Threat-based ecostate mapping:

Using big data to guide management across sagebrush landscapes

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All photos and figures by authors, unless otherwise noted.

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Why do we need ecostate maps?

For those of us who manage and care about sagebrush ecosystems, threat-based ecostate maps are like a one-stop weather report. These maps pull together decades of satellite and field data to show the condition of vegetation across the landscape — where it's healthy, where it's declining, and what's causing the change. They simplify complex information into a single, easy-to-read tool that helps land managers quickly understand what's happening on the ground.

Like weather reports — which integrate complex patterns of temperature, barometric pressure, precipitation, wind speed and more into a simple and actionable forecast — ecostate maps aren't perfect. But they're incredibly useful for spotting patterns, starting conversations and guiding decisions about where to act.

Why does this matter? The sagebrush biome — once the largest continuous ecosystem in the U.S. — is steadily shrinking. Each year, we lose around 1.3 million acres of ecosystem function primarily due to invasive grasses, more frequent wildfires and expanding conifer trees. That's on the scale of losing ecosystem function across a landscape the size of Glacier National Park annually.

Ecostate maps help us respond. They show where sagebrush landscapes are still functioning well, where they're in trouble and what threats are driving the change. With that information, land managers, conservationists and communities can make more strategic decisions to conserve and restore this vital ecosystem.

This publication seeks to ground our readers in the foundations and applications of threat-based ecostate maps. We start with background on the conceptual approach and how ecostate maps were made, and then present best practices and key limitations to note when using ecostate maps. We then provide examples of applying ecostate maps effectively across scales for different management applications.

Ultimately, this publication seeks to:

- Raise awareness among land managers and practitioners in the sagebrush biome about how ecostate maps can help them understand and map ecosystem threats.
- Provide a peer-reviewed resource that can guide the use of ecostate maps in making land-management decisions.
- Foster big-picture thinking and wider adoption of landscape-scale maps, leading to increased confidence in using satellite data.
- Highlight the efficiencies of using ecostate maps, such as streamlining landscape assessment to maximize limited field time (**see Appendix 1**).

A threat-based approach to sagebrush ecology and management

The sagebrush biome is rapidly shrinking as its defining plant communities are severely altered. Nearly three-quarters of the sweeping sagebrush biome declines are caused by three primary threats: widespread invasion by annual grasses that are not native to the ecosystem, altered fire regimes and expansion of conifers into sagebrush steppe (a vegetation community dominated by shrub and perennial grass species).

- See ***A sagebrush conservation design to proactively restore America's sagebrush biome:*** https://pubs.usgs.gov/publication/ofr20221081

Historically, fire was a periodic disturbance on the landscape, but over the last two centuries since European settlement, fire regimes (a measure of where and how often fires burn) have been altered by the displacement of Indigenous populations that historically practiced controlled burning, historical grazing practices, fire suppression, spread of invasive annual grasses and increased carbon dioxide in the atmosphere.

In warmer, drier areas of the sagebrush biome, invasive annual grasses that were introduced from Eurasia a century ago grow quickly and outcompete native vegetation. These species dry out early in the season, create a continuous mat of fuel for wildfire and often lead to more frequent and higher intensity fire, especially in lower elevations. These invasive annual grasses readily dominate burned areas but also spread across the landscape even in the absence of fire, resulting in large expanses increasingly dominated by invasive annual grasses. In wetter, cooler areas, where more abundant vegetation growth once fueled wildfire at a moderate frequency, changing climate, fire suppression and heavy livestock grazing in the late 1800s coincided to allow native conifer populations to expand into historic shrub steppe.

Across the landscape, the increased abundance of invasive annual grasses and the expansion of conifers have led to the loss of a foundational group of plants: large perennial bunchgrasses. Although hundreds of species of plants thrive in the sagebrush ecosystem, perennial bunchgrasses have deep roots that are key to maintaining ecosystem productivity, soil health, resiliency and resistance to threats and disturbances (**see sagebrush ecology references**).

The sagebrush ecosystem spans an incredible breadth of diversity, nuance, richness and complexity across elevations, soil types, moisture regimes and topography in 13 Western states. However, sagebrush land managers are responsible for managing hundreds of thousands or millions of acres, and do not have the luxury of managing every nuance acre by acre. Wildfires can consume a half-million acres in a matter of days, invasive annual grasses produce millions of seeds annually, and the constant march of conifers expanding into shrublands requires management to move at a rapid pace, focusing on large-scale threats before tackling nuanced management needs.

Management at these scales requires first addressing primary ecosystem threats using the metaphorical (or sometimes literal) "60-mile-per-hour approach" — focusing on broad vegetation patterns that can be seen out a window while moving at highway speeds.

Threat-based land management facilitates the 60-mile-per-hour approach by focusing on the three primary ecological threats and by grouping plants by similar functions. These vegetation functional groups (categories that capture the general form of plant species such as their structure and depth of roots in the soil) are used to more quickly assess ecological condition across large areas compared to a species-by-species approach.

- See ***Threat-based land management in the northern Great Basin: A manager's guide***, PNW 722: https://extension.oregonstate.edu/catalog/pub/pnw-722-threat-based-land-management-northern-great-basin-managers-guide)

Here we focus on four main functional groups: perennial herbaceous species (grasses and forbs), annual herbaceous species, shrubs and trees. The relationships among these groups are used in a model that simplifies the large range of ecological conditions across the sagebrush ecosystem into a small number of ecological states, or "ecostates" for short.

By simplifying the composition of vegetation into desirable (perennial grasses, shrubs, native forbs) and undesirable (invasive annual grasses and conifers encroaching into sagebrush systems) functional groups, managers can quickly assess landscape threats and assign ecostates. These simplified ecostates serve as a powerful communication tool and allow managers to strategize at scales from biome-wide to pasture-level.

Mapping threats using remote sensing

As our understanding of the primary threats to sagebrush landscapes has improved, so has the technology to better manage large landscapes across jurisdictional boundaries. Remote sensing, which uses satellites to obtain images and other information, has led to new ways to understand and map the Earth.

Satellite technology to map the Earth has existed for decades, but only in recent years has it been used to create vegetation maps that can reliably help us understand the condition and trend of sagebrush rangelands. In recent years, these maps have become more widely used and proven to be increasingly valuable in rangeland management.

Simple but powerful

Threat-based ecostate maps are particularly powerful because they marry the concepts of threat-based land management with the power of satellite technology. This allows us to characterize patterns and trends of landscape-scale threats across large and complex landscapes over multiple decades and link that information to potential management strategies and actions. From very large landscapes to a single pasture, ecostate maps can help us better manage sagebrush landscapes.

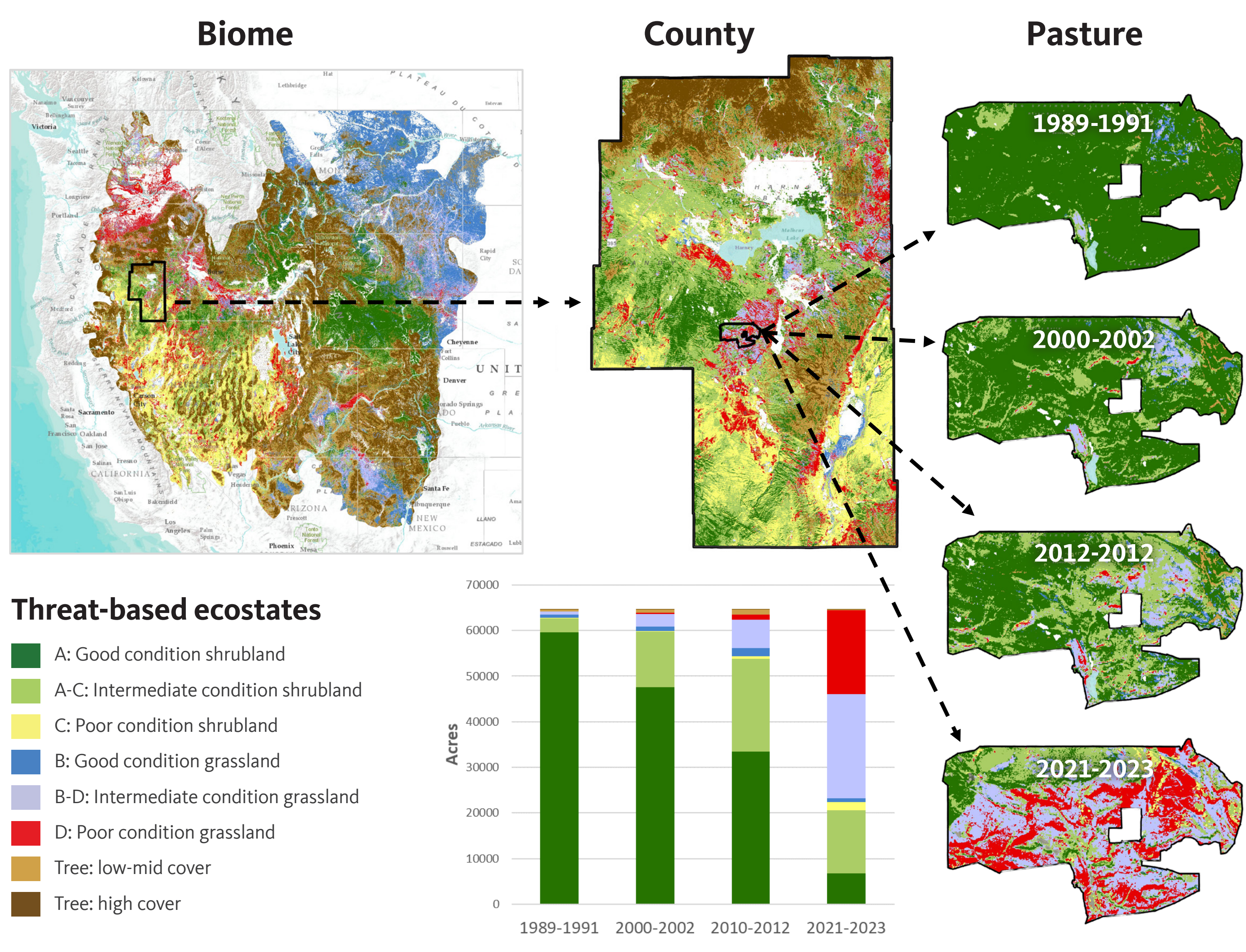
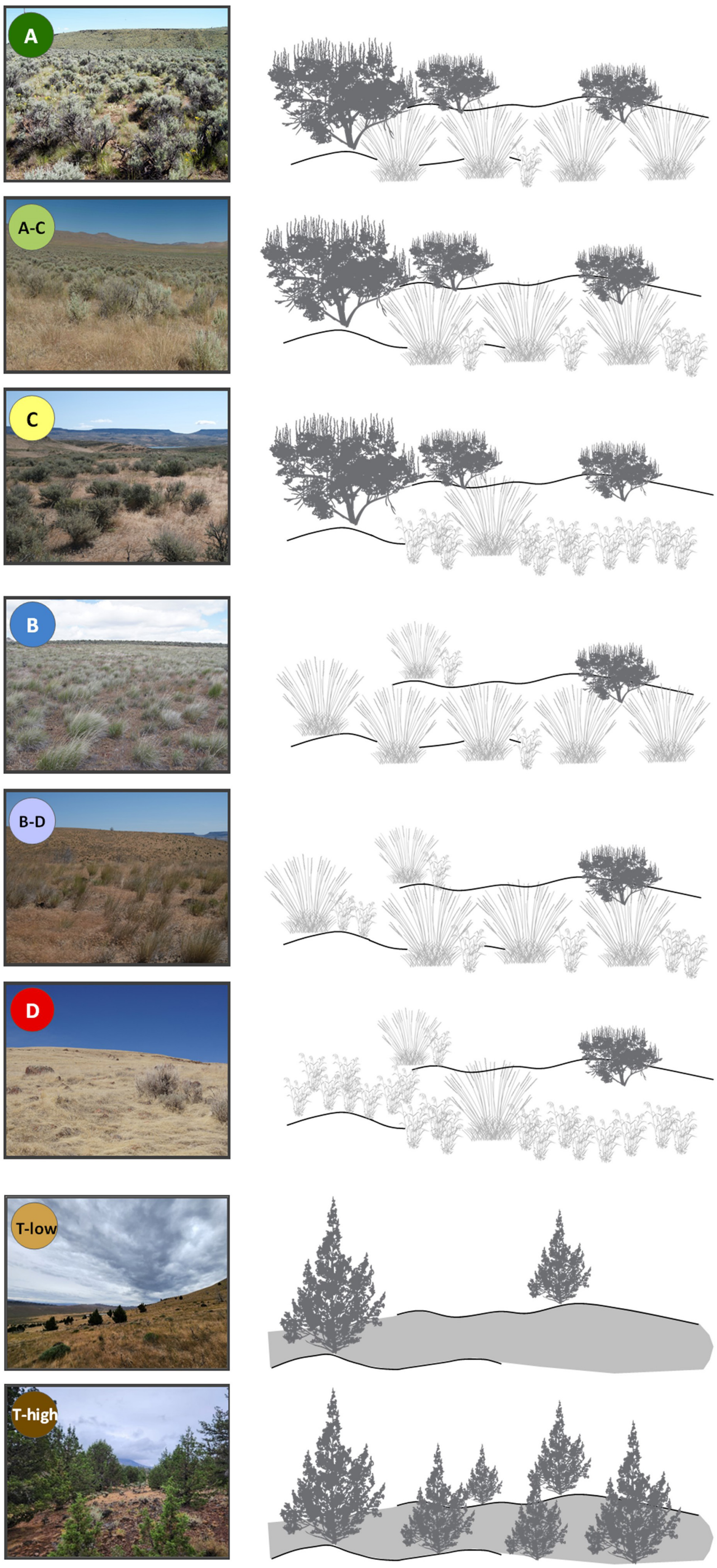


Figure 1. Ecostate maps provide a simple but powerful way to communicate ecosystem conditions over wide areas and long time frames.

Figure 2. Ecostate maps group sagebrush steppe vegetation into eight categories — three shrubland ecostates, three grassland ecostates and two woodland ecostates — by combining maps of vegetation functional groups into categories as shown in the figure below. AFG — annual forbs and grasses, PFG — perennial forbs and grasses. Illustrations © Kelly Finan and Oregon State University.

Description of threat-based ecostates



Shrublands

A: Good condition shrubland

- Few trees (cover <5%)
- Shrub cover >=12%
- Perennial herbaceous cover exceeds annual herbaceous cover by at least 3:1.

A-C: Intermediate condition shrubland

- Few trees (cover <5%)
- Shrub cover >=12%
- Perennial herbaceous cover is slightly greater than or co-dominant with annual herbaceous cover (PFG:AFG ratio is between 1:1 and 3:1).

