

BUREAU OF LAND MANAGEMENT



Ground-Based Image Collection and Analysis for Vegetation Monitoring

Technical Note 454



October 2021

Suggested citation:

Cox, S., D.T. Booth, and R. Berryman. 2021. Ground-Based Image Collection and Analysis for Vegetation Monitoring. Technical Note 454. U.S. Department of the Interior, Bureau of Land Management, National Operations Center, Denver, CO.

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Production services provided by:

Bureau of Land Management
National Operations Center Information and Publishing Services Section
P.O. Box 25047
Denver, CO 80225

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Bureau of Land Management**

October 2021

Acknowledgments

The authors appreciate the valuable input from the following reviewers and collaborators:

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Marcell Astle, BLM Rawlins Field Office

Jim Cagney (retired), BLM Northwest District Office

Ken Henke (retired), BLM Wyoming State Office

Douglas Johnson, Oregon State University

Dusty Kavitz, BLM Buffalo Field Office

John Likins (retired), BLM Lander Field Office

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Abstract

Vegetation monitoring is integral to maintaining healthy and productive public lands. Virtually all activities on public lands have the potential to degrade native vegetation, with cascading effects of soil erosion, loss of resources, and diminishing ecosystem services. Monitoring vegetation allows land managers to recognize problems and implement management solutions in a timely manner to preserve resources and ecosystem benefits. This technical note describes ground-based image collection for vegetation monitoring, including best practices and equipment details. This technical note also describes image analysis using SamplePoint software, which produces foliar cover measurements with potential accuracy exceeding 90% (Booth et al. 2006). By acquiring and analyzing ground-based images, land managers can monitor more area during a growing season, analyze imagery during the off-season, improve statistical power through larger sample sizes, and maintain permanent records of resources. These benefits allow land managers to make more informed and defensible management decisions.



Introduction

Vegetation monitoring is integral to maintaining healthy and productive public lands. The Bureau of Land Management uses various methods to monitor vegetation, such as line point intercept and ocular estimation. Digital images acquired vertically (nadir) over study plots and field transects provide a permanent visual record of the resource, suitable for numerous methods of analysis, both automated and manual. Ground-based image monitoring can be completed faster than other quantitative field methods, provides managers with a permanent record of the resource that can be reanalyzed or used for different purposes later, and allows rangeland specialists to divide their time efficiently by acquiring images during the growing season and analyzing them later in the year when vegetation is dormant and unsuitable for field identification.

Unlike aerial orthoimagery, which emphasizes continuous image coverage of an area, ground-based image collection strategies emphasize discontinuous, high-resolution, high-quality, consistent sampling, so images reveal fine-scale details, such as grass blades, pebbles, soil texture, flower petals, and similar attributes that frequently facilitate feature classification to the level of functional group (forb, grass, litter) or species. Derived measurements from these images are treated as individual observations suitable for statistical analysis.

Multiple methods and variations exist for ground-based image collection. The descriptions of three recommended image collection methods are subsequently described, but numerous variations to these methods are equally valid.¹

- The **transect** method involves acquiring images along a field tape at 5-meter intervals, usually at

permanently monumented transect locations. This method is congruent with traditional sampling methods, such as line point intercept. It is not statistically robust since each transect is considered the sampling unit—plots near each other are spatially autocorrelated and cannot be considered independent samples (Stohlgren et al. 1998; Goslee 2006). Transects are suitable for measuring trend of representative areas but are statistically insufficient for describing a large area of interest (Coulloudon et al. 1999).

- Sampling plots in a **systematic grid** over an entire area of interest achieves a broad measure of that area. Plots are located far apart and are thus not spatially autocorrelated to the degree of plots along a transect. Since each image is an independent sample, this method results in higher sample sizes and is more statistically robust than the transect method. Though the net area of plots may be equal between the transect and systematic grid (e.g., 20 plots of 1 m² each), high measurement precision is achieved more efficiently with larger sample size rather than larger plot size (Xiao et al. 2005). Additionally, because a systematic grid is inherently spatially balanced, the results can be extrapolated across the entire area of survey. Traveling to all points in a systematic grid, however, is more time consuming than sampling with transects.
- The **random plot** method utilizes plots that are randomly placed within the area of interest, often with a minimum buffer distance to improve spatial balance, resulting in less risk of systematic bias when measuring a heterogeneous vegetation distribution (Curran et al. 2020). Whysong and Miller (1987) reported that random plot placement was less susceptible

¹ For detailed information about plots and transects, see Herrick et al. 2017.

to bias due to vegetation clumping and resulted in a lower Type I error (false positive) than plots placed systematically, regardless of scale. Traveling to 20 random points typically involves less distance than traveling to 20 systematic plots, resulting in time savings.

The steps described in this technical note comprise a two-stage sampling design described by Elzinga et al. (1998). Each image is the principal sampling unit and is treated as an independent sample acquired using any of the three methods previously described (transect, systematic grid, or random plot). Individual sampled points

within each image are secondary sampling units and are also acquired using any of the three methods previously described. This technical note contains two parts that describe each of these two sampling units. Part 1 provides a protocol for ground-based image collection (principal sampling unit) to monitor vegetation, including equipment recommendations, instructions and tips for camera settings, sampling documentation, data storage, and steps for the three image collection methods. Part 2 describes a method for measuring cover from images using SamplePoint software for manual pixel classification (secondary sampling units).



Part 1: Ground-Based Image Collection

Materials

- Monopod with hinged, quick-release mount
- Digital single lens reflex (SLR) camera with zoom lens
- Remote shutter release cable
- One 100-meter field tape and two 2-foot rebar posts for transects

1.1 Use a high-resolution digital SLR camera.

1. Use a high-resolution digital SLR camera that produces images with at least 20 million pixels (20 megapixels). The increased cost and file storage requirements of higher resolution cameras are countered by the improved analytical utility of resulting imagery.
2. Digital SLR cameras are more responsive to user inputs (e.g., no shutter lag) and usually possess physical—as opposed to digital—shutter speed, aperture, focus, and ISO controls that can be readily accessed and adjusted in the field. This is a contrast to point-and-shoot cameras that do not usually have buttons or dials for these settings, and the settings are not as readily accessed through menus.
3. Remote shutter release cables, which are necessary for the steps described in this technical note, are typically only compatible with SLR cameras. Wireless shutter release mechanisms can also be used and are required when using a long camera boom; however, they are more expensive, require batteries, and are more complicated to use. Infrared wireless remotes are unsuitable for field work because they require a direct line of sight to the camera face.

