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United States
Department
of Agriculture

Forest Service

Intermountain
Research Station

Research Note
INT-417

August 1993

Comparing Revegetation Success on Monitored and Nonmonitored Gas Well Sites in Southwestern Wyoming

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Abstract—Council on Environmental Quality regulations implementing the National Environmental Policy Act authorize Federal land management agencies to monitor surface disturbance mitigation. But no standardized methods exist for monitoring the reclamation of sites disturbed by oil and gas exploration and development. This study examined the effects of compliance and revegetation monitoring on reclamation success of the Riley Ridge Natural Gas Project in Wyoming. It also evaluated various vegetation monitoring methods, including those used by the Bureau of Land Management. Monitoring increased reclamation success as problems were identified and remedial measures were promptly applied. Three to 5 years after revegetation, total ground cover on monitored well sites was less (91 percent) than on adjacent reference areas (96 percent), but higher than on nonmonitored well sites (44 percent) ($p < 0.05$). Species richness and the percentage of desirable species were higher on monitored than on nonmonitored well sites. Revegetation seed mixtures contained few reference area species, and species and life-form similarity (Spatz' index) between reference areas and monitored or nonmonitored well sites were low. The single Bureau of Land Management transect for monitoring basal cover provided general trends, but multiple transects or a replicated design using quadrats were necessary for variance estimates and statistical comparisons.

Keywords: compliance, reclamation, vegetation assessment, monitoring, oil

Well sites and road and pipeline rights-of-way associated with oil and gas exploration and development cumulatively disturb large areas of land. Council on Environmental Quality (CEQ) regulations implementing the National Environmental Policy Act (NEPA) (40 CFR 1505.2 and 1505.3, July 1989) authorize Federal land management agencies to monitor surface disturbance mitigation. But to date, no standardized reclamation monitoring procedures exist for oil and gas exploration and development such as those provided for under the Surface Mining Control and Reclamation Act (SMCRA) of 1977. Because no specifications for monitoring revegetation success exist, current monitoring programs developed for the oil and gas industry are often vague and vary among Federal land management agencies, regions, districts, and projects.

Lack of enforced monitoring, noncompliance with permit stipulations, and incorrect implementation of prescribed reclamation often result in revegetation failure and increased soil erosion (Ostler and others 1985). In an internal report from the Bureau of Land Management (BLM), U.S. Department of the Interior (USDI), Bauer (undated) stated that the negative consequences of noncompliance generally increase with the environmental sensitivity of the project area. For surface mining activities, revegetation monitoring data demonstrate compliance with performance criteria standards and are used to develop remedial measures necessary to ensure site stability (Edgar and others 1985; Grip and Bakken 1986; Office of Technology Assessment 1986). Changes in vegetation composition and structure monitored over time may also indicate whether reclamation was successful (Keamerrer 1986). In an effort to establish a monitoring framework for evaluating land reclamation success in the United Kingdom, Tomlinson (1984) viewed SMCRA as an important example of legislated standards for determining trends in soil stability and ecosystem development.

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Due to the magnitude of the proposed development in the Riley Ridge Natural Gas project area in southwestern Wyoming, the sensitive nature of the area, and limited agency personnel to do the monitoring, a joint agency/operator monitoring program was designed for Exxon Corporation's LaBarge Fogarty Creek Unit. The program ensures operator compliance with permit stipulations and successful reclamation of surface disturbances. In developing the program, the BLM and Forest Service were guided by CEQ directives implementing the NEPA, the Onshore Oil and Gas Order No. 1 (43 CFR 3164) of 1983, and the Riley Ridge Natural Gas Project environmental impact statement (USDI BLM and USDA FS 1984). This program provided an opportunity to study whether monitoring influenced the success of reclamation efforts at gas well sites.

The Fogarty Creek Unit monitoring program specified joint inspection of the well field development by the operator and authorizing agency to monitor success and maintenance of erosion control structures and revegetation for at least two growing seasons or until attainment of performance criteria standards. A task force of agency personnel and other resource specialists ensured that monitoring commitments made by the operator were carried out.

