Seventy-Five Years of Vegetation Treatments on Public Rangelands in the Great Basin of North America

Authors: Pilliod, David S., Welty, Justin L., and Toevs, Gordon R.

Source: Rangelands, 39(1) : 1-9

Published By: Society for Range Management

URL: https://doi.org/10.1016/j.rala.2016.12.001

Seventy-Five Years of Vegetation Treatments on Public Rangelands in the Great Basin of North America

By David S. Pilliod, Justin L. Welty, and Gordon R. Toevs

On the Ground

- Land treatments occurring over millions of hectares of public rangelands in the Great Basin over the last 75 years represent one of the largest vegetation manipulation and restoration efforts in the world.
- The ability to use legacy data from land treatments in adaptive management and ecological research has improved with the creation of the Land Treatment Digital Library (LTDL), a spatially explicit database of land treatments conducted by the U.S. Bureau of Land Management.
- The LTDL contains information on over 9,000 confirmed land treatments in the Great Basin, composed of seedings (58%), vegetation control treatments (24%), and other types of vegetation or soil manipulations (18%).
- The potential application of land treatment legacy data for adaptive management or for retrospective analyses of effects of land management actions on physical, hydrological, and ecological patterns and processes is considerable and just beginning to be realized.

Keywords: adaptive management, Bureau of Land Management, land treatment, restoration, rehabilitation, soil.

Rangelands 39(1):1–9

doi 10.1016/j.rala.2016.12.001

Published by Elsevier Inc. on behalf of The Society for Range Management.

The U.S. Department of the Interior has a long history of conducting land treatments on millions of hectares of public rangelands. Established under the Taylor Grazing Act of 1934, the Grazing Service aimed to increase forage quality and quantity for livestock production on public rangelands by removing native shrubs and sowing grasses. The Grazing Service merged with the General Land Office to form the Bureau of Land Management (BLM) in 1946, about the time the BLM began keeping records on land treatments, or those areas where vegetation or soil was manipulated intentionally. These treatments were generally planned and implemented to address local needs and concerns, but collectively began to influence vegetation across vast ecoregional landscapes. The Federal Land Policy and Management Act of 1976 mandated multiple-use management of public lands, including preserving their various natural resource values. To meet these federal mandates, treatments have become progressively more complex as resource managers attempted to accomplish multiple objectives, such as post-wildfire rehabilitation of vegetation, stabilization of soils, control of invasive plant species, reduction of hazardous fuels, and production of livestock forage. In the last 25 years, a greater emphasis has been placed on ecological restoration or "the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed."[1]

The sagebrush steppe ecosystem in the Great Basin has become a focal area for landscape conservation and ecological restoration.[2] The Great Basin is the largest desert in North America, spanning over 50 million ha, with nearly 60% managed by the BLM. This cold desert was once dominated by native perennial grasslands, salt desert scrublands, sagebrush-steppe shrublands, pinyon-juniper woodlands, and, at higher elevations, mixed conifer forests. Sagebrush steppe is the dominant vegetation type in the region, but it is also considered one of the most endangered ecosystems on the continent.[3] Vast areas of the Great Basin now also contain nonnative, seeded perennial grasslands planted as forage for livestock; nonnative, invasive annual grasslands perpetuated by frequent fires; and irrigated croplands.[4,5] Wildfire size and frequency have increased at lower elevations in the Great Basin, in part because of cheatgrass (*Bromus tectorum*), an invasive annual grass that was introduced from Asia in the late 1800s.[6–8] At higher elevations, native pinyon and juniper woodlands have encroached into sagebrush steppe shrublands in response to favorable climates and effective fire suppression.[9] The cumulative effects of altered fire regimes, invasive annual grasses, and human land use have resulted in the widespread degradation, loss, and fragmentation of Great Basin habitats. Today, land and resource managers are working closely with scientists to reverse this ecological erosion, backed by policies such as the Department of the Interior's Secretarial Order 3336 (2015), which aims to enhance the protection, conservation, and restoration of sagebrush-steppe ecosystems.

The long and varied history of vegetation management in the Great Basin, from improving livestock production to restoring native ecosystems, is unprecedented in both scope and scale in North America and might be considered one of the grandest field experiments ever created. The vast number, variety, and spatial extent of land treatments on public rangelands in the Great Basin provide a unique opportunity to study restoration implementation, results, and effectiveness, as well as other ecological topics that take advantage of these de facto field experiments. These treatments provide thousands of potential study sites for scientists interested in addressing basic and applied ecological questions related to topics such as 1) successional patterns and processes of plant, soil, and wildlife communities; 2) responses of communities and ecosystems to natural and human caused disturbance; and 3) factors influencing ecological restoration. Retrospective analyses also can help land managers evaluate past treatments and improve future restoration actions through adaptive management practices or by using past results to inform future actions. The outcome of these studies could guide policy decisions and allocation of resources for land management activities.

