

# Surveying Forest Diversity and Health Using the Point-Centered Quarter Method

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Fieldwork is often an overlooked component of many undergraduate biology courses however, forest surveys tend to resonate with students and have become increasingly important. Many forests in North America are undergoing rapid changes due to warming climate, alteration of the hydrological cycle, wildfire, and bark beetles. Given the importance of timber to humans and the role forests play in maintaining the biodiversity of higher elevation communities, assessing tree species diversity and health serves as a contemporary and relevant backdrop to expose undergraduates to field biology. The point-centered quarter method is an efficient and effective sampling strategy for species that lack clumped or uniform distributions. Undergraduates can easily apply this method to survey forest diversity and health.

**Keywords:** field laboratory, forest survey, point-centered quarter method

## Introduction

This lab activity was included in the major-workshop entitled *Using the Point-Centered Quarter Survey Method to Introduce Students to the Use of Geospatial Data in Field Biology*. The workshop focused on planning for a field laboratory activity and informing on the use and collection of geospatial data; components of any field biology project. These elements are not specific to this particular field activity and are not represented here. Consequently, I have changed the title of this manuscript to better reflect the specific field laboratory activity that served as the context for my workshop.

This field laboratory activity is used in a sophomore-level introductory field biology course with a maximum enrollment of 16 students. It is one of three larger-scale field projects that students work on to apply skills learned in other lessons and lab activities. Although the student outline that follows is written for a specific field site in Clark Co., NV, USA, it can be modified for other field sites that differ in tree species, disease dynamics, buffer zones, and field haz-

ards. This field laboratory activity would be best suited for courses that already have a field component but can be included in a general major-track biology course. The latter option requires some adaptation and will require students be taught basic compass and GPS skills as well as field safety. For suggestions on such adaptations or questions regarding planning a day in the field or collecting and using geospatial data, please contact the author ([brian.wainscott@csn.edu](mailto:brian.wainscott@csn.edu)).

## Student Outline

### Surveying Tree Diversity and Health of a Coniferous Forest in the Mt. Charleston Wilderness Area (Clark Co., NV USA) Using the Point-Centered Quarter Method

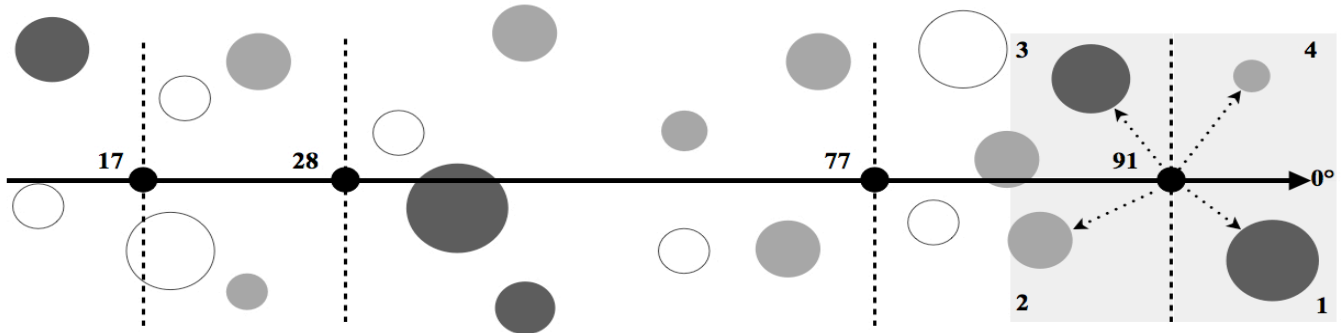
#### Introduction

Many forests in North America are undergoing rapid changes due to warming climate, alteration of the hydrological cycle, wildfire, and bark beetle infestation (Bentz 2008, Bentz et al. 2010). Given the importance of timber to human society and the role forests play in maintaining the biodiversity of higher elevation communities it is essential to monitor forests to document ongoing changes.

Ideally one would census all trees in a forest to have the most inclusive data set available to address questions about forest change over time however, limited resources preclude this option. Instead, a subset of trees are sampled to generalize about larger area of forest. Many plot-based sampling techniques have been devised to sample forest trees (Higgins et al. 2012) and would be appropriate for this project. Your class may have used some of these techniques (e.g., quadrat sampling) previously. Although plot-based techniques tend to yield better estimates of density of individual species, they require much more effort to carry out (Higgins et al. 2012). Given the rapid nature of forest change and the dearth of resources currently available to monitor such changes, we will employ a less time-consuming plot-less survey method in this project called the **point-centered quarter (PCQ)** method.

Using the PCQ method, we will sample trees nearest 4 random points along 100 m transects. Each sample point serves as an intersection of two perpendicular lines that define 4 sampling quarters. We will sample the tree whose stem is nearest the center point in each quarter (Figure 1). We will determine the distance (m) of the tree from the sample point, its geospatial data (northing, easting, and elevation in m), the slope and aspect of the terrain within the major drainage in which the tree is growing, stem diameter (cm) at a height of 130 cm above the surface ( $D_{130}$ ), taxonomic data of the tree (genus and species), phenological data (status of male and female reproductive organs), and basic tree health data (leaf and bark beetle status). These data will be summarized to make generalizations about tree diversity and health along the North Loop Trail (624730E 4018907N WGS84; elevation 2,572 m) in the Mt. Charleston Wilderness Area (23,240 ha) found in the Spring Range of Clark Co., Nevada. We will sample transects from 2,600 m (8,530 ft) to 3,100 m (10,170 ft). These transects fall largely within the White Fir-Ponderosa Pine alliance in lower elevations and within the Limber Pine-Bristlecone Pine alliance at higher elevation. A total of 8 tree species grow in our sampling area (Table 1, Figure 3).

Like all sampling techniques, the PCQ method is biased: it underestimates when working with taxa distributed in clumps (e.g., Quaking Aspen, *Populus tremuloides*) and overestimates when working with taxa that are uniformly distributed (e.g., Creosote, *Larrea tridentata*) (Higgins et al. 2012). The PCQ method works best when taxa are randomly distributed as tends to be the case in our sampling location along the North Loop Trail (but not the case along the South Loop Trail with its numerous avalanche chutes with Aspen groves). A number of PCQ modifications (e.g., angle-order method, corrected-point distance) have been devised to decrease sampling bias (Higgins et al. 2012) but all require prior working knowledge of PCQ. The amount of bias we expect will be minimal based on the distribution of our taxa in our field site. Furthermore, we will limit our generalizations to the major drainage in which we will be working (thus further limiting the impact of sampling bias).



**Figure 1.** Solid black line represents a 100 m transect oriented along a true bearing of 0°. Solid black dots represent 4 sample points located at 17, 28, 77, and 91 m, respectively. Vertical dashed lines divide a transect into quarters 1-4. Open and gray shaded circles represent tree species. Dotted arrows represent the distance between a sample point and the nearest tree. A total of 16 trees are sampled along each 100 m transect. In this example, 3 species were observed.

