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# *Bromus* invasions on the Nevada Test Site: present status of *B. rubens* and *B. tectorum* with notes on their relationship to disturbance and altitude

Richard Hunter
*U.S. Department of Energy Basic Environmental Compliance and Monitoring Program (BECAMP), Reynolds Electrical & Engineering Co., Inc., Environmental Health Division, Applied Studies Group, Las Vegas, Nevada*

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# *BROMUS* INVASIONS ON THE NEVADA TEST SITE: PRESENT STATUS OF *B. RUBENS* AND *B. TECTORUM* WITH NOTES ON THEIR RELATIONSHIP TO DISTURBANCE AND ALTITUDE

Richard Hunter[1]

ABSTRACT.—*Bromus rubens* and *Bromus tectorum* are now nearly ubiquitous components of the Nevada Test Site (NTS) flora. Introduced to the western United States in the late 1800s, they spread through the Mojave and Great Basin deserts in the early twentieth century. Since quantitative studies began on the NTS in 1957, *Bromus* spp. have greatly increased in frequency and density. By 1988 both species occurred in many places at densities exceeding 1000 individuals per square meter. They may significantly increase flammability of the vegetation and reduce success of native ephemeral species.

*Key words:* Bromus rubens, Bromus tectorum, *Nevada Test Site, introduced species, fire propagation, fire recovery.*

In the roughly 150 years of American settlement of the western United States approximately 20 species of *Bromus* have been introduced (Munz 1968). Of these species, two, *Bromus tectorum* and *B. rubens*, have dramatically spread over rangelands. In the Great Basin Desert *B. tectorum* has had major impacts on rangelands and agricultural yields (e.g., Morrow 1984), and in parts of California and the Mojave Desert *B. rubens* has come to dominate the annual plant floras.

The Nevada Test Site (NTS) is a 1350-square-mile enclave straddling the boundaries and transition zone between the Mojave and Great Basin deserts (Fig. 1). Eight *Bromus* species occur on the NTS, six of them introduced (Beatley 1976). Both *B. rubens* and *B. tectorum* are now widespread and significantly affect the NTS ecology. This paper is an attempt to document the present status of these two species and provide information on the nature of their increase in abundance.

## History of *Bromus* Introductions

### *Bromus rubens*

Frenkel (1970) considered *B. rubens* to have been introduced during the Mexican occupation of California between 1825 and 1848, and S. B. Parish called an 1889 roadside specimen from San Bernardino County, California, "a recent introduction" (California Academy of Science Herbarium). In the Mojave Desert it was not seen on an 1891 expedition to Death Valley (Coville 1893). M. E. Jones first collected *B. rubens* in 1907 at Searchlight, Nevada (Rancho Santa Ana Herbarium). Mrs. F. P. Morris collected it at Mojave, California, in 1917 (California Academy of Science Herbarium). V. Duran, in 1933, called it a "common grass between Mojave and Palmdale along roadsides and on cleared land" (Intermountain Herbarium, Utah State University). On the eastern edge of the Mojave, E. Snow collected *B. rubens* in 1931 near St. George, Utah (University of California, Davis Herbarium, Crampton Collection).

Near the NTS, I. W. Clokey (1951) collected plants in the Charleston Mountains from 1937 through 1941. He collected *B. rubens* from only one location, at 1550 m (5085 ft) in a disturbed area of the "juniper belt." The distribution on that specimen label was noted as "roadsides and waste places." O. V. Deming collected specimens of *B. rubens* on the Desert National Wildlife Range (directly east of the NTS) in 1946 (University of Nevada, Las Vegas Herbarium).

It appears, therefore, that *B. rubens* invaded the Mojave Desert during the 1920s, spreading first to disturbed areas. It was not common, however, until after 1950. By 1963

[1]U.S. Department of Energy Basic Environmental Compliance and Monitoring Program (BECAMP), Reynolds Electrical & Engineering Co., Inc., Environmental Health Division, Applied Studies Group, Box 98521, Las Vegas, Nevada 89193–8521.

