Vegetation Sampling Protocol for Xeric Habitats of the Northeast

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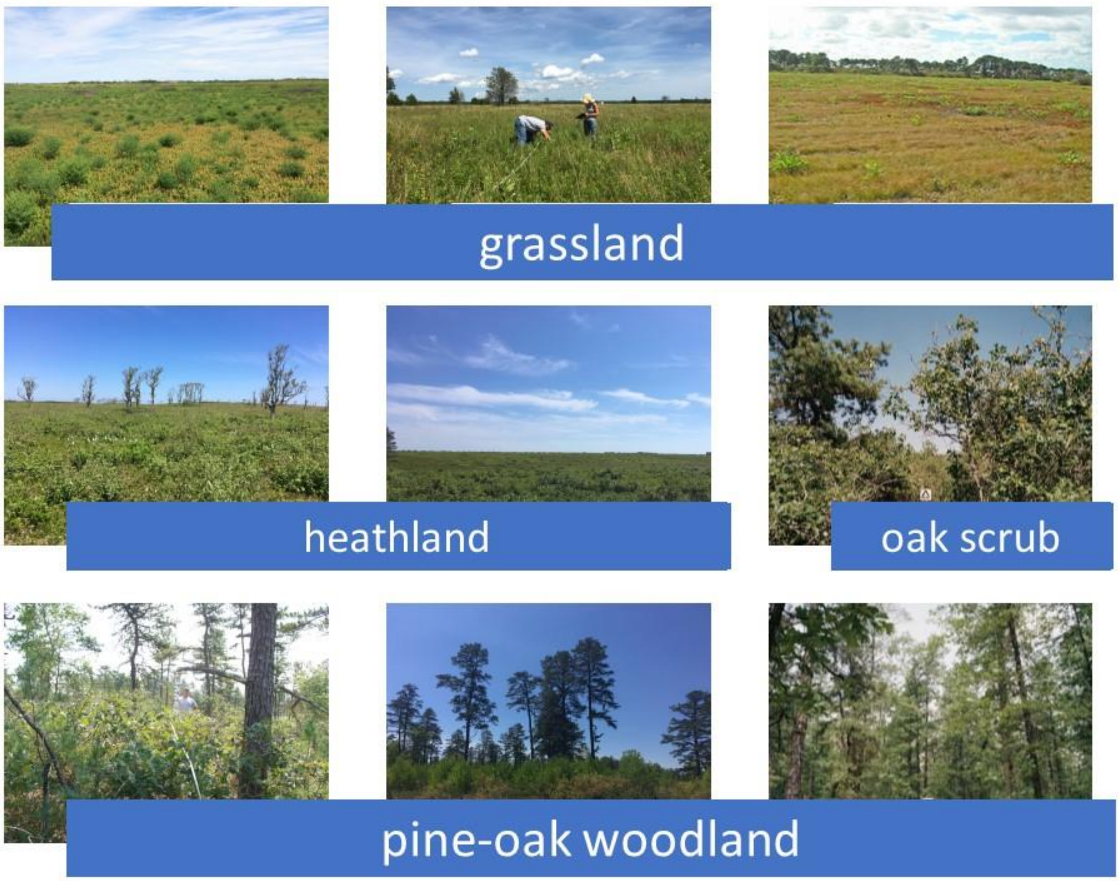

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Acknowledgments

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1. Introduction

The purpose of this manual

The goal of this manual is to provide land managers from xeric habitats across the Northeastern US with a standardized, but flexible, set of monitoring protocols for assessing ecological change in vegetation over time. The manual provides guidance for assessing changes in vegetation structure and plant species composition in response to adaptive management activities in grassland, shrubland, open canopy woodland, and successional forest communities. Monitoring is a crucial aspect of long-term conservation in which target outcomes are tested and adaptive management goals refined. Consistent and repeated monitoring of plant community dynamics provide an important foundation for informing managers about both the effectiveness of past management activities and for redirecting management to achieve desired outcomes. Conservation land managers are busy, and, accordingly, this manual is designed to take that into consideration by describing simple and expedient monitoring protocols in a concise, easily-navigated manual.

Monitoring indicators

Both quantitative and qualitative indicators are useful for understanding ecosystem health, changing environments, and the effects of management on vegetation structure and composition. Quantitative data are useful for generating and assessing specific goals associated with different management activities. Qualitative data, such as photographs, can be helpful in translating such data into new management approaches. This manual integrates these two types of data in an attempt to employ the advantages of each approach.

Sampling considerations before monitoring

The design of a useful and statistically-reliable monitoring system depends on the management goals, the size of the management unit, land use and management history, and variation in soils, topography, and vegetation. These factors should be considered prior to establishing an on-site vegetation monitoring network, as described below. Equally important, however, are the time and logistical constraints faced by management staff. Thus, time, labor, treatment block size, site size, and site variability will determine the distribution of sample plots, sampling intensity, and sampling methodology complexity. In light of these tradeoffs, we have attempted to provide a statistically-rigorous, but flexible sampling protocol that can be adapted to local site conditions, vegetation type, management activities, and time allotted for the sampling effort.

2. Practical use of the guide: steps for developing and implementing a monitoring protocol at your field site

The following sections provide a framework for developing a landscape- and regional-scale monitoring program based on the assumption that one of the primary objectives of the monitoring program will be to detect long-term changes in the grassland, heathland, woodland, and pine-oak ecosystems of the Northeast.

The manual is divided into the following steps, which are integral to the development of a monitoring program. Sections A-D discuss objectives and where and how many sample points to establish. Forming the bulk of the manual, section E provides instructions for a set of expedient and effective sampling techniques for monitoring. Section F briefly describes how to store monitoring data.

A. Defining the monitoring objectives based on management goals
B. Dividing up the management property into meaningful *monitoring units* (i.e., stratification)
C. Determining the number of sample *transects* to establish in each unit
D. Placing the transects
E. Sampling the transects
F. Storing your data

A. Defining management and monitoring objectives at your site

Vegetation monitoring makes sense only in the light of management objectives. It would be a waste of precious time for land managers to invest in monitoring unless the effort were directed at assessments and/or management objectives related to the vegetation. Moreover, vegetation monitoring programs should be devised specifically in accordance with these objectives, an issue we will revisit in future sections.

Vegetation monitoring can address a wide range of objectives, which divide into the following four overlapping categories:

- (1) Evaluate expected trends in vegetation or species so that management can be adapted accordingly. A good example would be an assessment of projections of vegetation change as a result of climate change. In this case, specific hypotheses would be tested over time. Managers might decide based on these trends to resist change (e.g. plant current resident species) or facilitate change (e.g., plant likely future resident species), depending on mission and objectives.
- (2) Monitor the populations of specific species or vegetation units of concern. These entities might be rare species, uncommon communities, or species, such as non-native invasives, that pose threats to management goals. Managers will use these data to design appropriate management schemes to favor or disfavor certain species.
- (3) Evaluate the effectiveness of management practices that aim to change or maintain vegetation units or species. These management practices generally will involve direct manipulations of the vegetation or environmental variables influencing vegetation. Typical manipulations include prescribed fire, mowing, soil disturbance, herbicide application, and planting. Statistical analyses of these monitoring results

would be helpful to effectively identify successful management interventions. As such, sample unit replication among the different management manipulation types will be an important factor under this objective category.

- (4) Identify a wide range of vegetation trends so that management can be adapted accordingly. The idea here is that, unlike 1-3 above, managers may not have specific future expectations or conservation concerns, but might, nevertheless, wish to monitor vegetation change over time. Such an approach would allow managers to respond before unforeseen problems become intractable. These trends could apply to the entire property or to vegetation units separately. Managers might want to know, for example, whether certain species are increasing and decreasing, without any particular reason to expect such trends. These monitoring objectives are the least specific and directed at desired future vegetation conditions.

Underlying these objectives are conservation principles and values, such as whether to let nature "take its course"; whether to prevent change or even facilitate change; whether to limit non-natives and favor natives; whether to shape vegetation for particular human and conservation purposes. These values, of course, will differ among properties, depending on their missions, and they will be informed by existing priorities and management plans; conceptual and quantitative models of populations, communities, and ecosystems; reference sites on and off the property; and historical information.

The four categories of management objectives above identify a range of vegetation target units for monitoring: (1) the entire property, (2) administrative units (e.g., active recreation, conservation, maintenance infrastructure, etc.), (3) vegetation type units, (4) target species, and (5) management units. The target unit for monitoring will depend strongly on the management objectives as described above. This will in turn determine the spatial design of monitoring, as described in future sections.

Full development of management and monitoring objectives will require identification of the following six specific attributes of the goals (Elzinga et al. 2015):

- The geographical area to be monitored;
- The *indicator* to be monitored, usually particular species, vegetation types, habitats, or entire properties;
- The *attribute* of the *indicator* to be monitored (e.g. density, cover, etc.);
- The desired or expected direction of change: increase, decrease, maintain;
- The degree of acceptable or desirable change of the *attribute* of the *indicator* to be monitored (qualitative or quantitative);
- The time frame over which monitoring data will be evaluated in order to trigger management adjustments.

Management and monitoring objectives related directly to specific attributes of vegetation indicators should be defined as specifically as possible. Qualitative approaches (e.g., statistically-significant trends for an attribute) will often be sufficient, but quantitative goals (e.g., a 20% increase in openness) can be even more powerful. If it is feasible, a very effective approach is to identify both the quantitative trigger and the specific management action to be implemented for indicator attributes. Whatever approach is taken, the take-home message of this section is that monitoring plans should be designed based on management objectives, the more specific the better.

B. Stratifying land into monitoring units

Stratifying a conservation landscape into meaningful *monitoring units* is a key step in developing a long-term vegetation monitoring protocol on any conservation property. Except for the smallest properties, managers will divide up the entire conservation area into *management units*, for practical reasons related to activities, history, geography, etc. These management units will often be further stratified into different *ecological units*, based on soils, topography, or vegetation. In some cases, the management units will be embedded within ecological units, and, in others, the two will be identical; that is, the management unit will be defined by its distinct ecology. Regardless, monitoring should occur at a scale defined by some combination of management and ecological units, or in other words, monitoring should be carried out within one of these *monitoring units*.

Different managers will have access to different types of landscape stratification resources including aerial photographs, satellite imagery, Google Earth Imagery, digital topographic maps, geographic information systems (GIS), soils maps, management unit maps, vegetation maps, etc. Myriad strategies exist for stratifying a landscape into ecologically-meaningful or practical monitoring units, and in some cases, pre-defined management units or vegetation blocks are already being used by managers in their adaptive management and vegetation monitoring activities.

Regardless of the stratification criteria, most managers will have some defined idea of how the sampling scheme should be divided up into monitoring units such as the treatment unit itself, or a particular vegetation, topographic, or soil type. In general, it is desirable to divide landscape monitoring units into areas that are relatively homogeneous with respect to vegetation type, topography, and management history, although logistics (e.g. topography, roads, fire fuel breaks, etc.) also play a large role in defining management unit boundaries.

At the very basic level, Google Earth Pro (https://www.google.com/earth/download/gep/agree.html) can be used to identify homogeneous sampling units within your study area using high-resolution satellite imagery. Temporal changes in the vegetation complex can also be evaluated for stratifying among monitoring units using the historical imagery tool in Google Earth Pro (Figure 1), and polygons of individual monitoring units can easily be delineated using the polygon tool. Such polygons can also be exported to ArcGIS shapefiles (.shp) directly from Google Earth Pro.

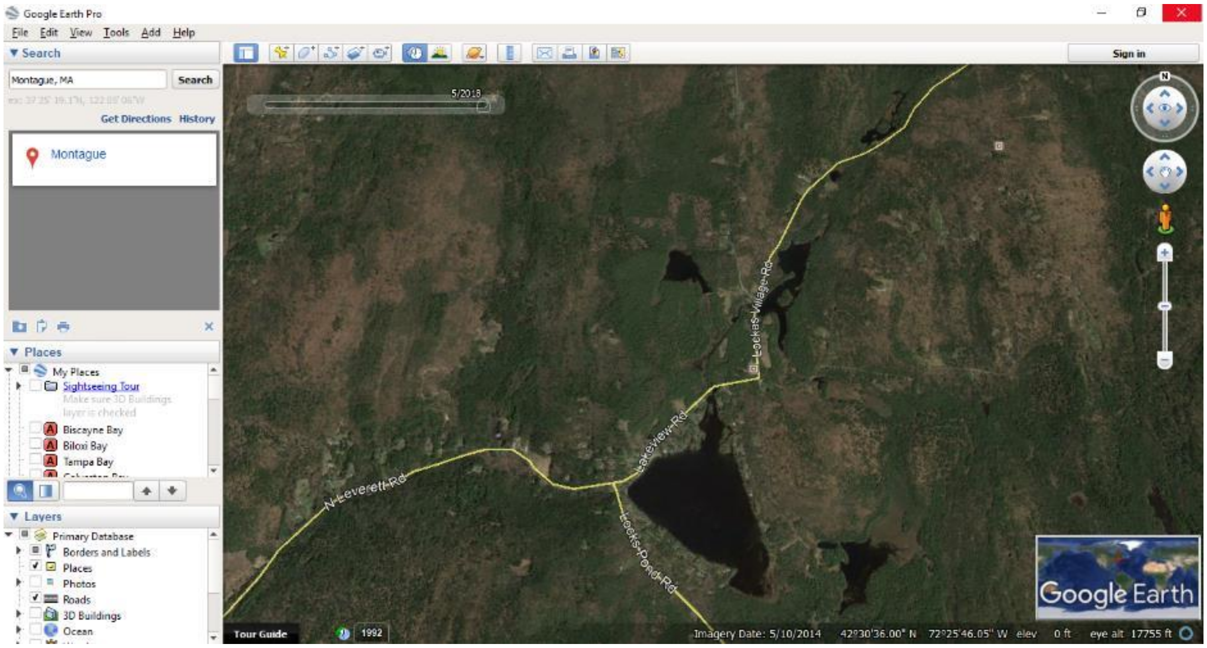

Figure 1: Example screenshot of Google Earth Pro depicting variation in land-cover surrounding Montague, MA.