## Lab Objectives

1. Use the point-centered quarter method to sample trees in the Mt. Charleston Wilderness Area.
2. Measure slope and aspect of the terrain where surveyed trees are located.
3. Identify trees to genus and species and record the geospatial position of each tree.
4. Measure the diameter of each stem at breast height ( $D_{130}$ ) using the caliper method.
5. Determine the reproductive status of each tree.
6. Determine the leaf status of each tree and record any evidence of bark beetle infestation.
7. Estimate density, coverage, and frequency statistics and determine importance value of each species.
8. Compare importance values of species across an elevation gradient.
9. Prepare a map of the locations of trees sampled using ESRI® ArcMap™ 10.0. (*optional*)

## Hazards/Safety

Hazards for this project include: 1) uneven terrain, 2) exposure to solar radiation and possibly extreme weather (e.g., rain, snow, hail, lightning, and powerful wind gusts), 3) elevation risks (e.g., falls, AMS), and 4) potentially getting lost from the field crew. Consider these hazards when preparing your field clothes/pack and when conducting yourself in the field. Our field site is above 2,600 m (8,530 ft) and will be, on average, 7 °C (20 °F) colder than the Las Vegas Valley (610 m)(2,000 ft) and weather conditions may change rapidly. Dress in layers and bring a warm hat and gloves, rain gear, and solar protection. There is no bathroom near our field site so bring a hygiene bag. We will not be working close to our vehicles so plan to take all of your gear with you. You will need enough food, water, and prescription meds (e.g., insulin, asthma inhaler, epi-pen) to sustain you for 10 hr. Bring at least 2 l of water to carry and keep an additional liter in your car. For your safety, follow all written protocols and oral instructions given to you. Ask if you have questions. If for some reason you become separated from the field crew and become lost, follow the lost crew member protocol discussed at the trailhead.

## Field Equipment

(*Per students and student teams of 4 students.*)

- Forestry Suppliers Emergency Medical Backpack (1 per field crew leader)
- Kestrel™ 3000 Pocket Weather Meter (1 per student team)
- Garmin® Rino® 650 GPS Receiver (1 per student)(2 per field crew leader)
- Trimble® Juno® 3B Handheld (*optional*)(1 per team)(2 per field crew leader)
- Silva® Ranger® 515 Compass (1 per student)(1 per crew leader)
- Topographic Map of Field Site (1 per student)(1 per field crew leader)
- Keson® 100 m Fiberglass Tape (1 per student team)
- Haglof® Mantax Black 950 mm Tree Caliper (1 per student team)
- Marking Tape (8 1-m pieces per student team)(1 roll per field crew leader)
- Bushnell® 7 x 35 Binoculars (1 per student team)(1 per field crew leader)
- Bausch & Lomb Hastings Triplet Magnifier 10X (1 per student team)(1 per field crew leader)
- Clipboard (1 per student team)(1 per field crew leader)
- *Flora of the Spring Mountains* by Niles and Leary, 2013 (1 per student team)(1 per field crew leader)
- *Pests of the California Conifers* by Wood et al., 2003 (1 per student team)(1 per field crew leader)
- Customized Tree Identification Key for Field Site (1 per student team)(2 per field crew leader)
- Scientific Calculator (1 per student team)(2 per field crew leader)
- Data Sheet (10 per student team)(10 per field crew leader)

## Lab Equipment

- Microsoft® Excel®
- Minnesota's Department of Natural Resources DNRGPS application
- ESRI® ArcMAP™ 10.0 (*optional*)

## Field Crew Organization

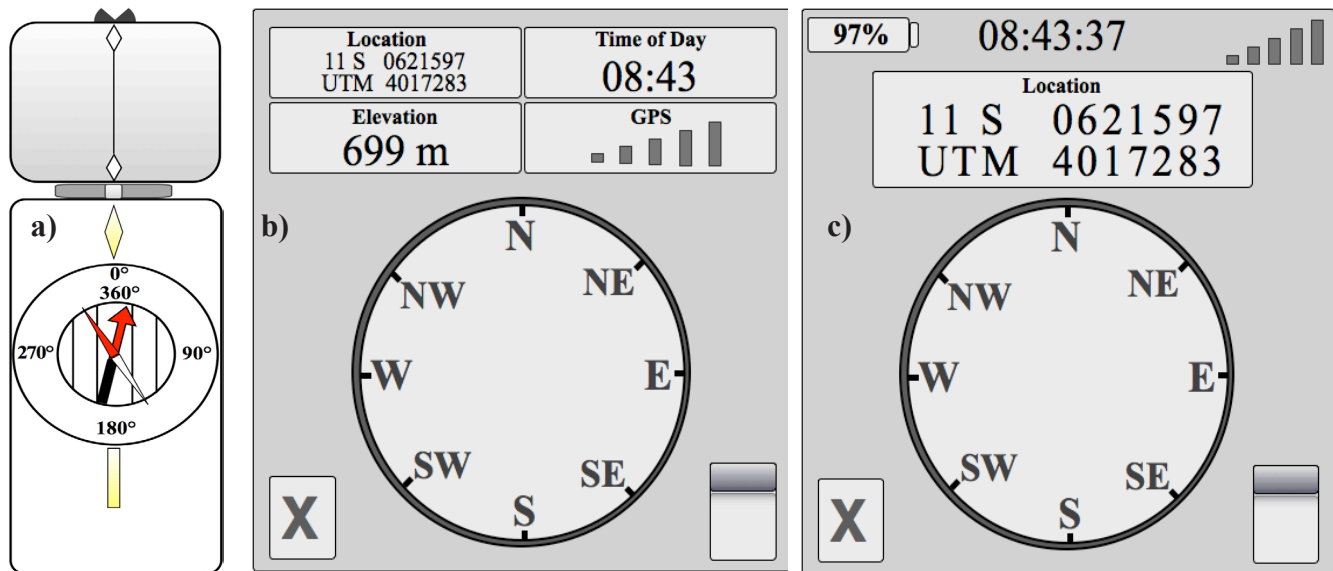
The field crew will be supervised by the *field crew leader*; your Instructor or his/her designee. Students will be organized into 4 teams of 4 students each. One student in each team will be assigned the role of team leader. The *team leader* is responsible for navigating the team to the assigned sample points along each transect and returning the team back to the beginning location, assessing hazards, communicating with the field crew leader, and overseeing the activities of the team ensuring its safety, efficiency, and collegiality. Another student will be assigned the role of data logger. The *data logger* must record all data onto the data sheet and double-check its accuracy before permitting the team to move on. The data logger must also resolve differences in interpretation of qualitative data and make notes where appropriate. Data loggers are also responsible for entering manual

data into an Excel spreadsheet and double-checking its accuracy after the conclusion of the sampling period. The remaining two students will be the data collection technicians. *Data collection technicians* will be responsible for collecting and calling out slope, aspect, species,  $D_{130^\circ}$ , and rapid health assessment data. If the field crew is using Trimble Juno 3B handhelds, data collection technicians will also be responsible for entering data they collect into the data dictionary of their handheld (the data loggers must still maintain manual records as a means of backup). The field crew leader may rotate these roles throughout the day. Teams will be assigned one of the following *Team IDs*: cedar, fir, mahogany, and pine.