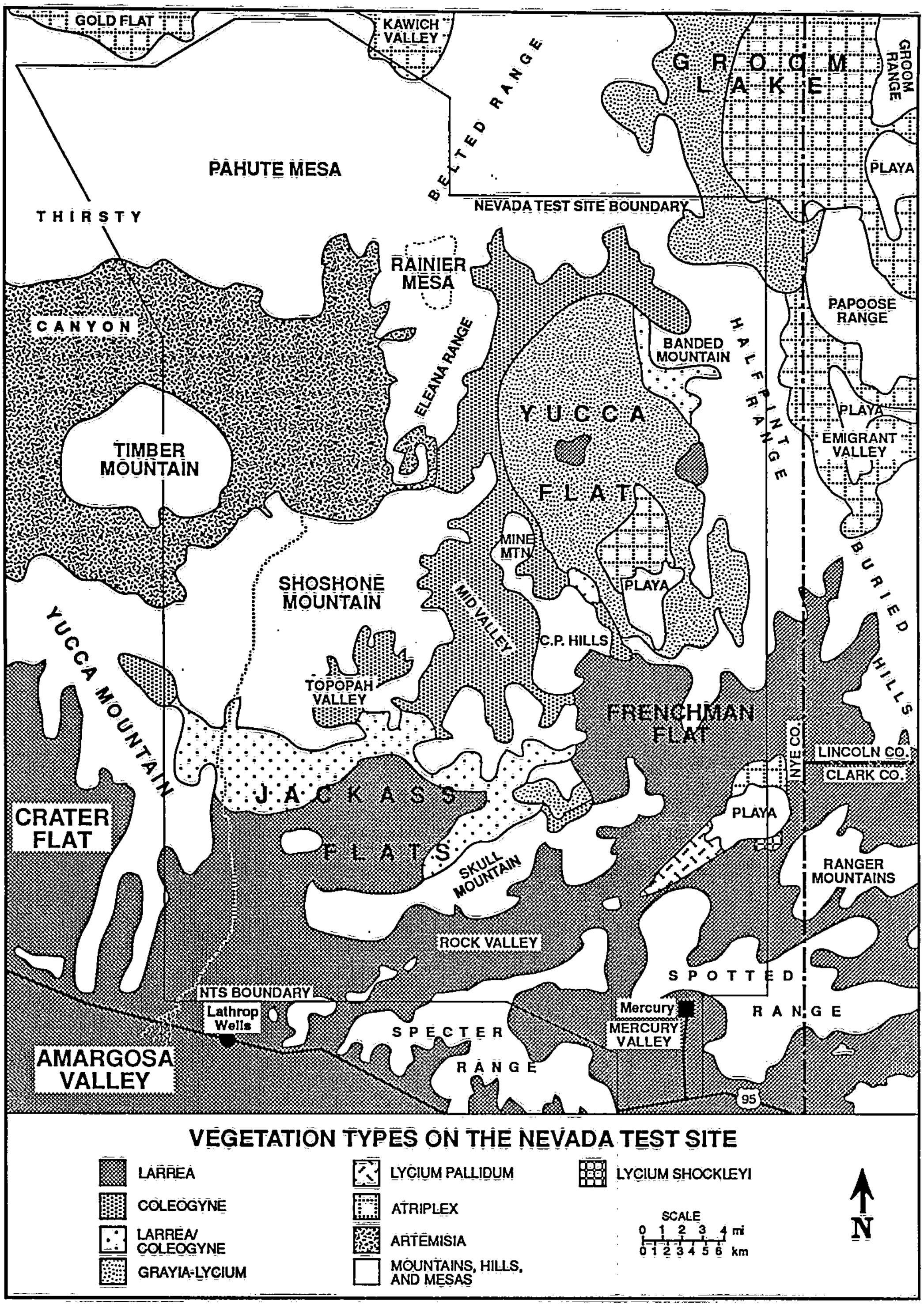


Fig. 1. Major landforms and vegetative communities on the NTS as determined by Beatley (O'Farrell 1976).

it was abundant on the NTS at elevations of 1219–1524 meters (4000–5000 feet), though infrequent in the *Larrea tridentata* associations below that altitude (Beatley 1966).