4. Use of mobile devices, such as tablets or cell phones, for image collection is discouraged. Although these will produce usable images, the basic monopod attachment, remote shutter, camera controls, lens adjustments, manual focus, and enhanced bit depth file capabilities (all subsequently described) present in SLR cameras are either not present or not readily accessible in mobile devices. Additionally, mobile device sensors are smaller, resulting in higher image noise given an equal resolution. Mobile device camera lenses are typically of lower quality than SLR camera lenses, resulting in imagery of an inferior quality. The quality difference is especially noticeable when an image is zoomed to maximum, which occurs with photo sampling during image analysis. Some advanced point-and-shoot cameras can be used successfully. Although point-and-shoot cameras are less expensive, they do not provide the equivalent image quality provided by SLR cameras. For these reasons, an SLR camera is recommended for this application.

1.2 Protect the camera in the field. Limit exposure to moisture, sand, temperature extremes, and violent shocks.

1. Most SLR cameras can withstand a small amount of light moisture. A light drizzle or fog is usually not enough to penetrate the environmental seals of the camera. Higher end SLR cameras typically have better weather sealing than cheaper models. If a camera will see heavy field use, look for models with enhanced weather seals. When operating a camera in such conditions, keep the lens glass

clean by keeping the camera pointing down and wiping the lens frequently with a lens cloth. Even under a clear sky, be mindful that dew, mud, or dust may collect on the lens, necessitating cleaning. In all cases, keep the camera protected from the elements as much as possible.

2. Sand damages a camera through abrasive action when the tiny grains come between moving surfaces, such as buttons, selection wheels, and lens barrels. Do not set cameras down on sandy surfaces in the field, guard against dropping a camera in sandy soil, and avoid using a camera, if possible, in high wind situations in sandy areas. If excessive sand is encountered, use a soft dust brush and/or canned air to clean the camera.
3. Cold temperatures reduce camera battery life. Store batteries at room temperature. If it is cool outside, carry spare batteries in a pocket close to your body. If camera batteries run low while sampling a transect, remove the battery and hold it in your hand or pocket for several minutes to heat it up. This will usually allow a short period of continued camera use.
4. For obvious reasons, avoid dropping the camera. A hard-sided storage case is preferable to a canvas bag. To avoid catastrophic lens damage, fit the lens with an ultraviolet (UV) filter. In addition to providing beneficial filtering of UV radiation, the UV filter acts as inexpensive, expendable protection for an expensive lens. For remote field work, it is a good idea to have a spare UV filter in the storage case in case the first filter breaks, is scratched, or is rendered too soiled for use.

1.3 Acquire images with a 0.5 m² field of view (FOV). Use a monopod with the camera as high as practical above the ground level.²

1. Strive for the highest resolution imagery possible. Image resolution is measured as ground sample distance (GSD), which is the distance of ground covered by one edge of a square image pixel. GSD should be ≤ 1 mm for accurate ground cover measurements (Booth and Cox 2011).
2. Mount the camera to a monopod at a 20-30° angle so that when the camera is in a nadir position, the monopod is 20-30° off-vertical and no part of the monopod is visible in the image FOV (Figure 1).
3. Remove camera straps to prevent them from hanging down into the image FOV.
4. Employ a bubble level, either by sticking it to the back of the camera or some other parallel plane, to ensure the camera is oriented in a nadir position.
5. Image FOV should be consistent across sites, users, and time. The FOV is determined by the lens focal length and the camera height above ground level (AGL). To reduce the FOV, either lower the camera height or increase the focal length. Most SLR cameras are sold as kits with a zoom lens, but if your camera has a fixed focal length lens (e.g., 35 mm), then FOV can only be adjusted by altering the camera height AGL.

² Modification of a method developed by Louhaichi et al. 2010.



Figure 1. A camera in nadir position mounted on an angled monopod with no part of the monopod in the camera's field of view.

- a. FOV should be 0.5 m^2 . Actual FOV dimensions depend on camera aspect ratio, of which there are commonly two:
 - **Typical of SLR cameras:** 2:3 (0.66) aspect ratio = $87 \text{ cm} \times 58 \text{ cm}$ plot = 0.505 m^2 FOV
 - **Typical of point-and-shoot cameras:** 3:4 (0.75) aspect ratio = $82 \text{ cm} \times 61.5 \text{ cm}$ plot = 0.504 m^2 FOV
- b. Determine camera aspect ratio by examining the pixel dimensions of the camera's image and dividing the short (y) side by the long (x) side.

Example: Using the Canon 6D camera as an example, $3,648 \text{ pixels} / 5,472 \text{ pixels} = 0.66$ aspect ratio, so this is a 2:3 aspect ratio, and the plot length should be 87 cm .

- c. Rarely, a camera has neither of the previously listed aspect ratios. In such cases, calculate the plot width to achieve a 0.5 m² plot, using values from the camera manual and the following formula:

$$W = \sqrt{(5,000x/y)}$$

where:

W = image width (cm)

x = pixels in the x axis of the sensor array

y = pixels in the y axis of the sensor array

6. Mount the camera so that it is positioned at least 0.5 m above the tallest vegetation and as high as practical for the user. A camera lens bends light from a large FOV onto a tiny sensor, creating radial distortion, where objects at the image edge appear to bend outward. Only the center pixel is truly nadir; all other pixels capture a view of a slightly oblique angle. This “fisheye” effect increases with decreasing lens focal length. Given a constant FOV, a camera positioned too close to vegetation exacerbates radial distortion through an increasingly oblique angle between the sensor and the vegetation near the image edge.

For example, an FOV of 0.5 m² can be achieved with a Canon 6D camera using a 35 mm lens from 0.85 m AGL or a 70 mm lens from 1.7 m AGL (Figure 2). Both images will have the same FOV and GSD, yet because of radial distortion caused by the lens, vegetation on the image edge will be viewed at a 14° angle from 1.7 m AGL and a 24° angle from 0.85 m AGL. The extra vegetation surface area revealed in the increasingly oblique view with the wider angle lens will slightly inflate vegetation cover measurements. Therefore, the highest practical camera height AGL should be employed.

7. Determine the appropriate focal length and camera height AGL for your camera. This can be done directly or mathematically. Regardless of which method is used, verify correct plot size with test plots of known size.