Land treatments on public lands in the Great Basin have been underutilized for adaptive management and research because data on treatment locations, activities, and outcomes were poorly organized and inaccessible. Traditionally, treatment data were stored in file cabinets and computers at the local field or district office that conducted the treatment, making procurement of the necessary documentation and spatial records difficult, costly, and time consuming.[10] Specific details about treatments (e.g., seed mix species and application rates) were difficult to obtain even when access to spatial information was available. To date, most analyses of land treatments have been short-term studies of individual or a select few treatments (e.g., Pyke et al.[11]). While these studies can yield meaningful results, their inferences are often limited to a single treatment at one location. Multiple treatments with similar characteristics are often required to increase inferences beyond the single site, but this requires having multiple treatments covering multiple locations. To effectively and efficiently study multiple treatments at larger spatial and temporal scales, a single repository that houses all treatment data and allows for it to be queried was needed. To accomplish this goal, the U.S. Geological Survey (USGS) partnered with BLM to design and implement the Land Treatment Digital Library (LTDL).

Development of the Land Treatment Digital Library

The LTDL was created by USGS to catalog legacy land treatment data for the BLM throughout the western United States.[12] The LTDL is a sophisticated database that contains data in text, tabular, spatial, and image formats. Original data were collected from BLM Field and District Offices (administrative units) and converted to digital formats. These data included project plans, implementation reports, monitoring information, maps, and photographs of land treatments. Specific data about treatments, such as type of treatment, date implemented, and area treated, were extracted from the documentation (see Welty and Pilliod[13]) and entered into the database so that they could be queried. Spatial representations of the area treated were created in a geographic information system. Original documentation was stored in portable document format (.pdf) and archived as a link within the database. All data were made accessible through the internet.[i] The highly organized and standardized data allow for rapid, specific, and repeatable queries or searches of information. Additionally, interactive maps allow users to search and portray land treatments for an area of interest relative to recognizable land features, such as roads and towns.

The BLM requested the development of this tool because of the need for resource managers to compile and synthesize information about land management actions at multiple spatial and temporal scales for internal and external data calls (e.g., Freedom of Information Act requests), project planning, adaptive management, and the development of ecoregional assessments, land use plans, and resource management plans. The USGS was interested in the development of the LTDL for research needs, such as identifying potential study sites during experimental design or stratifying sampling on the basis of treatment type (e.g., seeding, prescribed fire), seeded species, and other variables of interest.

The LTDL mirrors the terminology used by BLM for its vegetation management actions, especially the practice of nesting one or more "treatments" within each "project." Each treatment has specific management objectives and, collectively, the set of treatments within a project has a desired goal or outcome that is usually more holistic and representative of the landscape level. For example, a post-wildfire rehabilitation project may include an herbicide application treatment to reduce competition from noxious weeds, a seeding treatment to help establish desirable plant species and compete with weeds, and a livestock closure treatment to protect new seedlings from herbivory. These various treatments may or may not overlap spatially within the project area.

A Synthesis of Land Treatments in the Great Basin

We summarized data from the Great Basin to highlight the scope and scale of land treatment information in the LTDL and discuss how this information can be used for

[i] Access the Land Treatments Digital Library at https://ltdl.wr.usgs.gov/.

