NATURAL RESOURCES CONSERVATION SERVICE
CONSERVATION INNOVATION GRANTS
FINAL REPORT

Project Title: Development and demonstration of a sagebrush restoration planning tool based on ecological site descriptions

Principal Investigator: Jonathan Haufler, Executive Director, Ecosystem Management Research Institute

Project Timeframe: September 15, 2011 to September 30, 2014

CIG Grant Number: 69-3A75-11-185

Report Submission Date: December 15, 2014

Deliverables:

1) Web-based sagebrush planning tool (pending NRCS implementation) that is:
    - accessible and applicable to technical service providers, producers, agency biologists, range conservationists, or other parties interested in sagebrush ecosystem restoration, sage-grouse habitat improvement, or similar objectives, and
    - directly applicable to habitat improvement work by the sage-grouse incentive program.
2) Webinar to describe the use of the tool, once it is up and running on NRCS' website, to meet objectives including habitat improvement or restoration for a particular site;
3) Technical note and New Technology and Innovative Approach Fact Sheet produced once the tool is up and running on the NRCS website;
4) On-the-ground demonstration projects to provide examples of application of how the sagebrush planning tool can be used in sagebrush restoration projects;
5) Final project report; and
6) Presentation on the project findings at the 2015 Society for Range Management meeting, plus additional presentations once the tool is up and running on NRCS's website.

Contents

EXECUTIVE SUMMARY

The importance for sagebrush conservation continues to grow along with concerns for sagebrush obligate species such as sage-grouse and the uncertainty surrounding the impacts of climate change. The NRCS addressed the need for more information on sagebrush ecosystems, specifically those that support sage-grouse, by designating a special EQIP fund to support the Sage-Grouse Initiative or SGI. These funds are intended to be used for projects that restore, enhance, or increase our understanding of sage-grouse habitat.

Across the sagebrush biome, a consistent and readily available system and information source is lacking that would aid in identifying specific restoration goals in terms of desired plant communities, including detailed descriptions of the appropriate grass and forb components as well as sagebrush species for each specific location. A management tool that would provide this information using descriptions of native plant communities desired for sagebrush restoration and linked to a web-based mapping source for any selected location within the sagebrush biome would be extremely valuable and timely to on-the-ground habitat improvement and restoration efforts. The desired plant communities would be guided by reference to native plant communities for each specific ecological site, but which have also been adjusted for sustainability under future predicted climatic conditions for each location.

This report details an approach that uses an existing classification system, ecological sites, to highlight areas that have the highest potential to support sagebrush and sage-grouse. The tool covers the entire sagebrush biome which encompasses an area of 336.3 million acres across 11 states. Primary outputs of this tool are maps of potential sagebrush cover, sagebrush height, and dominate sagebrush species based on the reference plant community for each ecological site that can aid in selecting locations for sagebrush restoration of sage-grouse habitat improvements.

The objective of this project was to produce a web-accessible planning tool that complements on-going sage-grouse and sagebrush conservation efforts by providing descriptions of site specific plant communities evaluated for predicted climate change as reference conditions for restoration or habitat improvement objectives. The tool is designed to be available through the NRCS Web Soil Survey at the following address: http://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm

Two demonstration areas in Utah were used to test the application of the planning tool. The tool was used to evaluate the restoration treatments previously selected for the sites and the expected plant community responses to what the tool identified as desirable future conditions. Planned plant communities for the demonstration areas were evaluated in comparison to reference conditions for each site and for their predicted sustainability under predicted future climate conditions for each site.

Along with the development of the planning tool another primary output from this project was downscaled climate data for the sagebrush biome that is summarized by ecological site. These data represent the potential climate in the year 2099 based on the A2 emission scenario. The downscaled

climate data allowed for a variety of secondary data products. These included the percent change in temperature and precipitation from current conditions to future conditions in 2099, potential shifts in dominant sagebrush species based on precipitation changes, and potential shifts in dominant grass species based on precipitation and temperature changes.

The planning tool is useful for restoration at the landscape level as well as the local level. As noted, the tool has the ability to map dominant sagebrush type, potential sagebrush cover, and sagebrush height. This makes it possible to identify groupings of ecological sites that could potentially provide larger areas of sagebrush habitat. By concentrating restoration efforts into larger areas there are increased likelihoods that the restoration will benefit a wide variety of sagebrush-associated wildlife species. The mapping feature can also be used for conservation area planning or other efforts that seek to identify large areas of contiguous habitat.

INTRODUCTION

The Ecosystem Management Research Institute (EMRI) is a non-profit organization internationally recognized for its expertise in providing implementation assistance to native ecosystem restoration and biodiversity conservation efforts. In particular, EMRI has considerable expertise in using available vegetation classification tools and associated data to map and describe native ecosystem diversity as a reference for maintaining and restoring appropriate levels of ecosystem representation in diverse landscapes. EMRI works with state and federal agencies, as well as private landowners and other organizations to help identify and describe native ecosystem diversity restoration goals for a defined area or landscape.

Several key EMRI personnel participated in this project:

Dr. Jonathan Haufler, Project Manager
Dr. Haufler is the Executive Director of EMRI and has B.S., M.S., and Ph.D. degrees in wildlife biology. He was responsible for project coordination with NRCS staff and other cooperators on this project. In addition, Jon's considerable experience with NRCS ecological sites and broad understanding of grass and shrubland ecology as well as sage-grouse habitat needs were instrumental in the implementation of this project.

Carolyn Mehl, Ecologist
Ms. Mehl is a wildlife biologist and ecosystem ecologist with EMRI and has B.S. and M.S. degrees in wildlife biology. She assisted with project implementation, tool development, and report preparation.

Scott Yeats, GIS Analyst
Mr. Yeats is a wildlife biologist and GIS analyst with EMRI and has a B.S. degree in wildlife biology. He assisted with data compilation, GIS and mapping support, tool development, and report preparation.

Other project cooperators include:

Rory Reynolds, Utah Department of Natural Resources (UDNR)
Mr. Reynolds leads the Watershed Restoration Program at UDNR and was the primary contact for the demonstration projects and data collection used in this project.

Groups providing letters of support for the project include:

Utah Department of Natural Resources
North American Grouse Partnership
Theodore Roosevelt Conservation Partnership
Cooperative Sagebrush Initiative
Rocky Mountain Bird Observatory
Defenders of Wildlife

Project Funding:

The on-the-ground treatment costs associated with the demonstration projects and conducted by the Utah Department of Natural Resources were used as a matching cash contribution to this project. Treatments included various brush control, seeding, and grazing management practices in Utah.

PROJECT NEED AND PURPOSE

Considerable interest has been directed at the conservation of sage-grouse as their numbers have steadily declined over the last 90+ years (Connelly et al. 2000). Conserving and restoring sagebrush ecosystems is recognized by many biologists and interested organizations as the key to conserving this iconic species. More recently, efforts to conserve and restore sagebrush ecosystems have accelerated in reaction to the increasing complexity of threats to these ecosystems. Threats include wildfires, invasive plant species, and even lack of wildfire which can lead to expansion of native species such as juniper into sagebrush ecosystems. These threats coupled with the impacts of expanding energy development and uncertainty about the effects of climate change have all contributed to a heightened sense of urgency to address conservation issues in these important ecosystems (Miller et al. 2011). The recent USFWS determination of sage-grouse as a species warranted but precluded for listing under the Endangered Species Act (USFWS 2010) has further underscored the urgent need for sagebrush ecosystem conservation or restoration.

Numerous efforts are currently underway by federal and state agencies, as well as non-governmental organizations, to delineate and map; 1) sagebrush-dominated plant communities, 2) distributions of sage-grouse, and 3) designated core areas to be avoided by energy and other developments or conversely, as locations for sage-grouse habitat improvements. Many of these efforts are primarily focused on identifying key areas needed by sage-grouse and other sagebrush associated species by either mapping areas used by sage-grouse today or areas with sagebrush in sufficient amounts and densities to serve as sage-grouse habitat. While these efforts are certainly important, less focus has been directed at identifying the grass, forb, and sagebrush species associated with the desired plant community at a specific site to provide the best habitat for sage-grouse if the site can be managed to its optimum potential. In addition, a focus on existing vegetation does not incorporate available information on the potential of other sites providing future sagebrush plant communities through appropriate management actions to restore functional sagebrush ecosystems in appropriate locations.

In 2011, NRCS implemented its Sage-Grouse Initiative (SGI) which designated a special EQIP fund of $30 million for sage-grouse habitat improvement projects. Practices to improve sage-grouse habitat that may be applied through EQIP funding include reseeding expired CRP fields to diverse, native ecosystems and improving poor quality rangeland through seeding efforts. These types of projects would be enhanced by providing a landowner or land manager with the best available information on sustainable native plant communities to restore to any specific identified site, and the potential of each site for providing quality sage-grouse habitat (USDA, NRCS 2011). To accomplish this, a consistent delivery system and information source is needed across the sagebrush biome to aid in identifying specific ecosystem restoration goals in terms of the desired plant communities, including detailed descriptions of the appropriate grass and forb components in addition to the sagebrush species for each specific location. A Sagebrush Ecosystem Restoration Tool (SERT) that could provide descriptions of desired native plant communities and link to a web-based database and mapping interface for any selected location within the sagebrush biome would be extremely valuable and timely to on-the-ground habitat improvement and restoration efforts. Ideally, the tool output would utilize the best information on native plant communities for each specific ecological site, and this information could be further adjusted for sustainability under future predicted climatic conditions.

NRCS has an effective classification system for identifying and describing restoration objectives for native plant communities throughout the sagebrush biome. Specifically, this classification system is referred to as ecological site descriptions (ESDs) and is mapped using soils information within delineated Major Land Resource Areas (MLRAs). This landscape level system provides various benefits for setting sagebrush restoration goals. MLRAs identify areas with similar geo-climatic properties to help identify where similar plant communities and responses to various disturbances, practices, or treatments would be expected (USDA, NRCS 2006). As MLRAs are linked to climatic influences, they also serve as useful boundaries for evaluating climate change and incorporating recommendations to address predicted climate change effects. The combination of ESDs and MLRAs as a classification system for the sagebrush biome can also be used to:

- Compile and produce a seamless GIS map of the sagebrush biome displaying each ecological site or combination of similar sites based on soils and other associated variables,
- Map the differences in the ecological potential of each site relative to conditions that will support sagebrush ecosystems,
- Provide a basis for defining potential ecosystem services in a consistent manner, including each site's potential (not existing conditions) for quality sage-grouse habitat,
- Provide descriptions of specific reference plant communities for use in restoration that can be used by producers, landowners, technical service providers and land managers,
- Provide detailed state and transition models that describe and model plant community dynamics under historical disturbance processes and under current disturbances, and
- Provide an evaluation of the potential effects of climate change on plant community dynamics to ensure that restoration goals recommend conditions that will be resilient and sustainable under predicted future conditions.

Project Objectives

The primary objective of this project was to produce a web-based sagebrush restoration planning tool that would complement on-going sage-grouse habitat improvement and sagebrush restoration efforts by providing descriptions of site specific reference conditions for native plant communities. This capability is currently not available in a readily accessible format and easy to use tool for this purpose.

The project also had the objective of evaluating future climate conditions across the sagebrush biome. These predicted conditions could then be used to evaluate site specific reference conditions for their sustainability under the future predicted climate conditions.

The tool could then be used to assist in meeting a variety of land management or planning objectives by producers, landowners, land managers, federal and state agencies, industry, and non-governmental organizations. For example, as core areas for sage-grouse are identified, the restoration tool could be used to identify the optimal site-specific plant community(ies) to be maintained or restored in that location to maximize benefits to sage-grouse and other sagebrush-associated species and that will be sustainable under predicted climate conditions.

The project also demonstrated the application of the planning tool to achieve desired sagebrush improvements at selected treatment sites.

To summarize there are 3 objectives for this project:

1. Develop an easy to use, innovative web-based sagebrush restoration planning tool for use across the sagebrush biome that is based on ecological sites and provides information on specific desired plant communities, adjusted for future climate conditions to restore at any selected location.
2. Identify the relative potential of each ecological site to provide sage-grouse habitat in terms of nesting and wintering habitat needs.
3. Demonstrate how this tool can be used in projects to achieve desired climate-adjusted restoration conditions.

This project provides several innovations. First, development of the planning tool provides new information in a readily available format. It builds from existing information contained in ecological site descriptions while providing a consistent description of optimal potential plant communities as reference information for each site. The tool will be linked to this report to provide recommendations for adjusting native plant communities so that they will be resilient and sustainable under future predicted climate conditions. Each ecological site can be evaluated for its potential to produce sagebrush. The web-based accessibility of this information in a format readily usable by technical service providers, wildlife biologists, and interested producers is also new.

The remainder of the report will be divided into sections corresponding to the objectives of this project and will describe the implementation process, methods, results and discussions for each objective.

PROJECT AREA

The planning tool was developed for the sagebrush biome that extends across 11 western states (Figure 1), where ecological sites have been developed and described. The sagebrush biome encompasses roughly 336.3 million acres. Ecological sites are the primary analysis units used in the project, and they are developed and described within MLRAs. A total of 33 MLRAs covering an area of approximately 416 million acres comprised the entire project area (Figure 1).

Figure 1. Map of project area showing the sagebrush biome and the underlying MLRAs.

DEVELOPMENT OF A SAGEBRUSH ECOSYSTEM RESTORATION TOOL

Coordination of Tool Development with NRCS

The initial step in the development of the SERT was to evaluate the best solution for making the tool publicly available on the internet as this would be a primary influence on all other steps in the tool development. As part of the project scope, EMRI worked with NRCS to identify the best website location for the tool. At about the same time we were evaluating possible options, we noted continued and substantive improvements were being made to WEB SOIL SURVEY (WSS) that were complimentary to hosting the sagebrush ecosystem restoration tool. As stated on the WSS website, "WSS is produced and operated by the USDA Natural Resources Conservation Service (NRCS) and provides access to the largest natural resource information system in the world. WSS has soil maps and data available online for more than 95 percent of the nation's counties and anticipates having 100 percent in the near future. The site is updated and maintained online as the single authoritative source of soil survey information".

Ecological sites are based on groupings of soil types and are currently available as part of WSS's associated database and features. WSS provides a user friendly interface and the ability to identify and map an "Area of Interest" (AOI). Once an AOI is identified, a multitude of modules/tools are available to map, review, and provide tabular output for the associated data or modules that use and summarize the soil attribute data for a diversity of purposes. As an example, under the "Soils Data Explorer/Suitabilities and Limitations for Use/Land Management" tabs, tools currently exist to evaluate the potential of the soils within the AOI to support specific land management objectives; such as "Soil Restoration Potential", "Pygmy Habitat Potential", and "Pesticide Runoff Potential" which identify the "low", "moderate", or "high" potential of a soil polygon, relative to that tools purpose.

After reviewing the capabilities of WSS we determined it was an excellent interface to support the SERT. Our initial proposal was to add a Sage-grouse Habitat Restoration Tool that would identify the sagebrush ecosystems to restore at an identified site based on their value for sage-grouse nesting, brood-rearing, or wintering habitat. We made initial contacts with NRCS's David Hoover, Acting National Director of Soil Surveys, and Homer Sanchez, Rangeland Management Specialist, to discuss the potential of using WSS to house the tool. Both David and Homer were receptive to this idea, and David facilitated a meeting with additional NRCS staff to discuss this opportunity. The individuals participating in these discussions included:

EMRI	**NRCS**
Jon Haufler	David Hoover, National Director Soil Surveys
Carolyn Mehl	Homer Sanchez, RM Specialist
Scott Yeats	Curtis Talbot, RM Specialist
	George Teachman, National Soil Survey

Multiple conference calls were held in 2012, 2013, and early 2014 between EMRI personnel and NRCS personnel that included WSS specialists and Ecological Site Inventory System (ESIS) specialists to discuss this opportunity. As a result of these discussions, both EMRI and NRCS interest was high for making this a component of WSS but there were additional technical aspects to be discussed and evaluated. Three primary concerns were identified. First, EMRI was proposing to run a program housed within WSS that would interface with the Ecological Site Information System (ESIS) database and access ecological site plant community information to identify ecological sites with the potential to support sagebrush ecosystems. This tool would also provide the ability to evaluate and rate sage-grouse habitat potential for the potential sagebrush ecosystems that could be maintained or restored on each ecological site. The mechanism to accomplish this was not currently in place between WSS and ESIS and would require contractor programming from outside the agency. Additional contractor funds were not available in the timeframe needed to complete this project. Second, the development of a tool to rate sage-grouse habitat potential required input from NRCS wildlife biologists to evaluate the use of WSS for that purpose. That discussion took place between EMRI personnel, Homer Sanchez, and 3 NRCS wildlife biologists that included Marcus Miller, Shane Green, and Jeremy Maestas. The results of the biologists input were as follows:

1. Interpretation of sage-grouse habitat quality should not be provided by a WSS supported tool.
2. Preferred tool output should include the ability to identify sagebrush ecosystem restoration potential as well as to identify sagebrush community height potential in terms of tall (>1.0m), medium (0.5-1.0m) or short (<0.5m) sagebrush heights.
3. A final concern was related to incorporating the ability to provide information on projected climate change influences on species composition. NRCS personnel felt this was a direction that would require additional discussion internally and did not want to make this information available as part of the tool at this time. The information was developed and provided with this report and can be referenced with the supporting documentation provided with the tool when it is developed for WSS implementation.

As a result of these discussions, the final decision was to modify project objective #1 to not provide the online tool at this time but rather provide a description of the proposed tool for future integration with WSS when funding for programming is secured.

Description of Anticipated WSS Sagebrush Planning Tool

The following describes how the SERT is envisioned to work once it is made available in the WSS. The various steps are described and depicted below as examples of what the webtool might look like once implemented. An initial task is to identify an area of interest and to delineate this area in the WSS. Once into the system, the SERT should be found in the Land Management section under the Soil Data Explorer tab. The tool allows a user to graphically display the sagebrush potential for all soil map units within an AOI. The tool also provides a link to the primary plant community for a soil component of interest. Figures 2-11 depict how the tool would work and what it might look like in WSS. Appendix A provides an example of a proposed model to use SSURGO data to identify sagebrush potential for an ecological site.

Figure 2. Step 1. Enter the Web Soil Survey Interface at - websoilsurvey.nrcs.usda.gov . Select the State and County tab.

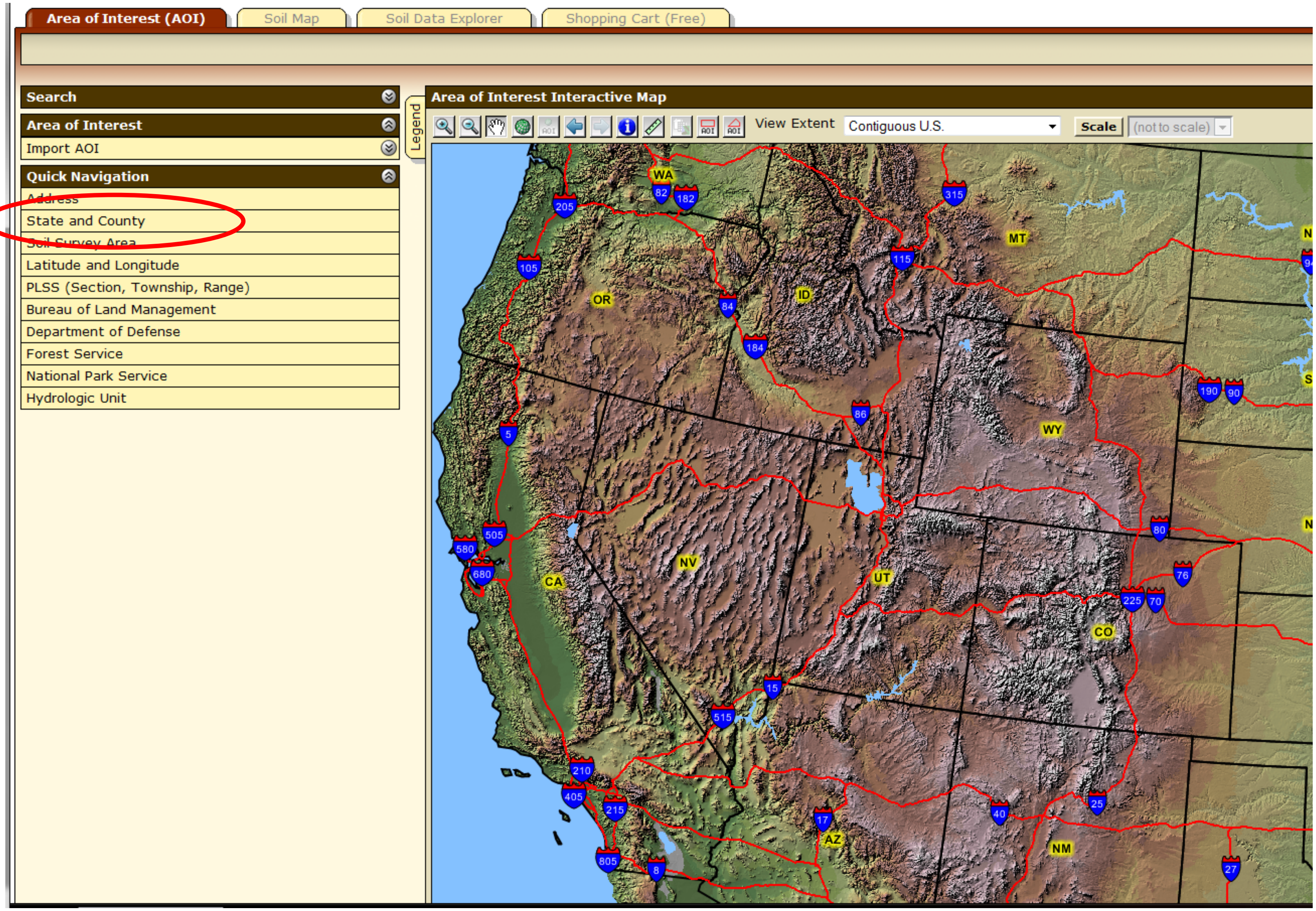


Figure 3. Step 2. Enter the state and county for the area you would like to display.

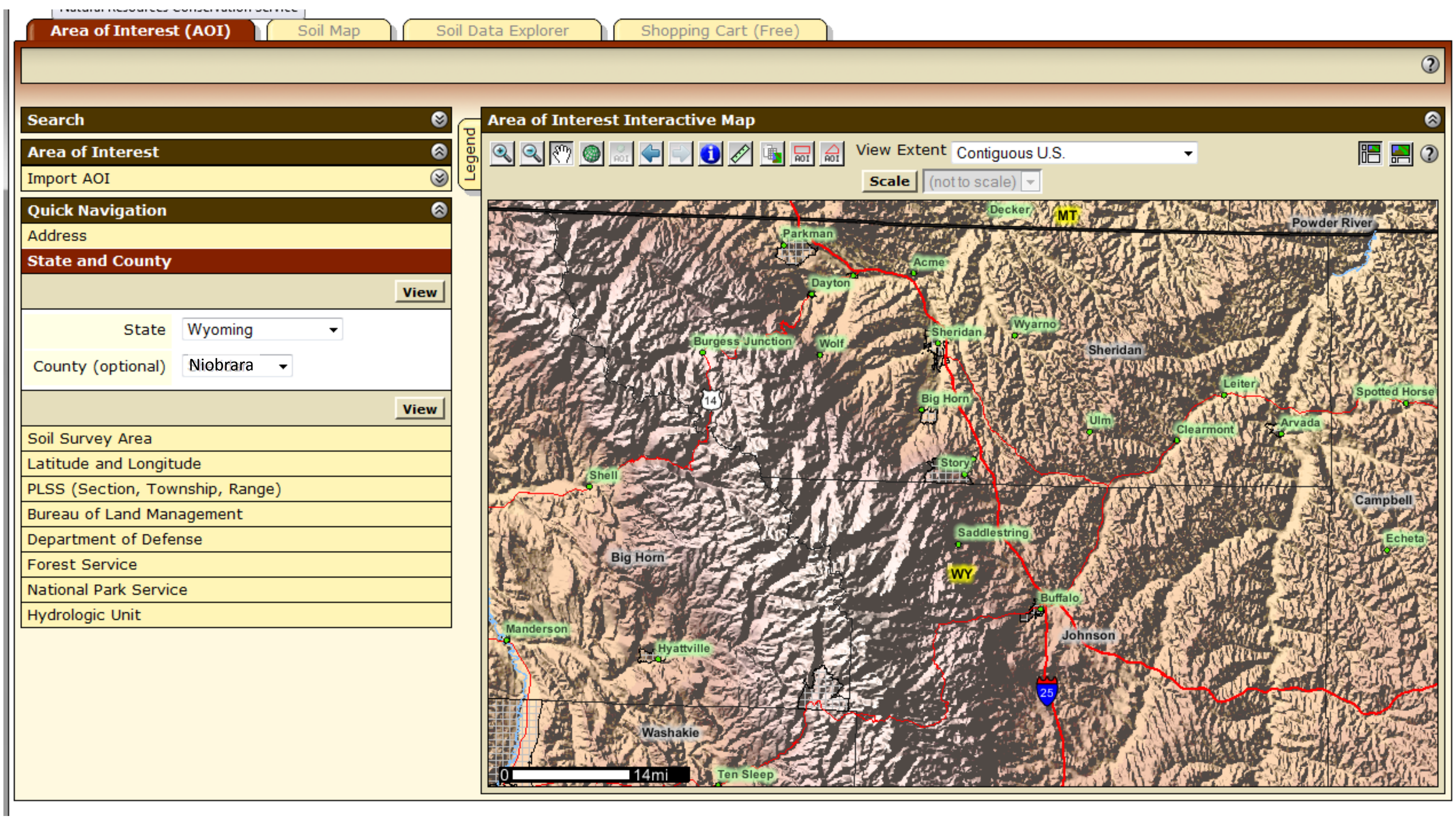


Figure 4. Step 3. Use the Area of Interest (AOI) tool to select the area you would like to evaluate.

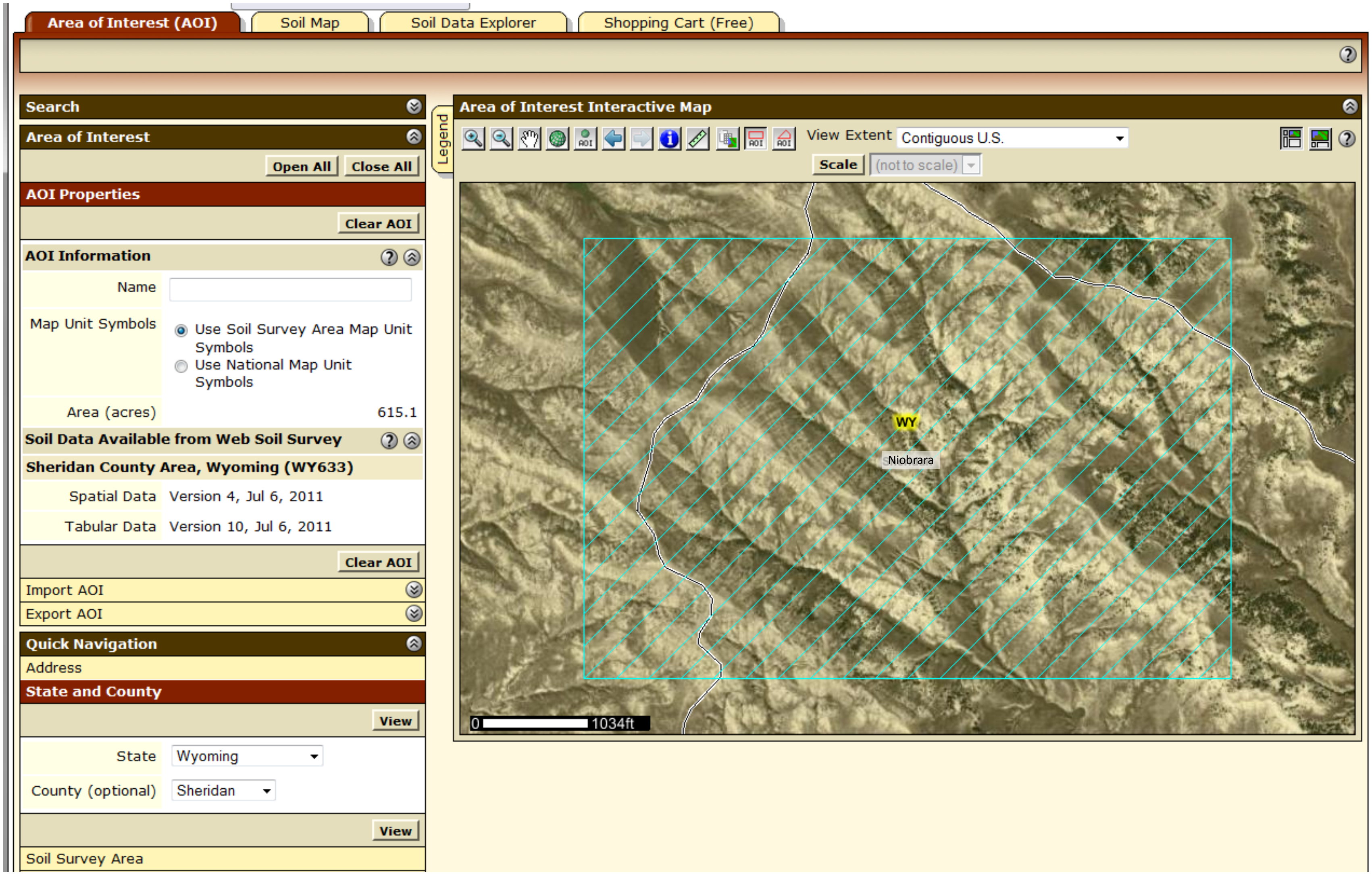


Figure 5. Step 4. Navigate to the “Soil Data Explorer” tab and then to the “Suitabilities and Limitations” for Use tab.

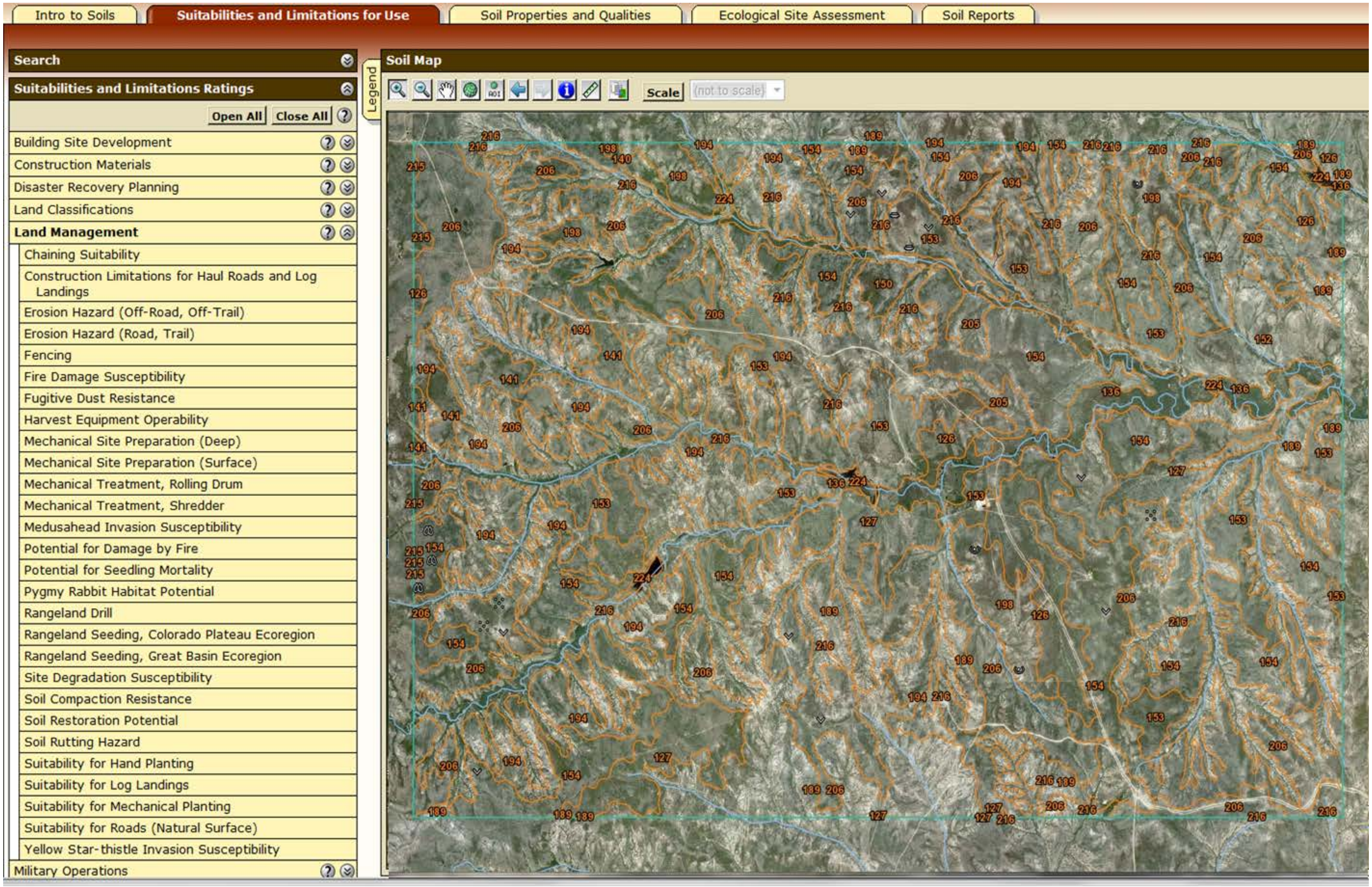


Figure 6. Step 5. Select the "Suitabilities and Limitations Ratings" sub-list – then select the "Land Management" sub-list to display the "Sagebrush Ecosystem Restoration Potential" tool.

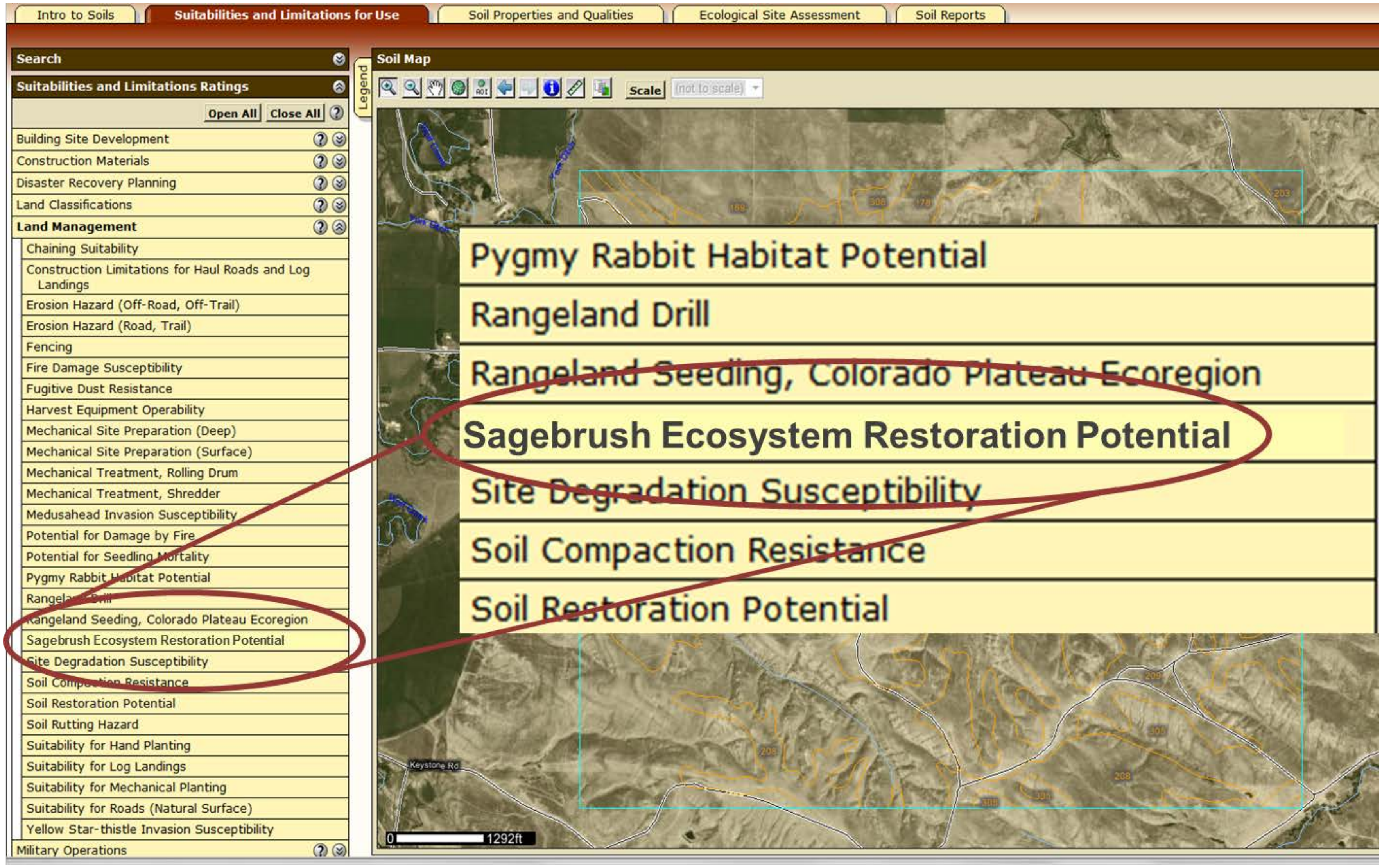


Figure 7. Step 6. Select the "Sagebrush Ecosystem Restoration Potential" tool and check the "map" box to display a map of sagebrush restoration potential for the Area of Interest.

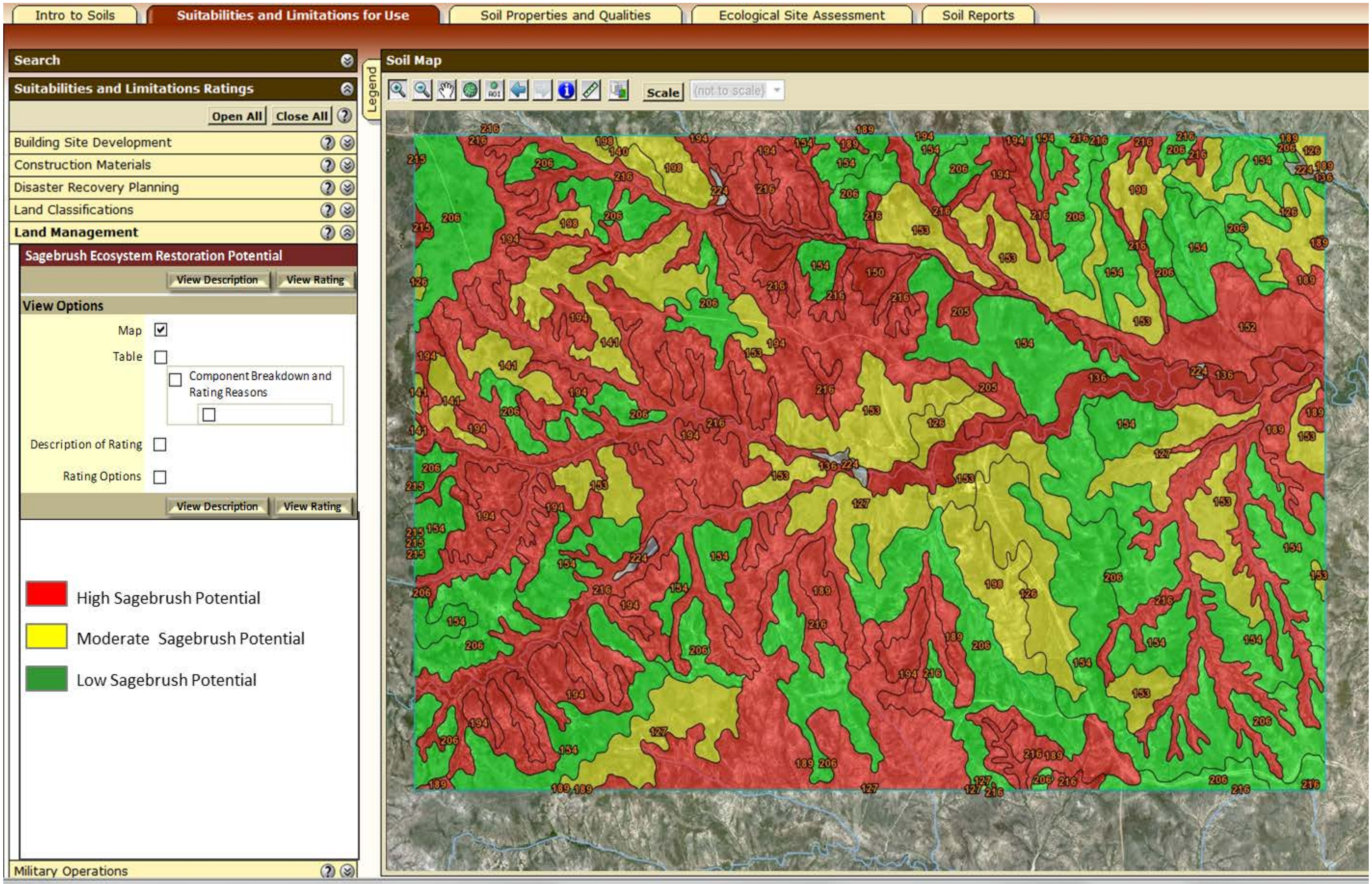
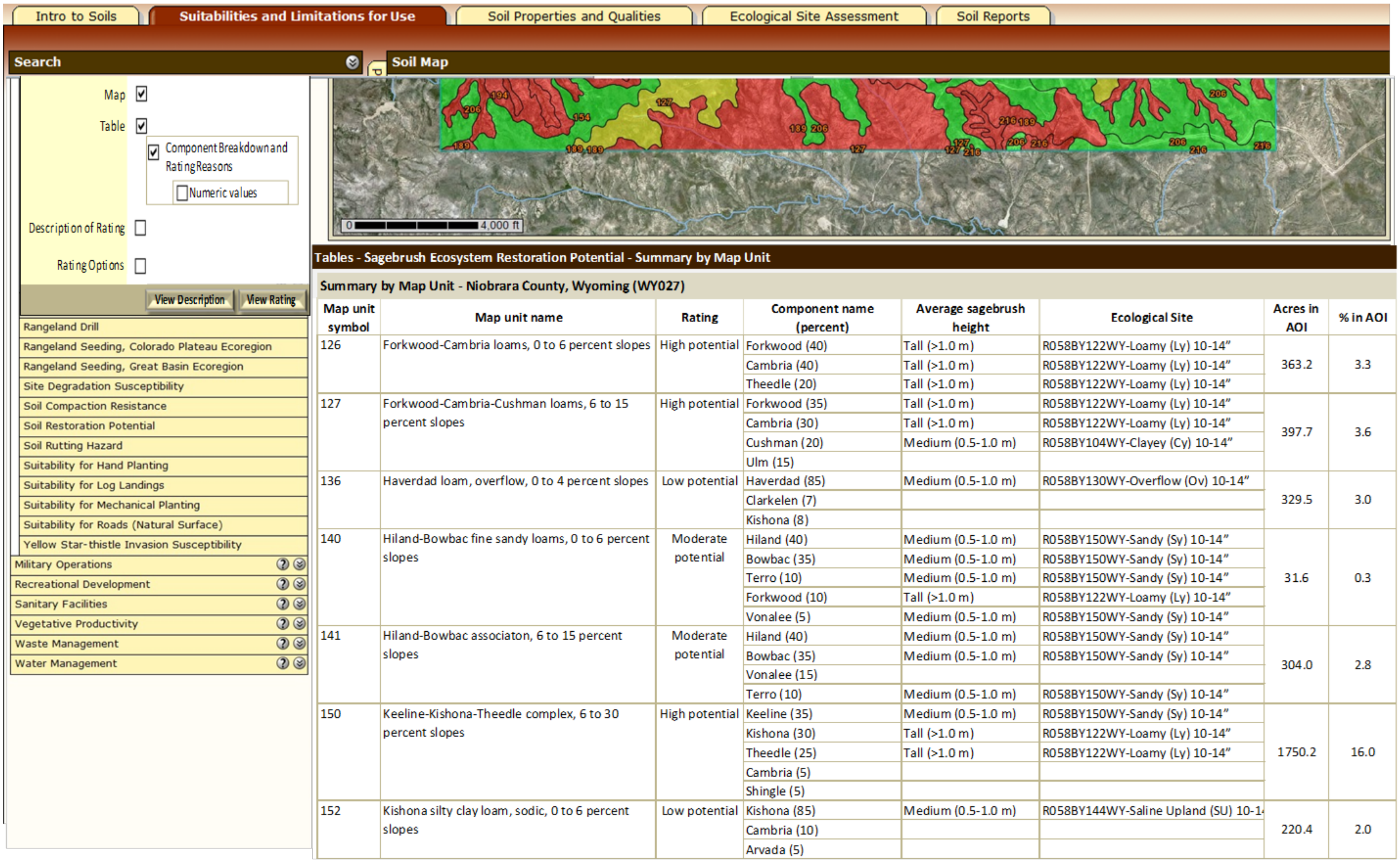


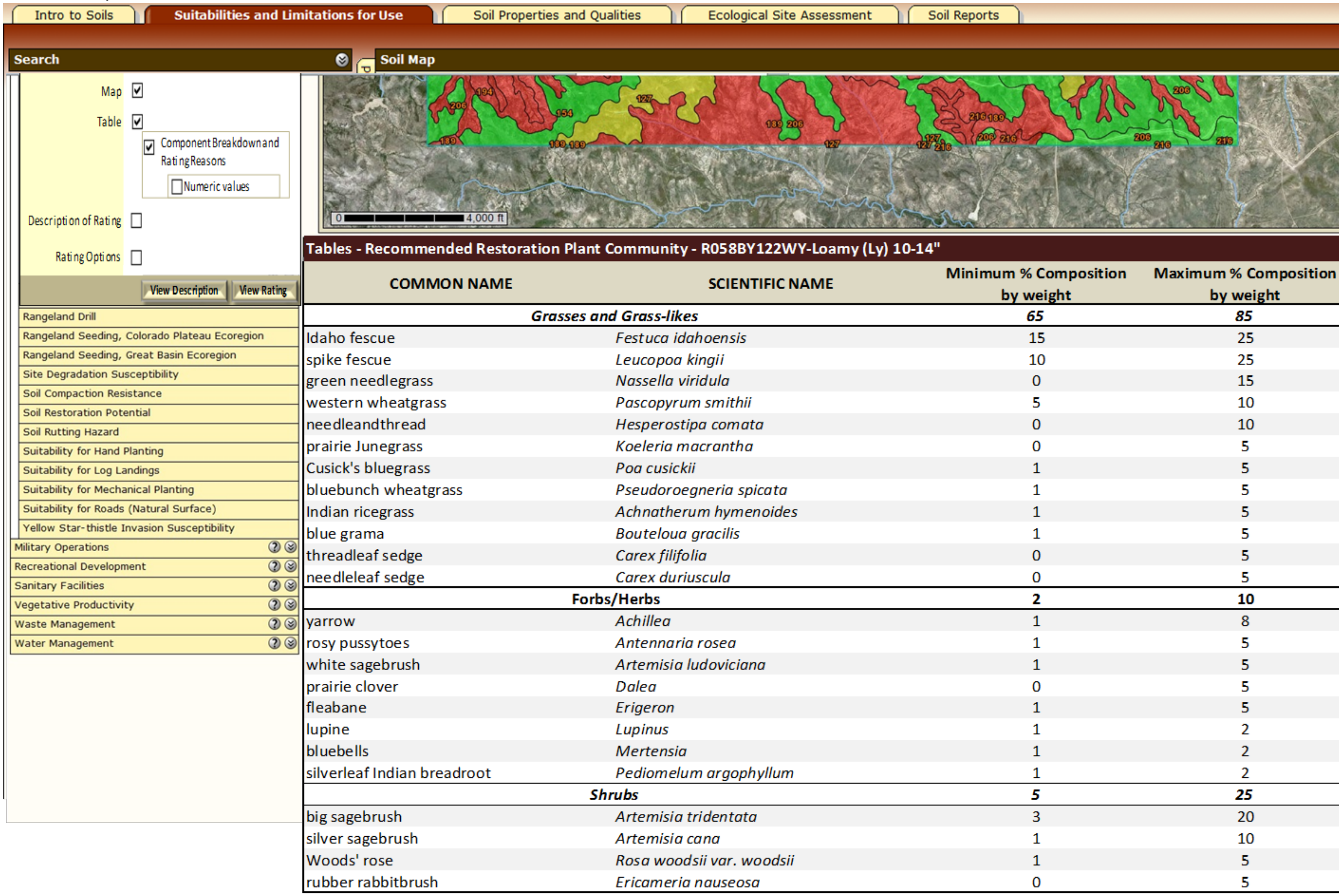
Figure 8. Step 7. Check the “table” box to display a summary table for each of the soil map units (numbered polygons) in the Area of Interest. This includes information on ecological site, average sagebrush height-classes (tall (>1m), medium (0.5-1m), and short (<0.5 m)), and number of acres in the AOI, etc.