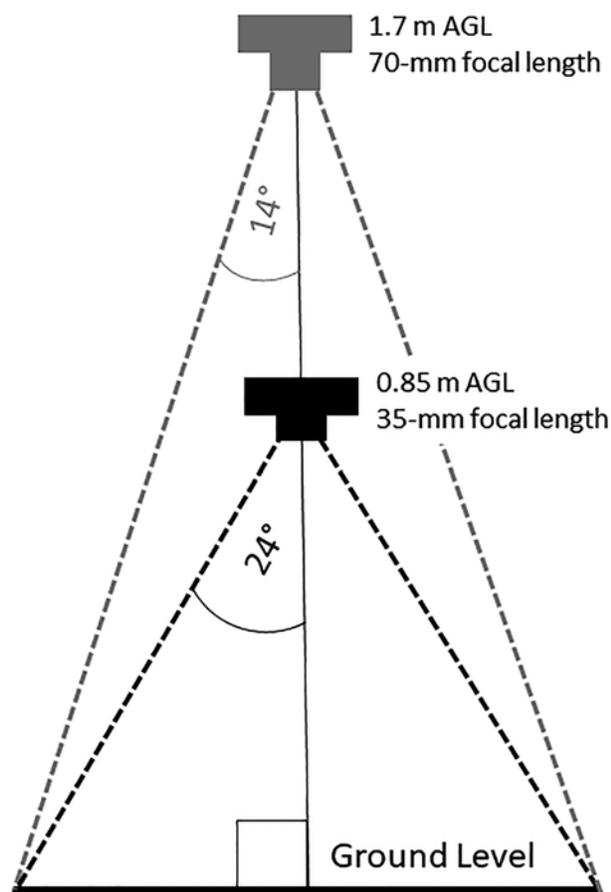


Figure 2. A shorter camera focal length (35 mm in this example) widens the field of view, allowing the camera to be held closer to the ground with the same field of view as a lens with a longer focal length (70 mm in this example). However, the shorter focal length yields greater radial distortion at the image edge.

- a. **Direct method:** This is typically the quickest and easiest method.
 - i. Mark a meter stick with tape at the appropriate FOV width (82 or 87 cm, depending on the camera’s aspect ratio), and place it on the ground.
 - ii. Affix the camera to the monopod at an approximately 20° angle. The monopod offset need only be sufficient to avoid photographing the monopod foot in the plot. Once the angle is set, tighten the adjustment and mark the monopod head with a

- piece of tape or paint marker so if it is moved, you can return the camera to the same angle.
- iii. Adjust the monopod height to fullest extent, and then position the leveled camera directly over the marked meter stick.
 - iv. Adjust the lens zoom until the FOV just encompasses the marked width on the meter stick, and no more.
 - v. Photograph the meter stick, and adjust lens as needed. Note that the viewfinder and preview sometimes only show 95% of the area the sensor will capture; verify the FOV by looking at an actual image.
 - vi. Once the appropriate focal length is reached, tape the lens zoom in place with blue painter's tape to prevent movement. The focal length will be recorded in the image metadata.³
 - vii. Alternatively, if working with a prime lens (fixed focal length), adjust the monopod height until the correct FOV width is just barely in view by adjusting the lowest section of the monopod (keep the top sections fully extended). Mark the lowest monopod section with paint marker so you can quickly return the monopod to the correct length in the field.

b. **Mathematical method:**

- i. With known lens focal length, determine camera height AGL:

$$\text{AGL} = (\text{IW} \times \text{FL}) / \text{AW}$$

where:

AGL = height above ground level (mm)

IW = image FOV width (mm)

FL = lens focal length (mm)

AW = camera sensor array width (mm)
[from camera manual]

- ii. Mark the calculated camera height AGL with tape on a wall. Level the camera and adjust the monopod length until the first lens element is even with the tape.
- iii. Verify that the correct FOV is captured by examining an image of a known plot size.

Example: With a Canon T3i camera, correct FOV is achieved with a 35 mm focal length and camera height AGL of 1.37 m.

Example: With a Canon 5D camera, correct FOV is achieved with a 65 mm focal length and camera height AGL of 1.58 m.

³ Be mindful that a lens can produce different FOVs when used with different cameras. High-end SLR cameras have digital sensors that approximate the size of 35 mm film frames, so the FOV between film cameras and these digital sensors is the same. However, most low- and mid-range SLR cameras have smaller, "cropped frame" sensors that yield a smaller FOV at an equivalent focal length. For example, the Canon 6D "full frame" sensor is 35.8 mm wide, approximately the same size as 35 mm film, while the Canon T3i sensor is 22.3 mm wide, or 40% smaller. Because of this, the "effective focal length" of a cropped-frame camera, like the T3i, is 1.6 times greater than the actual lens focal length (e.g., a 35 mm lens yields an effective focal length of 56 mm). Lenses always have the actual focal length printed on the barrel; it is up to the user to determine the effective focal length based on a crop factor that is invariably listed in the camera manual.

1.4 Document the sampling location.

- At each sampling unit, fill out an identification (ID) sheet or an 8 × 10-inch dry erase board and include:
 - Site name
 - Sampling unit name and/or ID (e.g., pasture name, transect)
 - Date
 - Operator name
- Acquire a landscape-oriented image of the study area with the ID sheet in the frame. This helps verify sample location (as do image geotags).
- Acquire a test nadir image with all adjustments set appropriately. Include a ruler in the middle of the frame. This allows confirmation of plot size and image GSD.
- If the camera is GPS-enabled, become familiar with this feature, and confirm the GPS is enabled in the field.

1.5 Place a label in each image to link images with plot locations.

- Since field notes regarding image files can be lost or provide insufficient detail to properly

link images, use small, preprinted labels, approximately 2 × 10 cm, with relevant information and a plot ID corresponding to the distance from transect origin (Figure 3). Only one label is needed for each sampling unit. Appendix 1 is a sheet of printable plot labels.

- Use card stock so the label does not fold or blow away. A paper clip on the label helps weigh it down. If needed, use a small nail to stake the plot label to the ground.
 - Place the label near the middle of the FOV.
 - Text in the label need not be legible from a standing position; the camera's resolution will allow magnification sufficient to read the text in the image.
 - Scratch out plot numbers as they are photographed, so that the lowest plot number visible corresponds to the plot currently being photographed.
- Alternatively, use a small dry erase board (approximately 20 × 25 cm) for plot labels.