### *Bromus tectorum*

The spread of *B. tectorum* has been described by several other authors and occurred primarily at higher altitudes and latitudes than that of *B. rubens*. It was first recognized in 1861 (Morrow and Stahlman 1984, citing Hitchcock 1950). Mack (1981) described the invasion of *B. tectorum* into western North America, a process that he considered completed by roughly 1928. Yensen (1981) and Morrow and Stahlman (1984) also reviewed this process.

Mojave Desert collections of *Bromus tectorum* were rare before 1950. Clokey (1951) cited six collections of *B. tectorum* in the Charleston Mountains during the late 1930s. F. W. Gould collected it in 1942 as a roadside weed in St. George, Utah, and P. Dalley (1943) and O. V. Deming (1946) collected *B. tectorum* on the Desert National Wildlife Range (University of Nevada, Las Vegas herbarium). Beatley (1966) reported it on the NTS in disturbed patches above 1524 m (5000 ft).

## METHODS

Plots for studies since 1987 were selected to be representative of either a particular disturbance or an undisturbed area nearby. Some plots were considered pristine, chosen specifically for lack of disturbance. *Bromus* densities were not considered when selecting a site. Altitudes of sampled locations were determined from United States Geological Survey 7.5-minute topographical maps.

Twenty .025-$m^2$ randomly placed quadrats within 1000-$m^2$ plots were used to monitor ephemeral plants (1987–1990). Monitoring also included harvesting of all annual plants within each quadrat. New quadrat locations were selected within approximately the same 1000 $m^2$ every year. Harvested plants were oven-dried at 66 C for three days, then equilibrated with room air before weighing.

## RESULTS

### Present Distribution

The distributions of the two *Bromus* species with respect to altitude and disturbance are shown in Table 1. *B. rubens* was present at all but one sampled location (Rainier Mesa, 2286 m [7500 ft]). It was present at less than two plants per square meter at only two locations, Jackass Flats and Pahute Mesa. The former was an area of deep, sandy soil at 945 m (3100 ft), near the lowest altitude on the NTS, and the latter was in an established *Artemisia nova* community at 1890 m (6200 ft), above the normal distribution zone for *B. rubens*. It was therefore essentially ubiquitous on the NTS below 1524 m (5000 ft). At four locations sampled in both 1987 and 1988, population densities increased an average of threefold (3.38 ± 0.89, sem), indicating both good reproduction in 1987 and good germination in 1988 (Table 1). The median density in 1988 was 362 ± 84 plants per square meter (± sem; 19 sites). The highest densities were found on areas where soils were softened and shrubs killed by gopher and small mammal activities, but several undisturbed locations had densities over 1000/$m^2$.

The populations of *B. rubens* were heavily infested with a smut (*Ustilago bullata* Berkeley) fungus. In 1987 the smut was present on 0–36% of *Bromus rubens* plants on 5 sites; in 1988 it ranged from 0% to 43% on 17 sites, with an average (± sem) of 15 ± 3%. The smutted plants produced no viable seed. Presumably this disease significantly reduced seed production. However, smut was noted by others in early populations (e.g., A. A. Beetle 1941, University of California, Berkeley Herbarium), and it apparently did not prevent increases in density.

In the early 1980s *Bromus tectorum* became noticeably common below 1524 m (5000 ft). In Yucca Flat on some of the ground zeroes (GZs are areas denuded by nuclear bomb blasts in the 1950s and early 1960s) it was seen in apparent near-monoculture patches surrounded by *B. rubens* monocultures. In Mercury townsite (the NTS base camp) it occurred in the vicinity of buildings and roads associated with *B. rubens*, while away from disturbance it was absent. In 1983 in the blast zone surrounding Sedan Crater, which resulted from a peaceful nuclear explosion excavation experiment, *B. rubens* was seen at all 12 sites on which perennials were measured, and *B. tectorum* was also present at 6 of those sites (Hunter and Romney, unpublished observations).