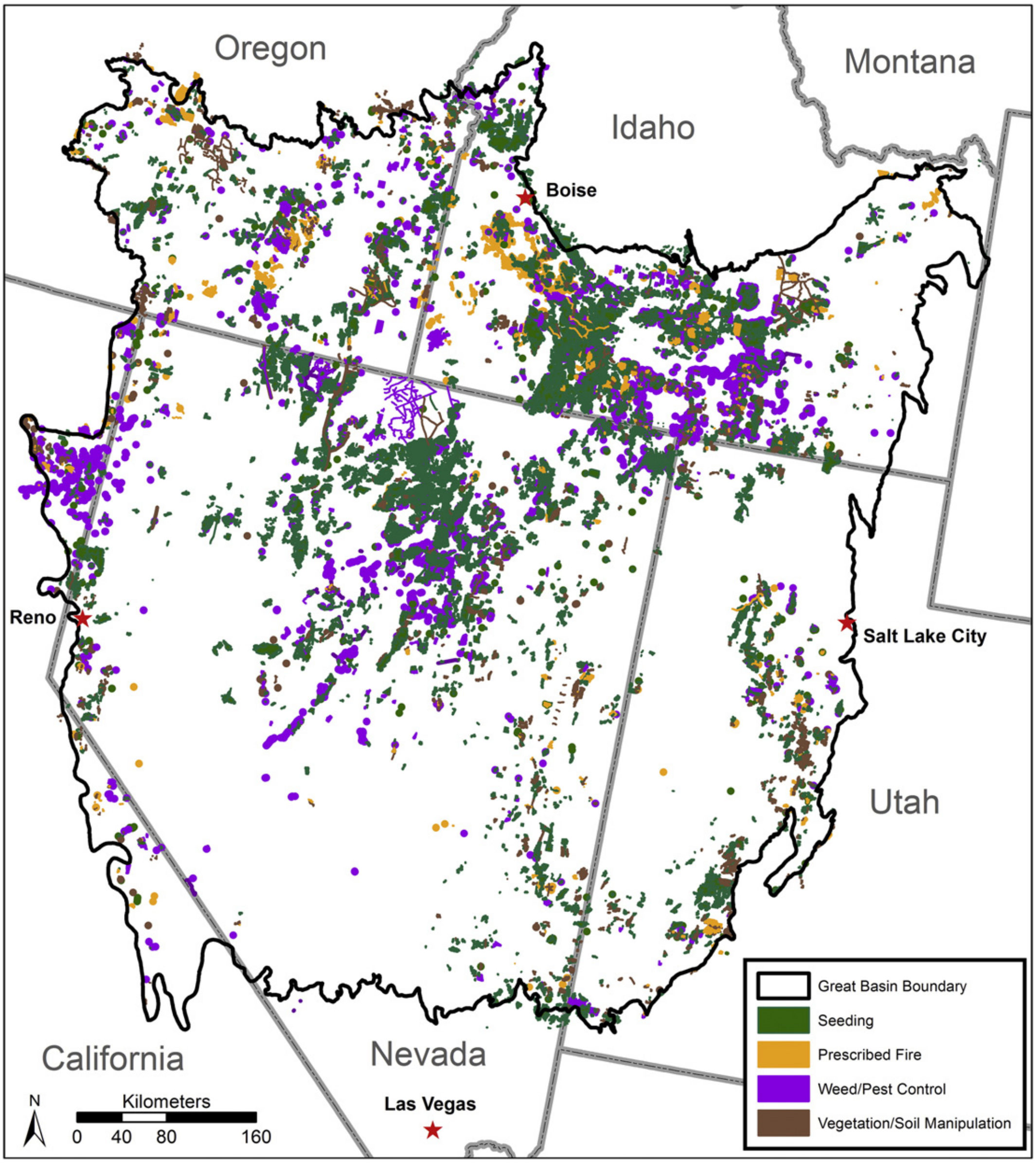

Figure 1. Map of spatially referenced, confirmed land treatments within the Great Basin, 1940 to 2015. Data from the Land Treatment Digital Library, accessed 27 May 2015.

adaptive management and ecological research. We defined the Great Basin as the combined areas of three Level III Ecoregions (Snake River Plain, Northern Basin and Range, and Central Basin and Range; U.S. Environmental Protection Agency; Figure 1). We focused our synthesis on confirmed projects only or those projects whose implementation was confirmed in the field through documentation. All projects used in the analysis involved some sort of major soil or vegetation manipulation or restoration effort. Grazing was not included unless part of a project plan, such as using livestock to control invasive plant species or excluding livestock for a period of time to rest recently disturbed or seeded areas. Reclamation projects (e.g., seeding after removal of an exploratory gas well) were excluded. Projects were all greater than 4 ha (about 10 acres), although some smaller treatments were included if they were among other larger treatments in a single project. This conservative approach resulted in 4,580 projects (Table 1) and 9,435 treatments (Table 2) within those projects. Some of these treatments (1,435 of 9,435) did not contain adequate spatial information to locate the treated area (polygon) in a geographic information system. Hence, we used 8,000 treatments for spatial statistics and the full 9,435 treatments for nonspatial statistics.

Of the 4,580 projects in the Great Basin that were compiled and analyzed from 1940 to 2015, the majority (43%) were conducted for purposes of post-wildfire rehabilitation (Table 1). Other common project goals include improving grazing conditions for livestock (15%), improving wildlife habitat (8%), reducing hazardous fuels (7%), and controlling invasive plants and noxious weeds (4%). Each of the project

Table 1. Summary of the main reasons for implementing treatments within a single project in the Great Basin, 1940 to 2015

Reason for project	Project count
Wildfire rehabilitation	1,999
Livestock grazing Improvement	702
Wildlife habitat improvement	394
Unknown (not specified)	337
Fuels reduction	326
Noxious weed control	163
Restoration	139
Brush control	81
Watershed development	66
Wildland urban interface	54
Erosion control	54
Experimental project	54
Timber harvest	47
Other	46
Hazard reduction	39
Invasive plant control	31
Wildlife forage improvement	27
Insect control	21
Total	**4,580**

Source: Land Treatment Digital Library 2015.

* Note. These totals are much lower than the treatment counts because multiple treatments within one project may be used to accomplish an overall goal.

types may involve multiple, specific treatments to accomplish these broad goals. Since 1940, at least 3.76 million ha of land or 7.4% of the Great Basin have been treated (Figure 1). This represents 12.5% of the lands administered by the BLM in the region. Of these treated lands, a minimum of 1.65 million ha were treated more than once and some areas were treated up to 10 times between 1940 and 2015. For example, a burned area may be seeded in the winter following a fire, but then re-burn 20 years later resulting in a second seeding that partially overlaps the first seeding. The total area of all individual treatments, including overlapping treatments, is over 6.38 million ha, almost twice the area of land treated.

The number of individual treatments on record varied through time, but with some interesting patterns (Figure 2). For the 35-year period between 1940 and 1975, the minimum number of treatments conducted annually ranged from 20 to 210. During this time, the number of treatments appeared to decline precipitously following major legislation, particularly the National Environmental Policy Act in 1969 and the Federal Land Policy and Management Act in 1976 (Figure 2). These inflection points may reflect changes in policy (e.g., additional regulation) and funding priorities, as well as periods of adjustment as proposed projects were modified to meet new mandates. After 1977 the proportion of treatments that were associated with wildfire began to increase, and between 1995 and 2015 the average number of treatments conducted annually nearly doubled (Figure 2). Some of this dramatic increase may have been associated with increased funding under the National Fire Plan of 2000.