- Advantages: versatile, reusable, more resistant to wind, and ability to add information to label

- Disadvantage: the larger size can cover areas of interest within the image

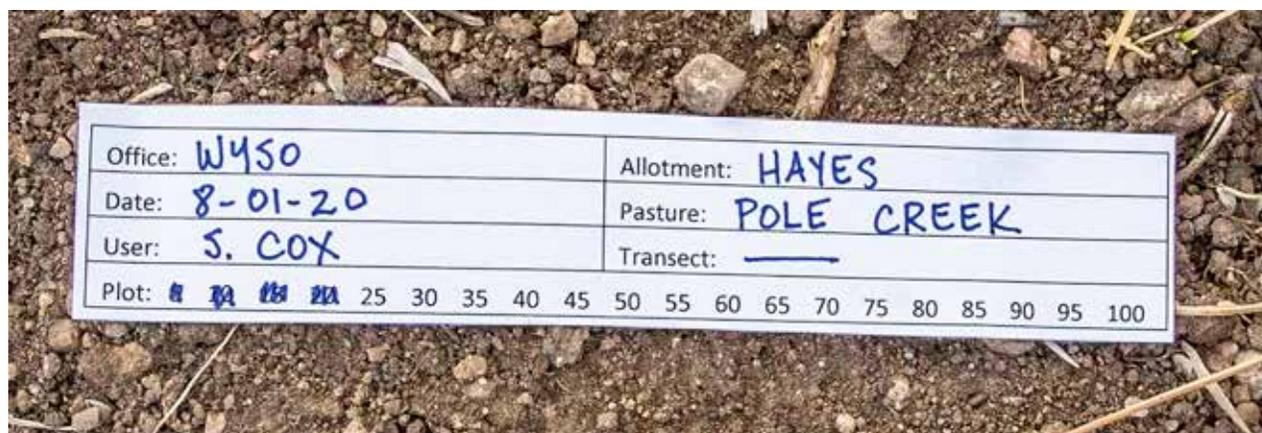


Figure 3. Plot label detailing relevant plot information for permanent information storage. This plot label indicates that this plot is at the 25-meter position along a 100-meter transect. A plot label in the image guarantees that the location and timing of this image will never be lost.

1.6 Adjust camera settings.

1. Adjust variables that can be controlled, which include shutter speed, aperture, and ISO, as depicted in the exposure triangle (Figure 4). When one variable is changed, one or both of the other variables must also be changed to achieve proper exposure.

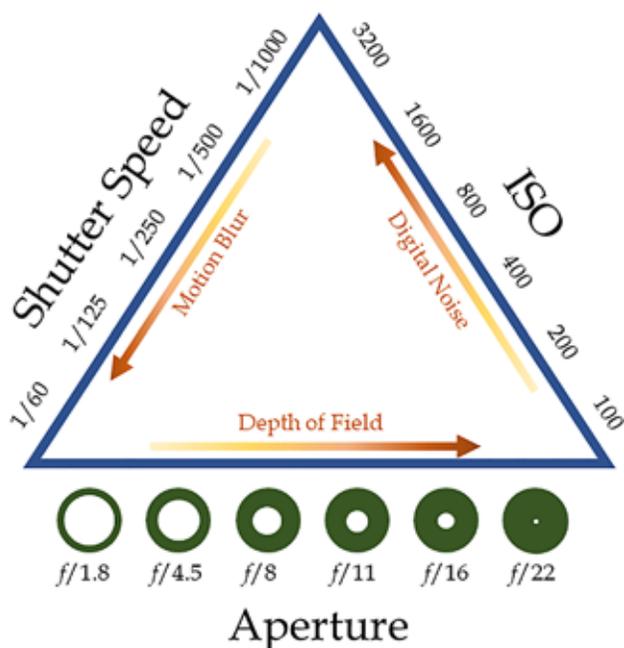


Figure 4. The exposure triangle illustrates the relationship between aperture, shutter speed, and ISO and the effect of increasing each variable. All three variables act in concert; changing one requires changing one or both of the others to achieve a correct image exposure.

- Shutter speed:** Strive for the fastest possible shutter speed. For consistent image sharpness, a shutter speed of 1/1,000 seconds, or faster, is good practice. Never use less than 1/125 seconds, or the image will likely be blurred. Think of 1/250 seconds as the minimum target.
- Aperture:** Larger apertures (smaller f-stops) have reduced depth of field. Virtually everything in an image is in focus at $f/22$, but only a small distance interval is in focus at $f/1.8$ (Figure 5). Seek to use the smallest possible aperture (largest f-stop)

to ensure both tall and short objects are in focus. A good target is $f/16$, since that aperture produces a relatively large depth of field while allowing more light to pass through to the sensor than $f/22$.

- ISO:** Higher ISO causes more digital noise and lower image quality. Keep ISO as low as feasible. A good target is 200, but ISO is the most forgiving adjustment for image quality and is therefore the first setting to consider changing in low light situations. It is not uncommon to use an ISO of 1,000 on cloudy days.

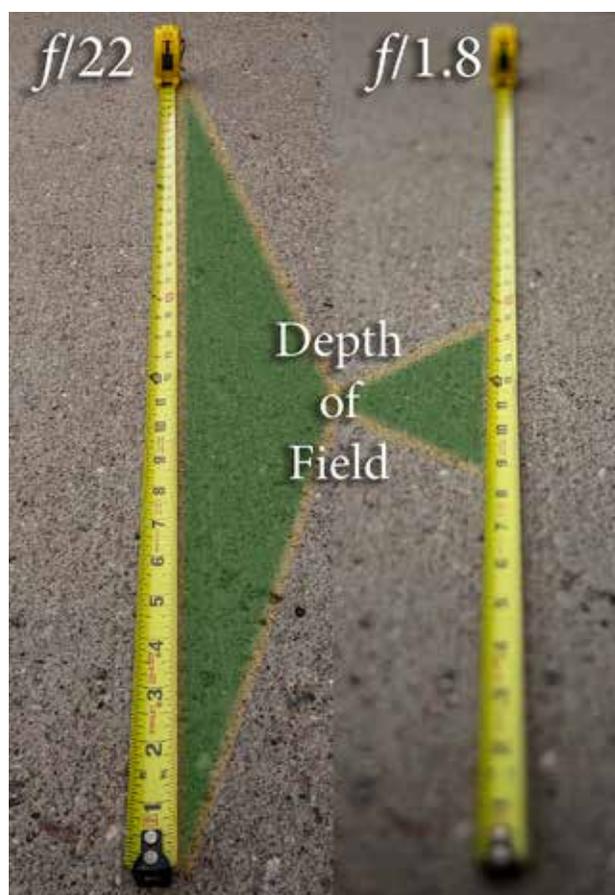


Figure 5. A large aperture (small f-stop), such as the image on the right, results in a shallow depth of field where objects are only in focus within an approximately 6-inch depth (highlighted in green). A small aperture (large f-stop), such as the image on the left, results in a very wide depth of field where virtually all objects, regardless of distance from the lens, are in focus. Monitoring data must be clearly focused at all depths, such as the image on the left.

