

# Tools and approaches for measuring ecosystem services in California's grasslands and oak woodlands



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## **Introduction: The need for monitoring approaches for ecosystem services**

Ecosystem services are the benefits humans receive from our natural ecosystems and working landscapes. These services include: forage production, erosion control, soil fertility, water storage, flood control, carbon storage, fire control, pollination, water purification, air purification, and others. While there is increasing interest in managing landscapes for multiple ecosystem services, very few management and restoration projects monitor their impacts, and thus we have little information on the effectiveness of management practices on ecosystem services.

We know that the effects of a given management practice can vary across sites, and from year to year, but we need a synthesis from hundreds of management projects in order to better assess which management practices are most effective in providing which ecosystem services, under a given type of site (depending on soil, local weather, topography, vegetation, land management history, etc.). We are addressing this challenge by two approaches:

- Developing a database of management practices and their outcomes in California's grasslands, oak woodlands, and the riparian areas within these systems (to be available to the public in the fall of 2017)
- Developing this monitoring handbook, to increase monitoring efforts across management projects, and to provide more consistent types of measurements across studies, which will make monitoring measurements more directly comparable.

Ecosystem services are often difficult to directly measure, and thus we rely on monitoring indicators of these services, which are important tools for comparison (e.g. which is the best management practice for a given ecosystem service), but often aren't able to provide a quantitative measure of the amount of a service provided.

The methods provided in this handbook provide straightforward, standard approaches to quickly measure indicators of ecosystem services in California's grasslands and oak woodlands. While these measures are valid in other ecosystem types, it is best to consult with local experts because the best indicator measures that serve as proxies for ecosystem services may vary by ecosystem type.

## **Guidelines to selecting sampling site/ design:**

How, where and when you sample greatly affects the monitoring data. It is rarely possible to measure every aspect of variability across a landscape, and thus the specific areas we do (and don't) measure, and the timing of our sampling can bias our results. Thus, in order to answer a specific question, it is critical to be sure that the sampling design can tease apart the differences you want to assess across sites and/or management practices.

The following are guidelines to site selection, concluding with a list of references that more thoroughly address this subject matter.

### **What do you want to compare? What questions do you want to answer?**

When assessing the impact of a management practice, ideally you will be able to measure the following comparisons:

- Measurements at the management site, and at a control site (a site with identical environmental conditions to your management trial, but without the management change of interest). For example, the control site for a restoration project would be one where restoration hasn't occurred. A control site for a change in grazing management depends on what you want to compare (e.g. ungrazed as a control to compare with grazed, or conventional season-long grazing as a control to compare with short-term intensive rotational grazing).
- Before, and after measurements at both the control and the management sites

**Control sites.** It is critical that control sites are similar in all ways except for management to the management trial (e.g. soils, topography, local weather patterns, vegetation types, land use history, etc.), because environmental conditions could have stronger impacts than the management practice. Not carefully choosing a comparable control site makes it impossible to assess whether the managed and control sites are different due to management, or due to inherent differences in site conditions. It is important to assess this because often we do a certain management practice on one type of site, and then stop as site conditions change (e.g. when the soil gets too difficult to till because of its slope or rockiness, in wetter vs. drier areas).

**Before and after measurements.** Having before vs. after measurements on both the control and managed sites, allows you to assess if there are underlying differences between these sites that were not easily discernable to detect.

The importance of having the control site to compare to the managed site is particularly important when assessing how the site has changed due to manage. If you just have before and after measurements at the managed site, it is impossible to assess if the changes seen are due to the management practice, or to a change to the broader landscape over time (e.g. weather patterns, accumulated nitrogen deposition, invasion of a broad area by a noxious weed). If a given change occurs

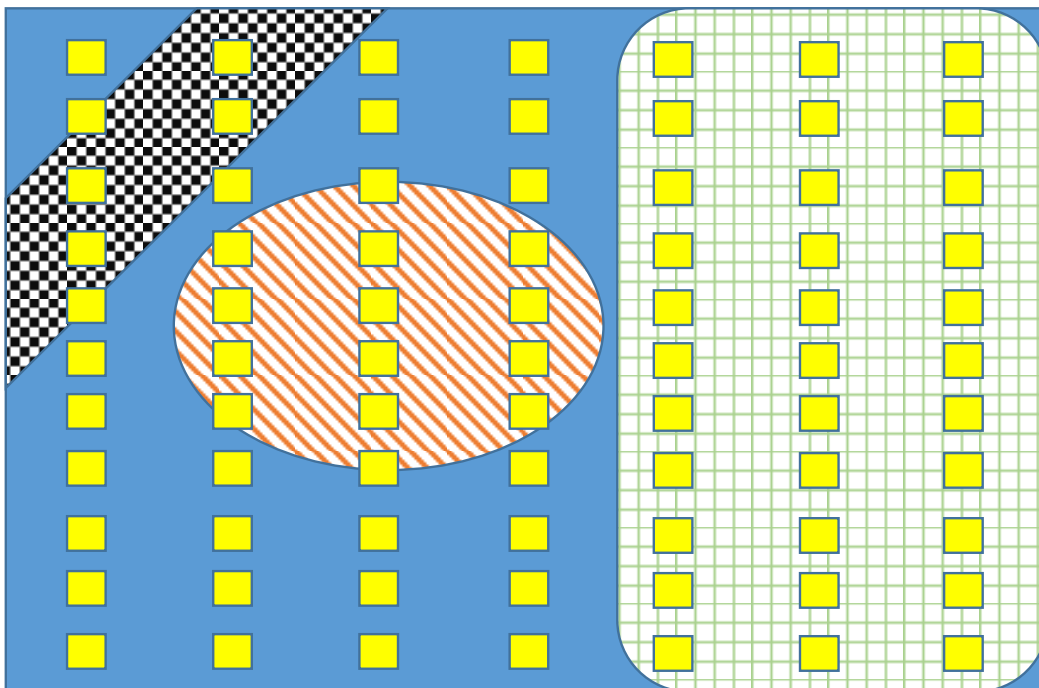
just in the managed site and not the control site over time, you can feel confident the change has occurred due to management. If both the control and managed sites change in the same way over time, then that is due to some change other than management.

When before and after measurements have not occurred, it is still possible to assess management effects by comparing to a control site, as long as a proper control site can be found (e.g. often comparisons across a fence line).

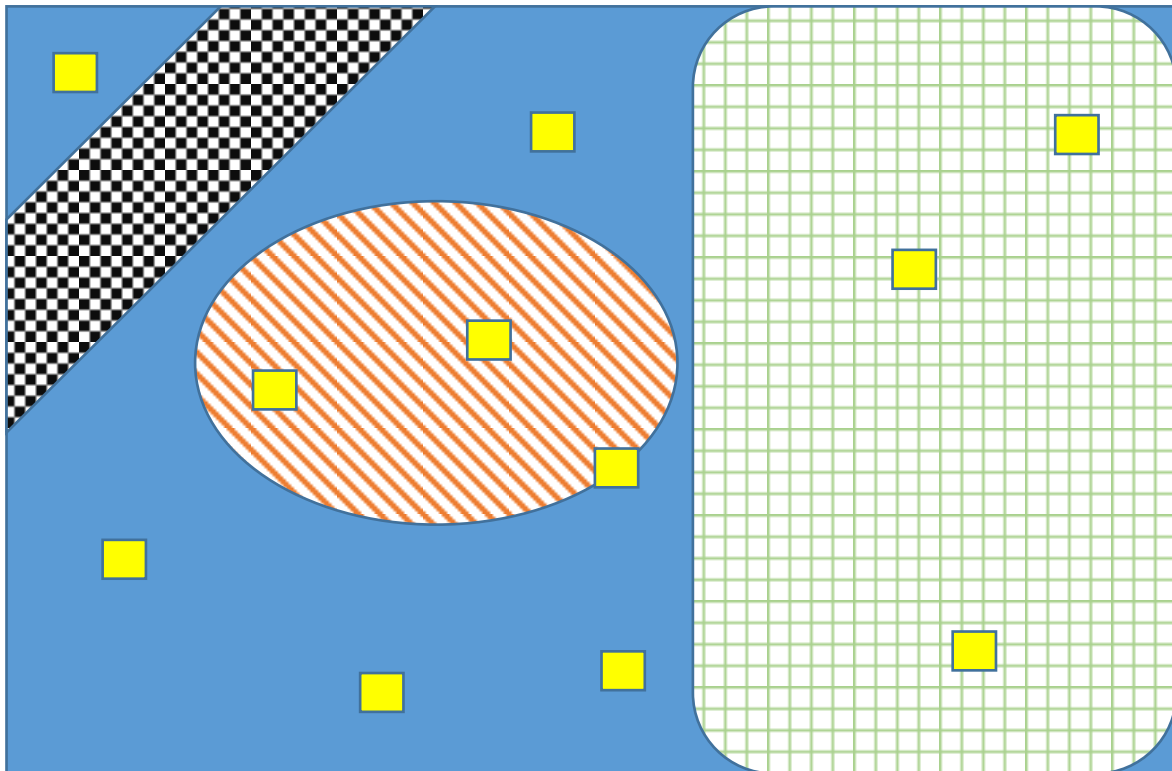
### **Monitoring site locations:**

When selecting sites for measurements, it is important that the sites you measure are representative of the variability in conditions across your site. This usually relies on taking multiple measurements. It is critical that sites for measurement aren't hand-selected because they represent the best or worst areas of the impacts of management. To avoid this, there are a number of ways to sample. These are listed below, with illustrations of a landscape with variable patches (shapes of different colors), and the sampling plots (in yellow).