Seeding, particularly after wildfire, is one of the most common and widespread land treatments in the Great Basin (Table 2). The number of hectares seeded annually remained relatively low (< 100,000 ha) until about 1980 when it began to increase (Figure 3). This coincided approximately with a greater emphasis on post-fire treatments in the Great Basin (Figure 2). From 1940 to 1980 nearly all treatments where seed mix was reported contained a nonnative forage grass, such as wheatgrass, and in many cases the entire seed mix was composed of nonnative grasses (Figure 3). The species composition of the seed mixes used in rangeland rehabilitation and restoration has steadily transitioned from nonnative grasses (often, single species) to a more varied mix incorporating native and nonnative grasses, forbs, and shrubs (Figure 4). About the turn of the 21st century, seeds of native plants became more common in seed mixes than nonnatives (Figure 4). Seeding of native species is likely to become even more common and complex as recent research suggests that locally adapted native seeds can perform better than seeds from distant locations or elevations,[14,15] and thus prioritizing sowing seeds that were collected within similar seed transfer zones[16] has added an additional level of complexity to Great Basin restoration projects.

Although shifting priorities and objectives in rangeland management have altered seed mix composition, some seeded species tend to dominate their functional group regardless of decade (Appendix 1 in the Online Supplemental Materials at http://dx.doi.org/10.1016/j.rala.2016.12.001). Crested wheatgrass (*Agropyron cristatum*) and Siberian wheatgrass (*Agropyron fragile*) comprise over two-thirds of the nonnative grass seed used since 1940. Alfalfa (*Medicago sativa*) is the preferred nonnative forb and forage kochia (*Bassia prostrata*) is the only nonnative shrub used, perhaps because it is considered to be fire resistant and competitive with cheatgrass.[17,18] Sandberg bluegrass (*Poa secunda*), Lewis flax (*Linum lewisii*), and big sagebrush (*Artemisia tridentata*) tend to dominate the native grasses, forbs, and shrubs respectively (Appendix 1).

Learning From the Past to Adapt Rangeland Management Practices

There is considerable interest in evaluating factors influencing treatment success and using that information to improve the likelihood of success of future land treatments in an adaptive management framework. For example, the importance of climate on local seed adaptability and local weather on seeding success are understudied in the Great Basin, but potentially important for restoration planning and outcomes. Ideally adaptive management would be

Table 2. Summary of implemented, major treatment types within the Great Basin by decade

Treatment type	1940-1949	1950-1959	1960-1969	1970-1979	1980-1989	1990-1999	2000-2009	2010-2015	Totals
Aerial seeding	2	23	132	57	137	383	923	224	1,881
Drill seeding	29	294	542	205	408	413	488	99	2,478
Ground seeding	25	107	56	26	101	98	189	63	665
Seeding	5	62	92	13	40	22	27	8	269
Seedling planting	0	0	3	5	41	31	65	49	194
Herbicide/weed control	2	39	286	36	44	121	374	109	1,011
Prescribed burn	5	39	11	15	171	124	252	32	649
Thinning/cutting	2	31	16	6	34	90	318	82	579
Vegetation/soil Manipulation*	35	332	453	42	136	111	348	75	1,532
Soil stabilization†	0	3	3	5	11	16	110	29	177
Totals	105	930	1,594	410	1,123	1,409	3,094	770	9,435

Source: Land Treatment Digital Library 2015.

* Includes plowing (627 treatments), chaining (558), pinyon or juniper removal (294), disc harrowing (292), mechanical thinning (270), mowing (152), and other similar activities.

† Other than seeding.

accomplished by creating a well-designed treatment and monitoring plan that uses clearly stated, reasonable, time-sensitive, and quantifiable objectives, and correctly evaluates the monitoring data within the appropriate time period. Monitoring data can provide critically important information for modifying future treatment methods when conducted properly and analyzed appropriately, including decisions about whether (and when or how) to re-treat an area previously treated. The LTDL can be a catalyst for implementing this adaptive management approach, especially if managers engage with scientists early in treatment and monitoring planning, partner on analysis and interpretation of monitoring data, and allow for timely decisions about additional treatment options and reapplication. We expect the LTDL will facilitate this process and allow data to be more easily shared with collaborators.

Meta-analyses of treatment effectiveness could provide an important tool for improving rangeland restoration practices. One difficulty of conducting meta-analyses of treatment effectiveness is that past measures of success are often subjective and dependent upon treatment objectives that can vary greatly. However, most treatments and their objectives can be grouped logically, such as assessments of germination and short-term (e.g., 1–3 years) survival rates of seeded species or suppression of undesirable nonnative species. BLM explicitly stated treatment success relative to treatment objectives as "Successful," "Partially Successful," or "Failure" for 10.5% of all available treatments in the Great Basin between 1940 and 2015. To examine the usefulness of these data, we assessed how precipitation influenced the success rate of post-fire seeding treatments with the expectation that seedings would be more successful at higher elevations as recently determined empirically by Knutson et al.[19] Our analysis included 608 treatment sites where post-wildfire seeding success was reported from 1980 to 2012 (success after 2012 had yet to be determined). We found that 62% (113 of the 182) of the successful seedings occurred in areas that, on average, receive more than 30.5 cm (12 in) of precipitation, whereas 69% (70 of the 102) of the failed seedings occurred in areas that receive less than 30.5 cm of precipitation (Figure 5). The strong, positive relationship between precipitation and elevation in the Great Basin indicates that seeding treatments are more likely to be successful at higher elevations.