Should more sophisticated, site-specific aerial imagery, elevation data (DEMs), LiDar, vegetation maps, or management unit shapefiles be available, homogeneous vegetation management units can be selected in ArcGIS, as described in the following sections.

Ultimately, homogeneous monitoring units will be selected either in Google Earth Pro or in ArcGIS by delineating polygons of each unit and classifying them by type (vegetation type, management unit, etc.). Often, classifying monitoring units by vegetation type is preferable, because subsequent sampling intensity and transect design will vary in accord with the density and type of vegetation in the monitoring unit. Vegetation types usually recur across the landscape, making stratification using this approach ecologically meaningful, relevant to management goals, and feasible. The use of vegetation types for stratification also ensures that monitoring captures the variation in plant community composition and the underlying environmental setting. Further stratification by adaptive management activities or other criteria can then be superimposed onto these landscape vegetation units as a means for monitoring the effects of different management activities on the plant community. Figure 2 provides examples of how managers may stratify their study areas by A) landscape feature, B) management unit, C) vegetation type unit, or D) a common case in adaptive management studies where managers will wish to stratify by vegetation cover type and then by treatment units within cover types.

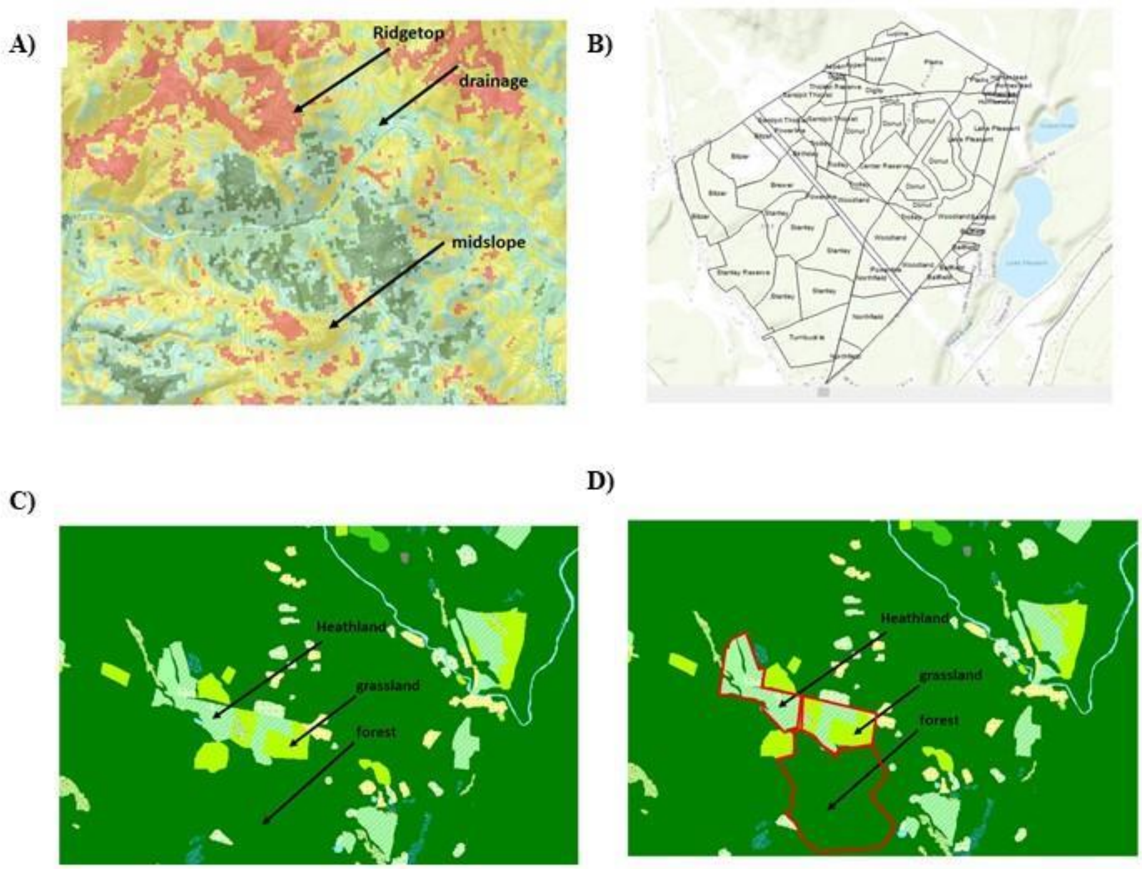

Figure 2: Three alternatives for stratifying your site by A) landscape feature, B) management unit, C) vegetation cover type, or D) treatment units (polygons in red) within vegetation cover type.

C. How many measurements?

Introduction. Implementing an informative sampling plan that captures ecological variability with limited time investment is challenging. A key aspect of this dilemma is how much sampling to carry out over time for effectively monitoring change in the plant community. On the one hand, more sampling is always better in terms of the ability to detect change or the success of a management treatment. For time-limited managers, however, monitoring more places than is needed is a waste of time. This section will discuss the issues surrounding the number of samples and will provide practical approaches for determining how many places to monitor

Terminology. First, a little terminology for the purposes of clarity. A *management property* is a preserve or part of a preserve designated for conservation. A *management unit* is a geographically-bounded area identified for practical reasons related to management. *Ecological unit*s are distinct types of areas distinguished by vegetation, topography, or soils. Management properties may be divided into management units, ecological units, or both. The combination of these (and possibly other) types of stratification produces individual *monitoring units* within which sampling should be carried out. Monitoring is carried out over time within *monitoring units* by sampling along randomly-placed *transect* lines (50 m for the purposes of this manual) to detect change or the impact of a management activity. In some cases, as described below, additional types of sampling (e.g., ground cover within circles or fuel loadings) will be carried out in association with a *transect*. A *sample point* is a single sample of data collected at a specific point along a *transect*. Multiple sample transects within a monitoring unit type are called *replicates*.

Key Issues. Ecological monitoring for management and scientific hypothesis testing are overlapping, but sometimes different approaches. For example, at times, it will be important for a manager to conclude (pro-actively) that change has occurred in a management area, when a scientific investigator might be more cautious in embracing such a conclusion. Other times—in adaptive management, for example, when applying a series of different treatments— a manager will want to stick more strictly to science norms of concluding statistical significance. This raises the general issue of the tradeoff between erring on the side of detecting change (when perhaps there was no true change) vs. erring on the side of caution (when perhaps there was a change that is not detected). Managers are constantly using their experience and intuition when faced with this tradeoff. Sometimes, as in the case of an invasive species, one might want to err on the side of concluding an increase in abundance; in other cases, such as the frequency of prescribed fire, one might want to be cautious about whether a current frequency is resulting in actual change. As a generality, ecological scientists use a 95% threshold (i.e., 5% chance of concluding a change when there wasn't actually one) and managers might use a higher figure, such as 20%, a percentage employed below.

Scale is another important consideration for successful monitoring, that is closely connected to the issue of the number of transects. The ideal monitoring design would divide a management property into distinct monitoring units, as described previously, each of which would be monitored separately, because they might be responding differently to environment change or because they need to be managed in different ways. The ideal monitoring design, then, would be to have sample transects in each management unit.

Number of Transects: A Minimum. What's the ideal number of replicate transects in each monitoring unit? Only one transect per unit will greatly limit the capacity for detecting changes or differences between that unit and others (or treatments). Thus, a minimum of two transects is critical within each unit. Below, we refine that recommendation. It goes without saying that these two transects should be spread across the monitoring unit to the extent possible.

We can now summarize our recommendations for laying out transects.

- ☞ Stratify the management property into monitoring units
- ☞ Spread sample transects across each monitoring unit
- ☞ Establish and monitor a minimum of two transects per monitoring unit

Number of Transects: Using Table 1. For managers with the capacity to monitor more than two transects per unit—and we would encourage that—you can use Table 1 below for deciding how many transects might be sufficient. Table 1[a] provides recommendations based on monitoring in grassland and shrub habitats in the Southwest USA, specifically at USDA-Agricultural Research Service La Jornada Experimental Range in New Mexico. In each of 8 vegetation *cover types*, 3 *transects* (each with 3 *transects*) were sampled for a total of 24 transects and 72 transects. These habitats exhibit similarities but also differences from xeric habitats in the Northeast, but they provide a starting point that can be refined as managers wish.

The table rows show recommendations for foliar cover, basal area, and ground cover. The columns provide choices of detecting changes in these parameters from 2 to 20%. Detecting a change of less than 10% demands many transects and might focus attention on minor changes that are less important for management. Setting a threshold as high as 20% decreases the number of transects required, but might result in missing important trends. Accordingly, we recommend the 10% detection level as a reasonable compromise. These recommendations for transect sample sizes assume a 20% error rate of concluding a change when one didn't occur (as well as a 20% chance of not detecting a change when one actually did occur).

The La Jornada recommendations are based on the line-point intercept method, using a very similar protocol to that provided in this manual. Accordingly, our recommendation from Table 1 is that managers should install 3-4 replicate transects per each monitoring unit for vegetative cover and 4-5 for soil surface cover. Below we provide a method for intensifying measurement of ground cover, which would obviate the need for an additional soil surface transect.

We can now update our recommendations for laying out transects.

- ☞ Stratify the management property into monitoring units
- ☞ Spread sample transects across each monitoring unit
- ☞ Establish and monitor at least 3-4 replicate transects per monitoring unit

You are welcome to go no further, but if you want to customize transect sample size recommendations for your monitoring data, read on.

[a] Jeffrey E. Herrick, Justin W. Van Zee, Kris M. Havstad, Laura M. Burkett and Walter G. Whitford. 2009. Monitoring Manual for Grassland, Shrubland and Savanna Ecosystems. Volume II: Design, supplementary methods and interpretation. USDA - ARS Jornada Experimental Range, Las Cruces, New Mexico

Table 1: Line-point intercept replication requirements for vegetation monitoring. Taken from Herrick et al. (2009).

Foliar cover	1 transect/plot			3 transects/plot		
	Minimum detectable change (%)*					
	5	10	20	5	10	20
Community	Number of plots required					
A	6	2	2	2	2	2
B	5	2	2	2	2	2
C	15	4	2	7	2	2
D	6	2	2	2	2	2
E	9	3	2	7	2	2
F	2	2	2	2	2	2
G[1]	32	8	2	11	3	2
H	16	4	2	6	2	2
Median	8	3	2	4	2	2

Basal cover	1 transect/plot			3 transects/plot		
	Minimum detectable change (%)*					
	2	5	10	2	5	10
Community	Number of plots required					
A	13	3	2	6	2	2
B	19	3	2	13	3	2
C	17	3	2	11	2	2
D	19	3	2	14	3	2
E	9	2	2	5	2	2
F	3	2	2	2	2	2
G	9	2	2	3	2	2
H	10	2	2	4	2	2
Median	12	3	2	6	2	2

Bare ground cover	1 transect/plot			3 transects/plot		
	Minimum detectable change (%)*					
	5	10	20	5	10	20
Community	Number of plots required					
A	2	2	2	2	2	2
B	7	2	2	3	2	2
C	14	4	2	6	2	2
D	13	4	2	7	2	2
E	5	2	2	2	2	2
F[2]	46	12	3	28	7	2
G[1]	22	6	2	8	2	2
H	9	3	2	4	2	2
Median	11	4	2	5	2	2

* Absolute change (e.g., increase from 10 to 15 percent is a 5 percent change).

[1]High values due to patch structure associated with banded vegetation.

[2]High values due to highly variable lichen cover (not counted as bare ground).

See website for revised recommendations based on more comprehensive data ("Monitoring and Assessment" link at http://usda-ars.nmsu.edu).

Number of Transects: Calculate Using Your Data. Let's say that you set up and sampled four transects in each cover type in year 1 and then resampled them in year 2. You are concerned about an invasive plant species in one particular cover type, and you wonder whether it increased from year 1 to year 2. Table 2 shows your data (percentages), with means and standard deviations calculated.

Table 2: Monitoring example: quantifying percent cover for an invasive plant species along four transects over two years.

TRANSECTS	YEAR 1	YEAR 2	DIFFERENCE
Transect 1	17.3	19.8	2.5
Transect 2	19.4	23.6	4.2
Transect 3	18.0	20.1	2.1
Transect 4	21.9	23.5	1.6
Mean	19.2	21.8	2.6
Standard Deviation	2.0	2.1	1.1

Here are the results from a paired t-test to assess whether the mean for percent cover of the invasive plant increased from year 1 to year 2: t=-4.6, df= 3, P<0.01. There was a statistically significant increase in the invasive plant at a probability level of 1%. In other words, if you conclude that it is increasing (and that perhaps you should take action), your chance of being wrong is <1%. You've made an important conclusion.

But what if your data were different, and you did not find a statistically significant difference? Maybe you simply hadn't set up enough transects to actually detect a difference. That would be important to know. How could you tell?

It's easy to calculate how many transects you'd need, and whether or not you actually sampled enough. Let's use the data above once again, and make the assumption we've used all along of detecting a 10% change. The standard deviation of the difference between year 1 and year 2 is the key, and we'll call that SD_{diff}. Here's how to do the calculation. The 19.2 is your mean for year 1; the 0.1 is the 10% detection level. The values 1.64 and 1.28 are explained in the footnote.[b]

Number Transects Needed = $((SD_{diff})^{2} * (1.64 + 1.28)^{2}) / (19.2*0.1)^{2}$ = 2.8 transects

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[b]The actual formula is Number Transects Needed = $((SD_{diff})^{2} * (Z_{alpha} + Z_{beta})^{2})$ / (Year 1 mean * % detection)^{2}

s_{diff} = Standard deviation of the differences between paired samples (see equation and examples below).

Z_{alpha} = Z-coefficient for the false-change (Type I) error rate. We assume the reasonable rate of 10% for concluding that there's a difference when there's not. That number would be 1.64.