C: Poor condition shrubland

- Few trees (cover <5%)
- Shrub cover >=12%
- Annual herbaceous cover exceeds perennial herbaceous cover (PFG:AFG ratio less than 1:1).

Grasslands

B: Good condition grassland

- Few trees (cover <5%)
- Shrub cover <12%
- Perennial herbaceous cover exceeds annual herbaceous cover by at least 3:1.

B-D: Intermediate condition grassland

- Few trees (cover <5%)
- Shrub cover <12%
- Perennial herbaceous cover is slightly greater than or co-dominant with annual herbaceous cover (PFG:AFG ratio is between 1:1 and 3:1).

D: Poor condition grassland

- Few trees (cover <5%)
- Shrub cover <12%
- Annual herbaceous cover exceeds perennial herbaceous cover (PFG:AFG ratio less than 1:1).

Woodlands

Tree: low-mid cover

- Tree cover 5-20%
- Shrubs and herbaceous vegetation a re not used in the ecostate determination.

Tree: high cover

- Tree cover >20%
- Shrubs and herbaceous vegetation are not used in the ecostate determination.

Threat-based ecostate maps (generally called ecostate maps throughout) provide a snapshot of rangeland condition by combining vegetation cover into eight broad ecostates (**Figure 1**) for each 30-meter square "pixel" in the underlying satellite images. Each pixel's ecostate category is determined by applying a simple set of rules (**Figure 2**) based on maps estimating percent cover of plant functional groups from the **Rangeland Analysis Platform v3** (https://rangelands.app/).

The Rangeland Analysis Platform uses machine learning to combine satellite imagery with thousands of on-the-ground measurements of vegetation cover from monitoring plots to map vegetation across the United States. The maps show vegetation cover each year from around 1990 to the present. Cover values for every pixel are extracted for the four main vegetative functional groups listed below and combined into ecostates as shown in **Figure 2**.

- Perennial herbaceous cover — Native bunchgrasses and forbs that live for multiple years, along with introduced non-native perennial species such as crested wheatgrass.
- Annual herbaceous cover — Annual species that regrow from seed each year, primarily invasive annual grasses and forbs but including some native annual species.
- Shrub cover — All species of shrubs, including sagebrush, bitterbrush, rabbitbrush and others.
- Tree cover — All species of trees, including pinyon, juniper, aspen, mountain mahogany and others. Note that while the ecostate maps were originally designed in Oregon with juniper encroachment in mind, they will also pick up pinyon encroachment as well as other species where they occur.

Thresholds and ratios used to define ecostates (**Figure 2**) are based on expert knowledge and relevant literature (when available). Although thresholds fail to capture all the intricacies of the natural landscape, they do provide a useful starting point for grouping ecologically similar areas in a way that helps guide management and can be tracked over time using a consistent set of rules.

Ecostates are calculated for three-year time slices (conditions averaged over a three-year window to reduce the effects of short-term variability between years resulting from variation in rainfall or plant production). Areas of agriculture, human development and other nonvegetated areas are omitted to help land managers focus on sagebrush landscapes.

As of spring 2025, 34 ecostate maps representing three-year averages are available starting from 1989–1991 and ending with 2022–2024 across the entire sagebrush biome (accessible from https://hub.oregonexplorer.info/pages/sagebrush-threat-based-mapping). The most recent time slice is added each year when the newest data from the Rangeland Analysis Platform is released. Note that although there are multiple satellite-derived vegetation maps available, the Rangeland Analysis Platform was chosen due to its accessibility via a well-functioning web application, high performance in field verifications and published accuracy assessments. **See Appendix 2** for a summary of how ecostate maps have evolved over time.

Applying ecostate maps in rangeland management

Ecostate maps apply the concepts of threat-based land management across large, remote landscapes and can be useful for landscape assessment, prioritization and monitoring. A decision-making framework (**Table 1 on page 6**) provides perspective on when and where ecostate maps can be most helpful in guiding management actions. Ecostates can be useful in several of the steps and can be a helpful communication tool throughout all stages — see the example applications in the sections below.

Best practices for using ecostate (and other) satellite-based maps

Even when the weather forecaster assures you there is unlikely to be rain, you may find yourself in a downpour. Likewise, anyone who has spent much time using satellite datasets has encountered situations where a map has been flat-out wrong or unusable for some reason. In the authors' experience, ecostate maps have been very useful, but it is important to remember that all vegetation maps, including ecostate maps, are imperfect and simplified models of reality.

Table 1. Key questions asked within a typical management decision-making framework and the potential use of ecostate maps in determining why, where and how to address threats to sagebrush ecosystems. Colors are used to indicate the potential utility of ecostate maps in each of these steps, ranging from high (green) to moderate (yellow) to lower (orange) utility. This framework was adapted from the Rangelands journal article ***Guiding principles for using satellite-derived maps in rangeland management*** (see mapping references section).

Planning step	Key questions	Potential utility and role of maps
Step 1. Vision	Where do we want to be?	Setting a vision is important in framing the broader ***why*** for potential management actions. Ecostate maps can provide context but are generally less useful in this step because setting a vision is a qualitative process based on values.
Step 2. Inventory and assessment	Where are we now?	Ecostate maps provide wall-to-wall data about sagebrush ecosystem condition across space and time, which can be very useful for assessment of current conditions, especially at larger scales. **See examples 1 and 2.**
Step 3. Strategy and prioritization	How do we get where we want to be?	Ecostate maps provide context about the spatial patterns of threats across large landscapes, which is needed to inform ***where*** management actions can potentially make the biggest difference. Ecostates also inform where threats are emerging vs entrenched and the degree of management intervention that may be required. **See examples 3 and 4.**
Step 4. Goals and objectives	What needs to change and when?	Ecostate maps may help managers set short-term and long-term ecological goals and objectives by helping to spatially identify and quantify threats within a landscape.
Step 5. Implementation	What are we going to do?	The utility of ecostate maps is limited during project implementation. Ecostate maps may aid in identifying areas for potential intervention and establishing targets for management, but more information is needed to determine ***what*** exactly needs to be done on the ground and ***how*** to do it.
Step 6. Monitoring and adaptive management	How do we evaluate progress?	Ecostate maps allow managers to track and quantify progress toward goals and objectives at multiple spatial and temporal scales. They are generally most effective when used over medium to longer-term time scales (>5-10 years) across larger landscapes. **See example 5.**

The article ***Guiding principles for using satellite-derived maps in rangeland management*** offers four reminders to help users think critically about using maps:

- **Use maps within a decision-making framework:** Ecostate maps focus attention on big-picture, ecosystem-level threats and directly link conditions to potential management actions based on the threat-based land management framework.
- **Use maps to better understand and embrace landscape variability:** Beyond capturing overall status and trends, spatial patterns and ecostate map summaries can represent the vegetative variability across the landscape.
- **Keep error in perspective:** By recognizing that all data sources are imperfect and embracing a threat-based approach, ecostate maps used in combination with other data sources can provide actionable information despite errors and uncertainties.
- **Think critically about contradictions:** If (or when) different data sources provide conflicting information, concepts of threat-based land management can help focus attention on the big-picture condition, threats and spatial context.

How do I validate ecostate maps?

Taking ecostate maps with you into the field on a mobile device is a great way to incorporate landscape-scale context into planning, validate map accuracy and identify questions or issues about the maps for follow-up. Although an overall accuracy assessment indicates ecostate maps have a reasonably high level of accuracy (Appendix 3), there are sources of error from both the underlying Rangeland Analysis Platform datasets as well as the classification thresholds used to assign ecostate categories.

Users of these maps must have confidence that the maps reflect reality to the best degree possible, and these steps provide a starting place for an informal field verification. In addition to map validation, discussing maps in the field with landowners or land managers has the added benefit of facilitating conversations about landscape and project-level management.

Think first about scale and accuracy. Remember that ecostate maps are intended to be a simple tool for managing the landscape-scale threats to the sagebrush ecosystem. It is generally best to apply maps at the broadest scale relevant to your management question — this helps keep your focus on the bigger picture and increases your chances of picking up relevant patterns in the maps.

Keep your eyes on the horizon and evaluate how well ecostate maps capture the most important variation in your landscape, recognizing that nuances will intentionally not be captured. Given the reality that decisions must be made with imperfect information, carefully consider the level of accuracy or precision in mapped vegetation patterns that is needed for your work by asking "how accurate is accurate enough?"

Also consider the tradeoffs among data sources — for instance, the accuracy of ecostate maps may be less certain or verifiable than plot-based data, but depending on the number and location of plots on the landscape, ecostate maps may be more representative of the diversity of conditions across a broader landscape (**see Appendix 1** for an example). Take both the maps and your perceptions of reality with a grain of salt!

If the maps don't line up with what you see in the field, check these three things:

- **Check No. 1: Are we looking at the same thing?** If a potential issue is identified, start by checking your understanding of what exactly is being mapped. For instance, shrubland ecostates are defined based on total shrub cover even though sagebrush cover may be of primary interest — so a field of rabbitbrush may be mapped accurately as ecostate A even though that may not match a conceptual categorization of ecostate A as a sagebrush-dominated shrubland. Similarly, annual herbaceous cover includes not just invasive annual grasses, which are of primary management interest, but also annual forbs. Try to determine if a problematic pattern you are seeing is a potential issue with the input datasets (for example, annual herbaceous cover may be overestimated) or if it is an issue with the ecostate mapping rule set (for example, the ratio of annuals to perennials does not provide meaningful information on herbaceous condition in your area). In this case, looking at individual functional group layers from the Rangeland Analysis Platform may assist in recognizing patterns across your landscape.
- **Check No. 2: What about timing?** Timing within the year (seasonal variation) and across years affects the vegetation visible in the field and detectable in satellite imagery. Because ecostate maps represent three-year time slices, they will always lag behind current conditions on the ground. Have any substantial disturbances occurred between the time frame represented by the maps and now? Have the conditions in the current or previous years resulted in patterns that may appear to cause a discrepancy? For instance, the time frame of the mapping may have reflected drier, less productive conditions, while your visit to the field may be during a time of high annual grass abundance.
- **Check No. 3: Are there systematic patterns?** If you detect a pattern in accuracy based on vegetation type or landscape features (slope, aspect, soils, etc.), this may be important information to identify the root cause of an issue. **See the "grains of salt"** below for known limitations of ecostate maps, and be on the lookout for broad, systematic patterns of accuracy in your area.

Decide if any known issues are deal-breakers. If there seem to be discrepancies between ecostate maps and either field-based data or expert knowledge, consider the impacts of any inaccuracies on the management decision at hand. Would inaccuracies or uncertainties lead to different management conclusions or actions?

However, inaccuracies in the map would not result in a different management action, and this may be an example of where keeping error in perspective and remembering that no dataset is perfect can allow you to see the bigger picture. However, inaccuracies in the map may be a deal-breaker and maps may be unusable or more data or information may be required.

If an issue is found, consider these options:

- Consider whether a process to "correct" your maps based on local knowledge may be appropriate. Although it is often not possible to create customized maps for small areas of interest (and those maps may not be more accurate anyway), users may be able to correct underlying issues in their applications of the maps. For instance, local data or map corrections can be incorporated into a more generalized strategy map (see **example 3**).
- It should go without saying that if the ecostate maps do not work for your purpose or location, ditch them and find another dataset that meets your needs. Ecostates are not applicable to all management questions and may not be useful in all settings across the sagebrush biome. Looking at the underlying Rangeland Analysis Platform data layers used to generate the ecostate maps is also always encouraged in this situation as it may prove helpful for addressing both your questions of interest and helping to think about any questions you have regarding the accuracy of the ecostate maps for your needs and area.
- Building useful and accurate vegetation maps requires feedback between map developers and users. Map users with knowledge on the ground should feel empowered to use and share their knowledge of the landscape when encountering broad-scale or systematic errors in the maps while recognizing that no model will work perfectly in every place. To provide feedback on the ecostate maps, please contact the authors.

How do I access ecostate maps?

See the ecostate map web page (https://hub.oregonexplorer.info/pages/sagebrush-threat-based-mapping) for the most up-to-date information on ecostate maps. The most recent ecostate map can be viewed through the SageCon Landscape Planning Tool (https://tools.oregonexplorer.info/viewer/sagecon_landscape_planning_tool) for the sagebrush biome, and the Ecostate Summarization Tool function allows users to summarize ecostates over time for a customized area (see Appendix 4, **Figure 18**, for an example).

Accuracy assessment and the 'grains of salt'

A recent accuracy assessment compared field-measured ecostate categorization with mapped ecostate categorization (**Appendix 3**). Based on this accuracy assessment and our collective experience using ecostate maps over multiple years, we put forth the following "grains of salt" as caveats and limitations of ecostate maps in everyday use.

- **Thresholds have limitations:** Although using thresholds of vegetation cover to define plant communities is challenging due to climate variability, we use them here for the sake of simplicity and communication. Herbaceous condition classes (good, intermediate and poor condition designation) rely on ratios of annual vs. perennial plants, but low herbaceous cover or extreme weather can lead to inaccurate classifications and/or unrealistic ecostate changes between time slices. Similarly, a shrub threshold of 12% is applied to separate grassland from shrubland ecostates, and in landscapes close to the threshold, mapped ecostate may change between shrubland and grassland ecostates over time in unrealistic ways.
- **Consider combining good and intermediate condition classes:** The accuracy assessment (**Appendix 3**) reveals that ecostates in "good condition" (A and B) are often mapped as "intermediate condition" (A–C and B–D), which matches observations on the ground. As a result, in some cases it may make sense to combine ecostate A with A–C and B with B–D during a landscape assessment, as good and intermediate condition indicate that perennial herbaceous cover exceeds annual herbaceous cover. Because the cover of annual vegetation in particular fluctuates widely from year to year, the exact ratio of annual and perennial herbaceous vegetation may be difficult to ground truth and is expected to fluctuate naturally over time.
- **Shrub detection is tricky in dynamic environments:** Sagebrush and other shrubs are difficult to map accurately with all satellite data, especially after fire, when sagebrush recovery is slow. The Rangeland Analysis Platform tends to overestimate shrub cover, and ecostate maps may not detect shrub recovery for several years after a fire. The accuracy assessment revealed that shrublands are rarely misclassified as grasslands by the ecostate map, but grasslands are sometimes misclassified as shrublands.

Also remember that shrub mapping is indiscriminate of species and includes sagebrush, rabbitbrush, bitterbrush and any other shrub species present.

- **Tree classes are very coarse:** The low- to mid-cover tree ecostate misses conifer cover under 5%, including areas of early conifer expansion where restoration treatments may be most cost-effective. Field visits are recommended for mountainous or riparian areas, as conifer and deciduous trees such as aspen and cottonwood are all combined. In some cases, landscape features like rock outcroppings or cliff faces are misclassified as trees.