A quality assurance/control program comprising agency and Exxon Corporation personnel monitored construction activities of access road and pipeline rights-of-way and well sites. A reclamation specialist for Exxon Corporation was assigned to oversee implementation of reclamation procedures to ensure compliance with lease stipulations and to determine the effectiveness of construction and reclamation measures. Following reclamation, an independent reclamation consultant monitored revegetation success and soil erosion condition annually until performance criteria standards were met. Areas requiring remediation were identified in agency task force reports and monitored more intensively until problems were resolved.

The objectives of this study were (1) to examine the effects of compliance, effectiveness, and revegetation monitoring on the success of reclamation efforts and (2) to compare the BLM vegetation monitoring methods with a more intensive sampling regime.

STUDY AREA

The Riley Ridge Natural Gas Project is within the Green River Basin of the Idaho-Wyoming Thrust Belt and extends across Sublette, Lincoln, and Sweetwater Counties in southwestern Wyoming. The gas well sites evaluated were at elevations ranging from 2,381 to 2,962 m. Throughout most of the Green River Basin, precipitation ranges from 17 to 23 cm per year, average annual air temperature is 6 °C, and the growing season

ranges from 90 to 100 days. The forested north-south trending ridges at 2,833 to 3,000 m receive 51 to 64 cm of precipitation, have a growing season of 60 to 75 days, and a mean annual air temperature of 0 to 2 °C. Soil textures include sandy loams, loams, and clay loams ranging from very gravelly or very cobbly loams to heavy clay loams.

The gas well study sites are generally within the mountain big sagebrush (*Artemisia tridentata vaseyana*)/bluebunch wheatgrass (*Agropyron spicatum*), and Wyoming big sagebrush (*A. tridentata wyomingensis*)/bluebunch wheatgrass vegetation types. In addition, a widespread sagebrush complex comprising mountain big sagebrush, alkali sagebrush (*A. longiloba*), and black sagebrush (*A. nova*) exists throughout the project area with each type dominating portions of a community. Douglas-fir (*Pseudotsuga menziesii*) and aspen (*Populus tremuloides*) communities occur primarily on cool, north-facing aspects in association with the mixed sagebrush types.

METHODS

Monitored and nonmonitored gas well sites selected for study were in similar elevational ranges and were reclaimed during a similar period according to final or production phase reclamation specifications. The BLM identified eight nonmonitored well sites, reclaimed in 1984, 1985, and 1986, that were within or near the vicinity of the Riley Ridge project area. All eight sites were evaluated and consisted of single gas exploration wells drilled by various operators. No formal operator or agency monitoring was conducted during project construction or following reclamation of nonproductive well sites or unused portions of producing well sites. Five monitored well sites were selected from Exxon Corporation's LaBarge Fogarty Creek Unit of the Riley Ridge Natural Gas Project area. They had also been reclaimed during 1984, 1985, and 1986. This unit contained the greatest number of well sites meeting the selection criteria. Compliance, effectiveness, and revegetation success monitoring was conducted at all monitored gas well sites from initiation of construction to attainment of revegetation and soil stability performance criteria standards.

Reclamation had been conducted from 3 to 5 years prior to this study and for monitored sites included recontouring, seedbed preparation, seeding, fertilization, mulching, and installation of surface runoff and erosion control structures. All nonmonitored well sites had been recontoured, but it was unknown whether proper seedbed preparation, fertilization, or reseeding had occurred. Seed mixtures for monitored well sites contained six native and introduced grass species and

three to four forbs (table 1). Seed mixes for nonmonitored well sites generally contained two to four native or introduced grass species (table 2).

Vegetation Monitoring

During the 1989 growing season, we conducted vegetation analysis of monitored and nonmonitored well sites using two methods: (1) BLM line transect methods and (2) more intensive sampling methods (quadrats and multiple transects) that would allow statistical comparison of monitored, nonmonitored, and reference areas.

The BLM line transect methods consisted of randomly placing one 33-m line transect in a revegetated portion of each of the five monitored and eight nonmonitored well sites and in an undisturbed adjacent reference area. Evaluation points were located at 30.5-cm intervals along each transect ($n = 100$). Basal ground cover was recorded at each point as vegetation, litter, bare ground, or rock/gravel. The BLM methods did not require species identification. For this study, vegetation cover was identified by species to determine composition and desirable species present and to evaluate species diversity and frequency. Desirable species were defined as those prescribed in seed mixtures or as recolonizing native perennials.