### Field Equipment Preparation

*Silva Ranger 515 Compass*: Our transects will be aligned with true North and we will use true bearings to determine aspect. Adjust the magnetic declination of your compass for  $12^\circ$  East (Figure 2a).

*Garmin Rino 650 GPS Receiver*: Adjust to *WAAS/EGNOS*. Change distance units to meters. Change time format to 24 hr and time zone to auto. Set position to *UTM UPS* and datum to *WGS84*. In the compass screen select the data parameter to display in the four *Small Data Fields*: set ULQ to *Location (selected)*; set LLQ to *Elevation*; set URQ to *Time of Day*; and set LRQ to *GPS Signal Strength*. To enlarge UTM values, use the rectangular toggle in the lower right of the screen to select *Large Data Field*. You will have to toggle back to *Small Data Fields* to see elevation values (Figures 2b and 2c).



**Figure 2.** Views of a) compass adjusted for  $12^\circ$ E magnetic declination, b) GPS compass screen with small data fields, and c) GPS compass screen with a large data field.

*Trimble Juno 3B Handheld (optional)*: Consult the setup/data entry addendum for Juno 3B.

### General Field Protocols

*Transects*: Transects are 100 m long oriented along a true bearing of  $0^\circ$ . Use your compass to navigate your transect. Note: if transects are bisected by the main trail, teams sampling south of the main trail navigate a true bearing of  $180^\circ$  and teams sampling north of the main trail navigate true bearing of  $0^\circ$ .

*Geospatial Data*: Use the compass screen (Figures 2b and 2c) of the Garmin Rino 650 to read easting, northing, and elevation for each tree sampled. Call these values out to the person recording data on manual data sheet. Mark a Waypoint > Save and Edit > Change Name. Name waypoints in lower case with no spaces or extra characters: transect (1-∞), point (1-100), quarter (1-4)(e.g., 1173; transect 1, point 17 m on transect, quarter 3).

### Sampling Data

Sampling data include the date and time (Garmin) and data about ambient conditions during the sampling period. Ambient data will be collected via a Kestrel 3000 Pocket Weather Station. Turn it on by pushing the power button. Turn your back towards the sun and hold the unit in front of you such that the sun does not directly shine on it but far enough away from your body that the anemometer records wind data. Rotate through options by pushing the arrow buttons. Record data on the data sheet.

*Date:* Enter the date of the sampling period (05MAY2014).

*Time:* Time (24 hr format) when temperature, average wind speed, and relative humidity were measured.

*Average Wind Speed:* Kestrel wind icon: record average wind speed to tenths place expressed in  $\text{m}\cdot\text{s}^{-1}$ .

*Temperature:* Kestrel thermometer icon: record temperature to tenths place expressed in  $^{\circ}\text{C}$ .

*Relative Humidity:* Kestrel droplet% icon: record relative humidity to tenths place expressed in %.

### Transect Data

Transect data are used to provide unique identifying information for each tree surveyed. Team ID data can be used to identify potential sampling biases.

*Team ID:* Enter the first letter of your team ID: c = cedar, f = fir, m = mahogany, or p = pine.

*Transect Number:* Enter the transect number (e.g., 1- $\infty$ ) assigned by the field crew leader for each transect sampled by your team.

*Sample Point:* Enter the distance (1-100 m) the sample point is from the beginning of the transect for each sample point your team surveys. Your team will be assigned 1-4 sample points to sample on each transect. The field crew leader will call out a random distance along the transect you must orient to traveling along the transect bearing. Record the distance prior to heading out on your sample point. Use the Keson fiberglass tape to measure the distance (m) to each sample point. Measure 'ground distance' by allowing the tape to follow the topography of the land.

*Quarter:* Enter the quarter number (1-4) for each of the 4 trees sampled for each sample point. To identify and mark your quarters, stand on your sample point facing a grid bearing of  $0^{\circ}$ . Lay one piece of marking tape on the ground with one end directed towards  $0^{\circ}$  and the other towards  $180^{\circ}$ . Lay the second piece of marking tape perpendicular to the first forming a cross shape with the intersection on the sample point. When standing on the intersection and facing  $0^{\circ}$ , Quarter 1 is  $0$ - $90^{\circ}$  (forward, right quadrant). Rotate clockwise to identify the remaining quarters (Figure 1).

*Distance:* Record the straight-line distance (0.1) m from the sample point to the center of the nearest tree. Use the Keson fiberglass tape to record this distance. Be sure to use the metric scale!

### Geospatial Data

Geospatial data summarize the  $x$ ,  $y$ ,  $z$  coordinate information for each tree sampled at the field site. These data can be imported into a **geographic information system** (GIS) and used to map species distribution and perform spatial analyses such as examining how species distribution varies in relation to other factors (e.g., temperature, precipitation).

In this course we record geospatial data using the **Universal Transverse Mercator** (UTM) planar coordinate system using the **World Geodetic System 1984** (WGS84) **map datum**. All values of an  $x$ ,  $y$ ,  $z$  coordinate are reported in m except the zone value (it has no units). UTM coordinates ( $x$ ,  $y$ ) are reported using a zone value, easting value, and a northing value (e.g., 11S 624249 4019041).

UTM **zone** values are comprised of *zone* (1-60) and a *band* (C-X; I and O omitted) designations. Zones are  $6^{\circ}$  of longitude that run from  $80^{\circ}$  S latitude to  $84^{\circ}$  N latitude. Zones increase in number as one moves eastward of the International Date Line ( $180^{\circ}$  long). Zones are subdivided into bands of  $8^{\circ}$  (or  $12^{\circ}$ ) of latitude that are coded with a C for the band that begins at  $80^{\circ}$  S and a X for the band that ends at  $84^{\circ}$  N. Our field site is found entirely within zone 11 and band S (reported zone 11S) so we have no need to record this value in our data sheets. However, if a field site overlaps more than one zone, you must record the zone value because each zone uses the same scales of easting and northing values.

The **easting** value is the distance ( $x$ ) from a zone's central north-south reference line that bisects the zone called the central meridian. The **central meridian** is assigned an arbitrary value, called a **false easting**, that equals 500,000 m. Easting values greater than the false easting are located east of the zone's central meridian whereas easting values lesser than the false easting are located west of the zone's central meridian. An easting value of 624249 is 124,249 m east of the zone's central meridian.

The **northing** value is the distance ( $y$ ) from a zone's east-west reference line. The Earth's equator serves as the northing reference line and is assigned the value of 0 for northing values recorded in the northern hemisphere. The northing value of 4019041 is 4,019,041 m north of the Earth's equator.

The **elevation** value is the vertical distance ( $z$ ) between the  $x$ ,  $y$  point and reference surface. For our work the reference



surface is defined as mean sea level. A tree that grows at an elevation of 2588 m is located 2,588 m above mean sea level. We will use a Garmin Rino 650 GPS receivers to collect geospatial data for this project.

*Easting (x)*: Select > *Compass*; record the top number listed in the ULQ *Location (selected)* box.