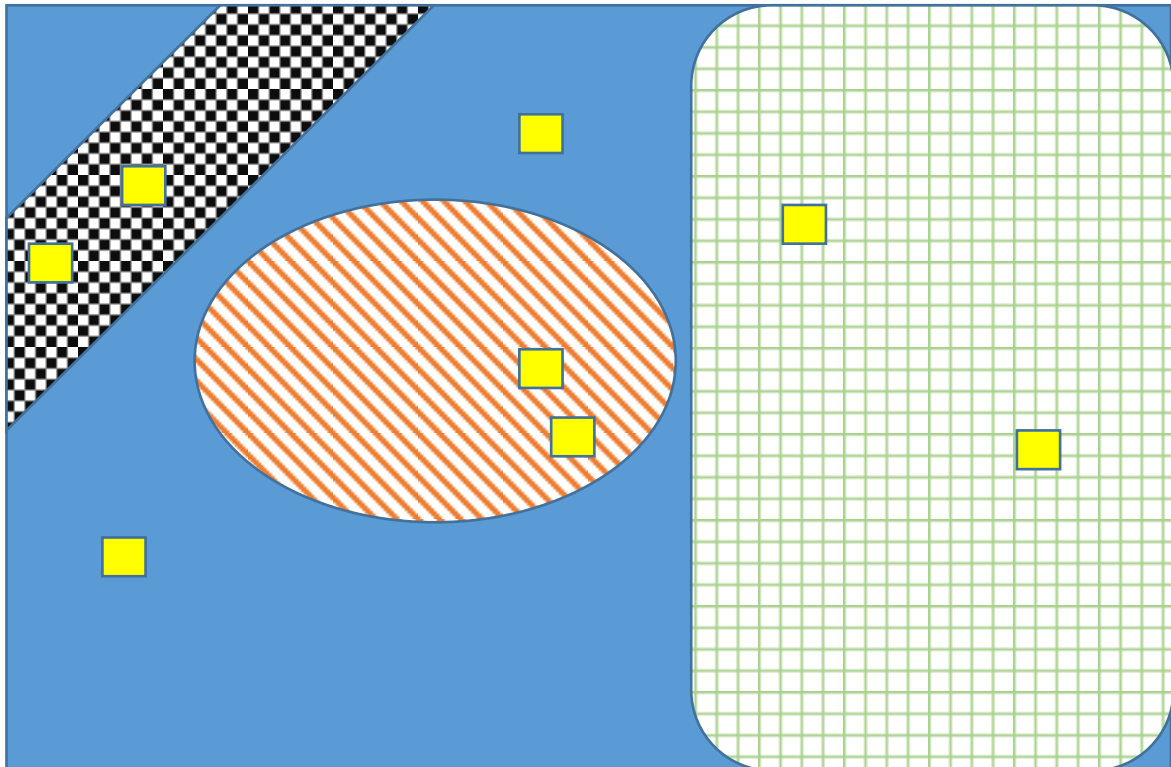
- Systematic sampling is the most intensive approach to sampling. It repeats measurements at regular intervals throughout the site, giving extensive coverage of the site. A key advantage of this approach is that as long as the number of samples, and the size of the sampling plots are large enough, the approach can pick up much of the variability in the landscape, often in proportion to its area in the landscape. Another advantage of this approach is that it eliminates any potential bias of site selection based on researcher choice of site. The disadvantage is that its intensive sampling can be very time consuming, and is often difficult to achieve in projects even solely devoted to research, so is unlikely to be feasible in most monitoring studies.



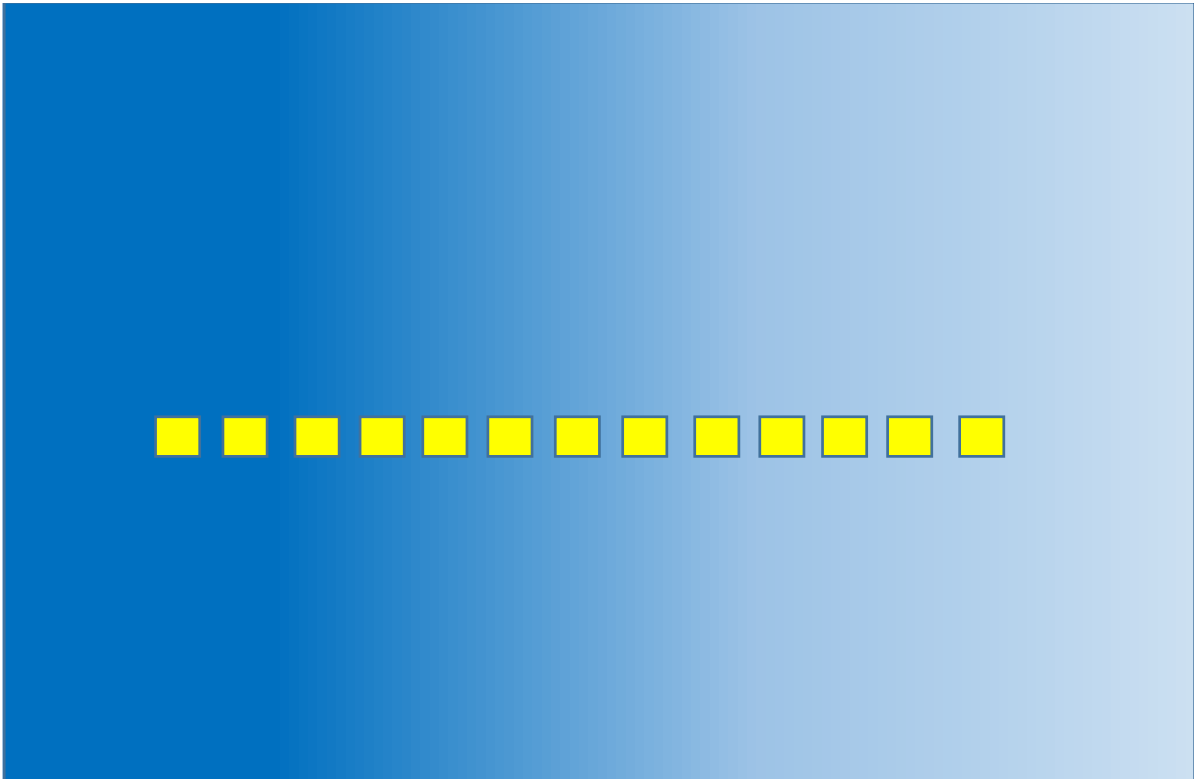
- Random sampling is frequently used when there is only low to modest sampling effort available (precluding systematic sampling). In this approach, sampling sites are selected at random. For example, the site is divided into a grid on a map, and numbers are randomly generated (e.g. on a tool such as: <https://www.random.org/widgets/> ) to select which grids are sampled. This approach is often the best choice when little is known about the site- providing the best balance of fewer sampling points while avoiding bias in selecting sites. However, as seen in the picture below, it could be effective in homogenous areas, but in variable landscapes, it will fail to detect gradients, and often key hotspots of variability. This can often “mask” the effect of management, because measurements across individual sites are so variable.



- **Stratified random sampling:** In this approach, the landscape is divided into “types” (areas that are different from one another, but relatively similar within each type). Looking at the picture below, the 4 different landscape types (black checkered, solid blue, striped red, and hatched green) would be designated as distinct areas (based on different potential criteria, such as vegetation, hydrology, soil type, slope, aspect, land use history, etc.)—see below (page 9) for more information on stratification. Once these types are designated, each will be sampled randomly. The benefit of this approach is that it separates out key landscape variation that is likely to affect the impacts of a management trial, while allowing for lower intensity sampling. It is often biased to the type of landscape variation that is more obvious, and if there’s a gradient rather than distinct patches, it is difficult to implement.



- Gradient sampling: When the landscape varies across one's management trial, but there aren't discrete types of boundaries, the gradient sampling approach is often effective. This can capture variation that is more gradual across the landscape (e.g., upslope to downslope, the wetland bottom up to the top of its banks, a stream bank from its edge to the upland). Sampling across the variation allows the data to delineate different zones of variation (rather than pre-determined variation in the stratified sampling approach). It provides a sensitive approach to mapping variation across the landscape, but can be intensive to sample.



- Other approaches: The approaches that we feel are most relevant in California's grasslands and oak woodlands are included here. Many other sampling approaches are available, and are reviewed in Elzinga et al. 2001.