- **Use caution on south-facing slopes:** On south-facing slopes with low shrub cover, the Rangeland Analysis Platform may overestimate annual forbs and grasses, leading to false ecostate D classifications. Although ecostate D has a relatively high accuracy (Appendix 3), ground-truthing is advised in these areas.

- **Look for longer-term patterns:** Ecostate maps average conditions over three years to reduce the impact of year-to-year fluctuations. As a result, analyzing changes between three-year periods is most effective for medium to long-term time frames (more than five to 10 years).

- **Use maps in sagebrush steppe ecosystems:** Ecostate maps were developed for southeastern Oregon's sagebrush steppe and expanded to the broader sagebrush biome. They are most reliable in the Great Basin (generally the western portion of the biome-wide map in **Figure 1**) and should be used with caution outside this region.

As always, remember that ecostates serve as a basic communication tool by intentionally simplifying rangeland condition to focus on the primary threats to ecosystem function. They do not include many important site-specific factors necessary for developing specific seed mixes, determining an appropriate herbicide or grazing plan, or conducting a species habitat assessment.

Ecostate maps will not work well at every site, and more detailed and localized information is crucial before planning any management action. But they provide a foundation for initial broad-scale planning and identifying needs for more nuanced information from ground surveys (**see Appendix 1**). The technology powering the Rangeland Analysis Platform and other satellite data will continue to evolve, and future versions of ecostate maps are likely to improve in accuracy.

Ecostates in rangeland assessment

One of the most efficient and obvious ways to use ecostate maps is in inventory and assessment of landscape condition (**Table 1, step 2**). Maps become an increasingly important tool for assessment when considering larger landscapes, remote or inaccessible locations, and multiple landownership types, and can be used to complement plot data, photo points and other knowledge of the landscape. **Appendix 4** provides an example of a succinct “snapshot” of condition using ecostate maps and plot data to summarize key information about an area through maps, tables and photos, and **examples 1 and 2** (pages 10-11) provide information about using ecostates in rangeland assessment.

Example 1. Preassessment (before heading into the field)

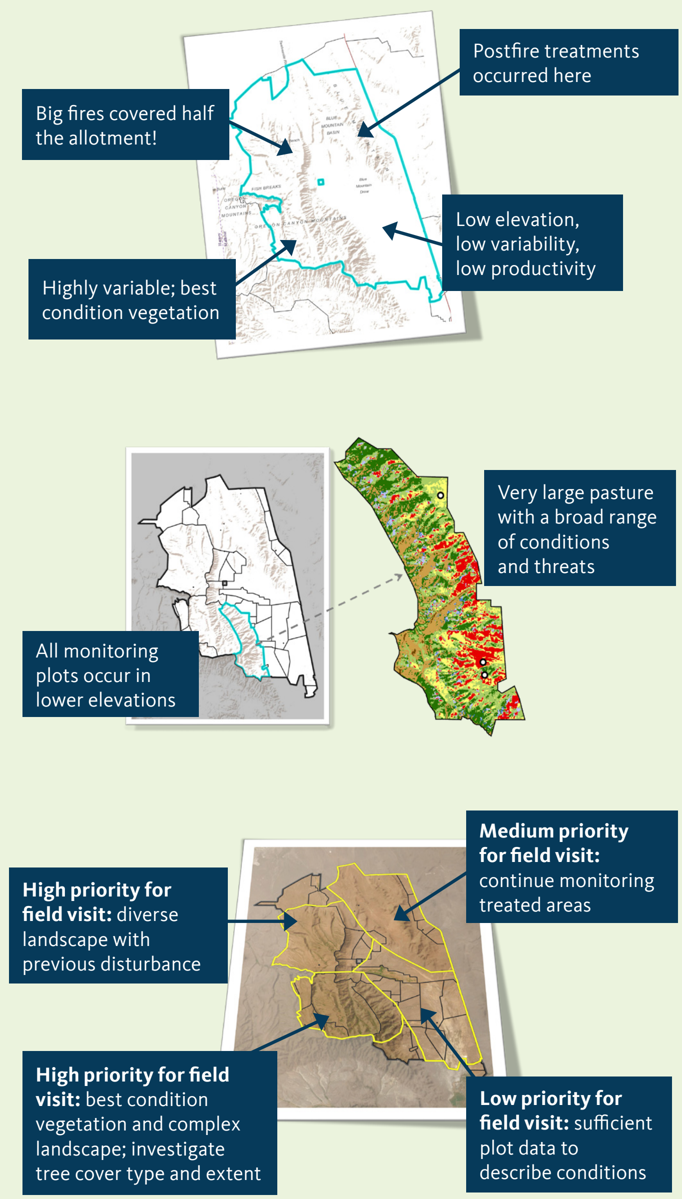
Managing large landscapes requires an understanding of current condition, but assessing condition across large areas of remote terrain is challenging and time-consuming. Early in the process of conducting an assessment, ecostate maps — alongside other datasets — can be used to maximize efficiency by guiding subsequent field visits and data collection.

Appendix 1 provides a preassessment workflow and example that consists of four steps and several prompting questions to determine what is known about the landscape, facilitate conversations about data needs and expected conditions, and develop an intentional process for determining where to strategically prioritize on-the-ground time in the field.

The four steps and prompting questions are shown in **Figure 3** as a short overview of the process. See **Appendix 1** for the full workflow using a grazing allotment and pastures within that allotment as an example.

Figure 3. A preassessment workflow walks through four steps to develop an efficient field approach. **Appendix 1** contains the full workflow with an example for a large, complex allotment.

1. Compile relevant datasets.
2. Start with the big picture: conduct a landscape-level preassessment.
   a. How variable are physical conditions? Are there large differences in elevation, slope, aspect (north- vs. south-facing slopes) or soil types?
   b. Were there previous disturbances or management actions that affect current conditions?
   c. What is the broad distribution of ecostates across the landscape?
3. Evaluate each assessment unit: pasture-level preassessment.
   a. What is the distribution of ecostates in each pasture?
   b. What existing plot data is available? How representative are plots of overall condition, and do available plot data and map data generally agree?
4. Putting it all together: developing a field assessment approach.
   a. Can maps be used to divide large and complex areas into units for assessment?
   b. Are there pastures with enough existing information to justify minimizing field time and data collection?
   c. Can you direct more field time to areas with higher complexity, conflicting information or less on-the-ground data?

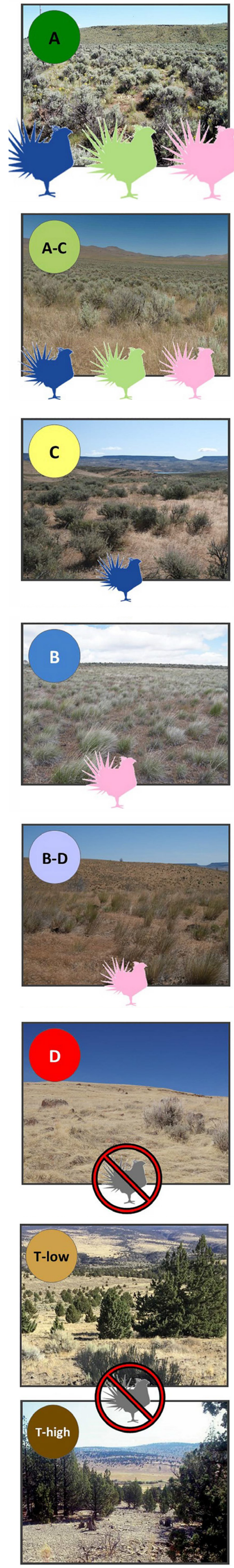


Example 2. Assessing wildlife habitat in broad brushstrokes

Ecostates are a useful tool for considering the quantity, quality and threats to habitat of wildlife species in the sagebrush steppe ecosystem. For instance, the size and arrangement of ecostate patches can provide a high-level assessment of habitat availability for sagebrush-associated wildlife, such as the greater sage-grouse (**Figure 4**).

The greater sage-grouse is a sagebrush-associated ground-nesting bird that forages exclusively on sagebrush during the winter, requires sagebrush and perennial grasses to obscure nests from predators, and needs abundant forbs and insects to support chick growth and survival. Sage-grouse avoid areas with even low tree cover because trees provide perches for birds that prey on sage-grouse nests.

The general patterns shown in **Figure 4** are synthesized from a broad body of literature on sage-grouse habitat use (**see sage-grouse references**), including a demonstration that maps based on threat-based land management are effective in predicting locations of sage-grouse breeding areas (leks). As in other applications, ecostates offer a broad-brush approach to assessing wildlife habitat, which should be used in conjunction with finer-scale vegetation metrics and tools to assess other habitat requirements, such as the presence and quality of conditions along waterways (**see *Threat-based management for creeks, streams and rivers***). Wildlife managers can utilize ecostate maps as a first step to identify areas to protect, enhance or restore wildlife habitat and connectivity (**Figure 5**).



A: Good condition shrubland provides food and nesting cover with sufficient sagebrush cover and abundant native perennial grasses and forbs to support sage-grouse breeding, nesting, chick-rearing, and winter survival.

A-C: Intermediate condition shrubland has sufficient sagebrush cover and perennial grasses and forbs remain dominant over annual grasses, likely supporting nesting, chick-rearing, and winter survival. If further invasion occurs, ecostate A-C is at risk of converting to poor condition shrubland.

C: Poor condition shrubland may provide sufficient sagebrush forage for sage-grouse winter survival, but annual grasses are dominant in the understory, which does not provide food resources for nesting and chick-rearing. This ecostate is also at risk of converting to poor condition grassland after fire.

B: Good condition grassland has an understory dominated by perennial grasses and forbs to support sage-grouse chick-rearing, but inadequate sagebrush cover does not favor sage-grouse nesting or winter survival.

B-D: Intermediate condition grassland has an understory co-dominated by annual and perennial grasses and forbs that may support sage-grouse chick-rearing, but insufficient sagebrush for sage-grouse nesting or winter forage. Ecostate B-D is at risk of converting to poor condition grassland.

D: Poor condition grassland lacks sagebrush cover and is dominated by annual grasses, providing little value to sage-grouse at any time of year.

Tree cover-low and -high
Research suggests that the presence of tree cover greatly reduces sage-grouse use of an area, though birds may sometimes pass through these habitats.

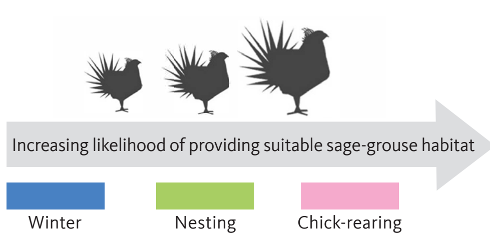
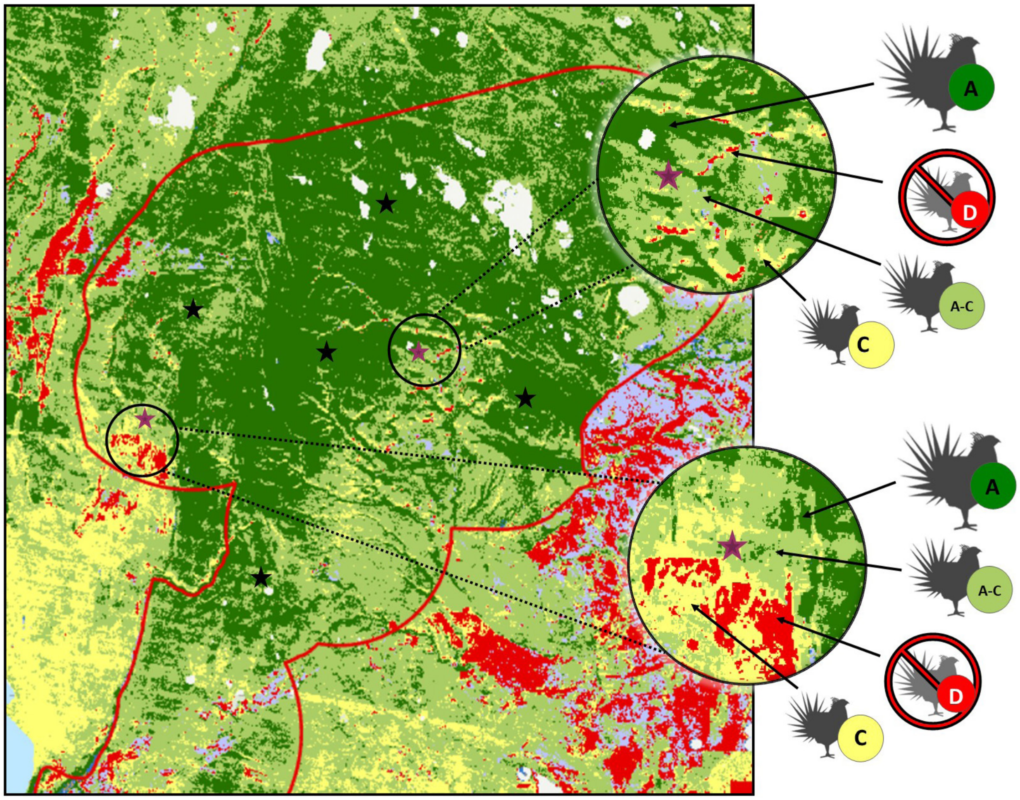


Figure 4. Each ecostate provides differing habitat resources for sage-grouse, as shown above. Larger sage-grouse icons correspond to increasing likelihood of each ecostate providing suitable sage-grouse habitat for winter (blue), nesting (green) and chick-rearing (pink).

Figure 5. Ecostates can be useful to identify areas for wildlife habitat management or restoration. The examples shown here demonstrate restoration opportunities identified using ecostates around two high-priority leks (purple stars) used by a large number of sage-grouse for breeding and nesting year after year. This information can help refine the relative importance of areas within a larger sage-grouse management area (outlined in red). Larger sage-grouse icons correspond to an increased likelihood of an ecostate providing suitable sage-grouse habitat.



'Keep the good good'

This priority (large population) lek is surrounded by ecostate A, likely to provide sage-grouse habitat requirements year-round. However, managers could address the small pockets of ecostate D and ecostate C before invasive annual grasses spread.

'Grow the good'

This priority lek is situated near lots of ecostate C and D, which do not support sage-grouse habitat requirements year-round. Because sage-grouse return year after year to leks and nest within close proximity to leks, the poorer habitat conditions near the lek could result in lower survival of nests, chicks, and adults. Managers could seek to improve the conditions in these problem areas adjacent to a larger zone of ecostate A.

Sage-grouse Priority Area for Conservation
Priority lek
Lek
A: Good condition shrubland
A-C: Intermediate condition shrubland
C: Poor condition shrubland
B: Good condition grassland
B-D: Intermediate condition grassland
D: Poor condition grassland

Ecostates in management planning and prioritization

Ecostate maps can be extremely helpful for planning and prioritizing actions across large landscapes **(Table 1, step 3).** Managing sagebrush ecosystems over millions of acres requires making decisions about where to focus effort given that it is not feasible to protect or restore every acre. Ecostates can provide helpful information on conditions, trends and spatial context to help set management up for success.