*Northing (y)*: Select > *Compass*; record the bottom number listed in the ULQ *Location (selected)* box.

*Elevation (z)*: Select > *Compass*; record the number listed in the LLQ *Elevation* box.

*Garmin Rino 650 Note*: Follow the waypoint naming convention mentioned previously to save a waypoint (geospatial position) of each tree sampled by your team. Do not deviate from this convention!

*Trimble Juno 3B Note*: The zone value indicated for our field site is reported as 11N by Trimble. The N in the Trimble designation refers to northern hemisphere and not UTM band N. A zone value of 11S on a Trimble refers to the portion of zone 11 in the southern hemisphere. Also, waypoints store automatically when one enters data into a Trimble data dictionary so enter data as near to the sampled tree as possible.

### Terrain Data

Terrain data provide information on the aspect and the steepness of the **slope** on which sampled trees grow informing about, drainage, erosion potential, and avalanche potential. **Aspect** is the orientation of a slope (i.e., direction it faces). Aspect influences solar radiation, prevailing winds, and other factors. Record slope and aspect data using a Silva Ranger 515 Compass with inclinometer. Ensure your compass is adjusted for declination so that 0° corresponds with true north.

*Aspect*: Record the azimuth (0-360°) in whole degrees (°) for the major slope each tree is growing on. Do not consider small ravines that are clearly part of the overall slope of the area. Stand with your back nearest your sample tree and rotate your entire body so that you face the direction that water flows down the major slope. Record the true bearing in whole azimuth degrees (°) of aspect.

*Slope*: Record the slope as the **angle of inclination** in whole degrees (°). Rotate your body 180° from previous aspect measurement and face the sample tree. Open the compass all of the way, rotate compass bezel such that 270° aligns with the index pointer, extend arms with compass in hand holding it such that the 1) index pointer points away from you, 2) the 180° graduation of the bezel is facing the ground, and 3) the long axis of the base plate is PARALLEL with the ground surface. Read the black **clinometer arrow** that is pointing towards the ground. (Note: the angle of inclination differs from percent grade and although you can convert between these units they are not synonymous.)

### Tree Data

Tree data provide taxa identification to the least inclusive sampling unit of the study (down to species level in our project) as well as the diameter of the trunk of sampled trees.

*Binomial Code*: Enter the 4-letter binomial code of the tree species sampled in lowercase letters with no spaces between letters (Figure 3, Table 1). If you are having difficult keying out a tree try using your flora to help. If this does not work, contact the field crew leader.

$D_{130}$ : Record the diameter of the stem at breast height (130 cm from surface) in whole cm. Round <0.49 down and >0.50 up to the next whole number. To increase measuring efficiency measure 130 cm from the surface to a point on your body and use that point to determine where to measure the diameter of subsequent trees. For trees less than 95 cm in diameter use the tree calipers to take your measurements directly. *Caliper method*: take two perpendicular measurements at breast height and average them; round to nearest whole number. For tree diameter greater than 95 cm use the tape method. Our Keson flexible tapes are not calibrated for direct diameter measurements so we must derive this parameter in the field. *Tape method*: measure circumference ( $c$ ) in cm 130 cm above surface and compute:  $D_{130} = c / 3.14159$ .

Some trees in our sample may have multiple stems. We must record the diameter of each stem to calculate coverage statistics. Record  $m-s$  in the  $D_{130}$  column for multi-stemmed trees. On the reverse of the data sheet record the transect, sample point, and quarter followed by the diameter of each stem. If your team is entering data into a data dictionary on the Trimble Juno 3B you must enter 0 in the  $D_{130}$  field. We must manually append all electronic data files so that these values are not excluded.

### Phenological and Rapid Health Assessment Data

These data provide information regarding seasonal, reproductive, and health status. Phenological data will not be particularly important to our class because we will only be sampling the field site one time during the semester (and early in the season). However, over several years these data may be used to assess for any changes in phenology of species. The rapid health assessment data are also limited in value however they can be collected rapidly and can be used to determine if more extensive health assessment is warranted. All of these data are qualitative and are recorded by various letter codes. Male, female, and leaf status will be treated as mutually exclusive and only one letter code should be recorded. Beetle categories will not be treated as mutually exclusive; mark all of the letter codes that apply.

*Male:* Male reproductive structures (staminate cones or flowers with stamens): *a* = absent; *b* = buds or immature structures present; *m* = mature male structures present with pollen.

*Female:* Female reproductive structures (ovulate cones or flowers with pistils): *a* = absent; *b* = buds or immature structures present; *m* = mature female structures present.

*Leaves:* Leaf/needle status: *a* = leaves/needles absent; *b* = estimated proportion of all leaves/needles lacking normal pigment or browning (0.25, 0.50, 0.75, or 1.00); *p* = most leaves normally pigmented.

*Beetles:* Bark beetle status: *n* = no evidence; *b* = bark beetles present; *g* = galleries evident; *h* = holes from bark beetles present; *p* = small pitch tubes present; *s* = sawdust from beetle boring present. Refer to Wood et al. (2003) for images of various beetle sign.

### Data Transfer and Processing

*Manual Data:* Enter manually recorded data into a Microsoft Excel spreadsheet. You must do this even though you may have recorded data in a data dictionary of a Trimble Juno 3B handheld.

*Garmin Rino 650 Waypoint Data:* Export waypoint data from the Garmin Rino 650 using Minnesota's Department of Natural Resources DNRGPS application. This application exports waypoints stored on a GPS receiver and exports them as ESRI shapefiles for import into ESRI ArcMap 10.0. You must export your data regardless if you intend to prepare the optional map. Your Instructor will help with this task.

Waypoint data only include *x*, *y*, *z* coordinates for each sampled tree. If you desire to use ESRI ArcMap 10.0 to conduct analyses to augment your map, you can upload the remainder of the data from Excel and join the attribute table with *x*, *y*, *z* shapefile using unique FID columns. You must double-check with your manual data sheets to ensure that you have successfully joined your import data to your shapefile. Your Instructor can help you with this task if you choose to proceed.

*Trimble Juno 3B:* If your field crew used a Trimble Juno 3B handheld, import the data from its data dictionary using Trimble® GPS Pathfinder® software and post-process the *x*, *y*, *z* coordinate data using nearby base stations to refine the accuracy of the geospatial positions. Export as an ESRI shapefile for use in ESRI ArcMAP 10.0. Append multi-stem  $D_{130}$  data in the attribute table of the shapefile. Your Instructor can help you with these tasks.

### Analyses

One goal of this project is to determine the importance value of each tree species in the sample. **Importance value (IVS)**, a value from 0 to 300, is derived from equal weighting of three factors: relative species density, coverage, and frequency. IVS can be used to rank tree species in their community by dominant biomass. IVS can be tracked at the same site over time to explore how abiotic factors (e.g., wildfire, climate change) or biotic factors (e.g., bark beetles) impact the community structure over time.

To calculate IVS, you must make a series of calculations that estimate absolute density for all trees, absolute and relative density of individual species, absolute and relative coverage of individual species, and absolute and relative frequency of individual species. The formulae used to make these estimates follow. Mitchell (2007) offers more extensive explanation and examples of these calculations.