Summary by Map Unit - Niobrara County, Wyoming (WY027)

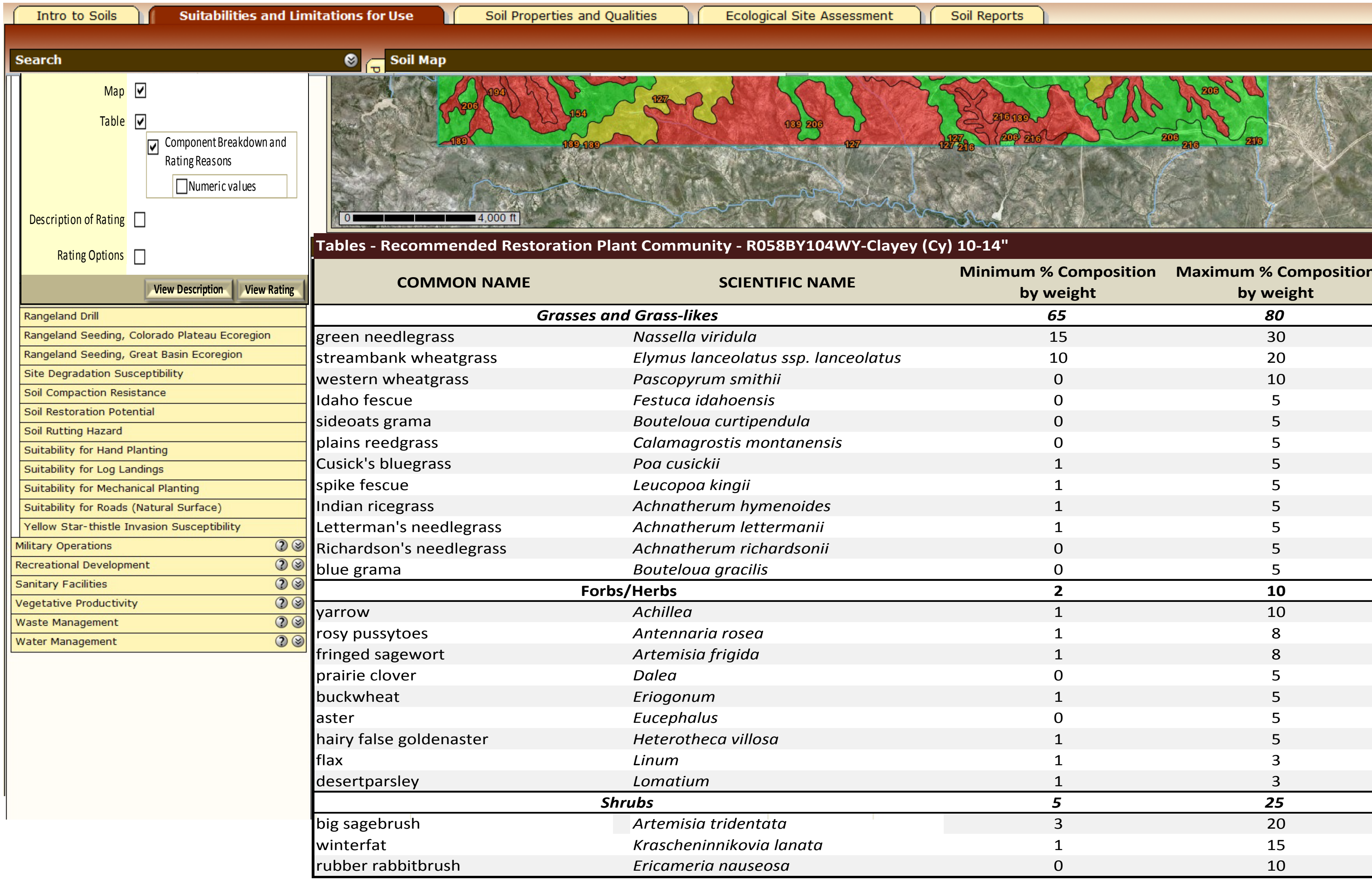
Map unit symbol	Map unit name	Rating	Component name (percent)	Average sagebrush height	Ecological Site	Acres in AOI	% in AOI
126	Forkwood-Cambria loams, 0 to 6 percent slopes	High potential	Forkwood (40)	Tall (>1.0 m)	R058BY122WY-Loamy (Ly) 10-14”	363.2	3.3
			Cambria (40)	Tall (>1.0 m)	R058BY122WY-Loamy (Ly) 10-14”		
			Theedle (20)	Tall (>1.0 m)	R058BY122WY-Loamy (Ly) 10-14”		
127	Forkwood-Cambria-Cushman loams, 6 to 15 percent slopes	High potential	Forkwood (35)	Tall (>1.0 m)	R058BY122WY-Loamy (Ly) 10-14”	397.7	3.6
			Cambria (30)	Tall (>1.0 m)	R058BY122WY-Loamy (Ly) 10-14”		
			Cushman (20)	Medium (0.5-1.0 m)	R058BY104WY-Clayey (Cy) 10-14”		
			Ulm (15)				
136	Haverdad loam, overflow, 0 to 4 percent slopes	Low potential	Haverdad (85)	Medium (0.5-1.0 m)	R058BY130WY-Overflow (Ov) 10-14”	329.5	3.0
			Clarkelen (7)				
			Kishona (8)				
140	Hiland-Bowbac fine sandy loams, 0 to 6 percent slopes	Moderate potential	Hiland (40)	Medium (0.5-1.0 m)	R058BY150WY-Sandy (Sy) 10-14”	31.6	0.3
			Bowbac (35)	Medium (0.5-1.0 m)	R058BY150WY-Sandy (Sy) 10-14”		
			Terro (10)	Medium (0.5-1.0 m)	R058BY150WY-Sandy (Sy) 10-14”		
			Forkwood (10)	Tall (>1.0 m)	R058BY122WY-Loamy (Ly) 10-14”		
			Vonalee (5)	Medium (0.5-1.0 m)	R058BY150WY-Sandy (Sy) 10-14”		
141	Hiland-Bowbac associaton, 6 to 15 percent slopes	Moderate potential	Hiland (40)	Medium (0.5-1.0 m)	R058BY150WY-Sandy (Sy) 10-14”	304.0	2.8
			Bowbac (35)	Medium (0.5-1.0 m)	R058BY150WY-Sandy (Sy) 10-14”		
			Vonalee (15)				
			Terro (10)	Medium (0.5-1.0 m)	R058BY150WY-Sandy (Sy) 10-14”		
150	Keeline-Kishona-Theedle complex, 6 to 30 percent slopes	High potential	Keeline (35)	Medium (0.5-1.0 m)	R058BY150WY-Sandy (Sy) 10-14”	1750.2	16.0
			Kishona (30)	Tall (>1.0 m)	R058BY122WY-Loamy (Ly) 10-14”		
			Theedle (25)	Tall (>1.0 m)	R058BY122WY-Loamy (Ly) 10-14”		
			Cambria (5)				
			Shingle (5)				
152	Kishona silty clay loam, sodic, 0 to 6 percent slopes	Low potential	Kishona (85)	Medium (0.5-1.0 m)	R058BY144WY-Saline Upland (SU) 10-1	220.4	2.0
			Cambria (10)				
			Arvada (5)				

Figure 9. Step 7, continued. The table information also displays the recommended sagebrush ecosystem restoration plant community for each of the ecological sites identified in the Area of Interest. Following is an example of the "Loamy 10-14" ecological site recommended plant community.



COMMON NAME	SCIENTIFIC NAME	Minimum % Composition by weight	Maximum % Composition by weight
	Grasses and Grass-likes	***65***	***85***
Idaho fescue	*Festuca idahoensis*	15	25
spike fescue	*Leucopoa kingii*	10	25
green needlegrass	*Nassella viridula*	0	15
western wheatgrass	*Pascopyrum smithii*	5	10
needleandthread	*Hesperostipa comata*	0	10
prairie Junegrass	*Koeleria macrantha*	0	5
Cusick's bluegrass	*Poa cusickii*	1	5
bluebunch wheatgrass	*Pseudoroegneria spicata*	1	5
Indian ricegrass	*Achnatherum hymenoides*	1	5
blue grama	*Bouteloua gracilis*	1	5
threadleaf sedge	*Carex filifolia*	0	5
needleleaf sedge	*Carex duriuscula*	0	5
	Forbs/Herbs	**2**	**10**
yarrow	*Achillea*	1	8
rosy pussytoes	*Antennaria rosea*	1	5
white sagebrush	*Artemisia ludoviciana*	1	5
prairie clover	*Dalea*	0	5
fleabane	*Erigeron*	1	5
lupine	*Lupinus*	1	2
bluebells	*Mertensia*	1	2
silverleaf Indian breadroot	*Pediomelum argophyllum*	1	2
	Shrubs	***5***	***25***
big sagebrush	*Artemisia tridentata*	3	20
silver sagebrush	*Artemisia cana*	1	10
Woods' rose	*Rosa woodsii var. woodsii*	1	5
rubber rabbitbrush	*Ericameria nauseosa*	0	5

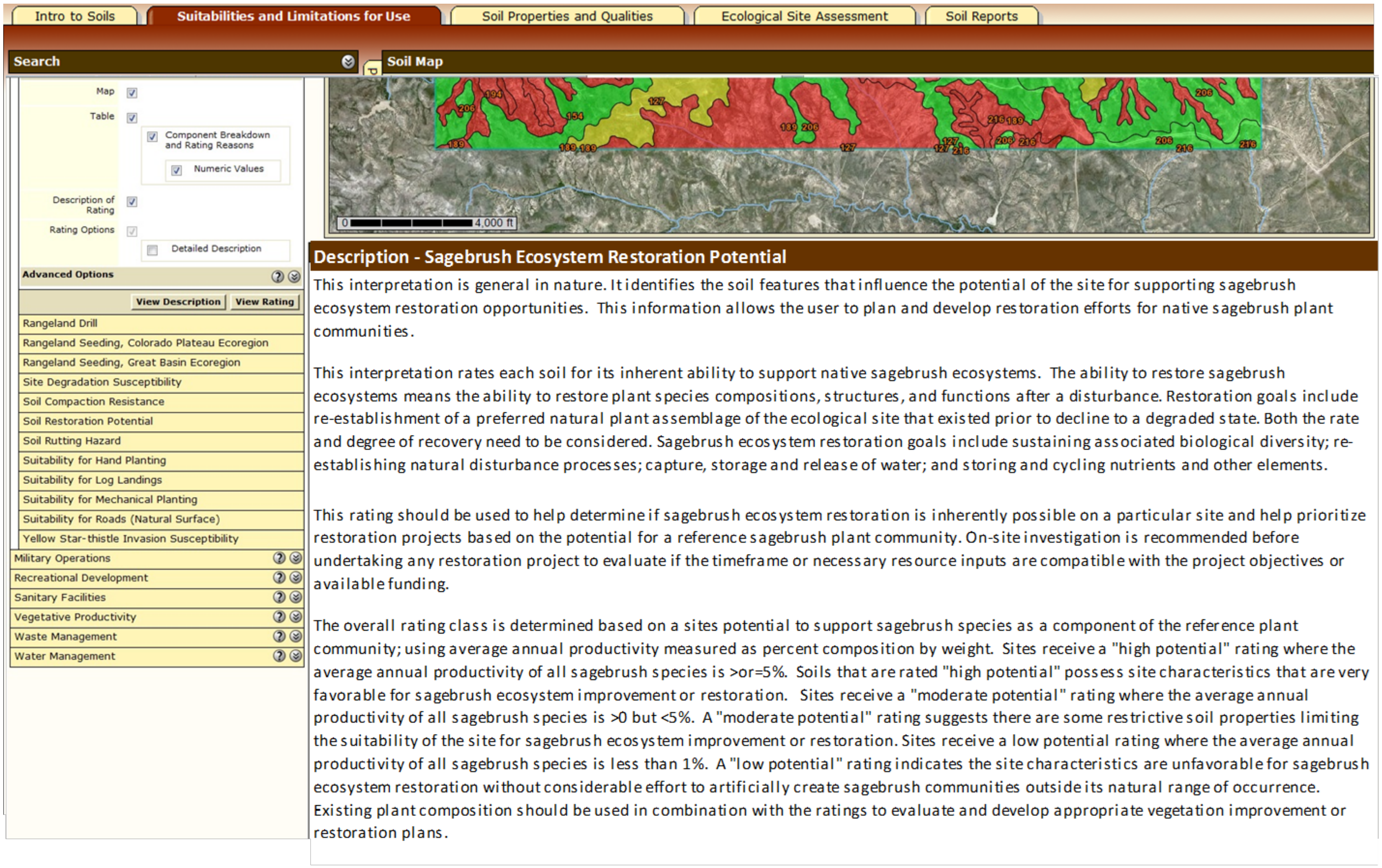
Figure 10. Step 7, continued. Another example of a recommended restoration plant community for the “Clayey 10-14” ecological site.



Tables - Recommended Restoration Plant Community - R058BY104WY-Clayey (Cy) 10-14"

COMMON NAME	SCIENTIFIC NAME	Minimum % Composition by weight	Maximum % Composition by weight
Grasses and Grass-likes		***65***	***80***
green needlegrass	*Nassella viridula*	15	30
streambank wheatgrass	*Elymus lanceolatus ssp. lanceolatus*	10	20
western wheatgrass	*Pascopyrum smithii*	0	10
Idaho fescue	*Festuca idahoensis*	0	5
sideoats grama	*Bouteloua curtipendula*	0	5
plains reedgrass	*Calamagrostis montanensis*	0	5
Cusick's bluegrass	*Poa cusickii*	1	5
spike fescue	*Leucopoa kingii*	1	5
Indian ricegrass	*Achnatherum hymenoides*	1	5
Letterman's needlegrass	*Achnatherum lettermanii*	1	5
Richardson's needlegrass	*Achnatherum richardsonii*	0	5
blue grama	*Bouteloua gracilis*	0	5
Forbs/Herbs		**2**	**10**
yarrow	*Achillea*	1	10
rosy pussytoes	*Antennaria rosea*	1	8
fringed sagewort	*Artemisia frigida*	1	8
prairie clover	*Dalea*	0	5
buckwheat	*Eriogonum*	1	5
aster	*Eucephalus*	0	5
hairy false goldenaster	*Heterotheca villosa*	1	5
flax	*Linum*	1	3
desertparsley	*Lomatium*	1	3
Shrubs		***5***	***25***
big sagebrush	*Artemisia tridentata*	3	20
winterfat	*Krascheninnikovia lanata*	1	15
rubber rabbitbrush	*Ericameria nauseosa*	0	10

Figure 11. Step 8. By checking the "Description of Rating" box, a text box is displayed that describes the objectives and rating categories for the SERT.



As shown, the planning tool is designed to be a module within the existing NRCS Web Soil Survey interface. For each ecological site, the tool describes the composition, structure, and other characteristics of each desired reference plant community for restoration or maintenance at a site. In addition, utilizing the climate change analysis described below, reference conditions have been evaluated for their potential sustainability under future predicted conditions so that desired conditions that will be sustainable can be recommended. The climate assessment is not planned to be included in the WSS, but will be linked to information contained in this report.

The SERT was designed to complement on-going sage-grouse evaluation and planning efforts. It uses ecological sites as a basis for developing the description and characteristics of the highest quality potential plant community in terms of sagebrush ecosystem conditions that would be favorable for sage-grouse and many other sagebrush-associated species at each specific site. As such, the tool identifies the potential of each site that can be produced through restoration/improvement treatments. It does not evaluate existing vegetation conditions. It will complement on-going efforts that seek to identify the most important areas for management of sage-grouse in terms of current habitat conditions and core areas to be protected from effects of energy or other developments. Areas that are identified through these efforts that are critical to the persistence of sage-grouse and other sagebrush-associated species can then be targeted for improvements by comparing their existing conditions to the desired potential conditions, and identifying the appropriate practices that will move the plant community towards these desired conditions. For example, in many areas, grass and forb compositions are sub-optimal, and the tool will provide a list of forbs that the ecological site can support and that will enhance habitat conditions. In other locations, cheatgrass or other invasive species have degraded habitat conditions, or juniper has invaded, reducing the quality of the site for sage-grouse and other species. The SERT would provide detailed descriptions of the appropriate plant communities to restore, factoring in its sustainability under future predicted conditions. It would also identify which locations in core areas have the greatest potential for restoring quality sage-grouse habitat for nesting or winter habitat needs, so that limited restoration dollars can be allocated to locations where maximum benefits can be achieved.

Developing Reference Plant Species Characteristics

The primary datasets for sagebrush and grass species compositions were acquired from the Ecological Site Information System (ESIS) database administered by the NRCS. The data represent a snapshot of the database on July 22, 2013, and included data for all MLRAs that intersected the project area (Table 1). Composition data were taken from the RANGE_SPECIES_COMPOSITION table. This table contains data for each plant species potentially occurring on an ecological site and provides a high and low production value in pounds per acre. The PLANT_COMMUNITY_ID column was used to select only plant species that occurred in the HCPC or reference state. In addition, the RANGE_ANNUAL_PRODUCTION table was used to get the total production for the site in pounds per acre for each growth form (grass, forb, shrub, and tree). The PLANT_COMMUNITY_ID column was also used in this table to select only data that described the HCPC or reference state. The values for annual production were used to generate estimates of percent composition for each plant species on the site. The composition values were summarized by ecological site ID.

In order to categorize sagebrush communities more completely data were also acquired from the SSURGO dataset administered by NRCS (Soil Survey Staff 2013). Composition data were queried from the COEPLANTS table and annual production was queried from the COMPONENT table. The SSURGO data listed each plant species' percent composition of total production. These data were summarized by ecological site ID.

Table 1. Major Land Resource Areas (MLRAs) with available data in the ESIS database when accessed on July 22, 2013.

MLRA Symbol	MLRA Name	MLRA Symbol	MLRA Name
6	Cascade Mountains, Eastern Slope	42	Southern Desertic Basins, Plains, & Mountains
7	Columbia Basin	43B	Central Rocky Mountains
8	Columbia Plateau	46	Northern Rocky Mountain Foothills
9	Palouse and Nez Perce Prairies	47	Wasatch and Uinta Mountains
10	Central Rocky & Blue Mountain Foothills	48A	Southern Rocky Mountains
11	Snake River Plains	48B	Southern Rocky Mountain Parks
13	Eastern Idaho Plateaus	49	Southern Rocky Mountain Foothills
21	Klamath and Shasta Valleys and Basins	51	High Intermountain Valleys
23	Malheur High Plateau	53A	Northern Dark Brown Glaciated Plains
24	Humboldt Area	54	Rolling Soft Shale Plain
25	Owyhee High Plateau	58A	Northern Rolling High Plains, Northern Part
28A	Great Salt Lake Area	58B	Northern Rolling High Plains, Southern Part
29	Southern Nevada Basin and Range	61	Black Hills Foot Slopes
30	Mojave Desert	67A	Central High Plains, Northern Part
32	Northern Intermountain Desertic Basins	67B	Central High Plains, Southern Part
34A	Cool Central Desertic Basins & Plateaus	69	Upper Arkansas Valley Rolling Plains
34B	Warm Central Desertic Basins & Plateaus	70A	Canadian River Plains and Valleys
35	Colorado Plateau	70B	Upper Pecos River Valley
36	Southwestern Plateaus, Mesas, & Foothills	70C	Central New Mexico Highlands
38	Mogollon Transition	77B	Southern High Plains, Northwestern Part
39	Arizona and New Mexico Mountains		

Potential Sagebrush

Potential sagebrush distribution under existing climate conditions was mapped across the 33 MLRAs that comprised the study area based on the potential vegetation communities identified in the ESD's. In addition, characteristics such as the potential height and potential amounts of sagebrush cover were also mapped. Within the study area there were approximately 100 million acres that did not have soils data or lacked plant composition data. There was an additional 105 million acres that did not support the soil and/or other characteristics to support sagebrush growth and reproduction. The remaining 211 million acres did have the potential site characteristics to support sagebrush growth and reproduction. Figure 12 shows potential sagebrush occurrence across the study area. This map is a representation of potential sagebrush occurrence as a percentage of the total ecological site production. "Low" sagebrush occurrence was mapped for sites with sagebrush listed as present but not in a sufficient quantity to have a composition value. "Moderate" sagebrush occurrence was mapped for sites with >0 to <5 % potential composition of sagebrush. Sites with 5% or more composition of sagebrush were mapped as "high" potential occurrence of sagebrush. These breaks were estimated to correlate with amounts of sagebrush cover that would be present in reference conditions, although data on the relationship of sagebrush productivity to cover percentages are lacking. As more and better data on amounts of sagebrush cover become available, these breaks may be adjusted for the overall tool or locally to better represent the desired conditions.

General categories of sagebrush height are shown in Figure 13. The heights are based on the average for the dominant sagebrush species that could potentially be present at the site. It is possible to have some variation in these categories due to site specific differences such as soil productivity or annual precipitation. Sites with sagebrush heights averaging <1.65 feet (0.50 m) characterized the "low" sagebrush height class. Sites with sagebrush height averaging from 1.65 to 3.3 feet (0.50- 1.0 m) were categorized as the "medium" sagebrush height class. Sites with sagebrush height averaging >3.3 feet (1.0 m) were categorized as the "tall" sagebrush height class. Sagebrush height was assigned categorically based on the dominant sagebrush species (Goodrich 2005, Shultz 2012, USDA-NRCS 2013).

The dominant sagebrush species present on each ecological site is displayed in Figure 14. This represents the sagebrush species with the largest average percent composition of production on each site.

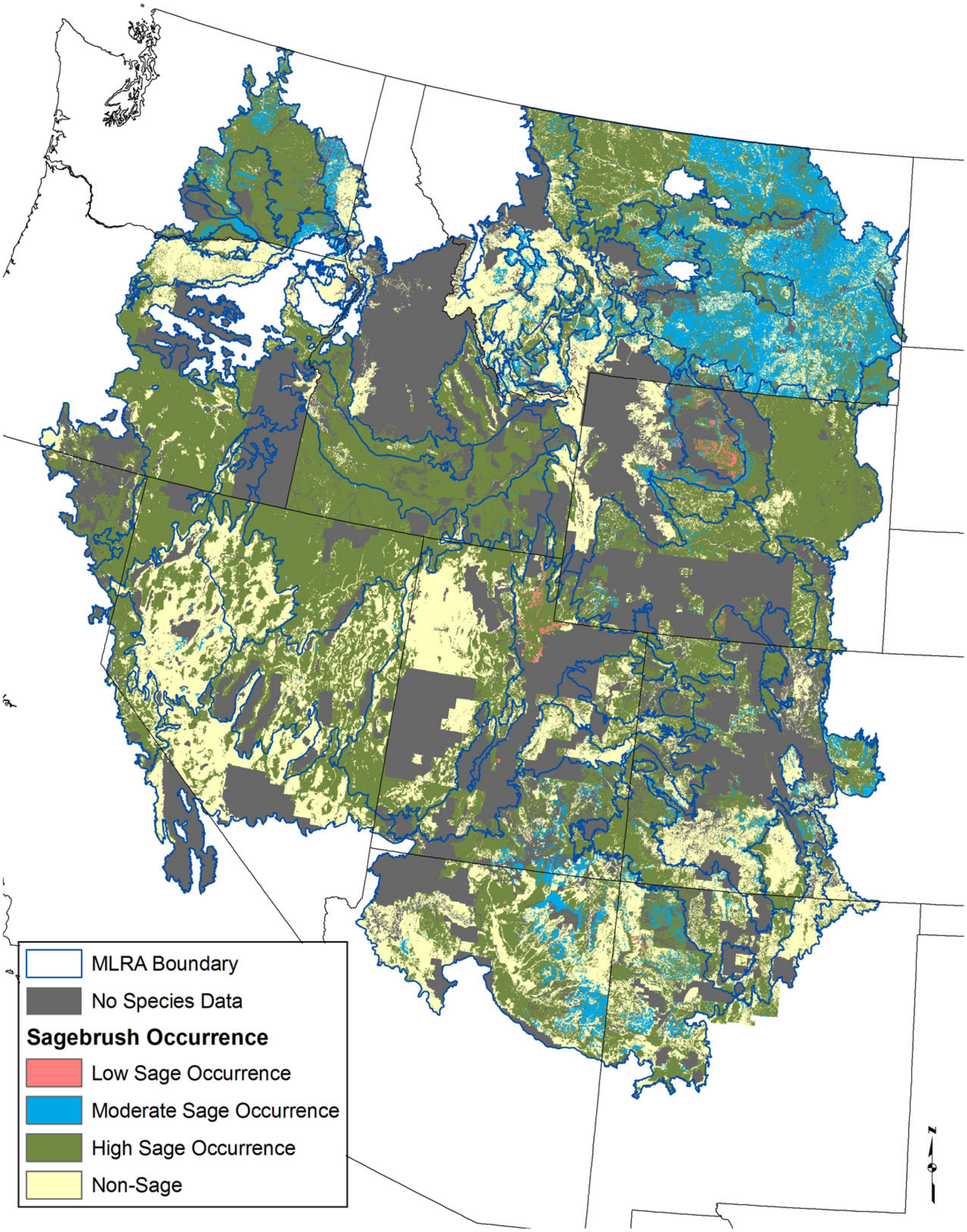


Figure 12. Sagebrush occurrence classes based on the percent composition of production by ecological site. See text for a description of each class.

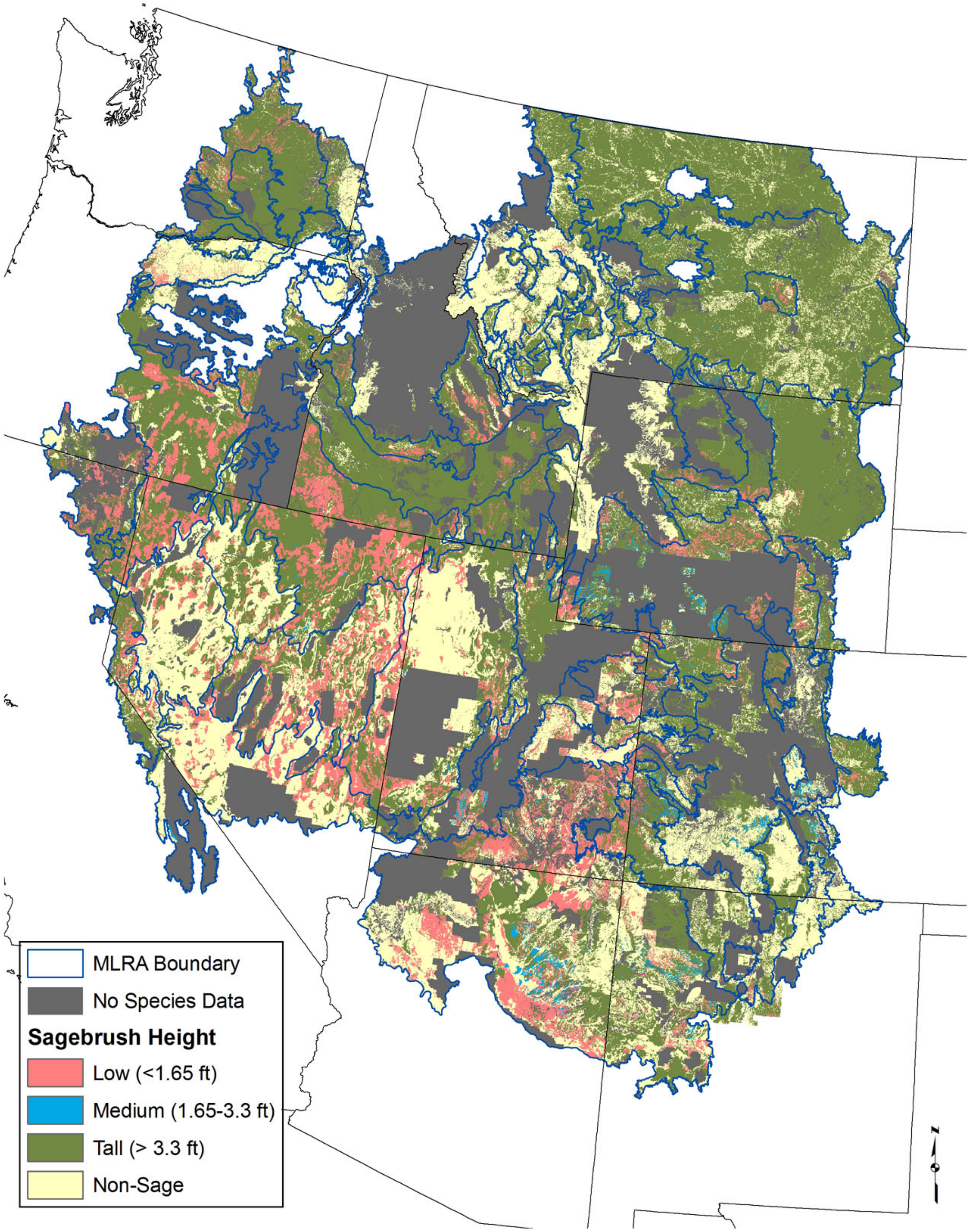


Figure 13. Sagebrush height class based on the average height of the dominant sagebrush species on each ecological site.

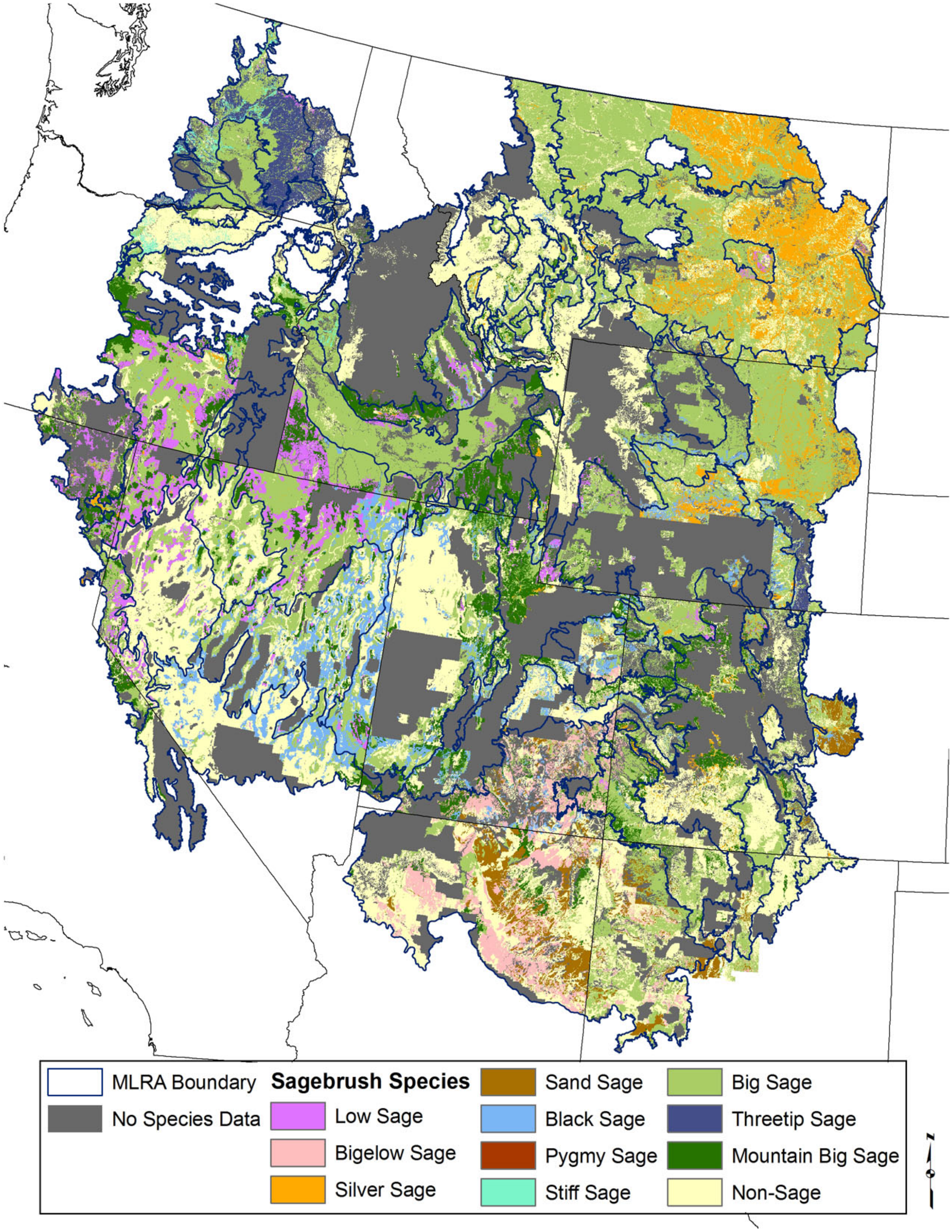


Figure 14. Dominant sagebrush species for each ecological site across the sagebrush biome.

Climate Adjusted Restoration in the Sagebrush Biome

Over the last 30 years, a growing recognition of the threat of climate change as a causal agent for indirect conversion of ecosystems and habitat loss has accelerated. A conclusion of the report of the U.S. Global Change Research Program (2009) is that “global warming is unequivocal and primarily human-induced.” While there are still many unknowns related to the effects of climate change, understanding how ecosystems will respond to climate change is important to evaluating the potential effects on fish and wildlife habitat (Saxon 2003). Terrestrial ecosystems are expected to change relative to plant species compositions, structures, and processes. Site-level changes to species compositions may result from temperature and/or precipitation changes that no longer allow a particular species to occur or through shifts in competitive advantages with other species at that site. Some ecosystems may become more vulnerable to invasion by nonnative invasive species. Primary productivity of ecosystems may increase or decrease depending on changes to available water or temperatures. The presence or amounts of some plant communities may change as a result of these influences. While many potential changes from climate change may be difficult to predict with great accuracy, models of projected climate change can be used to inform future management planning.

The base datasets for the climate analysis were comprised of downscaled Global Climate Models (GCMs) for the sagebrush biome from the World Climate Research Programme’s (WCRP) Coupled Model Intercomparison Project phase 3 (CMIP3) multi-model dataset. The datasets were downloaded from:
http://gdo-dcp.ucllnl.org/downscaled_cmip_projections/dcpInterface.html#Welcome

The downscaled temperature and precipitation projections of 16 CMIP3 models (Table 2) were used for analysis. Each model uses Bias Corrected Spatial Disaggregation (BCSD) statistical downscaling at the resolution of 1/8 degree to generate monthly estimates for precipitation and temperature. Data for the A2 emission scenario data were downloaded for years 2021-2099 to be used for estimating climate change. The A2 emission scenario is considered a higher rate of change scenario and was utilized over lower rates of change scenario for these comparisons, as the A2 scenario more closely represents the current directions influencing global response to moderating projected climate change impacts. In addition, data for existing conditions 1981-2012 were acquired from the PRISM website (http://www.prism.oregonstate.edu/normals/).

A series of steps were required to get the model outputs from their native format (netCDF) to a format that could be used for spatial analysis. The first step was to run a python script in ESRI ArcGIS (Appendix B). Each netCDF file is an encoded text file that includes monthly means for a single year. There are separate files for precipitation and temperature. The primary years considered for analysis were 2021-2050 and 2070-2099. These periods were selected to provide shorter term and longer term projected climate values. The python script was run 8 times for each CMIP3 model as it was necessary to run it separately for each climate variable, time period, and emission scenario. The output from the python scripts was a series of rasters (ESRI GRID format) that spatially depicted the climate data. There was a separate raster created for each permutation of month, year, emission scenario, and climate variable (temperature or precipitation).

Table 2. CMIP3 models used for downscaled climate predictions.

Originating Group	Country	CMIP3 ID
Bjerknes Centre for Climate Research	Norway	BCCR-BCM2.0
National Center for Atmospheric Research	USA	CCSM3
Canadian Centre for Climate Modelling & Analysis	Canada	CGCM3.1(T47)
Météo-France/Centre National de Recherches Météorologiques	France	CNRM-CM3.1
CSIRO Atmospheric Research	Australia	CSIRO-Mk3.0
Max Planck Institute for Meteorology	Germany	ECHAM5/MPI-OM
Meteorological Institute of the University of Bonn, Meteorological Research Institute of KMA, and Model and Data group.	Germany / Korea	ECHO-G
US Dept. of Commerce/NOAA/Geophysical Fluid Dynamics Laboratory	USA	GFDL-CM2.0
US Dept. of Commerce/NOAA/Geophysical Fluid Dynamics Laboratory	USA	GFDL-CM2.1
NASA / Goddard Institute for Space Studies	USA	GISS-ER
Institute for Numerical Mathematics	Russia	INM-CM3.0
Institute Pierre Simon Laplace	France	IPSL-CM4
Center for Climate System Research (The University of Tokyo), National Institute for Environmental Studies, and Frontier Research Center for Global Change (JAMSTEC)	Japan	MIROC3.2(medres)
Meteorological Research Institute	Japan	MRI-CGCM2.3.2
National Center for Atmospheric Research	USA	PCM
Hadley Centre for Climate Prediction and Research	UK	UKMO-HadCM3

The second step was to combine all of the rasters for a given CIMP3 model, emission scenario, and climate variable into a raster catalog, again using ESRI ArcGIS (specifically the Raster Tools in ArcCatalog). Each raster catalog was then used to create a new raster that averaged each climate variable for a given time period (2012-2050 or 2070-2099). The next step was to create new raster catalogs that were comprised of all the model results for each month. For example, a raster catalog named Jan_Prcp_A2_2070-2099 was created. The raster catalog contained 16 rasters (one from each CIMP3 model) with each one depicting the average January precipitation for the A2 emission scenario over the specified time period. There were 8 raster catalogs for each month and 96 total.

The final step in the creation of the downscaled climate grids was to mosaic the group of rasters within each raster catalog into a final GRID that contained the mean value for each climate variable (by month, year, and emission scenario) and depicted the continental United States. This was accomplished with the Raster Catalog to Raster Dataset tool in ESRI ArcCatalog using the mean mosaic method.

The second phase of analysis was to take the downscaled climate rasters and summarize them based on the Natural Resources Conservation Service's (NRCS) ecological sites. This was accomplished using the Zonal Statistics as a Table Tool in ArcGIS. The zone data were stored in a shapefile that depicted ecological site boundaries and the input value rasters were the downscaled climate grids created in the previous step. For each downscaled climate grid a DBF table was created with the mean value of the applicable climate variable by ecological site. The final step was to combine the monthly DBF tables into a single file that contained the data for all months by climate variable, year, and emission scenario.

Climate estimates for existing conditions were also summarized using NRCS ecological sites. The input value rasters for existing conditions were the PRISM normal data covering 1981-2012. The existing conditions were also summarized using the Zonal Statistics as a Table Tool in ArcGIS. The resulting monthly DBF tables were combined into a single file that contained the data for all months by climate variable, year, and emission scenario.

Plant Community Responses to Predicted Climate Change

The sagebrush composition data, along with information on precipitation requirements from the PLANTS database, were used in conjunction with the projected climate change data to predict future changes in sagebrush community species composition. This was first done for the dominant sagebrush species at each site. A good example of potential sagebrush change is found in MLRA 28A. Mountain big sagebrush (*Artemisia tridentata* ssp. *vaseyana*) occurs at higher elevation ecological sites within this MLRA. The PLANTS database lists the precipitation range for mountain big sagebrush as 14 to 45 inches annually. The projected climate change for the sites this sagebrush species occurs on predict that mean annual precipitation will drop to 12 inches. Sustainability is questionable at this precipitation level for mountain big sagebrush. This favors sagebrush species such as Wyoming big sagebrush (*Artemisia tridentata* ssp. *wyomingensis*) and basin big sagebrush (*Artemisia tridentata* ssp. *tridentata*) that have lower precipitation requirements of 8 to 20 inches and 6 to 35 inches, respectively. Restoration work at sites currently supporting mountain big sagebrush in this MLRA may want to consider shifting to Wyoming or basin big sagebrush in future efforts.

Future species composition for grass species was also predicted with the projected climate data. The three most dominant grass species at each site were included in the analysis. For grass species, changes were predicted based on both precipitation and temperature variables. The precipitation ranges for each species were acquired from the PLANTS database. For example, prairie Junegrass (*Koeleria macrantha*) in MLRA 28A is expected to decrease based on predicted changes in annual precipitation. The PLANTS database lists the annual precipitation range of prairie Junegrass as 14 to 20 inches. In many areas of MLRA 28A the annual precipitation is projected to drop to 12 inches. This is likely detrimental to prairie Junegrass and will favor species with lower precipitation requirements such as Sandberg bluegrass (*Poa secunda*), James' galleta (*Pleuraphis jamesii*), sand dropseed (*Sporobolus cryptandrus*), and Indian ricegrass (*Achnatherum hymenoides*).

Temperature changes could also affect sagebrush ecosystems. One approach to evaluating climate change has concentrated on evaluating the response of species by traits such as photosynthetic pathways (Dukes 2007). There are two photosynthetic pathways, C3 and C4, which characterize different grass species. The primary difference between these two functional types is the difference between the photosynthetic pathway where C3 grasses produce 3 carbon molecules and C4 grasses produce 4 carbon molecules during photosynthesis. C3 species are also frequently referred to as cool season grasses and C4 species are referred to as warm season grasses.

As the balance between C3 and C4 dominance within a plant community is believed to be responsive to climate change, this is often the focus of discussions aiming to predict future climate change conditions (Collatz et al. 1998, Hattersley 1983, Fischer et al. 2008). In general, there are three primary consequences of climate change on plant communities, elevated levels of CO_2 in the atmosphere and changes in average temperatures and precipitation. Elevated CO_2 improves photosynthesis in C4 plants but also leads to higher productivity in C3 plants. However, increasing temperatures generally decrease productivity of C3 plants, potentially counteracting the advantages of elevated CO_2 levels. Precipitation, depending on when it occurs, can have positive effects on productivity levels for both C3 and C4 species.

Morgan et al. (2008) described the expected effects of climate change on North America and the Great Plains:

> *"Along with rising global temperatures, predictions are for more frequent and longer-lasting heat waves, higher atmospheric humidity, more intense storms, and fewer and less severe cold periods. Warming in North America is expected to be greater than for the overall planet. Precipitation will tend to increase in Canada and the northeastern United States, and decrease in the southwestern United States. Seasonality of precipitation is also predicted to change, with relatively more precipitation falling in winter and less in summer. The desiccating effect of higher temperatures is expected to more than offset the benefit of higher precipitation, resulting in lower soil water content and increased drought throughout most of the Great Plains."*

While some believe the ability to predict how climate change will impact plant community compositions is limited (Morgan et al. 2008), other researchers have been evaluating variables that may be used to help predict how change may occur. Common variables which have been and continue to be evaluated are the use of temperature and precipitation to predict the future balance of C3 to C4 plant communities. Some researchers believe temperature plays a major role in determining the C3/C4 balance of grasslands (Ehleringer et al. 1997, Epstein et al. 1997). As an example, Fischer et al. (2008) analyzed the soil organic matter (SOM) and fine roots from 55 native grassland sites widely distributed across the US and Canadian Great Plains to examine possible indicators of the relative production of C3 vs. C4 plants at the continental scale. They observed the following:

> *"Our results reveal that not all climate indices are equally strong predictors of %C4. In particular, the results…. indicate that %C4 in the North American Great Plains grasslands are especially sensitive to the climate in July, suggesting that the outcome of competition between C3 and C4 plants was particularly sensitive to climate during this narrow window of time. Mixed C3 and C4 systems persist in Great Plains grasslands where July average temperature is* $70.7 \pm 5.6\,^{O}F$*; systems are C3 dominated (<33% C4) below this range and C4 dominated (>66% C4) above it."*

We reviewed the potential for composition changes in sagebrush communities caused by temperature shifts based on the photosynthetic pathway analyses as described for most genera by Waller and Lewis (1979). Ecological sites with a mean July temperature < 76.3ºF were considered better suited to C3 plants and sites with mean July temperature > 76.3ºF were considered better suited to C4 plants (Fischer et al. 2008). Sites that historically have been <76,3^{o}F but are predicted to move above this temperature were identified as potentially unsustainable for the existing plant community under predicted future conditions. Although precipitation appears to play a secondary role in determining competitive advantage, C4 grasses are also able to use the reduced summer moisture resources more effectively than C3 species, indicating that C4 species will likely become more dominant under the Fischer et al. (2008) model. For example, in MLRA 28A, prairie Junegrass is currently a common C3 species. However, as predicted July temperature increases above 76.3º F in many areas of this MLRA, prairie Junegrass can be expected to show reductions in amounts with possible corresponding increases in C4 species such as James' galleta and sand dropseed.

The changes in mean annual precipitation and temperature by MLRA are shown in Figures 15 and 16. When mapping these changes by ecological site, future climate change predictions for the year 2099 with the A2 emission scenario show several general patterns for precipitation (Figure 17) and temperature (Figure 18). In the southwestern portion of the study area consisting of Utah, northern New Mexico and southern Nevada the mean annual precipitation is predicted to decrease and the mean annual temperature is also expected to decrease. The majority of the sagebrush biome is predicted to see an increase in mean annual temperature. In addition, the northern half of the study area is predicted to see an increase in mean annual precipitation.

There were 1,000 ecological sites that had sagebrush present or the potential for sagebrush as well as climate data. Of these sites, we projected that 71 are likely to experience a predicted change in sagebrush type. These were sites where the predicted change in precipitation by year 2099 moved the site outside the range that current sagebrush species typically occur. Figure 19 shows the sagebrush ecological sites and depicts the sites with a predicted change in dominant sagebrush species.

There were 1,469 ecological sites with plant information for grasses and climate data. Projected changes in precipitation by year 2099 resulted in an estimated 5 sites where all three dominant grass species could change, 59 sites where two grass species could change, 144 sites where one grass species could change, and 1,261 sites with no predicted change in grass species composition. Figure 20 shows the ecological sites with grass species data and the location of possible changes in species composition due to changes in precipitation.

Projected changes in temperature by year 2099 resulted in an estimated 657 sites where all three dominant grass species could change, 210 sites where two grass species could change, 126 sites where one grass species could change, and 476 sites with no predicted change in grass species composition. Figure 21 shows the ecological sites with grass species data and the location of possible changes in species composition due to changes in temperature.