We recognize the limited inference and cautious interpretation of these findings: reported success was provided by the agency that conducted the treatment (i.e., potential conflict of interest) and success assessment was not standard or necessarily consistent (i.e., some monitoring was more quantitative and rigorous than others). Despite these caveats, the results of this simple analysis are consistent with ecological theory[20] and empirical data from field studies[19] and demonstrate the potential for formal meta-analyses of treatments in the future. For example, many treatments in the LTDL provide sufficient monitoring data or otherwise describe treatment outcomes in such a way that users may be

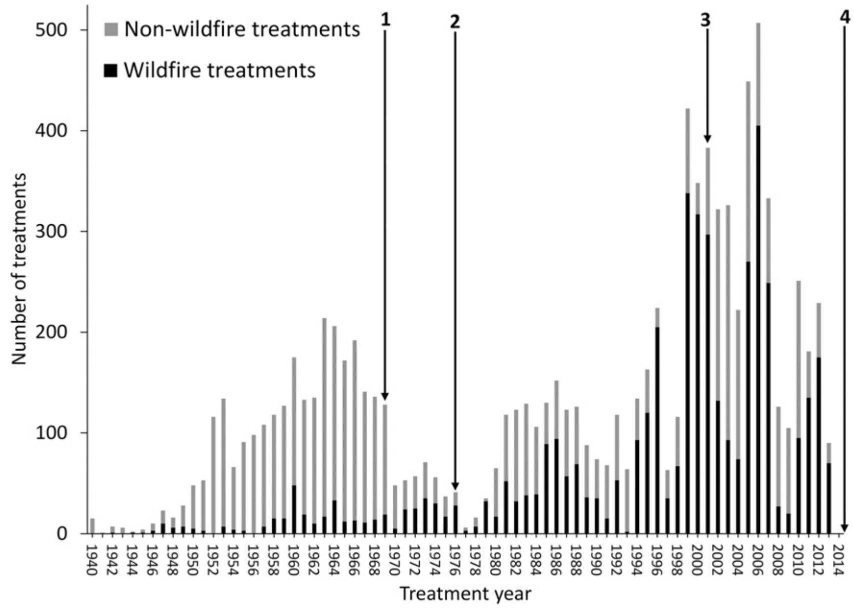

Figure 2. Count of vegetation treatments associated with (black bars) and without wildfires (gray bars) by year in the Great Basin, 1940 to 2015 (data from the Land Treatment Digital Library, accessed 27 May 2015). The black bars and gray bars together indicate the total number of treatments in a given year. The black arrows indicate major federal land legislation: 1) National Environmental Policy Act (1969); 2) Federal Land Policy and Management Act (1976); 3) National Fire Plan (2001); and 4) Secretarial Order 3336 (2015). Treatments in 2013 and 2014 have not been completely collected and entered into the LTDL and represent an underestimation of the total treatments for these years.

able to determine success of these treatments retrospectively. Of course, revisiting treatment areas to assess current condition at short-term (1–5 years), mid-term (6–10 years), and long-term (10–30 years) periods will provide the most defensible evidence about treatment outcomes (e.g., Knutson et al[19]).

A Large-Scale, Ongoing Field Experiment

Land treatment data from the LTDL have been used already in ecological research. Recent studies used the LTDL to identify potential post-fire seeding treatments of varying age to determine how vegetation, fuel conditions, and wildlife habitat are influenced by drill-seeding and aerial seeding

