisture during January (Figure 8). Moisture input during February, March, and April 1989 was more than twice normal, which helped plants recover from the extreme cold period experienced in February when low temperatures at the Hanford Meteorological Station dipped below -20°C. This cold period damaged the aboveground portions of most immature grasses, but the ample moisture supply and warmer-than-normal temperatures during April and May allowed them to make up much of their lost growth. Plants seeded in 1989 received slightly more than average moisture during their first month of growth in November, but much lower than normal moisture until late April 1990. Observations of plants emerging in November 1989 indicated all seeded sites were doing extremely well; observations in March and April showed most emergent plants had died as a consequence of the drought. Shallow-rooted, slow-growing plants such as bluegrass fared worst; deep-rooted plants such as ricegrass suffered little if at all.

Soil-type effects were examined using analysis of variance. Effects of seeding date were included in the bluegrass analysis to remove this source of significant variation. Soil-type differences were significantly related to grass density only for bluegrass (Table 8). Bluegrass density was significantly higher on Esquatzel silt loam than on other soil types (Figure 9); however, bluegrass performed no better on the fine-textured silt loams than it did on sandy soils, on average. Growth of bluegrass seeded in 1989 was everywhere less than that of bluegrass seeded in 1988. Ricegrass density was higher on average for plants seeded in 1989 than those in 1988, as was bottlebrush squirreltail on Burbank loamy sand and Rupert Sand. In general, soil type had some effects on bluegrass density, but these were not a consequence of texture alone.

Soil nutrient levels differ between soil types (Brandt et al. 1990a), though only to a small degree. The effects of the primary limiting nutrient, nitrogen, was examined in an experimental design in which different levels of ammonium nitrate were applied in a one-time liquid application to bluegrass seeded in 1988 on three different soil types. The plot layout was a Latin square in which variation along and across furrows was controlled by the Latin square layout. Plots were established on Enyeart (Warden silt loam), DH-32 (Hezel sand), and DH-35 (Burbank loamy sand)

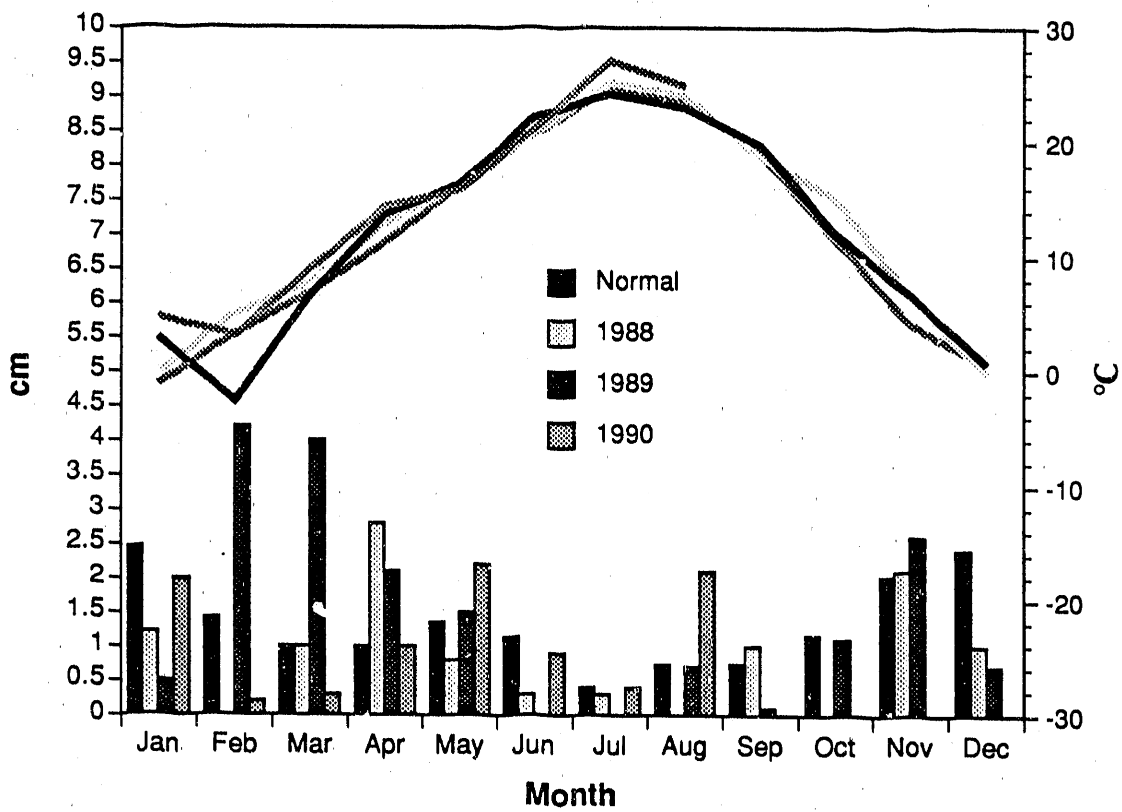

Figure 8. Temperature (upper) and Moisture (lower) Patterns at the Hanford Meteorological Station, 1988-1990