2. Keep in mind variables that cannot be controlled, which include:
 - **Light intensity:** Clouds, seasons, and times of day all effect light intensity.
 - **Wind:** Moving vegetation presents a problem that must be addressed.
 - **Reflectivity of the ground:** Wet soil and wetland vegetation absorb more light than dry soil or upland vegetation and will require different camera settings.
3. Under ideal conditions (i.e., high clouds; bright, diffuse light; no wind; moderately reflective vegetation and soil), use aperture priority (AV) mode, with an aperture of $f/22$, an ISO of 200, and ensure the resulting shutter is faster than 1/250 seconds.
4. Under less-than-ideal conditions, adjust the variables that can be controlled in response to those that cannot. The following are some examples:
 - If wind is moving the vegetation, use shutter priority mode at 1/1,000 seconds, or faster, to avoid blurred vegetation.
 - If the sky or the soil/vegetation is dark, and at the desired shutter speed the aperture is larger than $f/8$, increase ISO until aperture is smaller than $f/8$ (larger f-stop) to maintain an appropriate depth of field.
 - If vegetation is all short (e.g., < 20 cm), then a shallow depth of field should be acceptable, and the aperture can be increased (lower f-stop).
5. Avoid changing camera settings mid-transect, as this will negatively affect image consistency. If major changes are required, start over from the beginning of the transect.
6. Capture images in RAW file format, rather than JPG. Because RAW images have a greater bit depth (12 or 14 bits vs. 8 bits for JPG), post-processing RAW images allows more details to be recovered from shadow and highlights than from JPG images (Figure 6). Dark images can be lightened considerably without loss of detail if acquired in RAW format.
7. Set the camera for evaluative or matrix metering, which uses the entire scene within the camera's viewfinder to determine the appropriate aperture when in shutter priority mode.
8. Turn off auto-rotate, if the camera has this feature. Consistent landscape orientation of all images improves analysis efficiency.
9. Use autofocus (AF) most of the time. Use manual focus (MF) only when conditions require.
 - In bright, sunny conditions, use AF and an aperture of $f/22$ to ensure all parts of the image are in focus.
 - In low-light, cloudy conditions in which a larger aperture is required (e.g., $f/5.6$), use MF. In MF mode, manually focus the camera on median vegetation height, and then tape the focus ring with painter's tape to keep it in place. If AF is used in this scenario, the camera will focus on the closest vegetation, while low-growing vegetation and litter and soil on the ground will be blurry (Figure 7).
10. Some cameras allow bright sunlight to leak in through the viewfinder into the prism box, resulting in overexposed images. Test the camera for this phenomenon. If it is present, cover the eyepiece viewfinder with the viewfinder shutter or the commonly provided rubber viewfinder cover.
11. Always review images and confirm quality before rolling up the field tape and leaving the site.
 - Review images in a darker area to see them clearly, such as a truck cab or under the shade of a jacket.



Figure 6. RAW image format has a greater bit depth that allows details to be recovered from shadow and highlights in the original exposure. The bottom image is an adjusted version of the top image, with enhanced details that facilitate increased analysis accuracy.