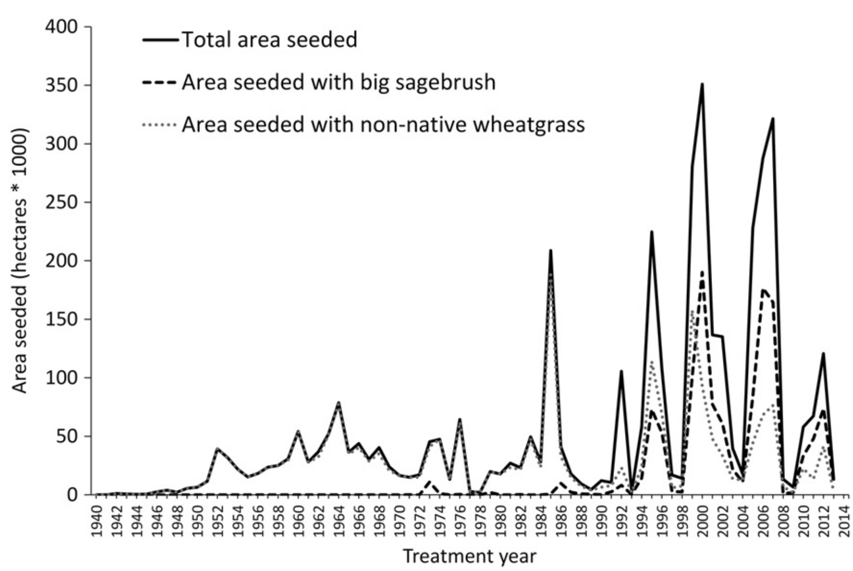

Figure 3. Total area seeded annually (solid line) in the Great Basin between 1940 and 2015. Of this total, we also show area seeded with big sagebrush (dashed line), and area seeded with nonnative wheatgrass species (dotted line). In all cases, area seeded annually is by treatment and thus overlapping treatments in the same year, including a blend of wheatgrasses, are only counted once so as not to inflate the hectares seeded. Nonnative wheatgrass species included Crested Wheatgrass (*Agropyron cristatum*), Siberian Wheatgrass (*Agropyron fragile*), Russian Wheatgrass (*Thinopyrum junceiforme*), Intermediate Wheatgrass (*Thinopyrum intermedium*), and Tall Wheatgrass (*Thinopyrum ponticum*). Data from the Land Treatment Digital Library, accessed 27 May 2015.

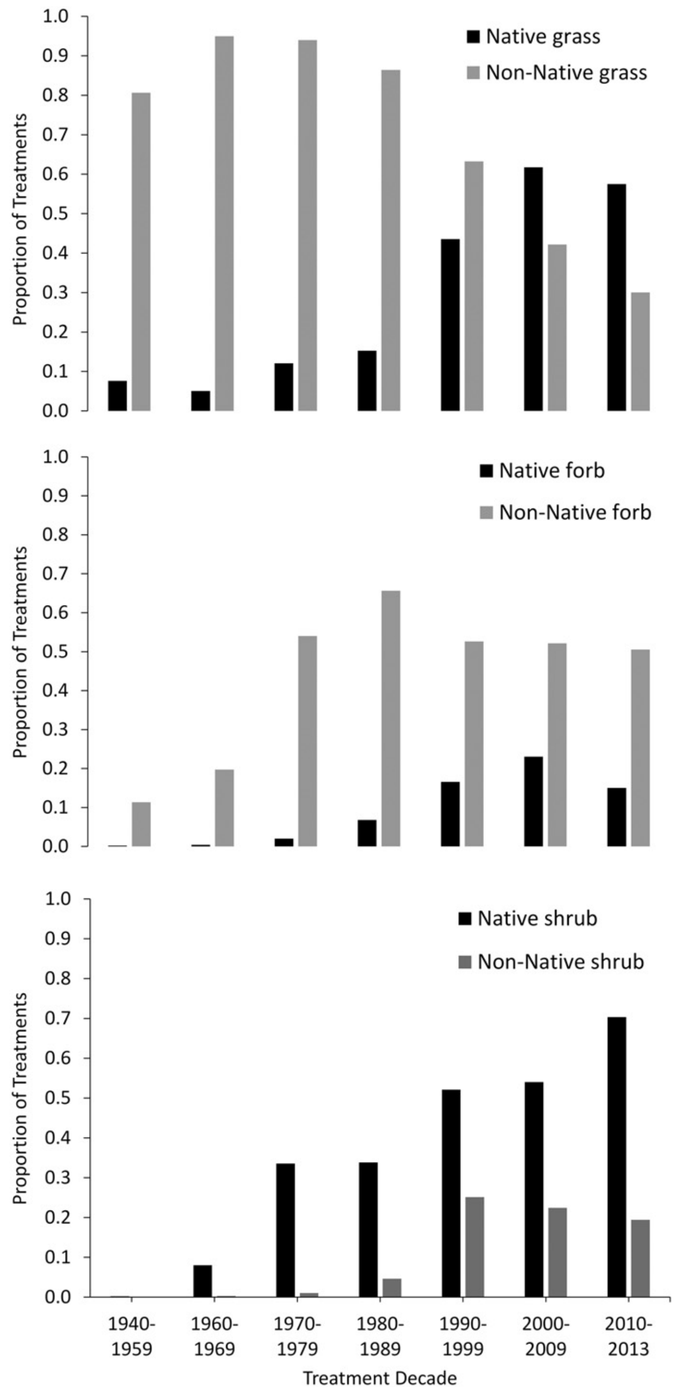

Figure 4. Proportion of treatments with at least one species of native or nonnative grass (panel A), native or nonnative forb (panel B), and native or nonnative shrub (panel C) in the seed mix. Data from the Land Treatment Digital Library, accessed 27 May 2015.

practices.[19,21] Other scientists have combined treatment information from the LTDL with satellite imagery to determine whether seeded sites establish seedlings more quickly than unseeded sites within areas burned by wildfires in the Great Basin.[22] These studies and others[23,24] demonstrate the utility of the LTDL as an effective tool for identifying potential study sites for research. The vast number of treatments in the LTDL can provide unparalleled spatial and temporal inference for many scientific research questions.