Table 8. Analyses of Variance for Seeding Date and Soil Type Effects on Grass Count/m Seeded Row (log transformation)

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Bluegrass					
Seed Date	1	36.117	36.117	93.705	0.0001
Soil Type	7	5.913	0.845	2.192	0.0336
Residual	526	202.736	0.385		
Bottlebrush					
Soil Type	7	0.214	0.031	0.436	0.8795
Residual	400	28.046	0.070		
Needle-and-thread					
Soil Type	4	0.564	0.141	1.110	0.3559
Residual	105	13.331	0.127		

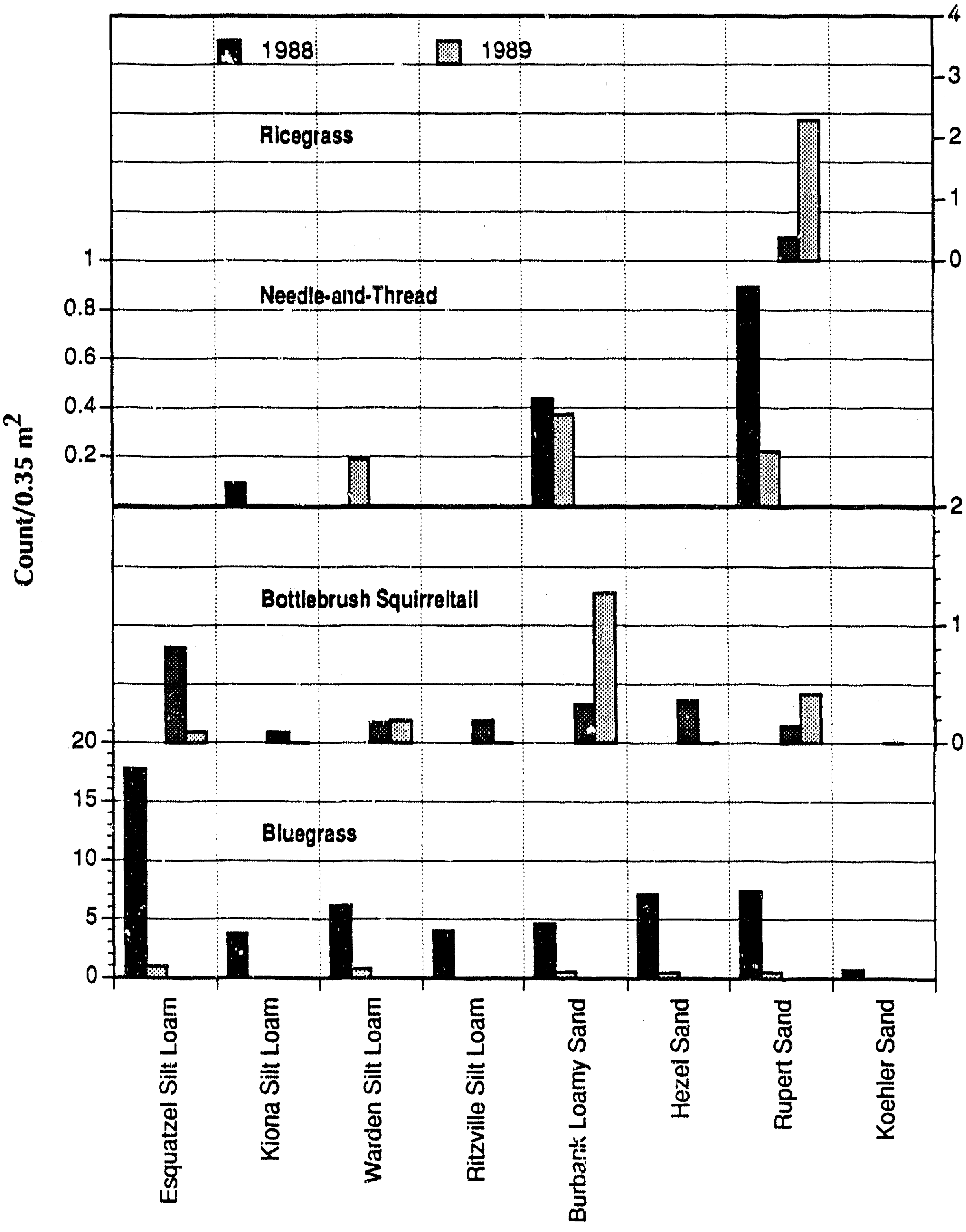

Figure 9. Grass Density by Soil Type and Seeding Date

that measured 24 by 6.9 m. Plots were subdivided into 16 subplots with liquid ammonium nitrate applied at rates of 0, 14, 28, or 56 kg nitrogen/ha. The 0 kg/ha rate received only distilled water. Fertilizer was applied on March 21, 1989. Data were collected in May and December 1989. Plant densities, leaf numbers, and average height were recorded for all plants growing on the subplots in May and on the central 2 rows within each subplot in December. Plant counts were transformed to logs and leaf counts to inverse square roots to normalize distributions as determined from normality plots.