### Criteria for stratifying the landscape

Variable	Examples of division	Resources to guide stratification
Overall site conditions (based on soil, vegetation, etc)	Ecological Sites	NRCS's Ecological Site descriptions, where available, are a strong tool for stratifying sites at larger scales (e.g. across a county) <a href="https://esi.sc.egov.usda.gov/ESI_Rangeland/frmMain.aspx">https://esi.sc.egov.usda.gov/ESI_Rangeland/frmMain.aspx</a>
Vegetation type-coarse divisions	Herbaceous vs. woody	Google earth <a href="https://www.google.com/earth/explore/products/">https://www.google.com/earth/explore/products/</a> aerial photos, site map
Vegetation type-subtle distinctions	Native vs. exotic Invaded (e.g. by medusahead, goatgrass) vs. uninvaded Forb vs. grass	These more subtle distinctions often rely on walking the area and mapping areas of different vegetation. There will likely be many areas that are "in between". Some progress has been made at using remote sensing (e.g. aerial photos) to determine patches
Soil type	Sandstone vs. serpentine Clay vs. sandy	<a href="http://casoilresource.lawr.ucdavis.edu/gmap/">http://casoilresource.lawr.ucdavis.edu/gmap/</a>
Other soil characteristics	Depth Texture Moisture	More subtle distinctions than soil type will require sampling. Some of these (particularly depth) can be measured with remote sensing.
Climate	Mean annual temperature and precipitation Seasonality of precipitation	<a href="http://ipm.ucanr.edu/WEATHER/wxactstnames.html">http://ipm.ucanr.edu/WEATHER/wxactstnames.html</a> <a href="http://www.cimis.water.ca.gov/">http://www.cimis.water.ca.gov/</a>
Slope	Slope angle (steep vs. gradual)	<a href="http://www.library.ucsb.edu/mil/usgs-topo-maps-california">http://www.library.ucsb.edu/mil/usgs-topo-maps-california</a>
Aspect	North- vs. South-facing	USGS topographic maps: <a href="https://nationalmap.gov/ustopo/">https://nationalmap.gov/ustopo/</a>
Disturbance history	Fire frequency, intensity, timing, time since last fire Flood frequency, duration, depth, time since last flood	Often will rely on local landowner recollection. In some cases, can use FEMA data, or local newspaper accounts.
Management history	Previous land use (e.g. specific crops, fertilization, irrigation)	Often will rely on local landowner records. Some can be assessed with remote sensing/ aerial photos.

### **Timing of monitoring:**

As with the location of sampling, the timing of sampling can impact the results of the monitoring data. California's seasonality of precipitation can greatly alter measures of ecosystem services, with many ecosystem services best measured in a particular time of year. Similarly, ecosystem services differ in how quickly they change in response to management. Some measure (e.g. plant production, vegetation composition) can often be detected within the year, but others (e.g. changes in soil carbon, water holding capacity) can take years to decades to be detectable. Others (e.g. water infiltration) can degrade over a relatively short amount of time (within a year), but may take many years to recover. For each ecosystem service, described below, guidelines on the best timing for sampling are provided.

For many ecosystem services, repeated sampling over the long-term is important for determining long-term changes, and for detecting how management effects change year-to-year depending on weather conditions. This is particularly important in California, simply because the weather can be so variable year to year, that the year-to-year fluctuations in weather may cause greater changes in ecosystem services than the management practice of interest. Coupling on-the-ground measures with long-term aerial images can be particularly insightful in terms of assessing spatial changes over time (e.g. in the spread of some types of vegetation, in the flooding patterns in a riparian area or vernal pool, etc.). Google earth's timeline feature can provide this function over a number of years, and Planet.com provides free (for now) coarse-scale imagery from California on a monthly basis (but is relatively new, so only provides data for the last couple of years, <https://www.planet.com/>).

### **References on sampling design:**

US Forest Service [https://www.fs.usda.gov/Internet/FSE\\_DOCUMENTS/fsbdev3\\_021209.pdf](https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/fsbdev3_021209.pdf)

Elzingha, Salzer, Willoughby and Gibbs. 2001. Monitoring plant and animal populations. Blackwell Scientific, Malden, Massachusetts, USA.

National Drought Mitigation Center, University of Nebraska, Lincoln.

<http://drought.unl.edu/ranchplan/InventoryMonitor/ForageRange/RangeEcologicalSite.aspx>

Pellant, Shaver, Pyke, Herrick. 2005. Interpreting indicators of rangeland health, version 4. Technical reference 1734-6 US Department of Interior, Bureau of Land Management, National Science and Technology Center, Denver, CO. BLM/WO/ST-00/001+1734/REV05

Swanson, et al. 2006. Nevada Rangeland Monitoring Handbook

<https://www.unce.unr.edu/publications/files/ag/2006/eb0603.pdf>

### **Special considerations for soil measurements:**

**Heterogeneity:** In general, soil conditions are highly variable, even over small spatial scales. To compensate for this, multiple soil samples are taken within a given plot. For point measures such as compaction or infiltration, individual measures are taken, and often averaged by plot (unless the question is how a given management practices changes variability in these conditions). For costly measures that require lab analyses (e.g. for soil fertility or soil C), multiple soil samples within a given plot are often mixed together before they are sent in for analysis, with that analysis providing the average value across those soil cores.

**Soil depth.** The depth of sampling is critical to consider, depending on your question, and the comparisons you are trying to make. The standard soil depth measured is the top 15 or 20 cm, which tends to be the layer of soil with the highest organic matter, nutrients, and biologic activity in grasslands. However, if one wants to compare annual invasive grasses with native perennial grasses or woody species, these latter species have far deeper rooting profiles, and much of their effect on the soil may be seen deeper in the profile (e.g. at 50-100 cm depths). These deeper depths are also critical for storage of soil moisture that is less vulnerable to evaporation, and soil carbon that is less vulnerable to disturbance (e.g. gopher mounds). When measuring these deeper depths, it is best to sample by layer (e.g. 0-20 cm, 20-40cm, 40-60 cm, 60-80 cm, 80-100cm), because the effects deeper in the soil may be masked when mixed with the topsoil.

**Timing of measurements.** The best timing for soil measurements will differ depending on the variable of interest. Most soils are difficult to sample when they are dry, so many measurements are preferable logistically during the rainy season, once soils are wet (roughly December- early April). Measures such as soil carbon, total soil nutrients, and bulk density will change little over the season (and will only gradually change over the years), but measures such as soil water availability or available nutrients can change rapidly across the growing season, and may require multiple measurements during the year, if your question of interest is focused on these. Measures such as soil compaction can be very sensitive to soil moisture changes, and thus must be done at a similar moisture level across all plots.

**Methods of sampling.** Because many soil properties vary greatly by depth (even across a few centimeters of depth), it is critical to collect a depth sample that includes an equal proportion of each depth. While this can be done by careful digging with a trowel or shovel, it is most easily done with a soil probe or soil auger, which are readily commercially available.

**Soil bulk density.** The mass of soil per unit volume is often an important measure on its own (gives an indication of soil compaction and soil porosity), but it is a critical measure when one wants to convert a soil measure from a concentration (e.g. soil % C or %N) to an area basis (e.g. grams of carbon per m<sup>2</sup>), which can be particularly important for assessing measures such as carbon storage of an area. To take bulk density, it is best to use a special type of coring device: with an outer cylinder that has a

beveled head, and an internal cylinder to collect the soil. This is so that the process of gathering the soil doesn't compact the soil in the corer. Cores should be at least 5, and ideally 10 cm diameter. For example: <http://www.ams-samplers.com/3-x-6-scs-complete.html>

Adapted from Robertson et al. 1999, Chapter 4; Grossman and Reinsch (in Dane and Topp) 2002 Chapter 2.1

### Materials

- Hammer-type soil corer- with coring attachment for depth appropriate to your sampling
- Coring sleeves (for inside the corer)
- Knife or spatula
- Plastic bag (1 per sample)

### Procedure- field:

- It is best to sample at moderate water contents—at higher water contents coring can cause compaction, at lower water contents it is difficult to drive the cylinder into the ground and the corer can snap
  - If soils are rocky, see Dane and Topp, page 205 for additional sampling needs
1. To ensure that the corer can move unimpeded into the soil, clear all plant material (live and dead) from the soil surface
  2. Take the soil core to the desired depth.
  3. Lift the cylinder out of the soil (if it's difficult, use the hammer in reverse to nudge the core up). Check to make sure the soil does not fall out the bottom of the core—ensure that soil is flush with the *bottom* of the core sleeve. To ensure that compaction is minimal, be sure that the depth of the soil inside the sleeve matches the depth of sampling. If not, it is best to take another core.
  4. Remove the sleeve from the soil cylinder and place soil core into a ziploc bag.

### Procedure- lab:

1. Place soil into large weigh dish or small bag and dry at 105°C until there is no more mass loss (need to determine how long this is for each new site, usually 24- 48 hours).
2. Weigh soil

### Calculations:

$$\text{Bulk density (g/cm}^3\text{)} = W/V$$

W= oven-dry soil weight in grams

V= volume of core in cm<sup>3</sup>

The volume is the core of the cylinder sleeve, not the overall soil corer

Bulk density typically ranges between 0.6 and 1.8 g/cm<sup>3</sup> (more typically 1-1.4)

**Alternative methods for bulk density** are described by NRCS:

[https://www.nrcs.usda.gov/Internet/FSE\\_DOCUMENTS/nrcs142p2\\_050957.pdf](https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_050957.pdf)

**References for soil sampling:**

Carter and Gregorich. 2008. Soil sampling and methods of analysis, 2<sup>nd</sup> edition. Canadian Society of Soil Science. CRC Press. Boca Raton, Florida.

Dane and Topp. 2002. Methods of Soil Analysis. Part 4: Physical Methods. Soil Science Society of America. Madison, Wisconsin.