Example 3. Developing a spatial game plan to 'defend and grow the core'

Ecostate maps can be a foundational data layer in strategic spatial planning, such as developing a localized map to "defend and grow the core." The Sagebrush Conservation Design uses maps of sagebrush ecological integrity to identify large blocks of intact, functioning sagebrush steppe vegetation communities (core sagebrush areas) across the Western U.S. and emphasizes proactive management to "defend and grow the core" within these intact areas alongside strategic actions in adjacent areas (growth opportunity areas) to improve the surrounding landscape. These maps are useful at very coarse scales, but ecostates and other datasets are needed to identify finer-scale patterns and specific threats.

Ecostate maps have proven useful for regional working groups focused on large, multi-jurisdictional landscapes such as counties or watersheds where there is a need to identify specific threats and map more localized core sagebrush areas, growth opportunity areas and other areas that are heavily impacted or not managed as sagebrush steppe (**Figure 6, Table 2**).

Figure 6. In this example landscape of 315,000 acres, ecostate maps (top) can be generalized into broad spatial units of core sagebrush areas, growth opportunity areas, impacted areas and other rangelands (black outlines). This exercise can result in a strategy map (bottom) to guide and prioritize management actions strategically across multiple land ownerships.

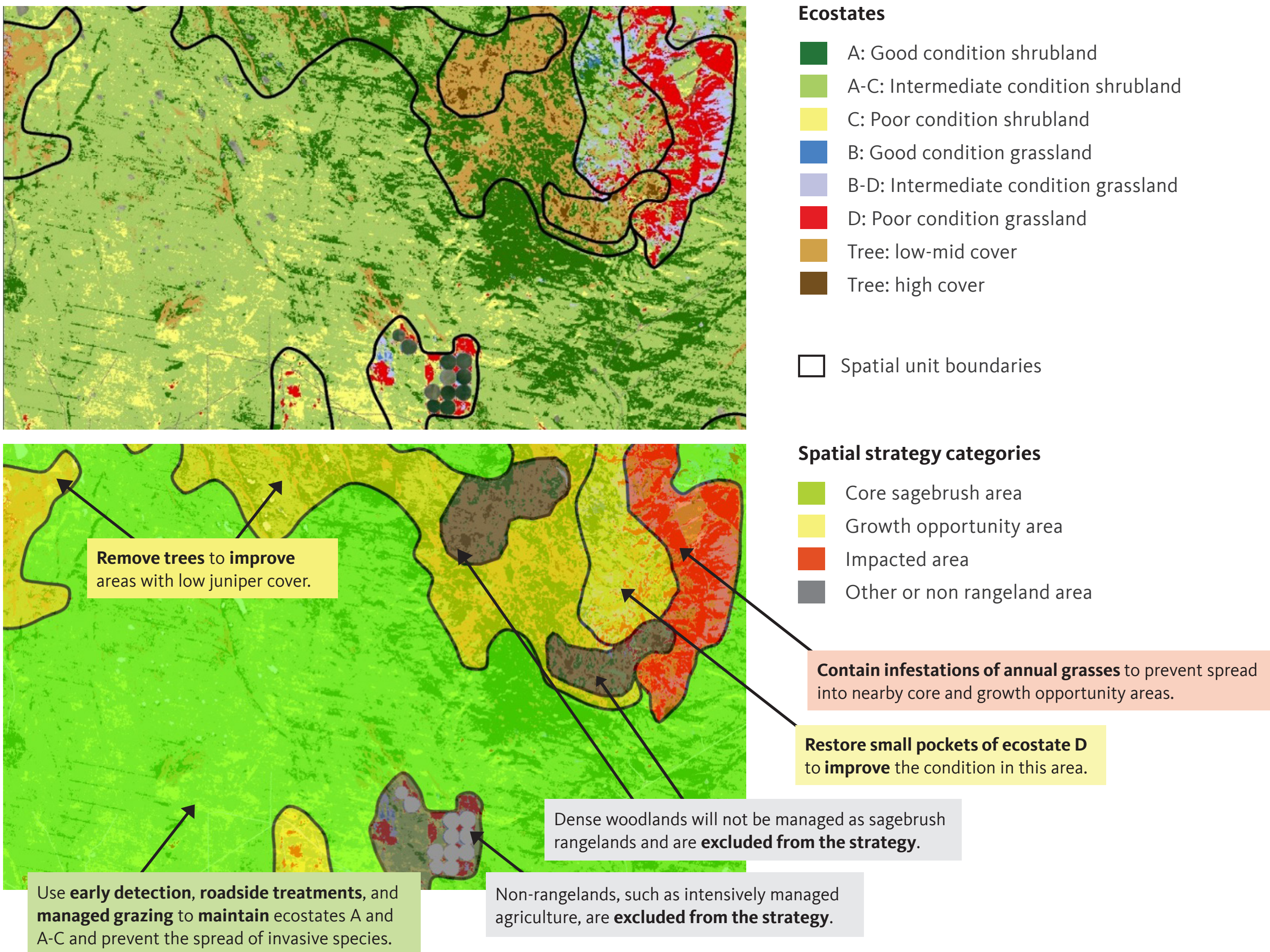


Table 2. Description of categories used in the spatial strategy to "defend and grow the core" in an example landscape (Figure 6, bottom map), with potential management strategies and actions for each.

Category	Description	Potential management strategies and actions
Core sagebrush area	Intact areas with healthy sagebrush and bunchgrasses — ideally large tracts of **ecostate A and A-C with some ecostate B.**	**Maintain** these areas by identifying threats early and conducting treatments where threats occur in small patches. Prevent spread of invasive species from roadways and areas of concentrated use, and remove encroaching conifers at the seedling stage if possible.
Growth opportunity area	Areas with one or more threats that have relatively high potential to return to intact core, often mapped as **ecostate C, B-D, and tree: low-mid cover.**	**Improve** these areas, especially when adjacent to core sagebrush, with activities like conifer removal, herbicide, and seeding, while adaptively managing existing activities such as livestock grazing. Management is most cost-effective and successful in areas where threats are not yet entrenched and in more resilient sites.
Impacted area	Areas unlikely to return to intact sagebrush communities. These areas often have **high tree cover or large blocks of ecostate D.**	**Contain** threats to minimize risk to adjacent areas, especially core sagebrush areas. Restoration success is often low, requires ongoing intervention, and involves substantial time and investment.
Other or non-rangelands	Other land cover types such as older woodlands, agriculture, salt desert shrub vegetation communities, etc.	Not applicable — these areas are not managed as current or historic sagebrush steppe and are not part of a sagebrush conservation strategy.

This approach to developing a localized spatial strategy (**Figure 6, Table 2 on the previous page**) helps to identify primary threats in a region while also simplifying ecostate maps into broader spatial units of the defend and grow the core strategy. This process allows people from different groups, including management agencies, local landowners and interest groups, to discuss threats and patterns on the landscape, incorporate local knowledge and develop a shared strategy map that is applicable to their local geography.

Once a basic strategy map is developed (**Figure 6, bottom map**), the map can be refined using additional information such as wildlife habitat, likelihood of wildfire, annual grass invasion risk and layers depicting the physical conditions on the landscape such as elevation and aspect.

In every step, local knowledge can help partners understand context like site history, correct known errors in the maps and provide more detailed knowledge. For example, ecostate maps will identify all areas with tree cover, but some of these areas may be aspen stands instead of expanding conifers, which would be mapped and managed differently in a spatial strategy.

Ecostates can also be used to quantify more specific management needs, targets and goals. For instance, an analysis of the distribution of ecostates within the example core sagebrush area (**Figure 6, bottom map, bright green area**) shows an estimated 188,600 acres of ecostates A and A–C, where proactive weed surveys and spot treatments can be deployed across a large area to "keep the good, good" as a high-priority management action. Within that area, approximately 1,800 acres of ecostate D are shown, where targeted containment efforts or strategic restoration actions will help prevent expansion of invasive annual grasses into adjacent areas. An estimated 2,900 acres of juniper encroachment in this area would also be a high-priority management target, with a focus on eliminating small seedlings expanding into core sagebrush areas as a low-risk and cost-effective management action.

Example 4. Informing regional sagebrush conservation strategies

Threat-based mapping is exceptionally useful for analyzing and tracking landscape condition and change over time at a state or regional scale. In addition to merely enhancing our understanding of the status of natural resources across a large landscape, broad trends in landscape condition can support the development of strategic "business plans" that can make the case for significant conservation investments, guide legislative and administrative policy development, and provide critical context to elected officials and others who may not be intimately familiar with issues in the sagebrush ecosystem.

As an example from the state of Nevada, an estimated 32 million acres (nearly half the size of the state) historically supported sagebrush vegetation communities. However, ecostate maps show that from approximately 1990 to 2020, good and intermediate condition shrublands (ecostates A and A–C) in Nevada declined from an estimated 70% to roughly 36% of potential habitat. Along with this shift, poor condition grasslands (ecostate D) rapidly expanded from 2% of the landscape to 12% — representing 3.7 million acres crossing an ecological threshold from relatively intact sagebrush steppe to invasive-dominated communities (**See Figures 7 and 8 for ecostate trends over time**). These areas are exceedingly difficult to restore to functional condition.

These numbers tell a powerful story about the immediate and critical need for conservation action across Nevada's sagebrush ecosystems, which can serve as the basis for multiagency funding and management strategies, especially when considered alongside treatment costs, likelihood of success and "conservation readiness." To be "conservation ready," we must know where to work — areas where we are most likely to be successful in maintaining or restoring large blocks with high ecological integrity. But we must also have willing partners and communities as well as the necessary laws, regulations, staff, funding and other conditions that enable on-the-ground work.

- See ***Assessing conservation readiness: The where, who, and how of strategic conservation in the sagebrush biome***: https://doi.org/10.1016/j.rama.2024.08.013

Spatial approaches, at scale, are powerful tools for building an understanding of need and opportunity. In turn, this shared understanding can inform necessary policy and action to address critical gaps in funding, staff capacity, permitting, or other barriers to effective conservation and engagement.

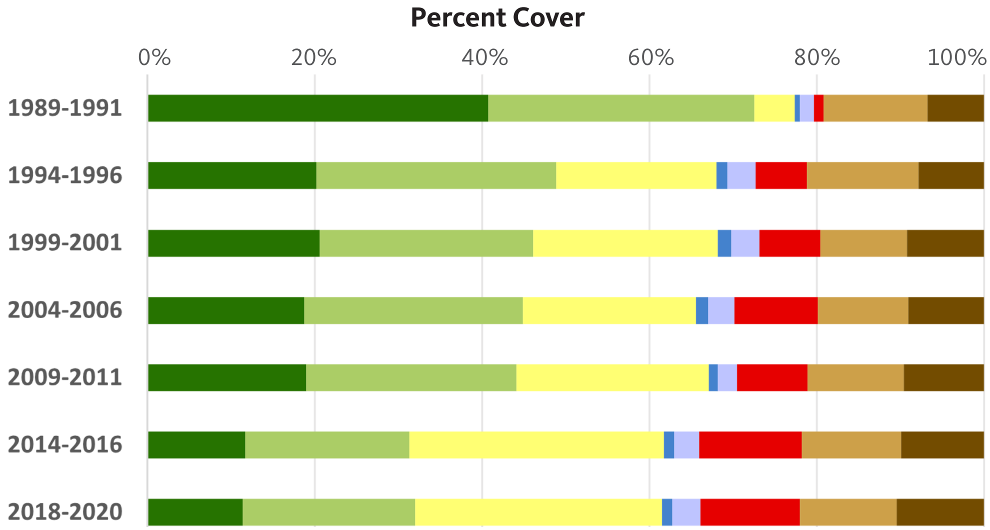


Figure 7. Ecostate trends over multiple decades across Nevada highlight widespread expansion of invasive annual grasses (ecostates C and D) and decreases in good condition sagebrush steppe (ecostate A).

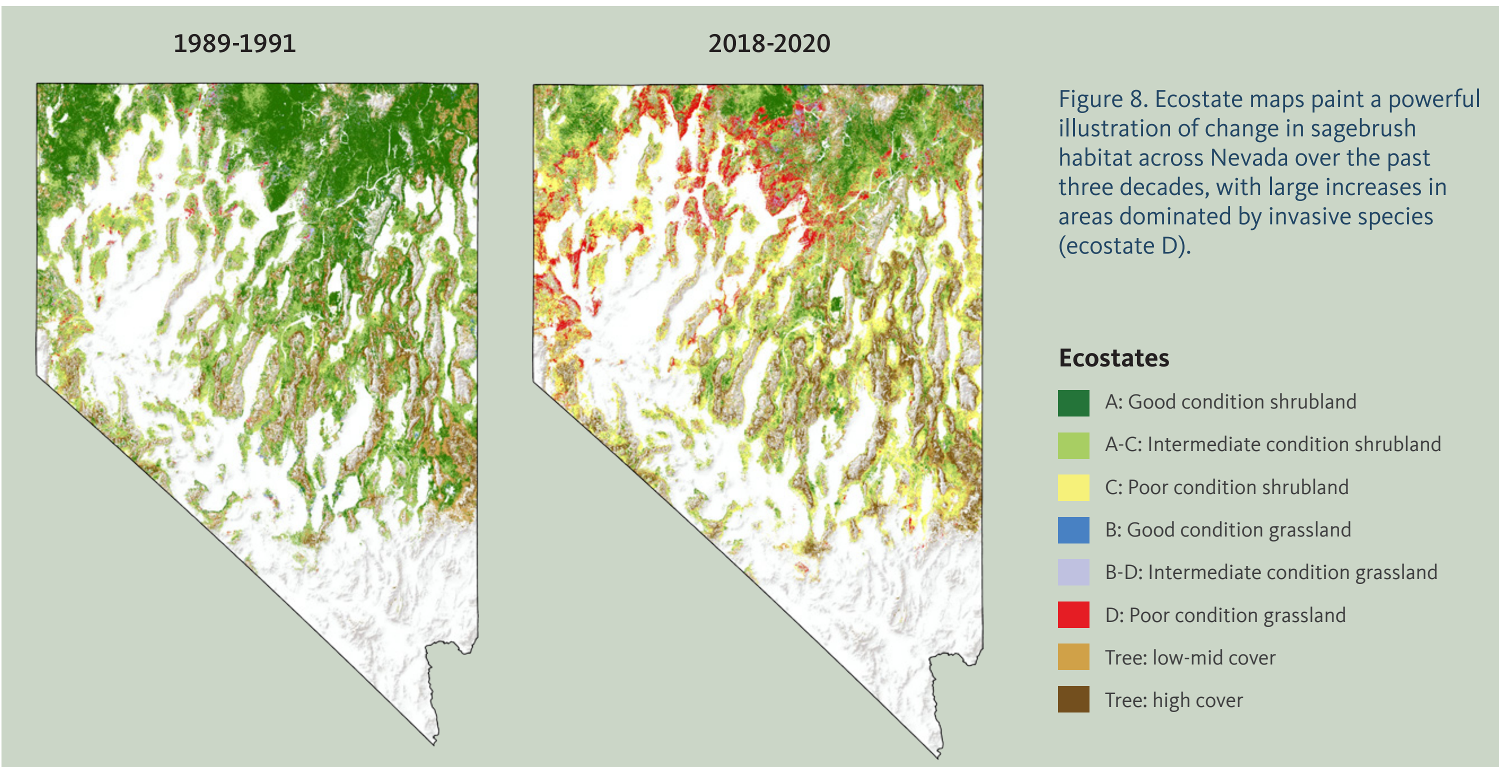


Figure 8. Ecostate maps paint a powerful illustration of change in sagebrush habitat across Nevada over the past three decades, with large increases in areas dominated by invasive species (ecostate D).