Nitrogen levels had no significant effects on bluegrass height, leaf number, or density at either assessment period (Table 9). Effects on leaf number and height caused by fertilizer addition were greater in December than in May, but still well below significance. Plant growth on the silt loam and loamy sand soils was extremely variable, with few plants remaining within the plots by December 1989. When fertilizer effects were examined using the sandy soil only, effects approached statistical significance (Table 10). Bluegrass plants growing under intermediate levels of nitrogen averaged 5.3 leaves per plant versus 3.9 for the high nitrogen and 3.6 for the controls. Effects on total count and plant height were not significant. The relevant conclusion to be drawn from this experiment is that nitrogen levels had minor effects on bluegrass growth in some soils but not others, and no effects on plant survival at least through parts of two growing periods and an intervening summer. Consequently, the addition of fertilizer to the seeding mixes under Phase II planting had no effects on bluegrass growth that could be detected by spring 1990.

The possible effects of furrow orientation on plant growth were examined by comparing north-south versus east-west furrow orientation across the different soil types. Furrow orientation could be important from the standpoints of resilience to wind erosion, snow capture, and shading of plants by the furrow walls. Overall, furrow orientation bore no significant relationship to bluegrass density (Table 11). Bluegrass density on east-west furrows averaged 4.4 plants/m of furrow, while north-south furrows averaged just over 4/m. However, north-south orientations supported greater numbers of bluegrass on Warden silt loam, Burbank loamy sand, and Koehler sand soils (Figure 10). The opposite was true on the remaining soils. Generally, sandy soils are expected to be more prone to erosion by wind because they do not form crusts after rains.

The possibility that furrows at right angles to the prevailing winds might have been filled by eroded

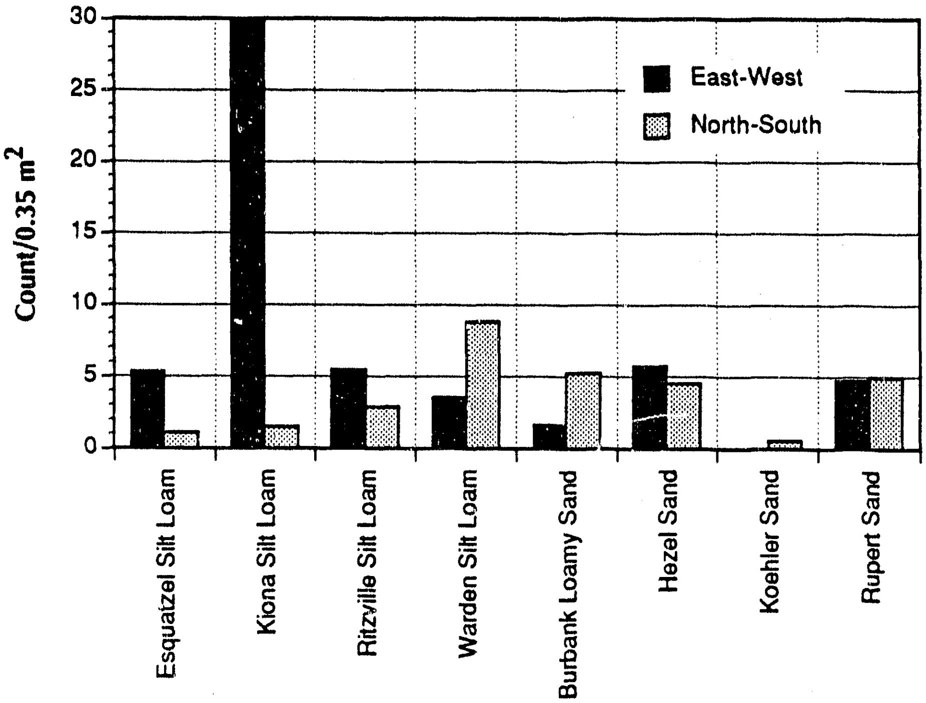

Figure 10. Relationship of Furrow Orientation and Soil Type with Bluegrass Density

Table 9. Analysis of Variance for Effects of Soil Type and Nitrogen on Bluegrass Growth in Latin Square Experimental Plots