Intensive sampling methods were conducted on one monitored well site, one nonmonitored well site, and

one reference area. Using a stratified random sampling method (Chambers and Brown 1983; Knight 1978; Vogel 1987), six 33-m line transects spaced at 5-m intervals were established on each area. Five quadrats (0.25 m² rectangular) were randomly placed along each transect ($n = 30$). Within each quadrat relative species importance and frequency of occurrence were determined by visually estimating the percentage aerial cover of each species. We used the following modified Daubenmire cover categories:

Category	Percentage
1	<1
2	1 - 5
3	6 - 15
4	16 - 25
5	26 - 35
6	36 - 45
7	46 - 55
8	56 - 65
9	66 - 75
10	76 - 85
11	86 - 95
12	96 - 100

To determine aerial ground cover, a 35-mm photographic slide was taken vertically over the center of each quadrat and analyzed according to methods described in Chambers and Brown (1983). Slides were projected onto a 100-square grid, and relative percentages of vegetation, bare ground, litter, and rock and gravel were obtained by counting the number of squares covered by each category.

To determine whether basal cover estimates varied with multiple transects and to permit statistical analysis of the BLM data, three of the line transects established during intensive sampling were randomly chosen within each monitored, nonmonitored, and reference area and evaluated according to the BLM methods.

Data Analysis

One-way analysis of variance (ANOVA) was used to compare differences among the five monitored and eight nonmonitored reclaimed well sites and 13 reference areas for which cover data were collected using the BLM line transect method. Differences among the intensively sampled monitored and nonmonitored well sites and reference area, and between the quadrat and BLM line transect methods, were evaluated with two-way ANOVA. Arcsine transformations were performed on percentage data. Mean comparisons were performed with Fisher's Protected LSD's. Similarity between reclaimed well sites and adjacent reference areas in species number and composition was calculated using Spatz' similarity index (Chambers and Brown 1983). We compared species lists to species identified in prescribed seed mixtures for both

Table 1—Seed mixtures specified for monitored gas well sites

Seed mix	Drill rate PLS ¹
	kg/ha
#1	
* <i>Bromus marginatus</i>	1.4
* <i>Agropyron trachycaulum</i>	1.4
* <i>Deschampsia cespitosa</i>	.2
<i>Astragalus cicer</i>	.7
<i>Alopecurus pratensis</i>	.5
* <i>Linum lewisii</i>	.5
<i>Festuca longifolia</i>	.2
<i>Poa compressa</i>	.2
<i>Trifolium hybridum</i>	.2
#2	
* <i>Agropyron trachycaulum</i>	1.4
* <i>Agropyron smithii</i>	1.4
* <i>Stipa viridula</i>	.9
<i>Sanguisorba minor</i>	.9
<i>Onobrychis viciaefolia</i>	.9
* <i>Agropyron spicatum</i>	.7
<i>Astragalus cicer</i>	.5
* <i>Festuca ovina</i>	.5
* <i>Poa ampla</i>	.2
<i>Kochia prostrata</i>	.2

¹PLS = pure live seed.

*Denotes native status.

Table 2—Dominant species present in 1989 on nonmonitored well sites and species specified for revegetation in seed mixtures. Data are from BLM line transect methods with one transect per site. Dates specify year gas well was drilled