Data Limitations and Caveats for Use

The compilation and use of legacy land treatment data have certain limitations that warrant consideration. For example, projects that were acquired for the LTDL were uploaded as found and sometimes were incomplete. To account for this issue, we carefully documented the completeness of all records to the best of our ability. We found that 20% of records had planning documents but no confirmation that the treatment occurred or occurred as planned. By noting this and other known sources of

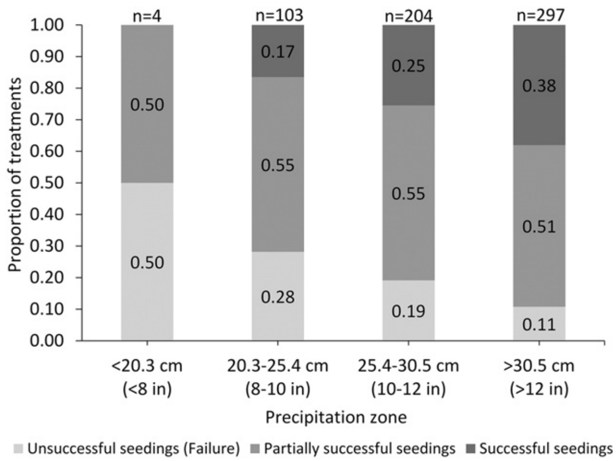

Figure 5. Post-fire seeding success relative to precipitation zone in the Great Basin as determined by BLM at 3 years after seeding (1950-2015). Successful seedings (dark gray) met objectives, partially successful seedings (gray) met some treatment objectives, and seeding failures (light grey) did not meet treatment objectives. Data from the Land Treatment Digital Library, accessed 27 May 2015.

uncertainty in the LTDL, we were able to exclude incomplete records from our analysis. Other issues are not as easily resolved. For example, we recognize that some aspects of treatments may not have been recorded, such as changes that were made during field operations (e.g., caused by weather or equipment malfunction) that were not reflected in planning documents or documented in implementation reports. These unknown and undocumented issues are sources of potential error for syntheses and analyses.

Missing project and treatment records are another limitation and may bias interpretation of LTDL data. We have no way of assessing what information was lost or destroyed from BLM offices over the years prior to our data compilation effort. This issue is inherent to inventories where full census information is impossible to acquire and the amount of missing information is unknown. We were informed that some known records were occasionally destroyed intentionally, such as for records management or to save space during relocation of administrative offices, but most cases were unintentional loss from fire, water damage, mold, and accidents. Unfortunately, there was insufficient information to account for this loss of records systematically or statistically. Hence, analyses and syntheses of LTDL data should be considered a sample that has unknown bias, and summary statistics should be reported as minimum values that under-represent the actual total area treated in a management unit (e.g., Major Land Resource Area) or year. We are more confident that record completeness and missing data become less of an issue with more contemporary records, especially after about 1990.

We also wish to emphasize a few other caveats for proper use of LTDL data. Most legacy land treatment records have not been validated, and validation may not always be possible because of the age of the records and lack of metadata (i.e., information about the data) for older treatments. Hence, use of the data should include a visit with local BLM Field Office resource managers to confirm treatment information and a site visit to further verify information as much as possible or reasonable given the time since treatment. This process could help improve the database if new or additional treatment information is then updated in the database.

Conclusions

For the foreseeable future, the BLM and other agencies will continue to conduct land treatments on millions of hectares across the western United States in an effort to manage fuels and wildfire, control invasive weeds, improve or maintain habitat for wildlife, and provide forage for livestock, among other efforts. The adoption of standardized monitoring methods, such as the Assessment, Inventory, and Monitoring Program,[25] has set the stage for considerable opportunities in adaptive management. These efforts could improve understanding of land condition and help guide land use policy at landscape levels.[10] The LTDL is an important tool in this assessment toolkit and yet its use in land and natural resource management and research is only now beginning to be realized.

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.rala.2016.12.001.

Acknowledgments

This work was supported by the Bureau of Land Management, U.S. Geological Survey, and Joint Fire Sciences Program. Linda Schueck (USGS) designed the website. We are especially thankful to all of the USGS staff who entered data and provided advice on database design, BLM staff who helped locate and provide original records, and the technical advisory team who guided the project development. We thank David Pyke and anonymous reviewers of this manuscript. Any use of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

References

1. Society for Ecological Restoration International Science & Policy Working Group, 2002. The SER Primer on Ecological Restoration. www.ser.org/.
2. Chambers, J.C., and M.J. Wisdom. 2009. Priority research and management issues for the imperiled Great Basin of the western United States. *Restoration Ecology* 17:707-714.
3. Noss, R.F., E.T. LaRoe, and J.M. Scott. 1995. Endangered ecosystems of the United States: A preliminary assessment of loss and degradation. Biological Report 28. Washington, DC, USA: U.S. Department of the Interior, National Biological Service. 95 pp.
4. Suring, L.H., M.J. Wisdom, R.J. Tausch, R.F. Miller, M.M. Rowland, L. Schueck, and C.W. Meinke. 2005. Modeling threats to sagebrush and other shrubland communities. In: Wisdom MJ, Rowland MM, & Suring LH, editors. Habitat threats in the sagebrush ecosystem-Methods of regional assessment and applications in the Great Basin. Lawrence, KS, USA: Alliance Communitcations. p. 114-139.
5. Knick, S.T., S.E. Hanser, R.F. Miller, D.A. Pyke, M.J. Wisdom, S.P. Finn, E.T. Rinkes, and C.J. Henny. 2011.