Logsdon, Clay, Moore, and Tsegaye. 2008. Soil Science: Step-by-step field analysis. Soil Science Society of America, Madison, Wisconsin.

NRCS Soil Quality Test Kit Guide

[https://www.nrcs.usda.gov/Internet/FSE\\_DOCUMENTS/nrcs142p2\\_050956.pdf](https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_050956.pdf)

Robertson, Coleman, Bledsoe and Sollins. 1999. Standard soil methods for long-term ecological research. Oxford University Press, Oxford, England.

Soil quality for environmental health. <http://soilquality.org/home.html>

Westerman, 1990. Soil testing and plant analysis. Third edition. Soil Science Society of America. Madison, Wisconsin, USA

## **Monitoring measurements:**

**Management practices:** In order to maximize what can be learned from a management trial, detailed records of the management are important, especially when comparing across multiple management trials. Important details to document include:

- What was done, specifically? (What type of fertilizer? How many livestock for how long? Which species were seeded, at what rate?). Be sure to include all management practices that occur (e.g. in restoration, that includes site preparation, site planting, and follow-up site maintenance).
- When was it done? Note the specific day/year, as well as if there were any cues used to indicate proper timing for the management.
- What were the specific goals of management?
- To what extent was the desired management achieved? What were the hurdles to this (e.g. weren't able to graze down the noxious weeds to the extent desired because of low stocking rates in large pastures).
- How many labor hours did the management activities take? Over what time period?
- What was the cost?

**Plant production:** Plant production (also known as aboveground primary production) is a measure of the amount of biomass gained by plants in a given time period, usually over a growing season, but sometimes considered at more frequent intervals. The overall biomass produced is often used as an indicator of forage production, but when there is substantial cover of unpalatable plants (e.g. late-season medusahead, goatgrass or yellow starthistle), a better indicator of forage production would be to measure just the palatable plants.

**When to measure.** To assess forage production, samples are typically taken at “peak biomass”, the time in the spring when biomass is at its highest, but largely still green (often around mid-April). The timing of peak biomass will vary by site, year, and depending on vegetation. For example, for a site dominated by wild oats and soft chess, peak biomass will be at least a few weeks earlier than a site dominated by medusahead or goatgrass.

To get a better sense of the timing of biomass production (e.g. which pastures support more plant growth through the fall and winter), biomass measures can be taken at various time points throughout the growing season (e.g. December, late February/early March, mid- to late-April, and late May/early June).

Effects of management on biomass can occur in days to years, with short-term effects and long-term effects often differing.

**How to measure.**

Clipping. Clipping is the most common, and best quantitative method.

- Lay out a ring or quadrat of known area (common areas sampled range from .25 m<sup>2</sup> to .5 m<sup>2</sup>), and can be the shape of a circle, rectangle, or square
- Biomass is projected as any plant material that lies within the 3-D volume of the sampling area (project the sampling quadrat aboveground). Some estimate biomass based on all of the biomass in that 3D volume, others only account for plants rooted in the sampling area. Note which method is used (Bonan 2013 prefers the volume approach, but this can be difficult to reliably assess in grasslands, thus moving plants as “in” or “out” of the sampling area based on whether they are rooted there is also acceptable, and often more consistent in grasslands, especially since the sampling grid can lodge plants)
- Gather all clipped biomass into a paper bag
- Dry the paper bag with its contents, in an oven at 50-60°C (122-140 °F) for 1-2 days
- Weigh biomass (without the bag)

This procedure is robust in any ungrazed area. It is always an underestimate, because it does not account for biomass that is consumed by various herbivores (insects, small mammals, large mammals). However, in ungrazed areas, the biomass taken by herbivores is often assumed to be minimal.

In areas that are grazed, this method can be used for standing biomass, but, on its own, cannot be used as a measure of forage production, because it can't account for the forage consumed by livestock. To assess production in a grazed area, a temporary cage (grazing

exclosure) must be used. These can be relatively small (e.g. 1m<sup>2</sup>), and to be effective indicators of production in a grazed area, must be measured, and then moved to a new location at least once each year. However, for maximum effectiveness (since grazing can stimulate or decrease production), these cages should be in place for a few weeks, measured, and then moved (with the cumulative measures over the year determining total seasonal production).

The clipping approach outlined here is similar to that for Residual Dry Matter (RDM), the amount of vegetation left, after grazing, before the start of a new growing season. The key difference is that RDM measures assume substantial herbivory by livestock, and the timing of RDM measures differ, occurring in the late summer/ early fall, before the autumn rains begin. RDM: Bartolome, Frost, McDougald. 2006. Guidelines for residual dry matter on coastal and foothill rangelands in California. <http://anrcatalog.ucanr.edu/pdf/8092.pdf>

**Other measures that are commonly used include:** (see the reference section, below for details on these alternatives).

- Clipping a subset of vegetation, and on this same area, assessing percent cover and vegetation height. This allows one to determine an allometric equation, using height and percent cover measures, and calculating expected biomass from these. The accuracy of this method varies greatly depending on vegetation structure.
- Rising plate/ disc method
- Photographs/ visual ranking
- Robel pole
- Livestock production (livestock weight gain/period of time)
- Remote sensing/ drones- good landscape level patterns (Malmstrom et al)

**Forage quality.** The quantitative determination of forage quality is determined by clipping vegetation, drying it (as above), and then sending it out to an analytical lab for forage quality. The timing of when forage is collected for quality will have large effects on the results, since most of the indicators of forage quality change significantly over the growing season, with better forage quality early in the season, when biomass is low, and lower forage quality after plants grow substantially (e.g. between late February and April), and then plummeting after the plants senesce at the end of the spring. Common indices of forage quality include:

- Tissue %N, protein analyses- Either of these can give a sense of the nitrogen present in plant tissue.
- Fiber digestibility- These analyses can be expensive, but give a good indication of how much of the forage material is digestible. Common measures include total fiber (neutral detergent fiber, NDF), acid digestible fiber (ADF, which is a measure of the less digestible fraction), and specific compounds such as lignin.



Labs that can measure forage quality include:

<http://anlab.ucdavis.edu/>

Increasingly, methods are being developed to assess forage quality by remote sensing and aerial photographs, or by hand-held optical devices.

**References on plant production and forage quality:**

Bonan. 2013. Measurements for terrestrial vegetation. 2<sup>nd</sup> edition. Wiley-Blackwell, Hoboken, NJ.

Bureau of Land Management's National Applied Resource Center. 1999. Sampling Vegetation Attributes. [https://www.nrcs.usda.gov/Internet/FSE\\_DOCUMENTS/stelprdb1044175.pdf](https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1044175.pdf)

Fahey and Knapp. 2007. Principles and standards for measuring primary production. Oxford University Press. Oxford, England.

Harmony, Moore, George, Brummer and Russell. 1997. Determination of pasture biomass using four indirect methods. Agronomy Journal 89: 665-672. <https://cals.arizona.edu/classes/ram456a/Harmony1997AJ89-665.pdf>

Mannetje and Jones. 2000. Field and laboratory methods for grassland and animal production research. CABI Publishing, New York, USA.

**Vegetation composition:** Measuring the composition of the plant community can address many key goals of management, including: plant diversity, plant structure (as suitable for multiple wildlife species), change in dominance of species, native vs. exotic species prevalence, the prevalence of noxious weeds, the prevalence and phenology of pollinator plants, and the prevalence of palatable vs. unpalatable (and sometimes toxic) plants. All of these questions can be addressed when percent cover methods, by species, are utilized to measure vegetation composition. Percent cover, by species, is far more sensitive to detecting vegetation changes than a simple change in presence/absence of species, or a count of species richness (without measuring their relative prevalence).

***When to measure.***

As with plant biomass, the timing of sampling matters when assessing vegetation composition, with the ideal times varying by year, by site, and depending on which species are dominant. The ideal time to measure will also vary based on your target questions.

- For overall community composition (to assess diversity, the phenology of pollinator plants, etc.), multiple time points in the spring must be sampled.
  - o Early spring sampling should coincide with the 1<sup>st</sup> peak bloom of grasses and forbs (usually mid-March). Many of these species (especially wildflowers) are undetectable in later samplings, as they shatter when they dry.
  - o Mid-spring sampling (usually early to mid-April to early May) is ideal for assessing most annual exotic grasses (e.g. wild oats, soft chess), and native species such as purple needle grass.
  - o The need for late-spring sampling depends on the prevalence of later-season species. For noxious weeds such as medusahead and goatgrass, a late-May sampling is often important to capture their percent cover (this is rarely captured well at earlier time points). This timing can also be ideal for many native grasses (e.g. wild ryes). For summer species such as yellow starthistle and native tarweeds, even later sampling may be necessary (into July or August).
- Measuring less frequently is possible, depending on the key questions, and the species at the site. For example, if the main question is focused on who the dominant grasses are, often a late-spring sampling on its own will be adequate (species like wild oats are easy to identify even after they've dropped their seeds). If no late season species are prevalent, a mid-season sampling can suffice.
- At times, an important response of vegetation is not a change in percent cover, but a change in phenology of peak growth and flowering (e.g. some management practices can extend, or truncate the growing season). In these cases, more intense sampling (e.g. on a weekly basis) may be needed to address this question.