Z_{beta} = Z-coefficient for the missed-change (Type II) error rate. We assume the reasonable rate of 10% for concluding that there's no difference when there really is one. That number would be 1.28.

MDC = Minimum detectable change size. If you want to detect a 10% change from the 19.2% found in year 1 when you sampled in year 2, then that would be 19.2 * 0.1 = 1.92.

Other values for the two Z values and MDC could be chosen.

This equation tells us that, given the data collected so far, 4 transects per cover type is sufficient to detect a 10% difference. This is a general approach to figuring out how many transects you need in order to detect change over time, given your actual data. This approach can also be used for figuring out how many transects are enough for detecting differences between transects subject to a management treatment, such as prescribed fire, vs. control transects. Similar analyses can be carried out for before vs. after a treatment combined with control vs. treatment, but the calculations are more complicated than those shown. An online paired t-test calculator is available here for this purpose:
http://www.socscistatistics.com/tests/ttestdependent/Default.aspx

The Issue of Tract Size. There is one additional issue to discuss before concluding this section. Should the guidelines provided previously apply differently to large vs. smaller tracts of land? What if one monitoring unit is one acre in size and another 500 acres? A statistician might claim that these are equivalent and that an equal number of transects in each is sufficient. Practically, most managers would disagree with that conclusion, and would want to monitor more transects in the larger areas, because there's bound to be more ecological variation across those larger areas.

There are three main approaches to this problem.

(1) One could ignore tract size and wait to assess the sufficiency of sampling after two years of sampling, using the techniques described previously, and make the necessary adjustments at that time.

(2) Given the high expectation that more transects will be needed in the large management unit, however, we would encourage a more pro-active approach of establishing more transects initially in that site. There's no magic number of transects, and managers should use their intuitive assessment of ecological variation across the large tract to decide how many additional transects should be established in comparison to a smaller area. For a 500-acre tract, 10 transects would be a reasonable minimum, but more would be better.

(3) There is an alternative approach to going with your intuition in determining the number of transects to use in a large monitoring unit. One could take advantage of what is known as the species-area curve. As one samples more and more area, the number of *new* species encountered declines until nearly all species have been included. When one has reached that asymptote, a reasonable assumption would be that you have adequately sampled the ecological variation in the area in question.

Thus, one could use a simple iterative sampling approach, first sampling one transect, writing down the constituent species, adding a second, adding new species, and continuing that process until few or no new species are being added (i.e., identifying the asymptote). Hypothetical data are provided in Table 3 and graphed in Figure 3. Notice that only one new species is added by sampling transect 9 and no new ones are added with transect 10. One could safely assume that 10 transects were sufficient for capturing most of the ecological variation in this tract of land.

Table 3: Hypothetical species-area data. Plants are sampled over ten transects in a sequential manner, starting with transect 1. New species are recorded for each newly-sampled transect, as is the cumulative species number. Area (number of transects sampled) and total species are graphed in Figure 3, revealing the species-area curve for this management site.

Transect	New Species	Cumulative Species
1	12	12
2	8	20
3	6	26
4	6	32
5	4	36
6	4	40
7	3	43
8	2	45
9	1	46
10	0	46

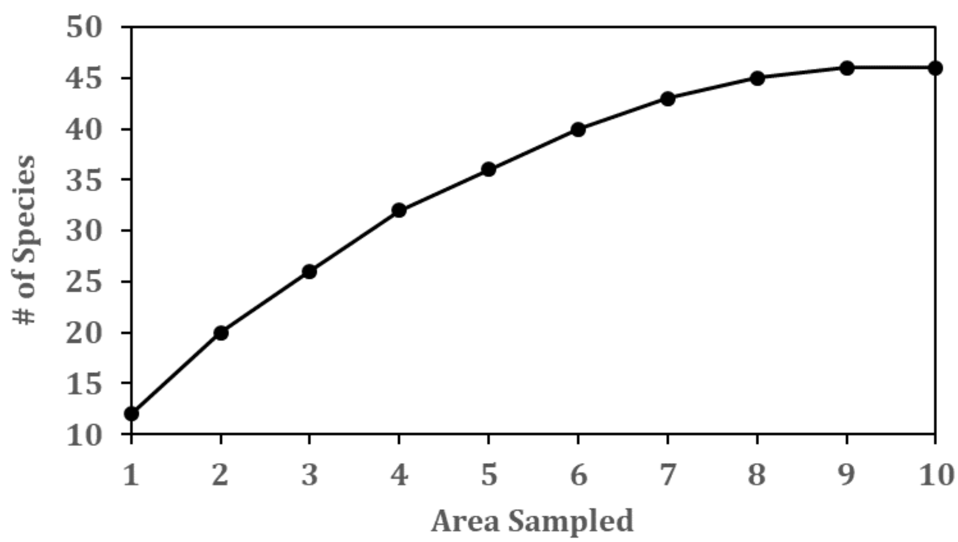


Figure 3: Example of the species-area curve relationship where the asymptote in the number of species is reached at 9 transects, as in the invasive species example in the text.

This species-area curve approach, in fact, would be a reasonable approach to use for determining the number of transects to use for any management unit, whether it encompasses a large or small area. If adding more transects does not add to the number of species, you've probably included most of the ecological variation in the cover type. One advantage over this approach compared to that described previously is that adequacy of sampling can be determined within one field season. Carrying out the calculations described previously after two years of monitoring would, then, be an effective check on this simpler method.

Here's our final summary for deciding how many transects to lay out.

- ☞ Stratify the management property into *monitoring units*
- ☞ Establish and monitor 3-4 replicate *transects* per monitoring unit initially, spread across the tract
- ☞ Add more transects, using the species-area approach to determine an adequate number of transects per monitoring unit
- ☞ After two years, use the statistical approach to assess ecological changes and whether a sufficient number of transects have been sampled.

D. Where do the transects go?

Transect placement usually falls into one of four categories: 1) completely randomized sampling, 2) stratified random sampling, 3) systematic sampling, or 4) subjective sample placement. While each method has advantages and disadvantages, in this protocol, we suggest adopting a stratified random sampling approach that stratifies by monitoring units, as described previously. A stratified random transect placement approach will ensure that transects are distributed among landscape units with a statistically-rigorous sampling intensity, as discussed in the previous section. This will allow managers to assess responses to management or environmental pressures at multiple scales, from individual monitoring units to the entire preserve.

The following set of instructions provides guidance for generating stratified random sample transect locations and associated coordinate data within sample units using ArcGIS. The ArcGIS 'Create Random Points' tool can be used to identify your sampling locations prior to going in the field (Figure 4). Note that this tool requires the Advanced Desktop License or the Spatial Analyst or 3D Analyst Extension with the Basic or Standard Desktop License of ArcGIS.

This tool can be found in the following toolbox: Data Management Tools > Sampling > Create Random Points tool. Depending on your landscape stratification scheme, the 'Constraining Feature Class' will be specified as one of the following elements you used previously in identifying your sampling units: A) landscape feature, B) management unit, C) vegetation type unit, or D) vegetation type unit stratified by management unit (Figure 2).

Specify the number of random points (i.e. the number of potential sample transects) by entering it in the 'Number of Points' field, and specify the name of the feature class ('transects' in this case). Then, specify the shapefile for your landscape stratification units ('constraining feature') so that ArcGIS will generate the specified number of points within each cover type. Also specify a minimum distance between points in the 'Minimum Allowed Distance' field. For this protocol, we recommend a minimum distance of 75 meters so that the transects do not overlap once the transects have been installed in the field. Specify the number of random points you wish to generate once you complete the protocol for determining the sampling intensity (i.e. the number of transects you will install). It is always a good idea to generate more transects than you need, so that you have room to throw out some transects from your sampling scheme should they be unsuitable once you visit them in the field.

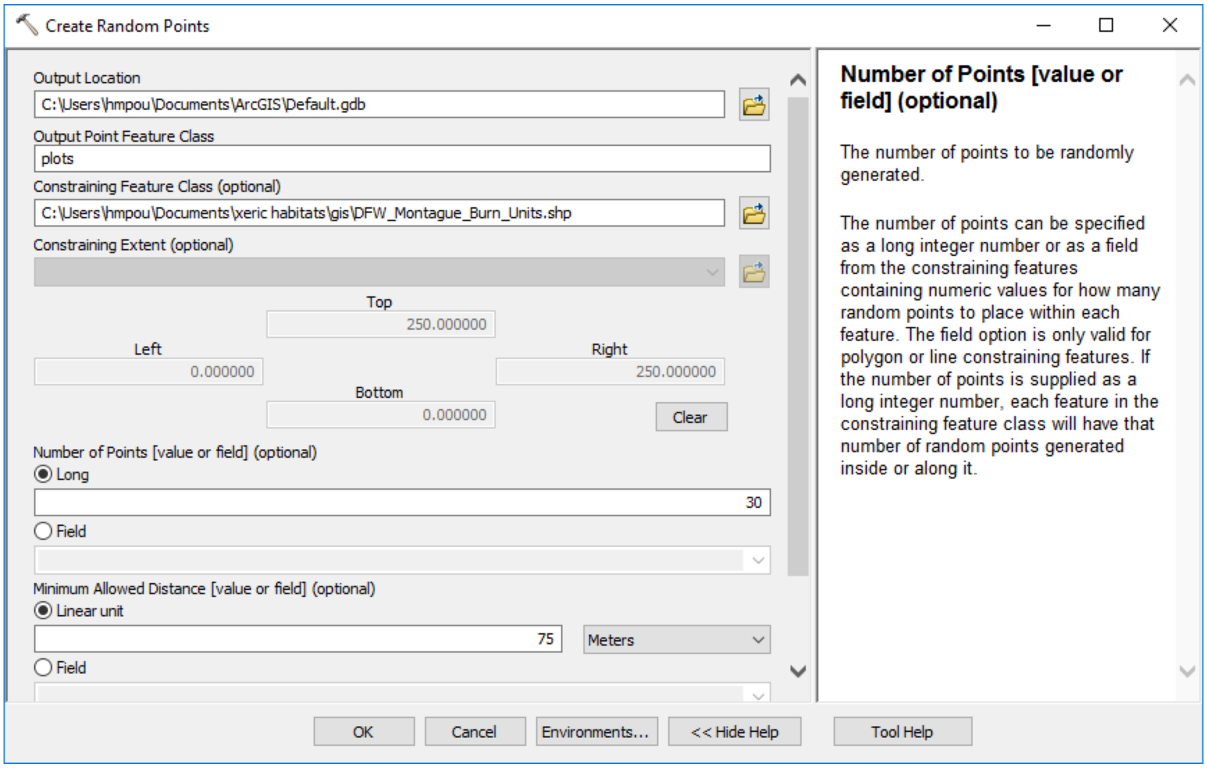


Figure 4: Screenshot of the Create Random Points tool in ArcGIS.

Below in Figure 5, you will find an example of random point generation across distinct landscape units (drainage, midslope, or ridgetop). After determining that you need 25 transects for your cover type in section C of this protocol, you would specify 30 points (to generate extra points in case some random points get thrown out in the field) that would be randomly distributed across each topographic position for a total of 90 points across your landscape (i.e. 30 points for each topographic position across the constraining surface).

Note that the vector to raster conversion tool may be necessary for creating random points across different topographic settings, as landscape position is generally defined in ArcGIS using digital elevation model (DEM) derivatives (i.e. slope, aspect, flow accumulation, etc.).

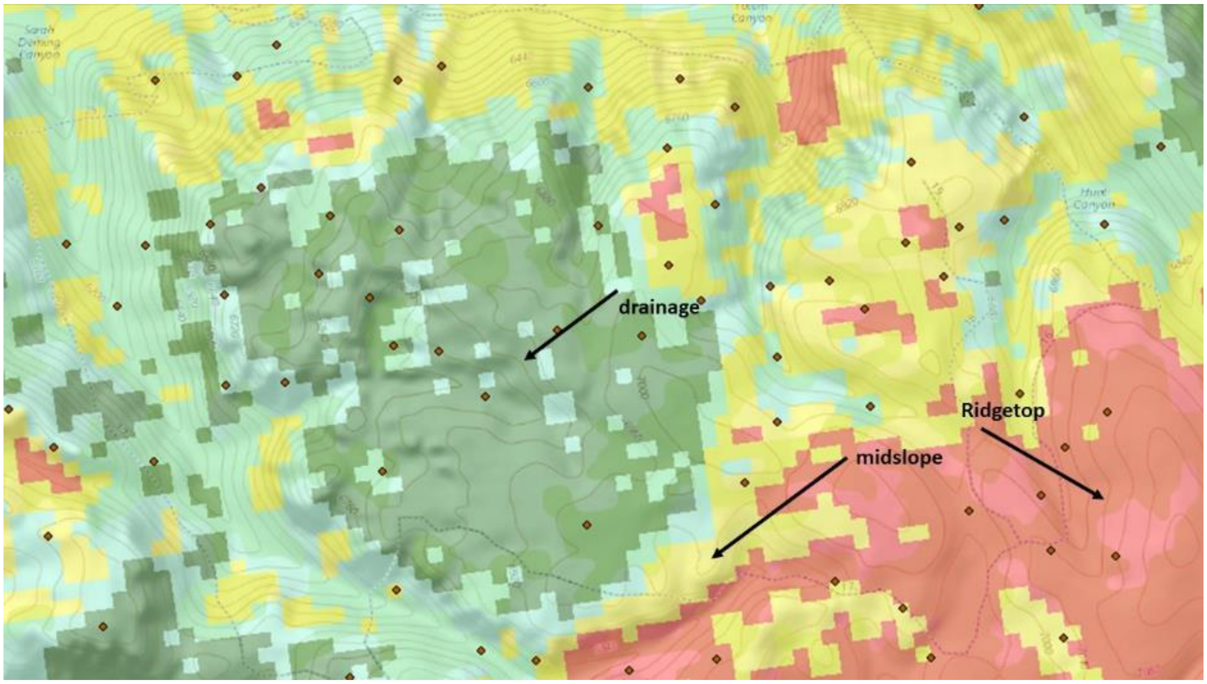


Figure 5. Example of random point generation in ArcGIS for landscape units (using the 'Create Random Points' tool.