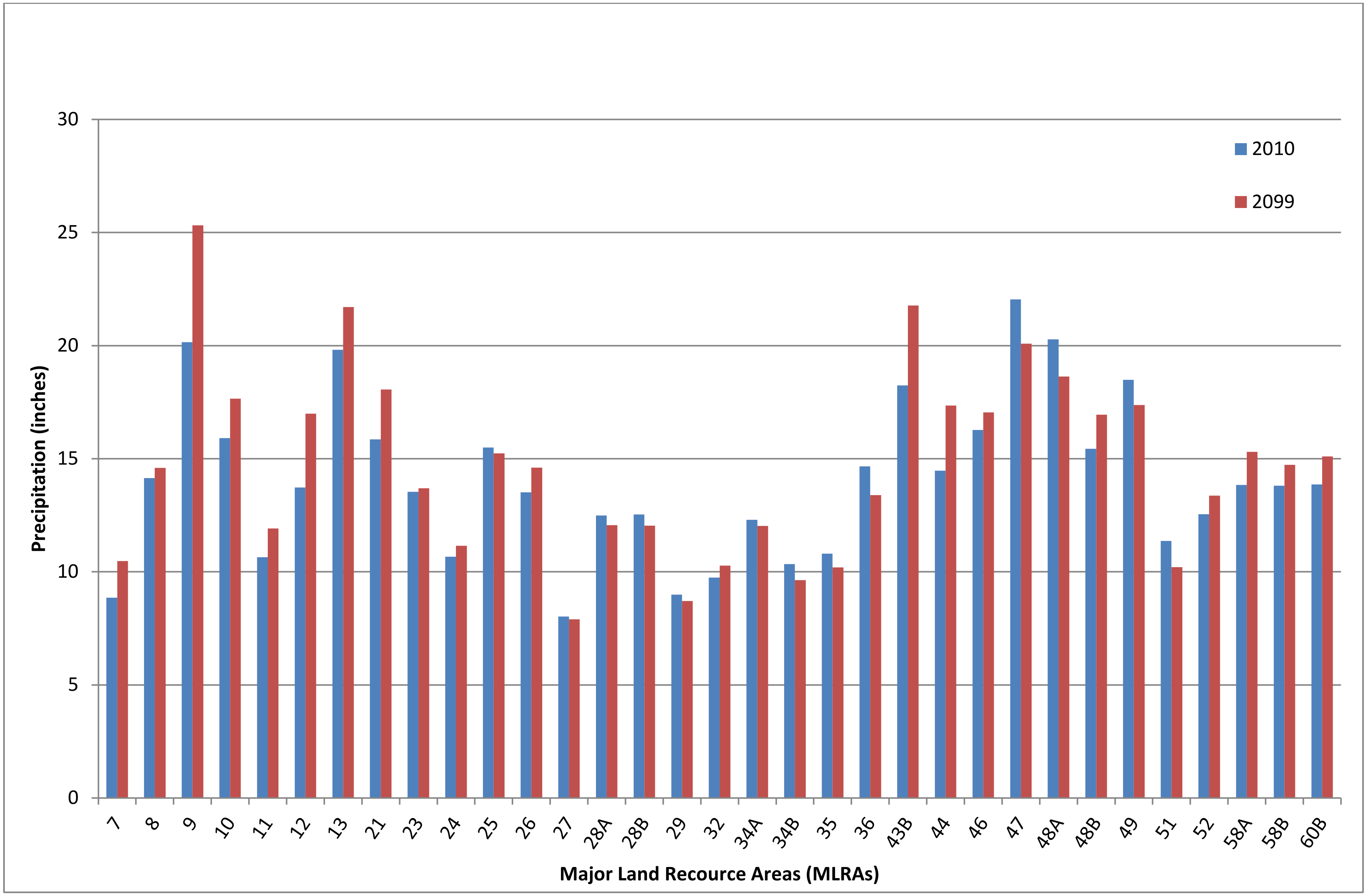


Figure 15. Predicted mean annual precipitation by MLRA for present and future conditions based on the A2 emission scenario.

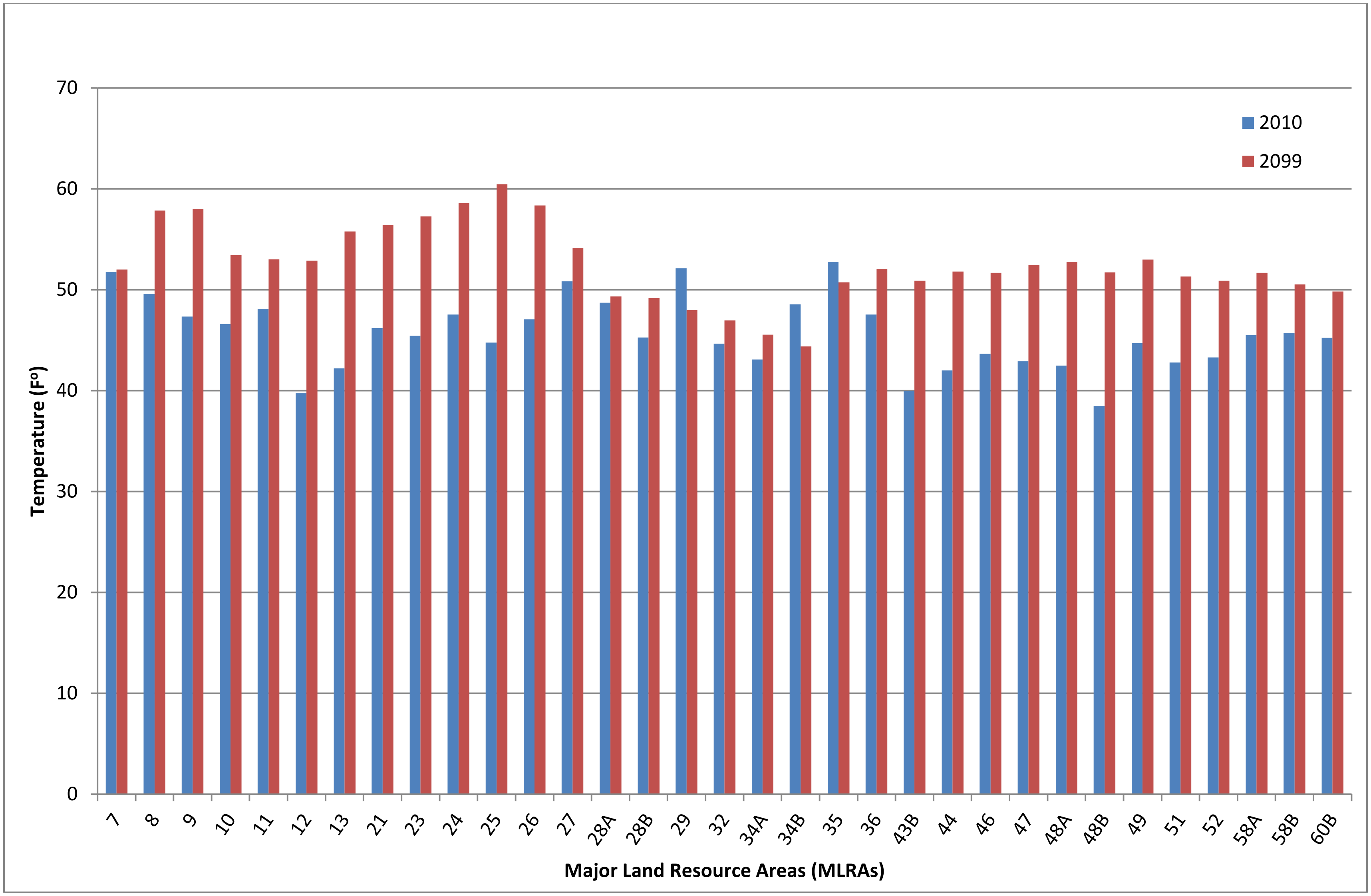


Figure 16. Predicted mean annual temperature by MLRA for present and future conditions based on the A2 emission scenario.

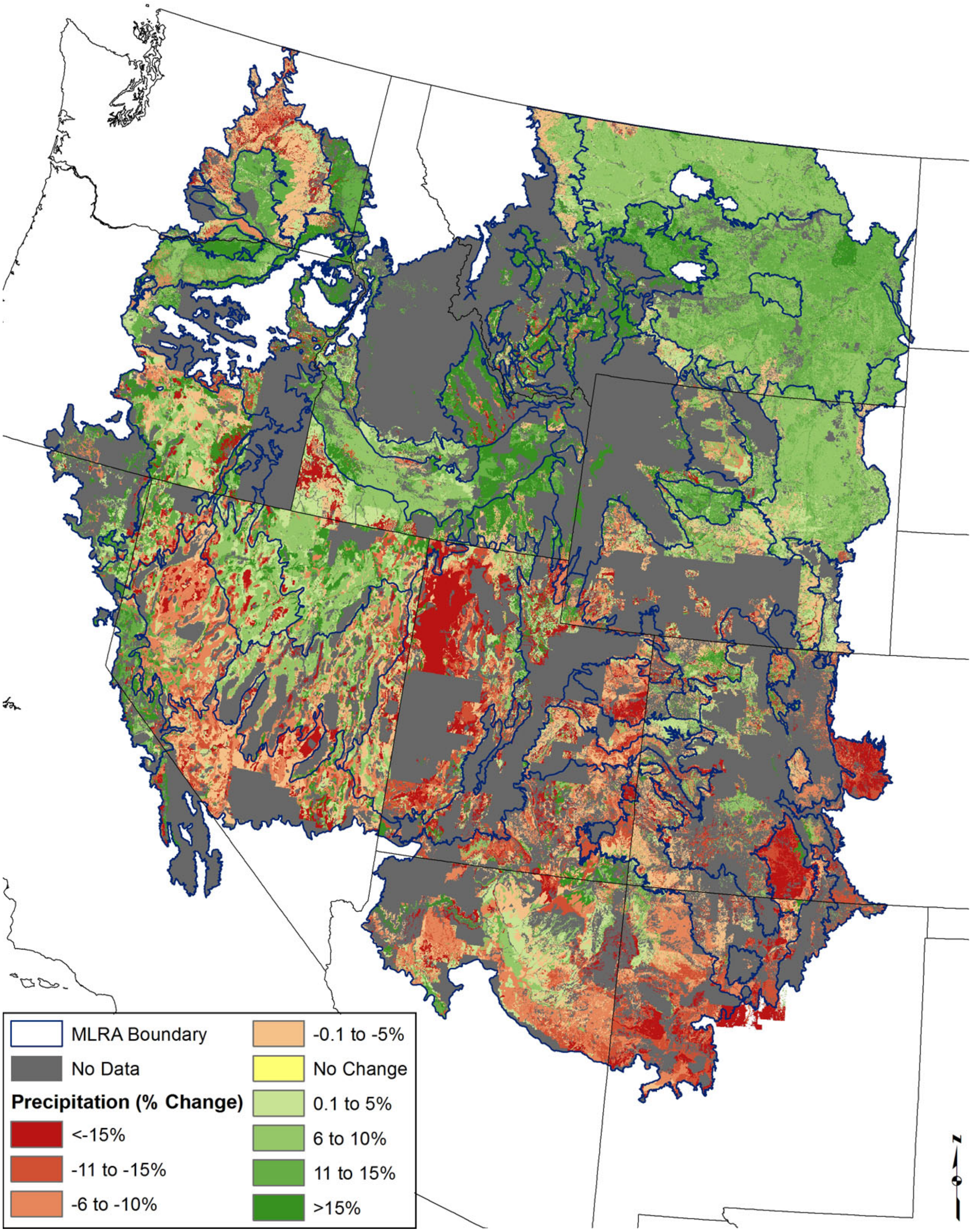


Figure 17. Predicted percent change in precipitation from 2010 to 2099 in the sagebrush biome.

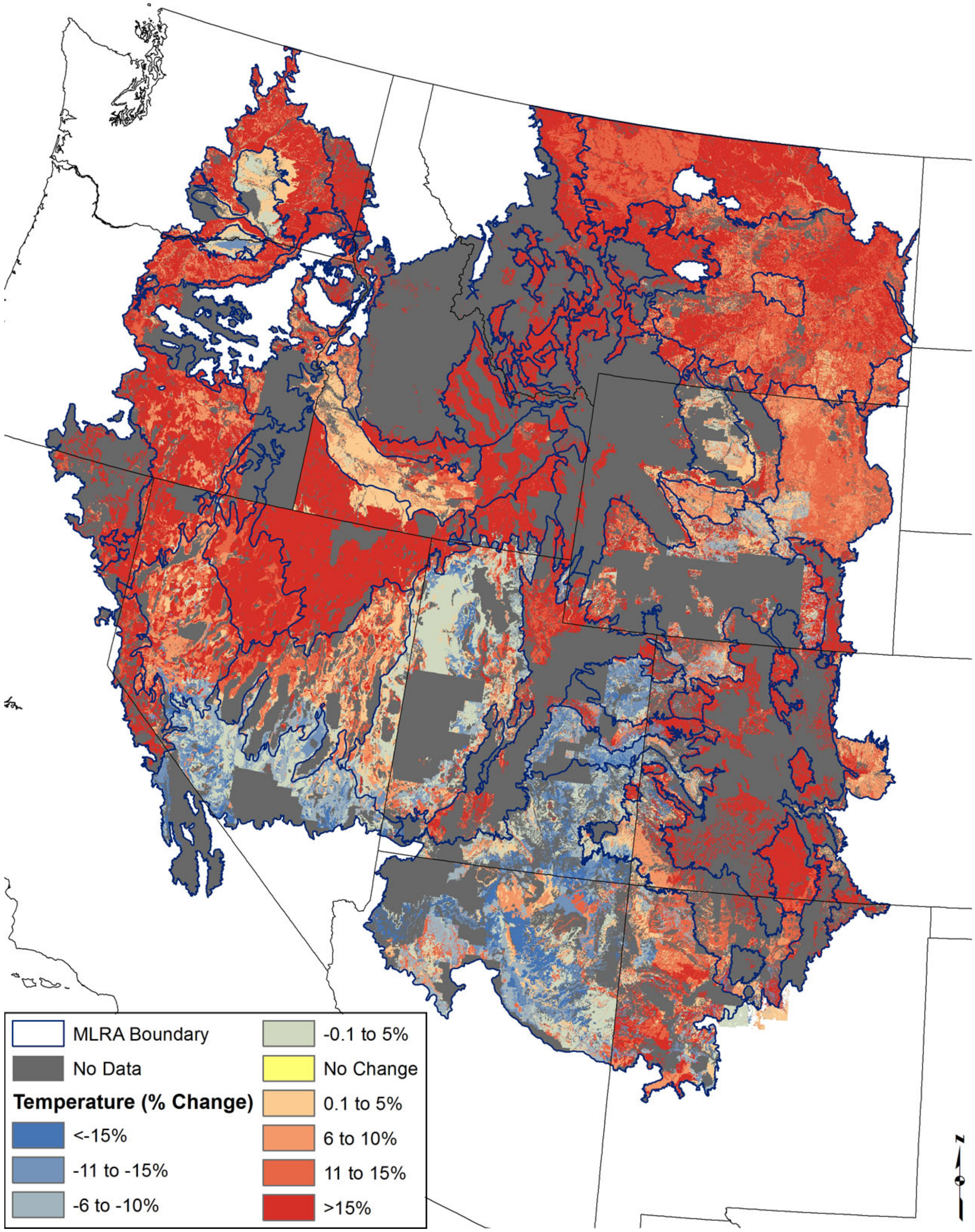


Figure 18. Predicted percent change in temperature from 2010 to 2099 in the sagebrush biome.

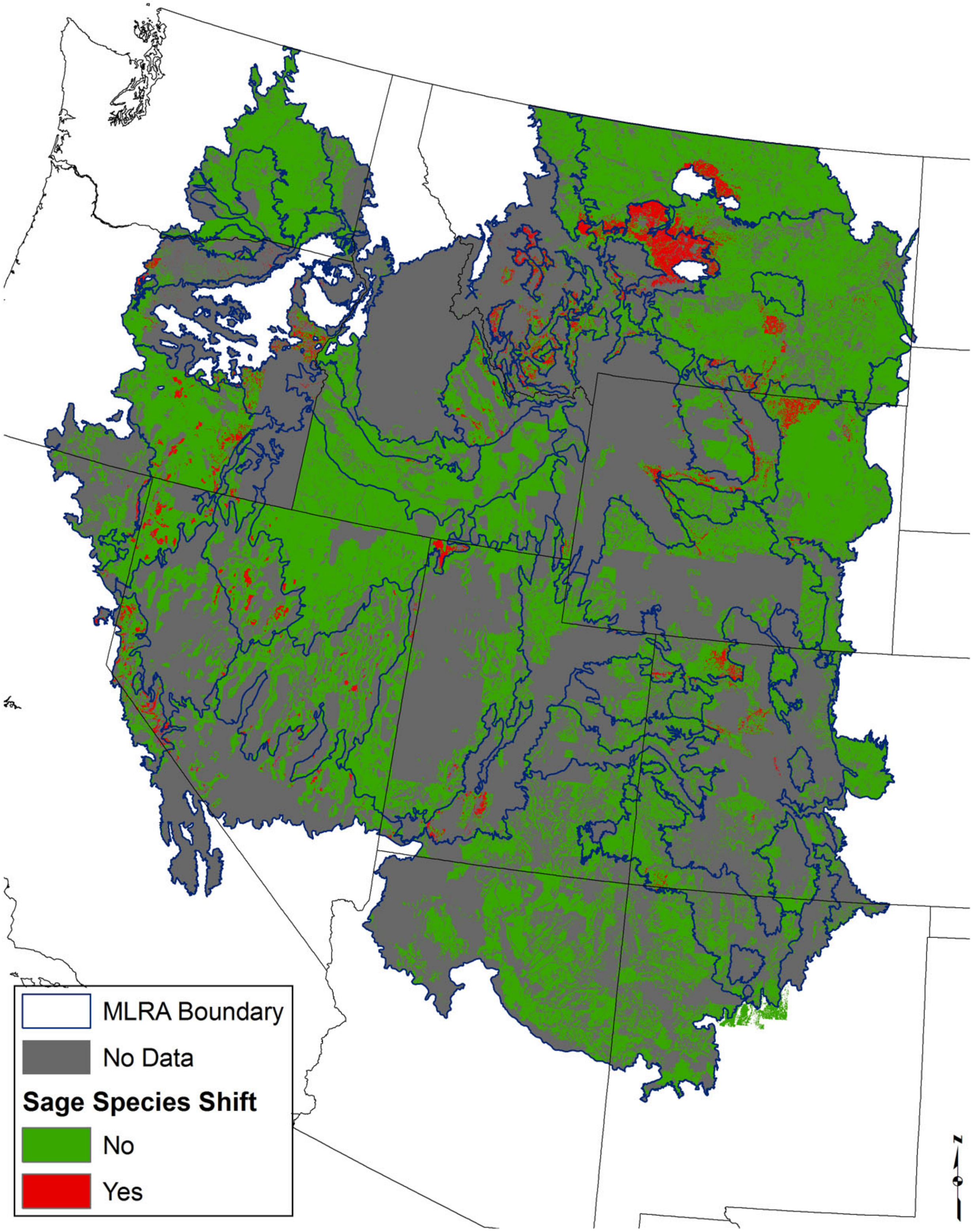


Figure 19. Predicted shift in dominant sagebrush species based on predicted changes in precipitation by year 2099.

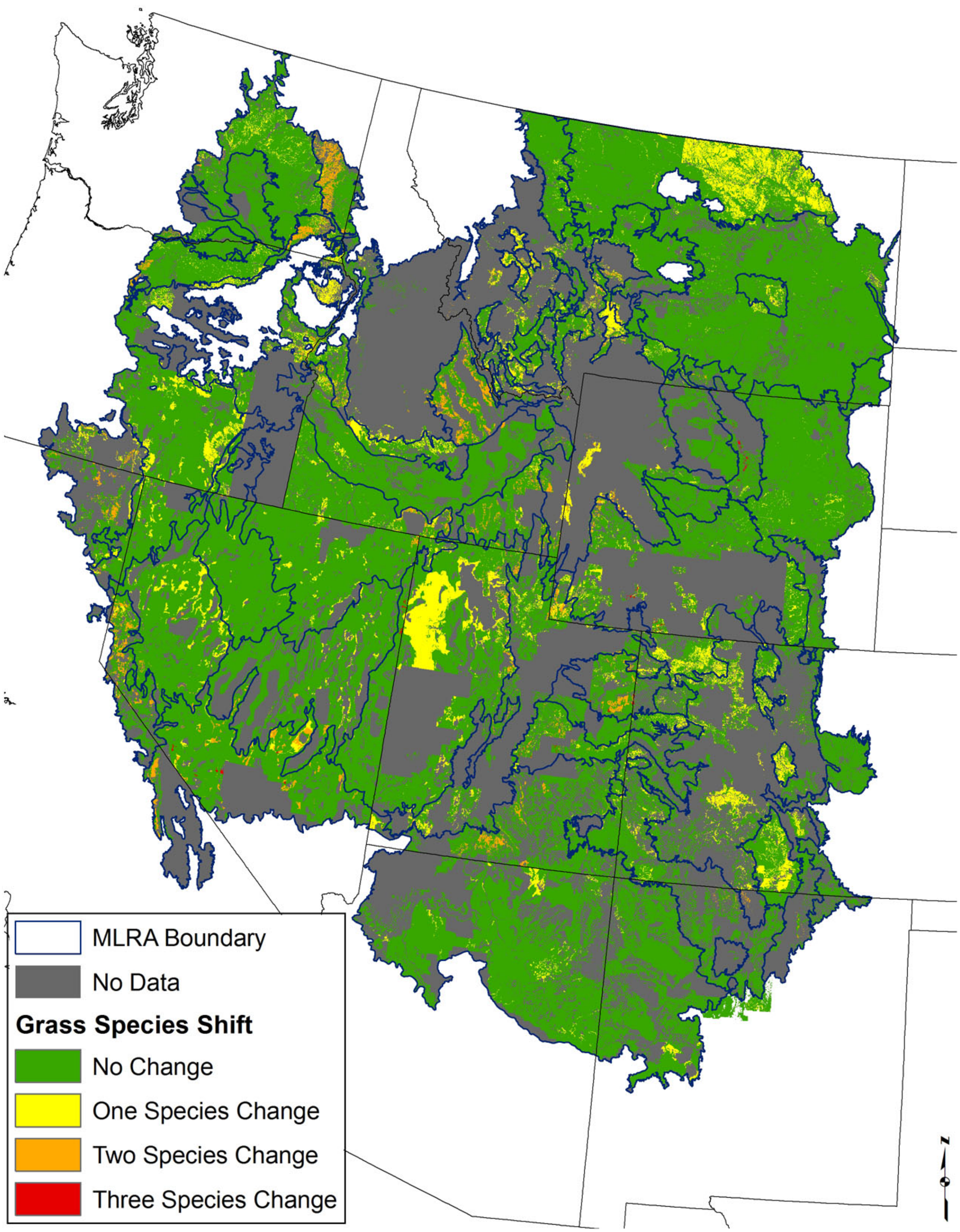


Figure 20. Predicted shift in dominant grass species based on predicted changes in precipitation by year 2099.

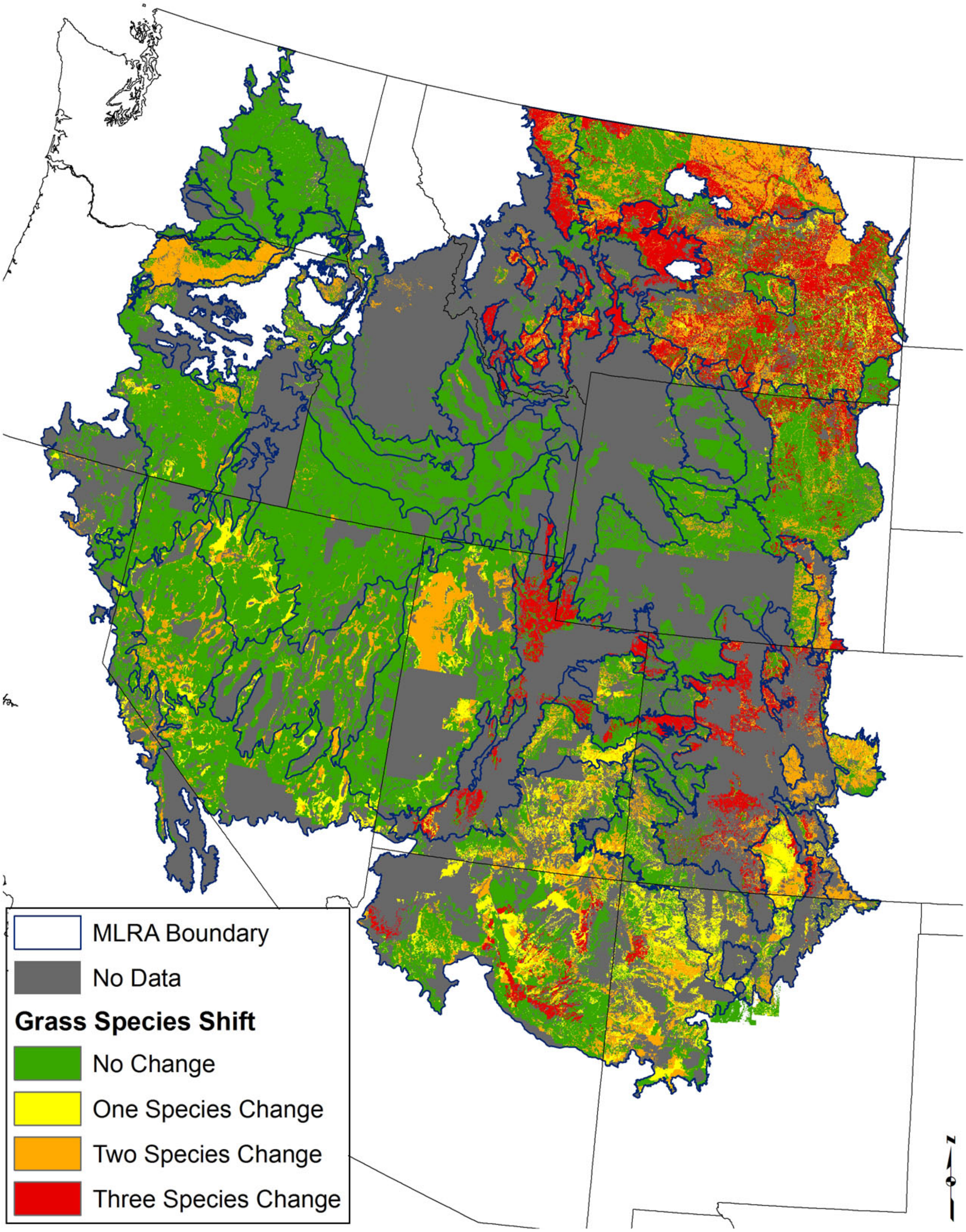


Figure 21. Predicted shift in dominant grass species based on predicted changes in temperature by year 2099.

Appendix C provides a list of sagebrush and grass species potentially occurring on each MLRA in the sagebrush biome and their projected response to climate change. In addition, 4 to 5 ecological sites within 4 MLRAs were selected as example areas to display climate change predictions in greater detail. The four MLRAs were selected to represent regional climate conditions across the sagebrush biome and are shown in Figure 22. The current and projected (2099) climate conditions relative to monthly precipitation and temperature values are presented for each ecological site. These figures can be found in Appendix D.

Figure 22. Example MLRAs used to display predicted climate change for year 2099 based on the A2 emission scenario

ECOLOGICAL SITES AND SAGE-GROUSE HABITAT

Sage-grouse habitat will be influenced by numerous factors. As discussed below, sage-grouse prefer selected species of sagebrush, as some offer better height and other characteristics. Ecological sites provide information on the potential of a site to support an appropriate environment for specific sagebrush species to occur. Similarly, sage-grouse have preferences for various herbaceous species, both grasses and forbs, and ecological sites again provide information on the potential of a specific location to support conditions required by preferred grass or forb species. Ecological sites only provide information on the potential of a site to support different plant communities. They do not provide information on what is the current plant community present at any location. Thus, current habitat conditions for sage-grouse may be of any quality, but ecological sites allow for the identification of locations where the site has the potential for producing high quality habitat conditions.

Doherty et al. (2011) examined ecological sites in comparison to a dataset of 119 sage-grouse nest locations in eastern Wyoming. They reported that "No ESD metrics were statistically significant at the 95% level ($P < 0.05$), although some were significant at the 80–90% level ($P = 0.09–0.14$)." On this basis they suggested that ESD's were not useful for identifying sage-grouse habitat use or management decisions. In their analysis, they treated ESD information the same as measures of existing vegetation and other landscape variables. Sage-grouse respond to the current vegetation conditions in a landscape to meet their habitat requirements. ESD's influence the potential for various vegetation conditions to occur at a site but do not describe the existing vegetation. Numerous other factors also influence existing vegetation including past management of fire regimes, grazing regimes, past mechanical or other site manipulations, and invasion by exotic species. Expecting significant influences of ecological sites to be measured through all of the variability present in the occurrence of existing plant communities is a very poor statistical design for evaluating the relationship of ecological sites to sage-grouse habitat. Rather, ecological sites have been documented to have significant influence on the plant communities that can potentially occur at a specific location, including differences in variables that have been shown to be significant influences on sage-grouse habitat. When examined from this perspective, ecological sites can clearly have a major influence on the quality of sage-grouse habitat that can occur at a specific location. We therefore advocate for their use in sagebrush restoration planning as well as for sage-grouse habitat planning where the potential for producing high quality sage-grouse habitat is a consideration. We acknowledge that ecological sites cannot indicate the vegetation conditions currently present at a location, as there are too many other factors that influence existing vegetation. However, knowing the inherent capability of the site to support desired habitat conditions indicates that they are a powerful tool in restoration and habitat management decision making.

Sage-grouse Habitat Requirements

In order to describe and map potential sage-grouse habitat it is necessary to understand the basic habitat requirements of sage-grouse throughout their life cycle. Sage-grouse have three primary life stages with different habitat requirements. These three stages are wintering, nesting, and brood rearing. Throughout all three life stages one constant is sagebrush. Preferred sagebrush species are big sagebrush (*Artemisia tridentata*) and its subspecies mountain big sagebrush (*A.t. vaseyana*), Wyoming big sagebrush (*A.t. wyomingensis*), and basin big sagebrush (*A.t. tridentata*), little sagebrush (*A. arbuscula*), black sagebrush (*A. nova*), silver sagebrush (*A. cana*), and three-tip sagebrush (*A. tripartita*) (Braun et al. 2005).

For winter habitat the entire focus is on sagebrush. To be considered adequate wintering habitat the site should contain sagebrush that has an average canopy cover of 10-30% exposed above snow and providing at least 10-14 inches (25.4-35.6 cm) of sagebrush height above the snow (Connelly et al. 2000). In addition, south and southwest aspects are preferred (Hupp and Braun 1989).

As reported by Connelly et al. (2000) suitable nesting habitat should have sagebrush cover between 15-25%. On dry sites sagebrush height should be 12-30 inches (30-80 cm) and on moist sites sagebrush height should be 15-30 inches (40-80 cm). Perennial grasses and forbs should exceed 7 inches (18 cm) in height. For ideal habitat grass heights will exceed 12 inches (30.5 cm) in height. The cover of perennial grasses should exceed 10% on dry sites and 15% on moist sites. In addition, the cover of forbs should exceed 5% on dry sites and 10% on moist sites (Connelly et al. 2000). Preferred grass species include a variety of native bunchgrasses such as: bluebunch wheatgrass (*Pseudoroegneria spicata*), Idaho fescue (*Festuca idahoensis*), Thurber's needlegrass (*Achnatherum thurberianum*), and basin wildrye (*Leymus cinereus*) (Stiver et al. 2010).

For brood rearing, sagebrush canopy cover should be between 10-25%, with sagebrush height between 15-30 inches (40-80 cm), and grass and forb canopy cover should exceed 15% with a good diversity and abundance of preferred sage-grouse forage species present (Connelly et al. 2000). A list of preferred forb species compiled by Stiver et al. 2010 can be found in Appendix E.

The detailed information on plant communities found in ecological site descriptions makes it possible to describe the potential of a given site to provide sage-grouse habitat for each of the three life stages. It is important to note that ecological site descriptions only provide the potential plant community and may not represent the plant community that currently exists on the site. When considering sites for restoration the greatest benefit to sage-grouse is realized on the sites with the potential to produce high quality sage-grouse habitat. As an example, we can compare the potential plant communities on two ecological sites within the same MLRA.

Site 1 is the shallow clayey (R034AY258WY) ecological site in Wyoming. The site receives 10-14 inches of precipitation annually. The historical reference plant community for this site consists of rhizomatous wheatgrass (e.g., western wheatgrass) and little sagebrush. Overall vegetative cover on the site varies from 40-50% and typical plant composition is 25-40% rhizomatous wheatgrass, 5-10% Indian ricegrass (*Achnatherum hymenoides*), 1-10% squirreltail (*Elymus elymoides*), 1-10% muttongrass (*Poa fendleriana*), 1-5% perennial forbs, and 5-10% little sagebrush. The representative annual production is 750 pounds per acre.

Site 2 is a loamy (R034AY222WY) ecological site in Wyoming. The site receives 10-14 inches of precipitation annually. The historical reference plant community for this site consists of mixed grasses and Wyoming big sagebrush (*Artemisia tridentata* ssp. *wyomingensis*). Overall vegetative cover on the site varies from 40-50% and typical plant composition is 10-30% rhizomatous wheatgrass, 5-15% bluebunch wheatgrass, 5-15% Letterman's needlegrass (*Achnatherum lettermanii*), 5-15% needle and thread (*Hesperostipa comata*), 5-10% Sandberg bluegrass (*Poa secunda*), 5-15% perennial forbs, and 10-20% Wyoming big sagebrush. The representative annual production is 1,100 pounds per acre.

Site 1 is low quality wintering habitat since little sagebrush is only 8-16 inches tall which is at the minimum height for sage-grouse use before taking snow cover into account. The low cover and structure of sagebrush also means the site will be low quality for nesting and brood rearing. Site 2 provides high quality wintering habitat with 10-20% sagebrush cover and Wyoming big sagebrush is typically between 24-36 inches in height. In addition, the diversity of grasses and forbs insures that site 2 will provide high quality nesting and brood rearing habitat. If choosing between these two sites for restoration or habitat improvements, site 2 has much higher potential for providing high quality sage-grouse habitat.

Sage-grouse Habitat Model

A rating for potential sage-grouse habitat quality was determined for each ecological site using a multi-step approach (Table 3). The input values for the model came from the ESIS and SSURGO plant composition data discussed previously, using the HCPC or other selected reference state. The first model step was classifying each ecological site as sage or non-sage based on the presence of sagebrush. All sites with any sagebrush present were considered sagebrush sites at this point in the model.

The second step assigned scores to sagebrush sites based on the potential habitat quality that could be provided by the dominant sagebrush species (Table 4). Where applicable, sites received separate scores for nesting and wintering habitat value. The third step refined the scores based on sagebrush percent of total site composition. Sites with sagebrush percent composition <1% received a low score, sites with percent composition from 1 to <5% received a moderate score, and sites with percent composition >=5% received a high score. The fourth model step compared percent composition of other shrubs to the percent composition of sagebrush. This step only applied to sites with percent composition of sagebrush <5%. If the composition of other shrubs was greater than the composition of sagebrush at the site then the rating was changed to a low.

The fifth model step was similar, but compared the percent composition of trees to composition of sagebrush. If the percent composition of trees was greater than the composition of sagebrush at the site then the rating was changed to a low. The rating was further modified using the total percent composition of trees. Sites with a percent composition of trees >=5% received a low score, sites with percent composition of trees <5% but >0% received a moderate score and sites without trees received a high score. The final step only applied to the nesting rating. For sites with a total percent composition of cool-season grasses <20% a rating for nesting of low was received. Sites with 20 to <50% cool-season grasses received a moderate rating, and sites with >=50% cool-season grasses received a high rating.

The final habitat quality rating for each ecological site was determined by using the lowest score a site received during any of the analysis steps. Each site was given separate ratings for nesting habitat and winter habitat quality. The final rating for wintering habitat is displayed in Figure 23 and the final rating for nesting habitat is displayed in Figure 24.

Table 3. Analysis matrix for sage-grouse habitat quality rating. Numbers represent the average annual productivity percent of total species composition, for that value or range of values.

	Non-Sage	**Nesting and Wintering**		
		Low	**Mod**	**High**
Is it a sagebrush type?	0%	--------------- >0% --------------		
What is the quality of the dominant sagebrush?		Table 4	Table 4	Table 4
What is the potential amount of sagebrush?		>0-0.9%	1-4.9%	>=5%
% other shrubs > SAGE, where SAGE <5%		>=5%	1-4.9%	<1%
% Productivity of trees		>=5%	1-4.9%	<1%
			Nesting Only	
Cool Season Grass Prod %		<20%	20-49.9%	>=50%

The development of a habitat quality model for sage-grouse comes with several caveats. First, this is only an example of one approach for using existing datasets to quantify sagebrush into sage-grouse habitat. Additional testing is needed in the field to identify specific characteristics that influence the habitat quality of ecological sites. Within each MLRA local conditions could require the model to be fine-tuned to properly quantify habitat quality. Second, topography and annual snowfall play large roles in determining wintering habitat quality for sage-grouse. This model focused primarily on sagebrush height to identify high quality winter habitat. The end user of the model needs to verify that local conditions do not adversely affect wintering habitat quality. Third, brood habitat typically occurs in close proximity or in conjunction with nesting habitat. At this time, data are insufficient to properly characterize brood habitat. The assumption with this model is that nesting habitat is more limiting then brood rearing habitat and it is likely that high quality nesting habitat will likely have brooding habitat in close proximity. Finally, it is worth noting that the relationship between estimates of plant canopy cover and productivity do not currently exist. While there are some ecological sites that have data on canopy cover by growth form and height class the availability is limited and coverage is sporadic. Future research is needed to bridge the gap between production estimates generated for rangeland management and canopy cover values needed for wildlife management.

Table 4. Sagebrush species characteristics and sage-grouse habitat quality ratings.

Scientific Name	Symbol	Common Name	Height (cm) Low	Height (cm) High	Annual Productivity Low	Annual Productivity High	Habitat Quality Rating Nesting	Habitat Quality Rating Wintering	Habitat Quality Rating Height
Artemisia arbuscula	ARAR8	Low sagebrush	10	50	350	650	Low	Low	Low
Artemisia arbuscula ssp. Arbuscula	ARARA	Low sagebrush	10	50	350	650	Low	Low	Low
Artemisia arbuscula ssp. Longicaulis	ARARL3	Lahontan sagebrush	10	30	0	0	Low	Low	Low
Artemisia arbuscula ssp. Longiloba	ARARL	Little sagebrush	10	50	350	650	Low	Low	Low
Artemisia arbuscula ssp. Thermopola	ARART	Little sagebrush	10	30	0	0	Low	Low	Low
Artemisia bigelovii	ARBI3	Bigelow sagebrush	10	30	0	0	Low	Low	Low
Artemisia cana	ARCA13	Silver sagebrush	18	150	0	0	Mod	Mod	Tall
Artemisia cana ssp. Cana	ARCAC5	Plains silver sagebrush	18	180	0	0	Mod	Mod	Tall
Artemisia cana ssp. bolanderi	ARCAB3	Sierra silver sagebrush	0	0	0	0	Low	Low	Tall
Artemisia cana ssp. viscidula	ARCAV2	Mountain silver sagebrush	18	150	855	1713	Low	Low	Tall
Artemisia filifolia	ARFI2	Sand sagebrush	50	150	0	0	Low	Low	Tall
Artemisia nova	ARNO4	Black sagebrush	30	60	0	0	Low	Low	Low
Artemisia nova var. nova	ARNON2	Black sagebrush	30	60	0	0	Low	Low	Low
Artemisia nova var. duchesnicola	ARNOD	Red clay sagebrush	0	0	0	0	Low	Low	Low
Artemisia papposa	ARPA16	Owyhee sagebrush	5	15	0	0	Low	Low	Low
Artemisia porter	ARPO5	Porter sagebrush	0	0	0	0	Low	Low	Low
Artemisia pygmaea	ARPY2	Pygmy sagebrush	5	15	0	0	Low	Low	Low
Artemisia rigida	ARRI2	Scabland sagebrush	30	60	207	0	Low	Low	Low
Artemisia tridentata ssp. spiciformis	ARTRS2	Spiked big sagebrush	0	0	0	0	Mod	Mod	Tall
Artemisia tridentata ssp. tridentata	ARTRT	Basin big sagebrush	100	220	593	0	Mod	Mod	Tall
Artemisia tridentata ssp. vaseyana	ARTRV	Mountain big sagebrush	60	120	373	2100	High	Mod	Tall
Artemisia tridentata ssp. Wyomingensis	ARTRW8	Wyoming big sagebrush	60	120	0	0	High	High	Tall
Artemisia tridentata ssp. xericensis	ARTRX	Xeric big sagebrush	0	0	0	0	Mod	Mod	Tall
Artemisia tripartita	ARTR4	Threetip sagebrush	20	100	0	0	High	Low	Tall
Artemisia tripartita ssp. tripartita	ARTRT2	Threetip sagebrush	20	100	0	0	High	Low	Tall
Artemisia tripartita ssp. rupicola	ARTRR2	Wyoming threetip sagebrush	6	18	0	0	Low	Low	Low
Artemisia	ARTEM	Sagebrush	5	200	0	0	-	-	Medium
Artemisia tridentata	ARTR2	big sagebrush	20	200	0	0	High	High	Tall

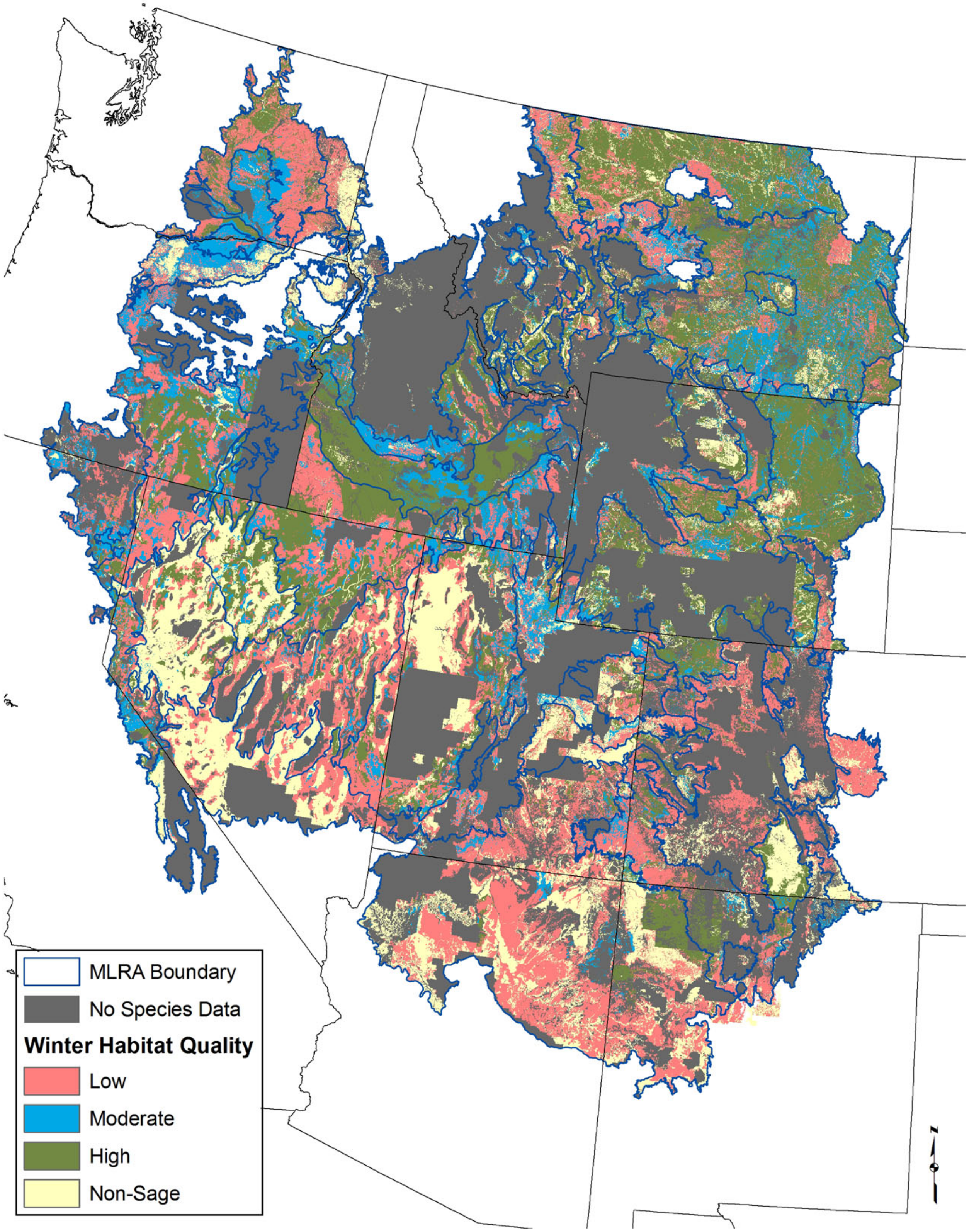


Figure 23. Sage-grouse potential winter habitat quality rating.

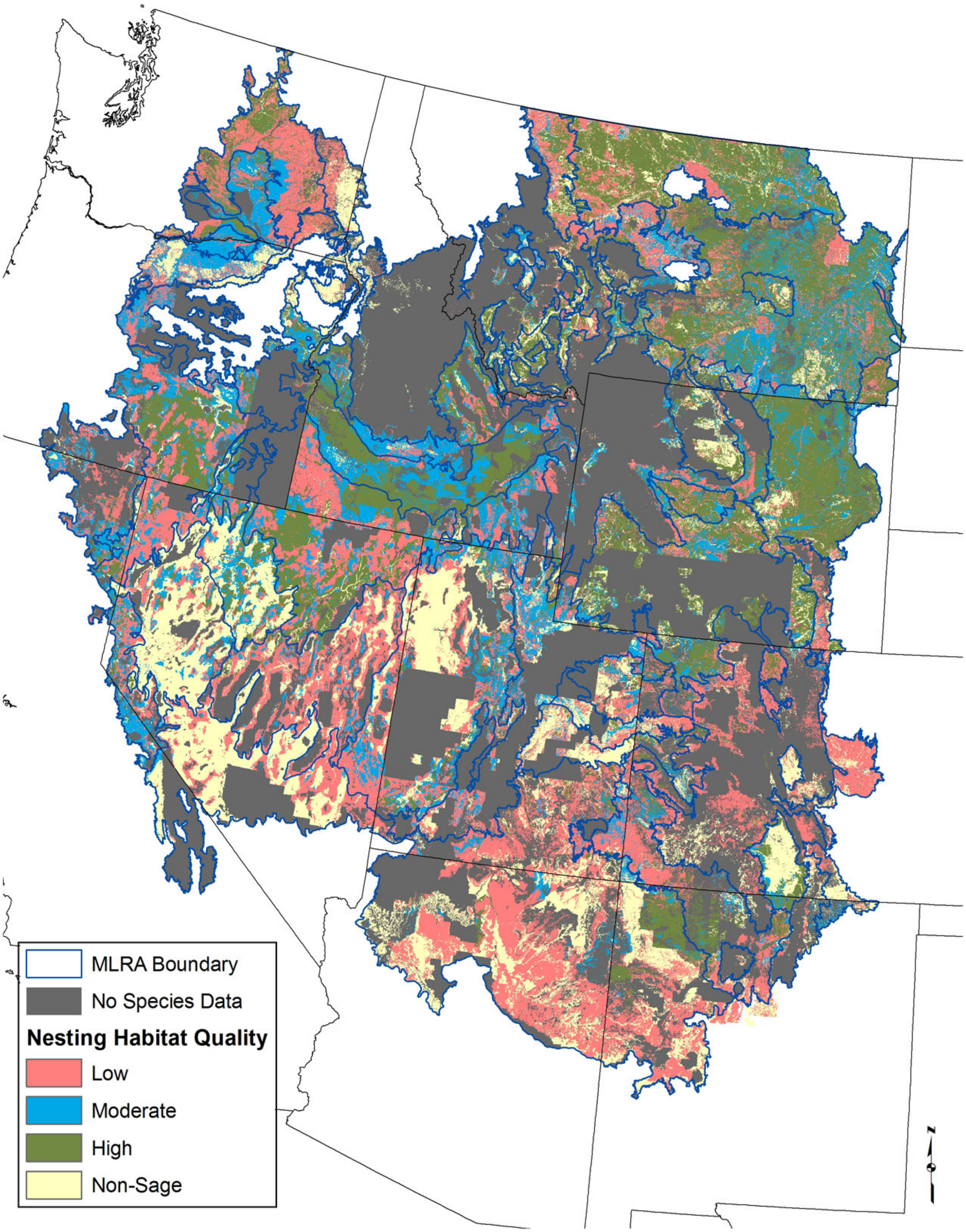


Figure 24. Sage-grouse potential nesting habitat quality rating.

DEMONSTRATING THE SAGEBRUSH ECOSYSTEM RESTORATION TOOL

This project focused on development of the SERT, which required most of the duration of the project to accomplish. Consequently it was not available to use in the planning stages of treatments used as demonstrations of the application of the tool. However, we did work with Utah Department of Natural Resources to evaluate two sagebrush improvement projects that they were conducting and that provided matching funds for development of the SERT. Had the tool been already available, we could have used it to evaluate the seeding mixtures and other project treatments prior to their application.

The objectives of the treatments were to restore sagebrush ecosystems to improve habitat for a number of sagebrush-associated species. Two sites were selected, both of which were degraded by encroaching pinyon pine and juniper. The encroaching trees were out-competing other shrubs including sagebrush as well as reducing grasses and forbs. Treatments were designed to return the site to a desirable community dominated by sagebrush and grasses and forbs with lesser amounts of other shrubs. Both sites included seeding as part of the treatment enabling an evaluation of the selected seed mixture using the SERT, although this evaluation occurred post-treatment.