Gas well	Drill rate PLS ¹ (kg/ha)	Dominant species (percent cover)
Shar Alan #1 (ABD ² 1986)	* <i>Bromus marginatus</i> (2.7) * <i>Festuca ovina</i> (2.7) <i>Astragalus cicer</i> (0.9)	<i>Polygonum</i> spp. (16) * <i>Sitanion hystrix</i> (2)
36X-12G (PGW ³ 1985)	* <i>Agropyron dasystachyum</i> (2.3) * <i>Stipa viridula</i> (2.3) * <i>Elymus cinereus</i> (0.9) * <i>Poa secunda</i> (0.9)	<i>A. cristatum</i> (17) <i>Elymus</i> spp. (12) <i>A. intermedium</i> (1) * <i>A. dasystachyum</i> (P) ⁴
21-28 (PGW 1981)	* <i>A. smithii</i> (2.3) * <i>A. dasystachyum</i> (2.3)	<i>B. inermus</i> (8) <i>A. intermedium</i> (7) * <i>A. dasystachyum</i> (5) <i>A. tricophorum</i> (1) <i>Polygonum</i> spp. (1)
22-28 (ABD 1985)	* <i>A. spicatum</i> (1.8) * <i>A. dasystachyum</i> (1.8) * <i>Oryzopsis hymenoides</i> (1.8) * <i>S. comata</i> (0.9)	<i>A. cristatum</i> (7) * <i>A. dasystachyum</i> (7) <i>Salsola kali</i> (3) * <i>O. hymenoides</i> (P) * <i>S. comata</i> (P)
22-21 (ABD 1984)	* <i>A. smithii</i> (2.7) * <i>A. dasystachyum</i> (2.7)	<i>B. inermus</i> (16) <i>A. tricophorum</i> (8) * <i>A. smithii</i> (1) * <i>Artemisia tridentata</i> (1)
20-24 (ABD 1986)	<i>A. cristatum</i> (2.7) * <i>A. dasystachyum</i> (2.7)	<i>Polygonum</i> spp. (12) <i>S. kali</i> (P)
22-32 (ABD 1985)	<i>B. inermus</i> (2.3) <i>A. intermedium</i> (2.3) <i>Alopecurus pratensis</i> (2.3) <i>P. pratense</i> (2.3)	<i>B. inermus</i> (15) <i>Phleum pratense</i> (1) * <i>A. dasystachyum</i> (1) * <i>Achillea millefolium</i> (1) <i>A. tricophorum</i> (P) <i>Salsola kali</i> (P)
43-20 (PGW 1984)	<i>B. inermus</i> (2.3) * <i>A. dasystachyum</i> (2.3) <i>A. tricophorum</i> (0.9)	<i>B. inermus</i> (19) * <i>A. dasystachyum</i> (5)

¹PLS = pure live seed.

²ABD = abandoned.

³PGW = producing gas well.

⁴P = present but <1 percent.

*Denotes native status.

monitored and nonmonitored well sites. We computed the number and percentage of species prescribed in seed mixes and total number of desirable species present on each well site.

RESULTS OF BLM LINE TRANSECT METHODS

To evaluate whether prescribed seed mixtures were applied, the dominant species on monitored and nonmonitored well sites were compared to those species identified for seeding (tables 1, 2, and 3). The number of seeded species present on each monitored

and nonmonitored well site averaged 3.2 and 1.3, respectively. In most cases, dominant grasses on both monitored and nonmonitored well sites were not those recommended at the highest seeding rates (pure live seed kg/ha). Two nonmonitored well sites (Shar Alan #1 and 20-24), both abandoned in 1986, were either not artificially seeded prior to abandonment or reseed-ing efforts failed. Vegetation ground cover on these two sites mainly comprised weedy species with minimal recolonization of native species (table 2).

The mean percentage desirable species present, as a proportion of the total number of species, was 92.4 percent on monitored well sites and 55.9 percent on

Table 3—Dominant species present in 1989 on monitored gas well sites from transect methods with one transect per site