Now that the random points have been generated, you will use the "Calculate Geometry Tool" to generate latitude and longitude coordinates for your points which can then be exported for GPS (geographic positioning system) use and field transect establishment. Open the attribute table of the point feature class in ArcMap. Do not start an edit session. Click the Table Options drop-down button, and select Add Field as shown in Figure 6.

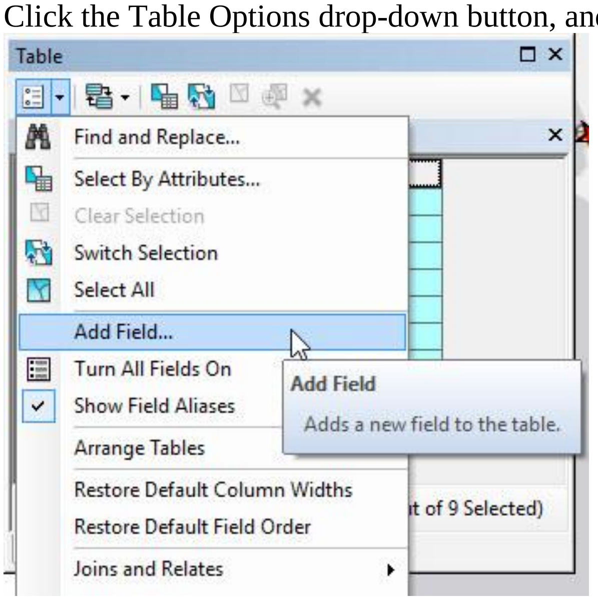


Figure 6: Dropdown menu for adding fields for spatial coordinate data generation.

In the Add Field window (Figure 7), name the field *Lat* (for latitude), with type Double. Click OK. Repeat this step and create another field named *Long* (for longitude).

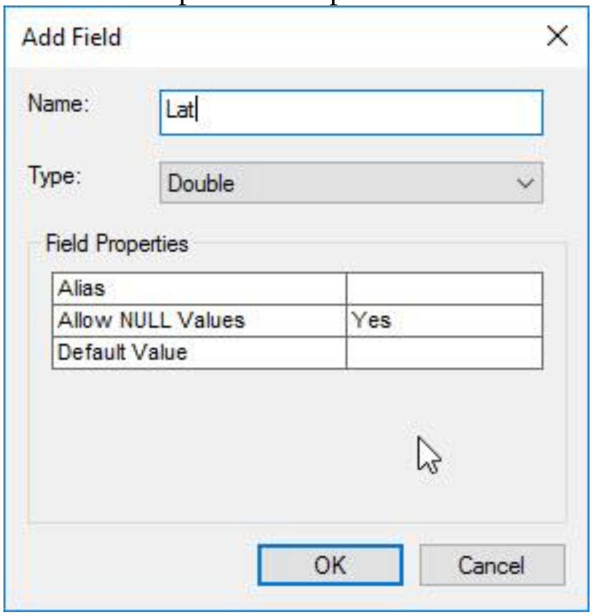


Figure 7: Pop up window for naming new attribute table fields for spatial coordinate data generation.

Start an edit session (Editor drop-down > Start Editing) (Figure 8).

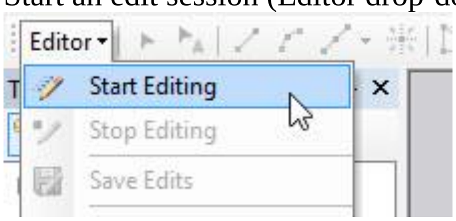


Figure 8: Dropdown menu example for starting and editing session in ArcGIS.

Highlight the Lat field, right-click the header, and select Calculate Geometry (Figure 9).

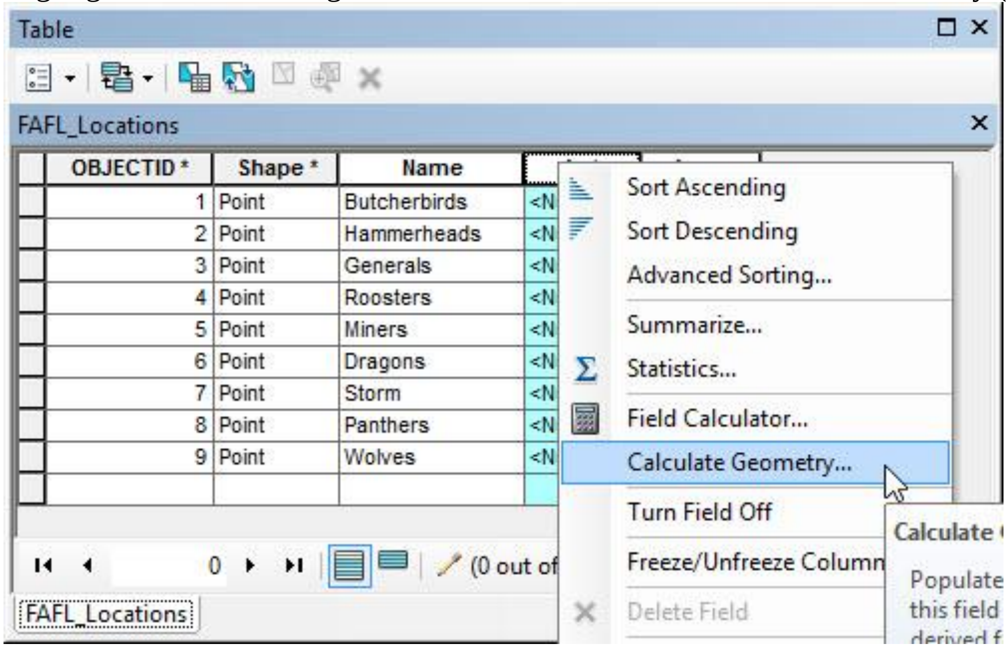


Figure 9: Dropdown menu for calculating latitude and longitude in ArcGIS.

In the Calculate Geometry window, ensure that Property lists the Y Coordinate of Point, and that you select the coordinate system of the data frame or feature layer (Figure 10). The coordinate system generated for your points will mirror the coordinate system of the data frame itself. Keep this in mind and set it accordingly. Set the units as desired (in this scenario, Decimal Degrees). Click OK.

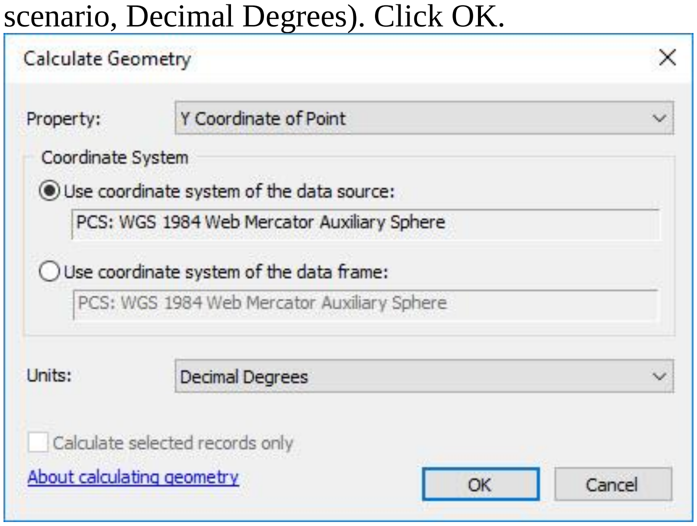
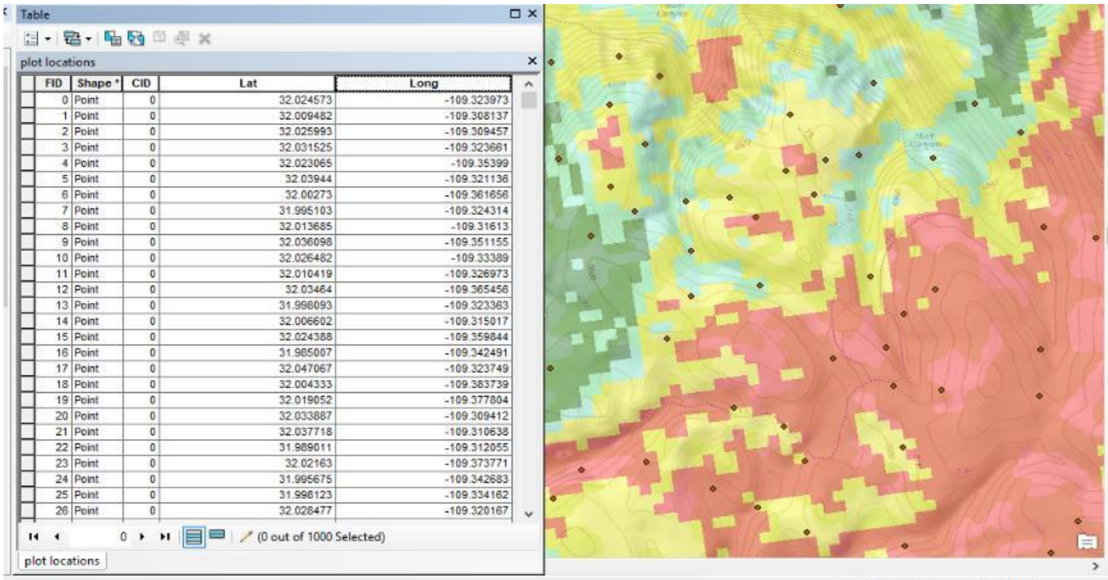


Figure 10: Pop up window for specifying the coordinate system parameters in your spatial coordinate data of the random points.

Repeat steps 5 and 6, applying the X Coordinate of Point property to the Long field.
The Lat and Long fields are populated with latitudinal and longitudinal data (Figure 11). If the point data is in a geodatabase feature class, it needs to be exported to a shapefile for this

step. You may open the .dbf file in excel or other software for GPS export or if you have a Trimble GPS unit, you may use the point location shapefile directly to navigate to the transect locations in the field.



FID	Shape *	CID	Lat	Long
0	Point	0	32.024573	-109.323973
1	Point	0	32.009482	-109.308137
2	Point	0	32.025993	-109.309457
3	Point	0	32.031525	-109.323661
4	Point	0	32.023065	-109.35399
5	Point	0	32.03944	-109.321136
6	Point	0	32.00273	-109.361656
7	Point	0	31.995103	-109.324314
8	Point	0	32.013685	-109.31613
9	Point	0	32.036098	-109.351155
10	Point	0	32.026482	-109.33389
11	Point	0	32.010419	-109.326973
12	Point	0	32.03464	-109.365456
13	Point	0	31.998093	-109.323363
14	Point	0	32.006602	-109.315017
15	Point	0	32.024388	-109.359844
16	Point	0	31.985007	-109.342491
17	Point	0	32.047067	-109.323749
18	Point	0	32.004333	-109.383739
19	Point	0	32.019052	-109.377804
20	Point	0	32.033887	-109.309412
21	Point	0	32.037718	-109.310638
22	Point	0	31.989011	-109.312055
23	Point	0	32.02163	-109.373771
24	Point	0	31.995675	-109.342683
25	Point	0	31.998123	-109.334162
26	Point	0	32.028477	-109.320167

Figure 11: Example attribute table of randomly-generated points and their spatial coordinate data in latitude and longitude.

Some randomly-generated sample transects may not be suitable for transect establishment once they are located in the field. Transect rejection criteria can vary tremendously by site. However, some examples include rejecting transects that (1) intersect roads, trails, or streams, (2) transects with significant edge effects, (3) transects are located on excessively steep slopes, and (4) areas of excessive runoff. The key is to establish a set of site-appropriate transect rejection criteria prior to selecting and visiting monitoring transect locations. This will avoid bias in simply rejecting transects in the field because they “don’t look right.”

3. Field Methods

Line-point intercept sampling and photo points are the core recommended monitoring methods described in this manual (Table 4, Figure 12). We anticipate that all managers will use (1) the first technique, the line-point intercept method, which generates core data on vegetative and soil surface cover, and (2) photo points, which provide a visual record of change. We recommend these methods because they are rapid to implement in the field, they generate both qualitative and percent cover data by species which is compatible with many existing plant community cover datasets across the region, and they can be implemented across a variety of vegetation types and site conditions.

A suite of additional supplementary methods are also included in this manual, which can be utilized when time is available for intensive sampling or on sites where managers wish to monitor changes in fuel loadings in response to adaptive management activities. Managers can choose to use some of these options based on their monitoring goals.

Method	Method number	Method type	Approximate time to implement method
Line-point intercept	1	Core	30 minutes
Photo points	2	Core	5 minutes
Ground cover estimation	3	Supplementary	10 minutes
Variable-radius forest and woodland sampling	4	Supplementary	20 minutes
Seedling density	5	Supplementary	10 minutes
Shrub transects	5	Supplementary	20 minutes
Fuel loadings	6	Supplementary	20 minutes

Table 4: List of core and supplementary monitoring methods in this guide, with approximate estimates of field effort requirements for each step.

Figure 12: Core and supplemental methods in this guide. Core methods should be implemented at all sites. Supplemental methods are add-on methods for particular vegetation types or specific adaptive management objectives.

4. Core field methods

Method 1: Line-point intercept sampling

Line-point intercept can be used to generate more indicators than virtually any other monitoring method. Line-point intercept is a rapid, accurate method for quantifying vegetation and soil surface conditions (Figure 13). By adding sampling at different vertical strata, from the ground to the tallest vegetation, information on vegetation structure can also be easily captured. We recommend that vegetation monitoring be completed prior to treatment and 1-year post-treatment. Vegetation sampling should be completed during the peak of the growing season, between mid-July and mid-August to ensure that plants are leafed out and to capture the most species possible at one sampling interval during the growing season.

Figure 13: Transect line for line-point intercept sampling, laid flush to the ground.