TABLE 1. Densities of *Bromus rubens* and *B. tectorum* (n/m$^2$ ± sem) in 1987 (*) and 1988 in relation to disturbance and altitude (m).

| Location | Disturbance | Altitude | *B. rubens* | *B. tectorum* |
|---|---|---|---|---|
| Jackass Flats | none | 950 | +* | 0 |
| Jackass Flats | none | 950 | 16 ± 14 | + |
| Frenchman Flat | gopher | 960 | 2644 ± 716* | +* |
| Frenchman Flat | none | 975 | 48 ± 35* | 0* |
| | | | 258 ± 153 | 4 ± 4 |
| Frenchman Flat | none | 1000 | 34 ± 22 | 0 |
| Frenchman Flat | roadside | 1000 | 4 ± 3 | 0 |
| West Mercury Valley | gopher | 1040 | 3550 ± 366 | 0 |
| Rock Valley | none | 1070 | 754 ± 298* | 0* |
| | | | 2034 ± 632 | + |
| Mercury town | none | 1150 | 352 ± 120* | +* |
| | | | 446 ± 130 | 2 ± 2 |
| Mercury town | shrubs removed | 1150 | 456 ± 192* | +* |
| | | | 1912 ± 476 | 8 ± 7 |
| East Yucca Flat | none | 1240 | 652 ± 328 | + |
| Southwest Yucca Flat | none | 1250 | 1872 ± 556 | 20 ± 11 |
| West Yucca Flat | none | 1280 | 188 ± 49 | 2 ± 2 |
| West Yucca Flat | ground zero | 1290 | 1472 ± 356 | 1884 ± 396 |
| Southwest Yucca Flat | none | 1300 | 1803 ± 474* | 0 |
| Southwest Yucca Flat | fire—1985 | 1300 | 720 ± 168* | +* |
| North Yucca Flat | Sedan GZ | 1325 | 19 ± 11 | 1155 ± 431 |
| North Yucca Flat | Sedan GZ | 1325 | 324 ± 154 | 2004 ± 424 |
| North Yucca Flat | none | 1325 | 142 ± 69 | 2 ± 2 |
| Northwest Yucca Flat | none | 1400 | 658 ± 344 | 4 ± 4 |
| Northwest Yucca Flat | T2 GZ | 1400 | 774 ± 169 | + |
| South Mid-valley | none | 1463 | 362 ± 84 | 414 ± 152 |
| South Mid-valley | fire—1986 | 1463 | 114 ± 37 | 3916 ± 752 |
| Pahute Mesa | none | 1900 | + | + |
| Rainier Mesa | none | 2300 | 0 | 0 |

*Bromus tectorum* densities in 1987–88 differed considerably from those of *B. rubens.* This species was absent or at densities $< 2/m^2$ below 1219 m (4000 ft). Above that altitude it was present at $>1000/m^2$ on several burned and GZ areas. It was not dense on all disturbed sites above 1219 m, however, as seen on the 1985 fire area and T2 GZ (Table 1). Its distribution was therefore considerably patchier than that of *B. rubens*, and it was associated more strongly with disturbance.

Data on plant size from locations where the two species occurred together show that *Bromus tectorum* is the larger of the two species ($p < .02$; Wilcoxon Signed Rank Test: Ostle 1963) and may therefore have a competitive advantage (Table 2). The vegetative and seed characteristics of the two species are very similar, and I would expect seed production to be similarly proportional to plant weight in both.

TABLE 2. Average weights per plant (mg ± sem) of *B. rubens* and *B. tectorum* when growing at the same location.

| Site | *Bromus rubens* | *Bromus tectorum* |
|---|---|---|
| Disturbed | | |
| Mid-valley | 26 ± 11 | 33 ± 7 |
| Yucca Flat–Sedan | 23 ± 9 | 47 ± 13 |
| Yucca Flat–Sedan | 9 ± 2 | 19 ± 6 |
| Yucca Flat–T1 GZ | 11 ± 3 | 17 ± 4 |
| Pristine | | |
| Mid-valley | 11 ± 1 | 20 ± 2 |
| Yucca Flat–001a | 14 ± 2 | 23 ± 6 |
| Yucca Flat–001b | 16 ± 2 | 38 ± 2 |