Gas well	Seed mix	Dominant species (percent)
14-05	#1, 2	<i>Poa compressa</i> (7) * <i>Agropyron trachycaulum</i> (4) <i>Phleum pratense</i> (3) <i>Agropyron intermedium</i> (3) <i>Astragalus cicer</i> (2) * <i>Agropyron smithii</i> (2) <i>Bromus inermus</i> (2) unknown annuals (1) * <i>Linum lewisii</i> (1) * <i>Agropyron dasystachyum</i> (P) ¹ <i>Alopecurus pratensis</i> (P)
21-03	#1	* <i>Agropyron trachycaulum</i> (8) * <i>Agropyron smithii</i> (4) <i>Astragalus cicer</i> (1) * <i>Linum lewisii</i> (1) * <i>Achillea millefolium</i> (1) unknown annuals (1)
15-28	#1, 2	<i>Bromus inermus</i> (8) <i>Agropyron intermedium</i> (7) * <i>Agropyron smithii</i> (2) unknown annuals (3) <i>Agropyron cristatum</i> (1) <i>Astragalus cicer</i> (1) <i>Phleum pratense</i> (P) * <i>Linum lewisii</i> (P) * <i>Agropyron dasystachyum</i> (P) <i>Alopecurus pratensis</i> (P)
19-35	#1	* <i>Linum lewisii</i> (15) * <i>Agropyron smithii</i> (7) <i>Poa compressa</i> (2) unknown annuals (2) <i>Astragalus cicer</i> (1) <i>Phleum pratense</i> (1)
17-16	#1	<i>Agropyron intermedium</i> (8) unknown annuals (6) <i>Poa compressa</i> (5) <i>Phleum pratense</i> (3) <i>Astragalus cicer</i> (2) * <i>Achillea millefolium</i> (P) <i>Bromus inermus</i> (P) <i>Elymus</i> spp. (P) * <i>Linum lewisii</i> (P)

¹P = present but <1 percent.

*Denotes native status.

nonmonitored well sites. The mean number of species present was 9.0 ($n = 5$) on monitored well sites and 4.6 ($n = 8$) on nonmonitored well sites, while the average number of species on adjacent reference areas was 14.0 ($n = 13$). Vegetation cover exceeding 5 percent weedy species occurred on one monitored well site and four nonmonitored well sites.

Spatz' similarity indices comparing both monitored and nonmonitored well sites with their adjacent reference areas were low when computed on a species basis (table 4). Values ranged from 0.00 to 0.72 percent for monitored well sites and 0.00 to 1.97 percent for nonmonitored well sites. Spatz' similarity indices computed by life-form (grasses, forbs, and shrubs) were higher for monitored well sites (ranging from 3.9 to 23.3 percent) and nonmonitored well sites (ranging from 0.0 to 6.2 percent with one site having a similarity index of 21.0 percent) when compared with adjacent reference areas.

Cover comparisons showed that basal ground cover was higher on monitored well sites than nonmonitored well sites for both vegetation and litter (fig. 1). Vegetation cover on both monitored and nonmonitored well sites was lower than vegetation cover on adjacent reference areas ($p < 0.05$). Litter cover on the monitored well sites was higher than that occurring on the reference areas, while litter cover on nonmonitored well sites was lower than that occurring on reference areas ($p < 0.05$). Rock/gravel cover was similar on monitored, nonmonitored, and reference areas. Bare ground on monitored sites was similar to reference areas while nonmonitored sites had the greatest bare ground area ($p < 0.05$). Total cover on monitored well sites and adjacent reference areas averaged nearly twice the amount of that present on nonmonitored well sites ($p < 0.05$).

Table 4—Spatz' similarity indices comparing monitored and nonmonitored gas well sites with their adjacent reference areas. Values were computed by both species and life-form. Data were derived from BLM line transect species lists and composition with one transect per site

Gas well site	Species similarity	Life-form similarity
----- Percent -----		
Monitored		
15-28	0.33	10.17
17-16	.33	23.33
21-03	0	21.75
19-35	0	3.89
14-05	.72	10.71
Nonmonitored		
21-28	0	1.43
22-21	.14	3.65
22-28	0	21.00
22-32	0	2.20
36X-12G	0	3.56
Shar Alan #1	0	.85
20-24	0	0
43-20	1.97	6.28

RESULTS OF INTENSIVE SAMPLING METHODS

Relative species importance was evaluated on intensively sampled monitored and nonmonitored well sites and a representative reference area for both quadrat sampling and multiple line transect methods (table 5). In general, dominant species on monitored, nonmonitored, and reference areas were accurately identified by both aerial and basal cover methods. Mean cover percentage varied by species for each method. Fewer species were identified by basal cover evaluation (line transects). Species frequency was higher for quadrats because these values were determined from an average of 30 plots per site (0.25 m²), while the values obtained using multiple line transects were determined from the average of only 300 points (three line transects with 100 evaluation points per transect) per site.