Materials (see Appendix A for sources for equipment)

• Metric 50 m measuring tape for marking the transect length
• Two permanent transect markers: 0.5-inch rebar with plastic rebar caps or low-profile survey markers at sites where managers wish to permanently monument transect locations.
• One steel chaining pin for anchoring the measuring tape
• One pointer—a straight piece of thick wire, rod, long pin flag, or wooden dowel at least 75 cm (2.5-ft) long. If using a dowel, use a small diameter dowel because larger diameters will bias results.
• A range pole or laser range finder for measuring the heights of vertical strata
• A clinometer
• A look-through compass
• An altimeter or GPS unit for measuring elevation
• Clipboard, Line-Point Intercept Data Form and pencil(s)

Plot set up

1. Mark the start of the plot with a permanent marker and record its name and spatial location (using a hand-held GPS unit) on the data sheet and record the coordinate system (i.e., State Plane, WGS1984, etc.) in which the spatial data are taken (Site Characteristics Data Form). Permanent monumenting of the plot may not be desirable in all cases since plot markers can potentially damage mowers and other machinery used in treatment applications. A good quality GPS (i.e. Trimble unit) can achieve sub-meter accuracy, so simply recording the spatial coordinates of the plot may be sufficient for relocating plots in future sampling intervals, especially if the transect bearing is also recorded. The key is to be in close to the same place for each vegetation sampling interval. If permanent plot monumenting is desired, use a low-profile survey marker or plastic rebar cap (see Appendix A for suppliers) to prevent damage to mowing equipment.

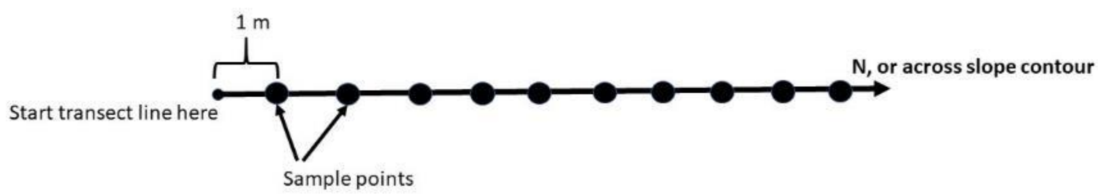


Figure 14: Standard plot layout for line-point intercept sampling for a 50-m transect. Vegetation occurrence data will be taken at 1 m intervals for a total of 50 sample points.

2. Run one 50-m transect line to the north. If the sample site has a steep slope, lay the transect line across the slope contour and record the azimuth of the transect line on the data sheet (Figure 14). If you are working in very dense vegetation, the transect line can be truncated to a shorter distance. For example, in dense scrub oak habitat, we recommend using a 25-m transect line. Record the length of the transect line on the data sheet. (The same length transect should be used in the future regardless of whether the area is altered by management.) The line should be taught and as close to the ground as possible.

3. If you are permanently monumenting the plot location, mark the end of the transect line with a low-profile survey marker or rebar with a cover cap.

4. Once the transect line is in place, record the environmental site characteristics (6-9 below). Also include a brief, handwritten site description on the datasheet to characterize the site and its identifying characteristics, which could be useful for interpretation and future plot relocation. Environmental characteristics need only be recorded at the first sampling interval since these variables are static over time, but the site description should be completed at every sampling interval.

Record the management or treatment history on the data sheet, if it is known. We recommend filling this out in advance on the data sheet and keeping a separate management table or GIS of site treatment history for accurately characterizing time since treatment, and treatment type, especially since this may be difficult to accurately determine in the field.

5. Record the elevation in meters on the data sheet using either an altimeter or GPS.

6. Measure the slope (in degrees) using a clinometer. Measure the slope of the site by siting the clinometer at eye-level of another field technician who is standing down slope (see Figure 15). Record the slope in degrees by reading the values on the left side of the dial inside the clinometer viewfinder.

Figure 15: Diagram explaining how to measure slope using a clinometer and two field technicians (Image taken from Fire effects monitoring and inventory system: https://www.fs.fed.us/rm/pubs/rmrs_gtr164.pdf).

7. Record the slope aspect, looking downslope, in compass degrees (e.g., 108°). In estimating slope aspect, estimate the direction that a raindrop would flow if it were to hit the slope surface.

8. Record the slope shape as convex, concave, or flat (straight, not curved) as shown in Figure 16.

9. Record the site moisture conditions, evidence of disturbance, and presence of microhabitats in the environmental characteristics data sheet.

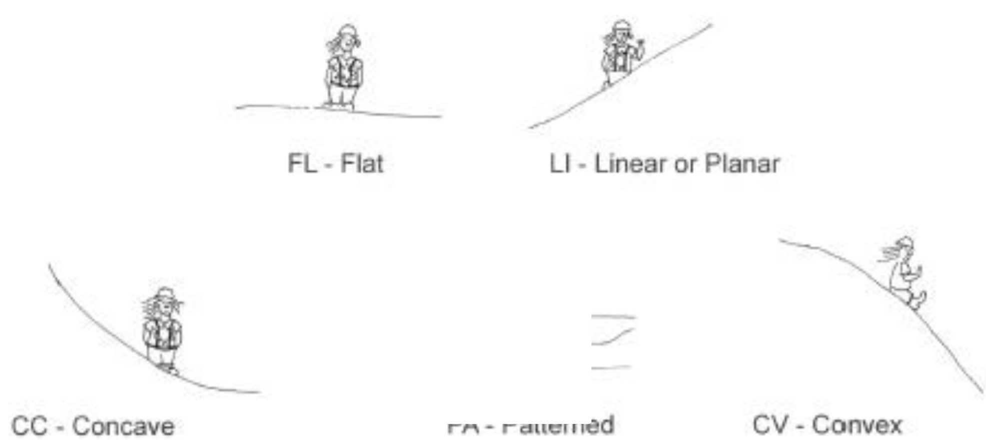


Figure 16: Examples of different types of slope shape that may be encountered in the field(Image taken from Fire effects monitoring and inventory system: https://www.fs.fed.us/rm/pubs/rmrs_gtr164.pdf).

10. Begin at the "0" end of the line for the line-point intercept plant survey. Sample 50 points along the transect at 1-m intervals if you are using a 50-m transect line. If the transect line is truncated to a shorter length, simply measure the vegetation at 50 equidistant points along the line. For example, a 25-m line would be measured at 0.50-m intervals.

11. Always stand on the same side of the line. Move from the plot center towards the end of the transect.

12. At each sample point, drop the pin to the ground from a standard height next to the tape (Figure 17). Make sure the pin is vertical. Be sure to drop the pin from the same height each time. A low drop height minimizes "bounces" off the vegetation but can also bias the sample.

13. Once the pin hits the ground, record every plant species it touches (or is projected visually through for strata above > 2-m height) in the following vertical strata, stopping when you have included all vertically-projected vegetation (Figure18):

- Ground
- 0-1 m
- 1-2 m
- 2-5 m
- 5+ m

For the ground stratum, record the ground cover where the pin hits the ground (Figure 17). If a plant is intersected, record the species. For each measurement, record the species of the first stem, leaf, or plant base intercepted by the pin in each stratum. Use the USDA, 6-digit, species codes to record species presence (https://plants.usda.gov/checklist.html). If litter, duff, rock, coarse woody debris, sand, or bare soil are intercepted by the pin in the ground stratum, record it using the following acronyms (L = litter, R = rock, D = duff, BS= bare soil, S= sand, and CWD = coarse woody debris). Record each species only once within each stratum, even if it is intercepted several times within that stratum. However, a species may be recorded in more than one stratum. For example, scrub oak (*Quercus ilicifolia*) could be encountered in both the 0-1 and the 2-5 m strata, thus it would be recorded as a hit in each stratum. Foliage can be live or dead. Also record the plant lifeform (F = forb, G = graminoid, or W = Woody plant). Use a dash (-) if no species/features were recorded in the stratum. Note that he data sheet for line-point intercept sampling has spaces for three species per stratum. Additional fields are available on the right of the data sheet if more than three species are encountered within 1 stratum. Simply specify the stratum for the additional species in that stratum and record the species code.

Distinguishing dead vs. live plants or plant parts is important. Record points where only dead plants or plant parts are intercepted by circling the species on the paper data form. If necessary, collect unknown specimens and take pictures of the plant for later identification, being careful to note the plot name associated with the unknown plant. For example, the first woody unknown plant would be recorded as WUNK1, and so on. Number unknown plants sequentially by lifeform being sure to assign a unique unknown identifier to each plant. Identify unknown plants as soon as possible upon return from the field while the plant is still in memory.

14. Repeat this for all other vertical strata at the sample point (Figure 18). Use the range pole to determine the heights of the taller strata above 1 m. A laser range finder can also be used instead of a range pole.

15. Repeat this procedure at 1-m intervals until you have intercepted the transect line at 50 points along the transect line.

16. Upon return from the field, identify any unknown plants, and key in your data into the ancillary line-point intercept .xls template (provided separately). Also maintain a master species list for your sample site with the full Latin name of each species and the 6-digit USDA plant code crosswalk. Percent cover calculations for each sampling stratum are also embedded in the Excel template.

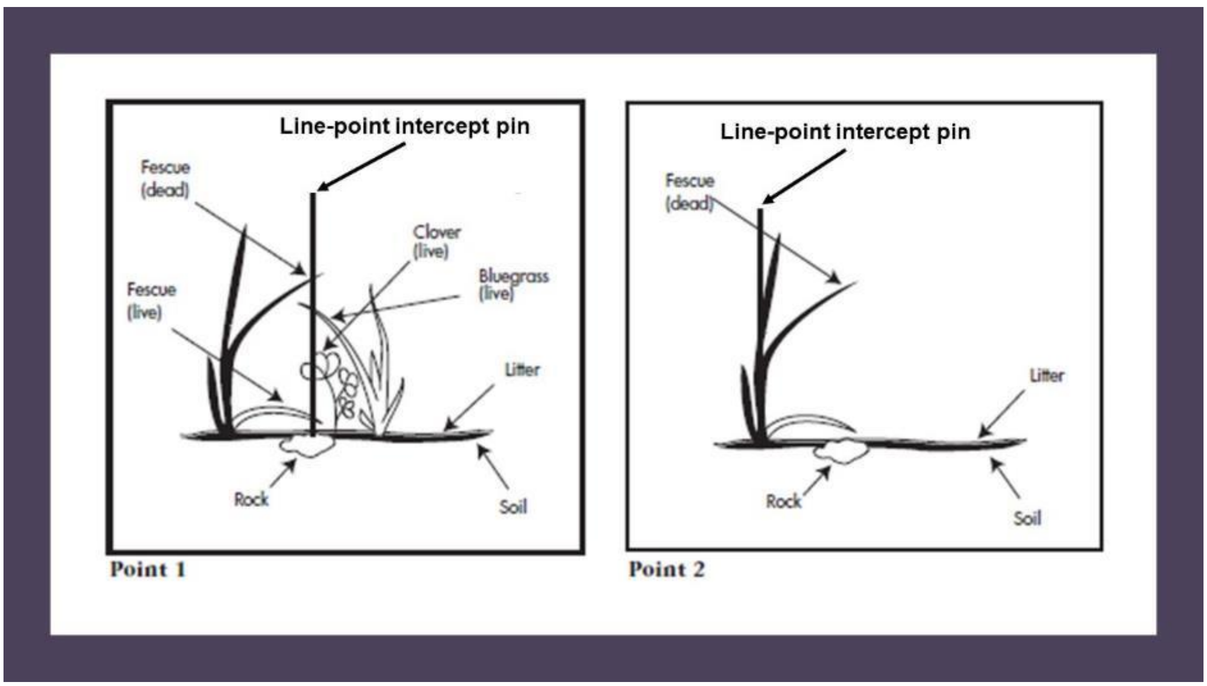


Figure 17: Two examples of line-point intercept hits for ground cover. In point 1, the pin intercepts rock at the ground, and then fescue, bluegrass, and clover in the 1-2 m stratum. In point 2, the pin hits fescue at the ground and at the 1-2-m interval, but no other ground cover or species in the 1-2-m stratum.

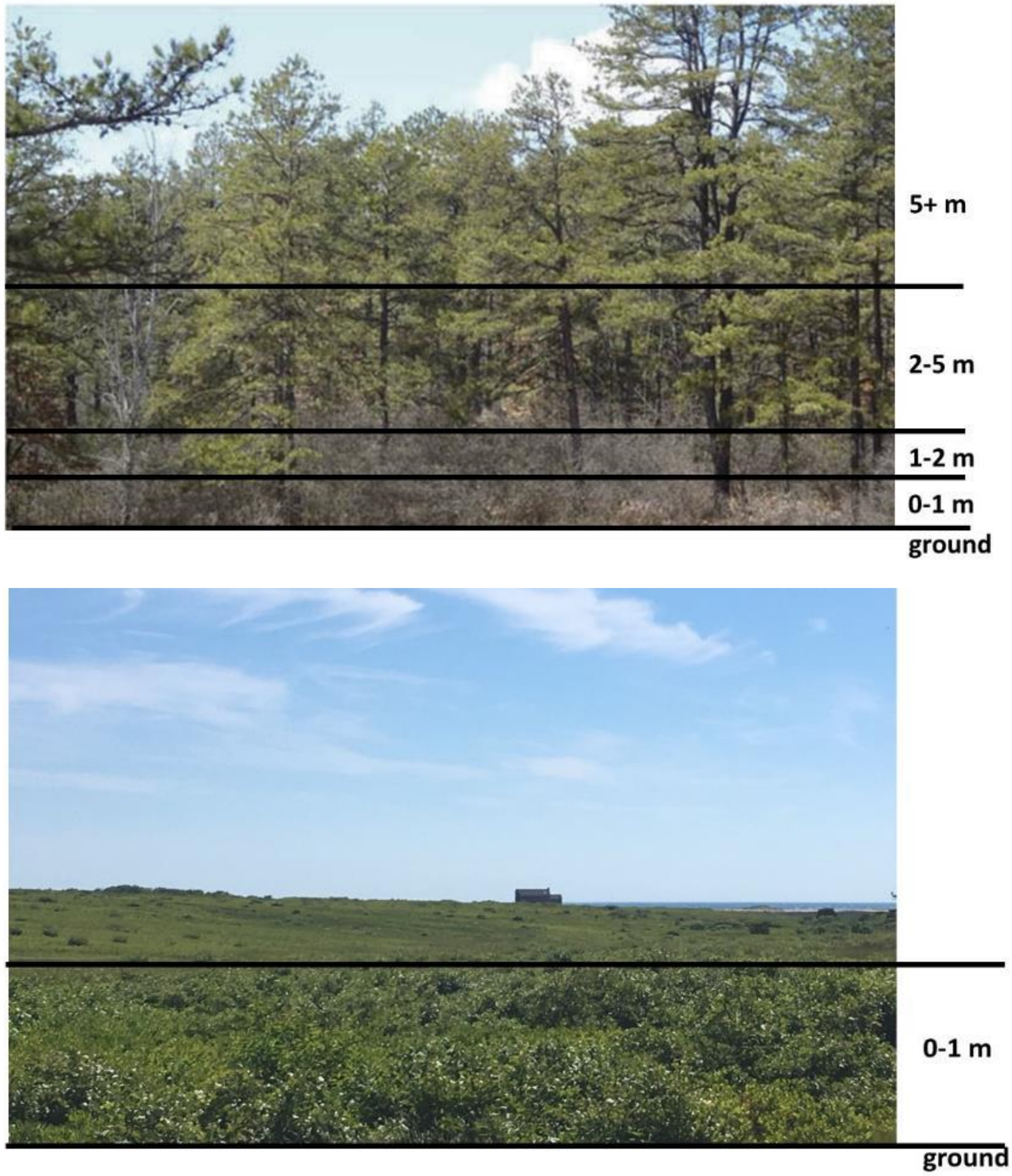


Figure 18: Example of the different sampling strata that would be included in the point-line intercept sampling in a pine forest where all strata are present (top) and in a heathland where only the ground and 0-1-m strata are present (bottom). Note that not all vegetation types will include all strata in the sampling effort (i.e. grasslands and heathlands may only include the ground and 0-1-m intervals, as shown in the lower panel).