### ***How to measure.***

There are a number of ways to assess percent cover quantitatively, and the effectiveness of these vary depending on your priority questions, vegetation structure, composition, and level of sampling intensity possible. A good overall review of which methods will be best under a given set of conditions can be found here:

[http://legacy.juniata.edu/projects/it110/ms/References/361\\_Marine%20Science%20Field%20methods/Coastal%20veg%20sampling/1\\_veg%20sampling%20methods.pdf](http://legacy.juniata.edu/projects/it110/ms/References/361_Marine%20Science%20Field%20methods/Coastal%20veg%20sampling/1_veg%20sampling%20methods.pdf)

- Two different quantitative methods will be described here, as these are often the most suitable for herbaceous vegetation determination. Different methods (as described in Elzingha et al. 2001) should be used when woody cover is a key goal of sampling. Quadrat sampling and point intercept methods both provide robust (and highly correlated) measures of plant percent cover. In both approaches, it is important to include bare ground, and litter (dead plant material) in the percent cover estimates.
  - Quadrat sampling tends to better detect rare species at a site, and is particularly effective when small-scale (e.g. areas around 10m<sup>2</sup>) stratification of vegetation occurs or in small-scale experimental plots. Drawbacks of this approach include: it tends to be more variable across different individual observers, and can be particularly difficult for assessing % cover of fine-grasses, particularly when they are intermixed. It is effective at quickly identifying large changes in vegetation, but will not detect more subtle changes in percent cover (particularly for species with low cover). Quadrat percent cover estimates are very sensitive to the time of year sampled, as that determines how visible different species are.
  - Point intercept sampling tends to be more consistent across observers, and can be particularly effective across large areas, and to identify gradients. It tends to miss detection of rare species, and can be more intensive sampling than the quadrats. This method requires more intense sampling, and is usually not suitable for relatively small management trials (e.g. 10 m x 10 m area).

**Quadrat sampling.** The size of the quadrat will vary based on vegetation density and structure, but generally a 50x50cm quadrat, or a 1m x 1m quadrat is common in California's grasslands.

The number of quadrats and where they are sampled depends on the size and heterogeneity of the area to be sampled. A general rule of thumb is to sample 40-50 plots (Elzingha et al. 2001). In areas that are relatively homogeneous, transects can be laid out and quadrats taken at regular, or random points along the transect (each transect is considered one sample unit, and should be long enough to capture most of the variation along the site). For example, along a 50 meter transect, quadrats can be sampled every 5 meters. In smaller areas that don't allow for transects, quadrats can be located randomly within the experimental, and then the control areas.

- At the randomly chosen site (over the whole site, or within your stratified random sampling location), lay out your transect in a randomized direction.
- The quadrat is placed on the ground (it is often helpful to mark, as a reference point on the quadrat, along one of the corners, the edges of a box that would represent 1% cover (e.g. in a 1m<sup>2</sup> quadrat, a 10 cm x 10cm quadrat)
- Vegetation that is pushed over by the quadrat, is moved to split vegetation that is inside vs. outside of the quadrat
- List all species seen in the plot
- For each species, identify its percent cover, into the following cover class bins. When doing this, remember that the calculation of cover will be the mid-point of this range, so rather than struggling with determining if percent cover is under or over 25%, for example, determine if it is closer to 15.5% or 38%.

Cover class	Mid-point used in calculation
Less than 1%	0.5%
1-5%	3%
6-25%	15.5%
26-50%	38%
51-75%	63%
76-95%	85.5%
96-100%	98%

A good guide for assessing % cover can be found in Point Blue's monitoring handbook on pages 24 and 25: [http://www.pointblue.org/uploads/assets/admin/RMN\\_Handbook\\_Jan\\_2016.pdf](http://www.pointblue.org/uploads/assets/admin/RMN_Handbook_Jan_2016.pdf)

**Point intercept sampling.** Transect numbers and lengths will depend on the area to be measured, but they should, cumulatively, cover most of the heterogeneity found in the sampling area. Measures of point intercept require at least 384 points to determine 50% cover at a +/- 5% accuracy range (Elzinga et al. 2001). Fewer points along more line transects is the most desirable approach to assess the heterogeneity across a site.

- At the randomly chosen site (over the whole site, or within your stratified random sampling location), lay out your transect in a randomized direction.
- Every one meter along a 50 meter transect (or more frequently in a small transect), drop a pin (let it randomly drop), and then adjust it to be sure it is vertical.
- Record all plants that hit the pin (from the top canopy to the ground surface). Include litter layer, bare ground, and rocks. Record each species only once, even if it crosses the pin multiple times.

## Other measures:

Many other approaches are also available, both quantitative and qualitative. See references below for a complete list of alternative methods.

Semi-quantitative methods are generally not publishable (and not accepted into some databases), but can be a strong tool for quick classification of the vegetation in broad areas. This uses a broad scale visual estimate of % cover, into broad cover classes. Examples include:

- Dry weight rank method:  
[https://www.fs.fed.us/psw/publications/documents/psw\\_rn410/psw\\_rn410.pdf](https://www.fs.fed.us/psw/publications/documents/psw_rn410/psw_rn410.pdf)
- Lists of species, along with a visual ranking of: Dominant, Abundant, Frequent, Occasional, Rare

Qualitative methods include

- Lists of species found as walking through a site
- Photo points- can be used in some cases to assess dominants at the canopy level, but are very sensitive to the timing of photos, compared to plant phenology. Some vegetation changes (e.g. invasion of medusahead into an annual grassland) can be detected at certain times of the year with aerial imagery.

Resources for identification of California grassland and oak woodland species include:

- CalFlora <http://www.calflora.org/>
- DiTomaso. Grass and Grasslike weeds of California, and Broadleaf weeds of California. <http://cal-ipc.org/resources/booksandcds/grasses.php>
- Forero et al. Field guide for common California rangeland and pasture plants <http://ceshasta.ucanr.edu/files/234771.pdf>
- Sampson et al. California grasslands and range forage grasses. [http://ucanr.edu/sites/UCCE\\_LR/files/180484.pdf](http://ucanr.edu/sites/UCCE_LR/files/180484.pdf)
- Smith. 2014. Field guide to grasses of California. University of California Press
- UC IPM [http://ipm.ucanr.edu/PMG/weeds\\_intro.html](http://ipm.ucanr.edu/PMG/weeds_intro.html)
- A number of good guidebooks exist for California wildflowers, many specific to the local region. A favorite for northern California is: Parker, 2015. Wildflowers of California's North Coast Range. New Creek Ranch Press.

## References for measuring vegetation composition

- Bartolome, Hayes and Ford. 2007. Monitoring California grasslands for native perennial grasses workshop handbook.  
[http://www.elkhornsloughctp.org/uploads/files/1184008843Monitoring%20Handbook%20Outline\\_LF3.pdf](http://www.elkhornsloughctp.org/uploads/files/1184008843Monitoring%20Handbook%20Outline_LF3.pdf)
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[https://www.nrcs.usda.gov/Internet/FSE\\_DOCUMENTS/stelprdb1044175.pdf](https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1044175.pdf)
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<https://www.blm.gov/nstc/library/pdf/MeasAndMon.pdf>
- Kercher, S. M., C. B. Frieswyk, and J. B. Zedler. 2003. Effects of sampling teams and estimation methods on the assessment of plant cover. *Journal of Vegetation Science* 14:899–906.
- Porzig, E., N.E. Seavy, R. T. DiGaudio, C. Henneman, and T. Gardali. 2016. The Rangeland Monitoring Network Handbook V1.0. Point Blue Conservation Science, Petaluma, California.  
[http://www.pointblue.org/uploads/assets/admin/RMN\\_Handbook\\_Jan\\_2016.pdf](http://www.pointblue.org/uploads/assets/admin/RMN_Handbook_Jan_2016.pdf)
- Rodwell. 2006. The National Vegetation Classification: User's Handbook. Joint Nature Conservation Committee. [http://jncc.defra.gov.uk/pdf/pub06\\_NVCusershandbook2006.pdf](http://jncc.defra.gov.uk/pdf/pub06_NVCusershandbook2006.pdf)

**Water availability.** In California’s Mediterranean ecosystems, water availability is a key constraint for plant growth, and water supply is a critical ecosystem service provided by our working landscapes. Multiple factors control water availability (e.g. precipitation, vegetation water use, soil infiltration and storage, ground water dynamics), and thus different indicators are used to give a relatively quick assessment of management effects on water availability, depending on the scale of interest.

Broad-scale effects on water export from a system can be assessed by measuring the duration and amount of stream flow. These can be assessed qualitatively, but require infrastructure for quantitative measurements, which will not be covered here. Databases also exist with measured streamflow, that can be useful in comparing areas close to your site across different months or years:

<https://maps.waterdata.usgs.gov/mapper/index.html>

<https://cdec.water.ca.gov/>

The measuring approaches described here are important indicators of *the potential* of sites to infiltrate and store water to support plant growth. These are the focal measures in this handbook because they are relatively stable properties of the soil (that management can affect), and thus are more robust measures for monitoring across multiple sites, when sampling can’t take place rapidly across all sites. The amount of water in the soil at a given time can change rapidly, due to precipitation, plant transpiration, evaporation and leaching (drainage), and thus will not be a focal measure discussed here.