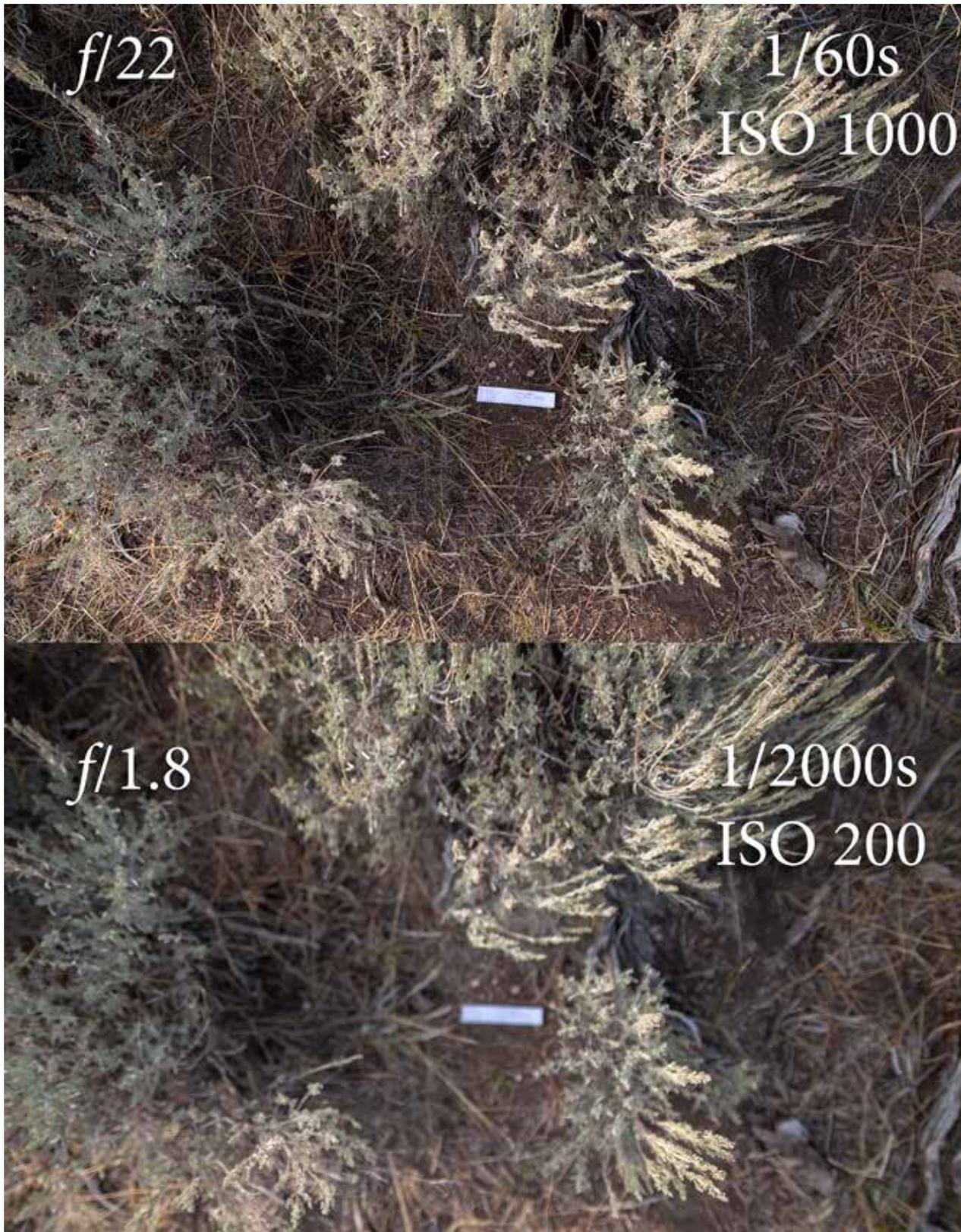


Figure 7. The bottom image shows the effect of a large aperture ($f/1.8$) that results in only the top of the vegetation in focus; the ground-level litter and plants are blurry. In contrast, the top image shows the same plot captured with a small aperture ($f/22$), which results in everything in the image in sharp focus. Note that changing the aperture requires changes to shutter speed and ISO (shown in top right of each image) to achieve the same exposure. This illustrates extremes in aperture size, but all apertures have a measurable depth of field that must be considered.

- Zoom in on images to 100% to ensure correct focus (Figure 8). Small thumbnails can appear sharp until magnified many times.
12. Stock the camera bag with a printed user manual to ensure camera setting adjustments can be made in the field as needed.
 13. See Appendix 2 for a ground-based image collection checklist for vegetation monitoring.



Figure 8. Always zoom in to 100% when reviewing images in the field. Images with slight motion blur can appear crisp and sharp at the small size of the camera display screen, illustrated by this marginal-quality image acquired with a shutter speed of 1/60 seconds. If noticed in the field, this plot could be rephotographed; this option is no longer available if the blur is not noticed until analysis commences weeks or months later.

1.7 Transect method

1. Place the field tape on the ground along a transect. If not already present, hammer in rebar stakes at 0 and 100 m marks so the field tape can be stretched tight between them.

Premark 5 m intervals directly on the tape with a bright paint marker for efficiency.

2. From the origin, stand on the opposite side of the tape from the sun to preclude operator shadow in the image (Figure 9). During mid-day in summer, it is often impossible to avoid the camera's shadow in the image.
3. Place the monopod foot directly on the 5 m mark.
4. Level the camera (nadir view), hold the monopod steady, and then actuate the shutter.
 - Maintain a level camera regardless of ground slope.
 - If the monopod is not steady, even a fast shutter speed may not prevent motion blur.
5. Move along the tape at 5 m intervals, placing the monopod directly on each 5 m mark, and repeat step 4.
6. For a 100 m tape, acquire 20 images, ending at the 100 m mark. For a spoke plot (Herrick et al. 2017), photograph all three transects in the same manner with 5 images along a 25 m tape.
7. Because diffuse lighting increases image quality, consider employing strategies to avoid illumination of plots by direct sunlight, when possible. Although directly illuminated images are readily analyzed, users report increased classification confidence when analyzing diffusely lit images, and automated analysis is more accurate when confounding shadows are not present.
 - Cloudy days are ideal for acquiring high-quality images. Complete field work on cloudy days, when possible.
 - The hours just before sunrise and after sunset avoid direct light and are still bright enough to acquire high-quality images.



Figure 9. Example of proper image collection using an angled monopod placed at intervals along a field tape, with attention to operator shadow.

- A partner can use a white bedsheet to shade the plot from low-angle sun (early morning/late afternoon). If wind is blowing, stand on the corners of the bedsheet and hold the upper corners in each hand to create a light-diffusing screen.

1.8 Systematic grid or random plot method

1. Using a GIS program, create 20 random sampling points, or create a fishnet grid of systematic sampling points, within the area of interest.
2. Plan the optimized travel route between all points that minimizes travel distance from the planned starting location (Figure 10). Label the points in order of their position along the optimized travel route.
3. Load the labeled coordinates into a GPS device.
4. Once in the field, navigate to the first sampling point, and stand on the opposite side of the point from the sun to preclude operator shadow in the image. Place the monopod foot as close to the defined point as possible. Avoid bias against a sample, for example, by not placing the monopod in an inconvenient location, such as a dense shrub.
5. Level the camera (nadir view), hold the monopod steady, and then actuate the shutter.
 - Maintain a level camera regardless of ground slope.
 - If the monopod is not steady, even a fast shutter speed may not prevent motion blur.