The two selected sites (Figure 25) were in different MLRA's within Utah. Utah Department of Natural Resources committed matching funds to conduct restoration treatments at these sites. Treatments used on the sites were evaluated relative to the identified reference community as well as to predicted climate conditions. The treatments used were developed by Utah Department of Natural Resources based on current conditions and desired changes to the sites.

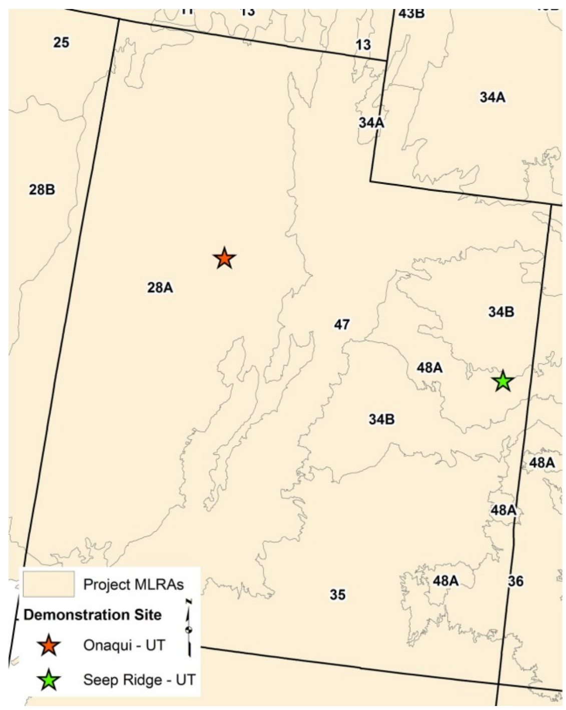


Figure 25. Project demonstration sites in Utah.

The Onaqui demonstration site was located in MLRA 28A in Tooele County, Utah (Figure 26). The site fell entirely on lands managed by the Bureau of Land Management (BLM). It consisted of 1,179 acres of sagebrush habitat that had been impacted by encroaching juniper. The site lies at the intersection of two ecological sites. The higher ground in the western portion of the site was a forested ecological site (F028AY320UT) and the lower ground in the eastern portion of the site was a semi-desert gravelly loam (R028AY215UT). The treatment involved interseeding grass species on 643 acres and masticating juniper using wheeled tractors with Fecon mulching heads throughout the site. Trees were not mulched until seed had been applied. The seed mixture selected for application is listed in Table 5.

Table 5. Seeding mixtures for the Onaqui and Seep Ridge demonstration sites.

ONAQUI SITE

Common Name	Scientific Name	Variety	Bulk Pounds (ac)
bluebunch wheatgrass	*Pseudoroegneria spicata*	Anatone	3
Indian ricegrass	*Achnatherum hymenoides*	Nezpar	1.5
Sainfoin	*Onobrychis viciifolia*	Any	2
small nurnet	*Sanguisorba minor*	Any	2
Palmer's penstemon	*Penstemon palmeri*	Any	0.5
blue flax	*Linum perenne*	Any	0.25
western yarrow	*Achillea millefolium*	Any	0.1

SEEP RIDGE SITE

Common Name	Scientific Name	Variety	Bulk Pounds (ac)
slender wheatgrass	*Elymus trachycaulus*	Any	1.5
thickspike wheatgrass	*Elymus lanceolatus*	Any	1.25
bluebunch wheatgrass	*Pseudoroegneria spicata*	Any	1.25
Indian ricegrass	*Achnatherum hymenoides*	Any	1
Sandberg bluegrass	*Poa secunda*	Any	0.6
nasin wildrye	*Leymus cinereus*	Any	0.75
green needlegrass	*Nassella viridula*	Any	0.75
Alfalfa	*Medicago sativa*	Any	1.5
small burnet	*Sanguisorba minor*	Any	2
Sainfoin	*Onobrychis viciifolia*	Any	2
blue flax	*Linum perenne*	Any	0.5
Bitterbrush	*Purshia tridentata*	Any	0.4
alderleaf mountain mahogany	*Cercocarpus montanus*	Any	0.2
Wyoming big sagebrush	*Artemisia tridentata ssp. wyomingensis*	Any	1

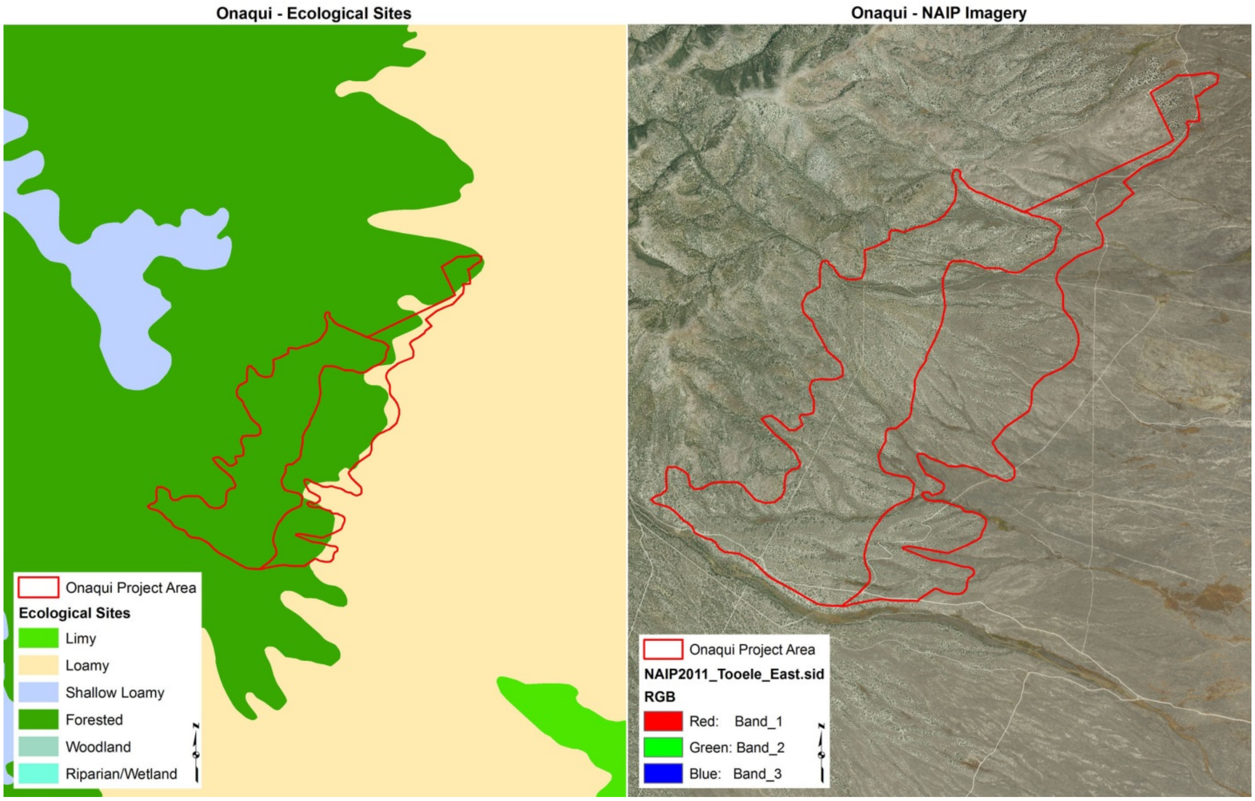


Figure 26. Onaqui demonstration site in MLRA 28 in Tooele County, UT.

The Seep Ridge demonstration site was located in MLRA 48A in Uintah County, UT (Figure 27). The site fell entirely on lands managed by the state of Utah. It consisted of 770 acres of sagebrush that had been invaded by pinyon pine and juniper (Figure 28). The northern portion of the site was classified as upland shallow loam (R034XY322UT) and the southern portion of the site was mountain stony loam (R048AY451UT). Pretreatment, the site was dominated by pinyon pine and Utah juniper. In the understory, basin big sagebrush occurred in a suppressed and decadent condition. Grasses occurred in moderate amounts in the understory with the dominant species being blue grama (*Bouteloua gracilis*) with lesser amounts of thickspike wheatgrass (*Agropyron dasystachyum*), sedge (*Carex sp*.), mutton bluegrass (*Poa fendleriana*), Sandberg bluegrass (*P. secunda*) and bottlebrush squirreltail (*Sitanion hystrix*). Forbs were not common with no single species dominating. The treatment removed pinyon and juniper using two passes of anchor chaining pulled between two bulldozers. After the first pass with the chain the area was aerially seeded with a grass and forb mix. During the second chaining pass the area was dribbler seeded from the bulldozers with bitterbrush and mahogany seed. The final step was an aerial seeding with sagebrush seed (Figure 29). The seed mixture used in this treatment is listed in Table 5. The area was rested from grazing after seeding to increase the success of plant establishment.

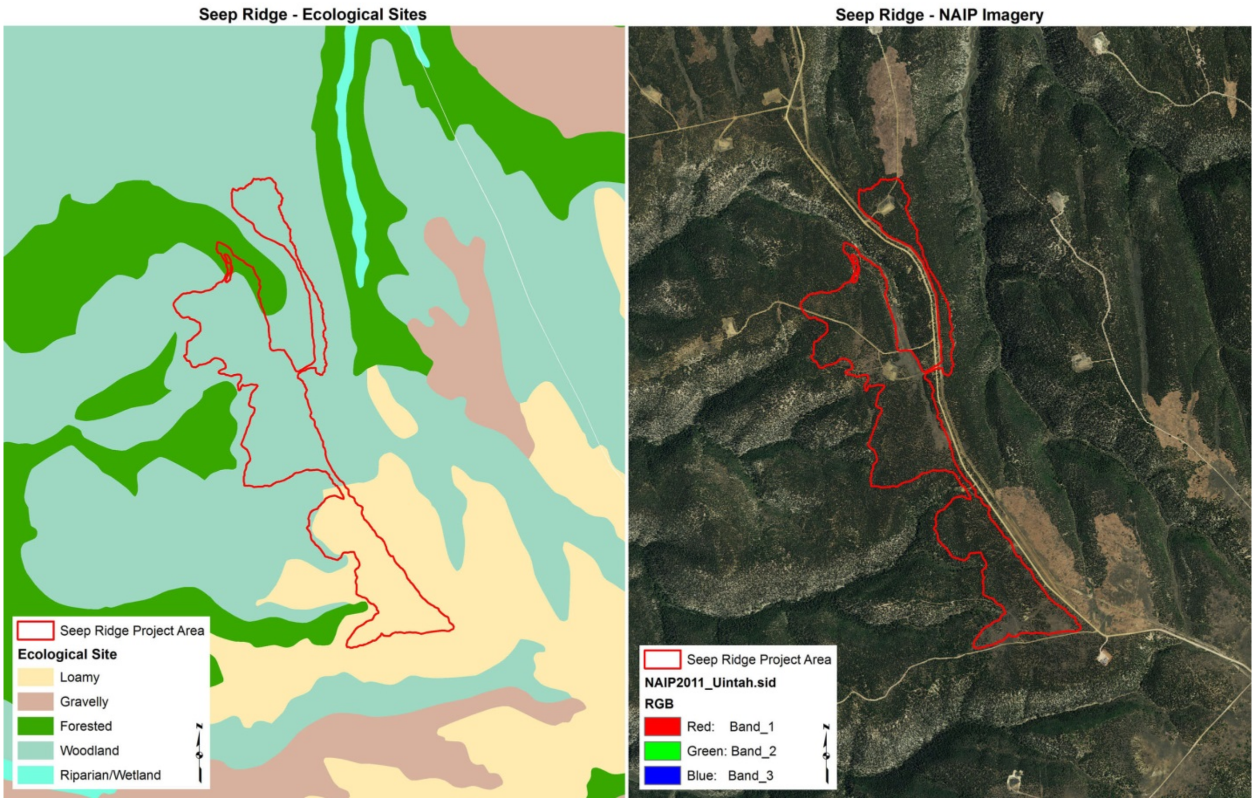


Figure 27. Seep Ridge demonstration site in MLRA 48A in Uintah County, UT.

Figure 28. Untreated area of Seep Ridge site in Utah.

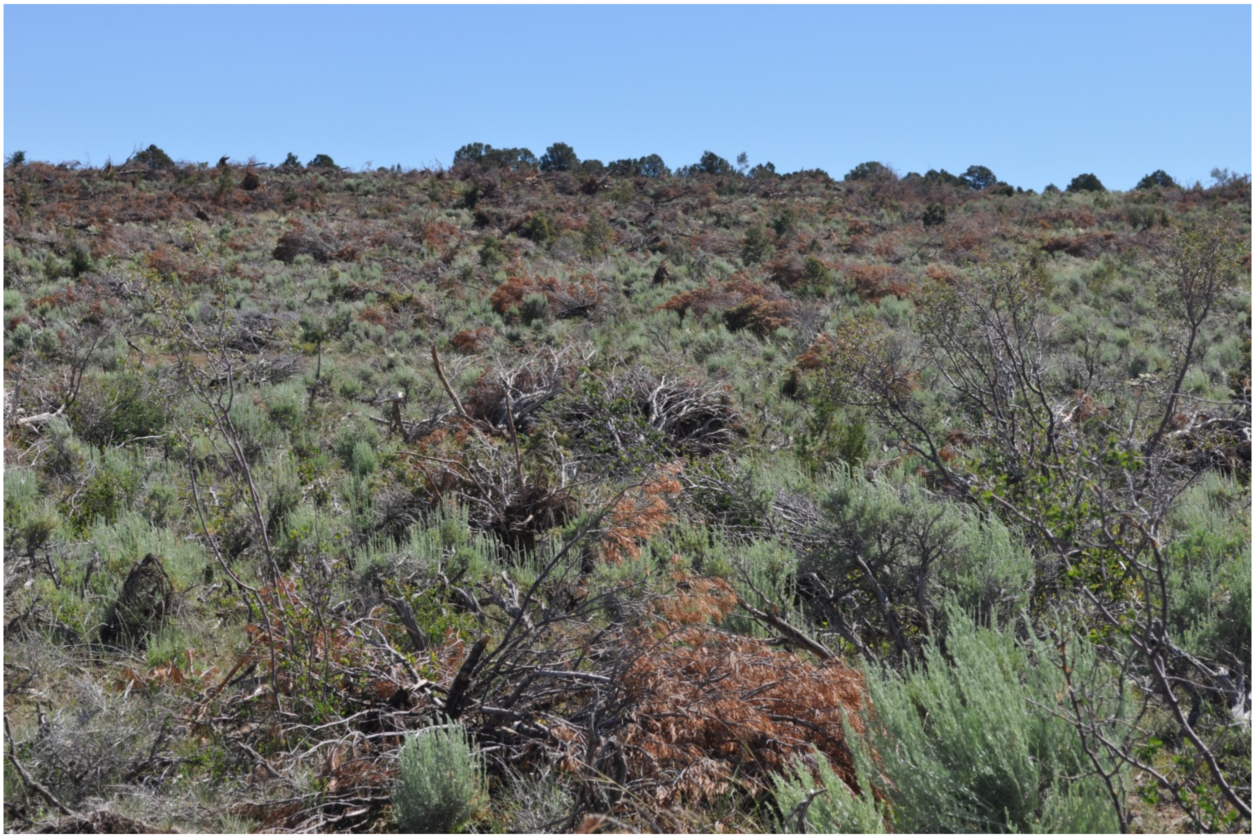


Figure 29. Treated area of Seep Ridge site in Utah.

The treatments were effective in removing the pinyon and juniper, as Figure29 displays. Smaller pinyon and juniper were still present, and will require additional treatments in the future. The effectiveness of the seeding could not be determined over the short duration of this CIG project.

The SERT described the reference condition for the range ecosite at the Onaqui location as being dominated by Wyoming big sagebrush with a corresponding tall height class. The rating for sage-grouse winter habitat is high quality and the rating for nesting habitat is moderate quality. The historical reference community for this ecological site was dominated by Wyoming big sagebrush with shadscale and winterfat also occurring in the shrub layer. Grasses were dominated by bluebunch wheatgrass and Indian ricegrass with bottlebrush squirrel tail also occurring. Abundant forbs include carpet phlox and scarlet globemallow. Composition presented as productivity percentages is 45% grass, 10% forbs, and 45% shrubs with an historical fire frequency estimated at 40 to 50 years. The seeding mixture used in the treatment (Table 5) corresponded to this reference plant community under current climate conditions. The climate projections for this area by the year 2099 indicate a slight increase in precipitation (2.7%) and a major increase in mean July temperature (14.1%). As the July temperature rises from 73.4 to 83.8^{o}F this indicates there will be a high potential for a shift from a dominance of C3 to C4 grass species. This could lead to a change in dominant grass from bluebunch wheatgrass to black grama. James and big galleta would potentially become important species as well. Whether this site will continue to function as a desired sagebrush plant community is questionable. Selection of this site for treatment could have been informed by this additional information.

As discussed previously, there are two sagebrush ecological sites at the Seep Ridge location, upland shallow loam and mountain stony loam, but only the mountain stony loam has a completed ecological site description in ESIS (https://esis.sc.egov.usda.gov/ESDReport/fsReport.aspx?id=R048AY451UT&rptLevel=all&approved=yes&repType=regular&scrns=&comm=). The reference community for the mountain stony loam is dominated by Utah serviceberry and birchleaf mountain mahogany. This site also contains juniper and a variety of other shrubs. The potential plant community productivity is composed of approximately 20 percent perennial grasses, 10 percent forbs, and 70 percent shrubs. For the mountain stony loam site the planning tool identifies the dominant sagebrush as mountain big sagebrush. As such, the height class is tall and the sage-grouse winter and nesting habitat qualities are both rated as moderate.

For the upland shallow loam, plant data for the SERT were not available from ESIS and so were obtained from SSURGO. This description does not identify the reference community and reported the dominant sagebrush species as Bigelow sagebrush (*A. bigelovii*). However, pre-treatment sampling reported above found the dominant sagebrush species to be basin big sagebrush. Bigelow sagebrush has low height, so the SERT rated the site as low for sagebrush height. However, basin big sagebrush is rated as a tall sagebrush species. The sage-grouse winter and nesting habitat quality, based on the description of the site as Bigelow sage are both low. However, basin big sagebrush would be rated as high, although the presence of large amounts of other shrubs would lower this rating. Obviously, for this ecological site, the lack of an accurate community description in the ESIS database caused inaccuracies in the ratings of this site.

The species planted in the Seep Ridge treatment (Table 5) generally corresponded to the reference plant community for the mountain stony loam ESD under current climate conditions. Mountain big sagebrush is listed in the reference community as a sub-dominant shrub while basin big sagebrush was identified on the site in pre-treatment sampling, yet Wyoming big sagebrush was included in the seeding mixture. The climate projections for this area by the year 2099 indicate a decrease in precipitation (-5.8%) and an increase in mean July temperature (16.7%). As such, seeding Wyoming big sagebrush to this site may be very appropriate. As the July temperature rises from 66.1 to 77.1 this indicates there may start to be a shift from C3 to C4 grass species, although the C3 species should still be able to be competitive in this temperature range. This could lead to a gradual shift in grasses from needle and thread and western wheatgrass to greater amounts of black grama and blue grama. James galleta would potentially become important species as well. Shrub species would likely remain consistent as the annual precipitation is still in an acceptable range for the dominant species, however the slight decrease in precipitation may make sagebrush more competitive on this site over time. Thus, this site appears to be well suited for treatment to maintain or increase the sagebrush community type.

INFORMATION TRANSFER

Demonstration of the sagebrush planning tool to additional technical service providers, wildlife biologists, and producers was conducted in several ways. A Technical Note was identified as a project deliverable, and would still be a desired product. The Technical Note would provide a description of the web-based tool and how to access it. However, until the tool is actually put out on the WSS site, preparation of a Technical Note isn't appropriate or feasible. However, once the tool is implemented on WSS, EMRI can prepare the Technical Note for use by producers, technical service providers, biologists, and others. Similarly, a webinar was planned to be offered to technical service providers, biologists, or other interested parties to explain the SERT and its uses. This can also be done once the tool is placed on the WSS. Presentations on the project will be made to professional audiences. An overview of the project will be presented at the 2015 meeting of the Society for Range Management. Other professional audiences will be targeted, particularly once the tool is available on the web. This project final report will be provided to NRCS and will be available to producers, agencies, and organizations through the EMRI website and potentially on other appropriate websites.

PROJECT DISCUSSION, CONCLUSIONS, AND RECOMMENDATIONS

This project was designed to produce a web-based tool that could assist in planning for sagebrush restoration and sage-grouse habitat improvement projects. The effectiveness of the SERT relies on its accessibility to producers, technical service providers, and biologists through the internet. All of the components of the tool have been prepared and are ready to be placed on WSS, the best location identified for this tool. The SERT should provide a useful and effective addition to on-going planning efforts once placed on the web. This report provides examples of what the SERT could look like on WSS. This design was reviewed by appropriate NRCS personnel and approved, and its implementation is awaiting some required programming by NRCS web developers.

Analysis of the information pulled together for the SERT demonstrates its utility for restoration planning. Figures 12-14 show how sites can be identified that have the best potential for supporting sagebrush as well as which of these sites will support desired sagebrush species and the normal height of sagebrush potential for each site. This can be important information when looking for locations to spend limited restoration funding. The SERT will also be useful for restoration at the landscape level. The SERT makes it possible to identify groupings of ecological sites that could potentially provide larger areas of sagebrush habitat. By concentrating restoration efforts into larger areas there are increased odds that the restoration will benefit a wide variety of wildlife species.

When considering site restoration it is very important to identify the desired plant community for a specific site. If this hasn't been done, then the desired outcome of restoration treatments is likely to be confused, and may not produce true restoration of functional sagebrush ecosystems. Determining the reference plant community as described in an ecological site description is an important first step, and the SERT will make this information readily available to producers, technical service providers, and biologists working on sagebrush restoration. By restoring sagebrush communities to conditions that existed historically not only will this provide important habitat for sagebrush obligates such as sage-grouse, but it also creates habitat for an entire suite of species that were adapted to the conditions of the sagebrush ecosystem at each site in a landscape.

The planning tool also shows the utility of ecological sites in planning. Efforts that only focus on existing vegetation conditions overlook valuable additional information on the potential for areas not currently supporting high quality sagebrush communities to contribute to restoration needs. Ignoring this information may waste restoration dollars by attempting restoration on sites that will not produce the desired results because of their inherent limitations.

This project developed downscaled climate change information for the entire sagebrush biome. The analyses show that there is a great deal of variation, especially when studying a diverse area covering over 400 million acres. However, for over 50% of the ecological sites that are currently mapped, temperature or precipitation changes of > or <10% are predicted to occur. These levels of change are expected to have significant effects on sagebrush plant communities.

Our analysis of climate effects on plant communities focused on likely responses by single species that we then interpreted for possible effects on the plant community. We focused our analysis on the 19 species of sagebrush occurring across the sagebrush biome, and the native species of grasses that also occur on sagebrush-dominated sites. We did not attempt to analysis effects on forbs, as these are even more diverse with limited information on each species response to climatic conditions. As more information on these species becomes available, analyses could be added to address likely responses by forbs.

While this report only considered ecological sites that support sagebrush under current climate conditions it is possible that future climate conditions will result in sagebrush colonizing new ecological sites. In addition, sites that currently contain sagebrush may become too moist, dry, or warm to support sagebrush. The SERT is designed to work with the data present in ESIS. If the descriptions of ecological sites change in the future the SERT will still be able to classify sites and provide restoration recommendations based on the new information.

Several example studies demonstrate how climate change effects may be anticipated. As C3 species, *Artemisia* (sagebrush) may respond similarly to grass species relative to predicted climate change. However, there is some variation among sagebrush species. Threetip sagebrush (*Artemisia tripartita*) had increased growth as summer temperatures increased while recruitment was greater during years of increased snow cover (Dalgleish et al. 2011). Similarly, mountain big sagebrush (*Artemisia tridentata* ssp. *vaseyana*) was also found to increase as summer temperatures increased. In addition, at locations with snowmelt occurring later in the year, the greater the annual growth of mountain big sagebrush

(Perfors et al. 2003). Increasing temperatures may cause earlier dates of snowmelt, causing reductions in growth in mountain big sagebrush.

One side effect to climate change could be the impact on juniper, which is an active invader in many sagebrush ecosystems. Increased juniper cover has been significantly correlated with decreased shrub, forb, and grass cover (Coultrap el al. 2008). Multiple studies have found that juniper invasion rates were higher in mountain big sagebrush compared to low sagebrush, but the juniper productivity and canopy cover was higher during periods of increased precipitation and milder temperatures (Miller and Rose 1999, Bradley and Fleishman 2008). Clifford et al. (2011) found that juniper cover was reduced by 55% during a period of drought. It is possible that in areas predicted to have lower precipitation rates that the rate of spread of juniper cover may be reduced.

In many cases, existing conditions in sagebrush ecological sites differ from the historical reference plant community (HPC) (Miller and Edelman 2000, Connelly et al. 2004). The SERT helps to identify the most appropriate reference plant community for a site which is the first step towards restoration. Once the reference plant community has been identified it is possible to determine the resiliency of the community in the face of climate change, and the practices needed to restore a desired and sustainable plant community. In many cases, returning the site from a degraded or invaded state back to the reference community will be enough to protect against the potential impacts of climate change. In other cases, where the predicted climate change is too great to support the reference community, more appropriate species can be identified for use in restoration.

Our analyses indicate that substantial changes in sagebrush plant communities are probable over the next 80 years if climate change continues on its current trajectories. Cool season grasses associated with many sagebrush sites preferred by sage-grouse may be particularly vulnerable. We identified relatively few sites where precipitation changes are likely to stress the current species of sagebrush. However, the effects of temperature changes on sagebrush have not been reported, and the combined effects of temperature and precipitation changes may cause more effects than we identified in this report.

In this report we also presented information on how ecological sites can be used to evaluate potential quality of sage-grouse habitat. While it was determined to not include this on the WSS site, our analyses clearly show how ecological sites can provide valuable information when planning sage-grouse habitat improvements. Ecological sites provide information on the potential plant communities that can be supported, and these plant communities can be evaluated based on known habitat requirements of sage-grouse. This provides a valuable dataset on the potential habitat quality for sage-grouse. As with sagebrush restoration, knowing what can be produced on a site in terms of sage-grouse habitat rather than just what the existing vegetation is like will substantially aide in planning for habitat improvements and mitigation.

Because of the timing of the development of the planning tool, we could not use it to pre-plan actual treatments. However, we worked with Utah Department of Natural Resources to evaluate on-going treatments that they were conducting in sagebrush ecosystems. In particular, we selected treatments that included a seeding component so that we could analyze the species compositions that were being selected. We analyzed these compositions for their comparison to reference plant communities and projected future climate conditions. The demonstration projects showed how the SERT could be used pre-treatment to add considerations into restoration projects to maximize their long-term potential success and contribution to wildlife needs.

Our outreach products from this project have been limited by the SERT not yet being placed on WSS. We have produced this report and will be presenting the results of this project at the 2015 Society for Range Management meeting. We anticipate producing a Technical Note and Fact Sheet once the SERT is available on-line. We are also interested in conducting a webinar to interested parties once the SERT is on the web.

Quality Assurance

This project relied on existing data for development of the SERT. It used the data contained in SSURGO and ESIS, and thus is reliant on the quality of these data in developing reference descriptions and recommendations. It relies on the accuracy of the mapping included in SSURGO for delineation of ecological site locations. The climate change analysis also used existing data produced by the CMIP3 and PRISM data sets spatially distributed across ecological sites. The accuracy and quality of these data sets is well documented in their cited reports. The application of the SERT to the field demonstration sites was a qualitative application rather than a quantitative sampling of conditions. As such, quality assurance of data collection was not an issue, rather the interpretation of how the SERT could provide assistance to restoration planning was the primary focus.

Literature Cited

Bradley, B.A., and E. Fleishman. 2008. Relationships between expanding pinyon-juniper cover and topography in the central Great Basin, Nevada. J. Biogeography 35:951-964.

Braun, C.E., J.W. Connelly, M.A. Schroeder. 2005. Seasonal habitat requirements for sage-grouse: spring, summer, fall, and winter. Pages 38-42 In: N. L. Shaw, M. Pellant, and S.B. Monsen, compilers. 2005. Sage-grouse habitat restoration symposium proceedings; 2001. Proceedings RMRS-P-38. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Clifford, M. J., N. S. Cobb, and M. Buenemann. 2011. Long-Term Tree Cover dynamics in a Pinyon-Juniper Woodland: Climate-Change-Type Drought Resets Successional Clock. Ecosystems 14:949-962.

Connelly, J. W., M.A. Schroeder, A.R. Sands, and C.E. Braun. 2000. Guidelines to manage sage-grouse populations and their habitats. Wildlife Society Bulletin. 28:967–985.

Connelly, J.W., S.T. Knick, M.A. Schroeder, and S.J. Stiver. 2004. Conservation assessment of greater sage-grouse and sagebrush habitats. Western Association of Fish and Wildlife Agencies. Unpublished Report. Cheyenne, Wyoming.

Collatz, G.J., J.A. Berry, and J.S. Clark. 1998. Effects of climate and atmospheric CO2 partial pressure on the global distribution of C4 grasses: present, past, and future. Oecologia 114:441–454.

Coultrap, D.E., K.O. Fulgham, D.L. Lancaster, J.Gustafson, D.F. Lile, and M.R. George. 2008. Relationships between western juniper (Juniperus occidentalis) and understory vegetation. Invasive Plant Science and Management 1:3–11.

Dalgleish, H.J., D.N.Koons, M.B.Hooten, C.A.Moffet, and P.B. Adler. 2011. Climate influences the demography of three dominant sagebrush steppe plants. Ecology 92(1):75-85.

Doherty, K. E., J. L. Beck, and D. E. Naugle. 2011. Comparing ecological site descriptions to habitat characteristics influencing greater sage-grouse nest site occurrence and success. Rangeland Ecology and Management 64:344-351.

Dukes, J. 2007. Tomorrow's plant communities: Different, but how? New Phytologist 176(2):235-237.

Ehleringer, J.R., T.E. Cerling, and B.R. Helliker. 1997. C4 photosynthesis, atmospheric CO2, and climate. Oecologia 112:285-299.

Epstein, H.E., W.K. Lauenroth, I.C. Burke, and D.P. Coffin. 1997. Productivity patterns of C3 and C4 functional types in the US Great Plains. Ecology 78:722–731.

Fischer, J.C., L.L. Tieszen, and D.S. Chime. 2008. Climate controls on C3 vs. C4 productivity in North American grasslands from carbon isotope composition of soil organic matter. Global Change Biology 14:1-15.

Goodrich, S. 2005. Classification and capabilities of woody sagebrush communities of Western North America with emphasis on sage-grouse habitat. Pages 17-37 In: Shaw, N.L., M. Pellant, S.B. Monsen, comps. 2005. Sage-grouse habitat restoration symposium proceedings, 2001 June 4-7, Boise, ID. RMRS-P-38. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fort Collins, CO

Hattersley, P.W. 1983. The distribution of C3 and C4 grasses in Australia in relation to climate. Oecologia 57:113–128.

Hupp, J. W., C.E. Braun. 1989. Topographic distribution of sage-grouse foraging in winter. Journal of Wildlife Management. 53:823–829.

Miller, R. F., S. T. Knick, D. A. Pyke, C. W. Meinke, S. E. Hanser, M. J. Wisdom, and A. L. Hild. 2011. Characteristics of sagebrush habitats and limitations to long-term conservation. Pp. 145–184 *in* S. T. Knick and J. W. Connelly (editors). Greater Sage-grouse: ecology and conservation of a landscape species and its habitats. Studies in Avian Biology (vol. 38), University of California Press, Berkeley, CA.

Miller, R.F., and L.L. Edelman. 2000. Spatial and temporal changes of sage-grouse habitat in the sagebrush biome. Technical Bulletin 151. Agricultural Experiment Station, Oregon State University, Corvallis, Oregon.

Miller, R.F., and J.A. Rose. 1999. Fire history and western juniper encroachment in sage-brush steppe. J. Range Management 52:550-559.

Morgan, J.A, J.D. Derner, D.G. Milchunas, and E. Pendall. 2008. Management implications of global change for Great Plains rangelands. Rangelands 30(3):18-22.

Perfors, T., Harte, J. and Alter, S.E. 2003. Enhanced growth of sagebrush (*Artemisia tridentata*) in response to manipulated ecosystem warming. *Global Change Biology* **9**: 736-742.

Saxon, E. C. 2003. Adapting ecoregional plans to anticipate the impact of climate change. Pages 345-365 *In*: C. Groves, editor. Drafting a conservation blueprint. Island Press, Washington, D.C.

Shultz, L. 2012. Pocket guide to sagebrush. PRBO Conservation Science. 82pp.

Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture. Soil Survey Geographic (SSURGO) Database. Available online at http://sdmdataaccess.nrcs.usda.gov/. Accessed 7-23-2013.

Stiver, S.J., E.T. Rinkes, and D.E. Naugle. 2010. Sage-grouse habitat assessment framework. U.S. Bureau of Land Management. Unpublished Report. Idaho State Office, Boise, Idaho.

USDA, NRCS. 2013. The PLANTS Database. National Plant Data Team, United States Department of Agriculture (USDA), Natural Resource Conservation Service (NRCS): http://www.plants.usda.gov.

U.S. Department of Agriculture, Natural Resources Conservation Service. 2011. Introduction to NRCS' new sage-grouse initiative: Wildlife conservation through sustainable ranching. PA-2078. 8 pp.

U.S. Department of Agriculture, Natural Resources Conservation Service. 2006. Land Resource Regions and Major Land Resource Areas of the United States, the Caribbean, and the Pacific Basin. U.S. Department of Agriculture Handbook 296.

U.S. Fish and Wildlife Service. 2010 Endangered and threatened wildlife and plants; 12-month findings for petitions to list the greater sage-grouse (*Centrocercus urophasianus*) as threatened or endangered; proposed rule. Federal Register 75:13910-14014.

U.S. Global Change Research Program. 2009. Global climate change impacts in the United States. Cambridge University Press, New York.

Waller, S.S. and J.K. Lewis. 1979. Occurrence of C3 and C4 photosynthetic pathways in North American grasses. Journal of Range Management 32:12-28.

Appendix A - Site Restoration Potential Model Details

The primary driver for the sagebrush site restoration potential rating is the mean sagebrush composition percent. For composition values >=5% the potential is high, for values ≥1 but <5% the rating is moderate, and for sagebrush composition percent <1 the rating is low. This rating is further modified based on the percent composition of trees and other shrubs on the site. For sites with tree composition >=5% the rating becomes low, for values ≥1 but <5% the rating is moderate, and for tree composition percent <1 the rating remains high. In addition, on sites with <5% sagebrush composition the composition of other shrubs can modify the rating. When sagebrush is <5% and other shrubs are >=5% the rating becomes low, for shrub values ≥1 but <5% the rating is moderate, and for shrub composition percent <1 the rating remains unchanged. The query steps are outlined below and also shown in a flowchart at the end of the appendix.

- Use two ESIS Tables – RANGE_ANNUAL_PRODUCTION and RANGE_SPECIES_COMPOSITION (Figures A-1 and A-2)

RANGE_ANNUAL_PRODUCTION

ES_TYPE	ES_MLRA	ES_MLRU	ES_SITE_NUMBER	ES_STATE	PLANT_COM	PLANT_TYPE	PLNT_TYI	PLNT_TY	PLNT_TYPE_ANNUAL_PRODUCTION_RV
R	010X	A	001	OR	1	Forb	9	63	36
R	010X	A	001	OR	1	Grass/Grasslike	621	819	720
R	010X	A	001	OR	1	Shrub/Vine	63	171	117
R	010X	A	001	OR	1	Tree	18	45	32

Figure A-1. RANGE_ANNUAL_PRODUCTION table.

RANGE_SPECIES_COMPOSITIONS

ES_TYPE	ES_MLRA	ES_MLRU	ES_SITE_NUI	ES_STATE	PLANT_COM	PLANT_TYPE	GROUP_NUI	PLANT_SYMI	POUNDS_PE	POUNDS_PEI
R	010X	A	001	OR	1	Forb	9	ACMI2	0	5
R	010X	A	001	OR	1	Forb	9	AGOSE	0	5
R	010X	A	001	OR	1	Forb	9	ANTEN	0	5
R	010X	A	001	OR	1	Forb	9	ASAR7	0	5
R	010X	A	001	OR	1	Forb	9	BASA3	0	5
R	010X	A	001	OR	1	Forb	9	CALOC	0	5
R	010X	A	001	OR	1	Forb	9	CRAC2	0	5
R	010X	A	001	OR	1	Forb	9	ERIGE2	0	5
R	010X	A	001	OR	1	Forb	9	ERIOG	0	5
R	010X	A	001	OR	1	Forb	9	ERNI2	0	5
R	010X	A	001	OR	1	Forb	9	LODI	0	5
R	010X	A	001	OR	1	Forb	9	LUPIN	0	5
R	010X	A	001	OR	1	Forb	9	PHDI3	0	5
R	010X	A	001	OR	1	Forb	9	TRDU	0	5
R	010X	A	001	OR	1	Grass/Grasslike	1	PSSP6	495	585
R	010X	A	001	OR	1	Grass/Grasslike	2	ACHY	9	18
R	010X	A	001	OR	1	Grass/Grasslike	2	ACTH7	9	18
R	010X	A	001	OR	1	Grass/Grasslike	2	FEID	9	45
R	010X	A	001	OR	1	Grass/Grasslike	2	LECI4	9	18
R	010X	A	001	OR	1	Grass/Grasslike	3	POSE	90	135
R	010X	A	001	OR	1	Shrub/Vine	11	ARTRT	45	135
R	010X	A	001	OR	1	Shrub/Vine	12	PUTR2	9	18
R	010X	A	001	OR	1	Shrub/Vine	15	ERMI4	0	5
R	010X	A	001	OR	1	Shrub/Vine	15	ERNA10	0	5
R	010X	A	001	OR	1	Shrub/Vine	15	ERTE18	0	5
R	010X	A	001	OR	1	Shrub/Vine	15	LEPU	0	5
R	010X	A	001	OR	1	Shrub/Vine	15	TECA2	0	5
R	010X	A	001	OR	1	Tree	16	JUOC	18	45
R	010X	A	002	OR	1	Forb	7	ACMI2	6	10

Figure A-2. RANGE_SPECIES_COMPOSITON table.

- Create Primary Key (ECOID) for each ESIS table that is a concatenation of the following columns (order is specific): ES_TYPE, ES_MLRA, ES_MLRU, ES_SITE_NUMBER, ES_STATE.

- SUM the column PLNT_TYPE_ANNUAL_PRODUCTION_RV by the newly created Primary key in the RANGE_ANNUAL_PRODUCTION table and create a new table that has the ECOID and SITE_ANN_PROD_RV columns.
- RELATE the newly created SITE_ANN_PROD_RV column to the RANGE_SPECIES_COMPOSITION table using the primary key (ECOID) in both tables. This will add the SITE_ANN_PROD_RV column to the RANGE_SPECIES_COMPOSITION table.
- In the RANGE_SPECIES_COMPOSITION table divide the POUNDS_PER_ACRE_LOW and POUND_PER_ACRE_HIGH columns by the newly added SITE_ANN_PROD_RV column and then multiply the result by 100 to get the percent composition for each species.
- AVERAGE the POUNDS_PER_ACRE_LOW and POUNDS_PER_ACRE_HIGH columns to calculate the mean percent composition for each species. Place result in new column, COMP_RV
- RELATE the following table (Table A-1), SAGE_SPP_RELATE, to RANGE_SPECIES_COMPOSITION on the SYMBOL column. Add the GROWTHFORM, HEIGHT, NEST, WINTER, and SAGE_RATE columns.

Table A-1. SAGE_SPP_RELATE table

PLANT_SYMBOL	GROWTHFORM	SCIENTIFICNAME	COMMONNAME	HEIGHT	NEST	WINTER	SAGE_RATE
ARAR8	SAGE	Artemisia arbuscula	low sagebrush	Low	1	1	5
ARARL	SAGE	Artemisia arbuscula ssp. longiloba	low sagebrush	Low	1	1	5
ARARL3	SAGE	Artemisia arbuscula ssp. longicaulis	low sagebrush	Low	1	1	5
ARBI3	SAGE	Artemisia bigelovii	Bigelow sagebrush	Low	1	1	5
ARCA13	SAGE	Artemisia cana	silver sagebrush	Tall	2	2	3
ARCAC5	SAGE	Artemisia cana ssp. cana	Plains silver sagebrush	Tall	2	2	3
ARCAV2	SAGE	Artemisia cana ssp. viscidula	silver sagebrush	Tall	1	1	3
ARFI2	SAGE	Artemisia filifolia	sand sagebrush	Tall	1	1	4
ARNO4	SAGE	Artemisia nova	black sagebrush	Low	1	1	5
ARNON2	SAGE	Artemisia nova var. nova	black sagebrush	Low	1	1	5
ARPY2	SAGE	Artemisia pygmaea	pygmy sagebrush	Low	1	1	5
ARRI2	SAGE	Artemisia rigida	stiff sagebrush	Low	1	1	5
ARTEM	SAGE	Artemisia	sagebrush	Medium	1	1	4
ARTR2	SAGE	Artemisia tridentata	big sagebrush	Tall	3	3	1
ARTR4	SAGE	Artemisia tripartita	threetip sagebrush	Tall	3	1	3
ARTRR2	SAGE	Artemisia tripartita ssp. rupicola	Wyoming threetip sagebrush	Low	1	1	5
ARTRS2	SAGE	Artemisia tridentata ssp. spiciformis	subalpine big sagebrush	Tall	2	2	3
ARTRT	SAGE	Artemisia tridentata ssp. tridentata	basin big sagebrush	Tall	2	2	3
ARTRV	SAGE	Artemisia tridentata ssp. vaseyana	mountain big sagebrush	Tall	3	2	2
ARTRW	SAGE	Artemisia tridentata var. wyomingensis	Wyoming big sagebrush	Tall	3	3	1
ARTRW8	SAGE	Artemisia tridentata ssp. wyomingensis	Wyoming big sagebrush	Tall	3	3	1
ARTRX	SAGE	Artemisia tridentata ssp. xericensis	xeric big sagebrush	Tall	2	2	3

- SUM the COMP_RV column by ECOID and GROWTHFORM to create a table that has species composition by GROWTHFORM for each ecological site.
- Apply the site potential rating. Table A-2 shows necessary conditions required for each rating. The MIN function can be used to select proper rating.

Table A-2. Analysis matrix for sage grouse habitat quality rating.

	Nesting and Wintering		
	LOW	MOD	HIGH
Sage productivity	>0-0.9999%	1-4.9999%	>=5%
% Productivity of trees	>=5%	1-4.9999%	<1%
% other shrubs > SAGE, where SAGE <5%	>=5%	1-4.9999%	<1%

- The final step is to use the NEST and WINTER columns in the SAGE_SPP_RELATE table to generate a rating for both nesting and wintering habitat. As with the other criteria use the MIN function to select the lowest value.
- Figure A-3 shows a flowchart of the modeling steps.

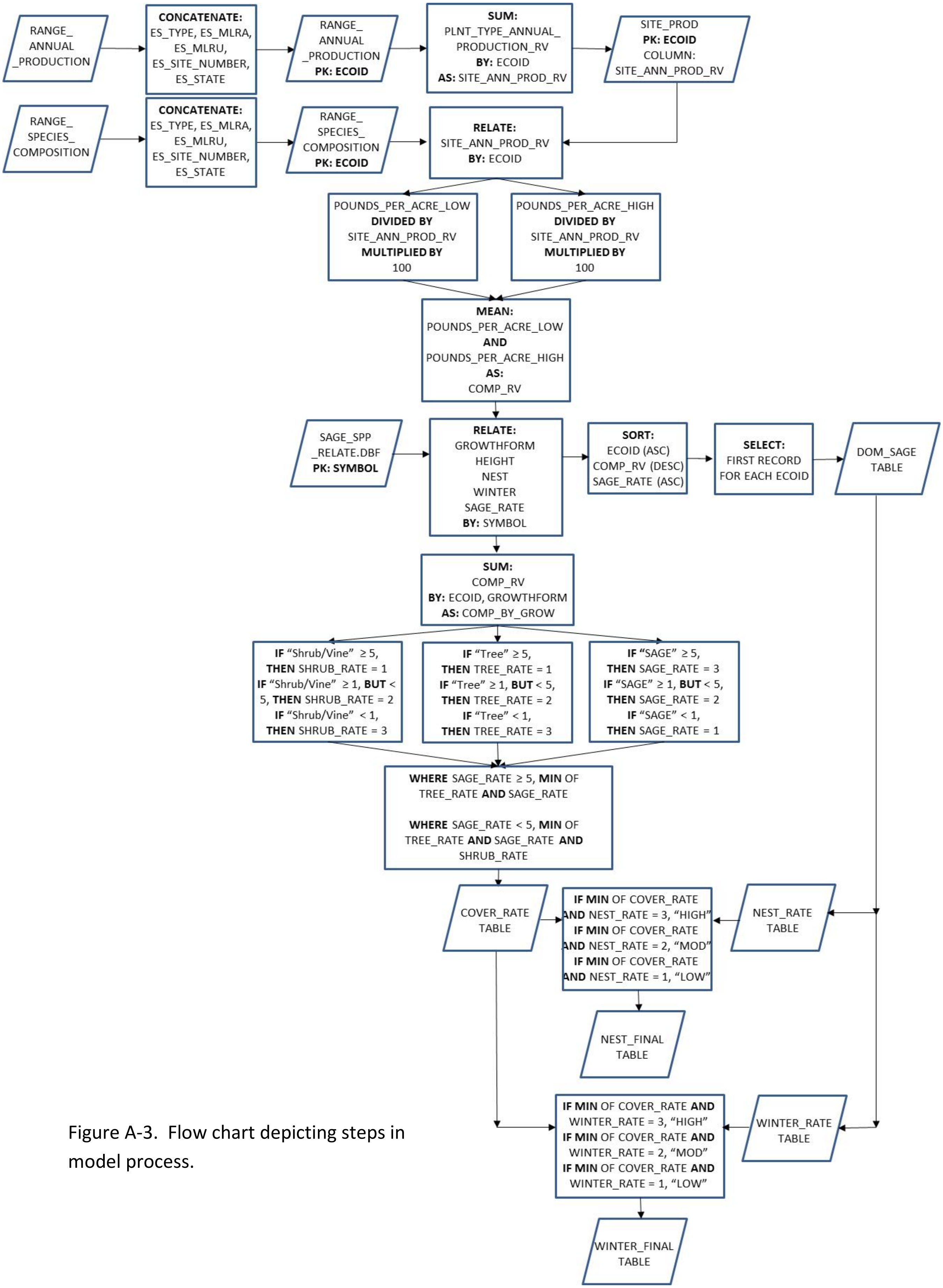


Figure A-3. Flow chart depicting steps in model process.