Ecostates for monitoring change over time

Because ecostate maps cover a multi-decade time frame, they may be used to track change at spatial scales ranging from specific management areas to the whole biome (**Table 1, step 6** on page 6). Satellite data is increasingly used to detect change in dynamic landscapes such as areas that have burned in wildfire or been treated using practices such as herbicide, seeding, planting or conifer removal.

Ecostate maps can help us evaluate when and where big-picture changes in ecosystem condition are occurring, whether we're looking at the pasture level or across a county or state.

Example 5: Monitoring treatment outcomes

Ecostate maps can be used to characterize change over time in dynamic environments, including tracking postfire recovery and outcomes of management treatments. **Figure 9** uses a combination of ecostate maps and monitoring plot data to capture pre- and postfire conditions in an area burned in 2017, seeded with perennial grasses in 2018 and monitored at five sites in 2020, 2021 and 2022.

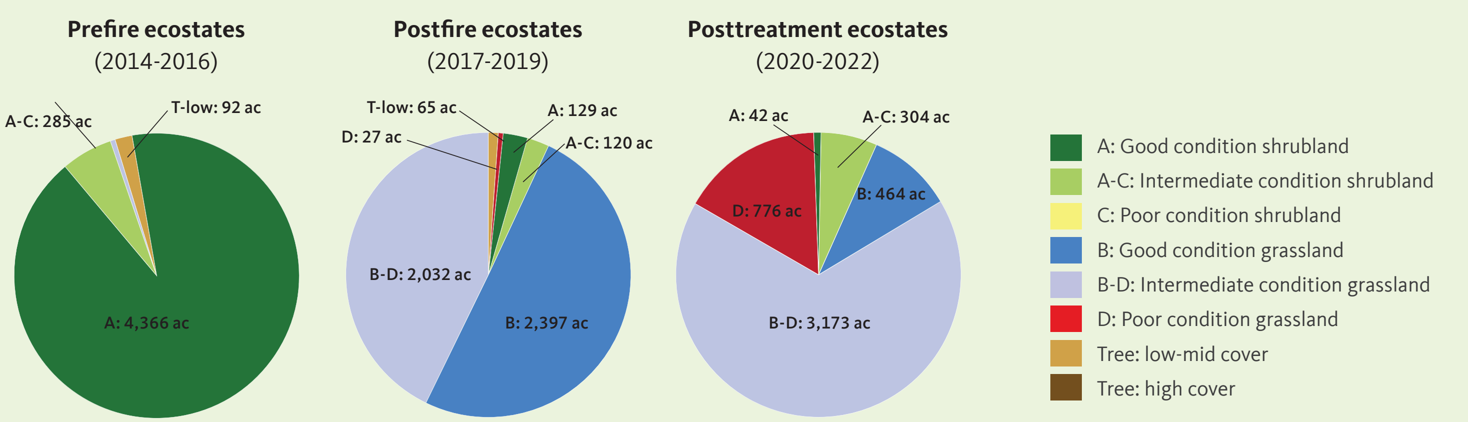
Quantitative plot data from five sites (**see table in Figure 9**) capture conditions as measured on the ground for verifying maps and interpreting patterns of recovery. The **Ecostate Summarization Tool** within the SageCon Landscape Planning Tool (https://tools.oregonexplorer.info/viewer/sagecon_landscape_planning_tool) provides maps, charts and tables depicting change in ecostates over time across the whole sagebrush biome.

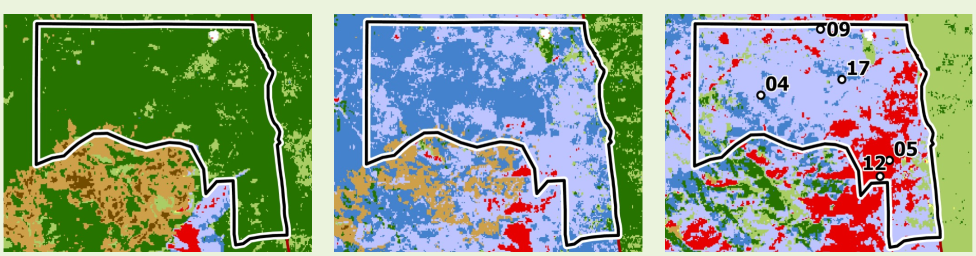
The maps and plot data show that perennial bunchgrasses are recovering after fire in many places but also highlight problem areas (ecostate D, red) that may benefit from herbicide treatment or other management actions. In this example, postfire monitoring data and ecostate maps match relatively well, although the maps generally depict greater cover of annual grasses relative to perennial grasses than the plot-measured data, with more ecostate D and less ecostate B as compared to field data. Although it is not shown here, plot data indicates that sites with high annual grass cover (plots 5 and 12) also have relatively high cover of perennial grass, resulting in a B–D classification in the plot data.

When using ecostates for tracking change following disturbances or restoration activities, remember that ecostates are best used for capturing trends over medium to long time frames, and in the slow-growing sagebrush ecosystem, vegetation conditions only three to five years after fire (as in this example) are still dynamic.

Maps are unlikely to accurately detect shrub recovery for several years after a fire, as small reestablishing shrubs are difficult to detect in satellite imagery. Also, when comparing maps to field data, remember that ecostate maps capture a three-year time slice and thus will always lag behind information collected in real time (**see the best practices section on page 5**).

Figure 9. For an area that was burned in 2017 and seeded in 2018 (black outline), charts, maps and tables capture change from prefire conditions (2014–2016) to immediately postfire (2017–2019), and several years after fire and treatment (2020–2022).





Plot	Mapped ecostate (2014-2016)	Field-measured ecostate (calculated based on plot data) 2020	2021	2022
Plot 04	A	B	B	B
Plot 05	A	D	B-D	B-D
Plot 09	A	B	B	B
Plot 12	A	D	B-D	–
Plot 17	A	B	B	–

No prefire monitoring plots were available, but ecostate maps prior to the fire indicate condition was likely an intact sagebrush-bunchgrass community.

Immediately after the fire, condition shifted from shrubland to grassland due to burned sagebrush. Annual grasses started to spread from previously invaded sites near the treatment area.

Several years after the fire, maps show more widespread annual grass invasion. Five monitoring sites are shown in the map above and data are summarized in the table at right.

For each monitoring site, ecostate is estimated from pre-fire maps (left map and left column in table) and calculated from field-measured cover data for years 2020, 2021 and 2022 (right map and center and right columns of table) using the same ruleset as the maps. Available data indicates relatively robust perennial grass recovery, but concerning levels of annual grasses in the southeastern area. Only three plots were revisited in 2022.

Take-home messages

Ecostate maps combine the concepts of threat-based land management with the power of satellite data to help us understand changes to sagebrush ecosystems across space and time. Over the past several years, ecostate maps have been used to improve management of sagebrush rangelands. They have shed light on landscape conditions and trends on landscapes both large and small, and have helped identify priority areas for management. They have also shown how areas have changed after wildfires or restoration actions.

In every case, ecostate maps are most effective when used with other information sources, especially knowledge from local managers and landowners. Inevitably, ecostate maps will not be accurate everywhere. But across broad landscapes, ecostate maps have proven to be incredibly useful. We highlight the following big-picture messages:

- **Embracing simplicity** — Threat-based land management is a reminder that sometimes simpler is better — we do not need to account for every dataset, nuance and scientific study when trying to chart a path forward. Ecostate maps are a simple but powerful way to clarify and focus efforts on primary threats to the sagebrush ecosystem.
- **Communicating with a shared language** — Ecostate maps illustrate ecological conditions with simple, accessible concepts and language centered on the primary threats to sagebrush ecosystems. When managers, landowners and others are able to have a conversation with a shared focus and understanding of the function and importance of "ecostate A," collaborative efforts can proceed with more clarity and buy-in. Effective storytelling and communications strategies built on a common understanding of big-picture ideas are essential for building coalitions and strategies needed to change the fate of the sagebrush sea.
- **Maps as a discussion support tool** — Ecostate maps are most powerful when used by groups to facilitate dialogue about how to steward the vast, remote landscapes of the sagebrush biome. These structured discussions help groups of people make difficult but necessary decisions about how to direct limited resources strategically — instead of evenly or randomly — for greatest conservation impact. Notice we use the term "discussion support tool" and not "decision support tool," recognizing that maps and other data cannot make decisions for us. Instead, they can help us move toward the shared understanding that is necessary for making durable decisions in complex landscapes. This framing highlights ecostate maps less for their answers and more for their ability to generate meaningful conversation focused on landscape-level threats.

Last, we will call to attention the recent, rapid evolution in technology that has enabled ecostate maps to exist, which continues at a rapid pace. Indeed, as the authors wrap up writing this document, a new vegetation map is being released that will provide finer-scale and more nuanced vegetation cover maps, which may be incorporated into future versions of ecostate maps. Satellite data has become widely used in rangeland management in recent years, and the breakneck pace of tool development and innovation means that we can surely expect more change on the horizon.

To close, those of us who manage and care for the sagebrush biome must prepare for tall orders of change, both on the land and in our toolkits. To do so, we must be willing to embrace approaches — such as ecostate maps — that help us understand and simplify complex patterns across large landscapes over time, while simultaneously keeping our minds open to evolving perspectives, complementary approaches and new information.

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Appendix 1. Preassessment workflow to guide efficient field work

A workflow using ecostate maps to efficiently gather assessment information

Managing large landscapes requires an understanding of current conditions, but assessing ecological conditions across large areas of remote terrain is challenging and time-consuming. This step-by-step preassessment workflow highlights a process to use ecostate maps and other datasets to: 1) compile relevant information ahead of the field season; 2) facilitate conversations about data needs, likely conditions and areas of interest; and 3) prioritize field time for additional on-the-ground data collection given limited resources and time.

The workflow walks through four steps and presents prompting questions for consideration at multiple scales, along with maps and examples of how to interpret information. For this example, we walk through a preassessment for a large 432,000-acre grazing allotment (area of public land designated and managed for grazing of livestock) in Oregon, which contains 32 smaller pastures (**Figure 10**).

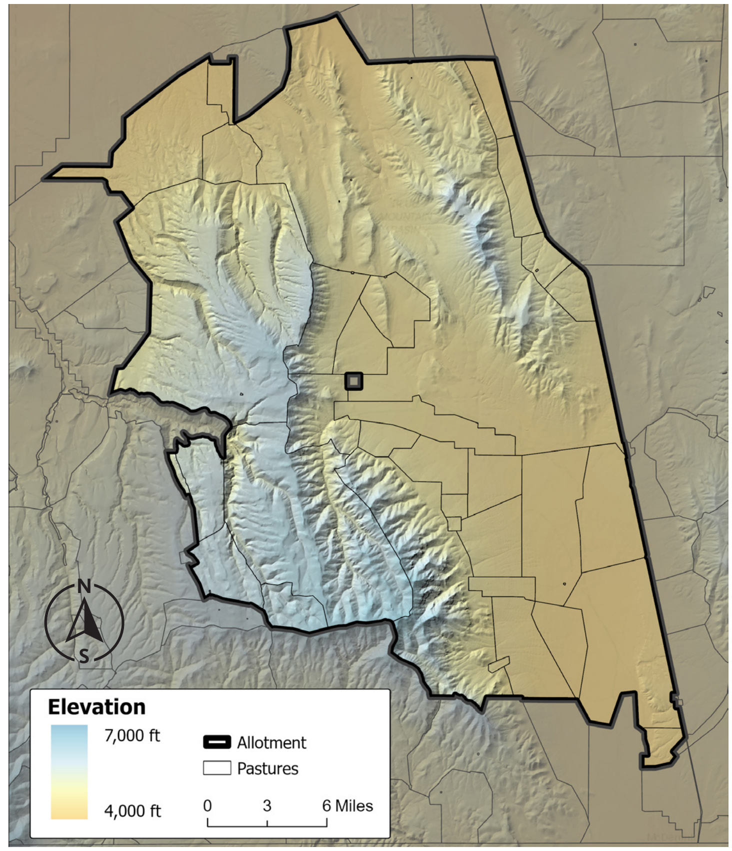


Figure 10 above. Elevation and hillshade highlight the complexity of the terrain, ranging from flat lowlands at 4,300 feet elevation (tan) to mountainous terrain at higher elevations, reaching up to nearly 8,000 feet in the western mountains (blue). Hillshade shows steeper terrain with the appearance of shadows.

Step 1. Compile relevant datasets

Gather relevant datasets for preassessment, including existing plot data as well as data layers depicting current vegetation, site characteristics, land use history such as disturbances and treatments, administrative boundaries and other relevant information. Key maps used in this example are shown in **Figures 10, 11 and 12**, but a wide range of datasets may be relevant. Compiling this information and walking through the steps below should help create confidence in understanding and documenting on-the-ground conditions for some areas while identifying other areas that warrant a closer look.

Step 2. Start with the big picture: landscape-level preassessment

Start by considering the broader landscape — we are using grazing allotments in this example, but this could also be a large watershed or county. This broad scale provides spatial context for assessing smaller units (pastures) in **step 3**.