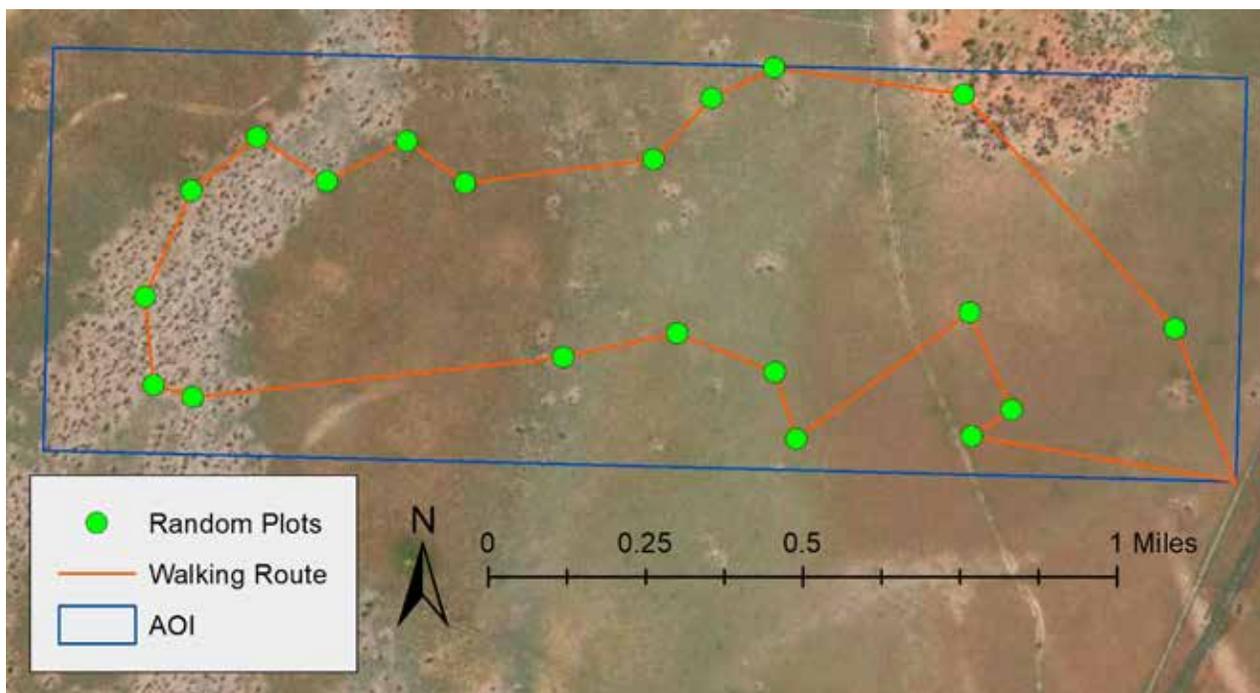


Figure 10. Twenty random sampling points generated in ArcMap 10.4 (ESRI, Redlands, California) within an 800-acre area of interest. Planning an optimized collection route minimizes walking or driving distance.

6. Move to each of the sampling points, placing the monopod as close to each defined point as possible, and repeat step 5.

either placing a rigid, properly sized plot frame at each plot or by settling on the proper lens focal length and camera height using a field tape.)

1.9 Alternative to the monopod: The “freehand” method

1. This method should be well-practiced before implemented to assure acquisition of quality imagery. An advantage of the freehand method is that a monopod and remote shutter release cable are not required. However, a significant disadvantage is a higher likelihood of obtaining off-nadir, blurred, and/or inconsistent-FOV imagery (Cagney et al. 2011).
2. At each plot, place markers on the transect tape to define the FOV. Markers can be brightly painted sticks, steel rods, small boards, etc. Alternatively, paint the FOV length on the tape at 5 m intervals so it can be seen clearly through the camera live view display. (If plots are not along a field tape, determine FOV by
 - For 2:3 aspect ratio, place the first marker at a 5 m interval and the second marker 87 cm beyond that.
 - For 3:4 aspect ratio, place the first marker at a 5 m interval and the second marker 82 cm beyond that.
3. At the first plot, stand on the opposite side of the tape from the sun to preclude operator shadow in the image.
4. Hold the camera with both hands in a nadir position at chest level (Figure 11).
5. While examining the camera live view display, frame the field tape and the markers (or paint marks on the tape) to achieve a 0.5 m² FOV (Figure 11). The screen may be difficult to see well in bright sunlight.

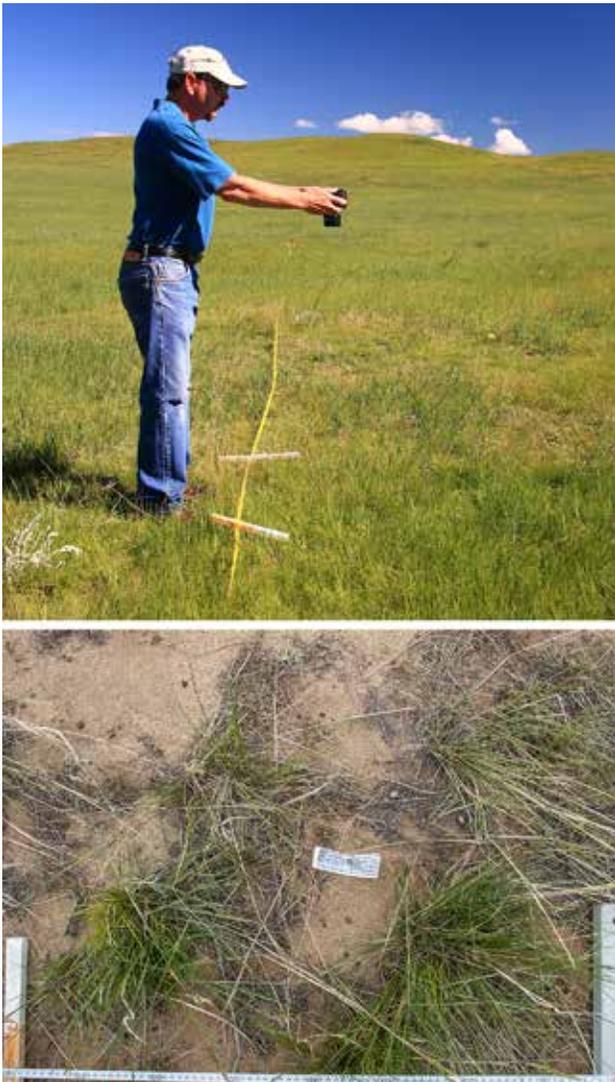


Figure 11. Example of the freehand method (top), showing the user holding the camera in a nadir position as high as practical while still seeing the live camera screen and (bottom) the markers and tape just visible in the 0.5 m² field of view.

- Avoid pulling the camera toward your body. This could result in an oblique view.
- Hold the camera as high as practical while still seeing the camera display screen. Utilize a flip display if the camera has one.

- Carefully zoom the lens or move the camera until the markers and field tape are just visible in the view.

6. Hold the camera steady to avoid motion blur, and then actuate the shutter.

1.10 Download images and convert RAW files to JPG.

1. Connect the camera to the computer via USB cable, or remove the data card from the camera and insert into a compatible computer port.
2. Download all images to the appropriate folder on the computer.
3. Place images from multiple sites into their respective site folders.
4. For RAW files, use photo-editing software (e.g., Adobe Camera Raw) or software bundled with the camera (e.g., Canon Digital Photo Pro) to adjust, as needed, brightness, contrast, saturation, and shadow luminance, or to correct chromatic and/or luminance noise or vignetting, before converting to low-compression (maximum quality) JPG files.
5. Store RAW files in a folder called RAW. Store JPG files in a folder called JPG. It is best to keep RAW files indefinitely, if possible; however, if space is limited, RAW files can be deleted after quality JPG file conversions are verified.
6. Store data outside individual employee workspaces. Use a centralized storage system with consistent naming and hierarchy, such as office/site/date. It is imperative to regularly backup such a storage system.

Part 2: Image Analysis

2.1 Manual image analysis with SamplePoint

SamplePoint software was developed and validated through a joint effort by the Agricultural Research Service and the Bureau of Land Management. SamplePoint produces foliar cover measurements with potential accuracy exceeding 90% (Booth et al. 2006). SamplePoint field measurements have shown equal precision to line point intercept but do not always return the same cover measurement (Cagney et al. 2011), though one method is not assumed to be more accurate than the other. SamplePoint measures foliar cover but not basal cover; inherently, this method is incapable of collecting multiple canopy cover data.