APPENDIX B – CLIMATE CHANGE DATA MODEL DETAILS

```
#Original program by Pam Froemke, June 2012, USDA FS Rocky Mtn. Research Station

# NetCDF.py
# Modified by Scott Yeats, June 2012

# Process:
#   Makes a raster layer of the NetCDF file.
#   Select one month in the NetCDF raster layer.
#   Project the raster layer to produce a permanent raster dataset.

import arcpy as ap
from arcpy import env
from arcpy.sa import *
import glob
import time

StartTime = time.ctime() # Mon Oct 18 13:35:29 2010

ap.CheckOutExtension("spatial")
ap.env.overwriteOutput = True

# Variables
NetcdfPath = "C:\\Scott\\EMRI\\Climate\\UKMO_HADCM3\\Prcp\\B1_2070-2099\\*.nc"
ap.env.workspace = "C:\\Scott\\EMRI\\Climate\\UKMO_HADCM3\\Prcp\\GIS"
ClimateVariable = "p"

try:
    # this will give you a Python list object that you can use to batch process all of your files
    # just insert the path to your folder holding the netCDF files
    cdfList = glob.glob(NetcdfPath)
    Counter = 2070 # represents the year

    # Start Loop 1
    # Loop through your list and process each NetCDF file (basin and year) one at a time
    for cdf in cdfList:
        print "  "+str(Counter)
        print "     Now processing: " + cdf

        # Make Raster Layer
        BasinYr = "_b1_"+str(Counter)
        Variable = "Prcp"
        RasterLyr = ClimateVariable+BasinYr
```

```
        print "     RasterLyr = "+RasterLyr
        ap.md.MakeNetCDFRasterLayer(cdf, Variable, "longitude", "latitude", RasterLyr, "", "time #", "BY_VALUE")

        # Start Loop 2
        # Monthlist is set in the format of the NetCDF
        MonthList = ["1/16/"+str(Counter), "2/16/"+str(Counter), "3/15/"+str(Counter),
                "4/15/"+str(Counter), "5/15/"+str(Counter), "6/15/"+str(Counter),
                "7/15/"+str(Counter), "8/15/"+str(Counter), "9/15/"+str(Counter),
                "10/15/"+str(Counter), "11/15/"+str(Counter), "12/15/"+str(Counter)]
        CounterMonth = 1

        for Month in MonthList:
            print "      "+Month

            # Select by Dimension
            Dimension = "time "
            SelectBy = Dimension+Month
            ap.SelectByDimension_md(RasterLyr, SelectBy, "BY_VALUE")
            print SelectBy + " has been selected"

            # Create Permanent Raster
            print RasterLyr + "_" + str(CounterMonth)
            TimeRaster = RasterLyr
            outRaster = RasterLyr + "_" + str(CounterMonth)
            ap.CopyRaster_management(TimeRaster, outRaster)
            print outRaster + " " + "created from NetCDF layer"

            CounterMonth = CounterMonth+1

        Counter = Counter+1

    print "Done!"
    EndTime = time.ctime() # Mon Oct 18 13:35:29 2010
    print "Started at "+StartTime+" and ended at "+EndTime

except ap.ExecuteError:
    # If an error occurred, then print the messages
    ap.AddError(ap.GetMessages(2))

except:
    print "Curses! An error!"
    print "Drat!!!!!"
    EndTime = time.ctime()
    print "Started at "+StartTime+" and ended at "+EndTime
```

APPENDIX D. List of sagebrush and grass species expected response to climate change by MLRA.

MRLA Symbol	PLANTS Symbol	Pathway	Scientific Name	Common Name	Climate Change Response
7	ARTRT		Artemisia tridentata ssp. tridentata	basin big sagebrush	No Change
7	ARTRW8		Artemisia tridentata ssp. wyomingensis	Wyoming big sagebrush	No Change
7	ACHY	C3	Achnatherum hymenoides	Indian ricegrass	Decrease
7	ACTH7	C3	Achnatherum thurberianum	Thurber's needlegrass	Decrease
7	ELEL5	C3	Elymus elymoides	squirreltail	Decrease
7	ELMA7	C3	Elymus macrourus	tufted wheatgrass	Decrease
7	HECO26	C3	Hesperostipa comata	needle and thread	Decrease
7	LECI4	C3	Leymus cinereus	basin wildrye	Decrease
7	LETR5	C3	Leymus triticoides	beardless wildrye	Decrease
7	POSE	C3	Poa secunda	Sandberg bluegrass	Decrease
7	PSSP6	C3	Pseudoroegneria spicata	bluebunch wheatgrass	Decrease
8	ARRI2		Artemisia rigida	stiff sagebrush	No Change
8	ARTRT		Artemisia tridentata ssp. tridentata	basin big sagebrush	No Change
8	ARTRW8		Artemisia tridentata ssp. wyomingensis	Wyoming big sagebrush	No Change
8	ACHY	C3	Achnatherum hymenoides	Indian ricegrass	Decrease
8	ACTH7	C3	Achnatherum thurberianum	Thurber's needlegrass	Decrease
8	DAUN	C3	Danthonia unispicata	onespike danthonia	Decrease
8	ELEL5	C3	Elymus elymoides	squirreltail	Decrease
8	FEID	C3	Festuca idahoensis	Idaho fescue	Decrease
8	HECO26	C3	Hesperostipa comata	needle and thread	Decrease
8	KOMA	C3	Koeleria macrantha	prairie Junegrass	Decrease
8	POCU3	C3	Poa cusickii	Cusick's bluegrass	Decrease
8	POSE	C3	Poa secunda	Sandberg bluegrass	Decrease
8	PSSP6	C3	Pseudoroegneria spicata	bluebunch wheatgrass	Decrease
9	ARRI2		Artemisia rigida	stiff sagebrush	No Change
9	ARTRT		Artemisia tridentata ssp. tridentata	basin big sagebrush	No Change
9	ACTH7	C3	Achnatherum thurberianum	Thurber's needlegrass	Decrease
9	DAUN	C3	Danthonia unispicata	onespike danthonia	Decrease
9	ELEL5	C3	Elymus elymoides	squirreltail	Decrease
9	FEID	C3	Festuca idahoensis	Idaho fescue	No Change
9	POSE	C3	Poa secunda	Sandberg bluegrass	Decrease
9	PSSP6	C3	Pseudoroegneria spicata	bluebunch wheatgrass	Decrease
10	ARAR8		Artemisia arbuscula	low sagebrush	No Change
10	ARRI2		Artemisia rigida	stiff sagebrush	No Change
10	ARTRT		Artemisia tridentata ssp. tridentata	basin big sagebrush	No Change
10	ARTRV		Artemisia tridentata ssp. vaseyana	mountain big sagebrush	Decrease
10	ARTRW8		Artemisia tridentata ssp. wyomingensis	Wyoming big sagebrush	No Change
10	ARTRX		Artemisia tridentata ssp. xericensis	xeric big sagebrush	No Change
10	ARTR4		Artemisia tripartita	threetip sagebrush	No Change
10	ACHY	C3	Achnatherum hymenoides	Indian ricegrass	Decrease
10	ACLE9	C3	Achnatherum lettermanii	Letterman's needlegrass	Decrease
10	ACNE9	C3	Achnatherum nelsonii	Columbia needlegrass	Decrease

APPENDIX D. List of sagebrush and grass species expected response to climate change by MLRA.

MRLA Symbol	PLANTS Symbol	Pathway	Scientific Name	Common Name	Climate Change Response
10	ACOC3	C3	Achnatherum occidentale	western needlegrass	Decrease
10	ACTH7	C3	Achnatherum thurberianum	Thurber's needlegrass	Decrease
10	ARPU9	C4	Aristida purpurea	purple threeawn	No Change
10	BRCA5	C3	Bromus carinatus	California brome	Decrease
10	BRMA4	C3	Bromus marginatus	mountain brome	Decrease
10	DAUN	C3	Danthonia unispicata	onespike danthonia	Decrease
10	ELEL5	C3	Elymus elymoides	squirreltail	Decrease
10	ELGL	C3	Elymus glaucus	blue wildrye	Decrease
10	ELLA3	C3	Elymus lanceolatus	thickspike wheatgrass	Decrease
10	ELMA7	C3	Elymus macrourus	tufted wheatgrass	Decrease
10	ELTR7	C3	Elymus trachycaulus	slender wheatgrass	Decrease
10	FEID	C3	Festuca idahoensis	Idaho fescue	Decrease
10	HECO26	C3	Hesperostipa comata	needle and thread	Decrease
10	KOMA	C3	Koeleria macrantha	prairie Junegrass	Decrease
10	LECI4	C3	Leymus cinereus	basin wildrye	Decrease
10	MEBU	C3	Melica bulbosa	oniongrass	Decrease
10	MURI	C4	Muhlenbergia richardsonis	mat muhly	Increase
10	PASM	C3	Pascopyrum smithii	western wheatgrass	Decrease
10	POCU3	C3	Poa cusickii	Cusick's bluegrass	Decrease
10	POSE	C3	Poa secunda	Sandberg bluegrass	Decrease
10	PSSP6	C3	Pseudoroegneria spicata	bluebunch wheatgrass	Decrease
11	ARTRT		Artemisia tridentata ssp. tridentata	basin big sagebrush	No Change
11	ARTRW8		Artemisia tridentata ssp. wyomingensis	Wyoming big sagebrush	No Change
11	ARTR4		Artemisia tripartita	threetip sagebrush	No Change
11	PSSA2	C3	×Pseudelymus saxicola	foxtail wheatgrass	Decrease
11	ACHY	C3	Achnatherum hymenoides	Indian ricegrass	Decrease
11	ACTH7	C3	Achnatherum thurberianum	Thurber's needlegrass	Decrease
11	ELEL5	C3	Elymus elymoides	squirreltail	Decrease
11	ELLA3	C3	Elymus lanceolatus	thickspike wheatgrass	Decrease
11	HECO26	C3	Hesperostipa comata	needle and thread	Decrease
11	KOMA	C3	Koeleria macrantha	prairie Junegrass	Decrease
11	LECI4	C3	Leymus cinereus	basin wildrye	Decrease
11	POSE	C3	Poa secunda	Sandberg bluegrass	Decrease
11	PSSP6	C3	Pseudoroegneria spicata	bluebunch wheatgrass	Decrease
13	ARTRV		Artemisia tridentata ssp. vaseyana	mountain big sagebrush	No Change
13	ARTR4		Artemisia tripartita	threetip sagebrush	No Change
13	ACLE9	C3	Achnatherum lettermanii	Letterman's needlegrass	Decrease
13	ACNE9	C3	Achnatherum nelsonii	Columbia needlegrass	Decrease
13	BRMA4	C3	Bromus marginatus	mountain brome	Decrease
13	ELEL5	C3	Elymus elymoides	squirreltail	Decrease
13	ELLA3	C3	Elymus lanceolatus	thickspike wheatgrass	Decrease
13	ELTR7	C3	Elymus trachycaulus	slender wheatgrass	Decrease
13	FEID	C3	Festuca idahoensis	Idaho fescue	Decrease

APPENDIX D. List of sagebrush and grass species expected response to climate change by MLRA.

MRLA Symbol	PLANTS Symbol	Pathway	Scientific Name	Common Name	Climate Change Response
13	KOMA	C3	Koeleria macrantha	prairie Junegrass	Decrease
13	LECI4	C3	Leymus cinereus	basin wildrye	Decrease
13	MEBU	C3	Melica bulbosa	oniongrass	No Change
13	POSE	C3	Poa secunda	Sandberg bluegrass	Decrease
13	PSSP6	C3	Pseudoroegneria spicata	bluebunch wheatgrass	Decrease
21	ARAR8		Artemisia arbuscula	low sagebrush	No Change
21	ARTRT		Artemisia tridentata ssp. tridentata	basin big sagebrush	No Change
21	ARTRV		Artemisia tridentata ssp. vaseyana	mountain big sagebrush	No Change
21	ARTRW8		Artemisia tridentata ssp. wyomingensis	Wyoming big sagebrush	No Change
21	ELEL5	C3	Elymus elymoides	squirreltail	Decrease
21	ELTR7	C3	Elymus trachycaulus	slender wheatgrass	Decrease
21	FEID	C3	Festuca idahoensis	Idaho fescue	Decrease
21	FEOC	C3	Festuca occidentalis	western fescue	Decrease
21	HOBR2	C3	Hordeum brachyantherum	meadow barley	Decrease
21	KOMA	C3	Koeleria macrantha	prairie Junegrass	Decrease
21	LECI4	C3	Leymus cinereus	basin wildrye	Decrease
21	MEBU	C3	Melica bulbosa	oniongrass	No Change
21	POCU3	C3	Poa cusickii	Cusick's bluegrass	Decrease
21	POLE	C3	Poa leibergii	Leiberg's bluegrass	Decrease
21	PONE2	C3	Poa nervosa	Wheeler bluegrass	Decrease
21	POSE	C3	Poa secunda	Sandberg bluegrass	Decrease
21	POWH2	C3	Poa wheeleri	Wheeler's bluegrass	Decrease
21	PSSP6	C3	Pseudoroegneria spicata	bluebunch wheatgrass	Decrease
21	TRSP2	C3	Trisetum spicatum	spike trisetum	Decrease
23	ARAR8		Artemisia arbuscula	low sagebrush	No Change
23	ARARL		Artemisia arbuscula ssp. longiloba	alkali sagebrush	No Change
23	ARCA13		Artemisia cana	silver sagebrush	No Change
23	ARTRT		Artemisia tridentata ssp. tridentata	basin big sagebrush	No Change
23	ARTRV		Artemisia tridentata ssp. vaseyana	mountain big sagebrush	Decrease
23	ARTRW8		Artemisia tridentata ssp. wyomingensis	Wyoming big sagebrush	No Change
23	PSSA2	C3	×Pseudelymus saxicola	foxtail wheatgrass	Decrease
23	ACHY	C3	Achnatherum hymenoides	Indian ricegrass	Decrease
23	ACLE8	C3	Achnatherum lemmonii	Lemmon's needlegrass	Decrease
23	ACOC3	C3	Achnatherum occidentale	western needlegrass	Decrease
23	ACTH7	C3	Achnatherum thurberianum	Thurber's needlegrass	Decrease
23	ACWE3	C3	Achnatherum webberi	Webber needlegrass	Decrease
23	BRCA5	C3	Bromus carinatus	California brome	No Change
23	BRMA4	C3	Bromus marginatus	mountain brome	Decrease
23	DAUN	C3	Danthonia unispicata	onespike danthonia	Decrease
23	DISP	C4	Distichlis spicata	saltgrass	Increase
23	ELEL5	C3	Elymus elymoides	squirreltail	Decrease
23	ELLA3	C3	Elymus lanceolatus	thickspike wheatgrass	Decrease
23	ELMA7	C3	Elymus macrourus	tufted wheatgrass	Decrease

APPENDIX D. List of sagebrush and grass species expected response to climate change by MLRA.

MRLA Symbol	PLANTS Symbol	Pathway	Scientific Name	Common Name	Climate Change Response
23	FEID	C3	Festuca idahoensis	Idaho fescue	Decrease
23	HECO26	C3	Hesperostipa comata	needle and thread	Decrease
23	HOBR2	C3	Hordeum brachyantherum	meadow barley	Decrease
23	KOMA	C3	Koeleria macrantha	prairie Junegrass	Decrease
23	LECI4	C3	Leymus cinereus	basin wildrye	Decrease
23	LETR5	C3	Leymus triticoides	beardless wildrye	Decrease
23	MURI	C4	Muhlenbergia richardsonis	mat muhly	Increase
23	POCU3	C3	Poa cusickii	Cusick's bluegrass	Decrease
23	POSE	C3	Poa secunda	Sandberg bluegrass	Decrease
23	PSSP6	C3	Pseudoroegneria spicata	bluebunch wheatgrass	Decrease
23	SPAI	C4	Sporobolus airoides	alkali sacaton	Increase
23	SPCR	C4	Sporobolus cryptandrus	sand dropseed	Increase
24	ARCA13		Artemisia cana	silver sagebrush	No Change
24	ARNO4		Artemisia nova	black sagebrush	No Change
24	ARTRT		Artemisia tridentata ssp. tridentata	basin big sagebrush	No Change
24	ARTRW8		Artemisia tridentata ssp. wyomingensis	Wyoming big sagebrush	No Change
24	ACHY	C3	Achnatherum hymenoides	Indian ricegrass	Decrease
24	ACTH7	C3	Achnatherum thurberianum	Thurber's needlegrass	Decrease
24	DISP	C4	Distichlis spicata	saltgrass	Increase
24	ELEL5	C3	Elymus elymoides	squirreltail	Decrease
24	HECO26	C3	Hesperostipa comata	needle and thread	Decrease
24	LECI4	C3	Leymus cinereus	basin wildrye	Decrease
24	LETR5	C3	Leymus triticoides	beardless wildrye	Decrease
24	MURI	C4	Muhlenbergia richardsonis	mat muhly	No Change
24	POSE	C3	Poa secunda	Sandberg bluegrass	Decrease
24	PSSP6	C3	Pseudoroegneria spicata	bluebunch wheatgrass	Decrease
24	SPAI	C4	Sporobolus airoides	alkali sacaton	Increase
25	ARAR8		Artemisia arbuscula	low sagebrush	No Change
25	ARNO4		Artemisia nova	black sagebrush	No Change
25	ARTRT		Artemisia tridentata ssp. tridentata	basin big sagebrush	No Change
25	ARTRV		Artemisia tridentata ssp. vaseyana	mountain big sagebrush	Decrease
25	ARTRW8		Artemisia tridentata ssp. wyomingensis	Wyoming big sagebrush	No Change
25	PSSA2	C3	Pseudelymus saxicola	foxtail wheatgrass	Decrease
25	ACHY	C3	Achnatherum hymenoides	Indian ricegrass	Decrease
25	ACLE9	C3	Achnatherum lettermanii	Letterman's needlegrass	Decrease
25	ACNE9	C3	Achnatherum nelsonii	Columbia needlegrass	Decrease
25	ACTH7	C3	Achnatherum thurberianum	Thurber's needlegrass	Decrease
25	BRCA5	C3	Bromus carinatus	California brome	No Change
25	ELEL5	C3	Elymus elymoides	squirreltail	Decrease
25	ELLA3	C3	Elymus lanceolatus	thickspike wheatgrass	Decrease
25	ELMA7	C3	Elymus macrourus	tufted wheatgrass	Decrease
25	ELTR7	C3	Elymus trachycaulus	slender wheatgrass	Decrease
25	FEID	C3	Festuca idahoensis	Idaho fescue	Decrease

APPENDIX D. List of sagebrush and grass species expected response to climate change by MLRA.

MRLA Symbol	PLANTS Symbol	Pathway	Scientific Name	Common Name	Climate Change Response
25	HECO26	C3	Hesperostipa comata	needle and thread	Decrease
25	KOMA	C3	Koeleria macrantha	prairie Junegrass	Decrease
25	LEKI2	C3	Leucopoa kingii	spike fescue	Decrease
25	LECI4	C3	Leymus cinereus	basin wildrye	Decrease
25	MEBU	C3	Melica bulbosa	oniongrass	Decrease
25	PASM	C3	Pascopyrum smithii	western wheatgrass	Decrease
25	POFE	C3	Poa fendleriana	muttongrass	No Change
25	POSE	C3	Poa secunda	Sandberg bluegrass	Decrease
25	PSSP6	C3	Pseudoroegneria spicata	bluebunch wheatgrass	Decrease
28A	ARNO4		Artemisia nova	black sagebrush	No Change
28A	ARPY2		Artemisia pygmaea	pygmy sagebrush	No Change
28A	ARTRT		Artemisia tridentata ssp. tridentata	basin big sagebrush	No Change
28A	ARTRV		Artemisia tridentata ssp. vaseyana	mountain big sagebrush	Decrease
28A	ARTRW8		Artemisia tridentata ssp. wyomingensis	Wyoming big sagebrush	No Change
28A	ACHY	C3	Achnatherum hymenoides	Indian ricegrass	No Change
28A	ACLE9	C3	Achnatherum lettermanii	Letterman's needlegrass	No Change
28A	ACNE9	C3	Achnatherum nelsonii	Columbia needlegrass	Decrease
28A	ARPU9	C4	Aristida purpurea	purple threeawn	No Change
28A	BOGR2	C4	Bouteloua gracilis	blue grama	Increase
28A	DISP	C4	Distichlis spicata	saltgrass	Decrease
28A	ELEL5	C3	Elymus elymoides	squirreltail	No Change
28A	ELLA3	C3	Elymus lanceolatus	thickspike wheatgrass	No Change
28A	ELTR7	C3	Elymus trachycaulus	slender wheatgrass	No Change
28A	FEID	C3	Festuca idahoensis	Idaho fescue	No Change
28A	HECO26	C3	Hesperostipa comata	needle and thread	No Change
28A	HOJU	C3	Hordeum jubatum	foxtail barley	Increase
28A	KOMA	C3	Koeleria macrantha	prairie Junegrass	Decrease
28A	LECI4	C3	Leymus cinereus	basin wildrye	No Change
28A	LESA4	C3	Leymus salinus	saline wildrye	Decrease
28A	LETR5	C3	Leymus triticoides	beardless wildrye	Increase
28A	MEBU	C3	Melica bulbosa	oniongrass	Increase
28A	MUPU2	C4	Muhlenbergia pungens	sandhill muhly	Decrease
28A	MURI	C4	Muhlenbergia richardsonis	mat muhly	Decrease
28A	PASM	C3	Pascopyrum smithii	western wheatgrass	No Change
28A	PLJA	C4	Pleuraphis jamesii	James' galleta	No Change
28A	POFE	C3	Poa fendleriana	muttongrass	No Change
28A	POSE	C3	Poa secunda	Sandberg bluegrass	No Change
28A	PSSP6	C3	Pseudoroegneria spicata	bluebunch wheatgrass	No Change
28A	PUNU2	C3	Puccinellia nuttalliana	Nuttall's alkaligrass	No Change
28A	SPAI	C4	Sporobolus airoides	alkali sacaton	Decrease
28A	SPCR	C4	Sporobolus cryptandrus	sand dropseed	No Change
28A	SPGR	C4	Spartina gracilis	alkali cordgrass	Decrease
28A	VUOC	C3	Vulpia octoflora	sixweeks fescue	No Change

APPENDIX D. List of sagebrush and grass species expected response to climate change by MLRA.

MRLA Symbol	PLANTS Symbol	Pathway	Scientific Name	Common Name	Climate Change Response
29	ARNO4		Artemisia nova	black sagebrush	No Change
29	ARTRV		Artemisia tridentata ssp. vaseyana	mountain big sagebrush	No Change
29	ACHY	C3	Achnatherum hymenoides	Indian ricegrass	Decrease
29	BOGR2	C4	Bouteloua gracilis	blue grama	Increase
29	ELEL5	C3	Elymus elymoides	squirreltail	Decrease
29	HECO26	C3	Hesperostipa comata	needle and thread	Decrease
29	HIJA	C4	Hilaria jamesii	galleta	No Change
29	KOMA	C3	Koeleria macrantha	prairie Junegrass	Decrease
29	PASM	C3	Pascopyrum smithii	western wheatgrass	Decrease
29	POFE	C3	Poa fendleriana	muttongrass	Decrease
29	PSSP6	C3	Pseudoroegneria spicata	bluebunch wheatgrass	Decrease
29	SPCR	C4	Sporobolus cryptandrus	sand dropseed	No Change
32		ARCA13	Artemisia cana	silver sagebrush	No Change
32		ARNO4	Artemisia nova	black sagebrush	No Change
32		ARTR2	Artemisia tridentata	big sagebrush	No Change
32		ARTRT	Artemisia tridentata ssp. tridentata	basin big sagebrush	No Change
32		ARTRW8	Artemisia tridentata ssp. wyomingensis	Wyoming big sagebrush	Increase
32	ACHY	C3	Achnatherum hymenoides	Indian ricegrass	No Change
32	ARPU9	C4	Aristida purpurea	purple threeawn	No Change
32	BOGR2	C4	Bouteloua gracilis	blue grama	No Change
32	CALO	C4	Calamovilfa longifolia	prairie sandreed	Decrease
32	DISP	C4	Distichlis spicata	saltgrass	No Change
32	ELAL7	C3	Elymus albicans	Montana wheatgrass	No Change
32	ELCA4	C3	Elymus canadensis	Canada wildrye	Decrease
32	ELEL5	C3	Elymus elymoides	squirreltail	No Change
32	ELLA3	C3	Elymus lanceolatus	thickspike wheatgrass	No Change
32	ELTR7	C3	Elymus trachycaulus	slender wheatgrass	Increase
32	HECO26	C3	Hesperostipa comata	needle and thread	No Change
32	KOMA	C3	Koeleria macrantha	prairie Junegrass	Decrease
32	LEKI2	C3	Leucopoa kingii	spike fescue	No Change
32	LECI4	C3	Leymus cinereus	basin wildrye	Increase
32	MURI	C4	Muhlenbergia richardsonis	mat muhly	No Change
32	NAVI4	C3	Nassella viridula	green needlegrass	Decrease
32	PASM	C3	Pascopyrum smithii	western wheatgrass	Increase
32	POSE	C3	Poa secunda	Sandberg bluegrass	Increase
32	PSSP6	C3	Pseudoroegneria spicata	bluebunch wheatgrass	No Change
32	SPAI	C4	Sporobolus airoides	alkali sacaton	No Change
32	SPCR	C4	Sporobolus cryptandrus	sand dropseed	No Change
34A	ARAR8		Artemisia arbuscula	low sagebrush	No Change
34A	ARARL		Artemisia arbuscula ssp. longiloba	alkali sagebrush	No Change
34A	ARCA13		Artemisia cana	silver sagebrush	No Change
34A	ARNO4		Artemisia nova	black sagebrush	No Change
34A	ARTR2		Artemisia tridentata	big sagebrush	No Change

APPENDIX D. List of sagebrush and grass species expected response to climate change by MLRA.

MRLA Symbol	PLANTS Symbol	Pathway	Scientific Name	Common Name	Climate Change Response
34A	ARTRW8		Artemisia tridentata ssp. wyomingensis	Wyoming big sagebrush	No Change
34A	ACHY	C3	Achnatherum hymenoides	Indian ricegrass	No Change
34A	ACLE9	C3	Achnatherum lettermanii	Letterman's needlegrass	No Change
34A	ARIST	C4	Aristida	threeawn	No Change
34A	BOGR2	C4	Bouteloua gracilis	blue grama	No Change
34A	CALO	C4	Calamovilfa longifolia	prairie sandreed	Decrease
34A	CAMO	C3	Calamagrostis montanensis	plains reedgrass	Decrease
34A	ELEL5	C3	Elymus elymoides	squirreltail	No Change
34A	ELLA3	C3	Elymus lanceolatus	thickspike wheatgrass	No Change
34A	HECO26	C3	Hesperostipa comata	needle and thread	Increase
34A	KOMA	C3	Koeleria macrantha	prairie Junegrass	Decrease
34A	LECI4	C3	Leymus cinereus	basin wildrye	No Change
34A	LESA4	C3	Leymus salinus	saline wildrye	No Change
34A	MUMO	C4	Muhlenbergia montana	mountain muhly	Decrease
34A	MUPU2	C4	Muhlenbergia pungens	sandhill muhly	No Change
34A	NAVI4	C3	Nassella viridula	green needlegrass	No Change
34A	PASM	C3	Pascopyrum smithii	western wheatgrass	No Change
34A	PLEUR12	C4	Pleuraphis	galleta grass	No Change
34A	POFE	C3	Poa fendleriana	muttongrass	No Change
34A	POSE	C3	Poa secunda	Sandberg bluegrass	No Change
34A	PSSP6	C3	Pseudoroegneria spicata	bluebunch wheatgrass	No Change
34A	SPAI	C4	Sporobolus airoides	alkali sacaton	No Change
34A	SPCR	C4	Sporobolus cryptandrus	sand dropseed	No Change
35	ARBI3		Artemisia bigelovii	Bigelow sagebrush	No Change
35	ARFI2		Artemisia filifolia	sand sagebrush	No Change
35	ARNO4		Artemisia nova	black sagebrush	No Change
35	ARTR2		Artemisia tridentata	big sagebrush	No Change
35	ARTRT		Artemisia tridentata ssp. tridentata	basin big sagebrush	No Change
35	ARTRV		Artemisia tridentata ssp. vaseyana	mountain big sagebrush	No Change
35	ARTRW8		Artemisia tridentata ssp. wyomingensis	Wyoming big sagebrush	No Change
35	ACAR14	C3	Achnatherum aridum	arid needlegrass	Increase
35	ACHY	C3	Achnatherum hymenoides	Indian ricegrass	Increase
35	ACSP12	C3	Achnatherum speciosum	desert needlegrass	Increase
35	ANHA	C4	Andropogon hallii	sand bluestem	Decrease
35	ARIST	C4	Aristida	threeawn	Decrease
35	ARPU8	C4	Aristida purpurascens	arrowfeather threeawn	Decrease
35	ARPU9	C4	Aristida purpurea	purple threeawn	Decrease
35	BLTR	C4	Blepharoneuron tricholepis	pine dropseed	Decrease
35	BOBA2	C4	Bouteloua barbata	sixweeks grama	Decrease
35	BOBA3	C4	Bothriochloa barbinodis	cane bluestem	No Change
35	BOCU	C4	Bouteloua curtipendula	sideoats grama	Decrease
35	BOER4	C4	Bouteloua eriopoda	black grama	Decrease
35	BOGR2	C4	Bouteloua gracilis	blue grama	Decrease

APPENDIX D. List of sagebrush and grass species expected response to climate change by MLRA.

MRLA Symbol	PLANTS Symbol	Pathway	Scientific Name	Common Name	Climate Change Response
35	BOHI2	C4	Bouteloua hirsuta	hairy grama	Decrease
35	BOSA	C4	Bothriochloa saccharoides	silver bluestem	No Change
35	DAPU7	C4	Dasyochloa pulchella	low woollygrass	Decrease
35	DECE	C3	Deschampsia cespitosa	tufted hairgrass	No Change
35	DISP	C4	Distichlis spicata	saltgrass	Decrease
35	ELEL5	C3	Elymus elymoides	squirreltail	Increase
35	ELTR7	C3	Elymus trachycaulus	slender wheatgrass	Increase
35	ERPI5	C4	Erioneuron pilosum	hairy woollygrass	Decrease
35	HECO26	C3	Hesperostipa comata	needle and thread	Increase
35	HENE5	C3	Hesperostipa neomexicana	New Mexico feathergrass	Increase
35	HIJA	C4	Hilaria jamesii	galleta	Decrease
35	HOJU	C3	Hordeum jubatum	foxtail barley	Decrease
35	KOMA	C3	Koeleria macrantha	prairie Junegrass	No Change
35	LESA4	C3	Leymus salinus	saline wildrye	Decrease
35	LYPH	C4	Lycurus phleoides	common wolfstail	Decrease
35	MUAR2	C4	Muhlenbergia arenicola	sand muhly	Decrease
35	MUHLE	C4	Muhlenbergia	muhly	Decrease
35	MUPO2	C4	Muhlenbergia porteri	bush muhly	No Change
35	MUPU2	C4	Muhlenbergia pungens	sandhill muhly	No Change
35	MURI	C4	Muhlenbergia richardsonis	mat muhly	No Change
35	MUSQ3	C4	Munroa squarrosa	false buffalograss	Increase
35	MUTO2	C4	Muhlenbergia torreyi	ring muhly	Decrease
35	MUWR	C4	Muhlenbergia wrightii	spike muhly	Decrease
35	NAVI4	C3	Nassella viridula	green needlegrass	No Change
35	PAHA	C4	Panicum hallii	Hall's panicgrass	Decrease
35	PAOB	C4	Panicum obtusum	vine mesquite	No Change
35	PASM	C3	Pascopyrum smithii	western wheatgrass	Increase
35	PIFI	C3	Piptochaetium fimbriatum	pinyon ricegrass	Increase
35	PIMI7	C3	Piptatherum micranthum	littleseed ricegrass	Increase
35	PLJA	C4	Pleuraphis jamesii	James' galleta	Decrease
35	POFE	C3	Poa fendleriana	muttongrass	Increase
35	POSE	C3	Poa secunda	Sandberg bluegrass	Increase
35	SCBR2	C4	Scleropogon brevifolius	burrograss	Decrease
35	SCSC	C4	Schizachyrium scoparium	little bluestem	Decrease
35	SPAI	C4	Sporobolus airoides	alkali sacaton	Decrease
35	SPCO4	C4	Sporobolus contractus	spike dropseed	No Change
35	SPCOC2	C4	Sporobolus compositus var. compositus	dropseed	Decrease
35	SPCR	C4	Sporobolus cryptandrus	sand dropseed	No Change
35	SPFL2	C4	Sporobolus flexuosus	mesa dropseed	No Change
35	SPGI	C4	Sporobolus giganteus	giant dropseed	Decrease
35	SPNE	C4	Sporobolus nealleyi	gyp dropseed	Decrease
35	SPPY2	C4	Sporobolus pyramidatus	Madagascar dropseed	Decrease
35	TRMU	C4	Tridens muticus	slim tridens	Decrease
35	VUOC	C3	Vulpia octoflora	sixweeks fescue	Increase

APPENDIX D. List of sagebrush and grass species expected response to climate change by MLRA.

MRLA Symbol	PLANTS Symbol	Pathway	Scientific Name	Common Name	Climate Change Response
36	ARTEM		Artemisia	sagebrush	No Change
36	ARBI3		Artemisia bigelovii	Bigelow sagebrush	No Change
36	ARFI2		Artemisia filifolia	sand sagebrush	No Change
36	ARTR2		Artemisia tridentata	big sagebrush	No Change
36	ARTRT		Artemisia tridentata ssp. tridentata	basin big sagebrush	No Change
36	ARTR4		Artemisia tripartita	threetip sagebrush	No Change
36	ACHY	C3	Achnatherum hymenoides	Indian ricegrass	Decrease
36	ACLE9	C3	Achnatherum lettermanii	Letterman's needlegrass	Decrease
36	ACNE9	C3	Achnatherum nelsonii	Columbia needlegrass	Decrease
36	ACSP12	C3	Achnatherum speciosum	desert needlegrass	Increase
36	ANGE	C4	Andropogon gerardii	big bluestem	No Change
36	ANHA	C4	Andropogon hallii	sand bluestem	Increase
36	ARIST	C4	Aristida	threeawn	Increase
36	ARPU9	C4	Aristida purpurea	purple threeawn	No Change
36	BLTR	C4	Blepharoneuron tricholepis	pine dropseed	No Change
36	BOBA3	C4	Bothriochloa barbinodis	cane bluestem	No Change
36	BOCU	C4	Bouteloua curtipendula	sideoats grama	Increase
36	BOER4	C4	Bouteloua eriopoda	black grama	No Change
36	BOGR2	C4	Bouteloua gracilis	blue grama	Increase
36	BOHI2	C4	Bouteloua hirsuta	hairy grama	Increase
36	BRAN	C3	Bromus anomalus	nodding brome	Decrease
36	BRCA5	C3	Bromus carinatus	California brome	No Change
36	BRMA4	C3	Bromus marginatus	mountain brome	Increase
36	DISP	C4	Distichlis spicata	saltgrass	Increase
36	ELEL5	C3	Elymus elymoides	squirreltail	Decrease
36	ELTR7	C3	Elymus trachycaulus	slender wheatgrass	No Change
36	ERIN	C4	Eragrostis intermedia	plains lovegrass	No Change
36	FEAR2	C3	Festuca arizonica	Arizona fescue	Decrease
36	HECO26	C3	Hesperostipa comata	needle and thread	Decrease
36	HENE5	C3	Hesperostipa neomexicana	New Mexico feathergrass	Decrease
36	HIJA	C4	Hilaria jamesii	galleta	No Change
36	KOMA	C3	Koeleria macrantha	prairie Junegrass	Decrease
36	LEKI2	C3	Leucopoa kingii	spike fescue	Decrease
36	LESA4	C3	Leymus salinus	saline wildrye	No Change
36	LYPH	C4	Lycurus phleoides	common wolfstail	Increase
36	MUMO	C4	Muhlenbergia montana	mountain muhly	No Change
36	MURI	C4	Muhlenbergia richardsonis	mat muhly	Increase
36	MUWR	C4	Muhlenbergia wrightii	spike muhly	Increase
36	NATE3	C3	Nassella tenuissima	finestem needlegrass	Not Available
36	PAHA	C4	Panicum hallii	Hall's panicgrass	Not Available
36	PAOB	C4	Panicum obtusum	vine mesquite	No Change
36	PAVI2	C4	Panicum virgatum	switchgrass	No Change
36	PASM	C3	Pascopyrum smithii	western wheatgrass	Decrease

APPENDIX D. List of sagebrush and grass species expected response to climate change by MLRA.

MRLA Symbol	PLANTS Symbol	Pathway	Scientific Name	Common Name	Climate Change Response
36	PIFI	C3	Piptochaetium fimbriatum	pinyon ricegrass	Decrease
36	PLEUR12	C4	Pleuraphis	galleta grass	Increase
36	PLJA	C4	Pleuraphis jamesii	James' galleta	Increase
36	POFE	C3	Poa fendleriana	muttongrass	Decrease
36	POSE	C3	Poa secunda	Sandberg bluegrass	Decrease
36	PSSP6	C3	Pseudoroegneria spicata	bluebunch wheatgrass	Decrease
36	SCSC	C4	Schizachyrium scoparium	little bluestem	Increase
36	SELE6	C4	Setaria leucopila	streambed bristlegrass	Not Available
36	SEVU2	C4	Setaria vulpiseta	plains bristlegrass	Increase
36	SONU2	C4	Sorghastrum nutans	Indiangrass	Increase
36	SPAI	C4	Sporobolus airoides	alkali sacaton	Increase
36	SPCO4	C4	Sporobolus contractus	spike dropseed	Increase
36	SPCR	C4	Sporobolus cryptandrus	sand dropseed	Increase
36	SPFL2	C4	Sporobolus flexuosus	mesa dropseed	Increase
36	SPGI	C4	Sporobolus giganteus	giant dropseed	Increase
36	SPWR2	C4	Sporobolus wrightii	big sacaton	No Change
43B	ARAR8		Artemisia arbuscula	low sagebrush	No Change
43B	ARARL		Artemisia arbuscula ssp. longiloba	alkali sagebrush	No Change
43B	ARCA13		Artemisia cana	silver sagebrush	No Change
43B	ARNO4		Artemisia nova	black sagebrush	No Change
43B	ARTR2		Artemisia tridentata	big sagebrush	No Change
43B	ARTR4		Artemisia tripartita	threetip sagebrush	No Change
43B	ACHY	C3	Achnatherum hymenoides	Indian ricegrass	Decrease
43B	ACLE9	C3	Achnatherum lettermanii	Letterman's needlegrass	Decrease
43B	ACNE9	C3	Achnatherum nelsonii	Columbia needlegrass	Decrease
43B	ACOC3	C3	Achnatherum occidentale	western needlegrass	Decrease
43B	ACRI8	C3	Achnatherum richardsonii	Richardson's needlegrass	Decrease
43B	ANHA	C4	Andropogon hallii	sand bluestem	Increase
43B	ARPU9	C4	Aristida purpurea	purple threeawn	No Change
43B	BOCU	C4	Bouteloua curtipendula	sideoats grama	Increase
43B	BOGR2	C4	Bouteloua gracilis	blue grama	Increase
43B	BRAN	C3	Bromus anomalus	nodding brome	Decrease
43B	BRMA4	C3	Bromus marginatus	mountain brome	Decrease
43B	BRPO2	C3	Bromus porteri	Porter brome	Decrease
43B	CALO	C4	Calamovilfa longifolia	prairie sandreed	Increase
43B	CAMO	C3	Calamagrostis montanensis	plains reedgrass	Decrease
43B	DACA3	C3	Danthonia californica	California oatgrass	Decrease
43B	DAIN	C3	Danthonia intermedia	timber oatgrass	Decrease
43B	DAUN	C3	Danthonia unispicata	onespike danthonia	Decrease
43B	ELAL7	C3	Elymus albicans	Montana wheatgrass	Decrease
43B	ELEL5	C3	Elymus elymoides	squirreltail	Decrease
43B	ELGL	C3	Elymus glaucus	blue wildrye	Decrease
43B	ELLA3	C3	Elymus lanceolatus	thickspike wheatgrass	Decrease

APPENDIX D. List of sagebrush and grass species expected response to climate change by MLRA.

MRLA Symbol	PLANTS Symbol	Pathway	Scientific Name	Common Name	Climate Change Response
43B	ELTR7	C3	Elymus trachycaulus	slender wheatgrass	Decrease
43B	FEID	C3	Festuca idahoensis	Idaho fescue	Decrease
43B	HECO26	C3	Hesperostipa comata	needle and thread	Decrease
43B	KOMA	C3	Koeleria macrantha	prairie Junegrass	Decrease
43B	LECI4	C3	Leymus cinereus	basin wildrye	Decrease
43B	LEKI2	C3	Leucopoa kingii	spike fescue	Decrease
43B	MEBU	C3	Melica bulbosa	oniongrass	No Change
43B	MUCU3	C4	Muhlenbergia cuspidata	plains muhly	No Change
43B	MUMO	C4	Muhlenbergia montana	mountain muhly	Increase
43B	NAVI4	C3	Nassella viridula	green needlegrass	Decrease
43B	PASM	C3	Pascopyrum smithii	western wheatgrass	Decrease
43B	POCU3	C3	Poa cusickii	Cusick's bluegrass	Decrease
43B	POFE	C3	Poa fendleriana	muttongrass	Decrease
43B	POPA2	C3	Poa palustris	fowl bluegrass	Decrease
43B	POSE	C3	Poa secunda	Sandberg bluegrass	Decrease
43B	PSSP6	C3	Pseudoroegneria spicata	bluebunch wheatgrass	Decrease
43B	SCSC	C4	Schizachyrium scoparium	little bluestem	Increase
43B	SPCR	C4	Sporobolus cryptandrus	sand dropseed	Increase
43B	TRSP2	C3	Trisetum spicatum	spike trisetum	Decrease
46	ARCA13		Artemisia cana	silver sagebrush	No Change
46	ARCAV2		Artemisia cana ssp. viscidula	mountain silver sagebrush	No Change
46	ARNO4		Artemisia nova	black sagebrush	No Change
46	ARTRT		Artemisia tridentata ssp. tridentata	basin big sagebrush	No Change
46	ARTRV		Artemisia tridentata ssp. vaseyana	mountain big sagebrush	No Change
46	ARTRW8		Artemisia tridentata ssp. wyomingensis	Wyoming big sagebrush	No Change
46	ACLE9	C3	Achnatherum lettermanii	Letterman's needlegrass	Decrease
46	ACNE9	C3	Achnatherum nelsonii	Columbia needlegrass	Decrease
46	ACOC3	C3	Achnatherum occidentale	western needlegrass	Decrease
46	ARPU9	C4	Aristida purpurea	purple threeawn	No Change
46	BOGR2	C4	Bouteloua gracilis	blue grama	Increase
46	BRMA4	C3	Bromus marginatus	mountain brome	Decrease
46	CAMO	C3	Calamagrostis montanensis	plains reedgrass	Decrease
46	DAIN	C3	Danthonia intermedia	timber oatgrass	Decrease
46	DAPA2	C3	Danthonia parryi	Parry's oatgrass	Decrease
46	DASP2	C3	Danthonia spicata	poverty oatgrass	Decrease
46	ELLA3	C3	Elymus lanceolatus	thickspike wheatgrass	Decrease
46	ELMA7	C3	Elymus macrourus	tufted wheatgrass	Decrease
46	ELTR7	C3	Elymus trachycaulus	slender wheatgrass	Decrease
46	FECA4	C3	Festuca campestris	rough fescue	Decrease
46	FEID	C3	Festuca idahoensis	Idaho fescue	Decrease
46	HECO26	C3	Hesperostipa comata	needle and thread	Decrease
46	HESP11	C3	Hesperostipa spartea	porcupinegrass	Decrease
46	KOMA	C3	Koeleria macrantha	prairie Junegrass	Decrease

APPENDIX D. List of sagebrush and grass species expected response to climate change by MLRA.

MRLA Symbol	PLANTS Symbol	Pathway	Scientific Name	Common Name	Climate Change Response
46	LEKI2	C3	Leucopoa kingii	spike fescue	Decrease
46	MUCU3	C4	Muhlenbergia cuspidata	plains muhly	No Change
46	NAVI4	C3	Nassella viridula	green needlegrass	Decrease
46	PASM	C3	Pascopyrum smithii	western wheatgrass	Decrease
46	POCU3	C3	Poa cusickii	Cusick's bluegrass	Decrease
46	POSE	C3	Poa secunda	Sandberg bluegrass	Decrease
46	PSSP6	C3	Pseudoroegneria spicata	bluebunch wheatgrass	Decrease
46	SCSC	C4	Schizachyrium scoparium	little bluestem	Increase
47	ARAR8		Artemisia arbuscula	low sagebrush	No Change
47	ARBI3		Artemisia bigelovii	Bigelow sagebrush	No Change
47	ARCA13		Artemisia cana	silver sagebrush	No Change
47	ARNO4		Artemisia nova	black sagebrush	No Change
47	ARPY2		Artemisia pygmaea	pygmy sagebrush	No Change
47	ARTR2		Artemisia tridentata	big sagebrush	No Change
47	ARTRS2		Artemisia tridentata ssp. spiciformis	subalpine big sagebrush	No Change
47	ARTRT		Artemisia tridentata ssp. tridentata	basin big sagebrush	No Change
47	ARTRV		Artemisia tridentata ssp. vaseyana	mountain big sagebrush	Decrease
47	ARTRW8		Artemisia tridentata ssp. wyomingensis	Wyoming big sagebrush	No Change
47	ACHY	C3	Achnatherum hymenoides	Indian ricegrass	Decrease
47	ACLE9	C3	Achnatherum lettermanii	Letterman's needlegrass	Decrease
47	ACNE9	C3	Achnatherum nelsonii	Columbia needlegrass	Decrease
47	ACPI2	C3	Achnatherum pinetorum	pine needlegrass	Decrease
47	ACSP12	C3	Achnatherum speciosum	desert needlegrass	Increase
47	ACTH7	C3	Achnatherum thurberianum	Thurber's needlegrass	Decrease
47	ARPU9	C4	Aristida purpurea	purple threeawn	Decrease
47	BOER4	C4	Bouteloua eriopoda	black grama	Decrease
47	BOGR2	C4	Bouteloua gracilis	blue grama	Increase
47	BRCA5	C3	Bromus carinatus	California brome	Decrease
47	BRMA4	C3	Bromus marginatus	mountain brome	Decrease
47	CAMO	C3	Calamagrostis montanensis	plains reedgrass	No Change
47	ELEL5	C3	Elymus elymoides	squirreltail	Decrease
47	ELGL	C3	Elymus glaucus	blue wildrye	Decrease
47	ELSC4	C3	Elymus scribneri	spreading wheatgrass	Decrease
47	ELTR7	C3	Elymus trachycaulus	slender wheatgrass	Decrease
47	FEID	C3	Festuca idahoensis	Idaho fescue	Decrease
47	HECO26	C3	Hesperostipa comata	needle and thread	Decrease
47	HIJA	C4	Hilaria jamesii	galleta	No Change
47	KOMA	C3	Koeleria macrantha	prairie Junegrass	Decrease
47	LEKI2	C3	Leucopoa kingii	spike fescue	Decrease
47	LECI4	C3	Leymus cinereus	basin wildrye	Decrease
47	LESA4	C3	Leymus salinus	saline wildrye	Decrease
47	MEBU	C3	Melica bulbosa	oniongrass	Decrease
47	MUPO2	C4	Muhlenbergia porteri	bush muhly	Decrease

APPENDIX D. List of sagebrush and grass species expected response to climate change by MLRA.

MRLA Symbol	PLANTS Symbol	Pathway	Scientific Name	Common Name	Climate Change Response
47	PASM	C3	Pascopyrum smithii	western wheatgrass	Decrease
47	POFE	C3	Poa fendleriana	muttongrass	Decrease
47	PORE	C3	Poa reflexa	nodding bluegrass	Decrease
47	POSE	C3	Poa secunda	Sandberg bluegrass	Decrease
47	PSSP6	C3	Pseudoroegneria spicata	bluebunch wheatgrass	Decrease
47	SPCR	C4	Sporobolus cryptandrus	sand dropseed	Increase
47	VUOC	C3	Vulpia octoflora	sixweeks fescue	Increase
48A	ARTEM		Artemisia	sagebrush	No Change
48A	ARAR8		Artemisia arbuscula	low sagebrush	No Change
48A	ARTR2		Artemisia tridentata	big sagebrush	No Change
48A	ARTRT		Artemisia tridentata ssp. tridentata	basin big sagebrush	No Change
48A	ARTRV		Artemisia tridentata ssp. vaseyana	mountain big sagebrush	No Change
48A	ACHNA	C3	Achnatherum	needlegrass	Decrease
48A	ACHY	C3	Achnatherum hymenoides	Indian ricegrass	Decrease
48A	ACLE9	C3	Achnatherum lettermanii	Letterman's needlegrass	Decrease
48A	ACNE9	C3	Achnatherum nelsonii	Columbia needlegrass	Decrease
48A	ANGE	C4	Andropogon gerardii	big bluestem	No Change
48A	BLTR	C4	Blepharoneuron tricholepis	pine dropseed	No Change
48A	BOCU	C4	Bouteloua curtipendula	sideoats grama	Increase
48A	BOGR2	C4	Bouteloua gracilis	blue grama	Increase
48A	BRAN	C3	Bromus anomalus	nodding brome	Decrease
48A	BRCA5	C3	Bromus carinatus	California brome	No Change
48A	BRMA4	C3	Bromus marginatus	mountain brome	No Change
48A	ELEL5	C3	Elymus elymoides	squirreltail	Decrease
48A	ELTR7	C3	Elymus trachycaulus	slender wheatgrass	Decrease
48A	FEAR2	C3	Festuca arizonica	Arizona fescue	Decrease
48A	HECO26	C3	Hesperostipa comata	needle and thread	Decrease
48A	KOMA	C3	Koeleria macrantha	prairie Junegrass	Decrease
48A	LECI4	C3	Leymus cinereus	basin wildrye	Decrease
48A	LEKI2	C3	Leucopoa kingii	spike fescue	Decrease
48A	LESA4	C3	Leymus salinus	saline wildrye	Decrease
48A	LYPH	C4	Lycurus phleoides	common wolfstail	No Change
48A	MUMO	C4	Muhlenbergia montana	mountain muhly	Increase
48A	MUWR	C4	Muhlenbergia wrightii	spike muhly	Increase
48A	PASM	C3	Pascopyrum smithii	western wheatgrass	Decrease
48A	PLJA	C4	Pleuraphis jamesii	James' galleta	No Change
48A	POFE	C3	Poa fendleriana	muttongrass	Decrease
48A	POSE	C3	Poa secunda	Sandberg bluegrass	Decrease
48A	PSSP6	C3	Pseudoroegneria spicata	bluebunch wheatgrass	No Change
48A	SCSC	C4	Schizachyrium scoparium	little bluestem	Increase
48A	SPAI	C4	Sporobolus airoides	alkali sacaton	No Change
49	ARNO4		Artemisia nova	black sagebrush	No Change
49	ARTR2		Artemisia tridentata	big sagebrush	No Change

APPENDIX D. List of sagebrush and grass species expected response to climate change by MLRA.