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Spring Density					
Soil Type	2	69.041	34.521	32.819	0.0001
Within Rows	3	1.678	0.559	0.532	0.6640
Among Rows	3	1.015	0.338	0.321	0.8098
Nitrogen	3	0.105	0.035	0.033	0.9916
Nitrogen*Soil	6	4.122	0.687	0.653	0.6873
Residual	30	31.556	1.052		
Spring Height					
Soil Type	2	72.362	36.181	22.625	0.0001
Within Rows	3	3.195	1.065	0.666	0.5796
Among Rows	3	2.072	0.691	0.432	0.7316
Nitrogen	3	0.045	0.015	0.009	0.9987
Nitrogen*Soil	6	4.642	0.774	0.484	0.8151
Residual	30	47.974	1.599		
Spring Leaf No.					
Soil Type	2	83.215	41.607	19.454	0.0001
Within Rows	3	2.501	0.834	0.390	0.7612
Among Rows	3	2.420	0.807	0.377	0.7701
Nitrogen	3	0.009	0.003	0.001	0.9999
Nitrogen*Soil	6	7.745	1.291	0.604	0.7253
Residual	30	64.162	2.139		
Winter Density					
Soil Type	2	51.536	25.768	33.236	0.0001
Within Rows	3	6.938	2.313	2.983	0.0364
Among Rows	3	0.154	0.051	0.066	0.9777
Nitrogen	3	0.838	0.279	0.360	0.7818
Nitrogen*Soil	6	2.206	0.368	0.474	0.8255
Replicate	1	2.270	2.270	2.928	0.0911
Residual	77	59.698	0.775		
Winter Height					
Soil Type	2	87.205	43.602	58.783	0.0001
Within Rows	3	11.424	3.808	5.134	0.0027
Among Rows	3	0.465	0.155	0.209	0.8898
Nitrogen	3	2.763	0.921	1.242	0.3005
Nitrogen*Soil	6	3.001	0.500	0.674	0.6707
Replicate	1	1.693	1.693	2.282	0.1350
Residual	77	57.115	0.742		
Winter Leaf No.					
Soil Type	2	129.347	64.674	27.798	0.0001
Within Rows	3	14.012	4.671	2.008	0.1199
Among Rows	3	2.817	0.939	0.404	0.7509
Nitrogen	3	7.978	2.659	1.143	0.3371
Nitrogen*Soil	6	8.405	1.401	0.602	0.7278
Replicate	1	11.340	11.340	4.874	0.0302
Residual	77	179.145	2.327		

Table 10. Analysis of Variance for Effect of Added Nitrogen on Bluegrass Growth in Experimental Plot on Sandy Soil

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Winter Density					
Within Rows	3	3.888	1.296	2.200	0.1181
Among Rows	3	0.274	0.091	0.155	0.9254
Nitrogen	3	1.311	0.437	0.742	0.5389
Replicate	1	1.201	1.201	2.039	0.1681
Residual	21	12.373	0.589		
Winter Height					
Within Rows	3	11.117	3.706	4.280	0.0166
Among Rows	3	0.649	0.216	0.250	0.8606
Nitrogen	3	4.634	1.545	1.784	0.1810
Replicate	1	0.973	0.973	1.124	0.3011
Residual	21	18.183	0.866		
Winter Leaf No.					
Within Rows	3	21.303	7.101	3.261	0.0418
Among Rows	3	6.783	2.261	1.038	0.3961
Nitrogen	3	19.231	6.410	2.943	0.0566
Replicate	1	1.575	1.575	0.723	0.4047
Residual	21	45.737	2.178		

Table 11. Analysis of Variance for Effect of Soil Type and Furrow Orientation on Bluegrass Density

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Furrow 1	0.343	0.343	0.772	0.3801	
Soil Type	7	4.887	0.698	1.573	0.1410
Furrow*Soil Type	7	8.287	1.184	2.667	0.0102
Residual	519	230.402	0.444		

soils more readily than furrows parallel to the winds was examined by categorizing sites into prevailing wind patterns according to the Hanford Meteorological Network wind roses (Brandt et al. 1990a). Sites were also classified as to whether the east-west or north-south furrows supported the greater density of bluegrass on a given site. Nine sites in the westerly wind zones had east-west furrows with higher densities of bluegrass than north-south furrows; 12 had the opposite. Only two sites where bluegrass was seeded occurred in the north-south wind zone, and on both sites the east-west furrows supported more bluegrass than did the north-south furrows. These results did not support the notion that prevailing wind direction was a factor in determining bluegrass success ($X^2 = 2.39$, df = 1, P = 0.1221).

Six sites that had been seeded in Phase I in 1988 were reseeded in Phase II. One of these, DB-14, had been severely disturbed after Phase I seeding by a work crew and machinery decommissioning the borehole. Another site, DB-12, had only weak growth that had completely disappeared by June. DC-23 plants were seeded into pit-run material that showed evidence of residual herbicide activity. Consequently, the few plants found alive in spring 1989 were dead by June. DC-15 occupied a sand area in active dunes; by spring 1989 none of the furrows remained, and most plants were dead. DC-7/8 and DH-26 never supported plants. These sites were all treated with 7% composted sludge in the summer of 1989 and reseeded with the same seeding mix and the same methods.

The effect of the sludge treatment produced growth rates in marked contrast to the general trend of much poorer performance of grasses seeded in 1989 than in 1988. Sludged sites produced significantly more bluegrass after treatment than before ($F_{1,74} = 4.034$, P = 0.048). However, not all sites performed in the same fashion. The greatest boost to productivity was realized at DC-15, where bluegrass density after reseeding in 1989 was over five times that of the previous year (Figure 11). DC-7/8, DC-23, and DH-26 experienced similar trends in growth, whereas DB-12 and DB-14 produced fewer plants after reseeding than before. Clearly, the problems existing at DB-12 and DB-14 that produced the need to reseed were not related to soil condition factors which could be addressed with composted sludge application.