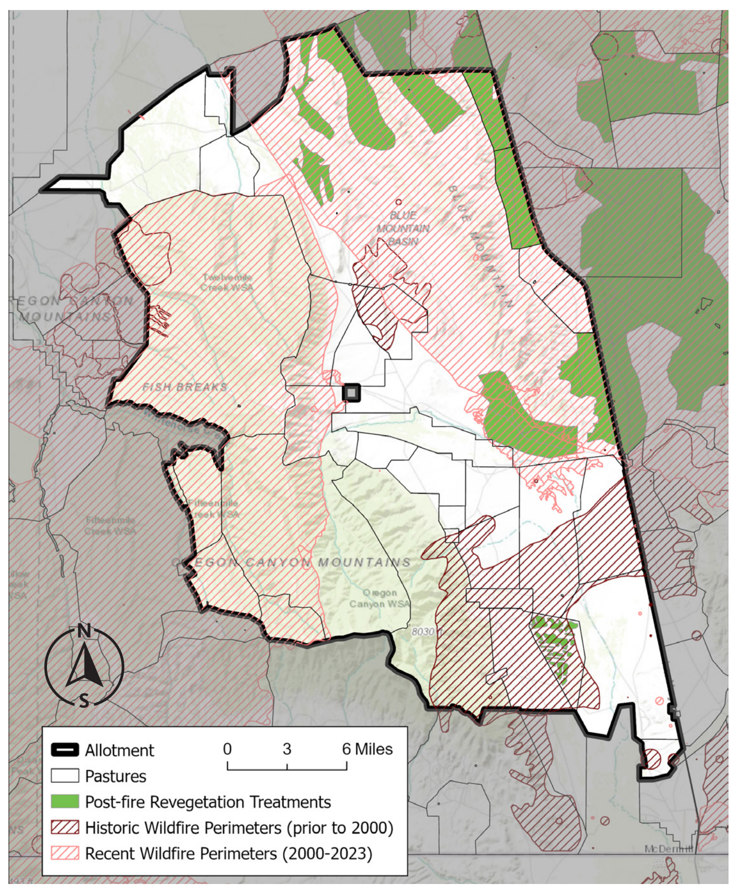


Figure 11 at right. Previous wildfires and recent postfire revegetation treatments span much of the allotment.

Question 2a: How variable are physical conditions? Are there large differences in elevation, slope, aspect (north- vs. south-facing slopes) or soil types?

This allotment is very large and has a high range of variability as shown in **Figure 10** on the previous page. There is undoubtedly a large range of soil types and other physical features across this diverse landscape, but this allotment could be simplified into two broad categories: roughly half of the allotment occurs in flatter and lower-elevation areas, and the other half occurs in more complex, mountainous terrain. These categories could form units that help guide the assessment approach, recognizing that areas with lower variability may need fewer data points on the ground to measure conditions compared to the more variable uplands (**see step 4**).

Question 2b: Were there previous disturbances or management actions that affect current conditions?

This allotment has experienced multiple wildfires over the past several decades, as shown in **Figure 11** on the previous page. Two large fires burned more than half of the allotment in 2012, and multiple historic fires also occurred in the area, including a large 1985 fire in the southern portion of the allotment. After the 2012 fires, postfire revegetation treatments occurred in many lower-elevation burned areas, also shown in **Figure 11**.

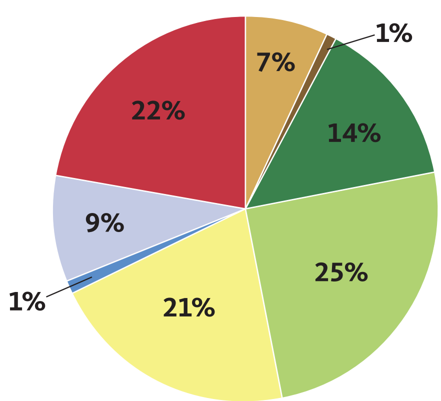


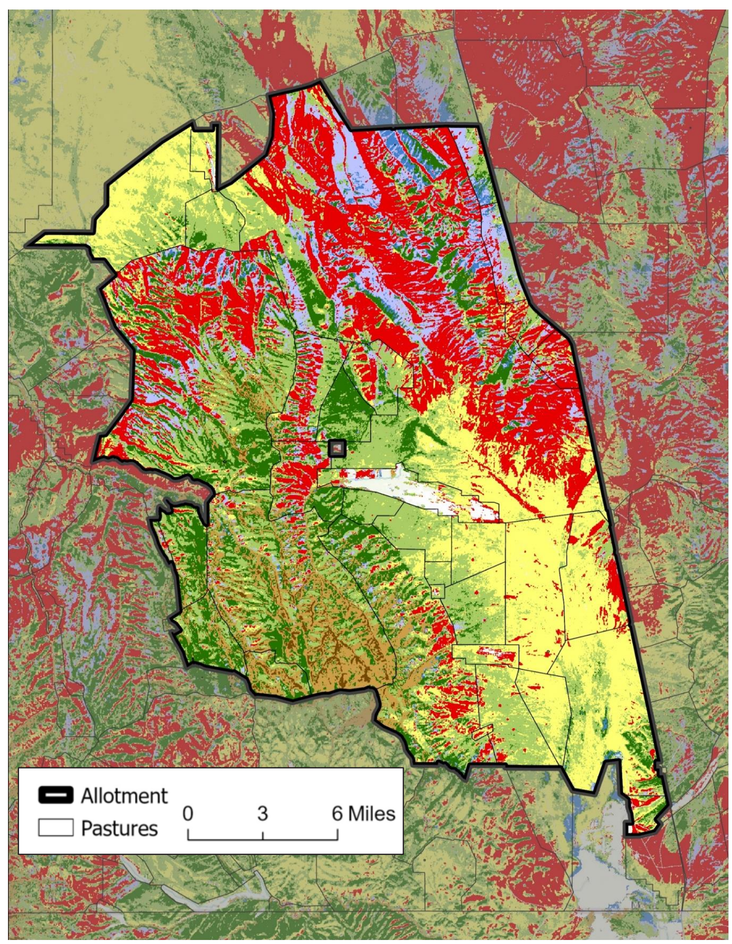
Figure 12. Distribution of ecostates across the allotment.

THREAT-BASED ECOSTATE	PERCENT	ACRES
A: Good condition shrubland	14%	32,145
A-C: Intermediate condition shrubland	25%	58,234
C: Poor condition shrubland	21%	48,702
B: Good condition grassland	1%	3,175
B-D: Intermediate condition grassland	9%	21,139
D: Poor condition grassland	22%	52,019
Tree: low-mid cover	7%	15,143
Tree: high cover	1%	2,327

Question 2c: What is the broad distribution of ecostates across the landscape?

Ecostates highlight the diversity of ecological conditions across this large allotment (**Figure 12**). Roughly one-third of the landscape is in relatively intact condition (ecostates A or A–C) and one-fifth of the area is in ecostate C with a sagebrush overstory but lacking desirable perennials and/or invaded by annual grasses. Over one-fifth of the area is mapped as ecostate D where invasive annual grasses are dominant, primarily in lower-elevation areas that had burned.

Many of the revegetation treatments (shown in green in **Figure 11**) are clearly visible as ecostates B or B–D in **Figure 12**, indicating successful establishment of seeded perennial grasses and some suppression of invasive annual grasses. Woodlands are present in the higher elevations, but the composition of tree species is not distinguishable in the maps. Although not shown here, examining ecostate change over time would help determine where threats are established compared to areas with more recent, emerging threats.



Step 3. Evaluate each assessment unit: pasture-level preassessment

After considering the broader landscape context, look more closely at individual pastures (or other finer-scale assessment units) and integrate plot data and field observations to provide a more complete picture of the conditions in a localized area.

Question 3a: What is the distribution of ecostates in each pasture?

There are 32 pastures within this allotment, covering a wide range of sizes, levels of complexity and severity of threats. We visualize the distribution of ecostates for 12 of those pastures in the southern part of the allotment in **Figure 13** to highlight the relative sizes and variability in condition among pastures.

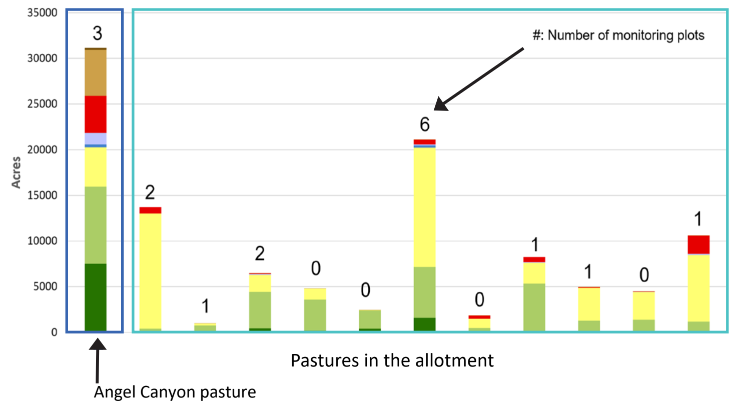
This group of pastures varies widely from one very large and diverse pasture (Angel Canyon, outlined in blue) to 11 smaller and more uniform pastures (covering a combined 112,000 acres and outlined in teal). This analysis of the distribution of ecostates will inform the assessment approach in **step 4** and could be repeated for all 32 pastures, but we show a subset here for simplicity.

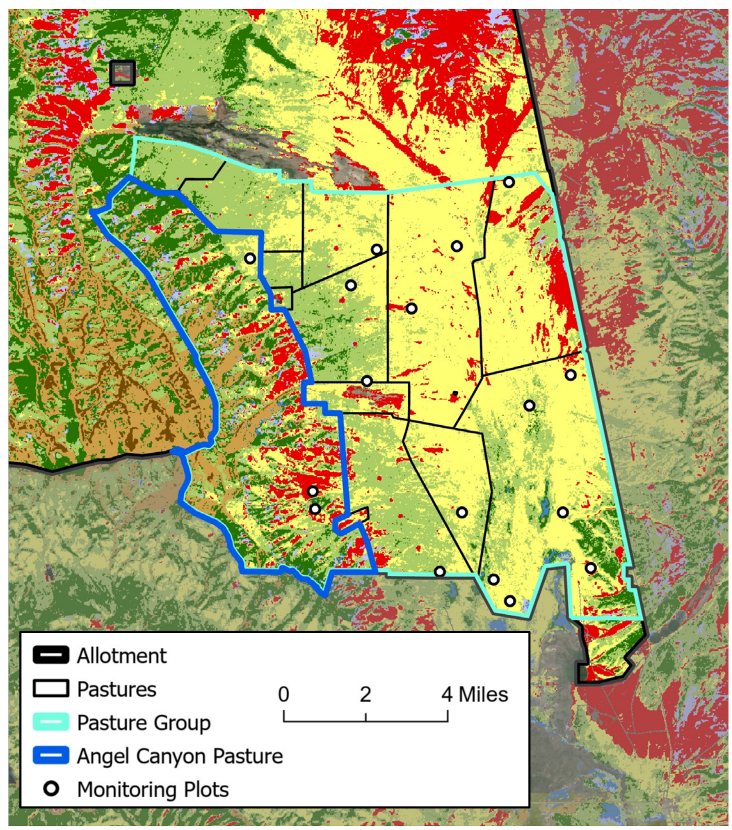
Question 3b: What existing plot data is available? How representative are plots of overall condition (for example, are plots concentrated in certain areas and are there gaps in others?) and does available plot data and map data generally agree in terms of overall condition?

The chart in **Figure 13** shows the number of plots in each pasture relative to its size and condition, but we need to dive deeper to determine how well the plot data characterizes each pasture and if there is agreement among data sources. We will focus in on the largest and most complex Angel Canyon pasture, which covers 31,100 acres and spans an elevational range from 5,100 feet in the east to 7,500 feet in the west.

This pasture was unburned in the large 2012 fires, but a previous fire in 1985 was likely a catalyst in establishing invasive annual grasses across much of the lower-elevation portions of this pasture several decades ago. In this pasture, there are only three existing monitoring plots, as shown in **Figure 14** on the next page, and both maps and plot data indicate there is substantial invasion by annual grasses in the eastern portion of the pasture. However, there is no coverage of field-based data in the middle and upper elevations of the pasture, and thus the plot data does not adequately represent the conditions throughout the pasture.

Figure 13. In the southern part of the allotment, ecostates in each pasture are summarized in columns to compare the sizes, conditions and variability within and among pastures. The large, complex Angel Canyon pasture is outlined in blue and the adjacent pastures are grouped in teal. The number of monitoring plots that have been established in each pasture is shown above each column to indicate the amount of field-based information that is already available.





Collecting additional data and spot-checking the map are important to confirm or correct the mapped conditions in that area, and one suggested approach for places to target field verification or data collection is shown in the callout boxes in the map in **Figure 14**. This process could be repeated for the remaining pastures, but is not repeated here for simplicity. However, **see step 4b** below for more information about monitoring plots available in other pastures within this allotment.

Step 4. Putting it all together: developing a field assessment approach

After reviewing the available preassessment information for each pasture as described in **step 3** on the previous page, you can use this information to develop an efficient and effective approach to your assessment. Unless sufficient time and resources are available for a more systematic method (for example, establishing a large number of randomly placed monitoring plots), ecostate maps and other information shown here can help direct where to spend additional time in the field.

Instead of collecting data evenly across the landscape (for example, establishing a fixed number of plots per pasture), focus on collecting data where conditions are complex, there is a lack of information or there is conflicting information. This will allow you to spend less of your valuable field time collecting new data where multiple existing data sources already point toward the same conclusion.

Question 4a: Can maps be used to divide large and complex areas into units for assessment?

The allotment used in this example highlights the opportunity to leverage ecostate maps and other information to maximize the efficiency of field data collection. The Angel Canyon pasture (**step 3b** and **Figure 14**) shows an area that is large and highly variable but with limited plot data representing a small subset of conditions within the pasture (see the bar chart in **Figure 13**).

Here, plot data is concentrated in the lower elevations with poor condition and no tree cover, which is not representative of the pasture. Collecting more field-based information is necessary to understand the broad conditions and threats in this pasture, and a combination of elevation and topographic complexity (**step 2a**), disturbance history (**step 2b**) and ecostate maps (**step 3b**) can inform an approach in determining where to prioritize field time as described in the callout boxes in the map in **Figure 14**.

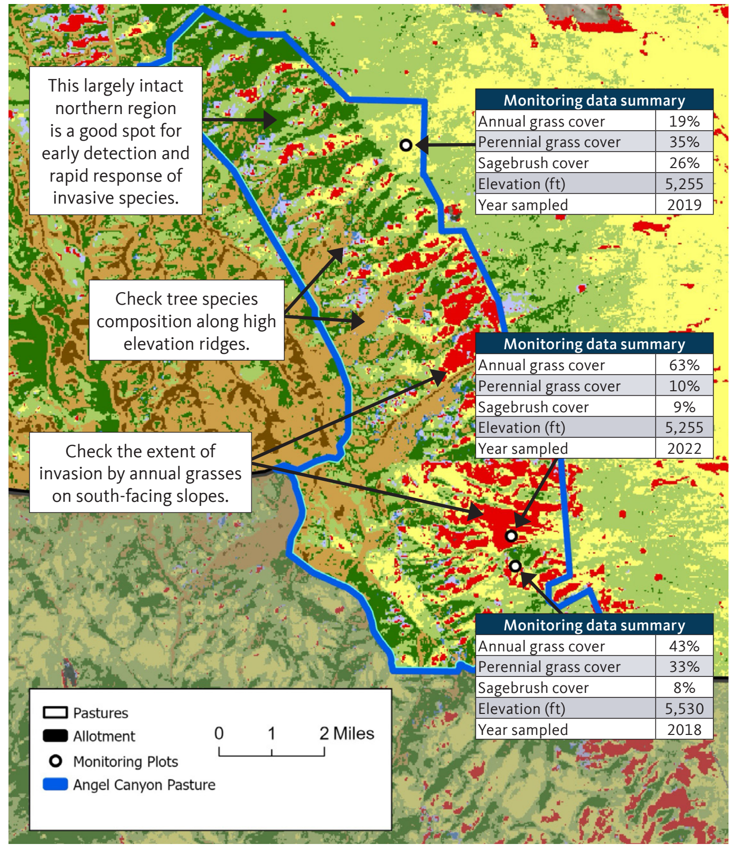


Figure 14. In the large and diverse Angel Canyon pasture, three monitoring plots are located in the eastern part of the pasture, and data summaries are shown in tables. Although the combination of plot and map data indicates widespread invasion by annual grasses in the eastern part of the pasture, the western part of the pasture has no on-the-ground monitoring data. Callout boxes note areas where targeted field data collection could help verify or correct patterns in the ecostate map.