MRLA Symbol	PLANTS Symbol	Pathway	Scientific Name	Common Name	Climate Change Response
49	ARTR4		Artemisia tripartita	threetip sagebrush	No Change
49	ACHY	C3	Achnatherum hymenoides	Indian ricegrass	Decrease
49	ACLE9	C3	Achnatherum lettermanii	Letterman's needlegrass	Decrease
49	BRPO2	C3	Bromus porteri	Porter brome	Decrease
49	CAMO	C3	Calamagrostis montanensis	plains reedgrass	Decrease
49	DAPA2	C3	Danthonia parryi	Parry's oatgrass	Decrease
49	DAUN	C3	Danthonia unispicata	onespike danthonia	Decrease
49	ELAL7	C3	Elymus albicans	Montana wheatgrass	Decrease
49	FEID	C3	Festuca idahoensis	Idaho fescue	Decrease
49	HECO26	C3	Hesperostipa comata	needle and thread	Decrease
49	KOMA	C3	Koeleria macrantha	prairie Junegrass	Decrease
49	LECI4	C3	Leymus cinereus	basin wildrye	Decrease
49	LEKI2	C3	Leucopoa kingii	spike fescue	Decrease
49	MUFI	C4	Muhlenbergia filiculmis	slimstem muhly	Increase
49	MUMO	C4	Muhlenbergia montana	mountain muhly	Increase
49	MURI	C4	Muhlenbergia richardsonis	mat muhly	Increase
49	PASM	C3	Pascopyrum smithii	western wheatgrass	Decrease
49	POSE	C3	Poa secunda	Sandberg bluegrass	Decrease
49	PSSP6	C3	Pseudoroegneria spicata	bluebunch wheatgrass	Decrease
49	TRSP2	C3	Trisetum spicatum	spike trisetum	Decrease
51	ARTR2		Artemisia tridentata	big sagebrush	No Change
51	BOCU	C4	Bouteloua curtipendula	sideoats grama	Increase
51	BOGR2	C4	Bouteloua gracilis	blue grama	Increase
51	ELEL5	C3	Elymus elymoides	squirreltail	Decrease
51	PASM	C3	Pascopyrum smithii	western wheatgrass	Decrease
52	ARCA13		Artemisia cana	silver sagebrush	No Change
52	ARTR2		Artemisia tridentata	big sagebrush	No Change
52	BOGR2	C4	Bouteloua gracilis	blue grama	Increase
52	CAMO	C3	Calamagrostis montanensis	plains reedgrass	Decrease
52	DISP	C4	Distichlis spicata	saltgrass	Increase
52	ELAL7	C3	Elymus albicans	Montana wheatgrass	Decrease
52	ELEL5	C3	Elymus elymoides	squirreltail	Decrease
52	ELMA7	C3	Elymus macrourus	tufted wheatgrass	Decrease
52	KOMA	C3	Koeleria macrantha	prairie Junegrass	Decrease
52	NAVI4	C3	Nassella viridula	green needlegrass	Decrease
52	PASM	C3	Pascopyrum smithii	western wheatgrass	Decrease
52	POSE	C3	Poa secunda	Sandberg bluegrass	Decrease
52	SPAI	C4	Sporobolus airoides	alkali sacaton	No Change
58A	ARCA13		Artemisia cana	silver sagebrush	No Change
58A	ARTRW8		Artemisia tridentata ssp. wyomingensis	Wyoming big sagebrush	No Change
58A	ACHY	C3	Achnatherum hymenoides	Indian ricegrass	Decrease
58A	ACLE9	C3	Achnatherum lettermanii	Letterman's needlegrass	Decrease

APPENDIX D. List of sagebrush and grass species expected response to climate change by MLRA.

MRLA Symbol	PLANTS Symbol	Pathway	Scientific Name	Common Name	Climate Change Response
58A	ACNE9	C3	Achnatherum nelsonii	Columbia needlegrass	Decrease
58A	ACOC3	C3	Achnatherum occidentale	western needlegrass	Decrease
58A	ANGE	C4	Andropogon gerardii	big bluestem	Increase
58A	ARPU9	C4	Aristida purpurea	purple threeawn	Increase
58A	BOCU	C4	Bouteloua curtipendula	sideoats grama	Increase
58A	BODA2	C4	Bouteloua dactyloides	buffalograss	No Change
58A	BOGR2	C4	Bouteloua gracilis	blue grama	Increase
58A	BRMA4	C3	Bromus marginatus	mountain brome	Decrease
58A	CAMO	C3	Calamagrostis montanensis	plains reedgrass	Decrease
58A	CALO	C4	Calamovilfa longifolia	prairie sandreed	Increase
58A	DASP2	C3	Danthonia spicata	poverty oatgrass	Decrease
58A	DISP	C4	Distichlis spicata	saltgrass	Increase
58A	ELAL7	C3	Elymus albicans	Montana wheatgrass	Decrease
58A	ELCA4	C3	Elymus canadensis	Canada wildrye	Decrease
58A	ELEL5	C3	Elymus elymoides	squirreltail	Decrease
58A	ELLA3	C3	Elymus lanceolatus	thickspike wheatgrass	Decrease
58A	ELMA7	C3	Elymus macrourus	tufted wheatgrass	Decrease
58A	ELTR7	C3	Elymus trachycaulus	slender wheatgrass	Decrease
58A	FEID	C3	Festuca idahoensis	Idaho fescue	Decrease
58A	HECO26	C3	Hesperostipa comata	needle and thread	Decrease
58A	HESP11	C3	Hesperostipa spartea	porcupinegrass	Decrease
58A	HOJU	C3	Hordeum jubatum	foxtail barley	Decrease
58A	KOMA	C3	Koeleria macrantha	prairie Junegrass	No Change
58A	LEKI2	C3	Leucopoa kingii	spike fescue	Decrease
58A	LECI4	C3	Leymus cinereus	basin wildrye	Decrease
58A	MUCU3	C4	Muhlenbergia cuspidata	plains muhly	No Change
58A	MURI	C4	Muhlenbergia richardsonis	mat muhly	No Change
58A	NAVI4	C3	Nassella viridula	green needlegrass	Decrease
58A	PAVI2	C4	Panicum virgatum	switchgrass	Increase
58A	PASM	C3	Pascopyrum smithii	western wheatgrass	Decrease
58A	POCU3	C3	Poa cusickii	Cusick's bluegrass	Decrease
58A	POSE	C3	Poa secunda	Sandberg bluegrass	Decrease
58A	PSSP6	C3	Pseudoroegneria spicata	bluebunch wheatgrass	Decrease
58A	PUNU2	C3	Puccinellia nuttalliana	Nuttall's alkaligrass	Decrease
58A	SCPA	C4	Schedonnardus paniculatus	tumblegrass	Increase
58A	SCSC	C4	Schizachyrium scoparium	little bluestem	Increase
58A	SPGR	C4	Spartina gracilis	alkali cordgrass	No Change
58A	SPPE	C4	Spartina pectinata	prairie cordgrass	Increase
58A	SPAI	C4	Sporobolus airoides	alkali sacaton	No Change
58A	SPCR	C4	Sporobolus cryptandrus	sand dropseed	Increase
58B	ARCA13		Artemisia cana	silver sagebrush	No Change
58B	ARTR2		Artemisia tridentata	big sagebrush	No Change
58B	ACHY	C3	Achnatherum hymenoides	Indian ricegrass	Decrease

APPENDIX D. List of sagebrush and grass species expected response to climate change by MLRA.

MRLA Symbol	PLANTS Symbol	Pathway	Scientific Name	Common Name	Climate Change Response
58B	ANGE	C4	Andropogon gerardii	big bluestem	No Change
58B	ANHA	C4	Andropogon hallii	sand bluestem	No Change
58B	ARPU9	C4	Aristida purpurea	purple threeawn	No Change
58B	BOCU	C4	Bouteloua curtipendula	sideoats grama	Increase
58B	BODA2	C4	Bouteloua dactyloides	buffalograss	Decrease
58B	BOGR2	C4	Bouteloua gracilis	blue grama	Increase
58B	BOHI2	C4	Bouteloua hirsuta	hairy grama	Increase
58B	CALO	C4	Calamovilfa longifolia	prairie sandreed	Increase
58B	CAMO	C3	Calamagrostis montanensis	plains reedgrass	Decrease
58B	DISP	C4	Distichlis spicata	saltgrass	No Change
58B	ELCA4	C3	Elymus canadensis	Canada wildrye	Decrease
58B	ELEL5	C3	Elymus elymoides	squirreltail	No Change
58B	ELLA3	C3	Elymus lanceolatus	thickspike wheatgrass	Decrease
58B	ELTR7	C3	Elymus trachycaulus	slender wheatgrass	No Change
58B	HECO26	C3	Hesperostipa comata	needle and thread	Decrease
58B	KOMA	C3	Koeleria macrantha	prairie Junegrass	No Change
58B	LECI4	C3	Leymus cinereus	basin wildrye	No Change
58B	MUCU3	C4	Muhlenbergia cuspidata	plains muhly	Decrease
58B	MURI	C4	Muhlenbergia richardsonis	mat muhly	No Change
58B	NAVI4	C3	Nassella viridula	green needlegrass	Decrease
58B	PASM	C3	Pascopyrum smithii	western wheatgrass	Decrease
58B	POCU3	C3	Poa cusickii	Cusick's bluegrass	Decrease
58B	POSE	C3	Poa secunda	Sandberg bluegrass	Decrease
58B	PSSP6	C3	Pseudoroegneria spicata	bluebunch wheatgrass	Decrease
58B	PUNU2	C3	Puccinellia nuttalliana	Nuttall's alkaligrass	No Change
58B	SCSC	C4	Schizachyrium scoparium	little bluestem	Increase
58B	SPAI	C4	Sporobolus airoides	alkali sacaton	Decrease
58B	SPCR	C4	Sporobolus cryptandrus	sand dropseed	No Change
58B	SPGR	C4	Spartina gracilis	alkali cordgrass	Decrease
58B	SPPE	C4	Spartina pectinata	prairie cordgrass	Decrease
60B	ARTR2		Artemisia tridentata	big sagebrush	No Change
60B	ACNE9	C3	Achnatherum nelsonii	Columbia needlegrass	No Change
60B	ACRI8	C3	Achnatherum richardsonii	Richardson's needlegrass	Not Available
60B	ANGE	C4	Andropogon gerardii	big bluestem	No Change
60B	BOCU	C4	Bouteloua curtipendula	sideoats grama	No Change
60B	BODA2	C4	Bouteloua dactyloides	buffalograss	No Change
60B	BOGR2	C4	Bouteloua gracilis	blue grama	No Change
60B	BOHI2	C4	Bouteloua hirsuta	hairy grama	No Change
60B	CALO	C4	Calamovilfa longifolia	prairie sandreed	Decrease
60B	DISP	C4	Distichlis spicata	saltgrass	Decrease
60B	ELAL7	C3	Elymus albicans	Montana wheatgrass	Increase
60B	ELEL5	C3	Elymus elymoides	squirreltail	Increase
60B	ELMA7	C3	Elymus macrourus	tufted wheatgrass	Increase

APPENDIX D. List of sagebrush and grass species expected response to climate change by MLRA.

MRLA Symbol	PLANTS Symbol	Pathway	Scientific Name	Common Name	Climate Change Response
60B	NAVI4	C3	Nassella viridula	green needlegrass	No Change
60B	PASM	C3	Pascopyrum smithii	western wheatgrass	No Change
60B	POCU3	C3	Poa cusickii	Cusick's bluegrass	No Change
60B	POPA2	C3	Poa palustris	fowl bluegrass	Decrease
60B	POSE	C3	Poa secunda	Sandberg bluegrass	Increase
60B	SCSC	C4	Schizachyrium scoparium	little bluestem	No Change

APPENDIX D – CURRENT AND EXPECTED CLIMATE CHANGE FIGURES FOR MLRAS 10, 28A, 52, AND 58B.

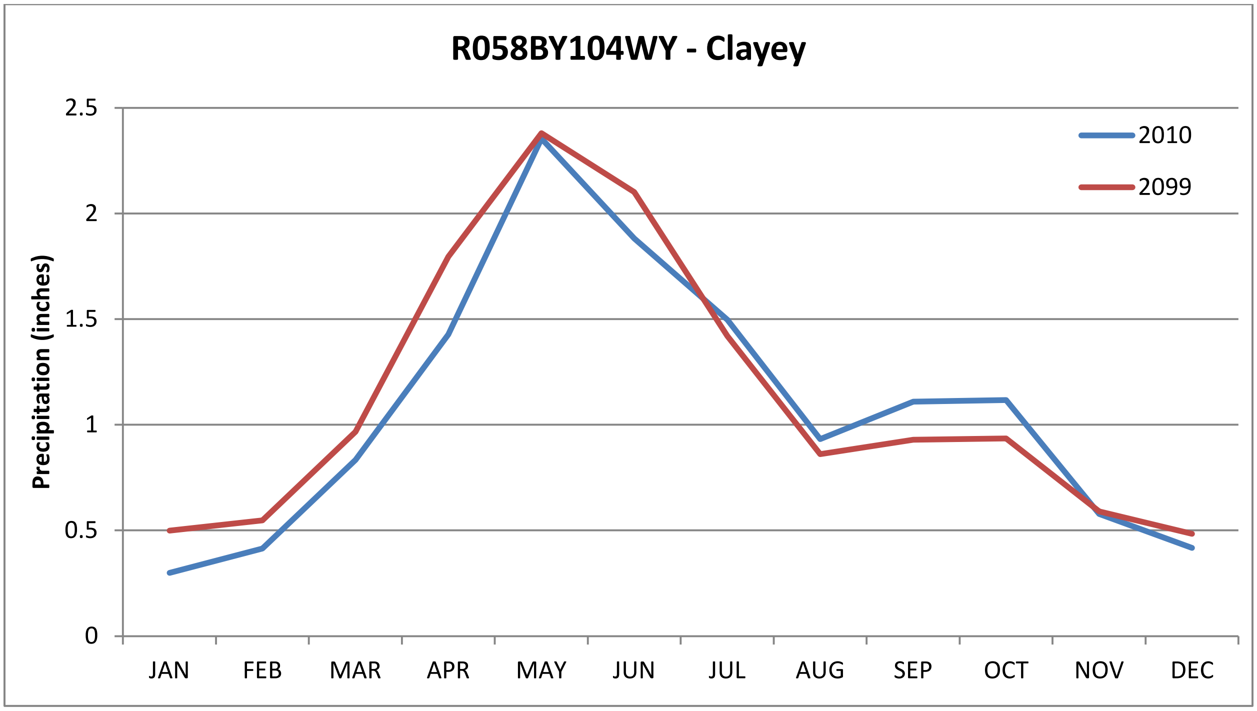


Figure D-1. Current (2010) and expected (2099) precipitation for R058BY104WY – Clayey ecological site.

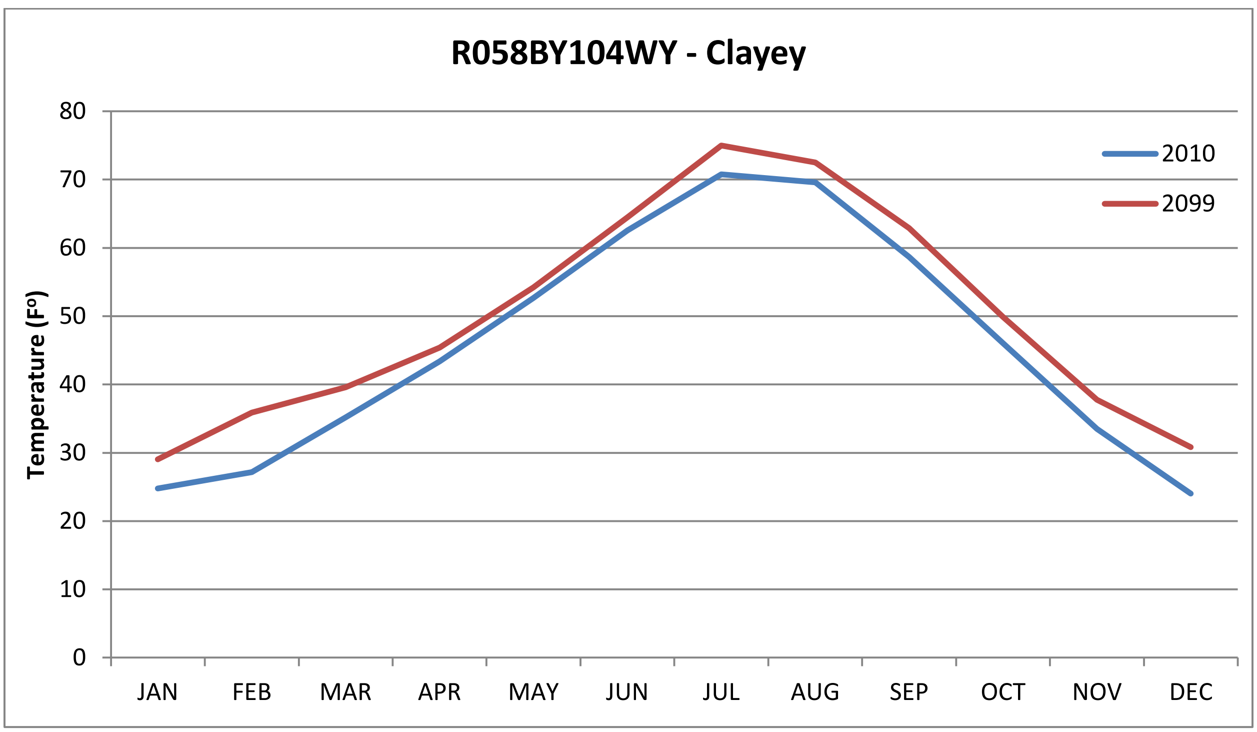


Figure D-2. Current (2010) and expected (2099) temperature for R058BY104WY – Clayey ecological site.

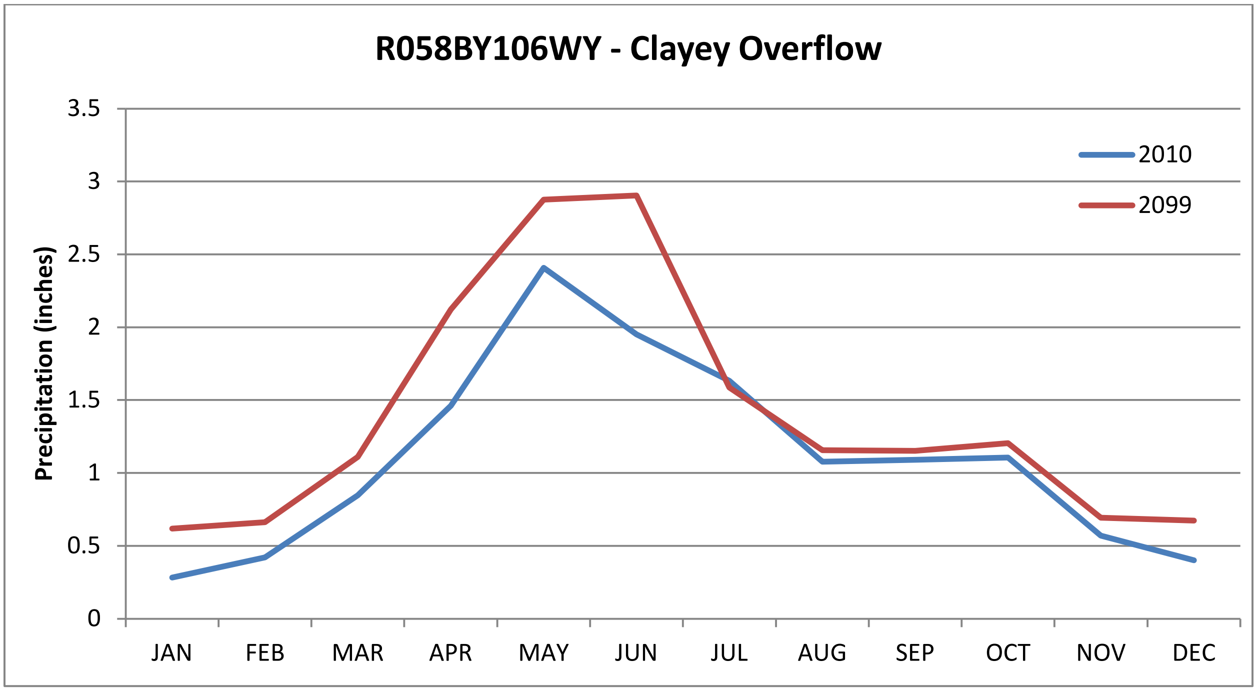


Figure D-3. Current (2010) and expected (2099) precipitation for R058BY106WY – Clayey Overflow ecological site.

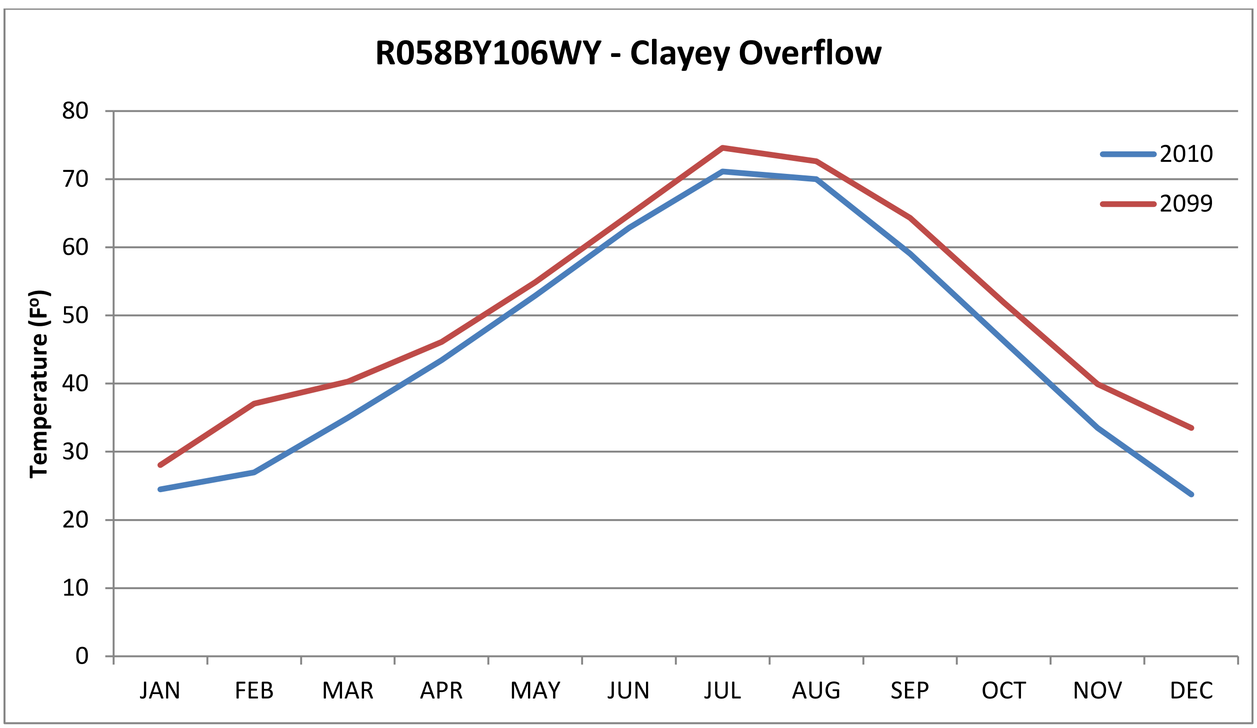


Figure D-4. Current (2010) and expected (2099) temperature for R058BY106WY – Clayey Overflow ecological site.

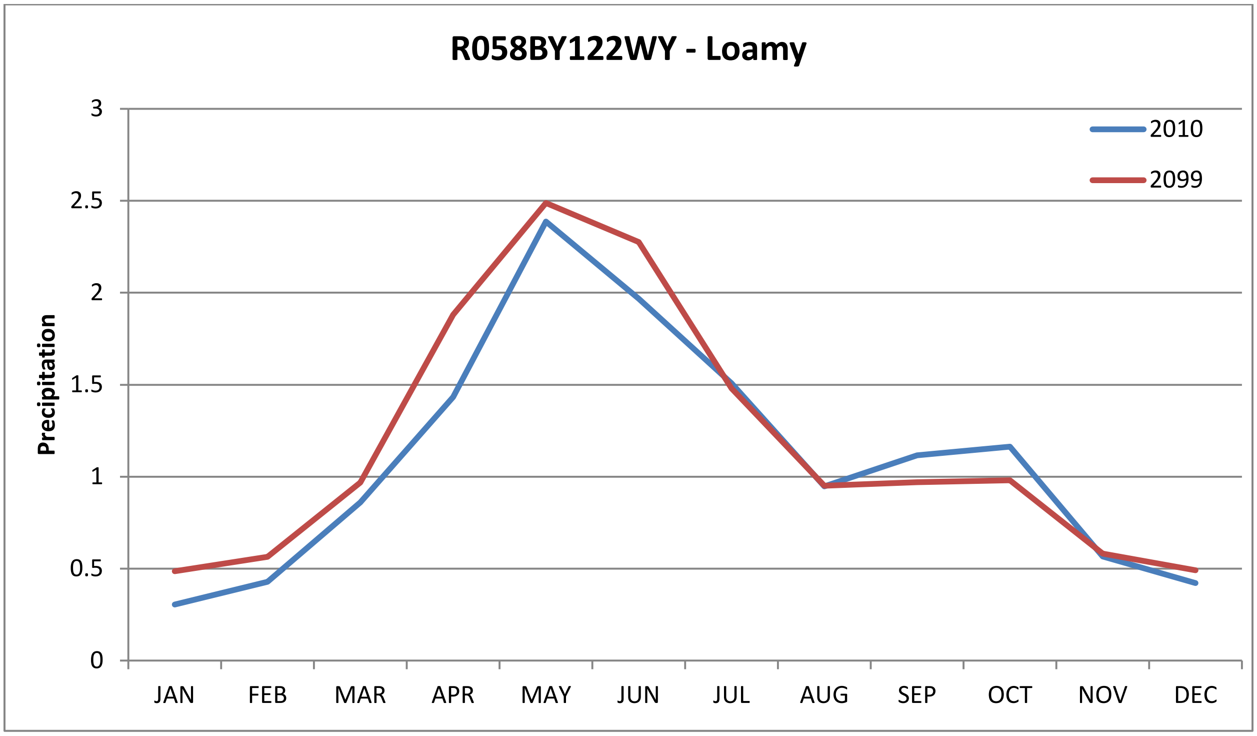


Figure D-5. Current (2010) and expected (2099) precipitation for R058BY122WY – Loamy ecological site.

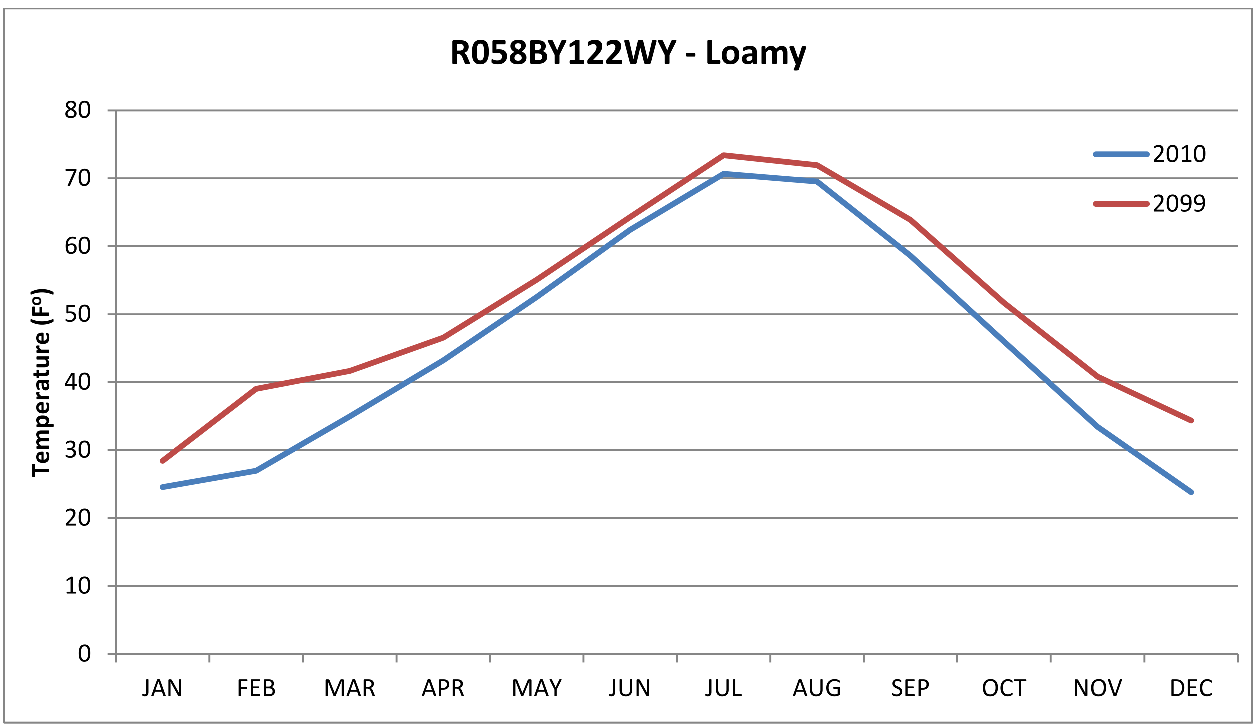


Figure D-6. Current (2010) and expected (2099) temperature for R058BY122WY – Loamy ecological site.

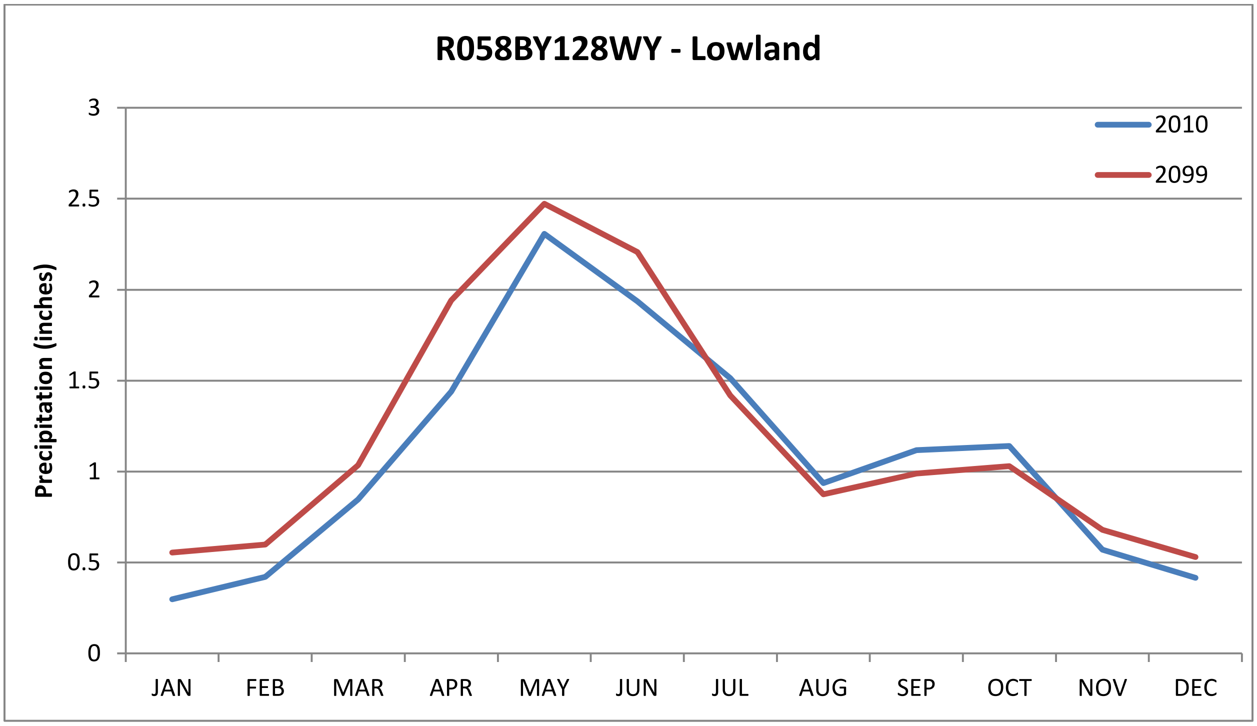


Figure D-7. Current (2010) and expected (2099) precipitation for R058BY128WY – Lowland ecological site.

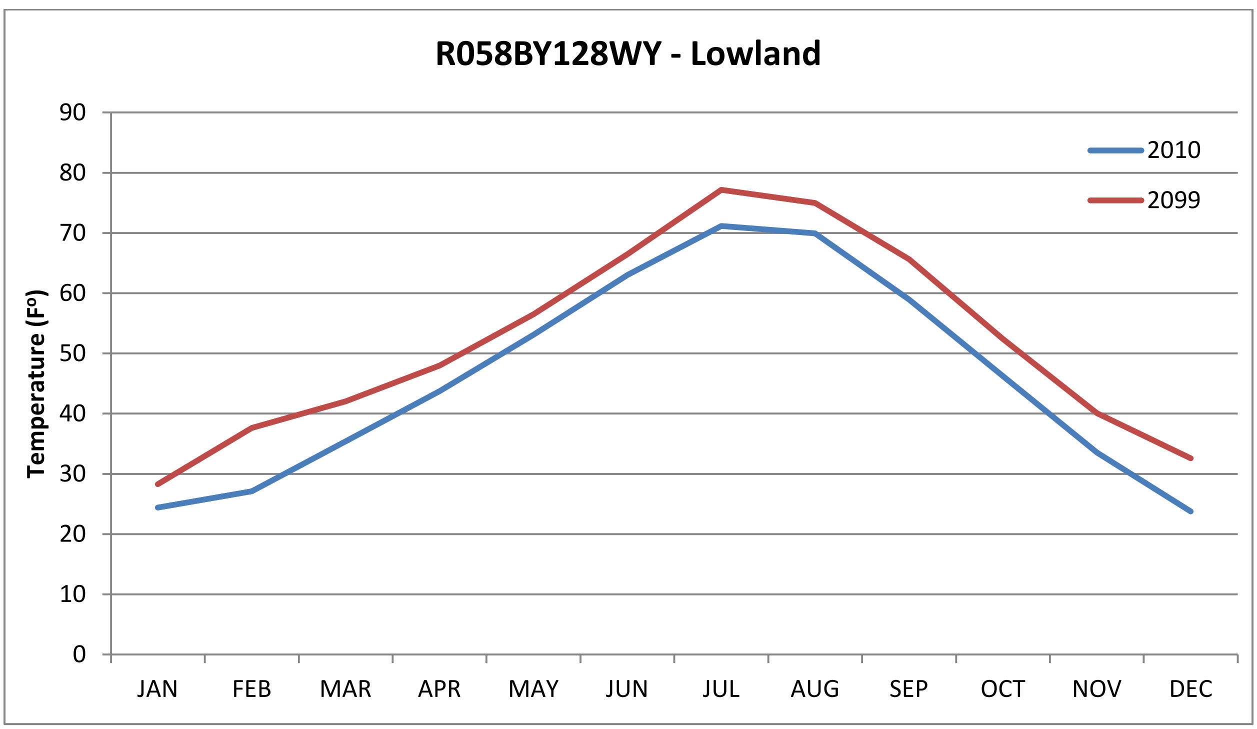


Figure D-8. Current (2010) and expected (2099) temperature for R058BY128WY – Lowland ecological site.

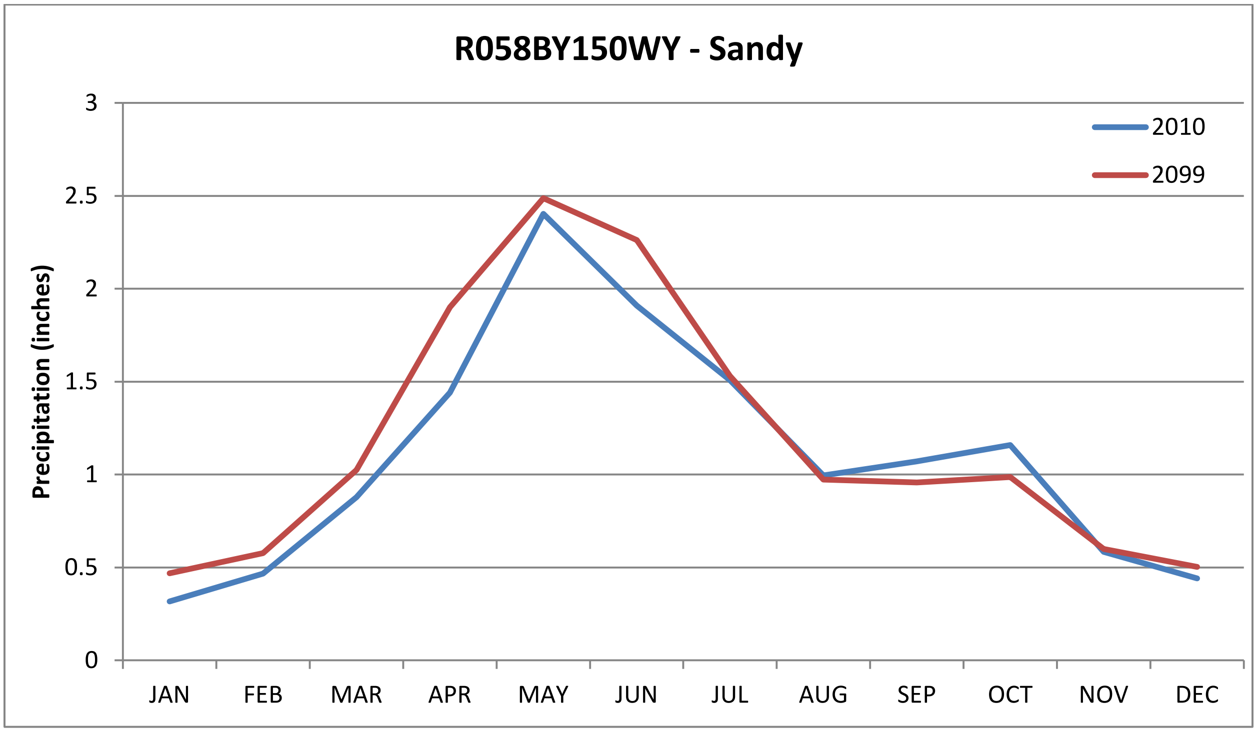


Figure D-9. Current (2010) and expected (2099) precipitation for R058BY150WY – Sandy ecological site.

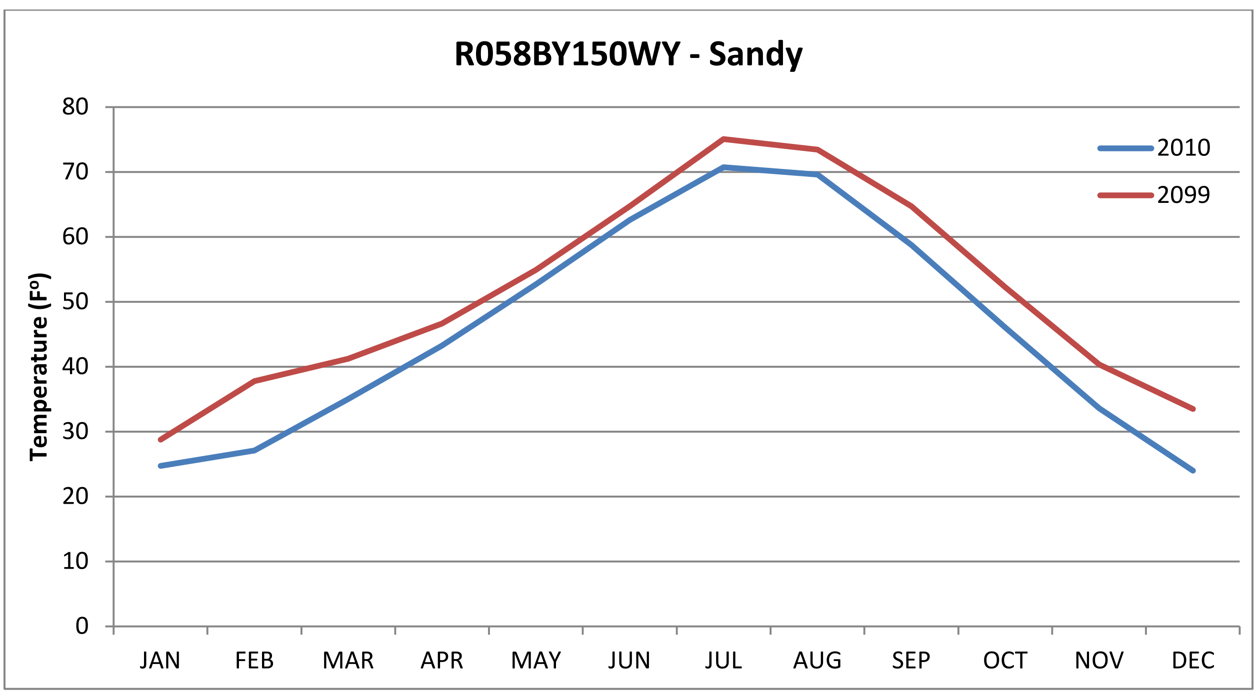


Figure D-10. Current (2010) and expected (2099) temperature for R058BY150WY – Sandy ecological site.

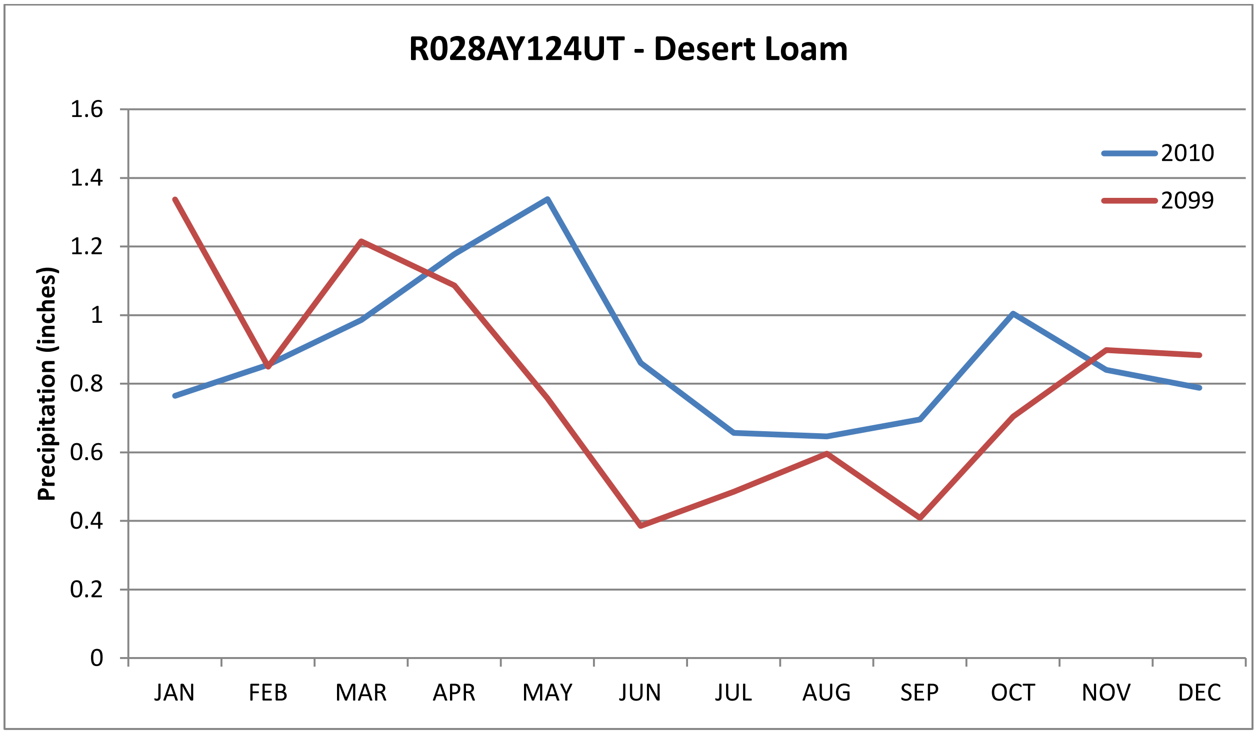


Figure D-11. Current (2010) and expected (2099) precipitation for R028AY124UT – Desert Loam ecological site.

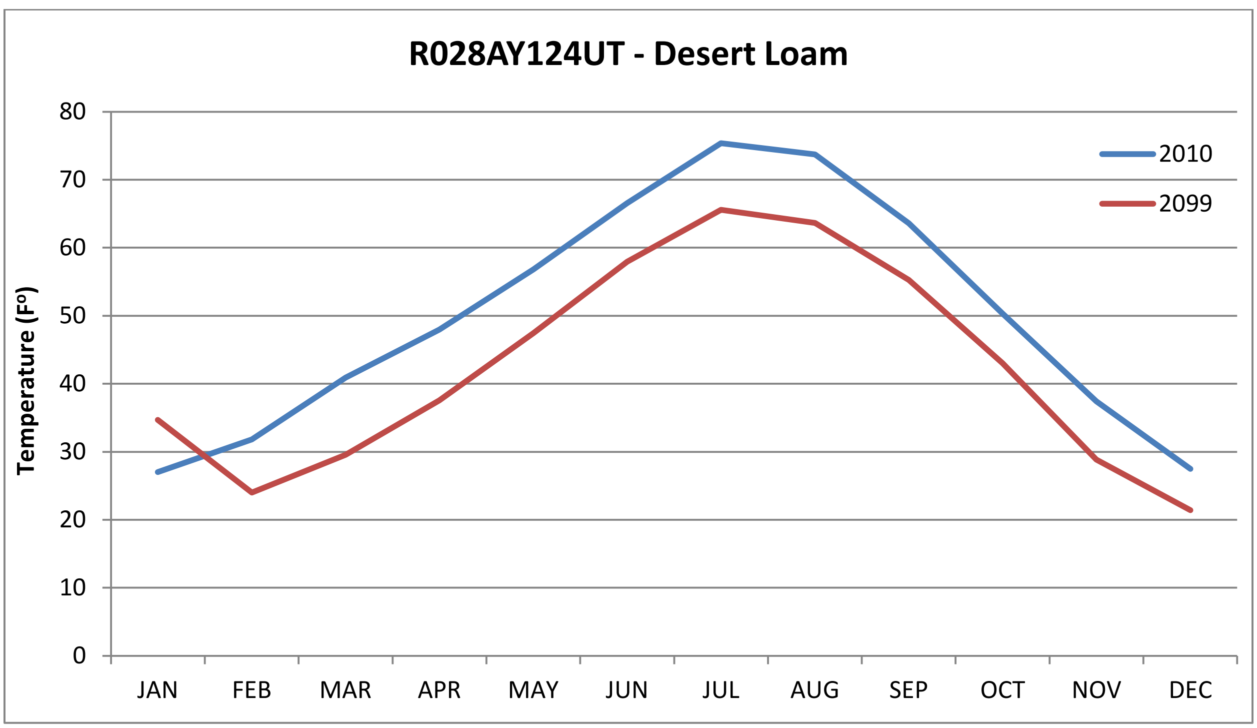


Figure D-12. Current (2010) and expected (2099) temperature for R028AY124UT – Desert Loam ecological site.