In summary, differences in grass growth on the revegetated sites were mostly a result of the failure of the winter rains during 1989-1990. Plants growing in different soil types responded differently to this stress. Furrow orientation had no effects on performance, and differing nutrient levels had no noticeable effects ex-

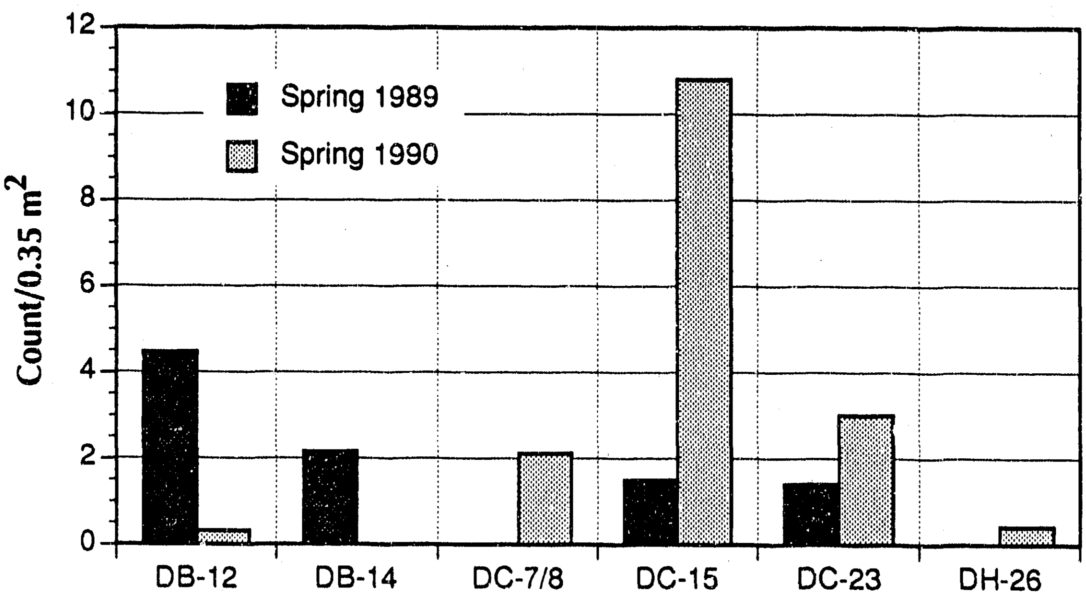

Figure 11. Bluegrass Density on Sites Before and After Sludge Treatment

cept in markedly poor or unstable soils (sands and pit-run material) where additional nutrients enhanced bluegrass growth. Deep-rooted grasses fared better during the drought than did the more shallow-rooted bluegrass.

4.2 SHRUBS

Mortality among shrubs was compared among soil types and location (strata) relative to the edge of the disturbed area (i.e., center, edge, or in between for large sites or edge and center for small sites). Mortality data were transformed to arcsine square roots to normalize distributions. Significant differences were found both among soil types and strata for most species planted (Table 12). Big sagebrush mortality was higher near the edge (mean mortality = 61%) versus the center (52%) of small sites, but lowest near the edge (38%) of large sites and highest in the center (53%). Lowest big sagebrush mortality was obtained on Warden silt loam soils (Figure 12), which includes sites at the extreme west edge of the Hanford Site. Highest mortality rates were in Burbank sandy loam and Ritzville silt loam. The latter soil underlies the Obrian site, which is also located at the extreme west edge of the Hanford Site at a slightly higher elevation than the Warden silt loam sites. The Burbank sandy loam site is DC-18, which lies at the western end of Gable Mountain.

Mortality of green rabbitbrush was unaffected by location relative to edge, but was significantly affected by soil type, being highest on the Burbank sandy loam soil and least on Hezel sand (Figure 12). Green rabbitbrush and hopsage were unaffected by soil type, but green rabbitbrush mortality showed a nearly significant trend toward higher mortality in the center (mortality = 52%) versus the edge of the disturbances (41%). Hopsage mortality was 69% at the margins, 33% in the center, and 54% in between. This was consistent with the predominant source of mortality of hopsage, which was grazing by blacktailed jackrabbits. The main source of mortality for the other species was not grazing, but was probably related to exposure to drying winds. Plants at the edge of the revegetated areas were somewhat sheltered from drying winds by the neighboring adult shrubs. Overall, the extreme mortality can probably be attributed to the drought during the critical period before the shrubs planted in fall of 1989 were able to establish a strong root system.