## DISCUSSION

A comparison of these recent data with those taken earlier demonstrates a significant increase in both frequencies and densities over the past 30 years. The earliest data taken in association with the nuclear bomb testing program were from 1957 to 1959 (Shields and Rickard, unpublished reports). They reported cover data, which could not be directly compared to our density data. However, in three valleys (Yucca Flat, Frenchman Flat, and Jackass Flats; altitudes 945–1524 m) Shields and Rickard measured ephemeral plants at 41 plots and found *Bromus rubens* at only 22 of them (54%). In 1987–88 I found *B. rubens* in those same three valleys at all 21 plots sampled (significantly different by chi square at $p < .001$). Similarly, Beatley (1966) reported *B. rubens* at 8 of 18 plots in Yucca Flat in 1964, while I found it at all 11 sampled locations (significant at $p < .01$). At the two sites where a direct comparison was reasonable, Beatley found 0.0, and 0.2 *B. rubens* per square meter in 1964, while I found 1803 ± 474 and 1434 ± 304 per square meter in 1987–88. At an undisturbed site near the Sedan GZ Martin (unpublished) found 0.6 *B. rubens* per square meter, while in 1988 at the same location I found 142 ± 69.

The most complete time series is for a small area in Rock Valley where records of Beatley, U.S. Desert Biome/International Biological Program researchers, and our studies are available covering 20 of the 26 years since 1962. Table 3 shows that there was an increase from fewer than 10 *B. rubens* per square meter in the 1960s and early 1970s to thousands per square meter in the late 1980s. This increase began in 1974, following the excellent growth year of 1973. Since then, years of good growth have resulted in a stairstep amplification of *B. rubens* population density. At the same time the populations of native annuals fluctuated without any dramatic trends toward increased or decreased density (Table 3). In 1989 and 1990 drought prevented germination of ephemeral plant species.

Biomass data from U.S. International Biological Program Desert Biome studies and our results show trends similar to those on density (Table 4). That is, *B. rubens* greatly increased in biomass at the same time it increased in density, while biomass of native species was highly variable without demonstrating any trends. Proportionately, *Bromus* biomass increased from approximately 10% of ephemeral biomass to 97% between 1972 and 1988.

Differences in sampling techniques and areas sampled, coupled with a naturally high year-to-year variability in richness, prevented any significant diversity comparisons among data of Shields, Beatley, IBP/Desert Biome, and BECAMP studies. However, high *B. rubens* densities resulting from irrigation and fertilization treatments were associated with a decrease in species richness of native species (Hunter, in press).

TABLE 3. Densities of *Bromus rubens* (n/m$^2$) and native species measured in several adjacent Rock Valley plots between 1963 and 1974.

| Year | *Bromus rubens* | Natives |
|---|---|---|
| 1963[1] | 5.0 | 10.0 |
| 1964[1] | 6.2 | 27.6 |
| 1965[1] | 2.2 | 2.4 |
| 1966[1] | 3.2 | 69.6 |
| 1967[1] | 3.6 | 7.0 |
| 1968[1] | 7.6 | 99.6 |
| 1969[1] | 14.0 | 109.8 |
| 1970[1] | 19.8 | 14.0 |
| 1971[1] | 0.2 | 2.0 |
| 1972[1] | 0.0 | 3.0 |
| 1973[3] | 0.4 | 118 |
| 1974[2] | 11.2 | 101 |
| 1975[2] | 13.2 | 216 |
| 1976[2] | 90.9 | 327 |
| — | — | — |
| 1983[4] | 89 | 108 |
| 1984[4] | 167 | 19 |
| 1985[4] | 156 | 111 |
| 1986 | — | — |
| 1987[5] | 754 ± 298 | 100 ± 22 |
| 1988[5] | 2034 ± 632 | 86 ± 33 |
| 1989[5] | 0 ± 0 | 0 ± 0 |
| 1990[5] | 16 ± 16 | 0 ± 0 |

[1]Beatley, unpublished
[2]Turner 1972–1976
[3]Turner and McBrayer 1974
[4]R. B. Hunter and K. B. Hunter, unpublished
[5]This paper

TABLE 4. Biomasses (g/m$^2$) of *Bromus rubens* and native species in Rock Valley. Data for the 1970s are from Turner 1972–76, Turner and McBrayer 1974, and Turner, unpublished.