Mean vegetation cover differed among monitored, nonmonitored, and reference areas ($p < 0.001$) but not between sampling methods (fig. 2). Vegetation cover on the monitored well site was higher than that on the nonmonitored well site ($p < 0.05$). On the reference area, vegetation cover was higher than that on either monitored and nonmonitored well sites ($p < 0.05$). Mean litter cover differed among both sites and methods (both, $p < 0.001$). Litter cover on the monitored well site was higher than that on the nonmonitored well site and reference area ($p < 0.05$). Multiple line transect evaluation resulted in higher litter cover than the quadrat method on both the nonmonitored and reference areas ($p < 0.05$). Mean ground cover for rock/gravel differed among sites ($p < 0.05$) but not among methods. Mean bare ground cover differed among both sites and methods (both, $p < 0.001$). Bare

ground on the monitored well site was less than that of the nonmonitored well site ($p < 0.05$) but similar to that of the reference area. The quadrat sampling methods resulted in higher bare ground on both monitored and nonmonitored well sites. Mean total cover (vegetation, litter, and rock/gravel) differed among sites and methods (both, $p < 0.001$). Total cover on the monitored well site was higher than that on the nonmonitored well site but similar to that on the reference area ($p < 0.05$). On the nonmonitored well site, total cover was lower than that on the reference area ($p < 0.05$).

Comparisons of mean basal cover on the intensively sampled monitored, nonmonitored, and reference areas using one, two, and three line transects were compared to the single BLM line transect data collected on each site (fig. 3). Ground cover values varied for each cover category among each transect and among samplers. Differences among samplers were greater than among transects for the single sample. For the multiple transects, the results were usually within ± 1 standard error.

DISCUSSION

Vegetation sampling data from both BLM line transect methods and intensive sampling methods indicated that, 3 to 5 years after revegetation, ground cover similarity between monitored well sites and adjacent reference areas was higher than between nonmonitored well sites and reference areas. Monitoring of compliance, effectiveness, and revegetation success appears to have contributed to the higher ground cover values observed on monitored gas well sites because problem areas were identified and prompt remedial measures were taken. Factors contributing to low vegetation cover on nonmonitored well sites may include improper site preparation (mixing of topsoil with subsoils, compaction, low fertility), improper seeding mixtures or methods (not planting at optimal seeding depths), low seeding rates, low seed viability, or low moisture availability during germination. Remedial measures at monitored well sites, as documented in annual agency task force reports, included maintaining surface runoff and erosion control structures, re-seeding areas with low perennial cover, and controlling noxious weed invasion, livestock, and wildlife grazing. Nonmonitored gas well sites where such measures were not taken appear more susceptible to revegetation failure and surface runoff and erosion control problems. Qualitative evaluation of soil erosion condition at both monitored and nonmonitored well sites revealed substantial rill and gully formation at a majority of the nonmonitored well sites, whereas monitored well sites exhibited minimal rill formation and no gullying.

Generally low similarity indices between monitored and nonmonitored well sites and adjacent reference

Figure 1—Comparison of mean percentage cover collected using BLM line transect methods for monitored ($n = 5$), nonmonitored ($n = 8$), and reference ($n = 13$) areas. Values are means ± 1 standard error.

Table 5—Mean aerial and basal cover and frequency of common species present on intensively sampled monitored and nonmonitored gas well sites and adjacent reference areas