#### ***How to measure.***

**Water infiltration.** The infiltration of water into the soil (rather than running over the soil surface) is a critical step for capturing precipitation on-site. Depending on your site concerns and questions, there are two key seasonal timings to perform water infiltration tests:

1. Early in the rainy season (or just before). Soils can have some amount of water repellency, particularly when they are dry. This is especially true in areas with plants that have waxes and other hydrophobic compounds, and can be of particular concern after fires. Measuring water infiltration early in the growing season can give a sense of how difficult it is to “wet up” the soil through infiltration. A quick and dirty method to assess this is to dig into the soil after successive rain storms and measure the “wetting front”, how deeply the water percolates.

<https://passel.unl.edu/pages/informationmodule.php?idinformationmodule=1130447039&topicorder=10&maxto=10>

2. During peak rainy season, under saturated conditions. Water infiltration under saturated conditions gives an indication of to what extent the soil can infiltrate additional precipitation, rather than having it run off the surface.

There are a number of different types of infiltrometers that can be used for measurements. These infiltrometers are inserted into the soil surface, and filled with water. The time it takes the water to infiltrate into the soil (and out of the infiltrometer) gives a measure of infiltration. In general, a double-ringed infiltrometer is preferred, giving a more accurate measure under diverse conditions

(Reynolds 2008). This is because the inner ring is measured, but an outer ring is also filled with water, preventing lateral flow from the inner ring (which would overestimate the rate of infiltration). Just using a single-ring could result in faster infiltration than seen under a rainstorm, because of the lateral movement of water. Recent studies have shown that under moist conditions, the single ring and double ring infiltrometers provide similar measurements (Walsh and McDonnell 2012). Thus, if the measures are just being taken when the soils are wet (the system has received a substantial amount of rain to wet up the soil, and it is within a few days after a rainstorm), the single-ring infiltrometer should be adequate, as described here:

[https://www.nrcs.usda.gov/Internet/FSE\\_DOCUMENTS/nrcs142p2\\_052494.pdf](https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_052494.pdf)

When taking measures at more remote sites, where the ability to haul a substantial amount of water is limited, a smaller version is available. This small size isn't as accurate, and it is difficult to get consistent results, and certain soil surfaces (slopes, uneven surfaces) make it tough to measure, but is the only feasible way to measure infiltration in remote sites.

<https://www.decagon.com/en/hydrology/hydraulic-conductivity/mini-disk-portable-tension-infiltrometer/>

A double-ring infiltrometer is more reliable in early-season conditions, or during frequent mid-winter droughts, where soil may not be close to saturation. It is an EPA-approved method, and is generally the most reliable method under variable conditions. An example of a commercially available infiltrometer is: <http://www.turf-tec.com/IN2lit.html>

Steps for analysis include:

- Drive the two rings into the soil (depth depends on the design of the infiltrometer, often around 3 inches)
- Tamp down the inside edges of the soil
- Cover the soil with a splashguard to prevent erosion from the force of water being poured (e.g. plastic wrap)
- Pour the water into the ring(s)—note that the volume of water will vary depending on which infiltrometer is being used, while starting a stopwatch
- Depending on the infiltrometer used, you'll either measure the time it takes for a given amount of water to infiltrate into the soil (when there is no standing water, and the soil surface is still glistening), or the amount of water that infiltrates within a given amount of time.
- If the soil is not saturated, the infiltration test is repeated to assess infiltration on wet soil

When infiltrometers are not available, NRCS has developed a good method to measure infiltration:

[https://www.nrcs.usda.gov/Internet/FSE\\_DOCUMENTS/nrcs142p2\\_052494.pdf](https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_052494.pdf)

A “quick and dirty”, non-quantitative method for water infiltration is to pour a liter of water on top of a small area of soil (e.g. by having a small opening, such as through a soda bottle), and visually assess if water is ponding or infiltrating. This won't be a strong comparison of infiltration rates, but can be a good visual assessment of if there are extreme compaction/ water drainage issues (Butterfield et al. 2006).



### References for measuring water infiltration

ASTM International. Standard Test Method for Infiltration Rate of Soils in Field Using Double-Ring Infiltrometer. <https://compass.astm.org/download/D3385.18647.pdf>

Butterfield, Bingham and Savory. 2006. Holistic Management Handbook: Healthy Land, Healthy Profits. Island Press.

Food and Agriculture Organization. <http://www.fao.org/docrep/s8684e/s8684e0a.htm>

NRCS. Infiltration test [https://www.nrcs.usda.gov/Internet/FSE\\_DOCUMENTS/nrcs142p2\\_052494.pdf](https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_052494.pdf)

Plant and Soil E-library:

<https://passel.unl.edu/pages/informationmodule.php?idinformationmodule=1130447039&topicorder=10&maxto=10>

Reynolds. 2008. Saturated hydraulic properties: ring infiltrometer. *In*: Carter and Gregorich. Soil sampling and methods of analysis, 2<sup>nd</sup> edition. Canadian Society of Soil Science. CRC Press. Boca Raton, Florida. Pp. 1043-1056.

Soil quality for environmental health. <http://soilquality.org/home.html>

Walsh and McDonnell, 2012. The Influence of Measurement Methodology on Soil Infiltration Rate. *International Journal of Soil Science*, 7: 168-176.

Water holding capacity. Water holding capacity is the ability of soil to hold water. This is usually impacted by soil texture, porosity, and soil organic matter (which can act as a sponge to hold water). Particularly in the drier times of the year (e.g. during spring dry-down, or during a mid-winter drought between rainstorms), water holding capacity is critical for providing plant-available moisture. While water holding capacity itself is difficult to measure, the following method provides a good indicator (Robertson et al. 1999, and Romano and Santini 2002). This measure is not sensitive to the time of year it is taken, but is likely to take at least a few years of management treatment until it is expected to change. It may be difficult to wet up soils that are hydrophobic, making this method challenging for those soils. The following method is adapted from: Robertson et al. 1999, and Romano and Santini 2002.

Materials:

- 2mm soil sieve
- Buchner filter funnel
- plastic wrap
- funnel rack
- bin for funnels to drip into
- aluminum weighing tins
- balance
- oven

Procedure:

1. Sieve soil through a 2mm sieve
2. Place approximately 20g of soil into a filter funnel
3. Saturate soil with DI water (gradually pour through approximately 200 ml of water through the soil)
4. Place plastic wrap over the funnel
5. Allow funnels to sit (they will drip down) for 24 hours
6. Place wet soil into a weighing tin
7. Weigh soil
8. Dry at 105°C until there is no more mass loss (need to determine how long this is for each new site, usually 24- 48 hours).
9. Weigh dry soil

Calculations:

For this index, water holding capacity is defined as the % soil moisture the soil retains after draining under gravity for 24 hours at 100% humidity.

$$\% \text{ soil moisture} = (\text{wet weight} - \text{dry weight}) / \text{dry weight}$$

### **References for measuring water holding capacity**

Robertson, Coleman, Bledsoe and Sollins. 1999. Standard soil methods for long-term ecological research. Oxford University Press, Oxford, England. Pp. 293.

Romano and Santini 2002. Water retention and storage. In: DANE, J.H. & TOPP, G.C., eds. Methods of soil analysis. Madison, Soil Science Society America. p.721-738.

**Water quality.** Management of upland and riparian ecosystems have strong impacts on the quality of water. Grasslands and riparian areas can function as buffer strips, filtering sediments, nutrients, pathogens and pollutants from water. On the other hand, erosion and leaching from uplands can compromise water quality. While measuring the full budgets of sediments, nutrients, pathogens and other pollutants requires significant infrastructure (e.g. watersheds with weirs, runoff plots, lysimeter setups), there are a number of indicators of water quality. These include:

Physical conditions: sediment load/ turbidity, temperature

Chemical conditions: nitrate, phosphate, toxins/ pollutants, dissolved oxygen

Biological: algae, macroinvertebrates, pathogens

#### **When to measure:**

As with all monitoring, when to measure depends on the exact nature of the question. To measure maximum loading of pollutants into waterways, most sediments, nutrients and pathogens runoff from terrestrial systems into aquatic systems in significant storms. Thus measurements during and a few days after large storms will provide an idea of the amount of peak loadings that occur. Nitrogen in stream water is at its highest once the soils are saturated enough that water flows through the soil profile into groundwater (around January). Measurements between storms will give an idea of the persistence of these pollutants. Water quality measures can change rapidly due to management, disturbances (e.g. fire, flooding), or weather (individual storms or seasonal patterns). Thus it is difficult to capture a broad general effect with any one measure.

#### **Where to measure:**

The choice of location to measure greatly affects the questions addressed by monitoring. To assess the impacts of a given area, samples are often taken in the stream before it enters that management unit, and after it leaves that management unit. Samples should be taken in areas that are representative of the questions at hand, ideally including a number of sampling points along a stream to assess its overall quality. Stratification of sampling can be appropriate (e.g. in moving streams, slow-moving pools, etc.).