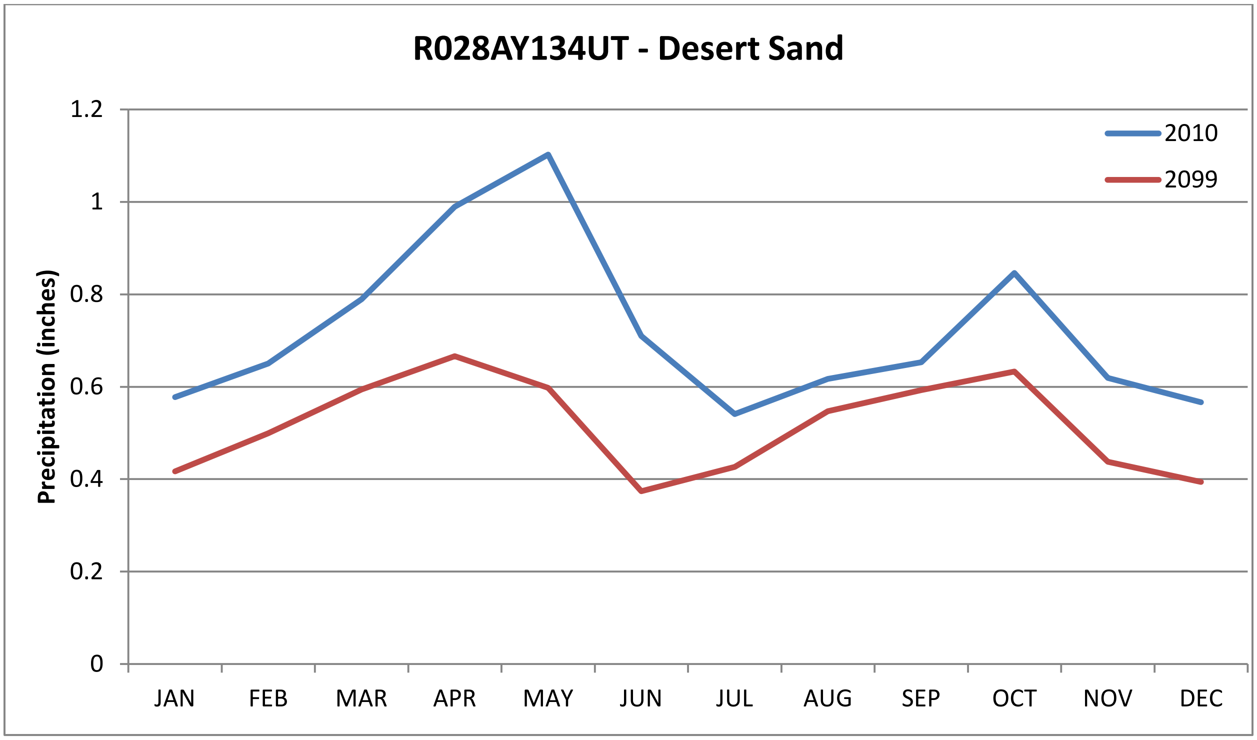


Figure D-13. Current (2010) and expected (2099) precipitation for R028AY134UT – Desert Sand ecological site.

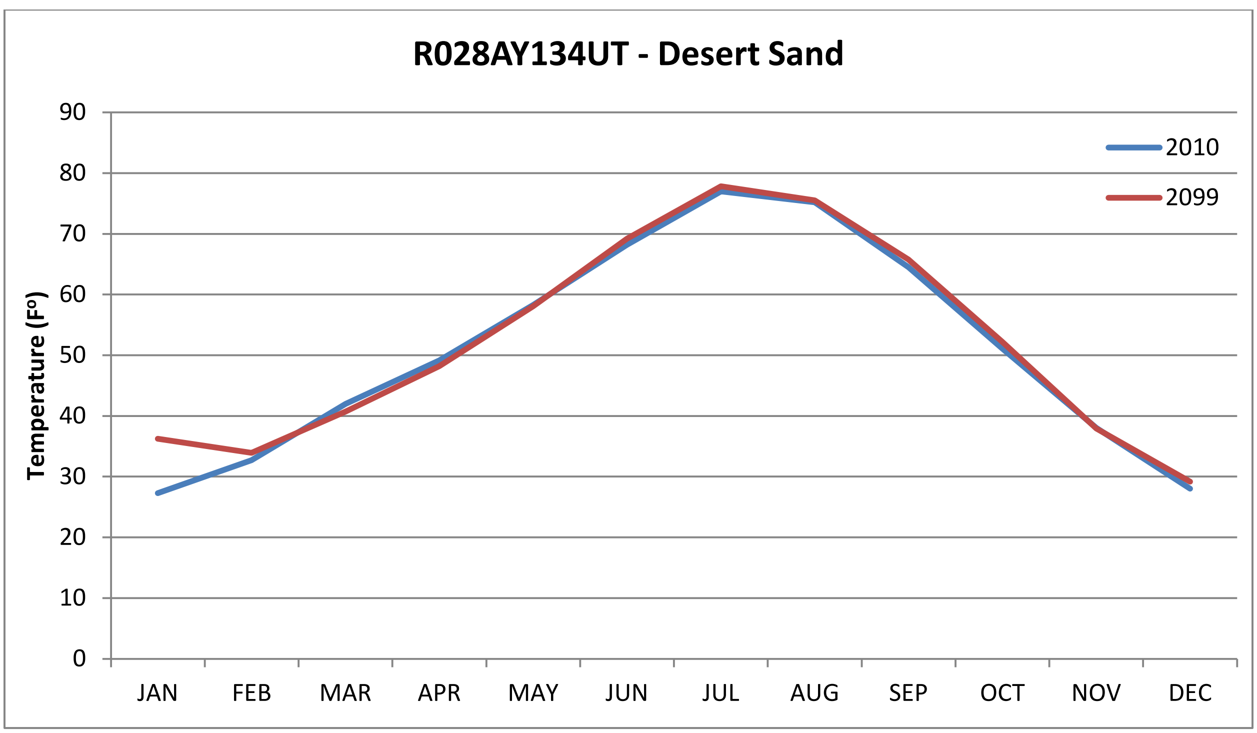


Figure D-14. Current (2010) and expected (2099) temperature for R028AY134UT – Desert Sand ecological site.

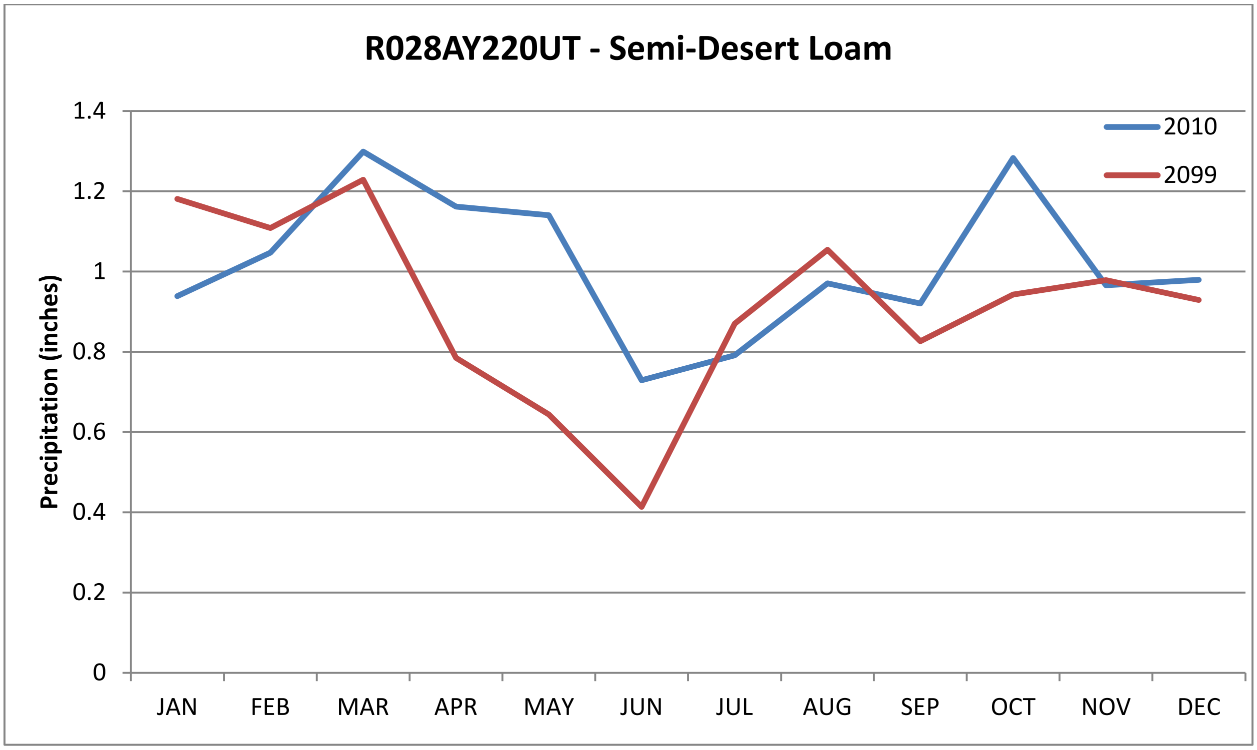


Figure D-15. Current (2010) and expected (2099) precipitation for R028AY220UT – Semi-Desert Loam ecological site.

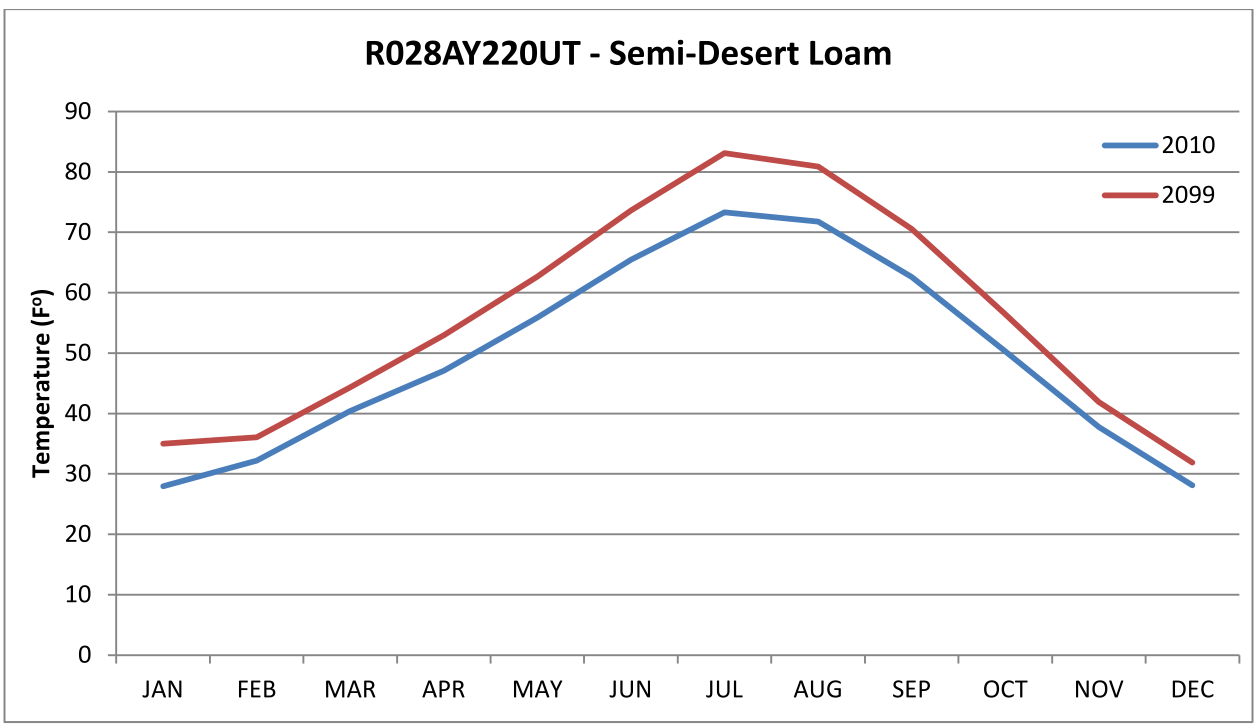


Figure D-16. Current (2010) and expected (2099) temperature for R028AY220UT – Semi-Desert Loam ecological site.

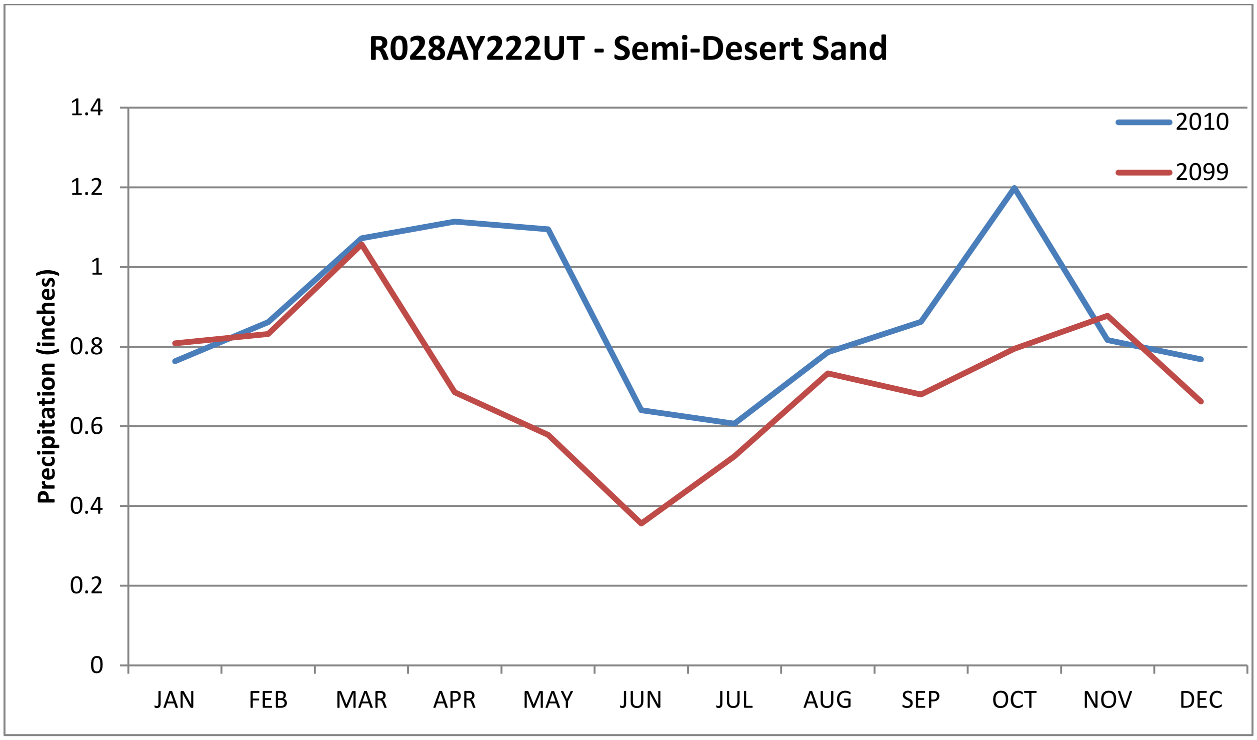


Figure D-17. Current (2010) and expected (2099) precipitation for R028AY222UT – Semi-Desert Sand ecological site.

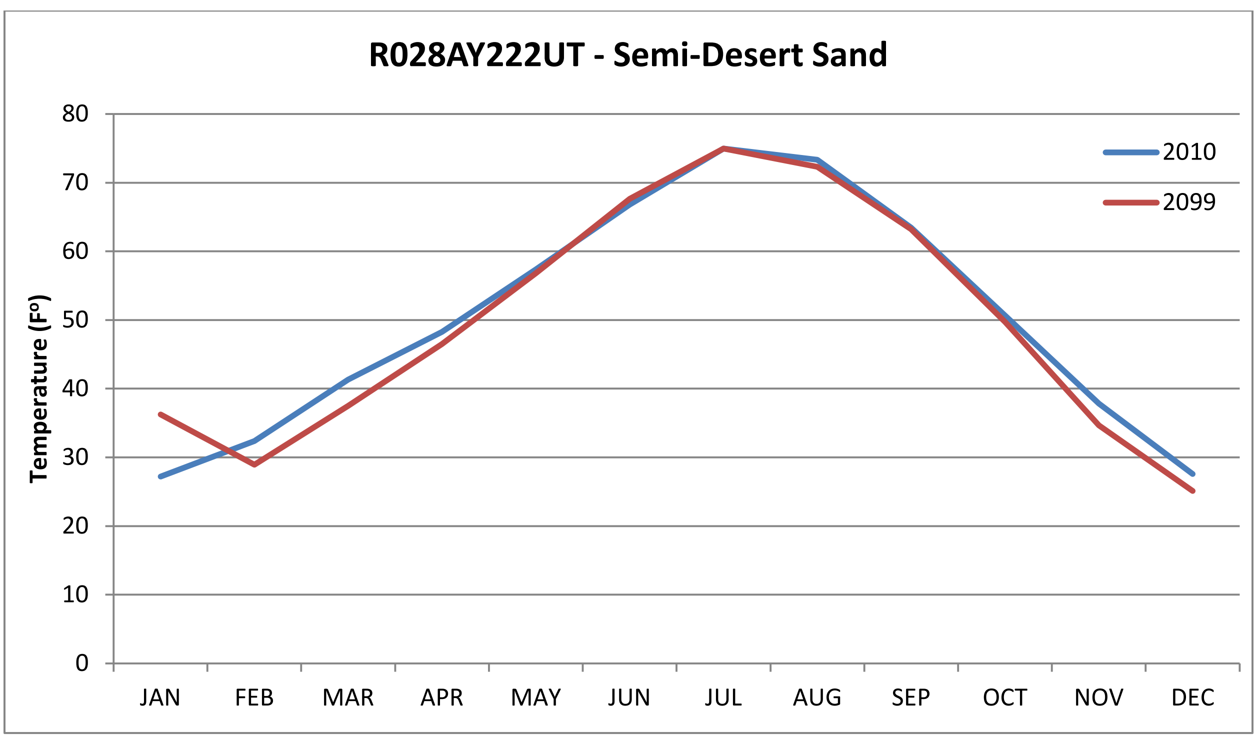


Figure D-18. Current (2010) and expected (2099) temperature for R028AY222UT – Semi-Desert Sand ecological site.

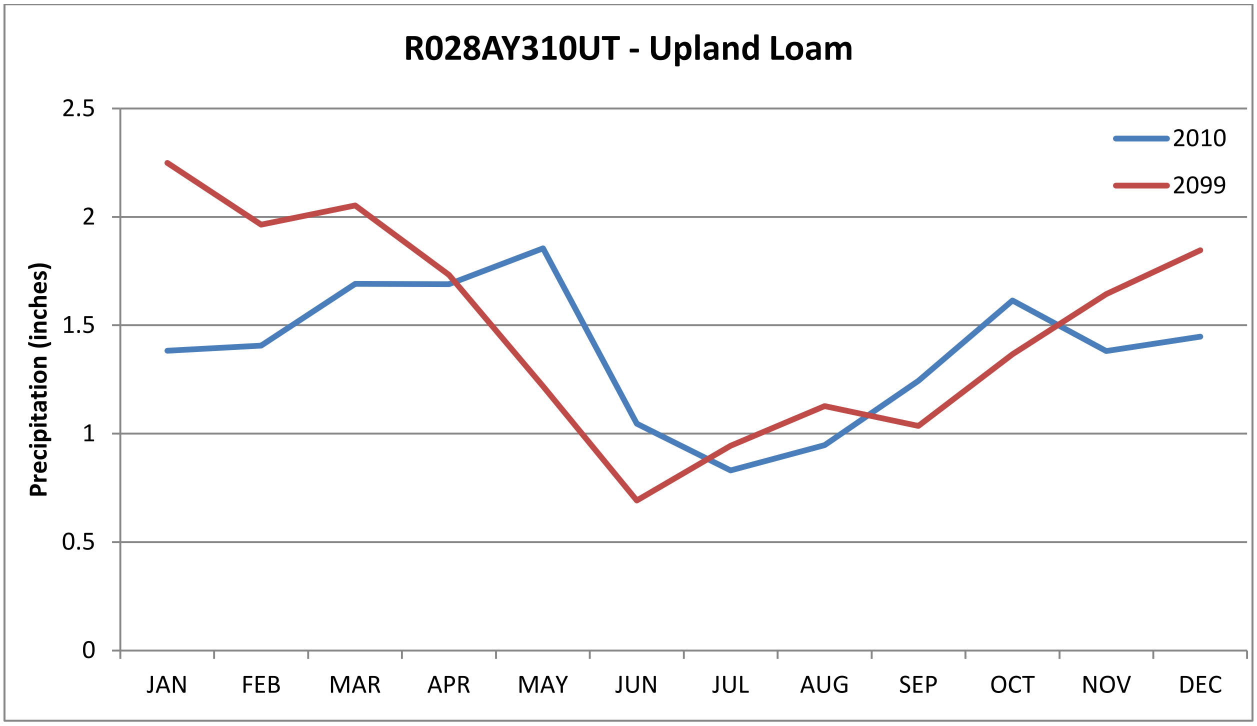


Figure D-19. Current (2010) and expected (2099) precipitation for R028AY310UT – Upland Loam ecological site.

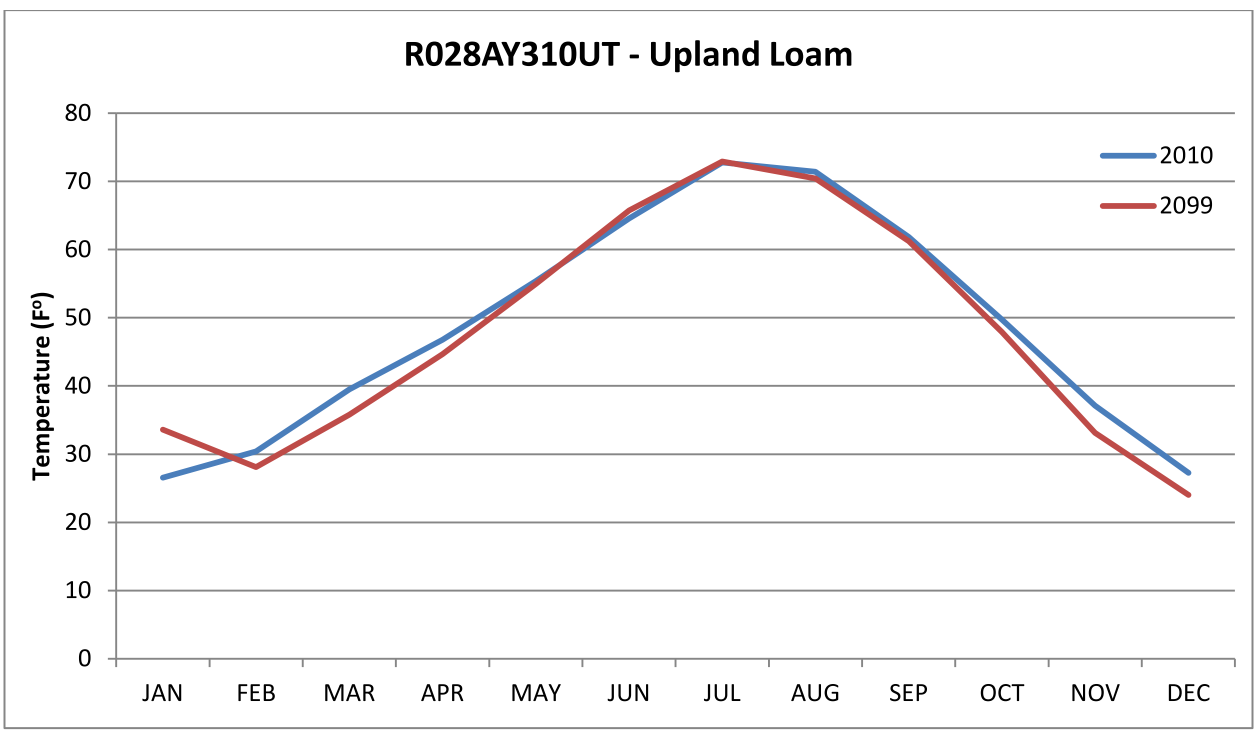


Figure D-20. Current (2010) and expected (2099) temperature for R028AY310UT – Upland Loam ecological site.

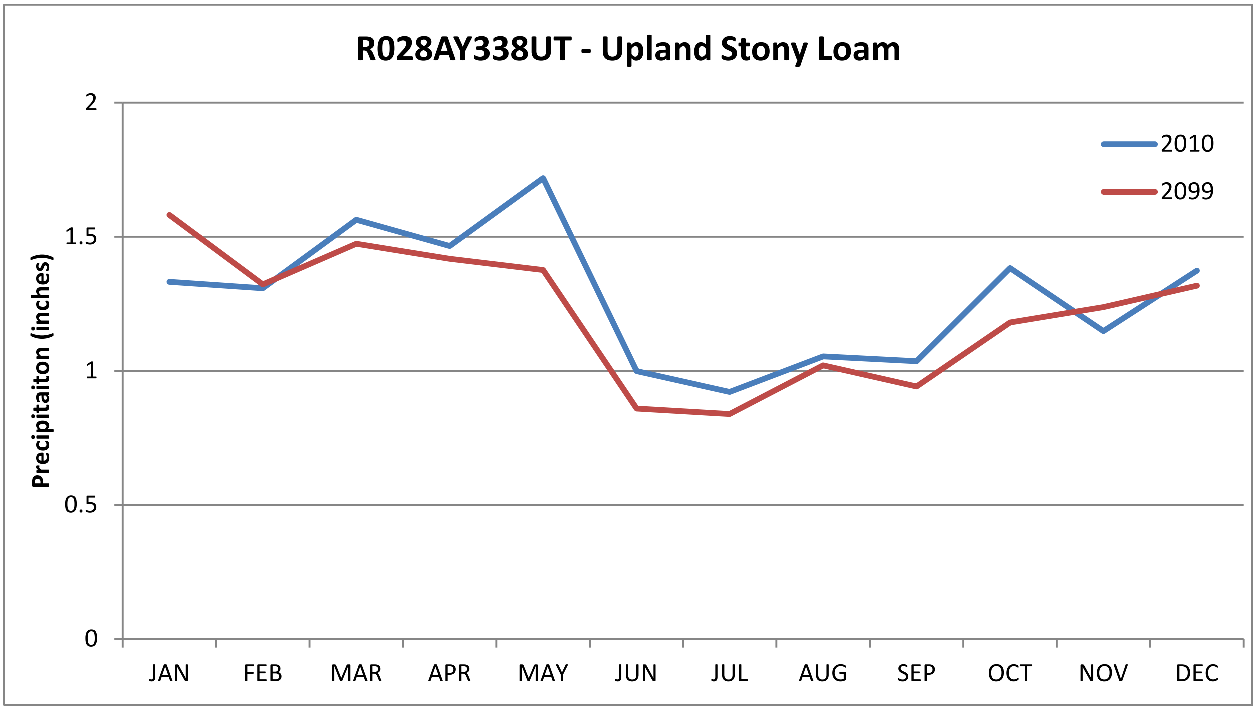


Figure D-21. Current (2010) and expected (2099) precipitation for R028AY338UT – Upland Stony Loam ecological site.

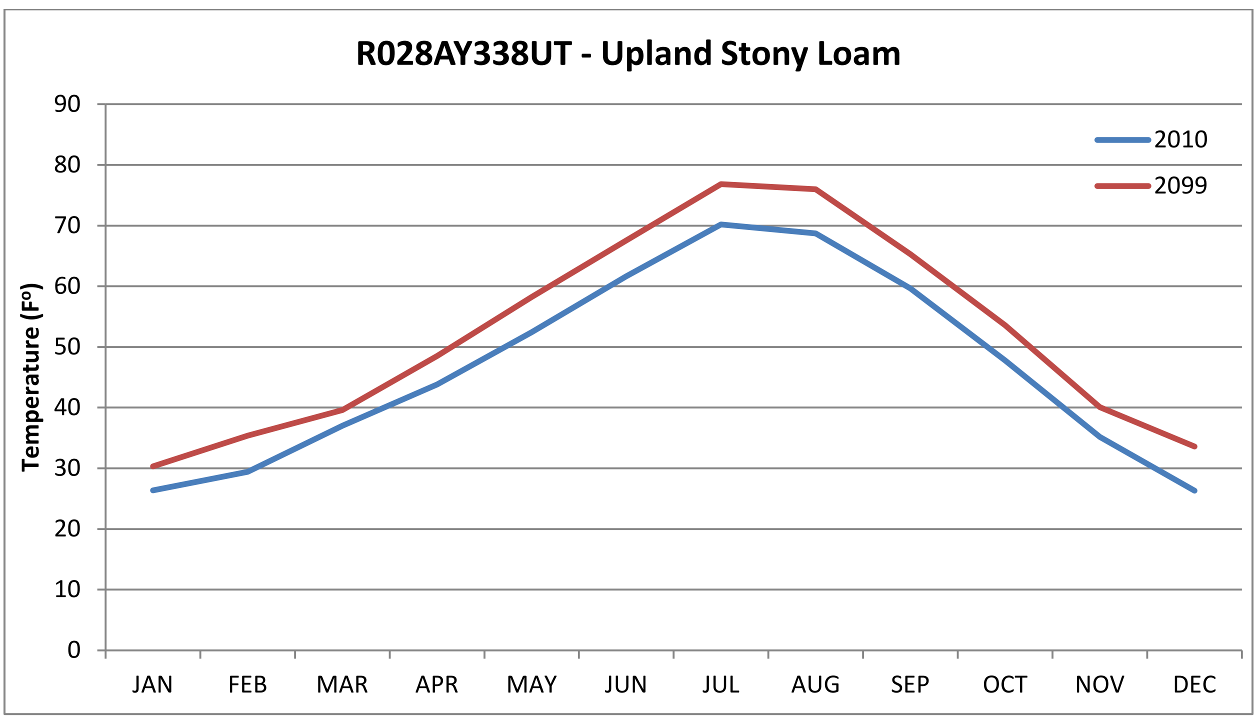


Figure D-22. Current (2010) and expected (2099) temperature for R028AY338UT – Upland Stony Loam ecological site.

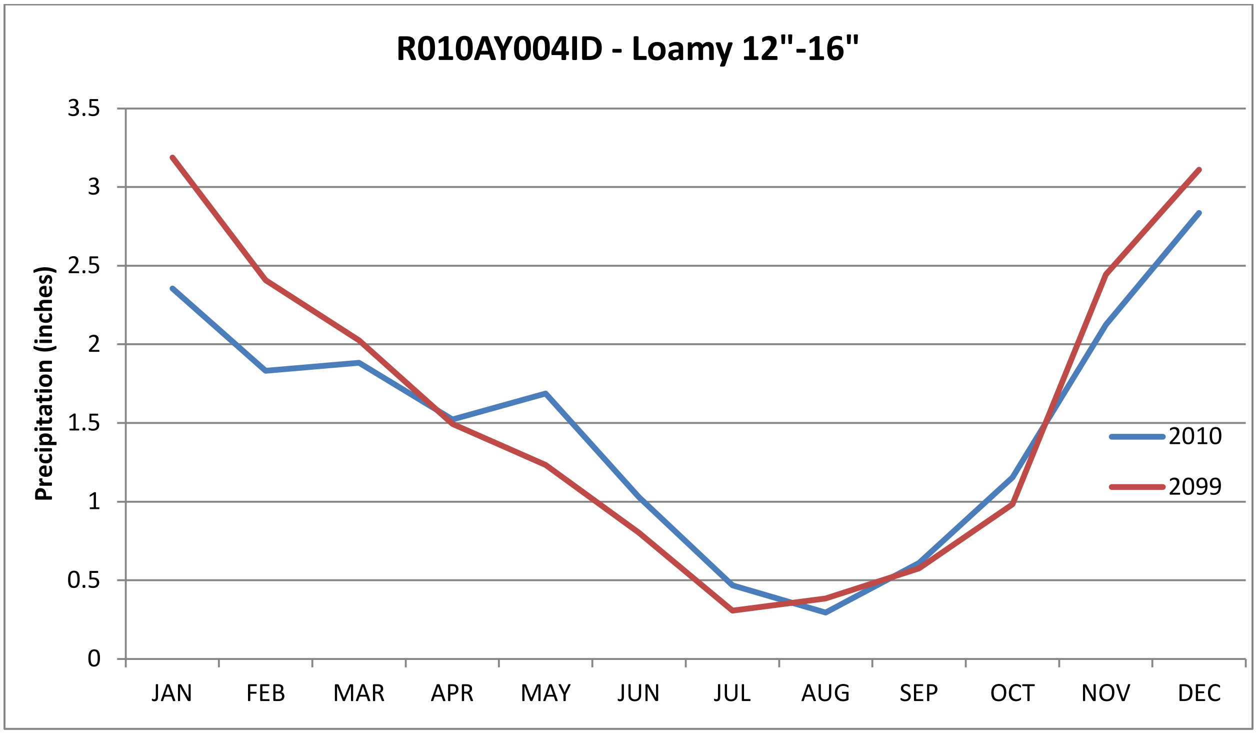


Figure D-23. Current (2010) and expected (2099) precipitation for R010AY004ID – Loamy 12”-16” ecological site.

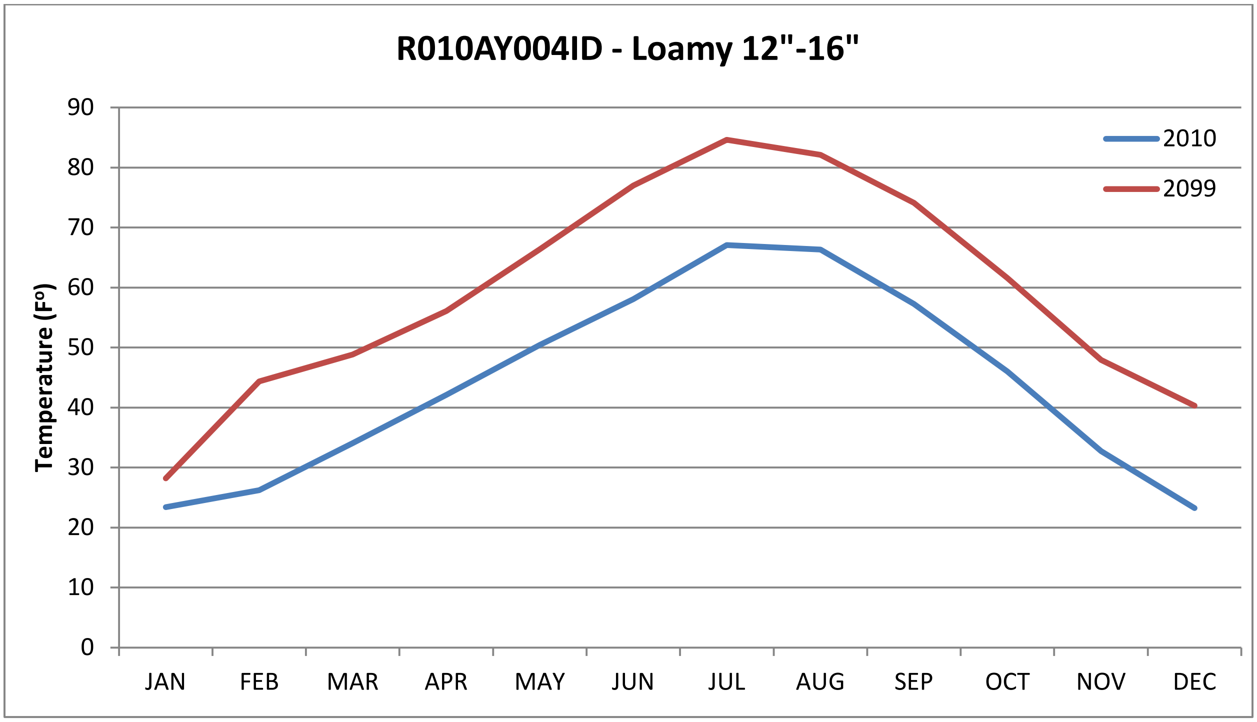


Figure D-24. Current (2010) and expected (2099) temperature for R010AY004ID – Loamy 12”-16” ecological site.

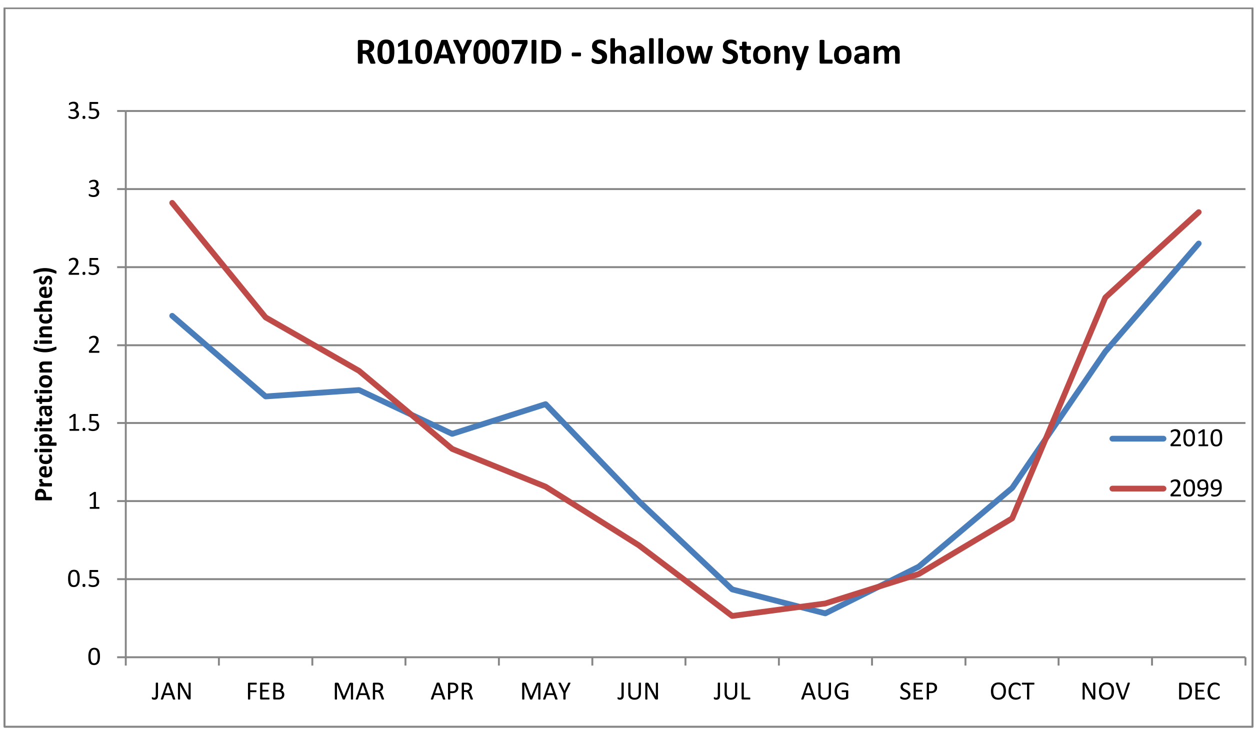


Figure D-25. Current (2010) and expected (2099) precipitation for R010AY007ID – Shallow Stony Loam ecological site.

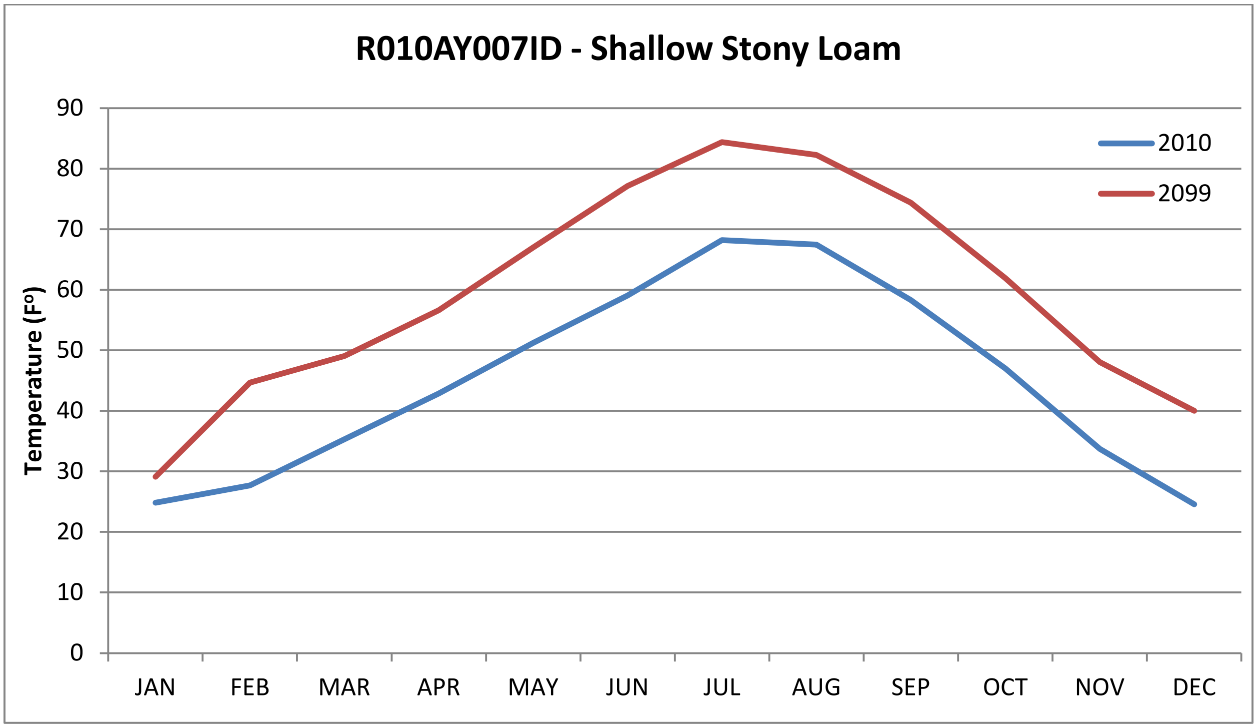


Figure D-26. Current (2010) and expected (2099) temperature for R010AY007ID – Shallow Stony Loam ecological site.

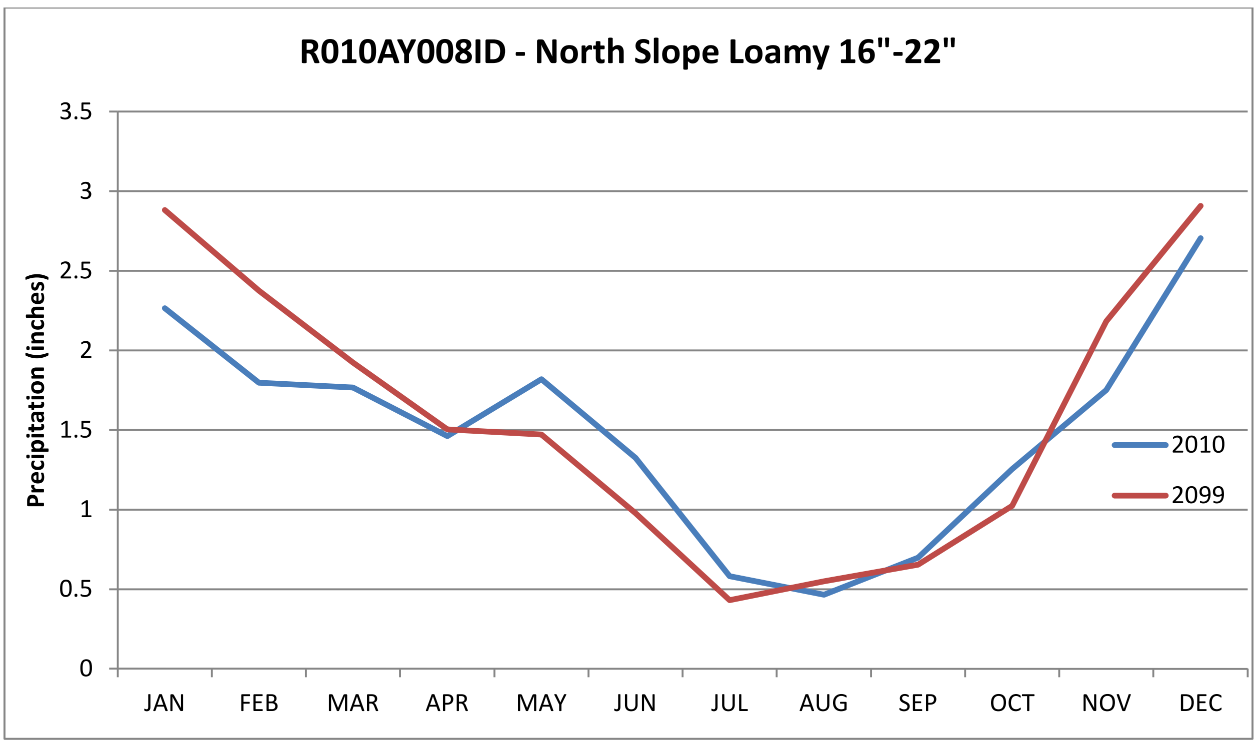


Figure D-27. Current (2010) and expected (2099) precipitation for R010AY008ID – North Slope Loamy 16”-22” ecological site.

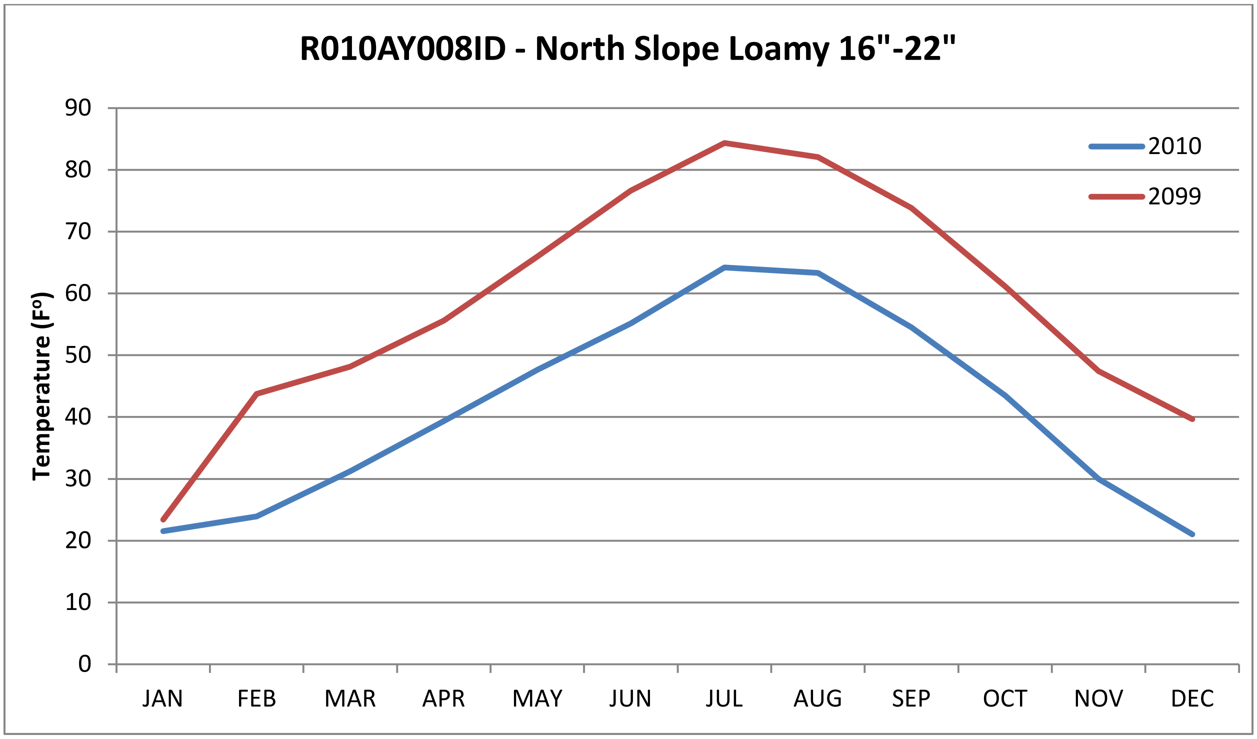


Figure D-28. Current (2010) and expected (2099) temperature for R010AY008ID – North Slope Loamy 16”-22” ecological site.