	Quadrats ¹		Transects ²	
	Aerial cover	Frequency	Basal cover	Frequency
----- Percent -----				
Monitored (14-05)				
<i>Phleum pratense</i>	10.18	68.0	11.17	9.0
<i>Agropyron dasystachyum</i> *	7.84	32.0	5.17	4.0
<i>Bromus inermus</i>	5.72	24.0	2.50	3.0
<i>Poa compressa</i>	4.42	84.0	7.83	6.7
<i>Agropyron trachycaulum</i> *	4.26	36.0	2.50	3.7
<i>Agropyron smithii</i> *	1.52	16.0	.83	1.7
<i>Alopecurus pratensis</i> *	1.26	12.0	.16	.3
<i>Linum lewisii</i> *	.48	16.0	—	—
<i>Descurania</i> spp.	.44	4.0	—	—
<i>Astragalus cicer</i> *	.22	12.0	1.00	1.3
<i>Salsola kali</i>	.04	2.0	—	—
<i>Achillea millefolium</i> *	.02	4.0	—	—
Nonmonitored (43-20)				
<i>Bromus inermus</i>	19.08	93.3	13.80	13.0
<i>Agropyron intermedium</i>	1.82	30.0	—	—
<i>Agropyron dasystachyum</i> *	1.45	23.3	1.83	2.0
<i>Agropyron smithii</i> *	.92	23.3	—	—
<i>Agropyron trichophorum</i>	.77	20.0	1.00	1.0
<i>Agropyron trachycaulum</i> *	.43	6.7	—	—
<i>Poa compressa</i>	.35	3.3	—	—
<i>Artemisia tridentata</i> *	.17	6.7	—	—
<i>Sitanion hystrix</i> *	.03	3.3	.17	.3
Reference (43-20)				
<i>Artemisia tridentata</i> *	36.33	96.7	20.50	10.7
<i>Lupinus</i> spp.*	2.97	56.7	7.17	5.3
<i>Erigonium</i> spp.*	2.80	66.7	7.83	10.7
<i>Linum lewisii</i> *	1.38	13.3	—	—
<i>Sitanion hystrix</i> *	.72	36.7	1.83	2.0
<i>Phlox hoodii</i> *	.30	20.0	—	—
<i>Astragalus</i> spp.*	.28	30.0	1.00	1.0
<i>Castilleja</i> spp.*	.15	13.3	—	—
<i>Geranium</i> spp.*	.13	26.7	.16	1.0
<i>Stipa comata</i> *	.05	3.3	—	—
<i>Poa secunda</i> *	.02	3.3	.83	1.0
<i>Agropyron smithii</i> *	—	—	2.50	3.0
<i>Arenaria</i> spp.*	—	—	.83	1.3
<i>Achillea millefolium</i> *	—	—	.16	.3
<i>Amelanchier alnifolia</i> *	—	—	.16	.3

¹Monitored ($n = 25$ quadrats); nonmonitored ($n = 30$ quadrats); reference ($n = 30$ quadrats).

²Three transects ($n = 300$ points).

*Denotes native status.

areas can be attributed to many factors including few reference area species in seed mixtures, substituting introduced species for natives prior to seeding, non-establishment or nonpersistence of seeded native species, competitive exclusion of native recolonizing species by persistent introduced species or annual species, and changes in soil physical and chemical properties.

In studies in the Bridger-Teton National Forest, Smith and others (1988) also found that Spatz' similarity indices were low on seeded and nonseeded well sites compared to adjacent reference areas after 3 to 33 years. Introduced species are typically seeded on disturbed lands because they exhibit high seedling establishment and rapid growth rates and provide

Figure 2—Comparisons of monitored (M), nonmonitored (NM), and reference (R) sites for the two intensive sampling methods. Values are means ± 1 standard error. Uppercase letters indicate significant differences among sites ($p < 0.05$). Lowercase letters indicate significant differences between methods within sites ($p < 0.05$).

Figure 3—Comparisons of mean percentage cover of intensively sampled monitored, nonmonitored, reference areas using one, two, and three transects, and one BLM line transect. Values are means ± 1 standard error.

rapid stabilization of the soil surface (Chambers and others 1984). In general, sagebrush communities, such as those that existed prior to exploration activities in the Riley Ridge project area, may require 20 to 40 years to return to the natural vegetation following disturbance (Tisdale and Hironaka 1981; USDI BLM and USDA FS 1983).

Relative species importance was similar for both intensive sampling methods in terms of identifying and ranking dominant species. However, percentage cover by species and the total number of species differed among methods. Smaller sample sizes and determining only basal cover with line transect methods may explain these findings. Species frequency also differed between the two intensive sampling methods due to different sample sizes and numbers of samples. Frequency is influenced by quadrat or sample size, and, therefore, is considered nonabsolute (Moore and Chapman 1986). Frequency often decreases as the number of points along a transect decreases. Differences in ground cover among intensively sampled multiple line transects and the single BLM line transect are most likely due to sampler variance.