Site Characteristics Data Form

Transect ID: ___________________

GPS Coordinates at transect start

Latitude:______________ Longitude: ______________

Coordinate system: _____________

Soil Moisture Level (circle one):

Xeric Mesic (moist for significant time) Hydric (water @ or near surface)

Evidence of Disturbance (circle one):

Fire Wind Insect Plow/Harrow Other: ______________

Unusual Microhabitats in Plot (circle one): Frost Pocket Scrape

Other: _______________

Topographic Position or Landform (circle one):

Valley bottom lower slope midslope upper slope ridetop

Elevation (m): _______ Azimuth:_______ Aspect:__________

Slope Shape (circle one): Concave Convex Straight

Last treatment date and treatment type: _________________________________

Site Description:

Line-point Intercept Data Sheet

Page _____of ______ Recorder names: __________ Transect ID: ___________

Azimuth: _______ Date: _________ Line length: ____________ Interval spacing: _____________

Pt.	ground	0-1 m			1-2 m			2-5 m			5 + m			overflow	
														stratum	species
1															
2															
3															
4															
5															
6															
7															
8															
9															
10															
11															
12															
13															
14															
15															
16															
17															
18															
19															
20															
21															
22															
23															
24															
25															

*Three spaces are included for recording species in each sampling stratum. If more than three species are encountered in a single stratum, use the overflow column to add extra species for that stratum.

Line-point intercept data sheet

Page _____of ______ Recorder names: __________ Transect ID: ___________
Azimuth: _______ Date: _______ Line length: ____________ Interval spacing: _____________

Pt.	ground	0-1 m			1-2 m			2-5 m			5 + m			overflow	
														stratum	species
26															
27															
28															
29															
30															
31															
32															
33															
34															
35															
36															
37															
38															
39															
40															
41															
42															
43															
44															
45															
46															
47															
48															
49															
50															

Line-point Intercept Data Sheet for 0-1 m stratum data only

Property/Unit:__________________ Property Community Monitoring Observers:___________________

Transect # _____________________ Date:_________________________

Transect #

Plant Species Name	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25

Property/Unit:___________________ Property Community Monitoring Observers:____________________

Transect # ______________________ Date:_________________________

Transect #

Plant Species Name	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50

Table 5AB. Example line-point intercept data form with field data for the first 3 line-point samples along a 50-m transect. For point 1, rock (R) was the ground cover, *Morella pensylvanica* (MORPEN) and *Nabalus serpentarius* (NABSER) are in the 0-1-m stratum, *Galussacia baccata* (GAYBAC) and *Elaeagnus umbellata* (ELAUMB) are intercepted by the sampling pin in the 1-2-m stratum, *Quercus ilicifolia* (QUEILI) is intercepted in the 2-5-m stratum, and *Pinus rigida* (PINRIG) is in the 5+-m stratum. At the third sample point, dead *Carex pensylvanica* (CARPEN) was intercepted by the wire pin, so it was circled, and more than 3 species were encountered in the 0-1-m stratum, so the overflow cells were used to specify that *Hudsonia ericoides* (HUDERI) was also encountered at the 3rd point on the transect.

Page 1 **of** 2 **Recorder names:** Poulos/Barton **Transect ID:** MONT12

Azimuth: 0° **Date:** 7/15/2018 **Line length:** 50 m **Interval spacing:** 1 m

Pt.	ground	0-1 m			1-2 m			2-5 m			5 + m			overflow	
														stratum	species
1	R	MORPEN	NABSER		GAYBAC	ELAUMB		QUEILI			PINRIG				
2	CWD	CARPEN	MORPEN		PRUMAR			QUEILI							
3	B	CARPEN	ARCUVA	VACANG										0-1	HUDERI
4															
5															
6															
7															
8															
9															
10															
11															
12															
13															
14															
15															
16															
17															
18															
19															
20															
21															
22															
23															
24															
25															

Table 5B: Example line-point intercept data form with field data for data sheets for the 0-1 m stratum only. This type of data collection may be more desireable on sites that are graminoid dominator or that have low shrub cover. Species names are recorded as rows, and presence of eac species at each line intercept point (26-50) are recorded with an X for each sample point where that species is counted as a hit. Lines arr added in to denote that this species or cover type was not present at that line intercept point. *Carex pensylvanica* (CARPEN) was encountered in the 0-1 m stratum at points 28 abd 29, 33-35, and 41-43. Arctostaphylos uvaursi (ARCUVA) was encoutnered at points 26 and 27, 34-36, and 40-43, and so on.

Property/Unit: Smooth Hummocks **Property Community Monitoring** **Observers:** Paules - Barton
Transect # SH 4 **Date:** 8/11/18

Plant Species Name	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
Litter	X	X							X	X	X	X									X				
Bareground			X	X	X								X	X	X	X	X						X	X	X
Sand						X	X	X										X	X	X					
Rock																						X			
Carpen			X	X				X	X	X						X	X	X							
Arcuva	X	X							X	X	X				X	X	X	X							
Vacang									X												X	X	X	X	X
Symdum										X	X	X	X	X											
Morpen					X									X	X				X		X			X	X

Method 2: Photo points

Photographs are extremely useful for providing visual documentation of vegetation change over time (Figure 19). These qualitative data cannot be used as a substitute for quantitative data, but they can be important supplements for designing management actions and for identifying perscribed fire fuel types. Take one photo from the zero towards the 50-m point of the transect. If you take digital photos, be sure to rename the digital images with a name that includes both the plot identifier as well as the year that the photo was taken. Slide the photo card label (Figure 19) behind the photo in the plastic storage sheet and clip it to your clipboard. After the first sampling interval, photo cards can also be printed in advance of the field sampling effort to save time in the field.

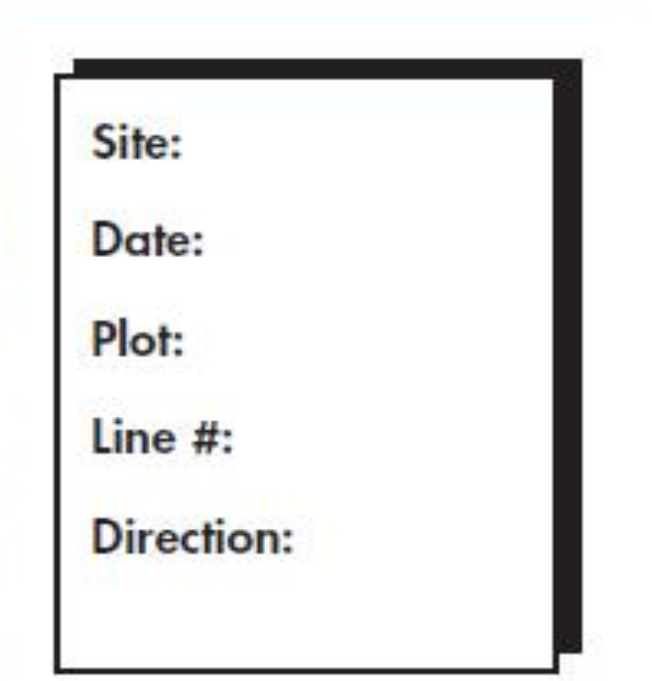


Figure 19: Photographer at the plot center and photo point ID board marking the beginning of the 50-m point-line intercept transect.

Materials (see Appendix A for sources for equipment)
• Compass
• 35 mm or digital camera with a 50-mm equivalent lens (1:1 ratio).
• Photo point (ID) board (chalk or whiteboard) or Photo point (ID) card (Figure 20) clipped to a clipboard
• Thick marking pen or dry-erase marker (if using a whiteboard)
• A monopod or one 1.5-m (5-ft) long, 3/4-in diameter PVC pipe
• A range pole section for scale
• The Context Camera app (https://appadvice.com/app/context-camera/662559044) for those who wish to add spatial location or date and time data to the photo.

Standard Method

1. Record the photo information on the photo board by recording the date, plot number, site, and the management history on the photo point board or photo point ID card.

2. Place the photo board into the field of view of the camera at the beginning of the line-point intercept transect line. Place one section of the range pole into the field of view for scale.

3. Center the monopod with your digital camera on top of the plot center. Set your focal length to the smallest setting possible (i.e. widest angle), and record the photo point information in the photo point .xls template. Alternatively, use Context Camera to record spatial location, date, and time data in the photo.

4. Holding the camera as level a possible (use the level in your camera if it has one), take the plot photo in the direction of the transect line.

5. Upon return from the field, rename your images with the transect ID and date of the field visit.

Site:

Date:

Plot:

Line Direction:

Treatment Cycle:

Figure 20: Photo point monitoring card. This can be printed and slipped into a clear plastic protector so that it can be written on with a dry erase marker and reused for multiple plots, or they can be printed in advance prior to field sampling.

5. Supplementary methods

Method 3: Ground cover estimation in graminoid-forb-dominated systems

While point-line intercept sampling offers a good estimate of vegetation structure and composition, ground cover can be underestimated by this method in graminoid- and forb-dominated systems. Small subplots that measure cover in frames can be used to better estimate coverage of smaller ground cover components at sites where graminoid and forb cover are management targets (Figure 21). This method is especially useful for characterizing ground cover on open sites with little shrub cover. Think of this method as an optional supplement that can be adopted by managers who have sufficient time and reason to suspect that the line-point intercept method won't sufficiently capture ground cover.

Materials (see Appendix A for sources for equipment)

- a 0.5 m-radius cover hoop
- Clipboard, ground cover data forms and pencil(s)
- The point-line intercept transect line in place

Standard methods

1. At 5-, 10-, and 15-m distance along the line-intercept transect line, throw the measuring hoop to the right of the tape. Note that ground cover should be taken during the growing season after leaf-out.

2. Estimate the cover of bare ground, graminoids, forbs, rock, and litter using the Braun-Blanquet scale and assign it a numbered code that corresponds to the cover-class as follows:

1 = < 1%

2 = 1-5%

3= 5-25%

4 = 25-50%

5= 50-75%

6 = 75-100%

3. Record % cover of graminoids, sedges, and forbs by species. In making Braun-Blanquet cover estimates it is helpful to work in a stepwise fashion in making your cover estimates. For each species, first ask, is the cover more than half or less than half? If it's less than half, then ask is it more than 25% or less than 25%? If, after those steps, you determine the cover to be more than 25%, assign a class of 3 for 5-25% cover.

Note also that total cover across all species can be greater than 100% because of vertical layering of plant biomass.

4. Enter your field data into the line-point intercept .xls template for storage.

5. Calculate the average % ground cover for each category (graminoids, forbs, bare ground, rock, litter, graminoids by species, forbs by species) by dividing the total percent cover for each category by 6 (the number of sampling frames across the two transect lines).

Figure 21: Ground cover sampling along the line-point intercept transect line using a 0.5-m diameter circular sampling frame.

Ground cover data sheet

Transect ID: _______________ Recorder names: ________________
Sample date: _____________

species	5 m	10 m	15 m	20 m	Cover scale	code
					< 1%	1
					1-5%	2
					5-25%	3
					25-50%	4
					50-75%	5
					75-100%	6

Table 6: Example herbaceous species ground cover data sheet. Ground cover is recorded at four intervals along the line-point intersect transect.

Ground cover data sheet

Transect ID: _____MONT12________ Recorder names: _Poulos/Barton__

Sample date: _07/15/2018_______

species	5 m	10 m	15 m	20 m	Cover scale	code
AGRHYE	2	2	5	5	< 1%	1
CARPEN	1	5			**1-5%**	2
DICSPH	3	3	2		5-25%	3
EUTCAR	2		4		25-50%	4
SYMDUM	3	1			50-75%	5
POTCAN	2				75-100%	6
JUNGRE	1	1	2	1		

Method 4: Variable-Radius forest and woodland sampling

Certain vegetation types will contain forest attributes that are not sufficiently quantified by the point-line intercept method. Quantifying temporal changes in live and standing dead tree size structure, density, and basal area (or stocking rate) is paramount for evaluating forest and woodland responses to adaptive management. So, for forested plots, superimpose a forest/woodland vegetation monitoring subplot onto the point-line intercept protocol.