For best practices when field-verifying maps, refer to the section **"How do I validate ecostate maps?"** (page 6). Remember that there will often be discrepancies between on-the-ground and satellite data. In some cases, both will be "correct" in their own ways due to mismatches in timing, scale, indicators measured, etc. In other cases, errors in one or both datasets will result in mismatches.

In this allotment, the available plot data and ecostate maps match well enough for ecostate maps to be a useful and reliable tool. In the authors' experience, this is commonly the case in southeastern Oregon, where ecostate maps are used widely. But more generally, highly precise data is not needed for a preassessment to generate a snapshot of overall condition and target additional data collection.

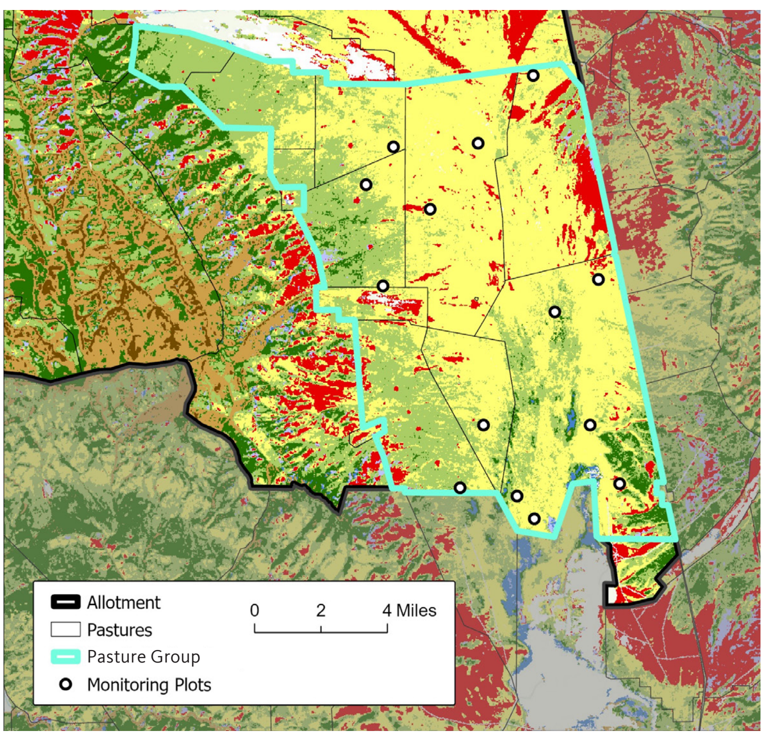
Question 4b: Are there pastures with enough existing information? Can you justify minimizing field time and data collection in areas that are more homogeneous or where current data coverage is adequate?

Turning back to our group of pastures highlighted in **step 3a**, a cluster of several pastures east of Angel Canyon all occur across the relatively flat, lower-elevation expanse in the southeast corner of the allotment (**Figure 15**). Across this group of pastures, 14 monitoring plots have been established over the past several years, with locations shown as circles in **Figure 15** and summarized in the data table.

While current and historic management may differ between pastures and managers will need more specific information for some decisions, the current information — including elevation, ecostate maps and existing monitoring plots — may be sufficient to conclude that the area is generally a mix of shrubland and grassland condition with significant annual grass invasion or potential for invasion throughout the area. New data collection may be a lower priority in this group of pastures compared to other areas of the allotment (such as the Angel Canyon pasture) where information is lacking, information sources disagree or the landscape is more complex.

Question 4c: Can you direct more field time to areas with higher complexity, or where there is conflicting information or less on-the-ground data?

In this allotment, ecostate maps and plot data generally match where plot data is available, but many data gaps exist. A glance at the distribution of plots (**Figure 13**) shows that the less complex lowlands generally have a greater sampling intensity than the more complex uplands, and directing field time in the mountainous regions would increase the understanding of the condition and potential management needs in this area. One potential approach to assessment of this broader allotment is shown in **Figure 16** on the next page.

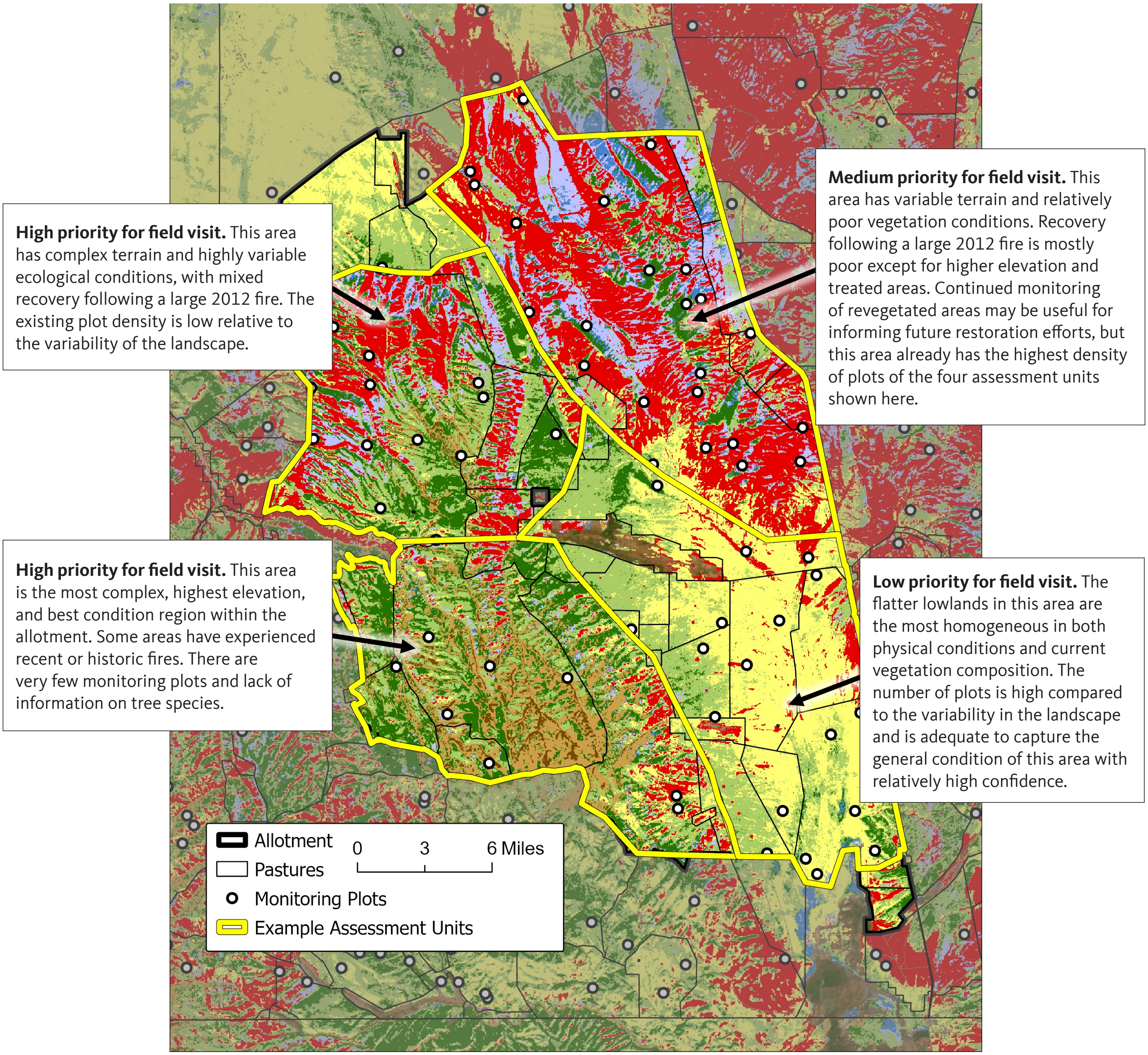


Monitoring data summary

Annual grass cover	Perennial grass cover	Sagebrush cover	Year sampled
5	1	0	2016
58	1	7	2016
46	19	6	2016
38	5	5	2016
1	0	33	2016
40	52	5	2016
22	0	17	2019
0	24	7	2019
19	35	27	2019
3	3	1	2020
37	1	8	2020
23	0	31	2020
1	4	6	2021
11	1	11	2022

Figure 15. Monitoring plots have been established at 14 locations within this group of 11 pastures. The figure and table show the locations and a short summary of plot data in the area. Taken as a whole and given the relatively homogeneous landscape, the available plot data may sufficiently describe conditions and threats across this group of 11 pastures, as compared to other parts of the landscape that are more variable in topography and condition. Note that plot data was collected between 2016 and 2022, so some plot information is several years older than the map.

Figure 16. Based on the four steps in this preassessment workflow, this figure presents one approach for efficiently allocating field time in this large and complex allotment, ranking four assessment units (outlined in yellow) in their priority for additional field-based information.



CONCLUSION

In this preassessment workflow, we followed a series of prompting questions using ecostate maps and other sources of information to evaluate what we already know about the landscape and think carefully about why and where we may need additional information to understand the condition of the landscape.

The multiscale, step-by-step process outlined here can be replicated in your landscape or elements can be adapted into a different process. Either way, the hope is that by leveraging available data, including satellite-based maps, and focusing on primary threats, preassessment can help design an efficient and effective assessment approach for large sagebrush landscapes.

Appendix 2. Evolution of ecostate maps over time

Threat-based land management, originally conceived over 10 years ago, has evolved over time. The 2019 publication ***Threat-based land management in the northern Great Basin: A manager's guide*** introduced the framework for simplifying the ecological condition of rangelands in the northern Great Basin into a set of ecological states that are grounded in three primary and interrelated threats to rangelands: invasive annual grasses, wildfire and conifer encroachment.

The original publication outlined three separate decision trees based on the primary threat — invasive annual grasses, conifer encroachment or both (dual threat) — and assigned a letter (A, B, C, D or E) to broad vegetation conditions. In this earliest iteration of ecostate mapping, these distinct categories were typically delineated in the field by land managers and digitized into a coarse map. This application continues at the property scale throughout Oregon, especially on private lands managed for conservation of sage-grouse through Candidate Conservation Agreements with Assurances.

As remote sensing technology has advanced, the opportunity emerged to apply the principles of threat-based land management across large, multijurisdictional landscapes in a wall-to-wall vegetation map. Multiple iterations of ecostate maps have been produced, starting with a single ecostate map using an Oregon-specific vegetation map in 2019.

With the release of version 2 of the Rangeland Analysis Platform maps in 2020, ecostate maps were remade with newer data and a simpler rule set, released as a series of five-year time slices. The next iteration incorporated newer Rangeland Analysis Platform version 3 maps released in 2021, depicted change over time in three-year overlapping time slices (as in the current version 4 maps), refined the rule set based on our experience and comparisons with field-based data, and expanded ecostate maps outside of Oregon.

The concept of threat-based ecostates continues to evolve as we apply principles of threat-based land management and as technology emerges and changes. The current version of ecostate maps (version 4) described in this publication differs from the original 2019 threat-based models in multiple ways — for instance, it includes intermediate ecostates (A–C, B–D) that provide a more nuanced interpretation of ecological condition, and it simplifies tree-encroached ecostates to only two categories.

Ecostates continue to evolve in other ways. For example, ecostates are being used to monitor restoration treatment outcomes through the Oregon Rangeland Monitoring Program, which uses sagebrush cover to differentiate between grassland and shrubland ecostates as well as conifer encroachment phases and understory condition. A newer conifer threat map (available from the SageCon Landscape Planning Tool) provides a complementary dataset to depict the nuances of conifer encroachment phases and understory condition while retaining the simplicity of the ecostate maps as a communication tool.

In addition, an update to ***Threat-based land management in the northern Great Basin: A manager's guide*** is planned to more seamlessly align different versions of ecostate maps and models.

Appendix 3. Accuracy assessment

An accuracy assessment was performed using a "confusion matrix" analysis to assess the ability of ecostate maps to predict conditions on the ground by comparing the predicted (mapped) classes with the actual (field-measured) classes (**Table 3**). The confusion matrix is a valuable tool for evaluating classification models — by showing true positives, false positives, true negatives and false negatives, it offers insights into the model's strengths, weaknesses and potential biases.

We compared map-derived and field plot-derived ecostate classifications for 1,584 plots collected in Eastern Oregon between 2021 to 2023 by the Bureau of Land Management Assessment Inventory and Monitoring program (**Table 3**). For each plot, ecostate was calculated from field-based cover estimates (based on the line-point intercept method) using the same rule set as the map and was compared to the mapped ecostate for the pixel in which the plot occurred.

The accuracy calculated for each ecostate in **Table 3** represents the number of instances the ecostate map both correctly identified a class (true positive) and correctly excluded other classes (true negative) relative to the total number of predictions. This does not quantify the accuracy of the underlying Rangeland Analysis Platform dataset, which has its own inherent error reported on the platform's website (**see references**).

True positives occur where plot-based and map-derived ecostates match each other (shown in colored cells along the matrix diagonal). Ideally, these values should be the highest in both the row and the column in which they appear, and this is true for six out of eight categories.

To interpret this table, start with the top left cell, where 118 represents the number of instances where the map-derived ecostate matched the plot ecostate. The cell below shows 26 instances where the map classified a pixel as ecostate A when the plot information indicated ecostate A–C, and the cell to the right shows 151 instances where a location was mapped as A–C when the field-based plot indicated it as ecostate A. We can conclude in this case that the maps more often overestimate than underestimate annual herbaceous cover. This type of comparison among rows and columns can be done for each ecostate. By examining other numbers in the table, you can also get a sense for the most common correct classifications (for example, ecostate D is often correctly classified) as well as common misclassifications (for example, ecostate B is often mapped as ecostate B–D).