Both intensive sampling methods provided data varying in applicability and level of accuracy and precision. The BLM line transect methods provided general trend data and were easily applied in the field. However, they did not provide sufficient data on which to base important decisions. Intensive quadrat sampling provided data with a high level of statistical confidence and repeatability but was more time consuming. Because line transects do not evaluate canopy cover, the plant's ability to provide protection from the erosive forces of raindrop impact and wind cannot be effectively determined. Although basal cover may be more constant throughout the year than canopy cover (especially on heavily grazed areas) and may provide information on plant-root-soil stabilization, measures of both basal and canopy cover are desirable to determine the ability of the entire plant to protect and stabilize revegetated disturbances.

Vegetation factors (cover, biomass, and species diversity) measured on an adjacent reference area often constitute the success standard (OTA 1986). A relatively high level of repeatability and accuracy is necessary when vegetation monitoring data will be used to determine whether a revegetated area has met the necessary criteria for reclamation bond release. Such levels of statistical confidence have been established under the SMCRA (30 USC 1201) of 1977 but do not exist for the oil and gas industry.

Vegetation sampling methods should reflect not only the desired objectives but also the vegetation types. In general, sampling adequacy depends on how accurate the estimates of measure must be (Knight 1978; Mannetje 1978). This is more easily achieved by increasing the number of replications rather than the sample size (Daubenmire 1959; Floyd and Anderson

1987; Greig-Smith 1983; Mannetje 1978). The type of sampling device (quadrats, transects, and point frame) and the size, shape, length, or number of plots used depends on the type of vegetation being sampled and the homogeneity of the community. A random sampling scheme is necessary to obtain an unbiased estimate of the variance and the mean of the measured factors (Bonham and others 1980; Chambers and Brown 1983; Knight 1978). The actual number of samples required to increase adequacy and repeatability depends on the inherent variability among samples and may be considered that number where the variance is relatively constant (Bonham and others 1980; Knight 1978; Moore and Chapman 1986).

CONCLUSIONS

Monitoring of compliance, effectiveness, and revegetation appears to have a positive effect on the success of reclamation efforts because problems are identified and remedial measures are taken. Our findings indicate that monitored well sites have higher percentage ground cover, higher species diversity, and are more similar to adjacent reference areas than nonmonitored well sites.

To minimize impacts to the environment and to restore soil stability and vegetation productivity of disturbed areas, the oil and gas industry needs clear and concise reclamation monitoring requirements designed to ensure operator compliance with lease stipulations and enhance revegetation success. Because vegetation is an integral component of soil stabilization and hence water quality, revegetation success monitoring following initial plant establishment is essential.

Reclamation success criteria for the oil and gas industry should include clearly defined performance standards and specific minimum levels of statistical confidence. Essential are sampling methods that will produce data with a statistical level of confidence and repeatability to meet these minimal requirements. Standardized reclamation monitoring methods should be specified that include the number of site visits per year, time of sampling, and minimum factors to be measured, such as aerial cover, basal cover, species diversity, and desirable species present. Sampling methods should be suitable to the situation, and more than one area per site should be sampled if conditions vary. We recommend a stratified random sampling scheme employing quadrat analysis to obtain data with a high level of accuracy and repeatability. Vegetation cover should be identified by species to attain information on the quality of revegetation success. Detailed descriptions of problem areas should be documented with remediation measures implemented in a timely manner. Vegetation sampling should be conducted at the same time each year and coincide with the maximum obtainable production value for the

current year's growth. Finally, we recommend a long-term monitoring program (at least 3 to 5 years) of revegetation and surface runoff and erosion control.

ACKNOWLEDGMENTS

Bill McMahan and Rick Canterbury of the Bureau of Land Management, Rock Springs District provided information imperative to the research project. We thank Drs. Richard Fisher and Christine Kelly, professors in the Forest Resources Department at Utah State University when the study was conducted, and Oliver Grah, consultant, for help with the study design. Review comments by Gary Wade, Jeff Skousen, and Paige Smith improved the manuscript.

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