Variable-radius plot sampling (also known as angle gauge sampling, prism sampling, or point sampling) is one of the most common and efficient tree inventory sampling methods. Herein, we present an overview of the method that should be sufficient to carry out variable-radius plot sampling in the field (Figure 22). However, for those who want more information on the method, a comprehensive explanation of the methodology by the Army Corps of Engineers can be found here at: http://acwc.sdp.sirsi.net/client/en_US/search/asset/1035564;jsessionid=FBB01D4D1D624839A7FF9E5DC3B342B8.enterprise-15000.

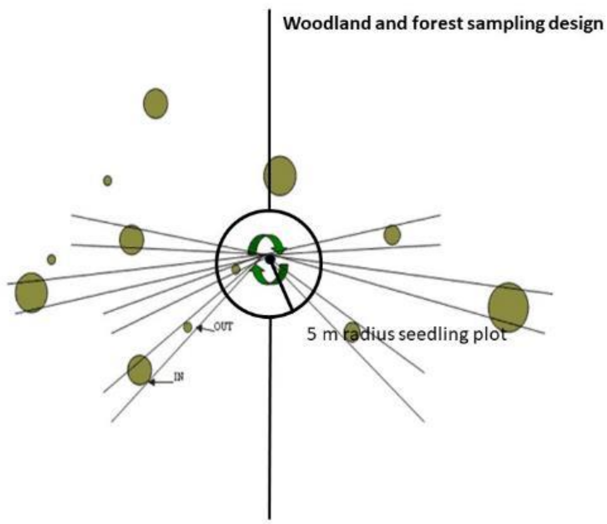


Figure 22: Diagram of variable radius plot sampling including the line-point intercept transects and the 5-m radius seedling plot. "In" trees are larger than the projected area of inclusion of the angle gauge. "Out" trees are smaller than the projected area of the angle of inclusion.

The easiest way to understand variable-radius plot sampling is by doing it in the field with an angle gauge. While the method sounds complicated, the technique itself is very simple; it is based on the concept of an angle gauge, where the probability of a tree being "in" is strictly proportional to tree diameter (or size). Each tree has its own plot size (and therefore also its particular inclusion zone). In variable-radius plot sampling, a tree is "in" the plot if the diameter at breast height (DBH) of the tree is wider than a given angle when sighted from plot-center (Figure 22). If the tree is wider than the angle, then it is "in" and should be measured. Deciding which angle (or basal area factor (BAF)) to use is equivalent to deciding which plot radius to use in fixed-radius plot sampling. The BAF is a multiplier that allows for a quick calculation of the stand basal area represented by one plot.

One simple way to understand the angle gauge concept is to use your thumb at arm's length from your eye based on the following proportion (Figure 23):

Distance from eye = width of object x 33

For example, a thumb width of 0.75 inches should be placed 24.75 inches away from your eye (0.75 x 33 = 24.75), which just happens to be about arm's reach. Maintain this approximate arm reach length between your eye and your thumb. Swing around in a circle and count the number of trees that are "in" or "out" using your thumb angle gauge. For the thumb angle gauge, your eye is centered over the point-line intercept plot center. The same is true for a Cruz All, but if you decide to use a prism, the prism itself, is centered over the plot marker and NOT the eye of the operator.

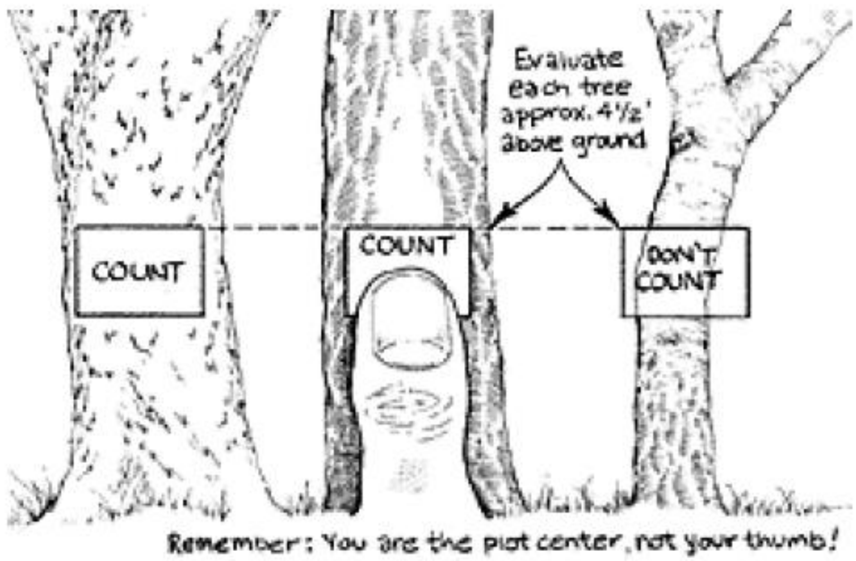


Figure 23: Example of using your thumb as an angle gauge for variable-radius sampling. Image taken from https://foreststewardshipnotes.wordpress.com/2012/04/26/simple-homemade-forestry-tools-for-resource-inventories-2/.

To determine the stand basal area from a given plot, multiply the number of "in" trees by the BAF. BAFs generally produce numbers in English units. Conversion factors from basal area in ft^2 per acre to m^2 per hectare are included in this document since the Jim Gem Cruz All is only available in English units. Metric BAF prisms are also available for purchase at Forestry Suppliers. However, they are more expensive, and the Jim Gem Cruz All has the advantage of having multiple BAFs in one piece of inexpensive field equipment.

You may be wondering why this type of sampling is called "variable-radius." The result of using the angle gauge to determine if a tree is "in" the plot is that different-sized trees effectively have different-sized plots. A very small tree would have to be very close to plot-center to appear wider than the minimum angle. Conversely, a very large tree could be relatively far from plot-center and still appear wider than the minimum angle (Figure 22). So, the radius of the plot varies depending on the size of the tree measured, hence the name "variable-radius" plot sampling.

Materials (see Appendix A for sources for equipment)

• A Jim-Gem Cruz All (available at Forestry Suppliers) or a metric BAF prism. If you are working on steep slopes, you may wish to use the cruz crutch which corrects for slope steepness.
• The same transects used for line-point intercept sampling
• Tree diameter tape
• Clipboard, seedling density, tree density, and size data forms and pencil(s)

Figure 24: Using a Jim Gem Cruz All for measuring forest basal area and tree density using variable-radius plot sampling.

Standard methods

1. Center your eye above the plot center that you marked for the line-intercept sampling component of the study (Figure 23). Use a flag or a chaining pin if needed to make the plot center clearly visible. For the Jim Gem Cruz All, you will stand over the center of the plot and extend your arm straight outward to take measurements (Figure 24). If you are using a prism, you will center the prism over the plot center with the prism at arm's length from your eye.

2. Starting at 0° (north), and holding the Cruz All at arm's length, determine the number of living "in" trees in your plot using a 10 BAF angle gauge by moving in a circle until all "in" trees have been identified. You should aim to get 6-10 "in" trees in your sample. If you have too many or too few trees in your sample, adjust the BAF you use until you hit the desired 6-10 "in" tree target. Note, that by using variable-radius sampling, it is possible to adjust the

BAF used in your forest inventories in accord with different adaptive management activities. For example, if forest thinning has been implemented since the last plot inventory, fewer trees may be present, and it may be necessary to adjust the BAF to adequately quantify tree basal area and density. Variable-radius sampling allows for this flexibility in vegetation monitoring.

3. Borderline trees can be a problem in variable-radius sampling. Often, field technicians will consistently either over- or underestimate the inclusion of borderline trees. The easiest way to account for borderline trees is to simply include every other tree in the tally.

Tree basal area and density calculations

Basal Area

1. Calculate tree basal area in m^2 ha^{-1}. While Jim-Gem Cruz All is efficient in the field, it is not sold in metric units.

2. Use table 7 to find the conversion factor between English and metric units for the BAF you used in the field. Then multiply the number of trees in your plot by the metric conversion factor for the appropriate BAF to obtain total tree basal area using Table 8.

3. If you wish to parse out your basal area data by species, simply multiply your tree tallies for each species by the appropriate metric BAF.

Table 7. Common English BAF and the metric BAF for that equipment.

English BAF (Square feet per acre)	Metric BAF (Square meters per hectare)
5	1.148
10	2.296
15	3.444
20	4.592
25	5.740
30	6.888
40	9.184

Tree density

1. Tree density calculations are more complex in variable-radius plot sampling due to the plotless nature of the methodology. Begin by tallying ‘in’ trees in 2-cm size-classes from your field data.

2. Enter your field data into the forest data sheet .xls template.

3. Use the multipliers for each size-class of trees in Table 8 to calculate tree density in trees per ha for your sample plot within each size class.

4. Calculate total tree density by summing these values across all size classes.

5. If you wish to evaluate tree density by species, simply tally your trees by species into the relative 2-cm size-classes and then use the conversion table to calculate tree density per ha by species.

Table 8: Conversion factor for trees per ha by size class. Multiply the number (tally) of trees in each size-class in from your variable-radius point sampling inventory to get tree density per ha in each size-class for your sample plot.

DBH (cm)	Trees per ha
10	254.6
12	179.8
14	129.9
16	99.5
18	78.6
20	63.6
22	52.6
24	44.2
26	37.5
28	32.4
30	28.3
32	24.9
34	22
36	19.65
38	17.63
40	15.92
42	14.4
44	13.2
46	12
48	11
50	10.2
52	9.4
54	8.7
56	8.1

Woodland and Forest Sampling Data Sheet

Page _______ of _______ Transect ID: ___________ Sample date: ___________

Plot Basal Area Factor:_____ Recorder names: ___________________

Species	Tree DBH (cm)	Species	Tree DBH (cm)

Table 9: Example data sheet for forest and woodland tree sampling. The 6-digit USDA species code is listed for each "in" tree, along with its diameter at breast height (DBH). Two data columns are provided for dense stands.

Woodland and Forest Sampling Data Sheet

Page ___1___ of _1_____ Transect ID: __MONT12____ Sample date: _07/15/2018_

Plot Basal Area Factor:__10__ Recorder names: ___Poulos/Barton

Species	Tree DBH (cm)	Species	Tree DBH (cm)
PINRIG	25.4		
PINRIG	16.2		
PINRIG	35.6		
PINRIG	22.9		
QUEILI	8.6		
QUEILI	15.2		
QUEILI	12.3		
QUEILI	19.6		

Method 5: Seedling density

Seedling regeneration may be another important indicator of adaptive management effects on woodland and forest vegetation plots. If you are working in wooded sites, you will sample seedling abundance in small, 1 x 2-m micro-plots using the shrub cover sapling pole at 5- and 10-m distance along the point-line intercept sampling line (Figure 25).

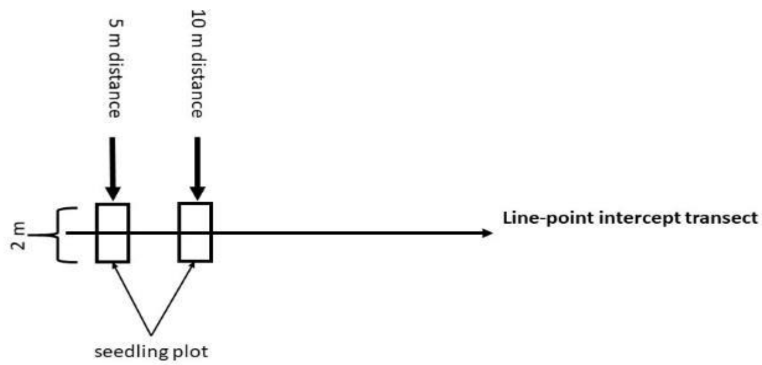


Figure 25: Plot layout for seedling inventories. Seedling counts are taken in 1 x 2-m frames at 5- and 10-m distance on each point-line intercept transect line using the 2-m shrub cover pole.

Materials (see Appendix A for sources for equipment)

• A 5-m length dbh tape

• Pencil(s)

• A clipboard

• 2-m shrub cover pole with tape marking the center point on a 2-m PVC pipe

Standard methods

1. Have one recorder stand at 5-m along the transect line and have the second technician walk with the shrub cover pole to 7-m on the transect line.

2. Tally seedlings (< 2-m height) by species for the entire micro-plot and record the data in the seedling data sheet. Tally seedlings (S) and clonal (C for coppice, including resprouts from trees top-killed by fire) individuals separately on separate lines in the data sheet. Repeat this at 10-, 15-, and 20-m distance along the transect line.

Seedling density calculations

1. Enter your data into the separately-provided seedling data .xls template.

2. The two 1 x 2-m seedling micro-plots represent 0.0004 ha. To convert your seedling counts into seedling densities on a per ha basis, divide the total number of seedlings across both subplots by 0.0004.

2. Separate your tallies over the two microplots by species and divide them each by 0.0004 to calculate seedling density per ha by species.

Tree Seedling Tally Sheet

Transect ID:	Recorders:	Date:	
Species name	Tally Marks	Total count	Type (seedling or coppice)
1.			
2.			
3.			
4.			
5.			
6.			
7.			
8.			
9.			
10.			

Table 10: Example seedling tally sheet for the two 1 x 2-m sample frames. Data will be lumped across the two seedling micro-plots on each transect line.

Tree Seedling Tally Sheet

Transect ID:	Recorders:	Date:	
Species name	Tally Marks	Total count	Type (seedling or coppice)
1. PINRIG		16	S
2. QUEILI		10	C
3. QUEiLI		5	S
4.			
5.			
6.			
7.			
8.			
9.			
10.			

Method 6: Shrub cover transects

Some sites may contain a significant shrub component in which managers may wish to monitor temporal changes in woody vegetation structure that may not be adequately characterized by line-point intercept sampling. Shrub cover belt transects provide a quantitative way of measuring shrub cover and distribution, specifically (Figure 25).