An overall accuracy of approximately 85% suggests that the ecostate rule set succeeded at generally representing broad vegetation conditions across eastern Oregon. This is consistent with the observations of the authors that ecostate maps, while certainly imperfect, are often accurate enough to be useful in capturing broad condition classes. See more specific takeaways and best practices for using ecostate maps in the **accuracy assessment section on page 8.**

Table 3. Confusion matrix showing the accuracy of map-derived ecostate classification (columns) compared to plot-derived ecostate classification (rows). Each number in the top table represents the number of instances in which a combination of plot-derived and map-derived ecostates occurs. Overall accuracy is shown in the bottom table and was calculated by dividing the sum of true positives and true negatives of each category by the total number of samples (1,584). For example, this calculation was made for ecostate A by adding true positives (118 — upper left cell where A was correctly predicted) to true negatives (1,140 — sum of all other cells except row 1 and column 1 where the model correctly identified that plots were not state A) and dividing by 1,584 (total number of plots).

		Map-derived ecostate v4 2021–2023 (predicted)								
		A	**A-C**	**C**	**B**	**B-D**	**D**	**Tree: low-mid**	**Tree: high**	**Total**
Plot-derived ecostate 2021–2023 (actual)	**A**	118	151	26	2	12	3	27	1	340
	A-C	26	67	16	2	10	6	6	1	134
	C	18	92	104	1	12	15	4	0	246
	B	51	53	13	19	70	36	10	0	252
	B-D	6	46	11	4	50	48	6	0	171
	D	2	41	33	3	44	187	2	0	312
	Tree: low-mid	1	1	2	0	8	8	48	9	77
	Tree: high	0	2	0	0	0	1	13	36	52
	Total	222	453	205	31	206	304	116	47	1584

Accuracy								
A	**A-C**	**C**	**B**	**B-D**	**D**	**Tree: low-mid**	**Tree: high**	**Overall**
79.4	71.4	84.7	84.5	82.5	84.7	93.9	98.3	84.9

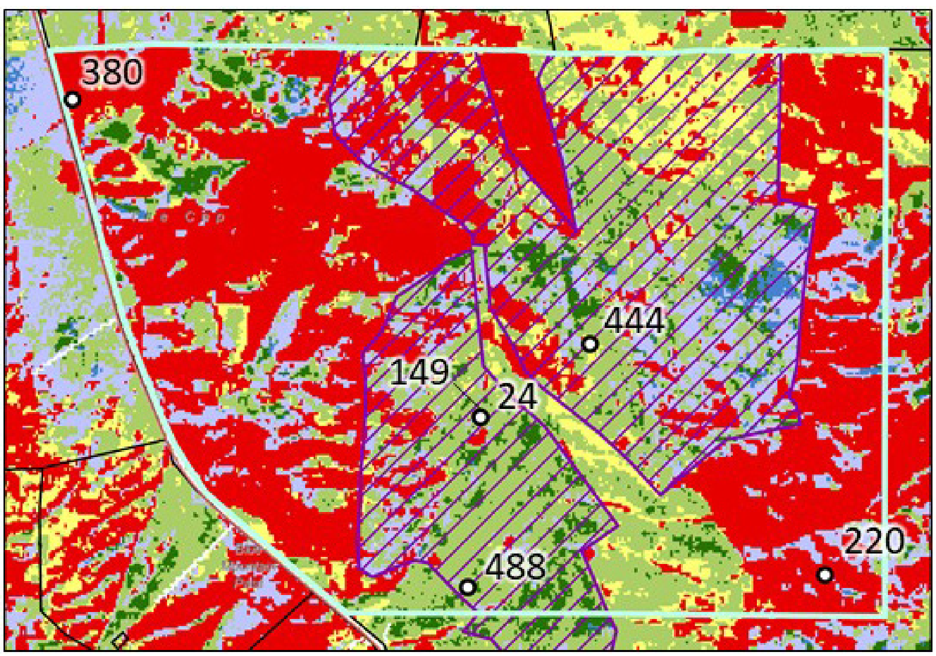
Appendix 4. Using ecostates for a snapshot of pasture conditions

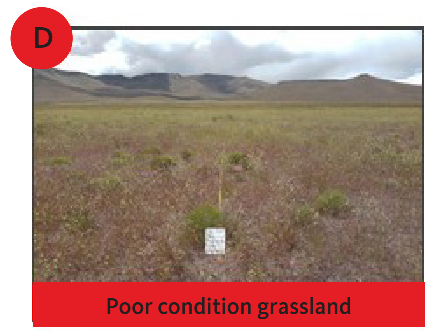
Threat-based ecostate maps can provide a snapshot of pasture conditions, especially when combined with field-based information. **Figure 17** summarizes map- and plot-based information for a 13,600-acre pasture that burned in a large 2012 fire, and **Figure 18** shows how the pasture has changed over the past 15 years. Six monitoring plots were established between 2016 and 2022, providing detailed information on species composition at each plot (for example, differentiating deep-rooted perennial grasses, invasive annual grasses, and non-native forbs from broader functional groups in the maps).

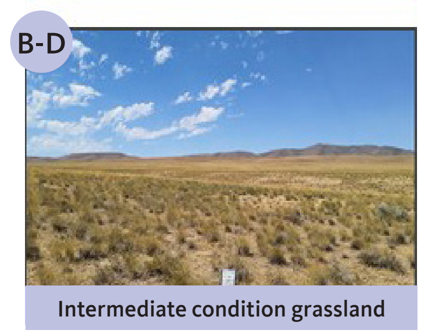
The most recent ecostate map reveals mixed conditions dominated by poor condition grasslands but with large pockets of intermediate condition shrubland, particularly where grass seeding occurred after the fire (shown in purple hash marks, **Figure 17**). Field data shows that most plots have high cover of undesirable vegetation, including invasive annual grasses and non-native forbs. Deep-rooted perennial grasses are present, providing soil stabilization and potential for recovery; however, the low elevation (less than 5,300 feet) and established levels of invasive species pose a challenging environment for restoration.

The main mismatch between map data and plot data is in the extent of shrublands occurring in the ecostate maps. Shrub cover appears to be overestimated in the maps with an estimated 41% of the landscape in shrubland ecostates (see pie chart and table in **Figure 18,** bottom right panel), while plot data indicates low shrub cover well below the threshold between grassland and shrubland ecostates in all plots. However, keep in mind that most of the plots were sampled several years before the time frame of the ecostate map (2021–2023), and therefore the map and plot data would not necessarily be expected to match. If recovery of rabbitbrush (a resprouting shrub) and sagebrush are occurring slowly, as may be expected, this trend may result in a mismatch between mapped conditions and older plots. Either way, mapped shrub cover is likely an overestimate.

Figure 17. The ecostate map depicting conditions from 2021–2023 (top left) complements field-based monitoring information (bottom table) collected between 2016 and 2022, with photos (right) shown for two monitoring plots. Plots 149 and 24 are so close together that they appear to overlap. Purple hashes show grass seeding treatments.



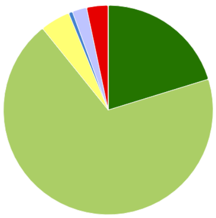




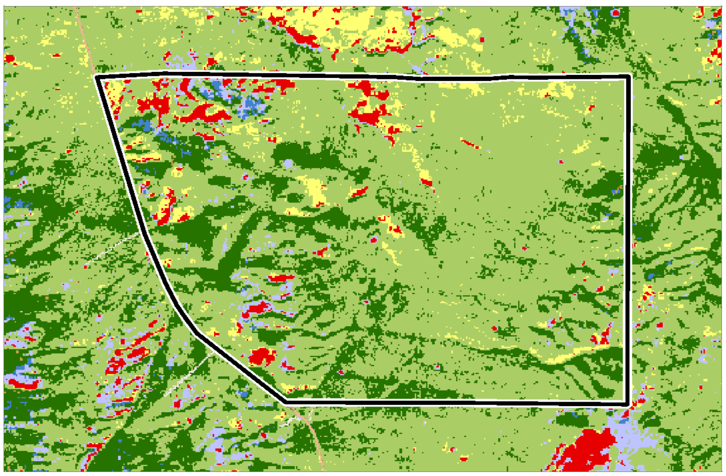
Plot	Year sampled	Elevation (ft)	Aspect	Plot-based ecostate	Invasive annual grass cover	Deep-rooted perennial grass cover	Bare soil cover	Non-native forb cover	Shrub cover	Sagebrush cover
149	2022	4869	NW	B-D	6	28	31	20	7	0
220	2020	5266	N	B-D	27	15	12	0	0	0
488	2018	5023	E	D	21	23	19	17	1	0
24	2016	4898	NW	D	30	11	12	46	0	0
380	2016	4803	NE	D	80	5	1	50	3	0
444	2016	4803	NW	B	0	18	37	0	0	0

Figure 18. The Ecostate Summarization Tool within the SageCon Landscape Planning Tool (https://tools.oregonexplorer.info/viewer/sagecon_landscape_planning_tool) provides maps, charts and tables depicting change in ecostates over time. This tool is publicly available and summarizes ecostate maps for any area of interest across the sagebrush biome for up to four time slices. Here it illustrates how the landscape has changed over roughly 15 years by summarizing ecostates for 2009–2011 (prior to the fire; top left), 2013–2015 (top right), 2017–2019 (bottom left) and 2021–2023 (bottom right).

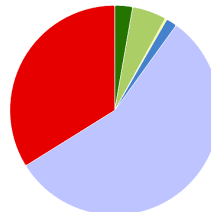
Threat-based ecostates (2009 to 2011)



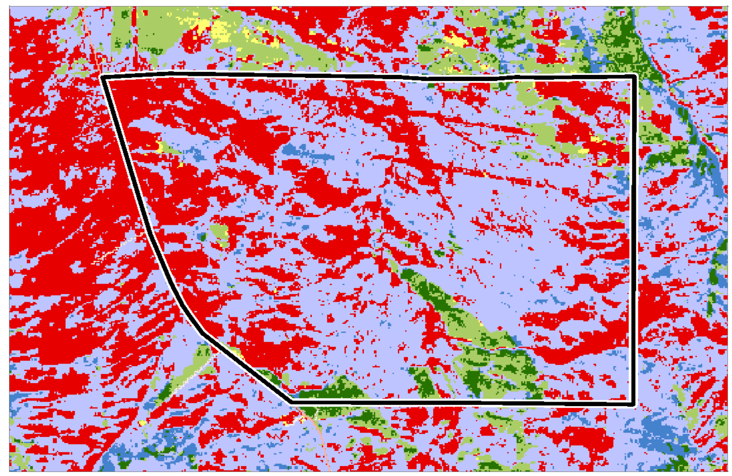
Category	% area	Acres
A: Good condition shrubland	20%	2758
A-C: Intermediate condition shrubland	69%	9399
C: Poor condition shrubland	5%	628
B: Good condition grassland	1%	82
B-D: Intermediate condition grassland	2%	305
D: Poor condition grassland	3%	450
Tree: low-mid cover	<1%	3
Tree: high cover		0



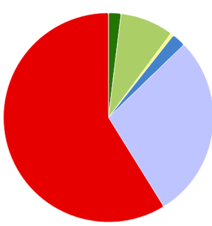
Threat-based ecostates (2013 to 2015)



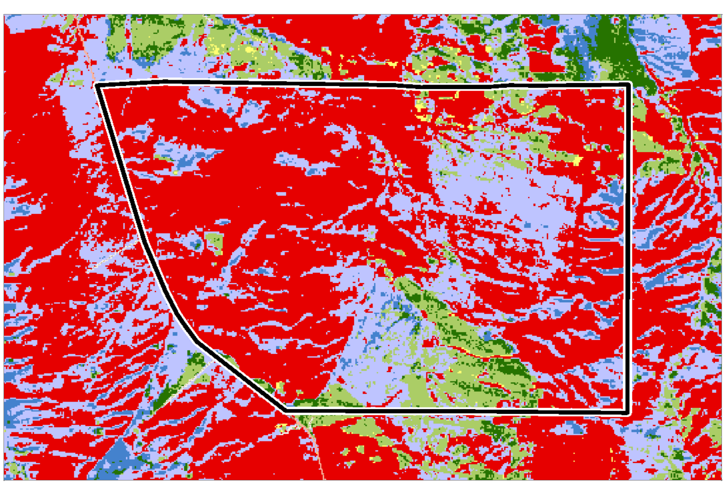
Category	% area	Acres
A: Good condition shrubland	3%	374
A-C: Intermediate condition shrubland	5%	718
C: Poor condition shrubland	<1%	39
B: Good condition grassland	2%	229
B-D: Intermediate condition grassland	56%	7652
D: Poor condition grassland	34%	4614
Tree: low-mid cover		0
Tree: high cover		0



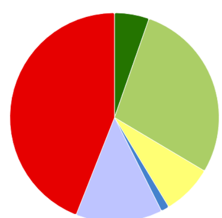
Threat-based ecostates (2017 to 2019)



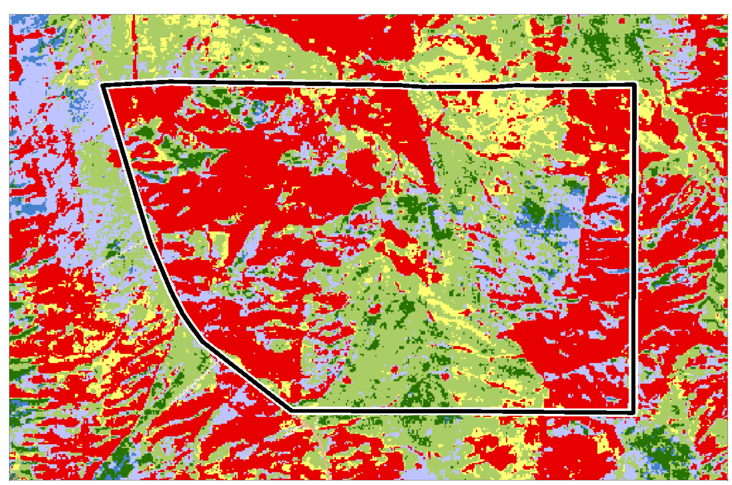
Category	% area	Acres
A: Good condition shrubland	2%	263
A-C: Intermediate condition shrubland	8%	1118
C: Poor condition shrubland	<1%	65
B: Good condition grassland	2%	290
B-D: Intermediate condition grassland	28%	3875
D: Poor condition grassland	59%	8014
Tree: low-mid cover		0
Tree: high cover		0



Threat-based ecostates (2021 to 2023)



Category	% area	Acres
A: Good condition shrubland	5%	731
A-C: Intermediate condition shrubland	28%	3838
C: Poor condition shrubland	8%	1061
B: Good condition grassland	1%	174
B-D: Intermediate condition grassland	13%	1825
D: Poor condition grassland	44%	5996
Tree: low-mid cover		0
Tree: high cover		0



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