Table 12. Analysis of Variance for Effect of Soil Type and Proximity to Edge on Shrub Mortality

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Big sagebrush					
Strata	4	0.001	0.00034	2.469	0.0448
Soil Type	7	0.003	0.00041	3.000	0.0046
Residual	306	0.042	0.00014		
Grey rabbitbrush					
Strata	4	0.00016	0.00004	0.873	0.4812
Soil Type	7	0.001	0.00020	4.490	0.0001
Residual	179	0.008	0.000045		
Green rabbitbrush					
Strata	4	0.00042	0.00011	2.389	0.0550
Soil Type	7	0.00041	0.000058	1.321	0.2467
Residual	115	0.005	0.000044		
Hopsage					
Strata	2	0.000045	0.000023	1.297	0.2966
Soil Type	2	0.000067	0.000033	1.921	0.1738
Residual	19	0.00033	0.000017		

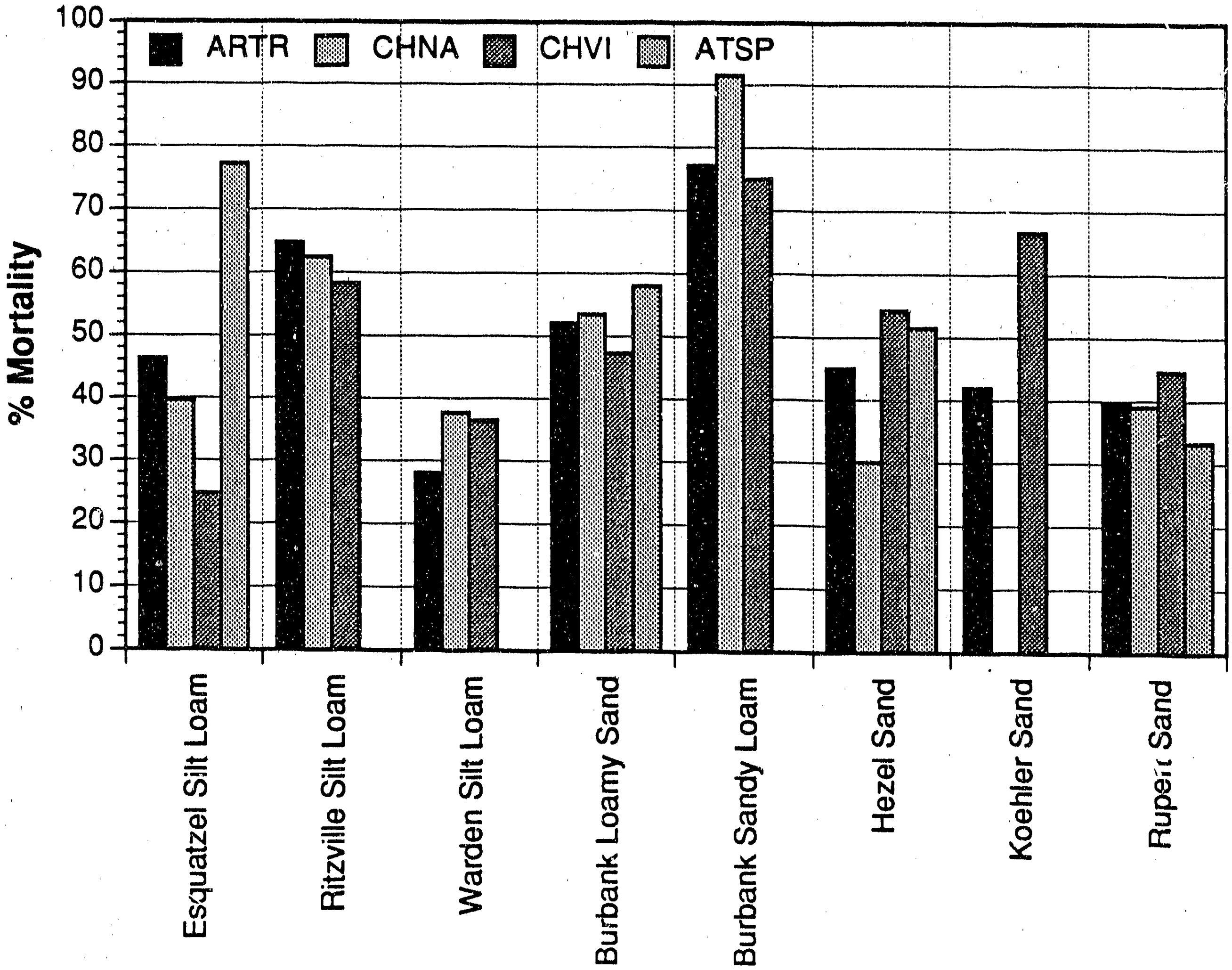

Figure 12. Shrub Mortality on Various Soil Types

5.0 CONCLUSIONS REGARDING CURRENT STATUS

Revegetation status at the end of the 1989-1990 growth season can be compared to the reclamation goals for each site. As of July 1990, sites meeting or failing to meet the criteria for mean grass density are shown in Table 13. No site met the criteria in terms of evenness of cover: all sites had large tracts where few or no introduced grasses were present. In general, sites seeded with ricegrass and wheatgrass performed exceptionally well, and all currently meet the standard for mean density. Bluegrass proved extremely variable, with sites seeded under Phase II generally failing to meet the necessary standards. Bottlebrush squirreltail and needle-and-thread grass cover was generally sparse on the revegetated sites, but that was also the case in the undisturbed habitats. Prairie junegrass could not be distinguished from the other larger-statured grasses, and so no conclusions can be drawn about its presence. However, it was a very minor component of the undisturbed habitat. Grass failed to grow on DB-2, DC-12, RRL-4, RRL-5, RRL-7, and RRL-16.