Materials (see Appendix A for sources for equipment)

- A PVC pipe cut to 2-m length (i.e. the transect width) with the center marked with a piece of tape
- The same transect line that was used for the line-point intercept methods
- The linear side of a dbh tape for shrub heights that are 0-2-m tall, and the 2-m length shrub transect PVC pipe or range pole for measuring taller shrub heights.
- Clipboard, Shrub Cover Data Sheet, and pencil(s)

Standard methods

1. Center the PVC pipe, or taped center point on the line-point intercept transect line on the ground (Figure 24).

2. Stand at the “0” end of the line and face away from the plot’s center.

3. Walk slowly along the transect and walk from 0- to 5-m along the transect line with the PVC pipe centered over the line (Figure 25). Estimate percent cover by species for all shrubs < 2-m height using the Braun-Blanquet scale described in the standard methods section of the ground cover supplementary methods. Include only live shrubs in your cover estimates.

4. Repeat the percent shrub cover estimate for each 5-m block up to 25-m length along the line-point intercept transect.

5. Enter the field data into the shrub cover .xls template upon return from the field.

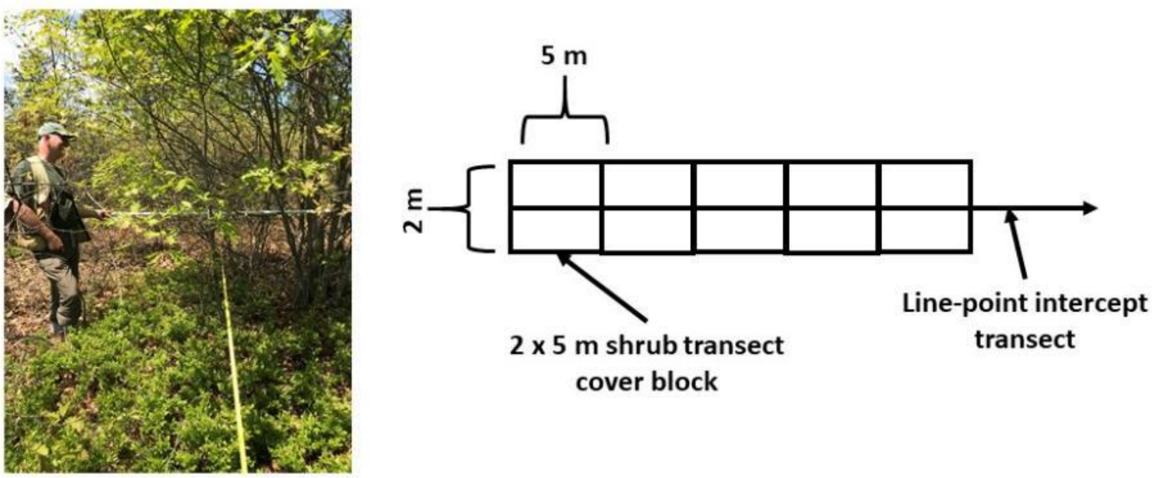


Figure 26: Shrub cover transect layout

Shrub cover data sheet

Transect ID: _______________　　　　　　**Recorders:________________**

Date: _________________

species name	% cover (0-5 m)	% cover (5-10 m)	% cover (10-15 m)	% cover (15-20 m)	% cover (20-25 m)

Cover scale	code
< 1%	1
1-5%	2
5-25%	3
25-50%	4
50-75%	5
75-100%	6

Table 11: Example shrub cover data sheet. Shrub cover are classified using the Braun-Blanquet cover class codes. In the worked example, *Quercus ilicifolia* QUEILI comprises 2-25% cover in the 5-10-m and 10-15-m blocks of the belt transect, and 50-75% cover in the 15-20 m block. It is absent from the 0-5 and 20-25-m blocks of the shrub belt transect. *Morella pensylvanica* (MORPEN) comprises 5-25% cover for both the 0-5- and 5-10-m transect blocks, but it is absent in the rest of the transect.

Shrub cover data sheet

Transect ID: _______________ Recorders:________________

Date: _________________

species name	% cover (0-5 m)	% cover (5-10 m)	% cover (10-15 m)	% cover (15-20 m)	% cover (20-25 m)
QUEILI		3	3	5	
MORPEN	3	3			
ROSVIR			2	2	
VIBDEN	3				
VACANG			4		2
GAYBAC	4	3			6

Method 7: Fuel loadings

Evaluating changes in fuel loadings over time may be critical on sites where prescribed fire is generally used as an adaptive management tool for altering the vegetation complex. Line-intercept sampling is the most common and widely-adopted method for inventorying fine and coarse woody debris, both of which heavily influence fire behavior.

Fine fuel particles are generally categorized into the following time-lag fuel particles: 1-hour (0-0.6 cm diameter), 10-hour (0.6-2.5 cm diameter), and 100-hour (2.8-8.0 cm diameter) fuels. Larger coarse woody debris, or 1000-hour fuels include pieces 8 cm or greater in diameter and at least 1-m in length. The time-lag is defined as the time period required for a fuel particle to reach ~ 63% of the difference between the initial moisture content and the equilibrium moisture content in a different environment (temperature, humidity). This characteristic of the fuel particle is strongly correlated to its diameter, where the time-lag period is estimated by measuring the particles' diameter such that that smaller fuel particle abundance (i.e. 1-, 10-, and 100-hour fuels) is a key fire behavior driver.

Materials

• One 50-m tape

• A go-no-go fuel particle gauge

• A metric metal ruler

• The linear side of a dbh tape, an additional 50-m tape, or a laser range finder for measuring log lengths

• Pencil(s)

• A clipboard

Standard methods

1. 1-hour (h), 10-h, and 100-h will be sampled using the same transect line as the line-point intercept sampling for plant community composition. If the site has burned since the last sampling interval, record the mean scorch height (specified by singed needles or char on the tree bole).

2. As with line-point intercept sampling, the length of the fuels transect can be shortened or lengthened based on the fuel complex and sampling time availability. The standard transect line length will be 25-m. This can be done by measuring fuels along the first 25-m of the line-point intercept transect line.

3. All time-lag fuel particle size-classes will be measured from 0-5 m along the transect line, 10-h, 100-h, and 1000-h fuels are measured from 5-10-m along the transect line (i.e. 1-h fuels drop out of the sample after 5-m), 100-h and 1000-h fuel particles are measured from 10-15-m (i.e. 1-h and 10-h fuels are excluded from this interval), and 1000-h fuels will be tallied along the entire 25-m transect line, from 5-25-m.

4. Tally the number of fuel particle intersections from each 1-h, 10-h, and100-h fuels from 0-15-m along the transect line.

5. Record the depth of litter and duff at 5- and 10-m distance in cm along the transect line using a metric metal ruler.

6. Measure the diameter of each piece of 1000-h fuel where it passes through the entire 25-m vertically-projected sampling plane of the transect line (Figures 27 and 28).

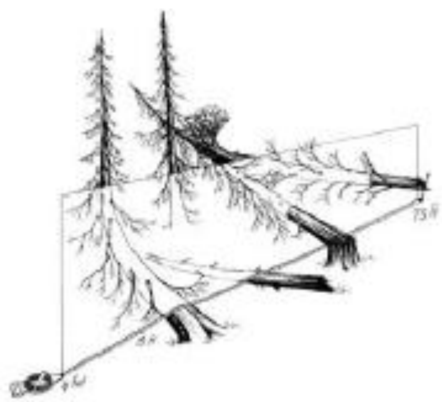


Figure 27: All of the pieces crossing through the sampling plane of coarse woody debris (1000-hr fuels) that would be measured in the line intercept fuels sampling method. Image taken from Fire effects monitoring and inventory system: https://www.fs.fed.us/rm/pubs/rmrs_gtr164.pdf.

Figure 28: Example of a fuel particle inventory for A) a 100-h fuel particle tally using a go-no-go gauge and B) measuring the particle length of 1000-h fuel that intersects the transect line.

7. Then record whether the 1000-h fuel particle is sound or rotten in the fuel sampling data sheet data sheet. A rotten log will crumble under your feet when stepped on.

8. If possible, also determine whether the 1000-h fuel particle is a softwood or hardwood and record this information on the data sheet.

9. Upon return from the field, enter your field data into the fuels spreadsheet to calculate the fuel loadings for various fuel particle sizes of the transect using the embedded formulae.

Fuels Sampling Data Sheet

Transect ID: _______________ **Recorders:________________**
Date: _________________ **Mean scorch height (m) if burned: _________________**

1000-h fuels				
log #	length (cm)	diameter (cm)	sound/ rotten	Charred (y/n)

Woody Fuel particle tally		
1-h	10-h	100-h

Litter/Duff depth (cm)		
	5 m	10 m
litter 1		
duff 1		
litter 2		
duff 2		

Table 12: Example fuels sampling data sheet.

Fuels Sampling Data Sheet

Transect ID: ____MONT12________ **Recorders:** _Poulos/Barton____

Date: ___07/15/2018 **Mean scorch height (m) if burned:** ___16_____

1000-h fuels				
log #	length (cm)	diameter (cm)	sound/ rotten	Charred (y/n)
1	350	35	S	
2	230	23	S	
3	510	36	R	
4	45	8	R	
5	130	10	R	

Woody Fuel particle tally		
1-h	10-h	100-h
𝍸 𝍸 𝍸	𝍸	𝍸 𝍸 𝍸 𝍸

Litter/Duff depth (cm)		
	5 m	10 m
litter 1	2	3
duff 1	0	0
litter 2	1	3
duff 2	0	1

6. Data storage

Data storage is a critical component of a long-term monitoring plan. Ancillary .xls data sheets for field data entry and storage are included with this manual. The following Excel templates are included as ancillary data storage files for this monitoring protocol:

1. **environmental_data_template.xls:** this template is designed to store all of the environmental data taken in the environmental data sheet.
2. **line_point_intercept_template.xls:** this template is for field data storage of the line-point intercept ground cover and vegetation data for the various measurement strata.
3. **Photo_point_template.xls:** this template can be used for recording photo point information if the Context Camera app is not used for taking photos.
4. **forest_seed_herb_shrub_templates.xls:** this template is for data entry and storage of the forest and woodland field data, seedling data, herbaceous cover data, and shrub cover data.
5. **fuels_template.xls:** this template is for entry and storage of small and large fuel particle, and litter and duff data. It also contains a template for calculating fuel loadings for each fuels transect.

These templates are designed to be used directly in the field at sites where field technicians have the capacity to take digital data using iPads or other data logging instruments, or data can be keyed into these templates from the field data sheets provided in this manual. Metadata are included in each template which describe the content of each column header. Species lists are also included.

Appendix A: Field equipment and suppliers

Low profile survey marker:
https://www.amazon.com/Survey-Marker-Profile-Stakes-Hi-Vis/dp/B00JHNZOT8/ref=sr_1_3?ie=UTF8&qid=1525444904&sr=8-3&keywords=low+profile+survey+stakes

Cotton gin spike:
http://www.forestry-suppliers.com/product_pages/products.php?mi=72941&itemnum=79301&title=Cotton%20Gin%20Spike

Rebar caps:
http://www.forestry-suppliers.com/product_pages/products.php?mi=57901&itemnum=39494&title=Permamark%20Plastic%20Surveyors%E2%80%99%20Markers

Chaining pins:
http://www.forestry-suppliers.com/product_pages/products.php?mi=57711&itemnum=39167&title=Chaining%20Pins%20(Steel%20Arrows)

Clinometer: http://www.forestry-suppliers.com/product_pages/products.php?mi=13161&itemnum=43830&title=Suunto%20PM5/360PC%20Clinometer%20with%20Percent%20and%20Degree%20Scales

GPS for taking location and elevation data: http://www.forestry-suppliers.com/product_pages/products.php?mi=48421&itemnum=39138&title=Garmin%20GPSMAP%2064s%20GPS

Tree diameter tape: http://www.forestry-suppliers.com/product_pages/products.php?mi=14281&itemnum=59571&title=Forestry%20Suppliers%20Metric%20Fabric%20Diameter%20Tape

Cruise crutch: http://www.forestry-suppliers.com/product_pages/products.php?mi=13961&itemnum=59778&title=Cruiser%E2%80%99s%20Crutch

10 BAF prism: http://www.forestry-suppliers.com/product_pages/products.php?mi=13911&itemnum=59026&title=JIM-GEM%C2%AE%20Rectangular%20Cruising%20Prisms

Jim-Gem Cruz All: http://www.forestry-suppliers.com/product_pages/products.php?mi=13951&itemnum=59795&title=JIM-GEM%C2%AE%20Cruz-All

Countgrass:
http://www.forestry-suppliers.com/product_pages/products.php?mi=73751&itemnum=78503&title=Vegetation%20Sampling%20Hoops

50 m tape:
http://www.forestry-suppliers.com/product_pages/products.php?mi=56534&itemnum=39978&title=Keson%C2%AE%20English/Metric%20Open%20Reel%20Fiberglass%20Tapes

36 inch Flag pins:
http://www.forestry-suppliers.com/product_pages/products.php?mi=11161&itemnum=33516&title=2-1/2%E2%80%9D%20x%203-1/2%E2%80%9D%20Fluorescent%20Color%20Plain%20Vinyl%20Stake%20Wire%20Flags

Look-through compass:
http://www.forestry-suppliers.com/product_pages/products.php?mi=13032&itemnum=37031&title=Suunto%C2%AE%20Vista%20KB-20%20Global%20Precision%20Compass

Range pole:
http://www.forestry-suppliers.com/product_pages/products.php?mi=29671&itemnum=43132&title=Sokkia%E2%84%A2%20Range%20Pole

Go-no-go gauge:
http://www.forestry-suppliers.com/product_pages/products.php?mi=86871&itemnum=89012&title=Wildland%20Fire%20Fuel%20Sizing%20Gauge

Monopod:
https://www.amazon.com/Vivitar-67-Inch-Monopod-Release-Colors/dp/B003WPTBAK/ref=sr_1_10?s=photo&ie=UTF8&qid=1525448842&sr=1-10&keywords=monopod