For SamplePoint basic operation, refer to the Tutorial or Help File at www.samplepoint.org. The following instructions provide specific analysis parameters for efficient and statistically robust vegetation cover classification.

1. Create a separate analysis database in SamplePoint for each transect.
 - a. Each database should include at least 20 images.
 - b. Store the database in the same folder as the images.
2. Create or use an existing custom button file.
 - a. Use an existing button file for the ecological site from which images were acquired.
 - b. If no button file exists, create a button file with necessary classification fields.
 - c. Button files should always include an “unknown” class, which would apply to shadows, unidentified objects or plants, and the plot label (if not on bare soil).
3. Manually classify all images in the database.
 - a. It is recommended to use at least 25 classification points per image (e.g., a 5 x 5-point grid). Thirty points per image is suggested as a good balance between species detection and classification time (Ancin-Murguzur et al. 2018). If a site has a particularly high species richness, more sample points in each image are justified.
 - Images can be reclassified with more points later, if needed.
 - The use of random points is generally discouraged because a user can never return to those points in the future, as opposed to the fully repeatable grid point placement. However, if there is apparent spatial periodicity in the vegetation (e.g., drill-seeded rows), the use of random points avoids a systematic classification bias (Curran et al. 2020) (see side box: Random or Systematic Points?).

Random or Systematic Points?

- Grid point locations are determined by an algorithm in SamplePoint. This results in identical point locations every time the point grid is applied to that image, allowing identical reanalysis of any image.
- Random sampling points are placed within the image using a random number generator every time the image is analyzed. Those sampling points will never all be in the same location between successive analyses.
- In general, a systematic grid reduces spatial autocorrelation between sample points as much as possible through spatial balancing and, therefore, produces population estimates with higher accuracy and precision than a random sampling where spatial autocorrelation will be higher due to random point locations in close proximity (Coulloudon et al. 1999). To reduce spatial autocorrelation of random points, use spatially balanced sampling (e.g., a minimum point-exclusion buffer around each sampling point) (Curran et al. 2020).
- Samples must be drawn randomly from a population (Coulloudon et al. 1999). Systematic grids satisfy this requirement when the population is randomly (normally) distributed (Elzinga et al. 1998; Scheaffer et al. 2006). However, when the population distribution is periodic, such as with newly drill-seeded rows, random sampling points must be used to satisfy this requirement (Coulloudon et al. 1999; Curran et al. 2020), or some sort of mechanism must be used that ensures both seeded rows and interspaces are measured (e.g., more points in the grid) (Scheaffer et al. 2006) to achieve an accurate population estimate. Otherwise, no statistical inference of the data can be made. More points obviously increase image analysis costs.

- Magnify the image sufficiently to observe the single, center pixel in each crosshair. To maximize accuracy, the classification decision should be made based on the single pixel at the center of the crosshair (Figure 12).
 - Zoom in on each crosshair to fully recognize the pixel and its context, or use two monitors to view each sample point at different magnifications simultaneously.
 - Near the end of a database classification, use the “Check Margin of Error” tool to determine if the classification is yielding desired precision. Add images or sample points if precision is lacking.
- Create the classification summary file (statistics file), which summarizes cover data by plot and by dataset. Ensure that the intended number of points have been classified for all plots.



Figure 12. This SamplePoint screenshot shows the red classification crosshair. The white box outlines an area magnified in the inset, with the single pixel that should be classified highlighted in yellow here for illustration.

Summary

Ground-based image collection in combination with SamplePoint vegetation cover analysis described in this technical note improves on traditional monitoring methods by reducing cost, while increasing sample size, statistical power, and field work efficiency, as well as providing a permanent resource record that can be referenced or reanalyzed whenever the need arises. The general method outlined in this technical note has been utilized by researchers affiliated with the Agricultural Research Service, Bureau of Land Management, Department of Energy, National Park Service, Natural Resources Conservation Service, Smithsonian Institution, and U.S.

Geological Survey. As of early 2021, SamplePoint software has been downloaded by thousands of users in more than 80 countries and is a research method in more than 100 peer-reviewed journal articles published by researchers from more than 85 universities, government agencies, and nonprofit groups. Ground-based image collection paired with SamplePoint for vegetation cover measurements is the majority method among these published studies. SamplePoint has become a standard for cover-measurement accuracy; this is evidenced by its use to validate new image analysis methods (Nielsen et al. 2012; Patrignani and Ochsner 2015; Owen et al. 2020).



Appendix 1: Printable Plot Labels

Office:	Allotment:
Date:	Pasture:
User:	Transect:
Plot: 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100	

Office:	Allotment:
Date:	Pasture:
User:	Transect:
Plot: 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100	

Office:	Allotment:
Date:	Pasture:
User:	Transect:
Plot: 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100	

Office:	Allotment:
Date:	Pasture:
User:	Transect:
Plot: 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100	

Office:	Allotment:
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User:	Transect:
Plot: 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100	

Office:	Allotment:
Date:	Pasture:
User:	Transect:
Plot: 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100	

Office:	Allotment:
Date:	Pasture:
User:	Transect:
Plot: 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100	

Office:	Allotment:
Date:	Pasture:
User:	Transect:
Plot: 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100	

Appendix 2: Ground-Based Image Collection Checklist for Vegetation Monitoring

- Camera is suitable for the operation
- Battery is charged
- Storage card space is sufficient for intended collection
- Lens cap is removed
- Lens is clean
- Camera settings are verified:
 - Shutter priority 1/250 seconds or faster
 - Aperture $f/8$ or higher (smaller aperture)
 - ISO set as low as possible while allowing minimum shutter and aperture
 - Image quality RAW
 - GPS geotagging ENABLED
 - Auto rotation DISABLED
 - Release shutter without card DISABLED
 - Beep/shutter release sound ENABLED
 - Image review DISABLED
 - Exposure compensation = 0
 - Autofocus ENABLED (except when using large f-stops; then manual focus at midpoint of vegetation height)
 - White balance AUTO
- Quick release mount is secured on monopod
- Shutter release cable is attached
- Monopod height is adjusted correctly
- Camera is at nadir
- Lens zoom is adjusted to achieve 0.5 m² plot
- Test shot confirmation (focus, exposure, $f/8$ or higher (smaller aperture))
- Photograph ruler
- Plot card is filled out and in the image frame
- Photographer orientation avoids shadows in plot
- At end of transect, confirm all images acquired and check quality

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