Use an Excel worksheet to carry out your calculations. Include one worksheet for each transect sampled. Before you begin make a new copy of your Excel workbook file and rename it team id\_analyses (e.g., cedar\_analyses.xlsx). Graph the importance values for the species along each transect using a simple bar graph.

### Tree Density Statistics

Density refers to how many individuals are found in a defined area (m<sup>2</sup>). We estimate density with the PCQ method by determining how many trees of each species are distributed in the quarters of our sample. Density estimates are used to calculate importance values and can also be used in conjunction with frequency data to make statements about the distribution of individuals in the study area. You must estimate three density parameters.

*Absolute Density of All Trees (ADT)*: ADT is the number of all trees per m<sup>2</sup>. Since we did not census our field site and count all of the individual trees we must estimate density of all trees. Mitchell (2007) explains the derivation of this estimate. Here, I describe a straight-forward way to calculate ADT.

First, calculate the average distance between sample points and sampled trees (PT<sub>avg</sub>). To calculate ADT, divide 1 by the square of PT<sub>avg</sub>. It is customary to report density per hectare (ha) instead of m<sup>2</sup> (10,000 m<sup>2</sup> = 1 ha). Consequently, multiply ADT by 10<sup>4</sup> to report density of all trees ha<sup>-1</sup>.

$$PT_{avg} = \text{sum of all point to tree distances} / \text{the total number of trees sampled}; \quad ADT = 1 / (PT_{avg})^2 \times 10^4$$

*Absolute Density of Each Tree Species (ADS)*: ADS is an estimate of the density (ha<sup>-1</sup>) of a particular species. It is based on how a species is distributed in the quarters of a sample. ADS is estimated by multiplying the proportion of all sample quarters with a given species by ADT. Repeat for each species of tree sampled.

$$ADS_{abco} = (\text{nr. of quarters with } abco / \text{total number of quarters}) \times ADT; \text{ Repeat for each species.}$$

*Relative Density of Each Tree Species (RDS)*: RDS is calculated to standardize estimates of ADS for each tree species and scale them to 100 for comparison.

$$RDS_{abco} = (ADS_{abco} / ADT) \times 100; \text{ Repeat for each species.}$$

### Tree Species Coverage (Dominance)

Coverage refers to how much of the area is covered by vegetation. Coverage statistics can be based on canopy or **basal area** (BA). Since we sampled trees in our project, we will compute BA using stem diameter to calculate coverage values.

We will assume our trees have stems with circular cross-sections and use the area of a circle ( $\pi r^2$ ) in our formula.  $BA = \pi d^2/4$  and is expressed in cm<sup>2</sup>. You must use this formula to calculate BA for every tree in the sample. If a tree has multiple stems, you must calculate BA for each stem and sum to express a single value for that individual. Calculate the sum and the mean BA for the sampled trees within each species. This step will require patience and judicious use of your spreadsheet.

*Absolute Coverage of Each Tree Species (ACS)*: ACS is the estimated coverage (BA) of each tree species sampled expressed in m<sup>2</sup> ha<sup>-1</sup>. [mean BA cm<sup>2</sup> × ADS/ha × 1 m<sup>2</sup>/10,000 cm<sup>2</sup> = ACS in m<sup>2</sup> ha<sup>-1</sup>]

$$ACS = (\text{mean } BA_{abco} \times ADS) / 10,000; \text{ Repeat for each species.}$$

Before you continue, sum ACS values for all species to calculate the *total coverage of all trees* (TCT).

*Relative Coverage of Species of Each Tree Species (RCS)*: RCS is calculated to standardize estimates of ACS for each tree species and scale them to 100 for comparison.

$$RCS_{abco} = (ACS_{abco} / TCT) \times 100$$

### Tree Frequency

Frequency is a measure of how common a species is along a transect. Unlike density, frequency of trees is occurrence based on sample points and not quarters.

*Absolute Frequency of Each Tree Species (AFS)*:  $AFS = (\text{nr. of sample points with species}_{abco} / \text{total nr. of sample points}) \times 100$ ; Repeat for each species.

Before you continue, sum AFS values for all species to calculate the *total frequency of all trees* (TFT).

*Relative Frequency of Each Tree Species (RFS)*: RFS is calculated to standardize estimates of AFS for each tree species and scale them to 100 for comparison.

$$RFS_{abco} = (AFS_{abco} / TFT) \times 100; \text{ Repeat for each species.}$$

### Tree Importance Values

Importance values rank tree species based the dominant biomass in a community.

*Importance Value of Each Species (IVS)*: IVS of a species is simply the sum of its relative density, coverage, and frequency estimates. Each are equally weighted and scaled to 100. IVS, therefore, will range from 0-300. Greater numbers reflect species with more dominant biomass within the community.

$$IVS_{abco} = RDS_{abco} + RCS_{abco} + RFS_{abco}; \text{ Repeat for each species.}$$



## Diversity Statistics

Species importance values (IVS) are very useful in ranking tree species in a community based on their relative frequency, density, and coverage. However, field biologists also typically summarize the species diversity of the communities they sample. We will do the same for the tree species along the transects we sampled.

Diversity can be expressed simply as the number of tree species and is called the **species richness** of the sample. Assuming all tree species along transects were detected, samples with more species are considered to be more diverse than those with fewer species. Sometimes, however, samples yield the same species richness and are, therefore, considered equally diverse via this measure.

Another approach to summarizing species diversity not only considers how many species are present in a sample, but also considers the relative abundance of each. If two samples have the same richness they likely differ in the relative abundance of each species. Assuming all tree species along transects were detected at their natural relative abundance, the sample with more even distribution of individuals across species is considered more diverse than a sample that has most individuals in only one species and relatively few individuals in the remaining species. There are many indices that are used to express the **evenness** of sample. We will use **Simpson's E** as an index of how evenly distributed species abundance is within each transect. *Simpson's E* is based on *Simpson's Reciprocal Index* that reports how probable it is that two random individuals from a sample will be different species. *Simpson's E* varies between 0 (no evenness) to 1 (maximum evenness; all species have equal abundance).

Samples that have the same species richness may differ in which species they include. Field biologists typically calculate some measure of species overlap to express how similar two samples are in species composition. We will use the **Sørensen Similarity Index (SSI)** to compare the similarity in species composition. *SSI* ranges from 0 (no species overlap) to 1 (complete species overlap).

*Species Richness (S)* is a count of the number of tree species per transect.

$S_1$  = count of species on transect<sub>1</sub>

$S_2$  = count of species on transect<sub>2</sub>

*Simpson's Evenness Index (E)* is an index of the relative abundance of species along a transect.

$E_1 = 1/\sum p_i^2 \times 1/S_1$  where  $p_i$  is the proportional abundance of the  $i^{\text{th}}$  species along transect<sub>1</sub> and  $S$  is species richness of transect<sub>1</sub>.