Ecological influence and pathways of land use in sagebrush. *Studies in Avian Biology* 38:203-251.
6. D'Antonio, C.M., and P.M. Vitousek. 1992. Biological invasions by exotic grasses, the grass/fire cycle, and global change. *Annual Review of Ecology and Systematics* 23:63-87.
7. Brooks, M.L., C.M. D'antonio, D.M. Richardson, J.B. Grace, J.E. Keeley, J.M. DiTomaso, R.J. Hobbs, M. Pellant, and D. Pyke. 2004. Effects of invasive alien plants on fire regimes. *BioScience* 54:677-688.
8. Balch, J.K., B.A. Bradley, C.M. D'Antonio, and J. Gómez-Dans. 2013. Introduced annual grass increases regional fire activity across the arid western USA (1980–2009). *Global Change Biology* 19:173-183.
9. Miller, R.F., and J.A. Rose. 1999. Fire history and western juniper encroachment in sagebrush steppe. *Journal of Range Management* 1999:550-559.
10. Herrick, J.E., V.C. Lessard, K.E. Spaeth, P.L. Shaver, R.S. Dayton, D.A. Pyke, L. Jolley, and J.J. Goebel. 2010. National ecosystem assessments supported by scientific and local knowledge. *Frontiers in Ecology and the Environment* 8:403-408.
11. Pyke, D.A., T.A. Wirth, and J.L. Beyers. 2013. Does seeding after wildfires in rangelands reduce erosion or invasive species? *Restoration Ecology* 21:415-421.
12. Pilliod, D.S., and J.L. Welty. 2013. Land Treatment Digital Library. U.S. Geological Survey Data Series 806. https://pubs.er.usgs.gov/publication/ds806.
13. Welty, J.L., and D.S. Pilliod. 2013. Data entry module and manuals for the Land Treatment Digital Library. US Geological Survey Data Series 749. https://pubs.usgs.gov/ds/749.
14. Brabec, M.M., M.J. Germino, D.J. Shinneman, D.S. Pilliod, S.K. McIlroy, and R.S. Arkle. 2015. Challenges of establishing big sagebrush (*Artemisia tridentata*) in rangeland restoration: effects of herbicide, mowing, whole-community seeding, and sagebrush seed sources. *Rangeland Ecology & Management* 68:432-435.
15. Brabec, M.M., M.J. Germino, and B.A. Richardson. 2016. Climate adaption and post-fire restoration of a foundational perennial in cold desert: insights from intraspecific variation in response to weather. *Journal of Applied Ecology* 54:293-302.
16. Bower, A.D., J. Clair, and V. Erickson. 2014. Generalized provisional seed zones for native plants. *Ecological Applications* 24:913-919.
17. Clements, C.D., K.J. Gray, and J.A. Young. 1997. *Forage kochia*: to seed or not to seed. *Rangelands* 19:29-31.
18. Harrison, R.D., B.L. Waldron, K.B. Jensen, R. Page, T.A. Monaco, W.H. Horton, and A.J. Palazzo. 2002. *Forage kochia* helps fight range fires. *Rangelands* 24:3-7.
19. Knutson, K.C., D.A. Pyke, T.A. Wirth, R.S. Arkle, D.S. Pilliod, M.L. Brooks, J.C. Chambers, and J.B. Grace. 2014. Long-term effects of seeding after wildfire on vegetation in Great Basin shrubland ecosystems. *Journal of Applied Ecology* 51:1414-1424.
20. Beatley, J. 1975. Climates and vegetation pattern across the Mojave/Great Basin Desert transition of southern Nevada. *American Midland Naturalist* 93:53-70.
21. Arkle, R.S., D.S. Pilliod, S.E. Hanser, M.L. Brooks, J.C. Chambers, J.B. Grace, K.C. Knutson, D.A. Pyke, J.L. Welty, and T.A. Wirth. 2014. Quantifying restoration effectiveness using multi-scale habitat models: implications for sage-grouse in the Great Basin. *Ecosphere* 5:1-32.
22. Sankey, J.B., C.S. Wallace, and S. Ravi. 2013. Phenology-based, remote sensing of post-burn disturbance windows in rangelands. *Ecological Indicators* 30:35-44.
23. Gray, E.C., and P.S. Muir. 2013. Does *Kochia prostrata* spread from seeded site? An evaluation from southwestern Idaho. *Rangeland Ecology & Management* 66:191-203.
24. Leger, E.A., and O.W. Baughman. 2015. What seeds to plant in the Great Basin? Comparing traits prioritized in native plant cultivars and releases with those that promote survival in the field. *Natural Areas Journal* 35:54-68.
25. Toevs, G.R., J.W. Karl, J.J. Taylor, C.S. Spurrier, M.S. Karl, M.R. Bobo, and J.E. Herrick. 2011. Consistent indicators and methods and a scalable sample design to meet assessment, inventory, and monitoring information needs across scales. *Rangelands* 33:14-20.

Authors are Supervisory Research Ecologist (Pilliod, dpilliod@usgs.gov) and Ecologist (Welty), U.S. Geological Survey, Forest and Rangeland Ecosystem Science Center, 970 Lusk St., Boise, ID 83706, USA; and Assessment, Inventory and Monitoring Lead (Toevs), Bureau of Land Management, 1849 C Street NW, Washington DC 20240, USA.