All sites support some growth of Russian thistle, bur ragweed, and tumble mustard (*Sysimbrium altissimum*), all alien colonizers of disturbed lands. These were expected to invade the sites within a year after seedbed preparation (Brandt et al. 1990a), and should not interfere with growth of native plants on these sites. Cheatgrass was also present on the revegetation sites, but in low numbers. Cheatgrass is not an early successional species. It generally requires an established cover of such colonizers as Russian thistle before it is able to establish (Brandt and Rickard 1990).

Shrub status at the end of July 1990 is somewhat more complex to estimate. In general, sites requiring large amounts of big sagebrush (planting mixes 1 and 2) failed to meet their objectives because of the heavy mortality experienced during the 1989-1990 growing season. Sites currently meeting the objective for big sagebrush are Benson Ranch, DC-20, DC-23, DC-32, DC-33, DH-19, DH-27, DH-32, DH-33, DH-34, McGee, and RRL-17. No site meets the objective for hopsage. Sites planted using mix 1 do not meet the objective for rabbitbrushes, but sites planted with mix 2 do. Growth of bitterbrush and grey rabbitbrush on DC-15 currently is within the reclamation objective for that site.

Table 13. Classification of Sites According to Current Status Regarding Grass Density

Meeting Criteria	Below Criteria
Benson Ranch	DB-2
DB-1	DB-12
DC-19	DB-14
DC-22	DB-15
DC-24	DC-7/8
DC-25	DC-12
DC-32	DC-15
DC-33	DC-16
DH-27	DC-18
DH-28	DC-20
DH-30	DC-23
DH-31	DH-19
DH-34	DH-26
DH-35	DH-32
Enyeart	DH-33
Ford	Laydown Yard
Obrian	McGee
RRL-14	RRL-4
	RRL-5
	RRL-6
	RRL-7
	RRL-8
	RRL-9
	RRL-10
	RRL-16

6.0 PROSPECTS FOR FUTURE GROWTH

Although many sites currently meet the reclamation standards in terms of grass cover, there is no evidence to suggest that they will continue to do so. Only longitudinal studies of mortality, reproduction, and colonization of the sites will provide an answer as to whether the sites will be judged successful over the next 5 years. One year of longitudinal data has been obtained for grasses seeded in 1988, and the results are not promising. Bluegrass density in spring of 1989 averaged 15.6 plants/m of seeded row. By spring of 1990, the average density at these same locations was 2.5 plants/m ($F_{1,408} = 2.939$, $P = 0.005$), a statistically significant reduction. This effect was consistent across all seed mixes involving bluegrass (Figure 13). Should this rate of mortality continue, bluegrass would disappear from the revegetated sites within a few years. There is currently no basis for concluding that eventuality would not come about. Another exceptionally dry winter could guarantee the demise.

Shrub prospects look somewhat brighter. The shrubs currently growing on the sites are likely to be past their critical needs for water and are not likely to repeat the catastrophic mortality rates seen during the first 6 months of growth. As evidence of this, total mortality of big sagebrush planted in the spring of 1989 was only slightly higher in the summer of 1990 than it was in the summer of 1989 (Figure 14). The outlook for most of the shrubs is therefore favorable: those sites currently above the reclamation goal may well stay there for a number of years. Sites below the goal are not expected to deteriorate much further. Hopsage is an exception: predation rates on hopsage have been extremely high and are not likely to decrease with time. Because this species has not been known to reproduce locally in living memory, it is unlikely that sites where it is a key component, such as RRL-10, will support any hopsage in the next few years.

In summary, although many sites currently meet their respective goals, there is little evidence to suggest that condition can be maintained. The time period allowed for a determination of success (1 yr) is insufficient to assess performance relative to the reclamation objectives. Longer-term monitoring (5 years is suggested for the Yucca Mountain, Nevada site) is required to address questions regarding longevity, resil-