$E_2 = 1/\sum p_i^2 \times 1/S_2$  where  $p_i$  is the proportional abundance of the  $i^{\text{th}}$  species along transect<sub>2</sub> and  $S$  is species richness of transect<sub>2</sub>.

[To calculate *E*, determine the proportional abundance of each species by dividing the number of trees of each species by the total number of trees sampled along the transect. Square each proportion and, then, sum them. Divide 1 by the sum. Finally, divide the resulting answer by  $S$ .]

The *Sørensen Similarity Index (SSI)* compares the species overlap in two datasets; in this case the tree species sampled along the two transects being compared.

$SSI = 2(c)/a + b$  where,  $c$  is the number of tree species common to both transects;  $b$  is the number of tree species found in Transect<sub>1</sub>; and  $a$  is the number of tree species in transect<sub>2</sub>.

## Frequency of Bark Beetle Sign

Frequency is a measure of how common bark beetle sign is along a transect. Of the five categories of beetle sign, bark beetles present ( $b$ ), small pitch tubes present ( $p$ ), and saw dust from bark beetle boring present ( $s$ ) are the most useful in determining if a potential outbreak is ongoing. The likelihood of observing these beetle sign depend on the time of sampling and the climatic conditions that preceded the sampling period. Visible galleries revealed from bark delamination ( $g$ ) and holes ( $h$ ) are sign of cumulative infestation and are, therefore, typically always present.

*Absolute Frequency of Bark Beetle Sign Categories (AFBS):*

$AFBS = (\text{nr. of sample points with bark beetle sign}_{\text{bark beetles present}} / \text{total nr. of sample points}) \times 100$ ; Repeat for each category or bark beetle sign.

Sum AFBS values for all categories to calculate the *total frequency of all beetle sign categories (TFBS)*.

*Relative Frequency of Bark Beetle Sign Categories (RFBS):* RFBS is calculated to standardize estimates of AFBS for each category of beetle sign and scale them to 100 for comparison.

$RFBS_{\text{bark beetles present}} = (AFBS_{\text{bark beetles present}} / TFBS) \times 100$ ; Repeat for each category of beetle sign.

**Frequency of Leaf/Needle Browning**

Frequency is a measure of how common leaf/needle browning is along a transect. Leaf/needle browning can be caused by numerous factors (e.g., drought, temperature extremes, infestation by beetle and non-beetle pest species) all of which cause stress to trees. We can use the degree of leaf/needle browning to gauge the degree of stress of the trees growing along each transect.

*Absolute Frequency Leaf/Needle Browning Categories (AFNB)*:  $AFNB = (\text{nr. of sample points with leaf/needle browning}_{0.25} / \text{total nr. of sample points}) \times 100$ ; Repeat for each category of leaf/needle browning.

Before you continue, sum AFNB values for all categories to calculate the *total frequency of all leaf/needle browning categories (TFNB)*.

*Relative Frequency of Leaf/Needle Browning Categories (RFNB)*: RFNB is calculated to standardize estimates of AFNB for each category of leaf/needle browning and scale them to 100 for comparison.

$RFNB_{0.25} = (AFNB_{0.25} / TFNB) \times 100$ ; Repeat for each category of needle browning.

**Key to Trees (Division Tracheophyta) along the North Loop Trail, Spring Mountains, Nevada**

- 1. Leaves with flat blades; reproduce via flowers.....Class Magnoliopsida
- 2. Leaves either needle-like or scale-like; reproduce via cones.....Class Pinopsida

**Key to Trees in the Class Pinopsida along the North Loop Trail, Spring Mountains, Nevada**

- 1. Leaves scale-like; decussate; ovulate cones resemble ‘berries’ .....*Juniperus scopulorum (jusc)*
- 1. Leaves needle-like; ovulate cones with several ovuliferous scales.....Go to 2
- 2. Needles flattened with blunt tips; one needle per node; lacks fascicle sheath; needles bisected with faint white line; needles pointing towards sky; bark silver/white in younger specimens; ovulate cones that disintegrate on tree.....*Abies concolor (abco)*
- 2. Needles pointed with facile sheath .....Go to 3
- 3. One needle per fascicle sheath; needles round in cross-section; ovulate cones with few scales; seeds lack a wing.....*Pinus monophylla (pimo)*
- 3. More than one needle per fascicle.....Go to 4
- 4. Needles 2-3 per fascicle; bark rust colored often smells of butterscotch, ovulate cones typically possess relatively short spines on umbos.....*Pinus ponderosa (pipo)*
- 4. Needles more than three per fascicle.....Go to 5
- 5. Needles 5 per fascicle; needles convergent within fascicle bundles; needles potentially grow along branch length; spent ovulate cones dark brown and possess long spines on umbos; branches long and resembling bottle brush.....*Pinus longaeva (pilo)*
- 5. Needles 5 per fascicle; needles divergent splaying from fascicle; needles tend to grow more so on branch termini; spent ovulate cones golden and possess terminal umbos that lack spines; ovuliferous scales with broad, deep apophyses.....*Pinus flexilis (pifl)*

**Key to Trees in the Class Magnoliopsida along the North Loop Trail, Spring Mountains, Nevada**

- 1. Leaves simple, entire, alternate to clustered, linear to oblong about 1-4 cm long by 0.3-1.0 cm wide, resinous; perfect apetalous flowers; achenes with plumose tails.....*Cercocarpus ledifolius (cele)*
- 2. Leaves simple (or rarely as 3 leaflets), serrate or doubly serrate, opposite, palmate with 3-5 lobes 2-10 cm in length, glabrous, flowers as cymes; winged samaras.....*Acer glabrum (acgl)*

**Figure 3.** A taxonomic key customized for the 8 tree species, Division Tracheophyta, that occur along the North Loop Trail (Table 1). Additional information about these taxa can be found in the *Flora of the Spring Mountains, Clark and Nye Counties* (Niles and Leary 2013). This key will likely perform poorly in helping to diagnose these taxa in other locales.

**Table 1.** Summary of tree species, in the Division Tracheophyta, encountered along the North Loop Trail, Clark Co., NV. All taxonomic names are considered valid according to the Integrated Taxonomic Information System (ITIS)(<http://www.itis.gov>) as of March 01, 2014.

Class	Family	Common Name	Binomial	Code
Pinopsida	Cupressaceae	Rocky Mountain Juniper	<i>Juniperus scopulorum</i>	<i>jusc</i>
Pinopsida	Pinaceae	White Fir	<i>Abies concolor</i>	<i>abco</i>
Pinopsida	Pinaceae	Bristlecone Pine	<i>Pinus longaeva</i>	<i>pilo</i>
Pinopsida	Pinaceae	Limber Pine	<i>Pinus flexilis</i>	<i>pifl</i>
Pinopsida	Pinaceae	Single-Leaf Pinyon Pine	<i>Pinus monophylla</i>	<i>pimo</i>
Pinopsida	Pinaceae	Ponderosa Pine	<i>Pinus ponderosa</i>	<i>pipo</i>
Magnoliopsida	Sapindaceae	Rocky Mountain Maple	<i>Acer glabrum</i>	<i>acgl</i>
Magnoliopsida	Rosaceae	Curl Leaf Mahogany	<i>Cercocarpus ledifolius</i>	<i>cele</i>

**Student Assessment**

The assessment of this laboratory includes: an Excel workbook file (.xlsx), Summary Statistics Worksheet, and Interpretation/Conclusions. If you completed the optional map in ESRI ArcMap 10.0, please include it in your submission.