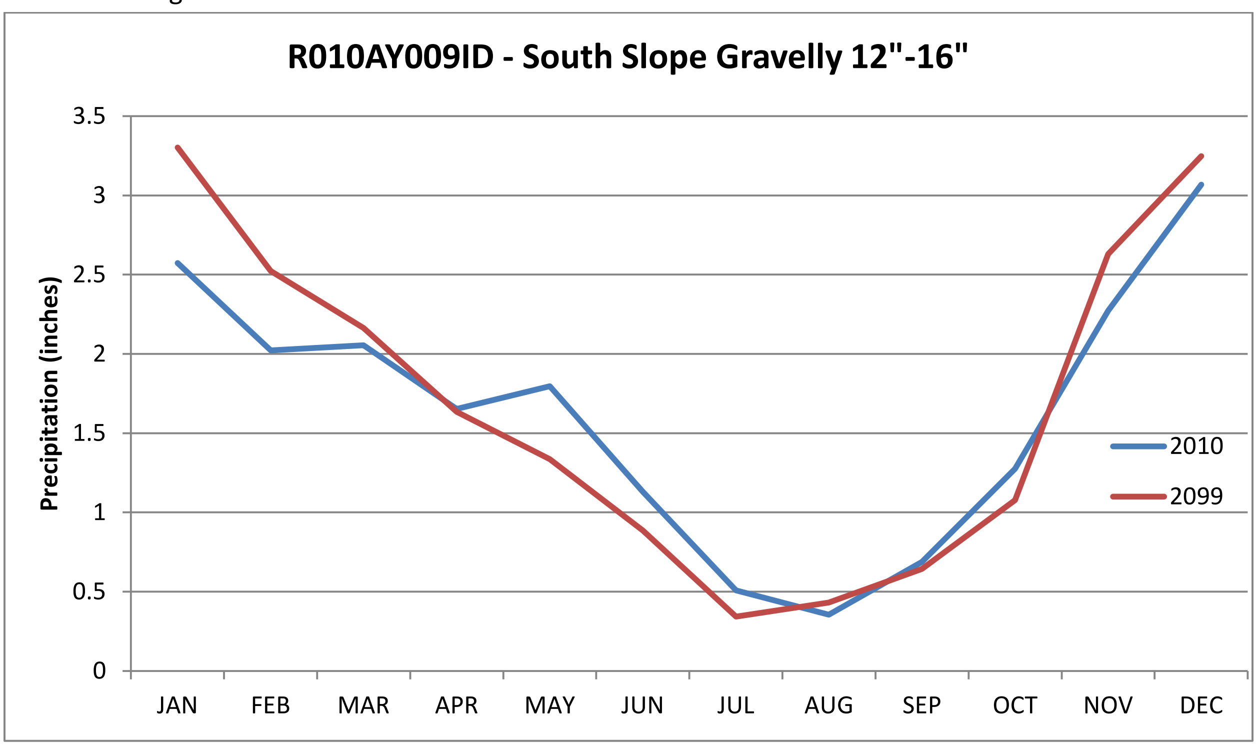


Figure D-29. Current (2010) and expected (2099) precipitation for R010AY009ID – South Slope Gravelly 12-16pp ecological site.

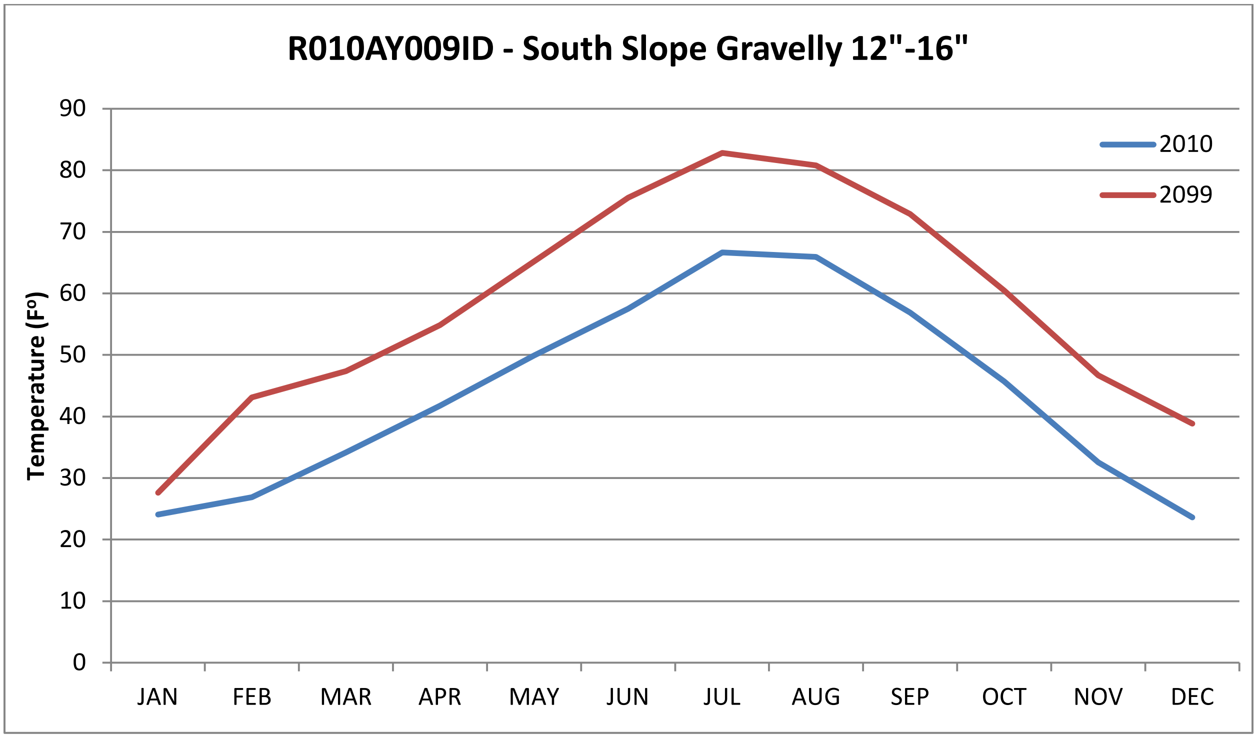


Figure D-30. Current (2010) and expected (2099) temperature for R010AY009ID – South Slope Gravelly 12"-16" ecological site.

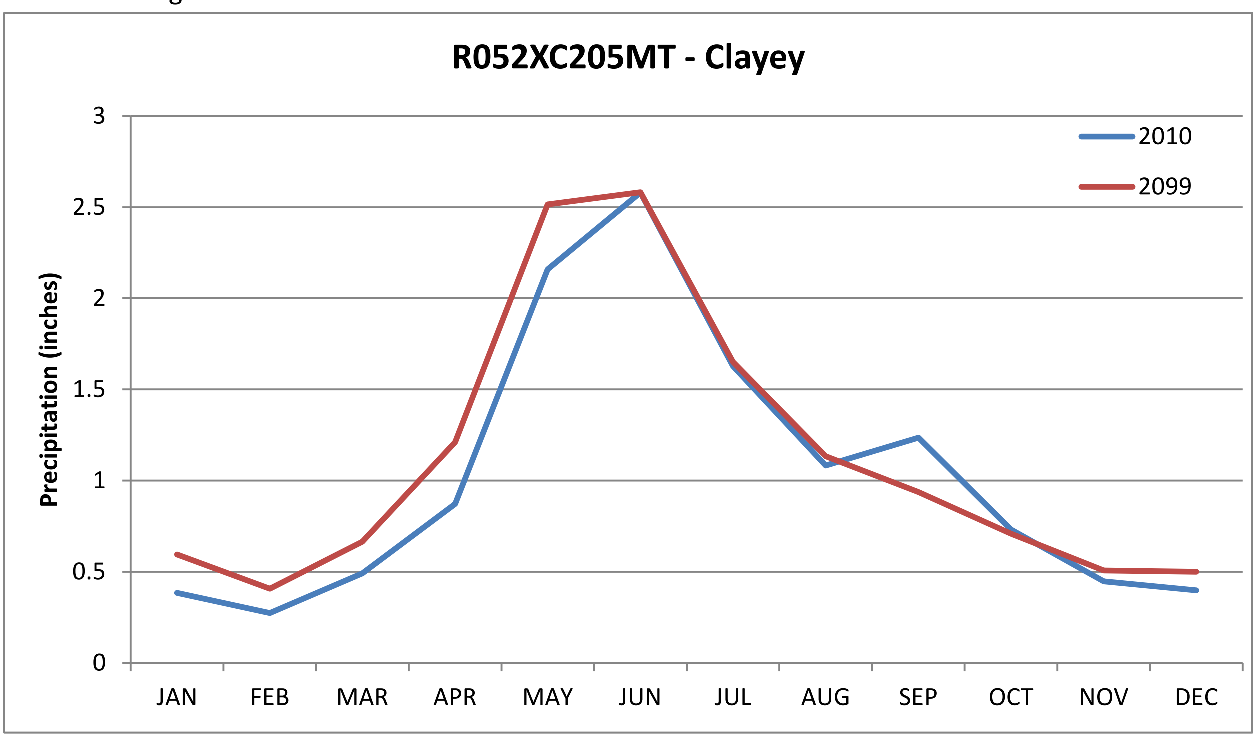


Figure D-31. Current (2010) and expected (2099) precipitation for R052XC205MT – Clayey ecological site.

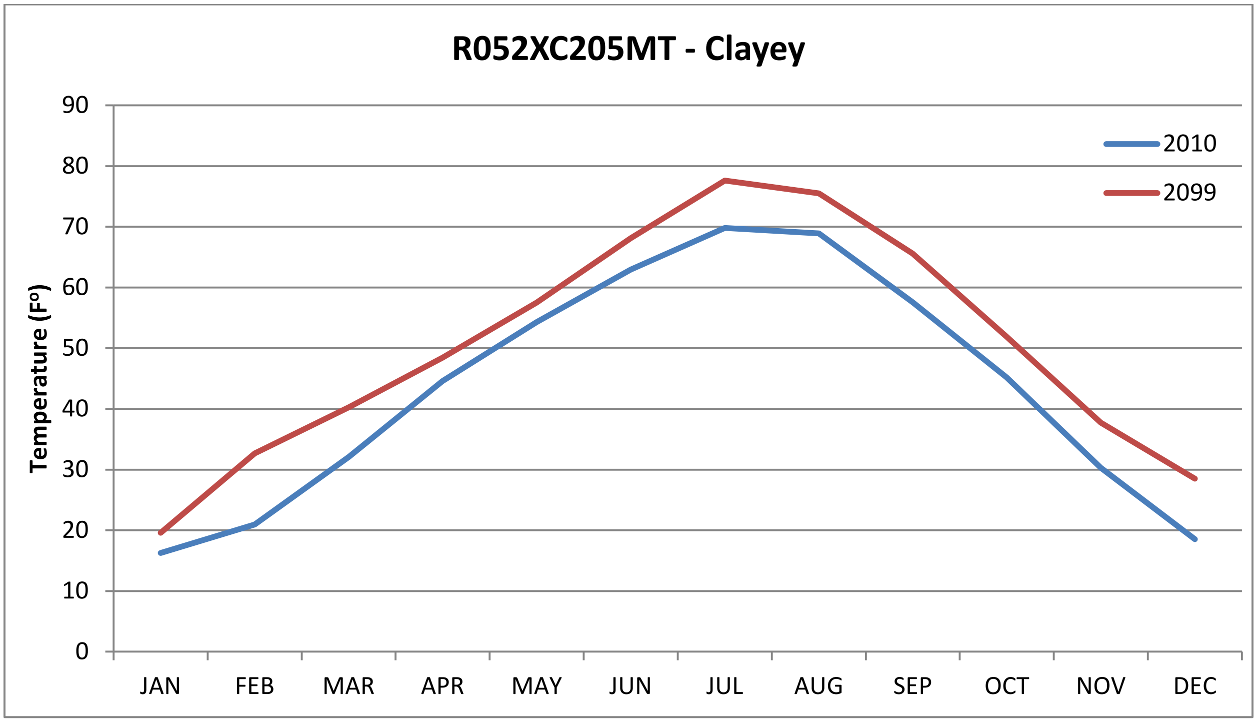


Figure D-32. Current (2010) and expected (2099) temperature for R052XC205MT – Clayey ecological site.

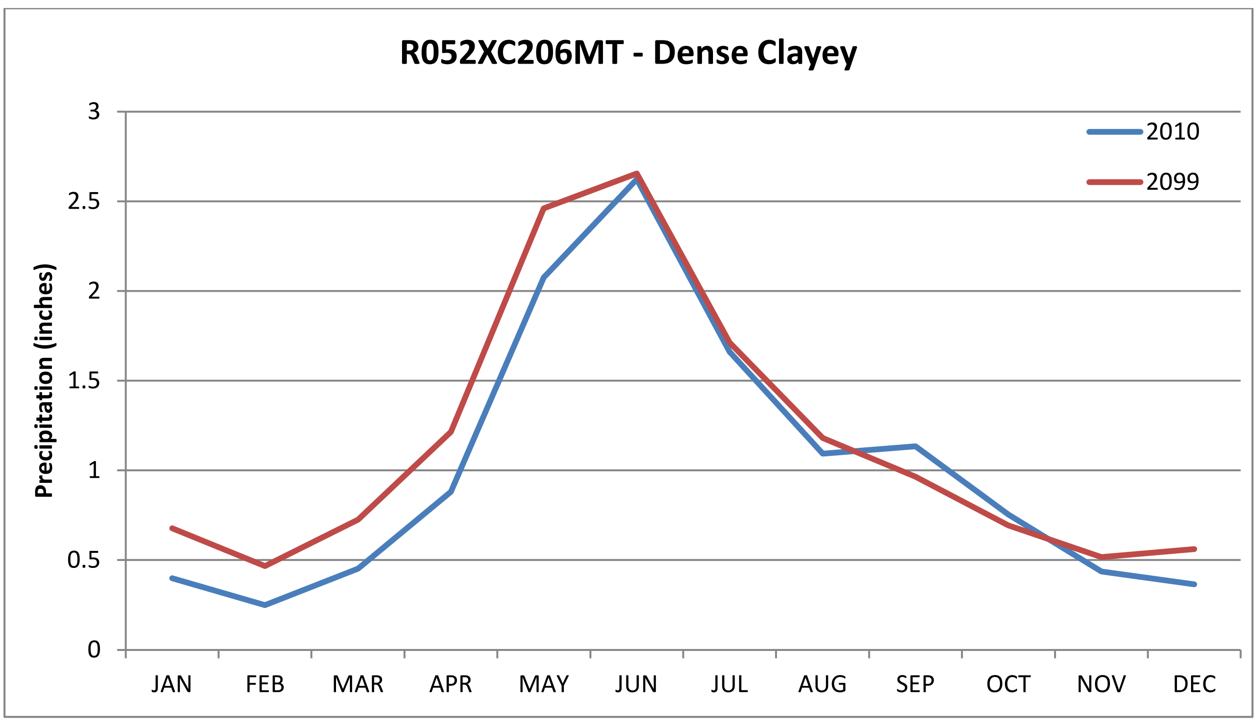


Figure D-33. Current (2010) and expected (2099) precipitation for R052XC206MT – Dense Clayey ecological site.

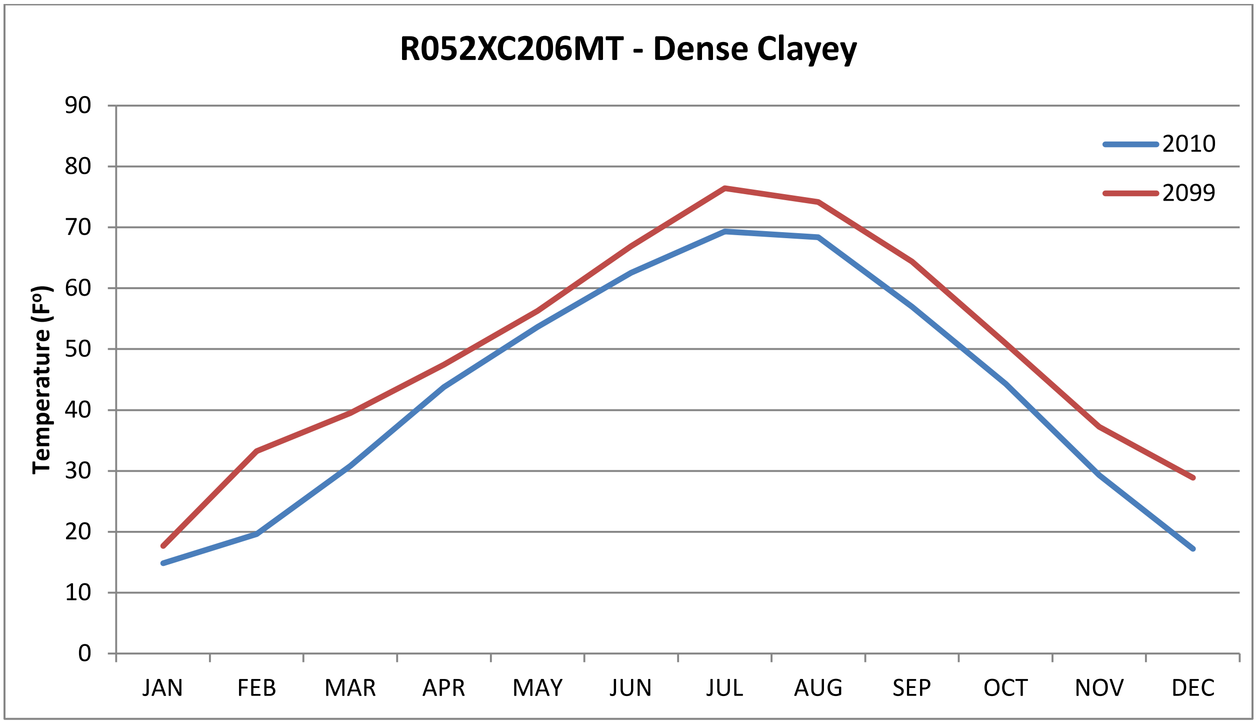


Figure D-34. Current (2010) and expected (2099) temperature for R052XC206MT – Dense Clayey ecological site.

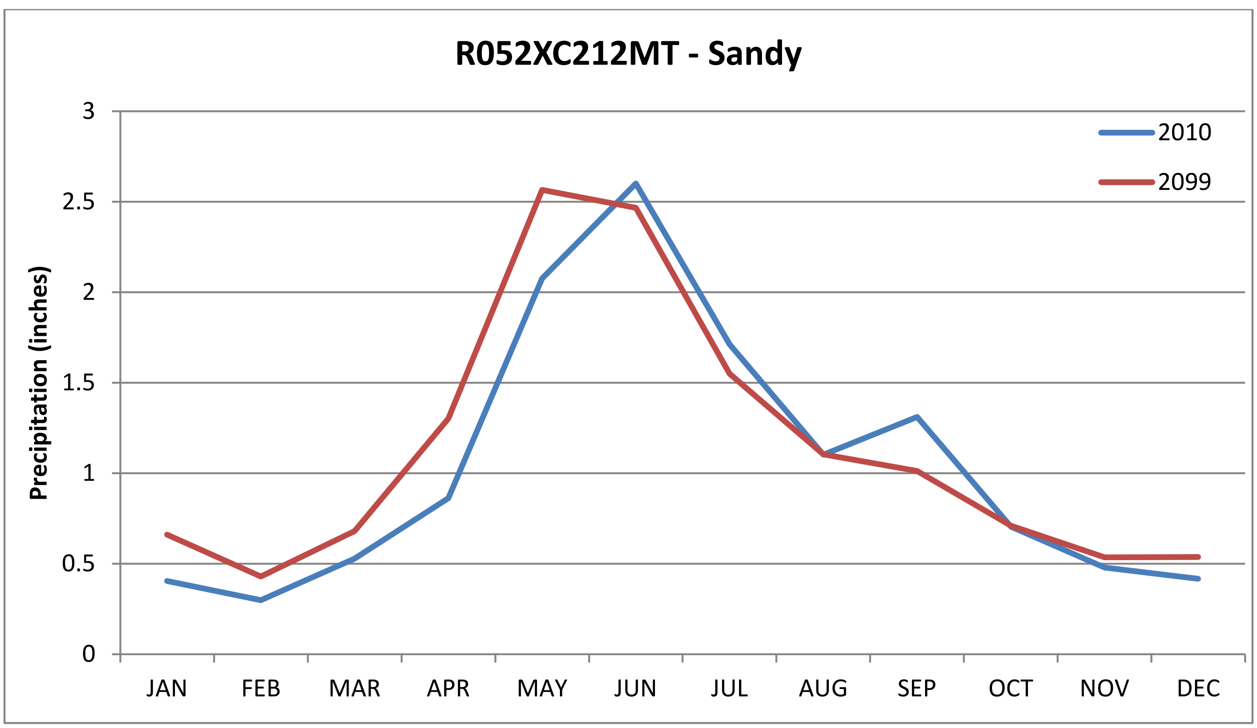


Figure D-35. Current (2010) and expected (2099) precipitation for R052XC212MT – Sandy ecological site.

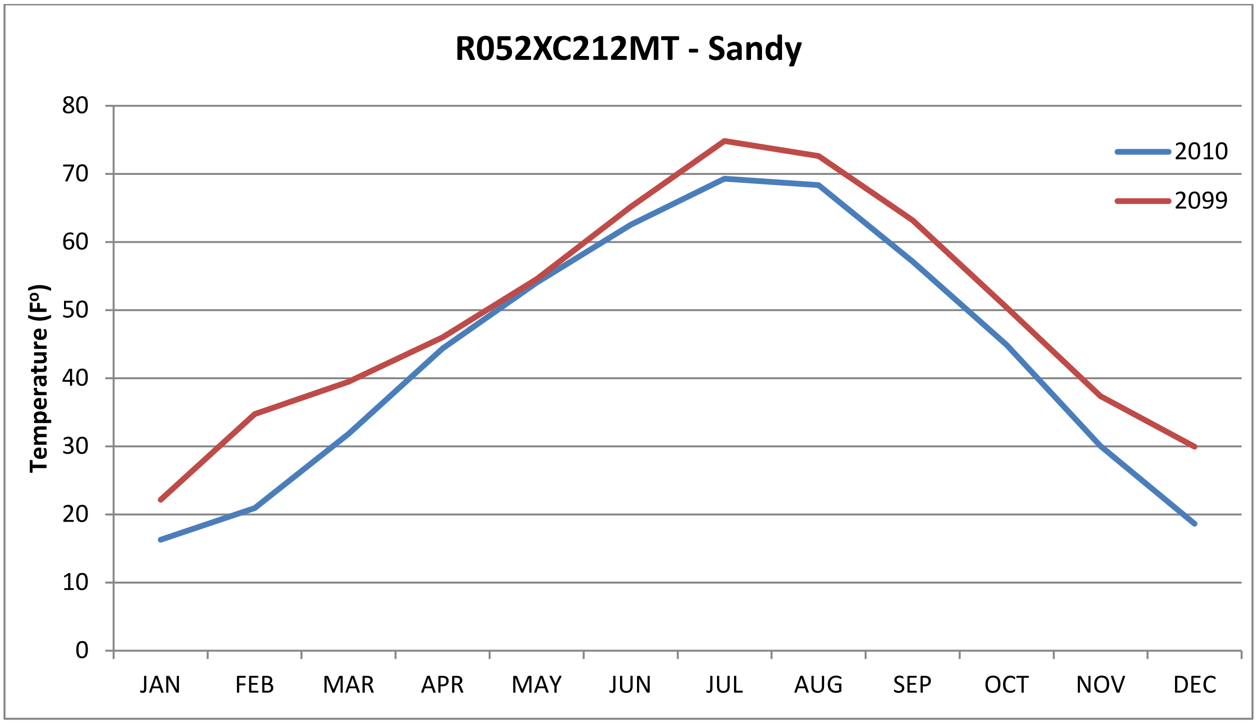


Figure D-36. Current (2010) and expected (2099) temperature for R052XC212MT – Sandy ecological site.

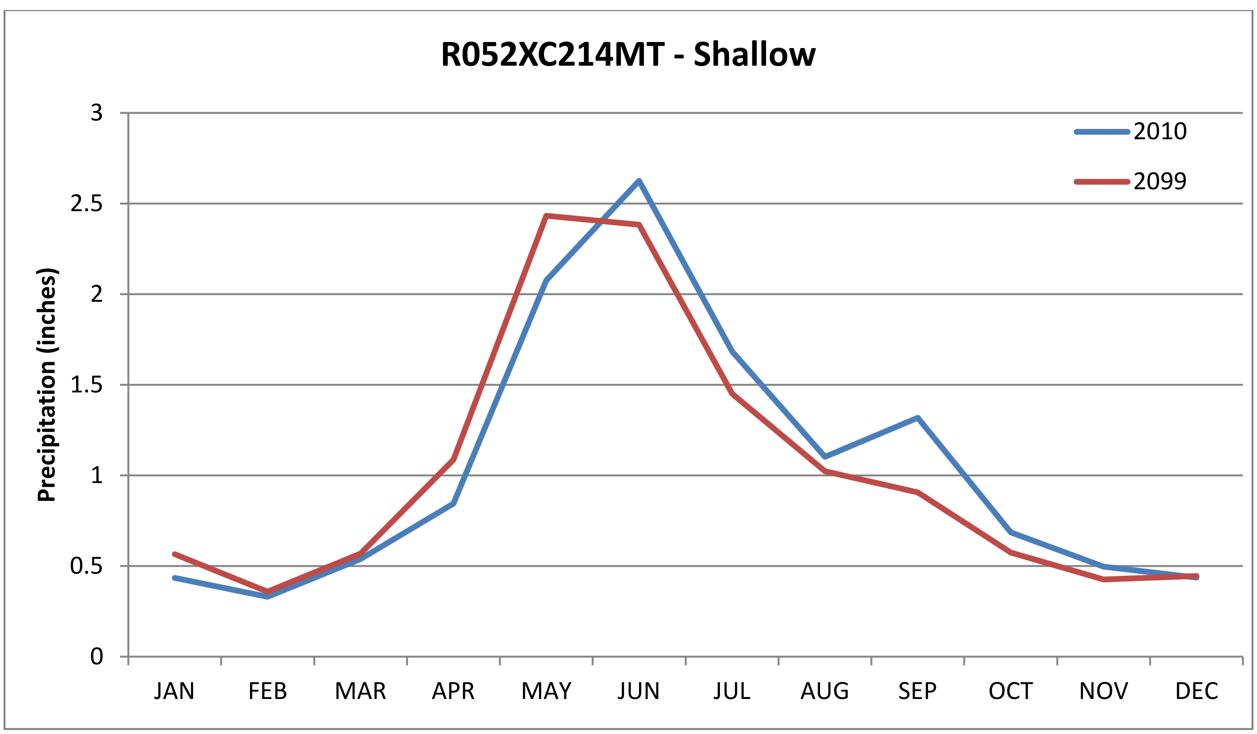


Figure D-37. Current (2010) and expected (2099) precipitation for R052XC214MT – Shallow ecological site.

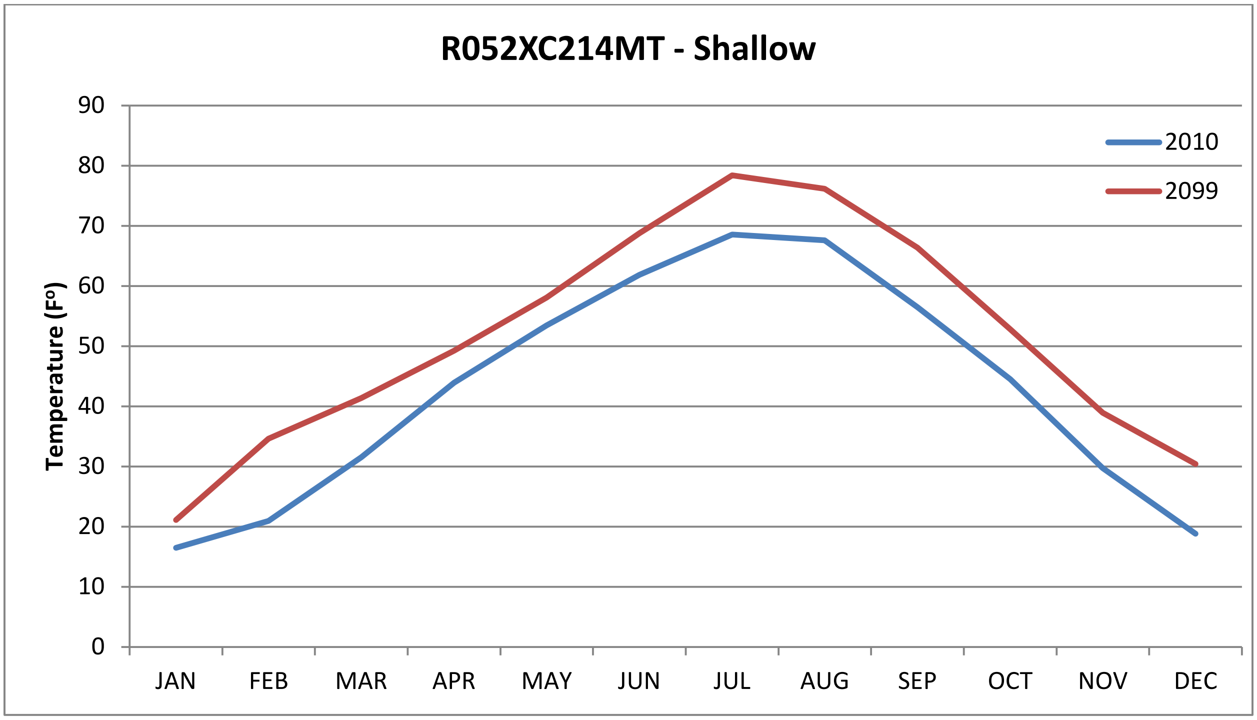


Figure D-38. Current (2010) and expected (2099) temperature for R052XC214MT – Shallow ecological site.

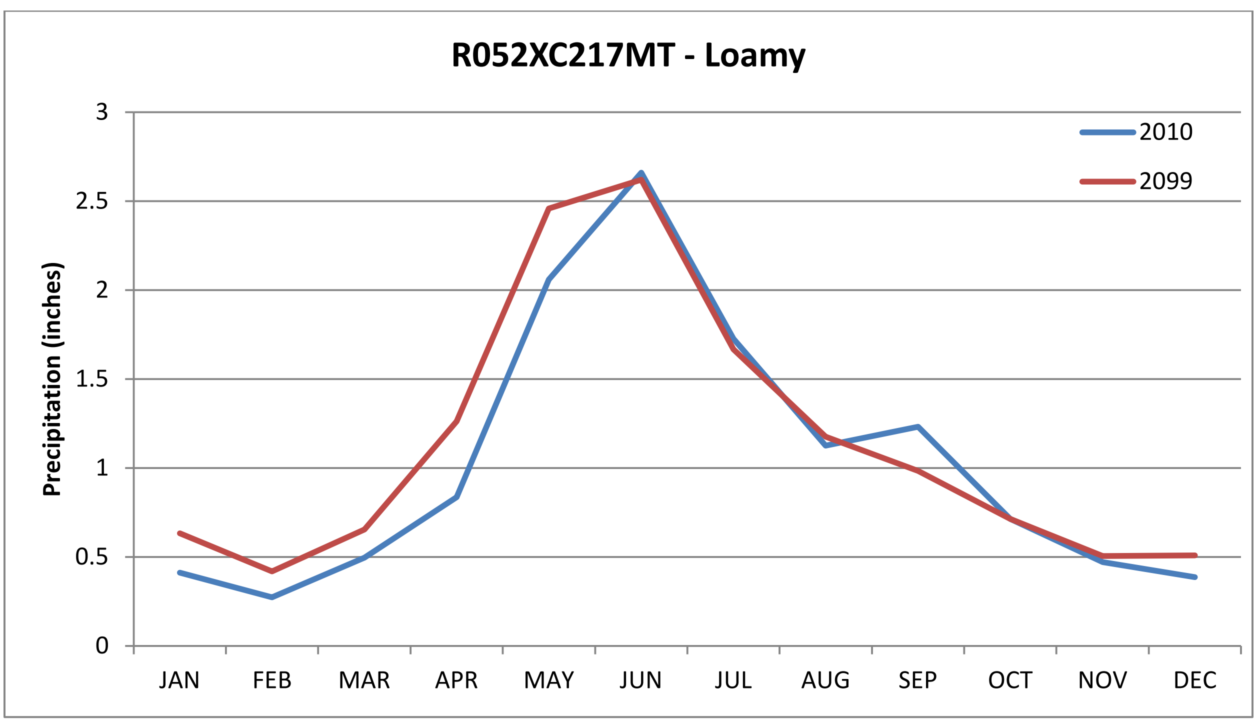


Figure D-39. Current (2010) and expected (2099) precipitation for R052XC217MT – Loamy ecological site.

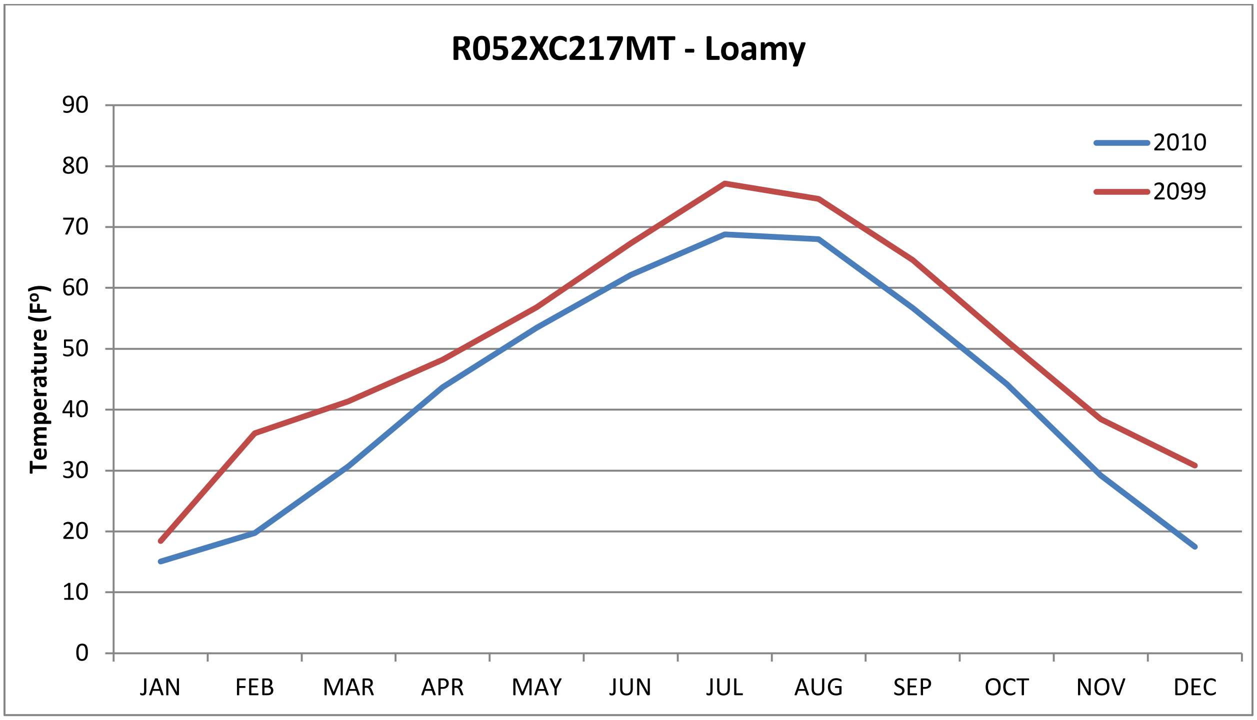


Figure D-40. Current (2010) and expected (2099) temperature for R052XC217MT – Loamy ecological site.

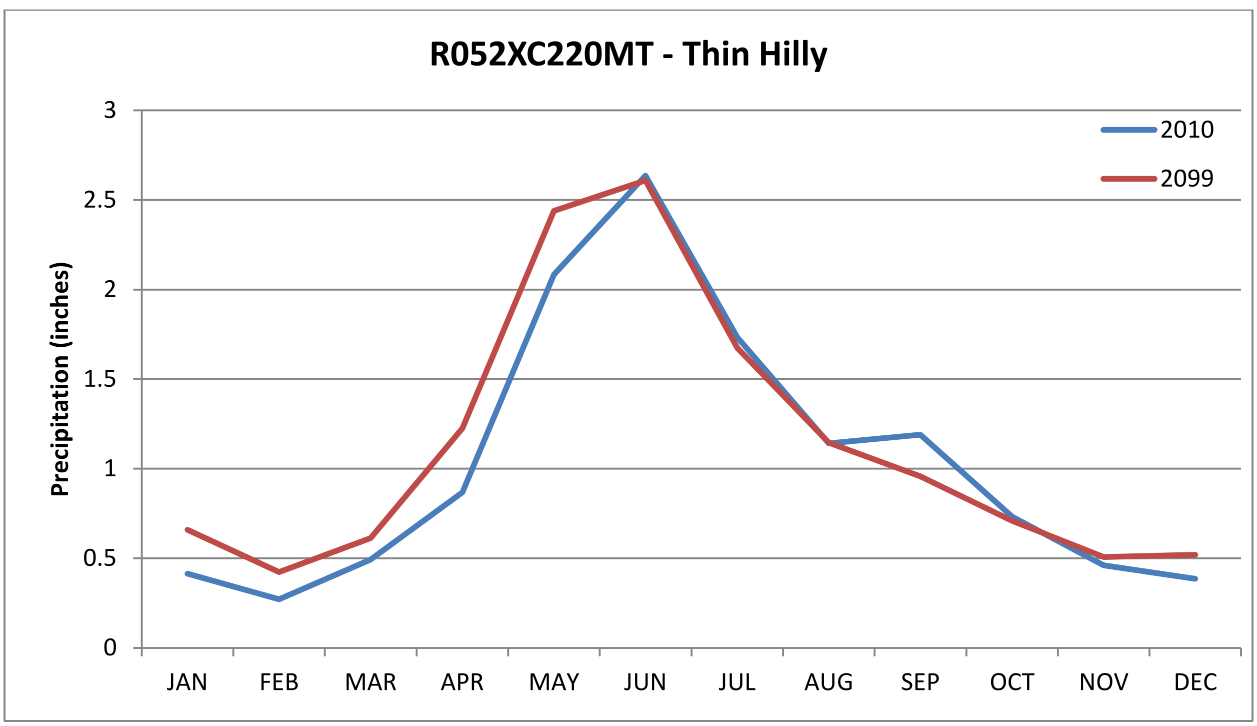


Figure D-41. Current (2010) and expected (2099) precipitation for R052XC220MT – Thin Hilly ecological site.

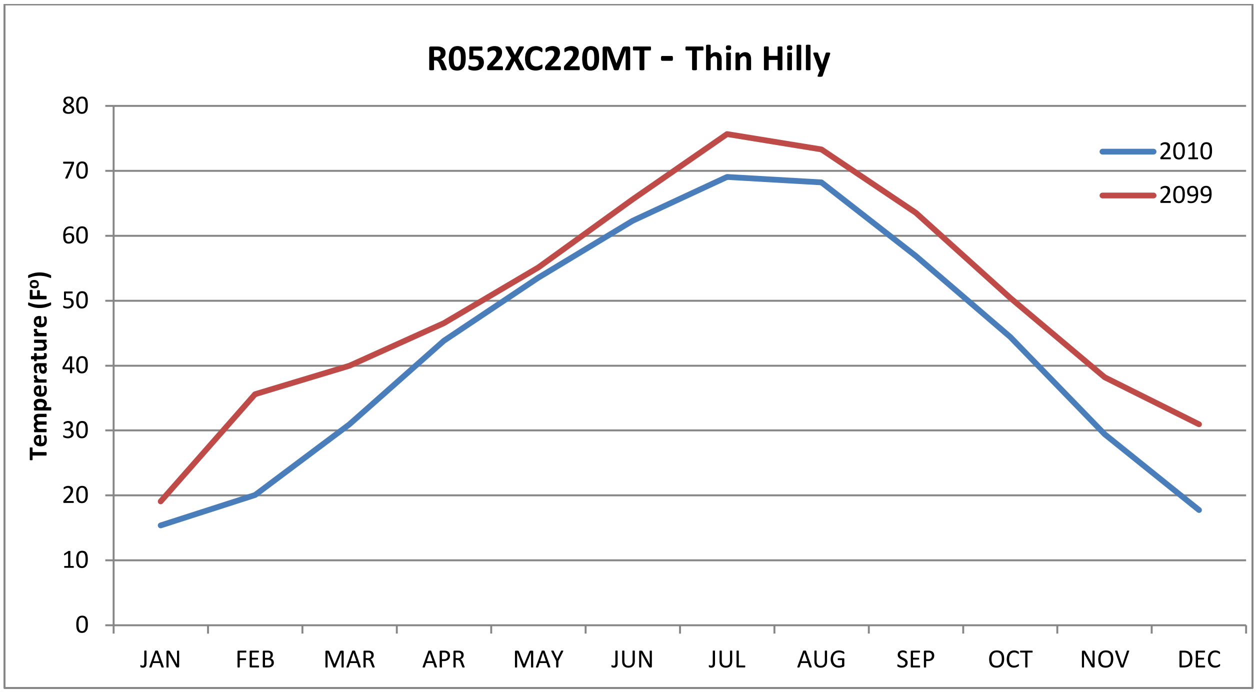


Figure D-42. Current (2010) and expected (2099) temperature for R052XC220MT – Thin Hilly ecological site.

APPENDIX E - PREFERRED FORB SPECIES USED BY GREATER SAGE-GROUSE

Scientific Name	Common Name	Symbol
Annuals		
Chenopodium album	Lambsquarters	CHAL7
Chenopodium fremontii	Fremont's goosefoot	CHFR3
Chenopodium leptophyllum	Narrowleaf goosefoot	CHLE4
Collinsia parviflora	Blue eyed Mary	COPA3
Collomia grandiflora	Grand collomia	COGR4
Collomia linearis	Tiny trumpet	COLI2
Cryptantha scoparia	Pinyon desert cryptantha	CRSC2
Epilobium minutum	Chaparral willowherb	EPMI
Epilobium brachycarpum	Tall annual willow-herb	EPBR3
Eriastrum sparsiflorum	Great Basin woollystar	ERSP3
Eriogonum spp.	Buckwheat	ERIOG
Erodium cicutarium	Stork's bill	ERCI6
Helianthus annuus	Common sunflower	HEAN3
Lactuca serriola	Prickly lettuce	LASE
Medicago polymorpha	Burclover	MEPO3
Medicago sativa	Alfalfa	MESA
Melilotus officinalis	Yellow sweetclover	MEOF
Microsteris gracilis	slender phlox	MIGR
Plantago patagonica	Woolly plantain	PLPA2
Plectritis macrocera	Plectritis	PLMA4
Polygonum aviculare	Prostrate knotweed	POAV
Tragopogon dubius	Salsify	TRDU
Trifolium spp.	Clover	TRIFO
Biennials		
Ipomopsis aggregata ssp. *aggregata*	Scarlet gilia	IPAGA3
Machaeranthera canescens	Hoary aster	MACA2
Perennials / Occasionally Biennials		
Achillea millefolium	Common yarrow	ACMI2
Agoseris glauca	Pale agoseris	AGGL
Allium acuminatum	Tapertip onion	ALAC4
Antennaria dimorpha	Low pussytoes	ANDI2
Antennaria spp.	Pussytoes	ANTEN
Arabis holboellii	Holboell's rockcress	ARHO2
Arenaria kingii	King's sandwort	ARKI
Artemisia dracunculus	Tarragon	ARDR4
Astragalus argophyllus	Silverleaf milkvetch	ASAR4
Astragalus beckwithii	Beckwith's milkvetch	ASBE3

Appendix E continued. Preferred forb species used by Greater Sage-grouse.

Scientific Name	Common Name	Symbol
Astragalus calycosus	Torrey's milkvetch	ASCA9
Astragalus convallarius	Lesser rushy milkvetch	ASCO12
Astragalus lentiginosus	Freckled milkvetch	ASLE8
Astragalus purshii	Woollypod milkvetch	ASPU9
Balsamorhiza hookeri	Hooker's balsamroot	BAHO
Balsamorhiza sagittata	Arrowleaf balsamroot	BASA3
Berberis repens	Creeping barberry	MARE11
Calochortus nuttallii	Sego lily	CANU3
Castilleja angustifolia var. *dubia*	Wavyleaf Indian paintbrush	CAAND
Castilleja linariifolia	Wyoming Indian paintbrush	CALI4
Chaenactis douglasii	Douglas's dustymaiden	CHDO
Comandra umbellata	Bastard toadflax	COUM
Crepis acuminata	Tapertip hawksbeard	CRAC2
Crepis spp.	Hawksbeard	CREPI
Cymopterus spp.	Springparsley	CYMOP2
Delphinium nuttallianum	Twolobe larkspur	DENU2
Erigeron corymbosus	Longleaf fleabane	ERCO5
Erigeron humilis	Arctic alpine fleabane	ERHU
Erigeron pumilus	Shaggy fleabane	ERPU2
Eriogonum microthecum	Slender buckwheat	ERMI4
Eriogonum ovalifolium	Cushion buckwheat	EROV
Eriogonum umbellatum	Sulfur-flower buckwheat	ERUM
Erysimum capitatum var. *capitatum*	Sanddune wallflower	ERCAC
Fritillaria pudica	Yellow fritillary	FRPU2
Geranium viscosissimum	Sticky purple geranium	GEVI2
Geum macrophyllum	Largeleaf avens	GEMA4
Hedysarum spp.	Sweetvetch	HEDYS
Helianthella uniflora	Oneflower helianthella	HEUN
Hydrophyllum capitatum	Ballhead waterleaf	HYCA4
Iva axillaris	Povertyweed	IVAX
Lathyrus nevadensis	Sierra pea	LANE3
Linanthus pungens	Granite prickly phlox	LIPU11
Linanthus spp.	Linanthus	LINAN2
Linum perenne	Blue flax	LIPE2
Lithophragma spp.	Woodland-star	LITHO2
Lithospermum ruderale	Western stoneseed	LIRU4
Lomatium grayi	Gray's biscuitroot	LOGR
Lomatium spp.	Desertparsley	LOMAT
Lomatium triternatum	Nineleaf biscuitroot	LOTR2
Lotus corniculatus	Bird's-foot trefoil	LOCO6

Appendix E continued. Preferred forb species used by Greater Sage-grouse.

Scientific Name	**Common Name**	**Symbol**
Lygodesmia juncea	Rush skeletonplant	LYJU
Maianthemum racemosum ssp. *racemosum*	Feathery false lily of the valley	MARAR
Mertensia oblongifolia	Oblongleaf bluebells	MEOB
Microseris spp.	Silverpuffs	MICRO6
Nothocalais nigrescens	Speckled false dandelion	NONI
Oenothera pallida	Pale evening-primrose	OEPA
Packera dimorphophylla var. *dimorphophylla*	Splitleaf groundsel	PADID3
Packera streptanthifolia	Rocky Mountain groundsel	PAST10
Penstemon cyaneus	Blue penstemon	PECY3
Penstemon procerus	Littleflower penstemon	PEPR2
Penstemon spp.	Beardtongue	PENST
Perideridia spp.	Yampah	PERID
Phacelia hastata	Silverleaf phacelia	PHHA
Phlox hoodii	Spiny phlox	PHHO
Phlox longifolia	Longleaf phlox	PHLO2
Rumex salicifolius	Willow dock	RUSA
Sanguisorba minor	Small burnet	SAMI3
Sedum lanceolatum	Spearleaf stonecrop	SELA
Senecio integerrimus	Lambstongue ragwort	SEIN2
Solidago missouriensis	Missouri goldenrod	SOMI2
Sphaeralcea munroana	Munro's globemallow	SPMU2
Sphaeralcea spp.	Globemallow	SPHAE
Stenotus acaulis	Stemless mock goldenweed	STAC
Symphyotrichum chilense var. *chilense*	Pacific aster	SYCHC
Taraxacum officinale	Common dandelion	TAOF
Viola nuttallii	Nuttall's violet	VINU2
Viola purpurea	Goosefoot violet	VIPU4
Wyethia amplexicaulis	Mule-ears	WYAM
Zigadenus paniculatus	Foothill deathcamus	ZIPA2