#### **How to measure:**

In general, water quality measures should focus on the issues of most concern for your project (e.g. erosion causing turbidity, land management practices leading to excess nutrients in the water, fecal loading adding pathogens to the water). In-depth manuals exist for comprehensive measures of water quality. Since this handbook focuses on getting measures of multiple ecosystem services, only a few key indicators will be discussed here. Details on more comprehensive suites of measurements can be found in the reference section for water quality. Water quality test kits to measure various indicators are

available from companies such as LaMotte. High-quality numbers can be determined by sending to various analytical labs, including:

<http://anlab.ucdavis.edu/>

[http://cnal.cals.cornell.edu/forms/pdfs/CNAL\\_Form\\_L.pdf](http://cnal.cals.cornell.edu/forms/pdfs/CNAL_Form_L.pdf)

[http://www.soiltestinglab.colostate.edu/documents/water\\_pricelist.pdf](http://www.soiltestinglab.colostate.edu/documents/water_pricelist.pdf)

### **How to measure.**

Taking water samples. Water samples should be taken, when possible, from moving water and away from the stream bank. Minimize disturbance of sediments if entering the stream, and take samples upstream from where you are standing. A sampling bottle can also be affixed to a sampling pole, so that water samples can be taken away from the streambank, without entering the stream.

Samples should be collected in clean glass or plastic containers by submerging the bottle (open side down), and then tipping it up until it fills, then capping it. Care should be taken not to touch the inside of the bottle or cap. Samples should be kept in a cooler while in the field, and then refrigerated until sent to a lab. In general, samples should be sent to a lab quickly. If sending to a lab for water quality analysis, see the specific water testing facility for the quantity of water needed (e.g. UC Davis lab requires at least 250-500 ml, depending on what is being analyzed).

Water clarity. The amount of soil, small organisms (plankton, algae) and other substances in the water can increase its cloudiness, decreasing the amount of light that can filter through water, and increasing water temperature. When these particles settle they can cover organisms (e.g. invertebrates, fish eggs), and can build up to decrease the volume of dams and other water structures for holding water.

Turbidity is a measure of the light that is scattered by suspended particles. This can be measured with electronic turbidity meters (available from various companies, with a cost of at least around \$800). A more inexpensive option is using a turbidity tube. Instructions should be followed on the specific device used. The least expensive is a qualitative assessment available through LaMotte's water testing kit.

Suspended sediments. The amount of sediments in the water is a more direct way of assessing the quantity of sediments that can settle when water movement slows. This can be done in an analytical lab, or by drying the water sample in a 103-105°C oven and weighing the sediments.

Nitrate and Phosphate. Phosphate and nitrate are the key nutrients that, in excess, can lead to eutrophication of water bodies. Water samples should be taken, as described above, and then kept cold and sent to a lab for analysis. For large differences in water nutrients, a water test kit can be used for coarse changes. For example:

[https://www.nrcs.usda.gov/Internet/FSE\\_DOCUMENTS/nrcs142p2\\_050958.pdf](https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_050958.pdf)

### **References on water quality measurements**

- Environmental Protection Agency. 1997. Volunteer Stream Monitoring: A Methods Manual.  
[https://www.epa.gov/sites/production/files/2015-04/documents/volunteer\\_stream\\_monitoring\\_a\\_methods\\_manual.pdf](https://www.epa.gov/sites/production/files/2015-04/documents/volunteer_stream_monitoring_a_methods_manual.pdf)
- Lewis, Tate, and Harper. 2000. Sediment Delivery Inventory and Monitoring: A Method for Water Quality Management in Rangeland Watersheds. UC-DANR Publication 8014  
[http://rangelandwatersheds.ucdavis.edu/publication%20list%20and%20files/lewis\\_8014.pdf](http://rangelandwatersheds.ucdavis.edu/publication%20list%20and%20files/lewis_8014.pdf)
- Natural Resources Conservation Service: Soil Quality Test Kit.  
[https://www.nrcs.usda.gov/Internet/FSE\\_DOCUMENTS/nrcs142p2\\_050958.pdf](https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_050958.pdf)
- US Geological Survey Water Science School <https://water.usgs.gov/edu/waterproperties.html>
- World Health Organization. Water sampling and analysis.  
[http://www.who.int/water\\_sanitation\\_health/dwq/2edvol3d.pdf](http://www.who.int/water_sanitation_health/dwq/2edvol3d.pdf)

**Soil carbon** Soil carbon provides many key roles in an ecosystem. It is critical for providing and maintaining soil nutrients and providing water infiltration and storage. Carbon stored in the soil is also important for greenhouse gas mitigation—with some portions of soil C being stable for thousands of years, providing most reliable storage mechanism.

**When to sample.** Soil carbon changes slowly. Management effects (other than adding compost or other organic materials directly) are expected to take at least 3-5 years before a change is detectable. Seasonal differences are miniscule, thus soil sampling can be done when it is most feasible- when soils are relatively moist during the wet season.

**Where to sample.** Soil carbon can vary in the soil across short distances. Some variation can be relatively easy to predict (e.g. soil carbon is generally higher under shrubs and trees, compared to grasslands), but other variation is inherent for no obvious reason. Thus, it is common to take multiple soil samples and combine them for analysis (to decrease cost of analysis).

Soil carbon also varies greatly by depth from the soil surface. The standard measure is to assess soil carbon in the top 15 or 20 centimeters of the soil. However, depending on your question, going to deeper depths can be beneficial. For example, native grasses or woody species can increase carbon at depth (helping with critical functions such as nutrient and water storage), requiring sampling at multiple depths. See soil sampling section, above (page 11).

**How to measure.** There are two key measures that are indicators of soil carbon.

Soil carbon assesses the percent of carbon in a soil sample, and can be used for quantitative estimates of carbon storage in the soil, when coupled with bulk density measures.

Soil organic matter is indicative of the quantity of all organic constituents, and can include water tightly held by clays. Thus it is a coarser measure of carbon (which comprises approximately 50% of organic matter measures), and can be affected by soil texture and its ability to tightly hold water. Soil organic matter is used as substitute for direct soil carbon because it is much less expensive to measure. It does not directly get at soil carbon, but it does portray the importance of organic matter in terms of its effects on carbon in general, water holding capacity, and for nutrient supply and storage (through ion exchange capacity).

Soil carbon. Soil samples must be sent to an analytical lab for analysis. Labs include:

<http://anlab.ucdavis.edu/>

<http://ccmg.ucanr.edu/files/51308.pdf>

Soil organic matter is most often measured as the mass loss of the soil after being exposed to high temperatures (loss on ignition). This can also be sent to a lab, or can be measured in a basic equipped lab as follows:

Adapted from Robertson et al. 1999

1. Weigh and record id # of crucible and mass of crucible
2. Fill crucible ¼- ½ full with DRY soil (from the drying oven, dried at 105 °C), record mass of crucible + dry soil
3. Combust samples in muffle furnace at 550 °C for 5 hours.
4. Wait for the furnace to cool down to at least 200 C. Once it has reached this point, you can CAREFULLY crack the door open *a little bit* to speed up cooling. You MUST stand behind the door when doing this, and be sure the overhead vent is still on.
5. DO NOT REMOVE THE SAMPLES until the furnace temperature is lower than 60 C! When removing samples, be sure to be wearing temperature resistant gloves (white gloves near the furnace) and safety glasses. If you are using the crucible racks, never touch the racks without gloves! If you aren't using the racks, always use both the gloves and crucible tongs when removing samples.
6. Weigh and record the mass of crucibles + ashed sample. If you have a lot of samples, or cannot immediately weight the samples, keep the samples in the drying oven until you can weigh them, to prevent the samples from picking up water weight.

#### **Calculations:**

When using SOM as a comparative measure (differences in % SOM across sites), calculate % SOM on the basis of ash-free soil:

$$\% \text{ SOM} = ((\text{crucible} + \text{dry} - \text{crucible}) - (\text{crucible} + \text{ashed} - \text{crucible})) / (\text{crucible} + \text{ashed} - \text{crucible})$$



**References for soil carbon:**

Carter and Gregorich. 2008. Soil sampling and methods of analysis, 2<sup>nd</sup> edition. Canadian Society of Soil Science. CRC Press. Boca Raton, Florida.

Logsdon, Clay, Moore, and Tsegaye. 2008. Soil Science: Step-by-step field analysis. Soil Science Society of America, Madison, Wisconsin.

NRCS Soil Quality Test Kit Guide

[https://www.nrcs.usda.gov/Internet/FSE\\_DOCUMENTS/nrcs142p2\\_050956.pdf](https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_050956.pdf)

Robertson, Coleman, Bledsoe and Sollins. 1999. Standard soil methods for long-term ecological research. Oxford University Press, Oxford, England.

Soil quality for environmental health. <http://soilquality.org/home.html>

Westerman, 1990. Soil testing and plant analysis. Third edition. Soil Science Society of America. Madison, Wisconsin, USA

**Soil fertility.** In California's grasslands and rangelands, the most commonly limiting nutrients to plant growth include: nitrogen, phosphorus and sulfur. Soils should provide these nutrients for plant growth, while also retaining these in the soil, preventing loss from the system (both to support long-term productivity of the system, and to avoid pollution of aquatic systems by loss of these nutrients).

There are a number of ways to assess each of the soil nutrients, all of which can be measured by being sent to one of the analytical labs listed below. Soil kits can measure available nutrients, but these are usually only appropriate for intensive agricultural sites with high soil fertility. These kits are not sensitive enough to measure available nutrient differences due to the most common management practices in grasslands and oak woodlands.