*Excel Workbook File* (first name\_last name.xlsx)

Your workbook file must include two worksheets: one for each transect. Each worksheet must include all of the raw data collected in the field (sampling date and time, average wind speed, temperature and relative humidity during sampling period, transect number, sample point, quarter, point to tree distance, tree easting, northing, and elevation, slope and aspect, binomial code, D<sub>130°</sub>, male and female status, leaf status, and beetle status), derived data (ADT, PTavg, ADS, RDS, BA, Mean BA, ACS, RCS, AFS, RFS, IVS, S, and E for trees in each transect, SSI, AFBS and RFBS for beetle sign, and AFNB and RFNB for needle browning), and graphs of tree IVS, RFBS, and RFNB for each transect.

*Summary Statistics Worksheet*

Summarize the derived data from each transect in the following tables. (Round answers to tenths place.)

**Transect<sub>1</sub>**, min/max elevation:                      min/max easting:                      min/max northing:

Species Code	ADS ha <sup>-1</sup>	RDS	BA <sub>avg</sub> cm <sup>2</sup>	ACS m <sup>2</sup> ha <sup>-1</sup>	RCS	AFS	RFS	IVS
Total								

Transect<sub>1</sub> min/max elevation:                      min/max easting:                      min/max northing:

Species Code	ADS ha <sup>-1</sup>	RDS	BA <sub>avg</sub> cm <sup>2</sup>	ACS m <sup>2</sup> ha <sup>-1</sup>	RCS	AFS	RFS	IVS
Total								

**Tree Diversity Statistics for Transect<sub>1</sub> and Transect<sub>2</sub>** (Round *E* and *SSI* to thousandths place.)

S <sub>1</sub> =		E <sub>1</sub> =		SSI =		S <sub>2</sub> =		E <sub>2</sub> =	
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*Interpretation/Conclusions*

Type your answers using complete sentences! Double-space your answers please.

- How similar are the two sampled transects in species diversity? Use *SSI* in your answer.
- Which transect had greater species diversity? Use *S* and *E* in your answer.
- If there is a difference in species diversity, hypothesize why. If there is no difference in species diversity, hypothesize why not.
- It is often argued that communities with greater species diversity are less prone to undergo an outbreak of a host-specific pest than communities with lesser species diversity. If this is true and applies to bark beetle infestation in the Mt. Charleston Wilderness, which region, near transect<sub>1</sub> or transect<sub>2</sub>, is least likely to undergo a bark beetle outbreak considering only the *S* and *E* values obtained for each transect? Explain your answer.
- Rank the tree species in each transect in descending order based on *IVS*.
- Compare tree *IVS* between the two transects. Hypothesize which abiotic and/or biotic factor(s) that vary with elevation likely explain the difference in tree *IVS* across transects. Explain your answer.
- Consider the tree species with the greatest important value (*IVS*) in each transect as providing the greatest opportunity to serve as hosts to bark beetle infestation. Consult the literature and determine which genus (or genera) (*Dendroctonus*, *Ips*, *Scolytus*) of bark beetle is most likely to break out in the Mt. Charleston Wilderness considering only *IVS* values of potential hosts. Explain your answer.
- Consider your beetle sign graph. Do you see evidence of an ongoing bark beetle outbreak in the Mt. Charleston Wilderness? Explain your answer.
- Is there evidence of prior bark beetle infestation in the Mt. Charleston Wilderness? Explain your answer.
- Consider the graph of leaf/needle browning. If trees with 0.25 of their leaves/needles that are browning are experiencing low stress, and 0.50 are moderately stressed, and 0.75 are highly stressed (an arbitrary scale), how stressed are the trees along each transect? Explain your answer.
- If moderately stressed to highly stressed trees are most prone to attack by pests, how likely is a bark beetle outbreak in the Mt. Charleston Wilderness? Explain your answer.
- Consult the literature to determine two abiotic and two biotic stressors that cause leaf/needle browning in tree species such as those growing in the Mt. Charleston Wilderness. Hypothesize how likely each stressor is to occur in the Mt. Charleston Wilderness.
- Assuming equal growth rate by all tree species (a poor assumption), which tree species is likely the oldest in each transect? Explain your answer.
- How might tree age impact potential stress and bark beetle attack? Explain your answer.
- Examine the data collected by your class. Is there any detectable relationship among tree age (based on *D*<sub>130</sub>), leaf/needle browning, and beetle sign? If so, describe this relationship.
- Which region, near transect<sub>1</sub> or transect<sub>2</sub>, would you monitor if you only had resources to monitor a single area? Explain your answer using data collected from the field by your class.

## Notes for the Instructor

### Choosing the Right Sampling Method

Assess your potential field site(s) to determine if the point-centered quarter method (PCQ) is appropriate. If tree species tend towards clumped or uniform distributions, try one of the PCQ modifications reviewed by Higgins et al. (2012). The random wander method reduces bias but may be difficult to carry out with a large class and could be potentially hazardous at some field sites. You may choose to abandon plot-less techniques altogether and employ plot-based sampling techniques such as those reviewed by Higgins et al. (2012) to acquire density, coverage, and frequency statistics while collecting the remaining data as described in this laboratory.

### Identifying Beetle Sign

Bark beetles (e.g., *Dendroctonus*, *Ips*, *Scolytus*) are ever present in coniferous forests of North America. Close inspection of trees typically yields an accumulation of beetle sign (e.g., holes, galleries) resulting from many generations of beetles carrying out their life cycles. However, in recent time warming climates and drought-stress have resulted in massive outbreaks of bark beetle infestations in the major mountain ranges of the U.S and Canada. During such outbreaks, beetle sign indicating evidence of ongoing attack (e.g., beetles, numerous pitch tubes, sawdust from boring, and needle discoloration) begins *en masse*. The specifics of beetle sign for a particular area depend not only on the species of beetle infesting trees but also on the tree species that are being attacked and other factors such as the time of year. Needle discoloration may occur in response to numerous abiotic (e.g., drought, heat stress, early or late frost, air pollution, pesticides) and biotic (e.g., weevils, moths, fungi) factors. Furthermore, many signs of tree attack are the result of complex interactions among various pest species such as bark beetles and blue-stain fungus or mistletoe and fungal cankers.

There are numerous resources available to help one become familiar with bark beetle sign in a particular region. I work in the western U.S. and recommend *Pests of the Native California Conifers* by Wood et al. (2003). I also recommend contacting the USDA Forest Service website (<http://www.fs.fed.us/research/invasive-species/insects/western-bark-beetle.php>) for links to various resources. Beetle activity varies seasonally and regionally so it is important to consult local sources of information to know when to expect them to be most active (for many locations beetle activity will peak outside of the traditional spring/fall semester sequence). Other important sources of information come from various extension services associated with some institutions of higher education and consortium websites such as the *Bark and Wood-boring Beetles of the World* (<http://www.barkbeetles.org>).