| Year | *Bromus rubens* | Natives |
|---|---|---|
| 1971[1] | 0.10 | 0.54 |
| 1972[1] | 0.04 | 0.40 |
| 1973[2] | 1.29 | 78.9 |
| 1974[1] | 0.83 | 1.50 |
| 1975[1] | 2.13 | 22.5 |
| 1976[3] | 3.25 | 12.0 |
| — | — | — |
| 1987 | 17.0 | 0.51 |
| 1988 | 34.0 | 0.9 |
| 1989 | 0.0 | 0.0 |
| 1990 | 0.0 | 0.0 |

## *Bromus tectorum*

Beatley (1966) described the status of *B. tectorum* as present only above 1524 m (5000 ft), largely in disturbed areas of *Artemisia tridentata*-dominated vegetation. This constrasts with my data (Table 1), which demonstrated a significant presence of *B. tectorum* throughout Yucca Flat, 1219–1524 m (4000–5000 ft) in the late 1980s.

The propensity of the *Bromus* species to carry fire has been frequently noted (e.g., Stewart and Hull 1949, Beatley 1966, Yensen 1981). The dead stems and litter persist for a year or two and serve to carry fire across bare areas between shrubs and trees. On the NTS this is true for both *B. rubens* and *B. tectorum*. On the NTS fires burned an estimated 38,000 acres between 1978 and 1987 (R. R. Gudeman, personal communication), in spite of active control efforts. The *Bromus* species were significantly present both in control and previously burned areas (Table 1), suggesting a role both in fire propagation and recovery of vegetation following fire.

The effects of the *Bromus* populations on native ephemerals were not clear. Table 4 shows no significant downward trend in native population densities. The native ephemerals behaved somewhat differently from *B. rubens*, however. Following two very dry years (1971, 1972), the native species rebounded immediately (1973 was an unusually wet spring), while the *B. rubens* population required two years to reach its previous density. The native seeds therefore seemed better adapted than the *B. rubens* seeds to weather the severest drought, while the *Bromus* species appeared to reproduce better in the "normal" years. The driest and least productive years of record were 1989 and 1990, but the consequences are as yet unknown.

Some adaptations that give *Bromus* species advantages over desert ephemerals include better seed dispersal adaptations than natives (see Ellner and Shmida 1981, Levin et al. 1984), a greater response to nitrogen by the introduced grasses (Hunter, unpublished data), and a greater proportion of *Bromus* plants inhabiting the fertile soils under shrubs (Soholt and Irwin 1976, R. B. Hunter and K. B. Hunter, unpublished data). One disadvantage that seemed to limit *Bromus* growth in certain years was the fibrous root systems of the grasses as opposed to tap roots of the natives—sparse, frequent rains favored *Bromus*, while deep, infrequent ones favored species with tap roots. Given these genetic differences, one might expect the introduced grasses to find slightly different niches from the natives and possibly add to the diversity of the native flora, rather than diminish it. In the densities occurring in recent years, however, the environment of the desert surface appears to this author to be radically changed. I suspect that the surface shading by dead *Bromus* stalks, the changed fire frequencies, and the dense population of the introduced *Bromus* species on the "fertile islands" under shrubs will profoundly change the nature and diversity of the native flora.

The mechanisms of the increases in density and biomass of the *Bromus* species are not readily apparent, but they appear to be related to their biological adaptations. They coincided with a series of years wetter than the 1951–1980 average for southern Nevada, which occurred from 1973 through 1988 (NOAA 1989). I have considered, but rejected, the hypothesis that the activities of man were the cause of the rapid increase in *Bromus* densities. Certainly the two species are well adapted to disturbance (Table 1), and man disturbs a great deal of the landscape. Nevertheless, the area disturbed by man on the NTS is not as great as that disturbed by burrowing animals and fires. Furthermore, the range extension for *B. tectorum* appeared to be widespread, and not restricted to the NTS (Young et al. 1987, Robertson 1987, Young and Tipton 1989). Disturbance by man, natural events, and animals is almost ubiquitous. Urban centers, grazing, use of off-road vehicles, and recreational use of public lands promise to maintain disturbance at high levels for the foreseeable future. The Nevada Test Site has been protected from some of those disturbances (grazing, residential development, and recreation) by the security required by the nuclear testing program. The spread of the *Bromus* species should therefore be considered a natural biological phenomenon.

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