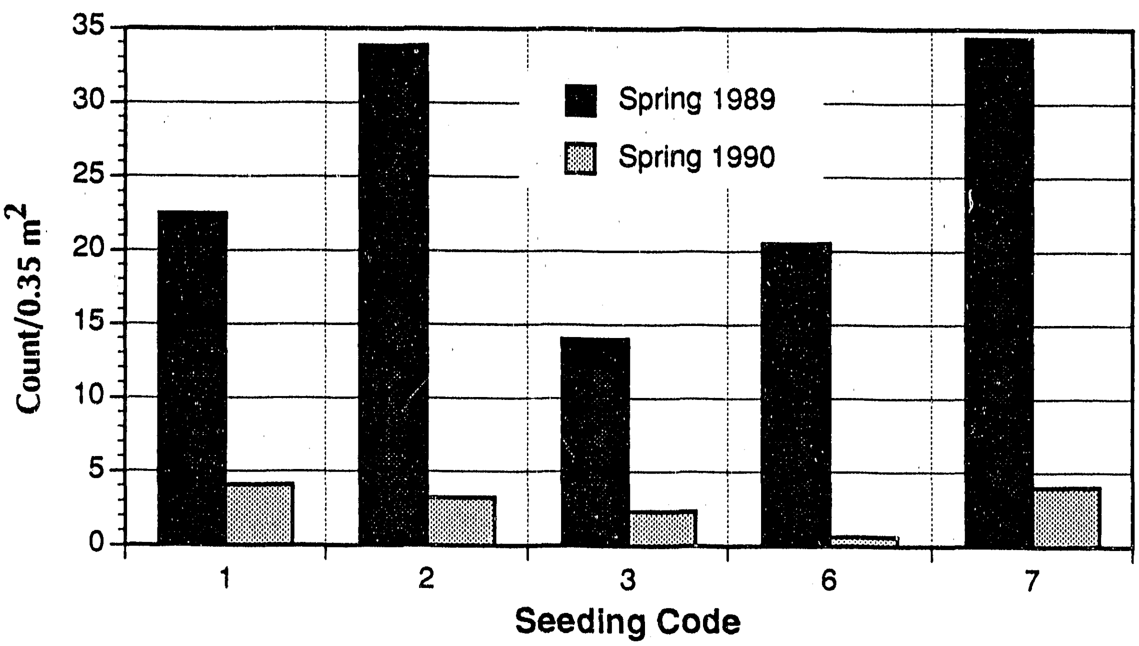

Figure 13. Density of Bluegrass Seeded in 1988 and Measured in Spring 1989 and Spring 1990

ience to weather fluctuations, and reproductive capability of revegetated plants. Cheatgrass is present in the habitats surrounding all revegetation sites. Cheatgrass is an effective competitor with native grasses when it is the first to colonize and can prevent their subsequent invasion of disturbed sites (Rickard and Sauer 1982). Without remediation, sites currently without cover will revert to nearly-pure cheatgrass. Sites below their goals are not likely to meet them without intervention. However, longer-term monitoring is necessary to determine whether the native grasses established during revegetation can be self-sustaining, which is a key requirement for reclamation of lands disturbed by the BWIP.

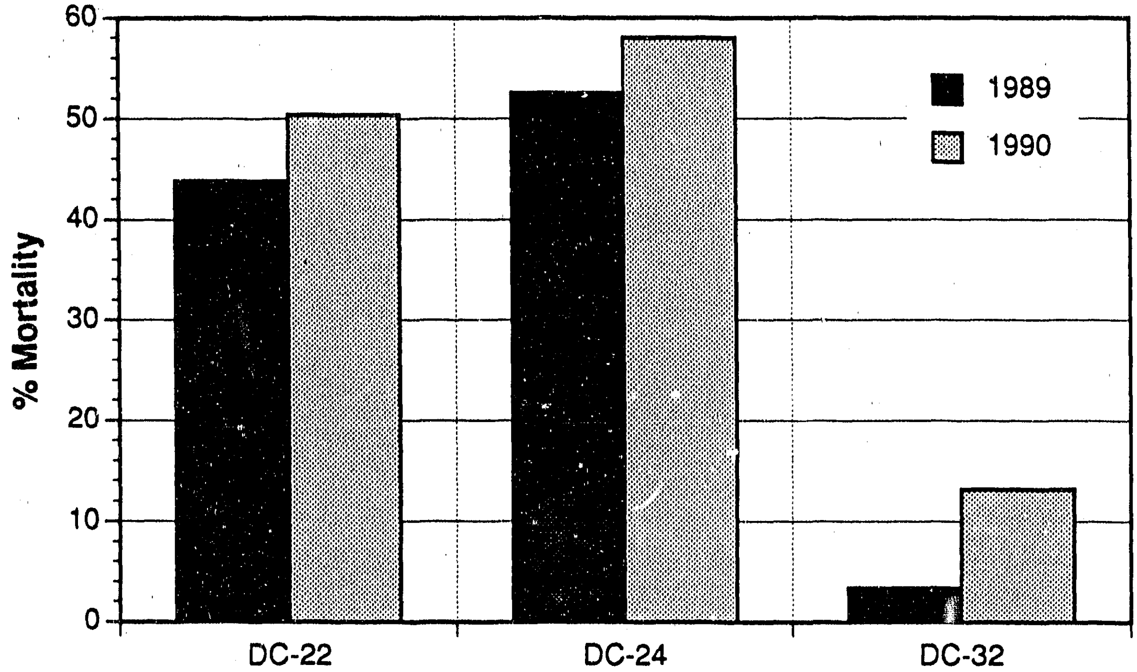

Figure 14. Mortality of Big sagebrush Planted in March 1989 and Measured in Summer 1989 and Summer 1990

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