### Before You Go into the Field

Planning and time management are essential. You will likely only work at the field site once during the semester so you need to make it count! Begin work early and stay late! A team of 8 students were able to survey 8-100 m transects in a 6 hr time period in a field site that ranged in elevation from 2,560 to 2,865 m. Students were generally lethargic because they were not used to working at elevation. I estimate that at least 2 more transects could have been sampled at lower elevation (or had my students maintained regular exercise).

Get your permissions and permits! Apply for them a few months ahead of time and check at least a month prior about the status of your permit application. Carry permits and a class roster with you in case you are stopped by a ranger.

Devise a customized biological key for the trees found at your field site. It is too cumbersome and too time-consuming to have students use more involved keys for every diagnosis. Bring a more detailed flora/key for each student team and a botanical dictionary for yourself. When walking into the forest from the parking area, point out species and their binomial codes (e.g., pipo) to familiarize your students. Assess them as you go. Advise students to ask about species diagnosis when in doubt. Also point out examples of phenological and health assessment data along the way to familiarize students with the various categories associated with these data. If your field site has too many species, consider sampling at a more inclusive taxonomic level (e.g., Genus).

Prepare an efficient equipment check out/check in procedure so that your field crew does not have to waste valuable field time with mundane tasks. Also devise a protocol for dealing with students who must depart the field day early.

You must have protocols to deal with instances in which you lose line of sight of your students. You will likely lose site of your students along a 100 m transect in uneven terrain associated with a montane forest. I use a hiking trail as the center point of 100 m transects and send two student teams out in opposite directions. They are instructed to return to the main trail via their transect line. If no person or field gear is present on the main trail, they are instructed to ascend the main trail until they locate the next transect already in progress (typically about 100 m up the trail). If they do not locate personnel or gear on the main trail, they are instructed to hold in position until I locate them. Our GPS receivers also possess two-way radios that provide some communication when line of sight is lost. If you need to call out for students in the field, hooting is more effective than yelling. Perform roll call at regular intervals and especially before descending to the parking area and at the parking area.

Be aware of the hazards at your field site and be prepared to address them. In my class we survey above 2,600 m. Known hazards include potential for falls, weather, and, more rarely, AMS. Lightning requires abandoning field activity until the storm has passed. Return to vehicles and wait out the storm with windows up. Our field site has minimal cell phone coverage. I have a protocol for communicating with SAR in case of an emergency. You should consider the



protocols you will use to deal with injury or other field concerns. Remember your field site is likely more than an hour away from emergency help.

Random sampling is important for statistical considerations. Prepare your random sample point distances using a random number generator prior to heading out for the field day (better yet, ask your students do work on this project to engage them in field preparations). This will require a preliminary visit to the field site to determine the size of buffer needed to ensure that no two sample points along a transect will be close enough that an individual tree can be sampled for two different sample points. Buffer size will vary with the density of trees in your sampling area. A reasonable buffer to begin with is 10 m. Consequently, if two random sample points on the same transect are within 10 m of each other you will need to choose a new random number for one of the sample points. Try this buffer at your field site and adjust up or down as necessary. You will need more random sample points than sample points you intend to survey because some will be rejected because they fall near field hazards.

Choose your transects based on embedded lessons. I chose elevation as a key variable that differed between our transects and had students sample across an elevation gradient that crosses a transition zone in community structure. This permitted me an opportunity to discuss various life zones found in the Basin and Range Province of North America. You can also choose other transect variables such as slope aspect, slope, management history, etc.

### Assessment Options

You can assess your students on this field activity in many different ways depending on your educational goals. An obvious method would be a report that summarizes the findings of the field work. You can also prepare worksheets that evaluate the students' ability to calculate the statistics, graph, and interpret their findings.

### Background Information on Planning and Geospatial Data

The bulk of my workshop focused on planning for a day in the field and geospatial data. This information is not submitted herein. If you are unfamiliar with these topics, you may contact the author ([brian.wainscott@csn.edu](mailto:brian.wainscott@csn.edu)) for more information.

### Future Directions

Needle browning is a consequence of many factors. Browning may adhere to particular patterns. At the level of the canopy, you might observe browning occurring from the top down or bottom up. Similarly, at the level of the branch you might observe browning in a proximo-distal direction or the reverse. Such patterns (and additional climatic data) can help narrow down which factors are likely causing the browning because different factors stress trees in different ways. I am working on relating the patterns of needle browning to local pests at my field site. I intend to modify the section on

needle browning to include these new parameters. Students will be asked to hypothesize about needle browning using data collected and then propose a method to determine if they are correct.

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I would like to acknowledge the tremendous efforts of the introductory field biology students at the College of Southern Nevada who have overcome many barriers to learn about fieldwork. I would also like to thank the Forest Service for allowing the next generation of field biologists to learn and train in the Mt. Charleston Wilderness.

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## About the Author

Brian C. Wainscott is a tenured community college professor at the College of Southern Nevada. He teaches freshmen and sophomore students in organismal biology, introductory field biology, and health-track biology. He also serves as President-Elect for the Arizona-Nevada Academy of Science. Brian earned his M.S. in Biological Sciences from Illinois State University where he trained as a herpetologist.

## Appendix Data Sheet

Tree Survey Data Sheet   Sampling Data: Date _____				Time(24hr) _____		Temperature _____		Wind Speed _____		Relative Humidity _____					
Transect Data				Geospatial Data of Tree				Terrain Data		Tree Data		Phenological and Health Data			
team ID	transect	point	quarter	distance	eastng	northng	elevation	aspect	slope	taxon	D <sub>130</sub> <sup>1</sup>	male <sup>2</sup>	female <sup>3</sup>	leaf <sup>4</sup>	beetles <sup>5</sup>
c, f, m, p	1-∞	1-100	1-4	m (0.1)	m	m	m	azimuth <sup>°</sup>	angle <sup>°</sup>	see key	cm	a, b, m	a, b, m	a, b, p	n, b, g, h, p, s
f	1	17	1	2.1	624730	408907	2572	20	7	pipo	84	a	p	0.25b	g, h

<sup>1</sup>For trees with multiple stems enter *m-s* = multi-stem in the D<sub>130</sub> column. On reverse of this page enter transect, point, and quarter designation and diameter of each stem.  
<sup>2</sup>Male reproductive structures (staminate cones or flowers with stamens): a = absent; b = buds present; m = mature male structures present with pollen  
<sup>3</sup>Female reproductive structures (ovulate cones or flowers with pistils): a = absent; b = buds present; m = mature female structures present  
<sup>4</sup>Leaf/needle status: a = leaves/needles absent; b = estimated proportion of all leaves/needles brown lacking pigment (0.25, 0.50, 0.75, or 1.00); p = most leaves pigmented  
<sup>5</sup>Bark beetle status: n = no evidence; b = bark beetles present; g = galleries evident; h = holes from bark beetles present; p = small pitch tubes present; s = sawdust present

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