- **Total soil nutrients:** This includes all forms of organic and inorganic nutrients. This type of measure is the least sensitive to change over the short term, and tends to have minimal seasonal changes. Thus, it provides a good long-term measure of impacts of a management practice on nutrient stores, and gives a broad comparison of fertility of a site. Its disadvantage is that it isn't a direct measure of the nutrients actually available for plants and soil biota.
- **Available soil nutrients.** To get a sense of the nutrients currently available for biota, the concentrations of inorganic nutrients (e.g.  $\text{NH}_4$ ,  $\text{NO}_3$ ,  $\text{SO}_4$ ,  $\text{PO}_4$ ) in soil solution provide a good indicator. While this is a more direct measure of availability than total soil nutrients, its drawback is that it changes extremely quickly (due to management, weather, plant uptake, etc.), and it is not straightforward to interpret. For example, a low amount of available nutrients could be due to low turnover of nutrients from organic materials, or due to high plant uptake (thus exhausting the soil solution pool).
- **Ion exchange capacity:** Soil mineral particles and organic matter have the ability to temporarily adsorb nutrient ions, and provide a critical mechanism of preventing nutrients from being lost to the system through leaching. Measurements of ion exchange (particularly cation exchange capacity, which is dominant over anion exchange in California soils), provides a measure of to what extent soils can temporarily store nutrients.

**Analytical labs for soil fertility:**

<http://ccmg.ucanr.edu/files/51308.pdf>

<http://anlab.ucdavis.edu/>

[http://cnal.cals.cornell.edu/forms/pdfs/CNAL\\_Form\\_L.pdf](http://cnal.cals.cornell.edu/forms/pdfs/CNAL_Form_L.pdf)

## Other nutrient measurements:

The most ideal measures for soil nutrient availability involve measuring the rates of nutrient provision (e.g. enzymatic assays, net mineralization). These are most feasible by collaborating with a researcher that focuses on these measures. Resins can also be used to measure cumulative nutrient concentrations over time. Again, these can be done in collaboration with a researcher, or through commercial companies such as:

Plant root simulation probes: <https://www.westernag.ca/professionalagronomy/prsanalysis>

Resin capsules: <http://www.wecca.com/SoilMon/Capsule.htm>

## **References for soil nutrients:**

Carter and Gregorich. 2008. Soil sampling and methods of analysis, 2<sup>nd</sup> edition. Canadian Society of Soil Science. CRC Press. Boca Raton, Florida.

Logsdon, Clay, Moore, and Tsegaye. 2008. Soil Science: Step-by-step field analysis. Soil Science Society of America, Madison, Wisconsin.

NRCS Soil Quality Test Kit Guide

[https://www.nrcs.usda.gov/Internet/FSE\\_DOCUMENTS/nrcs142p2\\_050956.pdf](https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_050956.pdf)

Robertson, Coleman, Bledsoe and Sollins. 1999. Standard soil methods for long-term ecological research. Oxford University Press, Oxford, England.

Soil quality for environmental health. <http://soilquality.org/home.html>

Westerman, 1990. Soil testing and plant analysis. Third edition. Soil Science Society of America. Madison, Wisconsin, USA

**Soil erosion control** Soil erosion can be a major impediment to plant production, soil quality, and water quality. Methods to quantify erosion potential vary from a local to landscape scale, and span qualitative to quantitative.

The susceptibility of soils to erosion obviously depend strongly on weather conditions, such as:

- particularly high rainfall events that exceed infiltration ability of the soil, leading to runoff over the soil surface, a major erosive force for soil particles
- high winds that dislodge and move soil particles

There are a number of ways to assess erosion:

- Visual assessment of erosion:
  - Sediment in nearby streams- see water quality measures (above) for turbidity and suspended sediment
  - The presence of rills, gullies, wind-scoured areas, depositional areas. These are well described in:
    - <https://www.blm.gov/nstc/library/pdf/1734-6rev05.pdf>
    - [http://rangelandwatersheds.ucdavis.edu/publication%20list%20and%20files/lewis\\_8014.pdf](http://rangelandwatersheds.ucdavis.edu/publication%20list%20and%20files/lewis_8014.pdf)
- Assessments of erosion potential:
  - % bare ground vs. vegetation cover (dead or alive)- see vegetation composition monitoring (above)
  - Resistance of soil to erosion
    - Soil stability test kit to measure how stable soil is when it is rapidly wet up:
      - <https://www.blm.gov/nstc/library/pdf/1734-6rev05.pdf>
      - [https://www.nrcs.usda.gov/Internet/FSE\\_DOCUMENTS/nrcs142p2\\_051287.pdf](https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_051287.pdf)
      - This is commercially available as the “Jornada Experimental Range Soil Stability Test Kit”
    - Soil shear strength, cohesion: This is a measure of the amount of force that a soil can withstand before it deforms in response to the forces acting on it. This can be measured with a torsional shear vane (which is commercially available). Shear strength increases as soil moisture decreases, so it is important to take measurements at similar times across sites you want to compare, and/or to take soil moisture measurements along with cohesion measurements. The shear vane instruments will have instructions specific to each, but it is important to have consistent pressure on the soil, while rotating the shear vane. This is difficult to do consistently, and thus we’d suggest practicing a few

times before each sampling day, and having the same person measure across sites.

**References for soil erosion potential:**

Carter and Gregorich. 2008. Soil sampling and methods of analysis, 2<sup>nd</sup> edition. Canadian Society of Soil Science. CRC Press. Boca Raton, Florida.

Dane and Topp. 2002. Methods of Soil Analysis. Part 4: Physical Methods. Soil Science Society of America. Madison, Wisconsin.

Lewis, Tate, and Harper. Sediment Delivery Inventory and Monitoring: A Method for Water Quality Management in Rangeland Watersheds. UC-DANR Publication 8014  
[http://rangelandwatersheds.ucdavis.edu/publication%20list%20and%20files/lewis\\_8014.pdf](http://rangelandwatersheds.ucdavis.edu/publication%20list%20and%20files/lewis_8014.pdf)

Pellant, Shaver, Pyke, Herrick. 2005. Interpreting indicators of rangeland health, version 4. Technical reference 1734-6 US Department of Interior, Bureau of Land Management, National Science and Technology Center, Denver, CO. BLM/WO/ST-00/001+1734/REV05  
<https://www.blm.gov/nstc/library/pdf/1734-6rev05.pdf>

**Soil compaction alleviation.** Soil compaction is when disturbances on the site lead to denser soils, with fewer pore spaces for air or water. Compaction can occur generally, or in a given layer of the soil, usually within the top 6 inches of soils in rangelands (Pellant et al. 2005). This compaction can impede plant root growth, water infiltration, and nutrient cycling.

- Visual assessment of compaction:
  - Presence of water ponding on the surface
  
- Quantitative measures of compaction:
  - Bulk density (see above, pages 11-12)
  
  - Penetrometer (or soil compaction tester). These devices are commercially available, measuring how resistant the soil is to penetration. These can be used to measure depth to an impenetrable layer, or the penetration resistance at various depths through the soil profile (for the latter, we highly recommend a digital penetrometer, such as: <https://www.humboldtmg.com/digital-static-cone-penetrometer.html>)

It is important to take multiple replicate measures, due to heterogeneity in soils. Because this measure is sensitive to moisture, it is advisable to also take moisture measures while taking penetrometer measures. This can be done with commercially available soil moisture sensors, or by collecting a soil sample, weighing it wet, then drying it at 105°C and weighing it dry (the difference is the moisture content). Alternatively, being sure to measure at a constant water amount (e.g. after a significant rain when soils are at field capacity), can lead to consistent measures across sites.

**References for soil compaction:**

Carter and Gregorich. 2008. Soil sampling and methods of analysis, 2<sup>nd</sup> edition. Canadian Society of Soil Science. CRC Press. Boca Raton, Florida.

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## **General references on sampling, including multiple methods relevant to California grassland ecosystem services:**

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- Carter and Gregorich. 2008. Soil sampling and methods of analysis, 2<sup>nd</sup> edition. Canadian Society of Soil Science. CRC Press. Boca Raton, Florida.
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- National Drought Mitigation Center, University of Nebraska, Lincoln.  
<http://drought.unl.edu/ranchplan/InventoryMonitor/ForageRange/RangeEcologicalSite.aspx>
- Natural capital project InVEST tool- helps to map estimates of ecosystem services  
<http://www.naturalcapitalproject.org/invest/#what-is-invest>
- Nevada Rangeland Monitoring Handbook  
<https://www.unce.unr.edu/publications/files/ag/2006/eb0603.pdf>
- NRCS Soil Quality Test Kit Guide  
[https://www.nrcs.usda.gov/Internet/FSE\\_DOCUMENTS/nrcs142p2\\_050956.pdf](https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_050956.pdf)
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[http://www.pointblue.org/uploads/assets/admin/RMN\\_Handbook\\_Jan\\_2016.pdf](http://www.pointblue.org/uploads/assets/admin/RMN_Handbook_Jan_2016.pdf)
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<https://www.unce.unr.edu/publications/files/ag/2006/eb0603.pdf>
- University of California ANR, Rangeland Ecosystem Services <http://ucanr.edu/sites/RangelandES/>
- US Forest Service [https://www.fs.usda.gov/Internet/FSE\\_DOCUMENTS/fsbdev3\\_021209.pdf](https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/fsbdev3_021209.pdf)
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